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Testimony of
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List of Exhibits

Acronyms and Abbreviations

CDC	Centers for Disease Control and Prevention
Centromin	Empresa Minera del Centro del Peru S.A.
CMLO	Complejo Metalúrgico La Oroya / La Oroya Metallurgic Complex
Complex	Complejo Metalúrgico La Oroya / La Oroya Metallurgic Complex
Convenio	Convenio de Cooperación
DRP	Doe Run Peru S.R. LTDA
GWI	Ground Water International
HHRA	human health risk assessment
MEM	Ministry of Energy and Mines
MINSA	Ministerio de Salud / Ministry of Health
PAMA	Programa de Adecuación y Manejo Ambiental
PM	particulate matter
µg/dL	micrograms per deciliter (i.e., micrograms of lead per deciliter of blood)
USEPA	U.S. Environmental Protection Agency

Glossary of Terms

Biomonitoring: Measuring chemicals or substances in biological tissues to evaluate exposure, such as measurement of lead in blood or arsenic in urine.

Cancer Risk: A theoretical risk generated using human health risk assessment tools that rely on a suite of health-protective assumptions regarding long-term exposure to a cancer-causing substance.

Concentration: The amount of a chemical present in a specified amount of air, water, soil, blood, or other medium.

Deposition: The processes by which chemical constituents settle from the atmosphere to the earth's surface, which include precipitation (wet deposition, such as rain or cloud fog) and particle and gas deposition (dry deposition).

Environmental Media/Medium: Specific environmental matrices—air, water, soil—that can contain chemicals.

Epidemiology: The study of the causes and distribution of disease or health status in a population, and/or the occurrence, incidence, and causes of health effects in humans.

Exposure: Contact with chemicals through inhalation, ingestion, or touch.

Exposure Assessment: The process of characterizing exposures among a population of interest, including how people come into contact with a chemical, how often, how long, and where the contact occurs, and how much of the chemical is contacted.

Exposure Medium: The contaminated environmental medium to which an individual is exposed, such as soil, water, sediment and air.

Exposure Pathway: The route by which a chemical can reach a person. Each exposure pathway includes the route the chemical takes from its source to where it comes into contact with people and consists of five components: 1) a chemical source, 2) an environmental medium or transport mechanism (e.g., deposition of air particulates onto soil), 3) an exposure point (e.g., bare soil at a park), 4) a route of exposure (e.g., touching, breathing), and 5) an individual or population, who may be potentially or actually exposed. All five components must exist for an exposure pathway to be considered complete.

Exposure Pathway Model: A model in which potential pathways of exposure are identified for the selected individual or population.

Exposure Point: The potential contact between a person and a contaminant within an exposure medium.

Exposure Scenario: A set of assumptions concerning how an exposure takes place, including assumptions about the exposure setting, stressor characteristics, and activities that can lead to exposure.

Fugitive Emissions: Air emissions that do not pass through a stack, chimney, vent, or other functionally-equivalent opening.

Human Health Risk Assessment: A qualitative or quantitative evaluation of the risk and/or hazard posed to human health by the actual or potential presence or release of hazardous substances, pollutants, or contaminants.

Noncancer Risk: The theoretical increased likelihood that an individual will suffer adverse health effects as a result of exposure to a chemical.

Particulate Matter: Material suspended in the air in the form of minute solid particles or liquid droplets, especially when considered as an atmospheric pollutant.

Remediation: Cleanup or other methods used to remove, contain, or otherwise prevent release of hazardous materials.

Resuspended Soil: Soil particles that are introduced, or resuspended, into the air through mechanical disturbances of soil, such as soil cultivation and vehicles operating on unpaved surfaces.

Risk Characterization: The integration of information on exposure and chemical toxicity to provide an estimate of the likelihood that any of the identified adverse effects will occur in exposed individuals.

Settled Dust: Particulate matter deposited on surfaces, which consists of a mixture of particles from multiple sources, including particulate airborne emissions and resuspended soil particles.

Stack Emissions: The particulate matter and vapors captured in facility processes and released to the atmosphere through a stack, chimney, vent, flue, or other functionally-equivalent opening.

Toxicity Assessment: An evaluation of a chemical's toxicity with respect to various concentrations, including a numerical expression of a chemical's exposure-response relationship that is used in risk assessment.

1 Introduction

I have been requested by King & Spalding LLP to provide testimony in the matter of an arbitration under the rules of the United Nations Commission on International Trade Law regarding a claim filed by the Renco Group, Inc. against the Republic of Peru for claims arising out of Renco's investment in the La Oroya Metallurgical Complex (the "Complex"), including the Contract of Stock Transfer (i. e., the stock transfer agreement) between Empresa Minera del Centro del Peru S.A. ("Centromin") and Doe Run Peru S.R. LTDA (DRP).

My testimony is based on my experience and expertise, as well as first-hand information gathered and considered during 2005 and 2008 human health risk assessments (HHRAs) for the Complex and the surrounding communities that I conducted for DRP and the Peruvian Ministry of Energy and Mines (MEM). After completing our work in both instances, my team and I generated and provided to DRP and MEM health risk assessment reports dated December 2, 2005 and November 21, 2008, respectively. I reserve the right to modify and supplement my opinions as additional information relevant to the subject of my evaluation becomes available or is otherwise discovered.

1.1 Qualifications

By education, training and experience, I am an expert in toxicology, the scientific discipline that studies the adverse effects of chemicals on living organisms.

Since February 2010, I have been a Principal at ENVIRON International Corp. Before that, I was a Principal at Integral from 2002 until January 2010. I have been board-certified by the American Board of Toxicology since 1986 (recertified in 1991, 1996, 2001, 2006 and 2011), and I am a Fellow of the Academy of Toxicological Sciences. I hold a Ph.D. in toxicology from the University of Cincinnati, as well as a B.A. in molecular biology from Wellesley College. I have more than 25 years of experience in assessing human health effects and exposures from chemical substances in the natural and built environment, and in products and foods. I have directed evaluations of chemical toxicity, derivation of risk-based exposure levels, health risk assessments for cancer and non-cancer end points, and multimedia assessments of exposure to environmental chemicals for diverse mining and mineral processing sites, manufacturing sites, landfills, incinerators, and community settings. I have served on numerous peer review panels for U.S. agencies and Canadian ministries, and have been a member of three National Academy of Sciences committees. I served as a member of the British Columbia Contaminated Sites Science Advisory Board and the Expert Advisory Panel for the Canadian Metals in the Human Environment–Research Network. Currently, I serve as a member of the Washington Department of Ecology Model Toxics Control Act Science Panel. Prior to my consulting career, I worked for the U.S. Environmental Protection Agency in the Office of Toxic Substances.

My research has focused on evaluation of exposures to lead, arsenic and other metals at smelting and mining sites. I have published scientific papers on the bioavailability of metals from soil and on dietary exposures to arsenic. I have also directed biomonitoring studies that directly measure exposure to lead and arsenic at mine and smelter sites, and have used biomonitoring data to help characterize the contribution of various environmental and household sources contributing to residential metal exposures. I have worked in communities with operating

smelters and mines, as well as communities with residual contamination from historical mine and smelter operations.

I have attached a copy of my current curriculum vitae as Exhibit A.

2 Summary of Opinions and Conclusions

My testimony below supports the following conclusions:

- Since acquiring the Complex in1997, DRP has undertaken multiple actions to reduce emissions from the Complex, and to characterize emissions and monitor air concentrations in the community. In addition, DRP has undertaken and supported numerous actions in the community designed to reduce exposures to Complex emissions and to mitigate the adverse health impacts in the surrounding community.
- From a human health perspective, we recommended in our 2005 and 2008 health and human risk assessments that DRP prioritize reductions of lead emissions over other metals or sulfur dioxide.
- Cerro de Pasco's and Centromin's prior operation of the La Oroya Complex created pervasive environmental contamination in the region of La Oroya that continued to contribute substantially to exposures of minors in La Oroya to lead and other metals after 1997, and continue to the present time.
- Any harm resulting from exposure or contamination that occurred between 1997 and the present cannot be exclusively attributed to DRP. Historical contamination of soil and settled dust by prior Cerro de Pasco and Centromin operations continues to contribute substantially to exposures of minors in La Oroya.
- Centromin should have investigated the magnitude and extent of contamination of soil and settled dust early during the PAMA period. The results of that investigation would have supported the development and implementation of corrective actions to reduce exposures to the existing contaminated soil and settled dust.

3 Background Principles of Toxicology and Risk Assessment

Understanding my testimony regarding assessment of potential health impacts in La Oroya due to current and historical Complex operations requires a basic understanding of some principles of toxicology and human health risk assessment (HHRA).

3.1 Principles of Toxicology

Toxicology is the study of the adverse health effects of chemicals. It is a fundamental premise of toxicology that the potential for a chemical to induce adverse health effects increases with increasing exposure or dose. All chemicals can be toxic at sufficiently large doses. The potential for a chemical to induce adverse effects is typically assessed by conducting studies in which animals are exposed to a range of chemical concentrations and the incidence of adverse health

effects is recorded. Association of adverse health effects may also be identified from epidemiology studies that assess groups of people with suspected chemical exposures.

Many chemicals such as those associated with smelter emissions have been studied for decades, and hundreds or even thousands of toxicity and epidemiology studies have been reported in the literature. All such studies have limitations with regard to the strength of associations between a chemical and observed adverse health effects[1], as well as in the precision and reliability of their ability to predict doses of a chemical that may cause health effects. Consequently, when public health or regulatory authorities conduct dose-response assessments to predict the dose of a chemical that may cause adverse health effects, a weight-of-evidence analysis is typically undertaken that considers all available studies for a chemical, evaluating the quality of the studies and reproducibility of the findings before drawing conclusions regarding the effects associated with the chemical and the doses at which those effects may occur.

In most cases available studies do not provide direct measures of the likelihood of adverse effects occurring at lower doses typically associated with environmental contamination. In those cases additional analyses are then conducted to extrapolate from high doses where adverse effects have been observed to predict the likelihood of adverse effects at lower doses.

Due to variations among people in behaviors, physiological make up, life stages and the presence of diseases, it is not possible to determine the exact dose that will cause an adverse effect in an individual. Consequently, when public health and regulatory authorities identify dose thresholds below which no adverse effects are expected for a chemical, the thresholds typically are set low enough to ensure that even the most susceptible person will not suffer an adverse effect.

3.2 Human Health Risk Assessment Methodology

An HHRA builds on the dose response assessments for chemical toxicity, and provides a quantitative evaluation of the exposures (or doses) people might experience from the presence or release of chemicals in the environment and the associated health risks from those exposures. Most risk assessments are focused on estimating high end exposures in a population. Thus, a risk assessment predicts the likelihood of health effects in the most highly exposed members of a population. These risk estimates are also very conservative in using effects thresholds that are designed to be protective for the most individuals.

HHRAs are useful tools in assessing exposure and potential risk to communities under current conditions, as well as predicting conditions in the future. HHRAs are used in evaluating the contribution of risk from various environmental media, such as soil, dust, or air, so that actions

[1] Human epidemiology studies have limitations with regard to their ability to link exposure to a particular chemical to specific health effects because such studies typically include exposures to multiple chemicals and because most health effects have multiple known and unknown causes or contributing factors. Animal toxicity studies may provide direct evidence that a particular chemical causes a specific health effect; however, for health effects with multiple causes, an observation that the health effect occurs in an individual who may also have had exposure to that chemical does not prove that the chemical exposure was responsible for that particular case.

may be taken to reduce exposures to specific media or to prioritize media-specific remedial actions.

It is important to note that a risk assessment does not directly measure the occurrence of health effects. A HHRA is very different from an epidemiology study that reports the incidence of specific health effects observed or a biomonitoring study that reports the concentrations of chemicals in people's bodies. Risk assessments cannot predict actual incidence of cancer or disease in a population. Similarly, risk estimates cannot be used to establish causality for individual incidences of disease.

U.S. Environmental Protection Agency (USEPA) provides detailed methods for conducting an HHRA (USEPA 1989). This framework is similar to approaches adopted by environment and health regulatory agencies world-wide, including Canada, Australia, and many countries in the European Union (Health Canada 2009, 2010; enHealth 2004; IOM 2012; Janssen and Speijers 1997). The human health risk assessment process as defined by USEPA (1989) contains four major steps.

1. Characterize the site and the chemicals associated with the site. This step includes many activities, including review of sources that release chemicals to the environment, the identification of the chemicals released, evaluation of the available data, and an assessment of how people in the community might contact the chemicals. The result of this step is the creation of an exposure pathway model, or a road map of how and where people might come into contact with the chemicals associated with the site.

2. Evaluate the potential exposure of people to the chemicals being evaluated. This portion of the risk assessment process looks in detail at how people may come into contact with the chemicals. As part of this step, potential doses or intakes of chemicals from air, dust, soil, water or other media are quantified.

3. Assess toxicity. The toxicological evaluation looks at the potential toxicity of the chemicals being evaluated and identifies doses that may cause toxicity and doses that are not expected to cause health effects. The highest safe doses are called toxicity values, and these toxicity values are typically much lower than doses that have actually been observed to cause adverse effects.

4. Characterize risk. The risk characterization combines the results of the exposure assessment and the toxicological evaluation to describe potential risks to human health associated with site-related chemicals. This step provides results that can be used to help decide if actions need to be taken to reduce chemical exposures at the site. At this step any uncertainties associated with the risk assessment methods, data, and assumptions are also described so that any limitations of the findings can be clearly understood and considered when actions are planned to reduce exposure sources.

The exact methods used in conducting an HHRA may vary for different kinds of chemicals. USEPA methods for assessing lead exposures are different than methods used to assess other metals, and sulfur dioxide and particulates in air are assessed differently than chemicals in settled dust or in soil.

4 Assessing Health Risks at Smelter Sites

As detailed in my curriculum vitae, I have studied chemical exposures and health risks for many smelter and mining communities in North America over the past 25 years. Through this direct experience and review of peer-reviewed literature, I have gained an in-depth understanding of the exposure, toxicity, and risk management issues surrounding smelter communities. In this section, I summarize the standard approach for evaluating smelter-related chemicals, primary health impacts, and challenges surrounding managing exposure and risks.

4.1 Characterizing Smelter Emissions and Exposures

As a general matter, air emissions from copper, lead and zinc smelters such as La Oroya fall into two categories. The first category is particulate matter which consists of small particles that are carried into the air along with the gases emitted from a facility. Particulate matter, in turn, may contain inert materials, as well as lead, cadmium, arsenic and other metals. The second category is gaseous emissions such as carbon dioxide, sulfur dioxide, and nitrogen oxides.

While gaseous emissions disperse and dissipate, the airborne particulate matter emitted from a smelter settles to all surfaces throughout the area of influence of the smelter – to soil, paved surfaces, waterways, rooftops, etc. – which may extend for tens of kilometers from the smelter. Over time, the particulate matter that settles directly onto, or ultimately gets washed onto, unpaved ground becomes incorporated into the existing soil and contributes to elevated metals concentrations in both settled dust and soil.

A key factor in assessing metal exposures in communities with smelters or other large air emissions sources is that ingestion (and not inhalation) of settled dust and soil impacted by current and past emissions is the primary exposure pathway of concern for many metals, including lead (Landrigan et al. 1975, Yankel et al. 1977, Roels et al. 1980, Bornschein et al. 1985, ATSDR 1988, Carrizales et al. 2006). Soil and settled dust are usually ingested primarily through hand-to-mouth behavior. In a less developed country such as Peru, dust that settles on food and cooking utensils may also contribute to exposures (i.e., by consumption of food exposed to dust).

Elevated metals levels in settled dust in smelter communities are a result of contributions from multiple sources, including (1) ongoing air emissions that settle out every day during smelter operation, (2) reservoirs of metals in dust previously emitted, (3) resuspended soil that has accumulated metals from emissions deposited since the facility's inception or in which slag or ore or other smelter-related wastes have been deposited, and (4) metals in soil and dust from other sources not related to the smelter that may be present in the community (e.g., combustion engine exhaust, residential cooking, outdoor trash burning, and other industrial operations).

Metal concentrations in soil may also be affected by other materials, such as ore being transported through the community or by slag or other smelter by-products that may be used in road and railroad construction or in businesses or residential yards. Soil containing metals may be resuspended by wind, vehicle traffic or other disturbances and contribute to metals in settled dust. In this manner, reservoirs of metals from historical sources continue to circulate through a community.

At smelters that have been in operation for a long time, such as in La Oroya, exposures of the population reflect impacts of both ongoing facility emissions and reservoirs of metals in soil and settled dust that have accumulated throughout the community, including settled dust within houses. Consequently, risk estimates for metals at these sites reflect exposures contributed by both ongoing emissions and the reservoirs of metals throughout the community from historical smelter operations.

Even after a smelter is updated with pollution-control devices or ceases to operate, historical emissions will still be contributing to exposures as people directly contact settled dust and soil that have accumulated metals and as metal-containing soil is resuspended and moves into outdoor and indoor settled dust. The relative contribution of past or current smelter operations to overall exposures will change over time and with respect to other sources of lead and other metals in the community.

Over the lifetime of older operating smelters the magnitude of emissions usually has been reduced as advancements in pollution-control technology have been developed and implemented. Furthermore, the geographical areas most affected by emissions will have changed based on the type or nature of facility improvements that have been implemented. Typically, reducing low elevation fugitive emissions from buildings and ducts at a smelter provides the greatest benefit in the immediate vicinity of the smelter, while emissions reductions from tall stacks result in more even emissions reductions over the entire region around the smelter because the emissions are more widely dispersed.

HHRA is often used both to assess the relative contributions of multiple sources of exposure and to predict future exposures in smelter communities. Current exposures of smelter community residents to some metals may be measured directly, in the case of lead by measuring levels in blood and for arsenic by measuring levels in urine. However, such biomonitoring studies cannot predict how exposures might change in the future if exposure conditions change.

Though other contaminants emitted from smelters may pose health risks, lead is the contaminant posing the most significant health risk in many smelter communities. Actions to reduce metal exposures often focus on lead because any of the measures to address lead also reduce exposure to other metals. While we evaluated sulfur dioxide in the La Oroya community and it was a focus of the original Programa de Adecuación y Manejo Ambiental (PAMA), our extensive research surrounding the 2005 and 2008 HHRAs clearly identified lead as the contaminant of greatest concern in La Oroya, which is what I discuss below.

4.2 Lead Exposure

Lead exposure may be due to multiple sources in homes and workplaces, including lead pipes and plumbing, leaded paint in homes and on toys and other products, residual lead in soil and settled dust from leaded gasoline, lead in ceramic glazes, and others. While current and

historical emissions may dominate in smelter communities such as La Oroya, these other potential sources must also be considered as contributing to exposures[2].

Measurement of blood lead levels provides an indication of the magnitude of lead exposures, including all sources to which a person is exposed, whether related to smelter emissions or other sources, such as lead in plumbing or paint or lead from gasoline. It must also be considered that blood lead measurements reflect both current and past exposures, as lead stored in bone can be released into the blood over time (Manton et al. 2000). Therefore, lead originating from past exposures can contribute to ongoing harm.

USEPA has developed exposure models that use estimates of lead intake from multiple sources to predict a distribution of possible blood lead levels for children and adults under predicted future conditions (USEPA 1994, 2003). USEPA focuses on predicting risks to young children and women because they are thought to be the groups most sensitive to the adverse effects of lead. The lead exposure models include a number of assumptions about how children are exposed to lead in their environments, including via drinking water, food, incidental ingestion of soil and dust, and inhalation of air.

These models can be applied at any site where lead is a concern, including smelter sites. The output of the child model is typically used for two general purposes under either current or future conditions: 1) to understand the relationship between blood lead in children and environmental lead levels, and 2) to estimate the risk of elevated blood lead exceeding a specified level of concern (USEPA 1994). However, the model is limited in that it is not intended to match the measured blood lead of a specific child. Instead, the model generates a distribution of blood lead levels that is used to predict the probability of elevated blood lead for a child under specific exposure conditions, or to predict the range of blood lead levels for a population of children under specific exposure conditions (USEPA 2002). When modeling the relationship between environmental lead levels and blood lead to predict future blood lead levels, model inputs representing exposure concentrations for various media (i.e., air, soil, dust, food, paint, and water) can be varied to simulate blood lead levels under various future conditions. By performing multiple simulations using varying media concentrations, the influence on blood lead resulting from reduction of lead levels in different exposure media can be understood. In this way, interventions can be focused on reducing exposures to those media, or reducing media concentrations, that will result in the greatest reduction in blood lead levels.

At the time we conducted the HHRAs for La Oroya, the U.S. and many other jurisdictions used 10 micrograms of lead per deciliter of blood (µg/dL) as a measure of the blood lead level in

[2] Lead exposures occur in both smelter and non-smelter communities alike, due to the pervasiveness of other lead sources including lead-based paint, lead in ceramic glazes, leaded gasoline, and others. The potential for exposure is greater in countries with a relatively short history of environmental regulation. For example, Ramirez et al. (1997) and Espinoza et al. (2003) have reported blood lead levels in adults from multiple non-smelter Peruvian communities reflecting a range in urbanization. Ramirez et al. (1997) report mean blood lead levels of 26.9 µg/dL for Lima, 22.4 µg/dL for Huancayo, and 14.0 µg/dL for Yaupi, a small, agrarian jungle village where automobiles are nearly absent. Espinoza et al. (2003) found mean blood lead levels of 9.9 µg/dL and 3.3 µg/dL in children and women, respectively, living in the port community of Callao, Peru. The blood lead levels reported for these communities demonstrate that even in non-smelter communities, lead exposures occur and measurable blood lead levels can be present.

young children at which some interventions should be undertaken to reduce exposures (CDC 2002). High blood lead levels have been associated with a variety of adverse health effects in exposed populations. Epidemiological studies have shown that the neurological system is particularly sensitive to the effects of lead, especially in young children; however, it is impossible to extrapolate from such studies to establish specific adverse effects in any single child (ATSDR 1999).

When evaluating exposures to lead, it is critical to consider the age at which exposure occurs. Susceptibility to the effects of lead varies by age, with young children more likely to experience adverse effects compared with similar magnitude exposures occurring at a later age (ATSDR 1999). Adverse effects observed at a later age may be due primarily to exposures that occurred at an earlier age.

5 Health Risks In La Oroya

Based on my prior experience, I was hired by DRP and approved by MEM to conduct an independent assessment of health risks in La Oroya in connection with anticipated upgrades to the Complex by DRP. We conducted our first HHRA in 2005 as part of the approval of the PAMA extension (Integral 2005). MEM also required a complementary HHRA to update the HHRA to reflect improvements to the Complex implemented during 2006 and 2007. The complementary HHRA was completed in 2008 (Integral 2008). Both of the reports that we prepared and provided to DRP and MEM in connection with these risk assessments are attached to this report as Exhibits B and C, and I refer the reader to them for a full discussion of our studies and findings.

In conducting the 2005 HRRA, I travelled to Lima and La Oroya multiple times with my project manager Alma Cárdenas, and worked closely with MEM, DRP and the community to obtain the information and data needed to create a study of health risks in the La Oroya area. During 2005 our sampling team, led by Ms. Cárdenas, spent a total of four weeks in La Oroya collecting samples of drinking water, soil, and settled dust outdoors and inside homes. One goal of the 2005 HHRA for La Oroya was to characterize current sources of exposure from the Complex. In reading my testimony, it is important to understand that “current sources of exposure” include historical reservoirs of metals in settled dust and soil throughout the community, as well as ongoing emissions from the operating Complex.

From the earliest discussions with MEM, the scope of the HHRAs was defined as focusing on the combined exposures of the population of La Oroya to smelter-derived chemicals in all environmental media (i.e., soil, outdoor and indoor settled dust, drinking water, air and food), and not on defining the broad extent of contamination resulting from the historical operation of the smelter or on determining the relative contribution of historical and current emissions to the exposures. As discussed above, risk estimates for settled dust and metals reflect exposures contributed by both current emissions and the reservoirs of metals throughout the community from historical smelter operations.

Additional goals of the 2005 HHRA were to use the understanding of current exposures to make recommendations for how to reduce exposures, and also to predict future exposures and health risks due to planned reductions in emissions from the Complex. The main goals of the 2008

complementary HHRA were to see if the exposure model used in the 2005 HHRA accurately predicted exposures after implementation of fugitive emissions controls and to predict future risks after implementation of additional stack emission controls. Fugitive emissions are uncontrolled emissions that escape from open smelting processes, or from buildings and duct work.

Our HHRAs were based on USEPA standards, but included much more comprehensive data than most HHRAs conducted in the U.S. Because we had air concentration data from multiple locations in the community, as well as data for soil, outdoor dust, indoor dust, drinking water, and dietary intakes we were able to more accurately estimate exposures than is typically the case in HHRAs. Furthermore, the availability of blood lead data allowed us to refine our exposure model.

The 2005 HHRA confirmed previous studies that identified lead exposures as the primary health risk factor for the population of La Oroya due to emissions from the Complex. Most of the children residing in La Oroya Antigua had blood lead levels that fell in the range of blood lead levels (i.e., 20 µg/dL to 44 µg/dL) at which the U.S. Centers for Disease Control and Prevention (CDC 2002) recommends an environmental hazard evaluation and more active medical monitoring. Historical blood lead data demonstrate that similar blood lead levels were present in the population of La Oroya since before DRP bought the Complex (Ramirez et al. 1997)[3]. Many adults in La Oroya Antigua and residents of other nearby communities were also shown to be at risk.

Due to the urgency of reducing lead exposures in children, our recommendations to DRP and MEM in the 2005 HHRA prioritized DRP's continuing efforts to reduce lead exposures over any other actions. Exposures to arsenic, cadmium and other metals, as well as sulfur dioxide, were expected to also be reduced by the actions recommended to reduce lead emissions. We also concluded that risks from other metals could be addressed in a longer time frame because the health effects from these other metals generally develop only after longer periods of exposure than those associated with lead.

Our assessment that lead exposures were the most urgent problem in La Oroya is supported by the comments of Dr. Scott Clark, who was hired by MEM to conduct a peer review of our 2005 HHRA (Clark et al. 2006). Dr. Clark's statements in the May 12, 2006 peer review report to MEM emphasized the need to take multiple actions to reduce lead exposures, while noting that actions to reduce lead exposures would reduce exposures to other metals. A copy of the peer review report including the appendix with Dr. Clark's comments is attached as Exhibit D to this report.

Our 2005 HHRA determined that the dominant exposure pathway for all of the communities was ingestion of outdoor settled dust. Indoor settled dust was the second greatest contributor to exposures in La Oroya Antigua, while in the other nearby communities diet was the second largest contributor. Inhalation of lead in air is a relatively minor exposure pathway.

[3] One study conducted in 1994 reported mean blood lead levels for young adults in La Oroya of 33 µg/dL (Ramirez et al. 1997).

Prior Complex operations by Cerro de Pasco and Centromin created pervasive environmental contamination in the region of La Oroya that I believe has contributed substantially to exposures of minors in La Oroya to lead and other metals since 1997. These contributions are due both to direct contact with the soil, as well as to the contribution of historically contaminated soils to the metals in outdoor and indoor dust and in food. Even Activos Mineros' (the state-owned successor to Centromin) own consultants concluded in a May 13, 2009 presentation made by Todd Hamilton of GWI that soil alone would cause a high prevalence of elevated blood lead levels in the children of La Oroya. A copy of the May 13, 2009 GWI presentation is attached as Exhibit E to this report. We considered that DRP's proposed actions to control fugitive emissions were important, though not sufficient to control blood lead levels. As discussed in our HHRAs, the benefits of reducing metal emissions from the smelter were predicted to be somewhat limited until these other sources of exposure are also addressed.

While emissions and deposition of metal-containing particulates continued during operation of the Complex during the PAMA period, this should not have prevented Centromin from investigating the magnitude of historical contamination, and developing and implementing corrective actions to reduce exposures to the existing contaminated soil and settled dust. Corrective actions could have included remediating the most contaminated areas (for example by removal, paving or capping) and reducing windblown soil and dust (for example by planting programs). Such corrective actions could have reduced the contribution of historical contamination to exposures.

The 2005 HHRA predicted that by controlling fugitive emissions (i.e., uncontrolled emissions leaking from open processes or buildings and duct-work), smelter emissions would be reduced thereby reducing the percent contribution of metals in settled dust to combined exposures. As exposure via ingestion of settled dust decreased, the percent contributions of exposure from soil and diet were predicted to increase.

The 2008 HHRA then showed that reduced lead emissions had resulted in reduced lead exposures in 2007 compared with those observed in 2004. However, risks remained high, particularly for children in La Oroya Antigua. In 2007, the mean blood lead level for all children under age 6 in La Oroya Antigua was over 30 percent lower than in 2004, yet the mean blood lead level for all La Oroya Antigua children in 2007 was twice the CDC goal of 10 µg/dL. Blood lead levels in adults had a more marked decrease in 2007 compared with 2004. Data collected in 2007 from pregnant women showed a mean blood lead level of 7 µg/dL for La Oroya Antigua, compared with 17 µg/dL in 2004.

Even if lead emissions were greatly reduced, blood lead levels were still predicted to exceed health-based goals in 2011. This is due to the fact that settled dust and soil in La Oroya would still have high residual concentrations of lead from historical emissions. In this instance, we considered that remediation of the soil was necessary to achieve desired reductions in lead exposures. We did recommend that DRP could, in the meantime, work with the Convenio de

Cooperación[4] (hereafter "the Convenio") to ensure the community had information about ways to reduce exposures to settled dust and soil, and to improve nutritional status (which helps to mitigate adverse effects of lead).

6 DRP's Actions During the PAMA Period Mitigated Health Impacts

During the 2005 and 2008 studies, it was my impression that DRP went far beyond the terms of the PAMA in pursuing numerous, diverse actions to attempt to reduce impacts of emissions to the residents.

The breadth of such community interventions in La Oroya was impressive when we began our work in 2005, and continued to be further developed before we returned in 2008. Ongoing activities in 2005 conducted by both DRP and the Convenio addressed hygiene education at the community and individual level. These activities ranged from regular street cleaning and waste disposal to provision of shower facilities and public dining rooms. DRP began worker hygiene programs soon after acquiring the Complex to ensure that workers were not taking dust from the Complex to their homes. Residents were also provided with information regarding home cleaning practices, personal hygiene, food preparation practices, and nutrition. It was evident that outreach efforts were pervasive in La Oroya Antigua with a high level of awareness among residents of the need to reduce exposure to settled dust containing lead. Most of the children we encountered had been tested and knew their latest blood lead levels, a telling sign of the active community interventions.

During 2005 we reviewed ongoing actions of DRP and made recommendations regarding programs that should be continued and new programs that might be needed. Our recommendations addressed specific actions related to facility operation, exposure assessment and environmental monitoring, community interventions, and dietary studies and nutritional interventions. In our 2008 HHRA we provided an assessment of DRP's progress in implementing our recommendations, finding that substantial progress had been made to mitigate health impacts.

The 2008 HHRA includes a detailed discussion of the recommendations and progress, including that numerous technological and operational changes had already been implemented to reduce emissions, that DRP had followed our air monitoring recommendations, including adding additional air monitoring stations and relocating one station, and making multiple changes in the analytical methods to provide better data on air quality, and that the recommended community interventions were being carried out.

It is important to recognize the unprecedented diversity and magnitude of the programs being carried out to attempt to mitigate exposure to lead and other metals in La Oroya, which I briefly

[4] The Convenio is a 2003 agreement between DRP and the Peruvian Ministry of Health (MINSA) whereby a clinic and community center were jointly established and overseen by the MINSA and DRP, with funding provided by DRP.

listed above. The programs that DRP implemented and supported in La Oroya were much more expansive than programs that I am aware of or have observed in other smelter communities.

7 Historical Emissions Continue to Contribute to Exposures in La Oroya

In the 2008 HHRA we assessed relative contributions from different media (soil, dust, air, water, and diet) to total exposure using the children's blood lead model. At that time, ingestion of outdoor settled dust (which, again, reflected resuspended soil, dust from ongoing emissions, reservoirs of dust from prior emissions, and dust from other sources) was the largest contributor to lead exposure in all communities[5]. However, we also noted that, without remediation of the soil, a reduction in Complex emissions would not be accompanied by proportional reductions in settled dust lead concentrations due to the reservoirs of lead in settled dust from prior emissions. Thus, future declines in blood lead levels will be limited by the reservoirs of lead in settled dust and soil from prior Complex operations. The same changes in relative contribution of sources to exposure and health risk will also apply to other metals.

This perspective, and the need for the soil remediation, was supported in 2006 by Dr. Scott Clark. Dr. Clark's statement in the May 12, 2006 peer review report of our 2005 HHRA to MEM emphasized the importance of addressing reservoirs of high lead soils and settled dust in La Oroya (Exhibit D). Dr. Clark stated "*Few efforts were observed that are directed towards controlling exposures of children to contaminated soil. Greatly expanded efforts need to be made immediately to prevent exposure from lead-contaminated soil. This source is thought to be a critical one for some of the children with high blood lead*." (Appendix C, page 23, Section 6.4)

Further support for the need to address historical soil contamination is found in a May 13, 2009 presentation made by the Activos Mineros consultant team, "Remediación de las Áreas Afectadas por Emisiones del CMLO." Slide 20 of this presentation states "*Existe una probabilidad significativa (entre 24 y 96%) de que un niño presente niveles de plomo en la sangre por encima de 10 µg/dL en todos los comunidades de interes evaluadas, solo en base de la exposición a los suelos contaminados,*" in other words, soil exposure alone was predicted to cause a large number of children in all the communities studied to have elevated blood lead levels (see Exhibit E).

In addition to direct soil contact by the residents, the residual highly contaminated soils in La Oroya will continue to contribute to exposures by additional pathways. La Oroya is a dry and dusty place, with periodic heavy rains that erode the soil and carry it onto roads and other surfaces where it will contribute to outdoor dust. Surface soil will also continue to be resuspended by wind, traffic and activities of the residents and settle as outdoor dust. Residents may contact outdoor dust directly, and will also track the dust into their homes. The dust will also settle on foods displayed in outdoor and open markets and during food preparation in homes. Thus, all of the exposure pathways identified in the 2005 and 2008 HHRAs will continue

[5] Ranging from 38 percent in Paccha to 56 percent in La Oroya Antigua.

to contribute to exposures, even in the absence of ongoing Complex emissions, until remediation of the contaminated soils is completed.

I believe this transfer of metals from soil to dust and food has been occurring throughout the PAMA period and up to the present time. Consequently, metals from historical emissions which are still present in soil and settled dust throughout La Oroya are continuously contributing to exposures to lead and other metals in La Oroya.

In conclusion:

- Since acquiring the Complex in 1997, DRP has undertaken multiple actions to reduce emissions from the Complex, and to characterize emissions and monitor air concentrations in the community. In addition, DRP has undertaken and supported numerous actions in the community designed to reduce exposures to Complex emissions and to mitigate the adverse health impacts in the surrounding community.
- From a human health perspective, we recommended in our 2005 and 2008 health and human risk assessments that DRP prioritize reductions of lead emissions over other metals or sulfur dioxide.
- Cerro de Pasco's and Centromin's prior operation of the La Oroya Complex created pervasive environmental contamination in the region of La Oroya that continued to contribute substantially to exposures of minors in La Oroya to lead and other metals after 1997, and continue to the present time.
- Any harm resulting from exposure or contamination that occurred between 1997 and the present cannot be exclusively attributed to DRP. Historical contamination of soil and settled dust by prior Cerro de Pasco and Centromin operations continues to contribute substantially to exposures of minors in La Oroya.
- Centromin should have investigated the magnitude and extent of contamination of soil and settled dust early during the PAMA period. The results of that investigation would have supported the development and implementation of corrective actions to reduce exposures to the existing contaminated soil and settled dust.

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Exhibit A

Curriculum Vitae of Rosalind Schoof, Ph.D., DABT, Fellow ATS

Rosalind A. Schoof, PhD, DABT | Principal

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Dr. Rosalind Schoof is a board certified toxicologist with more than 25 years experience assessing human health effects and exposures from chemical substances in a variety of settings such as contaminated sites, commercial/industrial/agricultural/residential projects, product uses, dietary exposures and general home and community exposures. Her projects have included numerous formal health risk assessments conducted under various US and international regulatory settings, as well as regulatory, research and litigation projects. Dr. Schoof has directed evaluations of chemical toxicity, derivation of risk based exposure levels, health risk assessments for cancer and noncancer end points, and multimedia exposure assessments.

Dr. Schoof is an internationally recognized expert on evaluation of arsenic and metals in the environment and in the diet, and on the bioavailability of metals from soil. Dr. Schoof has served on numerous peer review panels for US agencies and Canadian ministries, and on several National Research Council committees. She has served as a member of the British Columbia Contaminated Sites Science Advisory Board, the Expert Advisory Panel for the Canadian Metals in the Human Environment–Research Network, and the Washington Model Toxics Control Act Science Panel. Prior to her consulting career, Dr. Schoof worked for a pharmaceutical company conducting safety assessments for new drugs, designing and directing toxicity studies in accordance with Good Laboratory Practices. She also worked in the Office of Toxic Substances at US Environmental Protection Agency.

EDUCATION

1982 PhD, Toxicology, University of Cincinnati

1975 Molecular Biology, Wellesley College

EXPERIENCE

Risk Assessment for Mine and Smelter Sites

- Risk Assessments for Deloro Mine Site, Ontario—On behalf of the Ontario Ministry of Environment, directed human health risk assessment updates for onsite and offsite exposures to metals.
- Evaluation of Risks at Former Uranium Mine, Alaska—Assisted with planning for site investigation and human health risk assessment of metals, radionuclides and radon from waste rock. Participated in meetings with state, federal and Native community representatives.
- Evaluation of Smelter Wastes in a Reservoir, Washington—Assisted with planning for site investigation and human health risk assessment of slag and other smelter wastes present in a large reservoir. Participated in coordination with two Tribes and state and federal agencies.
- Evaluation of Metal Risks from an Operating Lead and Zinc Smelter, British Columbia—Oversaw multipathway probabilistic risk assessment for exposures to arsenic, cadmium, and other metals in a community with an operating lead and zinc smelter. Conducted earlier phases of the risk assessment on behalf of a community stakeholder group. Presented plans and results to stakeholders and government representatives.
- Metal Smelter Risk Assessment, South America—Directed assessment of current and future risks from sulfur dioxide, particulates, lead and other metals from an operating smelter in support of an extension of an operating agreement. The study included collection of outdoor dust, indoor dust, soil, and drinking water. Air modeling and a diet study were conducted by collaborators. Exposures of children to lead were assessed using a probabilistic exposure model that was modified to predict recently collected blood lead data. The adult lead model was also

modified to better reflect site conditions. Presented findings at public meetings attended by thousands of residents and workers. Update conducted after 3 years confirmed model predictions.

- Former Copper Mining Site Risk Assessment, Nevada—Directed study plans for potential exposures to metals and radionuclides from tailings and other wastes at a former mining site with multiple operable units being evaluated under CERCLA. Participated in coordination with Tribes and other local stakeholders.
- Former Uranium Mine Cleanup Negotiations, Washington—Provided comments on validity of a baseline human health risk assessment and rationale for cleanup plans for metals and radionuclides at a former uranium mine.
- Risk Assessment for Voluntary Cleanup of Mining Site, Colorado—Directed an assessment of risks from residential and recreational exposures to lead for a community affected by historic mining activities. The risk assessment was part of a site investigation under the 1994 Colorado Voluntary Cleanup and Redevelopment Act. Directed studies of the relative bioavailability and mineralogy of lead in site soils. Presented plans at community meetings and participated in negotiations with state agency staff. Directed a comprehensive community-wide blood lead and environmental monitoring study.
- Utah Metal Processing Site Risk and Bioavailability Support—Provided human health risk assessment support for evaluation of lead and arsenic in soils at a former mineral processing site in Utah. The site is currently a wildlife refuge. Recreational exposures onsite and exposures in an adjacent residential area were evaluated. In vitro bioavailability studies and mineralogical evaluations of lead and arsenic were conducted and results used in the site risk assessment.
- Nickel Refinery Risk Peer Review, Ontario—Member of international peer review panel for risk assessment of exposures to nickel and other metals in Port Colborne, Ontario. Participated in media briefing and community open houses to explain role of peer review panel. Named by the Ontario Ministry of the Environment as a testifying expert for executive review tribunal.
- California Mining Site Risk Assessment—Conducted a preliminary human health risk assessment evaluating metals in sediments, surface water, and other media downstream of a copper and sulfur mine site in California. Exposure scenarios included both recreational and Native American activities.
- Historic Copper Mine Site, Montana—Evaluated potential exposures and risks posed by elemental mercury, lead, and arsenic in basements of homes built on the site of former mining operations. Potential exposures to lead, arsenic and mercury in attic dust, indoor dust in living areas and in soils was also evaluated.
- Former Copper Smelter Site, Washington—For negotiations and legal action related to a former smelter site in Washington state, assembled and summarized literature related to assessment of exposures to arsenic in soil. Attended stakeholder meetings and made presentations on arsenic toxicity and risk assessment. Reviewed and commented on State documents. Prepared affidavit addressing issues related to arsenic toxicity and risk assessment.
- Copper Mining District Releases, Utah—Prepared deposition describing limitations of potential adverse effects associated with lead and arsenic in a riverbed near a residential area downstream of a mining site in Utah, was deposed by US Dept. of Justice and USEPA attorneys, and testified for an alternative dispute resolution.
- Zinc Smelter Risk Assessment and Bioavailability Research Program, Oklahoma—Managed human health risk assessment tasks for the work plan, remedial investigation, and feasibility study of cadmium, lead, and arsenic in soil at a former zinc smelter site in Bartlesville, Oklahoma. Planned for collection of site-specific data to fill gaps in EPA's baseline human health risk assessment, including paired soil and indoor dust samples, "hot spot" delineation, and a bioavailability study of cadmium and lead in soil. Directed development of revised remediation goals for arsenic, cadmium, and lead using site specific data and wrote position papers supporting the recommended goals. Consideration of reduced bioavailability from soil and reduced toxicity in the presence of

zinc resulted in soil cadmium cleanup levels of 100 and 200 mg/kg for residential and occupational land use, respectively. A lead cleanup level for occupational areas was derived using an adult lead exposure model. Monte Carlo analyses were used to document protectiveness of cadmium and arsenic cleanup levels. Presented plans and results to EPA and state staff and at public meetings. Assisted in negotiating cleanup levels for cadmium, lead, and arsenic that subsequently reduced remediation scope and cost by $50 million.

- Mining and Smelting Site Strategic Risk Assessment Support—Over an 8-year period, managed a multisite general risk assessment support contract for mining and smelting sites throughout the Rocky Mountain region. In addition to providing risk assessment support for specific sites, responsibilities included ensuring that risk assessment strategies and positions were consistent from site to site and that risk assessment strategies were coordinated with litigation strategies. Identified pivotal sources of uncertainty affecting risk estimates for many sites and helped design and conduct research to support more realistic assessments of risks. Presentations were regularly made to EPA and state staff on behalf of the client.
- Copper Mine Site Risk Assessment Program, Montana—Managed preparation of a series of position papers describing the proper methods for evaluating exposures to lead and arsenic from mining wastes in soils, groundwater, and surface water in Butte, Montana. Soil issues included evaluation of the uncertainties associated with EPA's oral carcinogenicity assessment for arsenic, bioavailability of lead and arsenic in soils, and discussion of appropriate ways to apply the uptake biokinetic model and community blood-lead studies to assessments of lead exposures. Prepared documents describing the proper methods to evaluate risks from groundwater and surface water contaminated with arsenic, lead, cadmium, and other metals released as mining by-products at several operable units. Comments were also prepared on baseline risk assessments and preliminary remedial goals from EPA and state agencies.
- Reservoir Sediment Risk Evaluation, Montana—Assisted in preparing a document describing the proper methods of evaluating human health risks associated with recreational exposures to arsenic, cadmium, and lead in sediments at a reservoir in Montana.
- Lead Mining District Risk Evaluations, Colorado—Advised client of best methods for assessing lead exposures at a historic mining site in the Rocky Mountains. Described available data and appropriate methods for comparing the bioavailability of lead from soil, slag, mining wastes, and tailings. Critiques were provided for community blood-lead studies and the application of the uptake biokinetic model to assess lead exposures at the site.
- Risk-Based Cleanup Goals for a Barium Ore Site, Modesto, California—Provided strategic guidance and senior review for development of risk-based preliminary remediation goals for barium in soil at a former ore processing plant in Modesto, California, that was expected to be redeveloped as an industrial or recreational park.
- Risk Assessment for Voluntary Cleanup of Mining Site, Colorado—Directed the development of risk assessment strategy for a mining site being addressed by the client under the 1994 Colorado Voluntary Cleanup and Redevelopment Act. Chemicals evaluated included arsenic, lead, and manganese. Extensive background investigations were conducted.
- Lead Smelter Risk Evaluations, Utah—Provided risk assessment support for agency negotiations, site investigation strategy, and document review for several smelter sites in the Salt Lake Valley in Utah. Evaluated risks associated with arsenic, cadmium, and lead in soil and slag, considering residential and occupational exposures. Provided comments on EPA risk assessment and represented client in meetings with agency. Designed and directed a study of lead bioavailability in rats, in which site soils containing lead were added to the rat diet.

Risk Assessment for Manufacturing, Landfill, and Waste Combustion Sites

- Soil Mercury Exposure Analyses—Supported analyses of role of soil mercury speciation and bioavailability in moderating potential mercury exposures near a former battery manufacturing site in New York.

- PAH Risks at Former Coal Gasification Site—Provided human health risk support to a city parks department evaluating risks from residual PAHs in soil.
- Risk Evaluation for West Virginia Brownfield (Landfill) Site—Directed evaluations of human health and ecological risks associated with sediment and soil affected by releases from an historic landfill along the Kanawha River in Nitro, West Virginia. Risk assessments were used to support a voluntary cleanup application so that the site could be redeveloped as a boat ramp park. Presented findings at City Council meetings and a meeting of the citizen's advisory group.
- Brownfield Human Health Risk Assessment, South Charleston, West Virginia—Performed evaluations of risks associated with soils, groundwater, and a river affected by chlorinated organic compounds released from a former carbon tetrachloride production facility in West Virginia. The risk evaluations were conducted in accordance with the tiered system established by the state for the Voluntary Remediation Program. Focus was on assessing potential risks from exposures to volatile chlorinated organic compounds infiltrating planned new commercial buildings as parcels are put up for sale and utility and construction trenches. EPA's latest versions (2001) of the Johnson & Ettinger advanced building infiltration via groundwater and soil models were used to evaluate potential impacts to indoor air in future buildings. Participated in stakeholder meetings and public briefings regarding assessments of potential site risks before and after redevelopment.
- Human Health Risk Assessment for a Wood Treating Facility, Minnesota—Oversaw an extensive human health risk assessment for a confidential wood-treating facility in Minnesota that included traditional tribal lifeways of Native Americans living in the community. Chemicals of potential concern included PCBs, carcinogenic PAHs, pentachlorophenol, and dioxins/furans.
- Brownfield Redevelopment Risks—Provided human health risk support to a Midwestern city environmental department for several redevelopment properties with possible arsenic and lead contamination. Activities included evaluation of background concentrations and human health risk assessment.
- Pesticide Manufacturing Facility Evaluation, New York—Directed the development of risk-based cleanup levels for arsenic in offsite soils near a former arsenical pesticide manufacturing facility in New York. Offsite areas included a public school complex. Presented client's position to New York State Department of Environmental Conservation RCRA staff and New York State Department of Health staff. Made presentations to a public advisory group for the facility and at school board and community meetings.
- Chemical Distribution Facility Risk Communication, New Jersey—Prepared fact sheets for a chemical distribution facility with chlorinated volatile organic chemicals present in soil and groundwater. Fact sheets were distributed to neighboring business as part of an indemnity and access agreement. Preparation of fact sheets required reviewing site data, evaluating vapor intrusion modeling, identifying chemicals of potential concern, researching chemical toxicity, and determining the nature of potential exposures and likelihood of these exposures being of concern.
- Brownfield Redevelopment Vapor Intrusion Risk Assessment, California—For large industrial/commercial Brownfield redevelopment project in California, conducted indoor air risk assessment using Johnson & Ettinger model to assess risks from chlorinated solvents in soil and groundwater. Presented findings to potential purchaser and to state regulators.
- Hazardous Waste Combustor Risk Assessment Work Plan, Idaho—Managed preparation of human health risk assessment work plans for a planned hazardous waste combustor at a phosphorous production facility. Project included extensive negotiations with EPA and Tribal representatives, as well as intensive coordination with the engineering design team.

- Evaluation of Nickel Carcinogenicity—Critically evaluated the potential carcinogenicity of different forms of nickel present at a former steel mill site.
- Mercury Bioavailability Research and Risk Analysis, New Jersey—Provided guidance for risk assessment strategy at a former manufacturing site in New Jersey with mercury and dioxin contamination. Guided the design of studies of mercury bioavailability from soil, and prepared a comprehensive report presenting the results and justifying the selected approach for submittal to the state. Directed study of evaluating mercury vapor release from soil. Assisted in a comparison of dioxin data with regional background values.
- Assessment of Soil Arsenic Background and Risks, Illinois—Provided support in assessing potential risks associated with arsenic in soil in residential areas surrounding an operating glass factory in Illinois. Prepared a presentation for the Illinois Environmental Protection Agency and Department of Health and developed statistically defensible sampling plans to compare site concentrations to background. Prepared a comprehensive report proposing an innovative approach to identifying safe arsenic concentrations in soil for submittal to the state.
- Pesticide Manufacturing Facility, Texas—Prepared an exposure pathway analysis for a former pesticide manufacturing facility in Texas that has elevated concentrations of arsenic in soil, interior dust, groundwater, surface water, and lake sediments. Assisted in designing a soil sampling plan for site investigations overseen by the Texas Natural Resources Conservation Commission.
- Evaluation of Vapor Intrusion from Groundwater, Minnesota—Provided support in assessing potential exposures of residents and workers at a site in Minnesota to chlorinated volatile hydrocarbons in a groundwater plume. The chemicals evaluated include vinyl chloride, 1,1-dichloroethene, trichloroethene, and tetrachloroethene. Exposure pathways include infiltration from groundwater into basement air.
- Risk Evaluation of Chromium in Groundwater, Montana—Directed a screening-level evaluation of human health and ecological risks associated with chromium(VI) in a golf course pond and ditch in Montana. Evaluated transport and fate of chromium in a groundwater plume and potential impacts to a nearby river. Efforts supported a response action based on natural attenuation, with groundwater monitoring and a continuation of existing institutional controls on groundwater and land use.
- Navy Site Risk Assessment Support—Provided strategic guidance for risk assessment efforts for several Navy facilities. Participated in stakeholder meetings and reviewed draft documents.
- Wood Treatment Site Risk Evaluations, Butte, Montana—Managed preparation of documents describing the proper methods of evaluating human health and ecological risks from PCP, PAH, and dioxin contamination at a pole-treating plant in Butte, Montana. Assessed risks from exposures to soil, groundwater, surface water, and air.
- Bulk Fuel Terminal Risk Evaluation, Seattle, Washington—Provided senior review for a project to develop risk-based cleanup levels for a former bulk fuel terminal in Seattle, Washington.
- Bulk Fuel Facility Risk Evaluation, Kirkland, Washington—Provided senior review for the development of soil and groundwater cleanup levels for a former bulk fuel facility, currently being used as a municipal park, in Kirkland, Washington. Cleanup standards were developed using Washington State's Model Toxics Control Act Method B. Substances included petroleum constituents such as BTEX and PAH compounds.
- Gas Station Risk Evaluation, Seattle, Washington—Provided senior review for development of soil cleanup levels using Washington State's Model Toxics Control Act Method B for a former gas station in Seattle, Washington.
- Risk Evaluation for Petroleum Transfer Station, Alaska—Assisted in preparing a work plan and risk assessment to assess risks and develop cleanup levels for benzene-contaminated groundwater from leakage of petroleum products at a transfer station in Alaska. Groundwater was demonstrated to be unsuitable as a domestic water

source, and the need for remediation was based on potential exposures to volatile chemicals transferred into homes from the basement or ground level.

- Navy Facility Risk Evaluations, Washington—Served as project manager for USEPA technical enforcement support oversight activities at several US Navy NPL sites in Washington. Provided human health risk assessment guidance, and coordinated review of all aspects of remedial investigation work plans and reports. Contaminants included chlorinated hydrocarbons, solvents, metals, and fuels. Primary exposure pathways included groundwater, surface water, and marine organisms exposed to contaminated sediments.
- Municipal Incinerator Risk Assessment, Seattle, Washington—For the City of Seattle Solid Waste Utility, performed public health and risk analysis for a municipal incinerator as part of an EIS on waste reduction, recycling, and disposal alternatives. Assessed risks from stack emissions of metals, dioxins, and other organic compounds. Presented methods and results to local, state, and federal officials, environmental groups, the public, and a peer review committee.
- Hazardous Waste Incinerator Risk Evaluation, Florida—Directed human health and ecological risk assessment support activities for a private client opposing the permit application for a hazardous waste incinerator in Polk County, Florida. Critiqued a risk assessment submitted to the state in support of the permit for the incinerator.
- Hazardous Waste Incinerator Risk Evaluation, New Jersey—Performed a preliminary risk assessment for the development of a hazardous waste incinerator in New Jersey.
- Hazardous Waste Incinerator Risk Assessment Peer Evaluation, Kentucky—Provided extensive peer review comments on methods and results of a risk assessment on a hazardous waste incinerator in Kentucky.
- Municipal Incinerator Risk Analyses, Washington—Developed procedures and preliminary assessments for a municipal incinerator planned by a Native American tribe in Washington.
- Petroleum Refinery RCRA Risk Assessment, Colorado—Prepared a human and environmental assessment work plan for a RCRA facility investigation of a petroleum refinery in the western United States. Key contaminants included BTEX, PAHs, and chlorinated hydrocarbons.
- Underground Storage Tank Evaluation, Alaska—For the Alaska Department of Environmental Conservation (as subcontractor), determined technical requirements and critically reviewed risk assessment and proposed groundwater cleanup levels for a gasoline leak from an underground storage tank. Provided guidance for risk management strategy.
- Hazardous Waste Site Risk Assessments, Oregon—For the Oregon Department of Environmental Quality, provided strategic guidance and senior review for two risk assessments on hazardous waste sites: a baseline risk assessment conducted for a former wood-treatment facility that used PCP, creosote, and arsenical fungicides and a screening-level human health risk assessment for a hazardous waste site located in a unique desert environment. Key issues evaluated at the wood-treating facility included uncertainties in the slope factor for PCDDs and PCDFs and the comparative risks associated with consumption of fish and crayfish from reference locations. Potential contaminants of concern at the desert site included PCDDs and PCDFs, chlorinated phenoxy herbicides, lead, TCE, and benzene.
- Chloralkali Manufacturing Site Risks, New York—Provided senior review and guidance for an assessment of risks associated with mercury and PCBs in fish in Onondaga Lake. The impact of a former chloralkali facility on site risks was evaluated in comparison to the impacts of other sources in Onondaga and other comparable lakes.
- Munitions Facility Risk Evaluations, Oregon—Provided human health risk assessment guidance and work plan review for CERCLA and RCRA investigations of a federal facility in Oregon contaminated with munitions.

- Bioavailability of Metals in Refinery Soil, New Jersey—Provided strategic guidance and senior review for an evaluation of the bioavailability of arsenic, beryllium, and lead from soil at an operating refinery in New Jersey.
- Manufacturing Facility Risk Assessment, Ohio—Provided senior review for human health risk assessment components of an expedited RI/FS for an alloy and chemical production facility in Ohio that has produced both radiological and chemical wastes. Tasks include designing and implementing the baseline risk assessment for an operating facility and participating in the selection of cleanup levels and remedial actions. Primary chemicals of concern include arsenic, chromium, vanadium, and the radionuclide decay chains of thorium-232 and uranium-238.
- Pulp Mill Risk Assessment, Alaska—Provided senior review of human health risk assessment issues for an RI/FS of marine areas potentially affected by releases from a pulp mill. Reviewed a work plan to identify potential human health risks associated with exposure to substances in sediments that may bioaccumulate to fish. Key issues include identifying appropriate background concentrations of PCDDs/PCDFs in fish and shellfish in the region and at other United States locations and selecting representative fish consumption rates for use in the risk assessment.
- Assessment of Mercury Risks for Instrument Manufacturing Site, Rochester, New York—Provided senior review for the development of alternative cleanup levels for mercury in site soils using site-specific bioavailability data from a former instrument manufacturing facility in Rochester, New York.
- Manufacturing Facility Risk Assessment, California—Provided technical review for a comprehensive baseline human health risk assessment for a former manufacturing facility in southern California. More than 30 chemicals of potential health concern were detected in soil, groundwater, or ambient air, including BTEX, nitro, phenolic, and chlorinated organic compounds.
- Military Installation Risk Assessment, San Francisco, California—Provided strategic guidance and senior review for multipathway human health and ecological risk assessments for a military installation in San Francisco, California, comprising 11 major study areas and more than 40 individual sites. The risk assessments were used to support the selection of sites to be considered in the feasibility study and for the development of preliminary soil cleanup levels. Chemicals of concern included metals, volatile organic compounds, PAHs, PCBs, and pesticides.
- Appliance Manufacturing Site Risk Assessment, Ohio—Assisted in developing an approach to assess human health risks from lead in soil and sediment at a television manufacturing facility in Ohio.

Product and Community Risk and Exposure Assessments

- Risks of PAH in Coal Tar Products—Provided critical review of study of influence of coal tar sealcoat on house dust PAH concentrations.
- Asbestos Exposure and Risk Evaluation for Sediment/Soil, Swift Creek WA—Analysis conducted on behalf of the county in support of wetland delineation for a creek that transported naturally occurring asbestos and was subject to flooding/dredging events. Reviewed and critiqued EPA sampling and risk evaluation. Key issues that affected interpretation of risk were related to the type of analysis performed in comparison with hose used to develop the standards.
- Risk Assessment of Arsenic in Gravel Products—Directed probabilistic risk assessment for potential exposures to arsenic in gravel used for road construction and landscaping.
- Evaluation of Dioxin Exposures from Dredged Material Disposal, Puget Sound, Washington—Provided comments for ports on an EPA/US Army Corps of Engineers analysis of potential exposures to polychlorinated dibenzo-p-dioxins and dibenzofurans in seafood affected by dredged material disposal in Puget Sound.
- Risks of Residual Petroleum, Suquamish, Washington—Provided oversight for evaluation of potential exposures to residual petroleum at a Tribal beach affected by a recent oil spill. Exposures due to consuming shellfish,

harvesting aquatic vegetation, and performing other activities at the impacted beach were assessed. Shellfish bed reopening criteria were evaluated. A statistical comparison of oil-impacted and reference location shellfish tissue and sediment data was conducted.

- Risks of Herbicide Application to Lakes, Washington—For Washington State Department of Ecology, updated and revised a human health risk assessment for an EIS on the application of herbicides to Washington lakes.
- School Property Pesticide Evaluation, New York—For a New York State school district, evaluated potential exposures of students to pesticide residues in athletic field soils. Arsenic was primary concern. Also evaluated potential association of lymphoma cases to pesticides detected in soil.
- School Property Evaluation, New York—On behalf of a school board in New York State, critically evaluated a state investigation of contamination at a high school built on a former industrial site. Presented findings at a public meeting of a citizen's advisory committee.
- Methylmercury Exposure Study, Nome, Alaska—For the Norton Sound Health Cooperative, participated in planning and design of a study of methylmercury concentrations in hair of native Alaskans subsisting on fish and sea mammals in Nome, Alaska.
- Risks of Road Fill, Alaska—Assisted the Alaska Department of Transportation (as subcontractor) in a preliminary assessment of risks from metals and pesticides in fill material used during construction of a road in Alaska.

Regulatory and Research Projects

- Prepared comments on USEPA's December 2011 Technical Support Document: National Scale Mercury Risk Assessment Supporting the Appropriate and Necessary Finding for Coal- and Oil Fired Electric Generating Units, focusing on assumptions about methylmercury uptake into fish and fish consumption rates, on behalf og Southern Company.
- Submitted comments on Washington Department of Ecology draft report titled "*Fish Consumption Rates Technical Support Document: A Review of Data and Information About Fish Consumption in Washington*" dated September 2011, on behalf of Pacific Coast Shellfish Growers Association.
- Made presentations, gave testimony and submitted comments in support of increases in the Maine ambient water quality criteria (AWQC) for inorganic arsenic (health protection) to 1.2 µg/L for water and organisms and to 2.8 µg /L for organisms only, and to increase the arsenic screening standard for the agronomic utilization of sewage sludge (biosolids) from 10 mg/kg to 34 mg/kg, on behalf of the Arsenic Legislation Coalition.
- Directed preparation of a report to address uncertainties in dermal absorption of contaminants from soil and sediments. Health Canada may use the report in a protocol for development of sediment quality guidelines and in guidance being developed for evaluation of human health risks associated with exposure to contaminated sediments, on behalf of Health Canada.
- Developed Guidance on Consideration of Oral Bioavailability of Chemicals in Soil for Use in Human Health Risk Assessment, on behalf of Health Canada.
- Provided peer review comments on the selection and derivation of bioaccessibility and bioavailability values for inorganic lead in the *Draft Revised Health Canada Human Health Soil Quality Guidelines* (2011), on behalf of Health Canada.
- SERDP Soil PAH Bioavailability Project—Participated in DoD Strategic Environmental Research and Development Program funded research project on PAH interactions with soil and effects on bioaccessibility and bioavailability to humans.

- SERDP Soil Metal Bioavailability Project—articipated in DoD Strategic Environmental Research and Development Program funded research project on soil metal bioaccessibility and bioavailability to humans.
- Bioavailability White Paper—Directed development of a white paper for the Ontario Ministry of Environment on the use of oral bioavailability adjustments in human health risk assessment. Peer-reviewed literature was critically reviewed and synthesized. The resulting white paper provides a background for use of bioavailability studies, site-specific and chemical-specific concerns, use of soil amendments to reduce bioavailability, methods for conducting in vitro and in vivo bioavailability studies, and other factors to consider when applying relative bioavailability adjustments in risk assessment.
- Arsenic Bioaccumulation and Speciation in Seafood—Conducted a literature review and prepared a document supporting a EPA re-evaluation of the ambient water quality criterion (AWQC) for human health effects of arsenic. Calculated AWQC using studies on bioconcentration factors and arsenic speciation acquired from the literature review. Directed the development of manuscripts evaluating bioaccumulation and speciation of arsenic in seafood.
- Regulatory Comment, California—Submitted comments on a California draft public health goal for arsenic in drinking water.
- New Facility Air Permit Support, Washington—On behalf of private developer, derived a risk-based acceptable new source impact level (ASIL) for use in evaluating predicted air releases of 1,3-butadiene from a proposed recreational facility in Washington.
- Department of Defense Bioavailability Field Guide—Updated a Department of the Navy Field Guide for use by Department of Defense project managers in evaluating the bioavailability of metals in soil to both ecological and human receptors at contaminated sites. Also contributed major sections of the original Field Guide.
- TPH Standards Guidance Review, West Virginia—Critically reviewed draft supplemental guidance on development of total petroleum hydrocarbons risk-based standards for the West Virginia Department of Environmental Protection. Verified applicability of analytical methods and TPH carbon range fractions proposed and evaluated appropriateness of toxicity factors developed in the guidance. Provided review comments in context of the TPH Criteria Working Group guidance documents and Massachusetts TPH risk policy.
- Metal Bioavailability Research Program—Managed a bioavailability research program of arsenic and lead in soils contaminated by mining and smelting wastes that demonstrated reduced absorption of these metals from soils. Mineralogic analyses and in vitro screening studies were used to help interpret the results of animal studies. Research results have been published in peer-reviewed journals and have been cited by EPA in support of precedent-setting changes in risk assessment assumptions that resulted in much higher cleanup levels.
- Taiwanese Dietary Arsenic Research Project—Directed investigation of inorganic arsenic intake in the diet of people living in areas of Taiwan with elevated arsenic concentrations in artesian well water. Samples of rice and yams collected in Taiwan showed that arsenic intake from the Taiwanese diet was much higher than previously assumed, suggesting that EPA's toxicity values might overestimate arsenic toxicity.
- US Dietary Arsenic Research Project—Directed an investigation of dietary arsenic intake in the US. A market basket survey of 40 commodities demonstrated the presence of inorganic arsenic as a normal occurrence in the American diet.
- Copper Smelter Risk Assessment Research Program, Montana—Provided strategic risk assessment support during an 8 year period for the evaluation of four operable units at a former copper smelter site in Anaconda, Montana. A research program was developed to fully characterize potential risks associated with arsenic, cadmium, and lead in soil and waste materials from copper smelting operations. Participated in review of work plans and data interpretation by a working group of client and EPA staff and consultants. An epidemiology study demonstrated

that current exposures were negligible, and studies of arsenic bioavailability and soil ingestion provided support for site-specific assumptions. Soil arsenic cleanup levels of 250, 500, and 1,000 mg/kg for residential, industrial, and recreational areas, respectively, were adopted based on the application of these site-specific studies in the human health risk assessments for the site.

- Regulatory Comment—For an industry association, directed the preparation of comments on the Proposed Rule on the Bevill Exclusion for Mining Wastes. Critiqued EPA's assessment of damages to human health and the environment caused by land-based units, and concluded that most of the damages cited by EPA are only of historical relevance and do not reflect current mining practices. Also critiqued the use of the toxicity characteristic leaching procedure as a means of measuring the toxicity of mineral processing wastes, and concluded that it is an overly aggressive and unrealistic test for evaluating these materials.
- Sub-title D Municipal Landfill Permitting, New Mexico—For client attempting to site a sub title D municipal landfill, prepared an affidavit rebutting assertions regarding potential adverse health effects of such landfills. Affidavit was submitted to the docket for the permit hearing and resulted in withdrawal of the allegations.
- Evaluation of Ocean Disposal of Dioxin-Containing Sediments, Grays Harbor, Washington—For the US Army Corps of Engineers, performed a risk assessment for ocean disposal of dioxin-contaminated sediments from Grays Harbor, Washington. Evaluated potential exposures to dioxins in Dungeness crabs that might contact contaminated sediments in an ocean disposal site for dredged materials. Evaluation included derivation of site-specific crab consumption values and crab life cycle evaluation.
- PCB Risk Assessment Sensitivity Analysis—Directed a PCB risk assessment sensitivity analysis project. Identifying those components of risk assessment methodology that have the greatest influence on PCB cleanup levels.
- EIS Health Impact Analysis, Washington—For the Washington State Department of Ecology, evaluated potential human health impacts of cleanup alternatives for an EIS for Washington State's Model Toxics Control Act. Participated in developing the risk-based alternative.

Litigation Projects

- Clean Water Act Violations—Provided expert opinions and trial testimony related to potential chlorine gas exposures for the defense (Federal Public Defender) in US v. Patrick Dooley, Case No. CR11-252MJP, US District Court, Western District of Washington at Seattle (January 2012).
- Shoreline Development Permit State Appeal, Washington—Provided testimony at hearing appealing County determination of nonsignificance for shoreline substantial development application for a shellfish-geoduck farm (March 1, 2012). Testimony addressed claims asserted by Appellants' experts regarding the toxicity of metals in polyvinyl chloride (PVC) tubing used in geoduck aquaculture. Shorelines Hearings Board, State of Washington, Case reference SHB No. 11-019. "Coalition to Protect Puget Sound Habitat and Case Inlet Association vs. Pierce County and Longbranch Shellfish LLC."
- Shoreline Development Permit County Appeal, Washington—Provided expert report and testimony at hearing appealing County determination of nonsignificance for shoreline substantial development application for a shellfish-geoduck farm (March 2011). Report and testimony addressed claims asserted by Appellants' experts regarding the toxicity of metals in polyvinyl chloride (PVC) tubing used in geoduck aquaculture. Pierce County Hearing Examiner case reference SD_22-06\688646, "Coalition to Protect Puget Sound Habitat vs. Longbranch Shellfish LLC."
- Evaluation of Coke Plant Emissions—Provided expert report regarding the potential for increased health risks due to SO_2 and $PM_{2.5}$ among residents and employees of the City of Monroe due to air emissions from the Middletown Coke Company Plant. Ohio Environmental Review and Appeals Commission. Robert D. Snook

Natural Resources Defense Council et al., City of Monroe, Ohio v. Chris Korleski, Middletown Coke Company, Inc., SunCoke Energy, Inc. Case Nos. ERAC 096432-8.

- Indoor Air Quality—Provided declaration in support of motion to strike opposing expert's declaration related to a residential indoor air quality evaluation in April Norton Rauch v. Ballard Leary Phase II, LP, BRCP/CPI Leary LLC, YOTM LLC, No. 09-2-21126-4 SEA in the Superior Court of the State of Washington, King County.
- Worker Compensation Case, Washington—Provided expert opinions and deposition for the defense for an appeal to the Board of Industrial Insurance Appeals regarding alleged solvent exposures and toxic solvent encephalopathy and Alzheimer's disease.
- Insurance Cost Recovery Litigation, Multiple Sites—Provided expert opinions and deposition regarding historical knowledge of arsenic toxicity in case related to remediation of arsenical pesticide production/formulation facilities. Case settled.
- Mining and Smelting Site Litigation, Idaho—Provided expert opinions for the defense regarding lead exposures in medical monitoring class certification proceedings. Certification denied.
- Mining Site Litigation, Oklahoma—Provided expert opinions and deposition for the defense regarding lead exposures in historic zinc mining district. Class certification ruling pending.
- Copper Chromated Arsenic Litigation, Indiana—Provided expert opinions for the defense regarding CCA exposures from residential deck. Case settled.
- Roxarsone Litigation, Arkansas—Provided expert opinions and deposition for the defense regarding exposures to roxarsone from poultry operations. Court sustained defendants' motion for summary judgment.
- Residential Mold Litigation, Washington—Provided expert opinions for the defense regarding mold exposures in a tenant/landlord dispute. Case settled.
- Asbestos Litigation, Washington—Provided expert opinions and deposition for the plaintiffs regarding exposures to asbestos-containing dusts by apartment tenants occupying a multiunit residential building during large-scale plumbing renovation that occurred in the absence of asbestos control measures. Case settled.
- Vapor Intrusion Litigation, Seattle, Washington—Named as testifying expert and prepared for deposition in litigation related to potential impacts of infiltration of vapors from volatile chemicals in groundwater into a business adjacent to a waste chemical processing facility. Conducted in-depth review of baseline risk assessment, inhalation pathway assessment, and state health consultation prepared for site; evaluating building vapor intrusion modeling; critically assessing EPA's Johnson and Ettinger model; assessing potential employee exposures; and researching toxicity assessments of chlorinated volatile organic chemicals and benzene. Compiled list of technical questions to be asked of opposing expert.
- Pesticide Manufacturing Facility Releases, Texas—Made a presentation to a district attorney and investigators conducting a manslaughter investigation related to chemical releases from a pesticide manufacturing facility.

Prior to joining ENVIRON, Dr. Schoof held the following positions:

- Integral Consulting Inc., Mercer Island and Seattle, WA, September 2002-February 2010 (7.5 years), Principal.
- Gradient Corporation, Mercer Island, WA, July 2000-July 2002 (2 years), Principal.
- Exponent, Bellevue, WA, September 1988-July 2000 (12 years), Principal and Senior Toxicologist.
- Environmental Toxicology International, Seattle, WA, November 1987-August 1988 (1 year), Senior Toxicologist.

- Ortho Pharmaceutical Corporation (Drug Safety Evaluation), Raritan, NJ, September 1982-July 1987 (5 years), Toxicologist.
- US Environmental Protection Agency (Office of Toxic Substances), Washington, D.C., December 1975-August 1977 (2 years), Chemist.

CREDENTIALS

Registrations and Certifications

Diplomate, American Board of Toxicology (certified in 1986, recertified in 1991, 1996, 2001, 2006, and 2011)

Fellow, Academy of Toxicological Sciences

Professional Affiliations and Activities

Society of Toxicology

Society for Risk Analysis

International Society for Exposure Science

PUBLICATIONS & PRESENTATIONS

Elert, M., Bonnard, R., Jones, C., Schoof, R.A., and Swartjes, F.A. 2011. Human exposure pathways. pp. 455–515. In: Dealing with Contaminated Sites. F.A. Swartjes (ed). Springer.

Schoof, R.A. 2008. How will new USEPA guidance affect research on the bioavailability of metals in soil? (editorial). Hum. Ecol. Risk Assess.14:1-4.

Lowney, Y.W., R.C. Wester, R.A. Schoof, C.A. Cushing, and M.V. Ruby. 2007. Dermal absorption of arsenic from soils as measured in the Rhesus monkey. Toxicol. Sciences. 100:381-392.

Schoof, R.A., and J.W. Yager. 2007. Variation of total and speciated arsenic in commonly consumed fish and seafood. Hum. Ecol. Risk Assess. 13:946-965.

Williams, L., R.A. Schoof, J.W. Yager, and J.W. Goodrich-Mahoney. 2006. Arsenic bioaccumulation in freshwater fishes. Hum. Ecol. Risk Assess. 12(5):904-923.

Schoof, R.A., and D. Houkal. 2005. The evolving science of chemical risk assessment for land applied biosolids. J. Environ. Qual. 34:114-121.

Kester, G.B., R.B. Brobst, A. Carpenter, R.L. Chaney, A.B. Rubin, R.A. Schoof, and D.S. Taylor. 2005. Risk characterization, assessment and management of organic pollutants in beneficially used residual products. J. Environ. Qual. 34:80-90.

Lowney, Y.W., M.V. Ruby, R.C. Wester, R.A. Schoof, S.E. Holm, X.Y. Hui, S. Barbadillo, and H.I. Maibach. 2005. Percutaneous absorption of arsenic from environmental media. Toxicol. Ind. Health 21:1-14.

Schoof, R.A. 2004. Bioavailability of soil-borne chemicals: Method development and validation. Human Ecol. Risk Assess. 10:637-646.

Wester, R.C., H. Xiaoying, S. Barbadillo, H.I. Maibach, Y.W. Lowney, R.A. Schoof, S.E. Holm, and M.V. Ruby. 2004. In vivo percutaneous absorption of arsenic from water and CCA-treated wood residue. Toxicol. Sciences. 79:287-295.

Yost, L.J., S.-H. Tao, S.K. Egan, L.M. Barraj, K.M. Smith, J.S. Tsuji, Y.W. Lowney, R.A. Schoof, and N.J. Rachman. 2004. Estimation of dietary intake of inorganic arsenic in US children. Hum. Ecol. Risk Assess. 10:473-483.

Schoof, R.A., J.S., Tsuji, R. Benson, and G.C. Hook. 2004. Response to Byrd et al. (2004) comment on health effect levels for assessing childhood exposure to arsenic in soil. Reg. Toxicol. Pharmacol. 40:374-375.

Tsuji, J.S., R. Benson, R.A. Schoof, and G.C. Hook. 2004. Response to additional support for derivation of an acute/subchronic reference level for arsenic. Reg. Toxicol. Pharmacol. 40:372.

Tsuji, J.S., R. Benson, R.A. Schoof, and G.C. Hook. 2004. Health effect levels for assessing childhood exposure to arsenic in soil. Reg. Toxicol. Pharmacol. 39(2):99-110.

Meacher, D.M., D.B. Menzel, M.D. Dillencourt, L.F. Bic, R.A. Schoof, L.J. Yost, J.C. Eickhoff, and C.H. Farr. 2002. Estimation of multimedia inorganic arsenic intake in the US population. Hum. Ecol. Risk Assess. 8:1697-1721.

Kelley, M., S. Brauning, R. Schoof, and M. Ruby. 2002. Assessing oral bioavailability of metals in soil. 136 pp. Battelle Press, Columbus, OH.

Ruby, M.V., R. Schoof, W. Brattin, M. Harnois, D.E. Mosby, S.W. Casteel, W. Berti, M. Carpenter, D. Edwards, D. Cragin, and W. Chappell. 1999. Advances in evaluating the oral bioavailability of inorganics in soil for use in human health risk assessment. Env. Sci. Tech. 33(21):3697–3705.

Schoof, R.A., L.J. Yost, J. Eickhoff, E.A. Crecelius, D.W. Cragin, D.M. Meacher, and D.B. Menzel. 1999. A market basket survey of inorganic arsenic in food. Food Chem. Toxicol. 37:839–846.

Schoof, R.A., J. Eickhoff, L.J. Yost, E.A. Crecelius, D.W. Cragin, D.M. Meacher, and D.B. Menzel. 1999. Dietary exposure to inorganic arsenic. pp. 81–88. In: Proc. Third International Conference on Arsenic Exposure and Health Effects. W.R. Chappell, C.O. Abernathy, and R.L. Calderon (eds). Elsevier Science Ltd.

Schoof, R.A., L.J. Yost, E. Crecelius, K. Irgolic, H.-R. Guo, and H.L. Greene. 1998. Dietary arsenic intake in Taiwanese districts with elevated arsenic in drinking water. Hum. Ecol. Risk Assess. 4(1):117-136.

Yost, L.J., R.A. Schoof, and R. Aucoin. 1998. Intake of inorganic arsenic in the North American diet. Hum. Ecol. Risk Assess. 4(1):137-152.

Schoof, R.A., and J.B. Nielsen. 1997. Evaluation of methods for assessing the oral bioavailability of inorganic mercury in soil. Risk Analysis 17(5): 545-555.

Slayton, T.M., B.D. Beck, K.A. Reynolds, S.D. Chapnick, P.A. Valberg, L.J. Yost, R.A. Schoof, T.D. Gauthier, and L. Jones. 1996. Issues in arsenic cancer risk assessment. Environ. Health Perspect. 104(10):1012-1013.

Ruby, M.V., A. Davis, R. Schoof, S. Eberle, and C. Sellstone. 1996. Estimation of lead and arsenic bioavailability using a physiologically based extraction test. Environ. Sci. Technol. 30(2):422-430.

Davis, A., M.V. Ruby, M. Bloom, R. Schoof, G. Freeman, and P.D. Bergstrom. 1996. Mineralogic constraints on the bioavailability of arsenic in smelter-impacted soils. Environ. Sci. Technol. 30(2):392-399.

Schoof, R.A., M.K. Butcher, C. Sellstone, R.W. Ball, J.R. Fricke, V. Keller, and B. Keehn. 1995. An assessment of lead absorption from soil affected by smelter emissions. Environ. Geochem. Health. 17:189–199.

Freeman, G.B., R.A. Schoof, M.V. Ruby, A.O. Davis, S.C. Liao, and P.D. Bergstrom. 1995. Bioavailability of arsenic in soil and house dust impacted by smelter activities following oral administration in Cynomolgus monkeys. Fund. Appl. Toxicol. 28:215–222.

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Freeman, G.B., J.D. Johnson, S.C. Liao, P.I. Feder, A.O. Davis, M.V. Ruby, R.A. Schoof, R.L. Chaney, and P.D. Bergstrom. 1994. Absolute bioavailability of lead acetate and mining waste lead in rats. Toxicology 91:151–163.

Steele, M.J., S.G. Whittaker, and R.A. Schoof. 1992. The impact of assumptions regarding metal concentrations in soil and dust on setting remedial objectives. In: Risk assessment/management issues in the environmental planning of mines. D. Van Zyl, M. Koval, and T.M. Li (eds.) Society for Mining, Metallurgy and Exploration, Littleton, CO.

Davis, A., M.V. Ruby, and R. Schoof. 1992. Comments on "Lead, cadmium, and zinc contamination of Aspen garden soils and vegetation," by D.Y. Boon and P.N. Saltanpow. J. Environ. Qual. 21:82–86, 509–510.

Katz, L.B., R.A. Schoof, and D.A. Shriver. 1987. Use of a five-day test to predict the long-term effects of gastric antisecretory agents on serum gastrin in rats. J. Pharmacological Methods 18(4):275–282.

Schoof, R.A., and C.S. Baxter. 1986. Topical application of a tumor promoter induces proliferation of an adherent cell population in murine spleen. Int. J. Immunopharm. 8:455–462.

Hahn, D.W., N. Hetyei, L. Beck, J.L. McGuire, and R.A. Schoof. 1985. Pharmacology and toxicology studies with microencapsulated norgestimate as a long acting injectable contraceptive. Adv. Contraception 2:235–236.

Baxter, C.S., R.A. Schoof, and A.T. Lawrence. 1984. Interaction of tumor promoting agents with immunofunctional cells in vitro and in vivo. International Agency for Research on Cancer Scientific Publications, No. 56.

INVITED PRESENTATIONS/PANELS/PEER REVIEWS/AWARDS

7/12—Synergies of HIA and Ecosystem Services in International Development Projects. Talk presented at session titled "Health Impact Assessment – A Key to Sustainable Development" at the World Congress on Risk in Sydney, Australia. Session co-chair.

3/12— Beyond Lead and Arsenic: How are other metals being addressed? Invited talk presented at workshop session titled "Assessing the Bioavailability and Risk from Metal-contaminated Soils and Dusts" at the 51st Meeting of the Society of Toxicology in San Francisco, CA.

2009 to present—Washington Department of Ecology MTCA Science Panel. Appointed member of Model Toxics Control Act Science Panel, serving 3-year term.

9/09—5th International Workshop on Chemical Bioavailability, Adelaide, Australia. Invited plenary lecture titled "Developing Oral Bioavailability Data for Risk Assessments: Method Development and Burden of Proof".

1/06 to 1/09—Metals in the Human Environment Research Network (a Canadian university research consortium funded by the Canadian National Science and Engineering Research Council): Expert advisory panel member, Gatineau, Quebec.

1/09—National Research Council: Peer review of "Contaminated Water Supplies at Camp Lejeune—Assessing Potential Health Risks," November 2008 Peer Review Copy.

10/08 to 6/09—DuPont-EPA PFOA Peer Consultation Panel. Peer consultation on exposure assessment for perfluorooctanoic acid released from DuPont Washington Works facility.

1/07 to 07/08—National Research Council: Committee on Beryllium Alloy Exposures, Washington, DC.

10/07—Lifetime Achievement Award given by the Annual International Conference on Sediments Soils and Water under the auspices of the University of Massachusetts for significant contribution to a field of science or engineering, as assessed by the level and longevity of contributions, assumption of responsibilities, and volunteerism for charitable organizations and not-for-profit groups.

10/07—International Society for Exposure Analysis annual meeting: Co-organizer of symposium titled "Use of In Vitro Bioaccessibility/Relative Bioavailability Estimates in Regulatory Settings: What Is Needed?" and talk titled "Method development and the application of oral bioavailability data in US risk assessments," Durham, NC.

12/06 to present—Human and Ecological Risk Assessment: Member editorial review board.

8/06 to 12/06—Toxicology for Excellence in Risk Assessment: Peer review panel member for review of the Sudbury Soils Study Human Health Risk Assessment, Sudbury, Ontario.

9/06—International Society for Exposure Analysis annual meeting: Invited speaker at symposium titled "Childhood exposures to bioavailable metals in soil and household dust in residential environments," talk titled "Method development and the application of oral bioavailability data in US risk assessments," Paris, France.

9/06—American Chemical Society annual meeting: Invited speaker at Agricultural & Food Chemistry Division symposium on Heavy Metals in Food, talk titled "Dietary intake of toxic forms of arsenic," San Francisco, CA.

9/06—Electric Power Research Institute: Invited speaker at Environment Sector meeting, talk titled "Critical evaluation of ambient water quality criterion for arsenic: bioaccumulation and speciation issues," Atlanta, GA.

11/05—University of Washington Department of Environmental Health seminar series: Invited lecture titled "Probabilistic lead model for an operating smelter in South America," Seattle, WA.

6/05—XIII International Conference on Heavy Metal in the Environment: Invited member of Arsenic Environmental Health Research Panel, talk titled "Arsenic speciation in commonly consumed organisms," Rio de Janeiro, Brazil.

6/04—Canadian National Science and Engineering Research Council: Research grant application site visit panel member, Guelph, Ontario.

3/04—Society of Toxicology annual meeting: Co-chair of risk assessment poster session, Baltimore, MD.

2/04—US Environmental Protection Agency: Peer review of Lead Bioavailability Technical Support Document.

1/04—Sustainable Land Application Conference: Invited lecture titled "The evolving science of chemical risk assessment as applied to land application of biosolids effluents and manures," Lake Buena Vista, FL.

1/04 to present—Science Advisory Board for Contaminated Sites in British Columbia: appointed member, Vancouver, BC.

8/02 to 3/04—National Research Council: Member of Subcommittee on Toxicological Risks to Deployed Military Personnel.

11/03—People to People Ambassador Program: Toxicology Delegation to China: Beijing, Guilin, and Shanghai.

4/03—US Environmental Protection Agency: Invited Speaker at workshop on bioavailability of metals in Tampa, FL. Gave talk on the role of bioavailability model validation in site-specific decision-making.

7/02—National Research Council: Peer review of "Bioavailability of contaminants in soils and sediments: Processes, tools and applications," Peer Review Copy.

8/02—US Environmental Protection Agency: Peer review of draft "Estimates of soil ingestion in children," by Cain et al.

6/02—Mealey's Emerging Toxic Tort Conference: Lecture titled "Up to date analysis of water contamination cases: The science," Pasadena, CA.

3/01 to 6/02—National Research Council: Appointment to Committee on Toxicants and Pathogens in Biosolids. Book issued titled Biosolids applied to land: advancing standards and practices. Participated in Congressional briefing of committee findings.

4/02—Center for Environmental & Occupational Risk Analysis and Management, College of Public Health, University of South Florida, Tampa: Lecture titled "Consideration of background exposures and bioavailability in designing arsenic biomonitoring studies."

3/02—Electric Power Research Institute Advisory committee meeting. Lecture titled "Arsenic exposure and risk: Public perception vs. likely exposure pathways."

10/01—Ontario Ministry of the Environment. Member of international peer review panel evaluating draft risk assessment for the Rodney Street community in Port Colborne, FL.

10/01—Contaminated Soils, Sediments and Water annual conference: Lecture titled "Methodological issues in assessing dermal absorption of chemicals" in Dermal Bioavailability session.

9/01—Northwest Biosolids Management Association annual conference: Keynote speech describing the National Research Council biosolids committee membership and charge.

4/01—US Environmental Protection Agency: Peer review of draft supplemental guidance for developing soil screening levels for Superfund sites.

3/01—Society of Toxicology annual meeting: Lecture on metal bioavailability in continuing education course on risk assessment of metals.

3/01—Society of Toxicology annual meeting: Co-chair of workshop on consideration of bioavailability in risk assessment.

2/01—Secretary of the Navy Environmental Awards FY 2000: Judge.

9/00—Agency for Toxic Substances and Disease Registry: Technical review of mercury releases from lithium enrichment at the Oak Ridge Y12 plant, July 1999.

9/00—US Environmental Protection Agency: Peer review of draft documentation for short-term arsenic toxicity value.

5/00—Agency for Toxic Substances and Disease Registry: Peer review of draft toxicity profile for creosote.

10/99—15th Annual International Conference on Contaminated Soils and Water (AEHS): Organized 3-hour workshop (taught with two colleagues) titled "Development of site-specific bioaccessibility and bioavailability data and their application to human health risk assessment." Co-organized and co-chaired technical session titled "Bioavailability of contaminants in soil," Amherst, MA, October 1999.

10/99—National Institute of Environmental Health Sciences Superfund Basic Research Program grant application review, special emphasis panel member, Research Triangle Park, NC, October 1999.

7/99—ASCE-CSCE Environmental Engineering Conference: "Application of bioavailability to environmental cleanup settings: case studies," Norfolk, VA, July 1999.

5/99—Chemical Manufacturer's Association Exposure Assessment Workshop: Member of panel making recommendations regarding research projects CMA should fund in the area of dermal exposure assessment, Research Triangle Park, NC, May 1999.

5/99—US Dept. of the Navy Remediation Innovation Technology Seminar series: One of four primary speakers for day long course. Topic was "The role of bioavailability in risk assessment," San Diego and San Francisco, CA, Silverdale, WA, Philadelphia, PA, Charleston, SC, and Honolulu, HI, May 1999.

12/98—US Environmental Protection Agency workshop on issues associated with dermal exposure and uptake: Peer consultant reviewing draft risk assessment guidance, Bethesda, MD, December 1998.

12/98—National Environmental Policy Institute Conference-Bioavailability: Using what we know, learning what we need: "Why consider bioavailability in risk assessment?" Washington, D.C., December 1998.

8/98—US Environmental Protection Agency Modeling Lead Exposure and Bioavailability Workshop: "Interpreting in vitro bioavailability studies," Durham, NC, August 1998.

7/98—Third International Conference on Arsenic Exposure and Health Effects: "A market basket survey of inorganic arsenic in food," San Diego, CA, July 1998.

12/97—IBC's International Congress on Human Health Bioavailability: "Practical experience in developing/negotiating the use of bioavailability adjustments," Scottsdale, AZ, December 1997.

9/96—US Environmental Protection Agency and US Department of Energy Mercury Speciation Workshop: "Biological models to predict soil mercury bioavailability to humans," Denver, CO, September 1996.

12/96—US Geological Survey Arsenic Workshop: "The role of bioavailability studies in deriving risk-based cleanup levels for arsenic in soil," Sutter Creek, CA, December 1996.

3/96—NJDEP Interagency Risk Assessment Committee: "Assessing the oral bioavailability of metals in soil," Trenton, NJ, March, 1996.

8/95—ATSDR Science Panel on the Bioavailability of Inorganic Mercury: Served as a member of an Agency for Toxic Substances and Disease Registry (ATSDR) expert science panel on the bioavailability of mercury in soil. Served as lead author on a manuscript reviewing methods and available data for assessing the oral absorption of various forms of inorganic mercury, Atlanta, GA, August 1995.

12/95—TNRCC Arsenic Symposium: Served as one of four invited experts at a 1-day symposium to brief toxicologists and project managers from the Texas Natural Resource Conservation Commission on the latest developments in assessing risks associated with arsenic in soil, Austin, TX, December 1995.

1992—Oregon DEQ Cross Media Advisory Committee: Appointed by the Director of the Oregon Department of Environmental Quality (DEQ) to serve on an advisory committee that reviewed and commented on the methodology developed by DEQ to evaluate cross media regulatory impacts and develop a more integrated approach to the permit process. Also participated in technical subcommittee of toxicologists that provided detailed technical review of a comparative risk assessment model developed to rank chemical exposure and hazard to human and ecological receptors, Portland, OR, 1992–1993.

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Exhibit B

Human Health Risk Assessment Report, La Oroya Metallurgical Complex, Prepared for Doe Run Peru. Integral Consulting Inc., Mercer Island, WA (2005)

HUMAN HEALTH RISK ASSESSMENT REPORT

LA OROYA METALLURGICAL COMPLEX

Prepared by

integral consulting inc.

7900 SE 28th Street
Suite 300
Mercer Island, WA 98040 USA
www.integral-corp.com

Prepared for

Doe Run Peru
Victor Andres Belaunde 147
Torre Real 3, Piso 9, San Isidro
Lima, Peru

December 2, 2005

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ACRONYMS AND ABBREVIATIONS

AEGLs	acute exposure guideline levels
ALAD	δ-aminolevulinic acid dehydratase
ALM	adult lead model (model)
As	arsenic
AT	averaging time
ATSDR	U.S. Agency of Toxic Substances and Disease Registry
bgs	below ground surface
BKSF	biokinetic slope factor
BW	body weight
CalEPA	California Environmental Protection Agency
CALPUFF	USEPA's air quality dispersion model
CCME	Canadian Council of Ministers of the Environment
Cd	cadmium
CD	community (outdoor) dust
CDC	U.S. Centers for Disease Control and Prevention
CF	units conversion factor
cm	centimeter
Complex	Doe Run Perú Metallurgical Complex
CR	contact rate
CS	community surface soil locations
CSF	cancer slope factor
CTE	central tendency exposure
DIGESA	Ministry of Health's Environmental Health Directorate
dL	deciliter
DMA	dimethyl arsenic acid
DRP	Doe Run Perú
ED	exposure duration
EF	exposure frequency
EMSAPA	municipal organization
EPC	exposure point concentration
FAO	Food and Agriculture Organization of the United Nations
FEV	expiratory volume
ft^2	square foot
FVC	forced vital capacity
GM	geometric mean
GSD	geometric standard deviation
HEAST	health effects assessment summary tables
HQ	hazard quotient

IARC	International Agency for Research on Cancer
IEUBK	Integrated Exposure Update Biokinetic Model
IIN	Instituto de Investigación Nutricional
INDECOPI	Peruvian Institute for the Defense of Competition and Protection of Intellectual Property
InhR	Inhalation rate
Integral	Integral Consulting Inc.
IR	ingestion rate
IRIS	Integrated Risk Information System
ISE	Integrated Stochastic Exposure Model
kg	kilogram
KCO	transfer coefficient
L	liter
LOAEL	lowest-observed-adverse-effect level
m^3	cubic meter
MCLs	maximum containment levels
MEM	Peruvian Ministry of Energy and Mines
mg	milligrams
MMA	monomethyl arsonic acid
NAAQS	U.S. National Ambient Air Quality Standards
NAS	U.S. National Academy of Sciences
ND	analyte not detected in any sample
NIOSH	National Institute of Occupational Safety and Health
NOAEL	No-observed-adverse-effect level
NTP	National Toxicology Program
OEHHA	Office of Environmental Health Hazard Assessment
ORNL	Oak Ridge National Laboratory
PAMA	Programa de Adecuación y Manejo Ambiental
Pb	lead
$PM_{2.5}$	particulate matter greater than 2.5 microns in diameter
PM_{10}	particulate matter less than 10 microns in diameter
ppb	parts per billion
PPRTVs	Provisional Peer-Reviewed Toxicity Values
PRG	preliminary remediation goals
QA/QC	quality assurance/quality control
RAF	relative absorption factor
RBA	relative bioavailability adjustment
RD	residential (indoor) dust
RfC	reference concentration
RfD	reference dose
RME	reasonable maximum exposure
RS	residential (indoor) soil

Sb	antimony
SO_2	sulfur dioxide
STSC	Superfund Health Risk Technical Support Center
Th	thallium
TLCO	transfer factor by the carbon monoxide method
UCLM	upper 95th percentile confidence limit of the mean
UNES	Unión por el Desarrollo Sustentable de la Provincia Yauli-La Oroya
µg	micrograms
µm	micrometers
USEPA	U.S. Environmental Protection Agency
W	water samples
WHO	World Health Organization
WOE	weight of evidence

GLOSSARY OF TERMS[1]

Accuracy: The degree to which a measurement reflects the true quantitative value of a variable.

Acute: Having a sudden onset or lasting a short time. An acute stimulus is severe enough to induce a response rapidly. The word acute can be used to define either the exposure or the response to an exposure (effect).

Air Quality Criteria: Maximum legally allowable concentrations for air pollutants that are intended to protect public health, including "sensitive" populations such as asthmatics, children and the elderly.

Carcinogen: An agent capable of inducing cancer.

Chronic: Involving a stimulus that is lingering or continues for a long time; often signifies periods from several weeks to years, depending on the reproductive life cycle of the species. Chronic can be used to define either the exposure or the response to an exposure (effect). Chronic exposures typically induce a biological response of relatively slow progress and long duration.

Confidence Limit: Either of the two numbers that specify the endpoints of the confidence interval.

Deposition: The processes by which chemical constituents settle from the atmosphere to the earth's surface, which include precipitation (wet deposition, such as rain or cloud fog) and particle and gas deposition (dry deposition).

Exposure: The contact of people with chemicals.

Exposure Medium: The contaminated environmental medium to which an individual is exposed, such as soil, water, sediment and air.

Exposure Pathway: The path a chemical or physical agent takes from a source to an exposed organism. An exposure pathway describes a unique mechanism by which an individual or population is exposed to chemicals or physical agents at or originating from a site. Each exposure pathway includes a source or release from a source, an exposure point, and an exposure route. If the exposure point differs from the source, a

[1] Definitions obtained from http://www.epa.gov/iris/gloss8.htm and http://www.epa.gov/iris/gloss8.htm, among other sources.

transport/exposure medium (e.g. air) or media (in cases of intermedia transfer) also is included.

Exposure Pathway Model: A model in which potential pathways of exposure are identified for the selected receptor species.

Exposure Point: The potential contact between a person and a contaminant within an exposure medium.

Exposure Point Concentration: The value that represents a conservative estimate of the chemical concentration available from a particular medium or route of exposure.

Exposure Route: The mechanism for which a contaminant comes in contact with a person (e.g., by ingestion, inhalation, dermal contact).

Exposure Scenario: A set of assumptions concerning how an exposure takes place, including assumptions about the exposure setting, stressor characteristics, and activities of an organism that can lead to exposure.

Fugitive Emissions: Air emissions that do not pass through a stack, chimney, vent, or other functionally-equivalent opening.

Gamma Distribution: In probability theory and statistics, the gamma distribution is a continuous probability distribution. In a probability distribution, every interval of the real number is assigned a probability so that the probability axioms are satisfied.

Hazard Quotient: The ratio of an exposure level to a substance to a toxicity value selected for the risk assessment for that substance.

Lognormal Distribution: In probability theory and statistics, the lognormal distribution is the probability distribution of any random variable whose logarithm is normally distributed.

Mean: The average value of a set of numbers.

Media: Specific environmental components—air, water, soil—which are the subject of regulatory concern and activities.

Median: The middle value in an ordered set of numbers.

Noncancer Risk: Characterized as the increased likelihood that an individual will suffer adverse health effects as a result of exposure to a chemical.

Non-carcinogen: An agent not capable of inducing cancer.

Particulate Matter: Material suspended in the air in the form of minute solid particles or liquid droplets, especially when considered as an atmospheric pollutant

Precision: A measure of the closeness of agreement among individual measurements.

Risk Assessment: A qualitative or quantitative evaluation of the risk posed to human health and/or the environment by the actual or potential presence or release of hazardous substances, pollutants, or contaminants.

Risk Characterization: The integration of information on hazard, exposure, and dose-response to provide an estimate of the likelihood that any of the identified adverse effects will occur in exposed individuals.

Risk Evaluation: The evaluation of scientific information on the hazardous properties of environmental agents (hazard characterization), the dose-response relationship (dose-response assessment), and the extent of human exposure to those agents (exposure assessment). The product of the risk assessment is a statement regarding the probability that populations or individuals so exposed will be harmed and to what degree (risk characterization).

Screening Criteria: A risk-based concentration of a chemical in an environmental medium (e.g., soil, air, etc) that is considered protective of public health and can be used to compare to chemical data to determine if a chemical is present in the environmental medium at concentrations that may present a hazard to public health.

Stack Emissions: The particulate matter and vapors captured and released to the atmosphere through a stack, chimney, vent, flue, or other functionally-equivalent opening.

Toxicity Values: A numerical expression of a substance's exposure-response relationship that is used in risk assessments

EXECUTIVE SUMMARY

This report presents the results of the human health risk assessment conducted by Integral Consulting Inc. (Integral) to assess emissions from the Doe Run Perú Metallurgical Complex (Complex) in La Oroya, Perú. Integral was commissioned by Doe Run Perú to conduct this risk assessment in order to comply with the Supreme Decree of the Peruvian Ministry of Energy and Mines (MEM). The risk assessment was conducted in accordance with guidance from the U.S. Environmental Protection Agency (USEPA) and other international standards for human health risk assessment.

A human health risk assessment is a quantitative evaluation of the risk posed to human health by the actual or potential presence or release of chemicals in the environment. Thus, a risk assessment predicts the likelihood of health effects in a population, but does not directly measure the occurrence of health effects. Therefore, a risk assessment is very different from an epidemiology study that reports the incidence of specific health effects or a biomonitoring study that reports the concentrations of chemicals in people's bodies. The value of a risk assessment is that it is a tool that may be used to predict conditions in the future. Risk assessment is needed for La Oroya to predict future health risks as emissions from the Complex are reduced.

INTRODUCTION

The human health risk assessment process as defined by USEPA (1989) contains four major steps. The first step is to characterize the site and the chemicals associated with the site. The second step is the exposure assessment, which evaluates the potential exposure of people to the chemicals being evaluated. The third step is the toxicological evaluation, which looks at the potential toxicity of the chemicals and identifies doses that may cause toxicity and doses that are not expected to cause health effects. The fourth step is the risk characterization that combines the results of the exposure assessment and the toxicological evaluation to describe potential risks to human health associated with site-related chemicals.

This human health risk assessment has three primary goals:

1. To evaluate current human health risks in the community from air emissions from the Complex and to characterize the ways in which people are currently exposed to chemicals released from the Complex.
2. To assess how planned reductions in Complex emissions will impact health risks in the future.
3. To provide MEM with an analysis of the interim impacts of extending the time required for achieving emissions reductions.

In 1997, Doe Run Perú purchased the Complex and entered into an agreement with MEM called the Programa de Adecuación y Manejo Ambiental (PAMA). The agreement outlines monitoring and emissions reduction requirements. Requirements imposed by MEM, as well as modifications to the PAMA projects and schedule proposed by Doe Run Perú, form the basis for the predicted changes in emissions. An amendment to the PAMA in 1999 provided for increased spending by Doe Run Perú to update engineering controls at the Complex. The main goal of the PAMA projects is to reduce Complex emissions below maximum permissible levels identified by MEM. Sulfur dioxide control is the most expensive project. Reduction of lead emissions, one of the principal health concerns in La Oroya, was not a focus of the original PAMA agreement.

This risk assessment focuses on air and dust because these are the exposure media that are most affected by current operations. Given the focus on current operations of the Complex, this risk assessment does not provide an assessment of the full extent of environmental contamination during the operation of the Complex in La Oroya since 1922. This risk assessment also provides information regarding future risks. Integral relied upon the results of air quality dispersion modeling, conducted by another North American company (McVehil Monnett), to assess how planned reductions in Complex emissions would impact health risks in the future.

SITE DESCRIPTION

The Complex is located approximately 175 kilometers northeast of Lima, Perú in the Andes Mountain Range, at an altitude of 3,745 meters. It is situated in the Mantaro River Valley at the confluence of the Mantaro and Yauli Rivers. Adjacent to and north of the Complex, across the Mantaro River is the town of La Oroya Antigua. The communities of La Oroya Nueva, Marcavalle, Chucchis, and Curipata are located upstream, along the Yauli River, at increasing distances west-southwest of the Complex. This risk assessment presents estimates of health risks for the four communities of La Oroya Antigua, La Oroya Nueva, Marcavalle and Chucchis.

The Complex was built by American Cerro de Pasco Copper Corporation and began smelting copper in 1922. Lead production began in 1928 and zinc production began in 1952. Recovery of precious metals began in 1950. The government-owned company, Centromin, operated the Complex from 1974 until 1997, when it was purchased by the Doe Run Company. The Complex is an operating smelter that processes approximately 600,000 metric tons of concentrate annually. A total of eleven metals, including lead, zinc, copper, silver, and gold, and eight byproducts are produced from the concentrate.

A main stack, rising 167.5 meters above ground level, emits gases and particulate matter produced during smelter operation. There is also a much smaller stack called the sinter

plant stack. In addition, fugitive gases and particulate emissions escape from various buildings, ductwork and machinery at the Complex. The emissions from the main stack and fugitive emissions contain heavy metal dusts and sulfur dioxide gas that migrate to the surrounding communities at levels capable of causing adverse health effects.

EXPOSURE PATHWAYS

In order to conduct this risk assessment, it was necessary to understand ways in which people might come into contact with chemicals released from the Complex. The path followed by a chemical from its release until it is contacted by people is called an exposure pathway. A diagram that identifies the main exposure pathways for people in La Oroya is presented in Figure ES-1. As shown in this figure, chemicals that are emitted from the Complex into the air from stacks or fugitive emissions may be inhaled (as vapors, such as sulfur dioxide, or in particulate matter). The particles also may settle out onto soil and paved surfaces, and later be ingested in soil or dust. Soil and dust may then be ingested when transferred to the hands of children or adults who then put fingers or hands in their mouths. Chemicals in soil or dust in outdoor areas also may be transferred to indoor areas, such as floors and furniture, and may then be ingested if transferred to hands. Airborne dust also may be deposited onto food sources, either stored in the home or at open markets, or meal preparation areas where it then may be ingested along with the food.

Based on identification of these main exposure pathways this risk assessment included evaluation of:

- Inhalation of metals and gases in air
- Incidental ingestion of metals in outdoor dust
- Incidental ingestion of metals in indoor dust
- Ingestion of lead in food, and
- Incidental ingestion of metals in surface soil.

This risk assessment focuses on chemicals that are known to be released from the Complex via stack and fugitive emissions to air. Surface water and groundwater that might be affected by releases from the Complex are not used by residents for drinking water, so water sources were not examined in detail. Other PAMA projects address those releases which will be done within the original PAMA timeframe. Also, releases from wastes stored in piles (e.g., slag) or impoundments were not characterized. Again, other projects address those issues within the original PAMA timeframe. Contributions from historic operations to soil metal concentrations could not be distinguished from impacts of current operations in this risk assessment; however, metals in air, outdoor dust, indoor dust and food are assumed to be principally due to current smelter operations.

DATA COLLECTION AND ANALYSIS

Based on the review of existing data and previous analyses, it was determined that supplemental data collection and analysis at the Complex was necessary to adequately characterize current human health risks related to the Complex's current operations. Therefore, three additional studies were conducted in 2005 to provide environmental, diet, and air data to support the risk assessment.

Dust, Soil, and Water Data. Integral collected samples of outdoor dust, indoor dust and soil, and drinking water from homes and communal areas from locations at various distances from the smelter. Outdoor dust and soil samples were collected in areas where Integral staff observed children playing. Integral scientists conducted two sampling events in La Oroya with observers from the Ministry of Health and Doe Run Perú during the wet season in March/April and during the dry season in June 2005.

Samples were submitted to EnviroLab in Lima, a laboratory certified by the Peruvian Institute for the Defense of Competition and Protection of Intellectual Property (INDECOPI). Prior to selecting this laboratory Integral chemists reviewed the laboratory qualifications and determined that EnviroLab was equipped with high quality analytical equipment and used USEPA sample preparation and analytical methods for all analyses. All samples were in the custody of Integral scientists from the time they were collected in La Oroya until they were delivered to EnviroLab in Lima. Following receipt of the analytical results from the laboratory, Integral chemists validated the data to make sure the analyses were of high quality.

Elevated concentrations of metals were found in all dust and soil samples, with the highest concentrations in La Oroya Antigua. Concentrations of arsenic, antimony, cadmium, lead, and thallium in some samples were greater than health-protective screening levels. Metals concentrations varied between the first and second sampling events at each sampling location, but no seasonal trend was apparent. Figure ES-2 demonstrates differences in lead concentrations detected during the first and second sampling events in outdoor soil, outdoor dust, and indoor dust, respectively, in La Oroya Antigua. Similar figures for arsenic and cadmium also are provided (Figures ES-3 and ES-4). Some metals were detected in drinking water samples, but concentrations were not consistently elevated.

Diet Study. Due to concerns that lead released from the Complex might be getting into foods consumed by the people of La Oroya, the Instituto de Investigación Nutricional (IIN) in Lima conducted a pilot dietary study in La Oroya Antigua at the request of Dr. Rosalind Schoof of Integral. This study used a duplicate diet method to evaluate the dietary intake of lead and iron, calcium, and zinc, three nutrients that may affect lead absorption and toxicity. Mothers and children between the ages of 12 and 35 months from 15 families participated in the study. The IIN representatives conducted the study

by staying with each family for 12 hours per day for two consecutive days and collecting samples of all the food each study participant consumed and recording the quantities consumed. Analytical results for the concentrations of lead, iron, calcium, and zinc in food and breast milk were used to estimate dietary intakes.

The IIN study identified food as a source of exposure to lead that needed to be included in the risk assessment. Although the means by which lead entered the prepared foods was not determined in the study, it is likely that much of the lead was transferred to the foods in the form of settled dust while they were for sale in markets or during contact with settled dust during cooking. Lead concentrations in breast milk were below detection limits.

The IIN study also confirmed that iron intakes by women and young children in La Oroya are inadequate. Confidence in this finding is supported by the knowledge that iron intakes are typically inadequate in populations residing in the Peruvian Andes. The pilot dietary study also found that calcium intakes were highly variable, and that many mothers and some children had inadequate intakes of calcium. Zinc intakes were generally found to be adequate, but may also reflect exposure to emissions from the Complex. While not a specific goal of this study, the IIN noted that review of the foods consumed by the study population and food composition tables indicated that vitamin C intake is adequate in La Oroya.

Air Model. To predict health risks in La Oroya after changes in operations at the Complex that will reduce stack and fugitive emissions, it was necessary to predict how reduced emissions would affect concentrations of chemicals in the air and in outdoor dust and indoor dust. An updated air modeling study was therefore performed using new estimates of fugitive and stack emissions at the end of 2007 and 2011. This study was conducted by McVehil-Monnett of Denver, Colorado. Model predictions for sulfur dioxide concentrations and for concentrations and deposition rates for lead, arsenic, and cadmium were generated for the populated areas being studied in the assessment.

Modeling utilized the CALPUFF model, an air quality simulation model recommended by the USEPA for application in areas of complex winds, terrain, and meteorology such as are present in La Oroya. The modeling of 2002 emissions and weather conditions provided model-predicted impacts that were compared to measured concentrations at Doe Run Perú air monitoring stations, and also provided a "base case" against which to compare predictions for later years. Subsequent modeling, for projection of future trends, utilized the same 2002 meteorological data with estimates of later year emissions. Doe Run Perú provided estimates of pollutant emissions for 2005, 2007, and 2011 based on implementation of planned projects as described in the PAMA. Integral understands that Doe Run Perú plans to construct some of the sulfur dioxide reduction equipment by 2008, but these plans are not considered in this risk assessment.

Performance of the model in simulating La Oroya air quality was tested by comparing predicted 2002 concentrations of sulfur dioxide, lead, arsenic, and cadmium to measurements obtained during the same time period at Doe Run Perú monitoring stations. It was concluded that the model properly simulates basic dispersion processes in the region of the Complex, and provides realistic estimates of maximum short-term and average long-term impacts in the area addressed in the risk assessment. The model results also imply that the characterization of emission sources and average emission rates that were used reflect reality with reasonably accuracy. On the basis of these conclusions, projections of future air quality impacts, with modified sources and reduced emissions, are expected to be realistic and appropriate for risk assessment.

The projection of future ambient air concentrations and deposition rates indicates that the planned smelter improvement projects will result in marked reduction in impacts for all pollutants addressed. The decrease in short and long-term concentrations and deposition rates from 2002 to 2011 is predicted to range from 60 to 85 percent. The greatest decrease in metals impacts will occur by 2007, with a further decrease for metals and a major decrease for sulfur dioxide between 2007 and 2011. The projections of air quality levels for future years have been utilized in this risk assessment to quantify changes in exposures for La Oroya residents.

In addition, model results (as well as monitoring records) indicate that the Doe Run Perú supplemental control strategy (emission curtailments at times of anticipated poor air quality) is effective in mitigating high short-term pollution levels during morning air pollution episodes. Based on the air modeling results, the supplemental control scenario produced a reduction (relative to normal 24-hour per day operation) of 25 to 50 percent in highest short-term morning sulfur dioxide concentrations, and approximately 25 percent in 24-hour average concentrations. This strategy, if continued, will contribute to additional improvement in air quality beyond that projected by the air modeling analysis.

SELECTION OF CHEMICALS EVALUATED

When conducting a risk assessment, it is first necessary to determine which chemicals may be posing health risks. These chemicals are identified by reviewing the operations at the facility being evaluated and by reviewing available data on chemical concentrations in the environment near the facility. From prior studies of copper, lead and zinc smelters from other parts of the world, it is known that sulfur dioxide emissions to air is a concern for operating smelters. Lead, arsenic and cadmium were expected to be the metals that would pose the greatest health risks. Copper and zinc were also expected to be emitted in great quantities, although these metals are not typically toxic to humans. Studies in La Oroya had already provided evidence that lead and sulfur dioxide exposures are high enough to pose health risks. Based on a description of the Complex operations,

particulates in air, and antimony, mercury, selenium, silver, and thallium were also evaluated.

A risk-based screening process was used to determine whether all of the metals were present in sufficient concentrations to require calculation of exposures and risks in each of the four communities evaluated. Through this screening process it was determined that mercury, selenium and silver did not need to be evaluated further in the risk assessment. Antimony and thallium were only evaluated in dust in some of the communities.

Although drinking water samples were collected, metals in water are not thought to be attributable to activities at the Complex. Metal concentrations in drinking water were compared to safe drinking water standards to determine if water might be a significant source of exposure to metals in La Oroya. Most metals did not exceed safe drinking water standards. Arsenic exceeded the U.S. drinking water standard of 0.01 mg/L in two of the communities of interest, La Oroya Antigua and Marcavalle. Arsenic did not exceed the current Peruvian drinking water standard of 0.1 mg/L in any community nor did it exceed Peru's proposed standard of 0.05 mg/L. Until recently the U.S. standard was 0.05 mg/L and health effects are typically not observed in population studies until arsenic concentrations exceeded 0.1 mg/L. Arsenic in drinking water was not evaluated further in this risk assessment, but the presence of arsenic in some drinking water supplies should be further investigated.

EXPOSURE ASSESSMENT

The exposure assessment includes calculation of exposures to chemicals released to the air from the Complex. Exposures were calculated for all the exposure pathways by which adult and child residents could come into contact with these chemicals. Chemical exposures quantified include inhalation of sulfur dioxide, airborne particulates, lead, arsenic and cadmium, ingestion of metals in soil, outdoor dust and indoor dust, and ingestion of lead in food.

For each chemical and exposure medium exposure concentrations were estimated. For oral exposures, intakes or doses were calculated. Consistent with USEPA risk assessment methods, approaches to estimating exposures and risks are different for sulfur dioxide, airborne particulates, and lead than for other chemicals evaluated in this risk assessment. The specific approaches used for sulfur dioxide and particulates, lead and other metals are described below. For this risk assessment, monitoring and sampling data were used to estimate current exposure while dispersion and deposition model outputs were used to predict future exposures.

Exposures to Sulfur Dioxide and Airborne Particulates

Inhalation exposure was confirmed to be a pathway of concern for sulfur dioxide and airborne particulates. Sulfur dioxide and particulate data from three of the monitoring stations operated by Doe Run Perú were used in the analysis of current conditions. Each of these monitoring stations was selected to represent a particular community near the Complex. Data from the Sindicato monitoring station were used to represent exposures in the La Oroya Antigua community. Data from the Hotel Inca monitoring station were used to represent exposures in the La Oroya Nueva community. Data from the Cushurupampa monitoring station were used to evaluate exposures for the Marcavalle community. No monitoring station was close enough to provide exposure estimates for Chucchis, which is located south of Marcavalle along the Yauli River.

Both 24-hour maximum concentrations and annual average concentrations were calculated for each of the three communities evaluated based on data from the year 2004. Future concentrations were predicted by applying the expected reduction in concentration by 2007 or 2011 to the 2004 concentration.

Exposures to Lead

Health risks associated with lead exposures in a study population are assessed by comparison of the observed or predicted blood lead concentrations in that population with concentrations associated with adverse health effects in other populations previously studied. Toxicokinetic models have been developed that allow for pathway specific evaluations of lead concentrations in blood. These models rely on estimates of lead intake from environmental media such as air, soil and dust, and other sources such as drinking water, diet, and lead-containing consumer products. The USEPA has issued several toxicokinetic models that may be applied to predict the distribution of blood lead concentrations in populations of children or adults. These models include many default assumptions for model parameters that are expected to be representative of the U.S. population. For a number of reasons, these default parameters may not be representative of the population of Perú or of La Oroya. Consequently, this risk assessment has required considerable effort to identify assumptions that will be more representative.

USEPA has developed two models for predicting blood lead concentrations in children. The integrated exposure uptake biokinetic (IEUBK) model is designed to predict blood lead levels in children (0-7 years old). The IEUBK model is the model used most frequently by USEPA to assess lead exposures; however, this model is designed to assess lead in soil at U.S. contaminated sites and does not have the flexibility needed to assess conditions in La Oroya where exposures are dominated by lead in outdoor dust. Consequently, Integral selected a second USEPA lead exposure model called the

integrated stochastic exposure (ISE) model for use in this risk assessment. The ISE model uses distributions of input parameters and lead concentrations to generate the predicted distribution of blood lead concentrations in children.

As with the IEUBK model, an underlying premise of the ISE model is the assumption that lead exposures at contaminated sites will be dominated by exposure to lead ingested from soil. Smaller contributions are assumed from exposure to lead ingested from indoor dust, with minimal exposure due to inhaled lead in air. These assumptions do not apply to sites with ongoing air emissions of lead, such as smelters. The smelter in La Oroya releases lead to the air in the form of particulates. While some of the airborne lead may be inhaled, much of the airborne particulate load settles out onto pavement, soil and other outdoor surfaces. This outdoor dust contains much higher concentrations of lead than does the underlying soil. Because children playing outdoors may ingest this dust after getting it on their hands, it is important to include outdoor dust as a separate exposure medium in lead exposure models. In this risk assessment, the ISE model was modified to add outdoor dust as an exposure medium independent of soil.

For each of the four communities evaluated, the data collected by Integral was used to estimate current exposures to lead in outdoor and indoor dust and soil. The IIN study data was used to estimate exposures to lead in the diet. Annual average air concentrations were estimated from 2004 air monitoring data. The distributions of the amounts of outdoor dust, indoor dust and soil that are expected to be ingested each day and the amounts of lead that might be absorbed into the body from these sources were modified from the standard USEPA assumptions so that the blood lead levels predicted by the ISE model matched the distribution of blood lead levels in children observed in the Ministry of Health's Environmental Health Directorate (DIGESA) biomonitoring study conducted in November 2004.

Future exposures were estimated by using or scaling the reductions in air concentrations and deposition rates predicted by the air modeling study. For example, it was assumed that the percent reduction in deposition would result in the same percent reduction in outdoor dust concentrations, but a smaller percent reduction in indoor dust and soil concentrations.

USEPA (2003b) recommends use of a toxicokinetic model called the adult lead exposure (ALM) model to assess exposures of adults to lead. Similar to the ISE model, the ALM model is based on the assumption that soil is the main source of lead exposures at contaminated sites. Because outdoor dust, rather than soil, is thought to be the primary source of lead exposures in La Oroya, the model inputs were modified to better reflect conditions in La Oroya. The ALM model version from USEPA is a much simpler model than the ISE model and does not include the option of entering site-specific values for outdoor dust, water, air and diet. Therefore, model inputs were adjusted to make

outdoor and indoor dust the principal exposure variables, while other site-related exposure sources (i.e., soil, diet and air) were accounted for by use of an elevated baseline blood lead value. Future exposures were predicted by assuming that both the dust concentrations and the baseline blood lead levels would be reduced in proportion to the future reductions in lead emissions from the Complex.

Exposures to Metals Other than Lead

Metals other than lead also are present in elevated concentrations in dust, soil and air. Ingestion of dust on outdoor and indoor surfaces is the primary exposure pathway of concern for exposure to metals. Dust may adhere to the skin surface (i.e., hands), and then may be ingested unintentionally when people touch their faces and mouths or eat without first washing their hands. Intakes were not estimated for metals other than lead in diet because site-specific data were not available. Dermal absorption of metal particles on the skin was not evaluated because metals have only very limited absorption through the skin.

For each of the four communities evaluated, the data collected by Integral was used to estimate current exposures to metals in outdoor and indoor dust and soil. Annual average air concentrations were estimated from 2004 air monitoring data. Future exposures were estimated by using or scaling the reductions in air concentrations and deposition rates predicted by the air modeling study. For example, it was assumed that the percent reduction in deposition would result in the same percent reduction in outdoor dust concentrations, but a smaller percent reduction in indoor dust and soil concentrations.

TOXICITY EVALUATION

The purpose of a toxicity evaluation is to summarize adverse health effects that may be associated with exposure to the chemicals included in the risk assessment and to identify the doses that may be associated with those effects. The dose-response assessment then forms the basis for the identification of toxicity values that may be used to predict the risk of adverse health effects from chemical exposures. Chemicals evaluated in this risk assessment include inhaled sulfur dioxide and particulates, and lead, arsenic, cadmium, antimony, and thallium.

A toxicological evaluation is conducted by reviewing relevant toxicity information for each chemical from governmental health authorities and in peer-reviewed publications. Toxicity values for carcinogenic and noncarcinogenic health effects have been developed for many chemicals by government agencies, including the USEPA, the U.S. Agency for Toxic Substances and Disease Registry (ATSDR), Health Canada, and the World Health Organization (WHO). These toxicity values are numerical expressions of chemical dose

and response, and vary based on factors such as the route of exposure (e.g., oral or inhalation) and duration of exposure.

Principal health concerns associated with chemicals evaluated in this risk assessment include effects on respiratory, neurological, hematological, gastrointestinal, dermal, and renal systems of the body. For exposures to sulfur dioxide in air, primary effects include lung irritation, and airways constriction that may result in breathing difficulties, wheezing, and chest tightness. Sensitivity to such effects may be greater in individuals with pre-existing respiratory conditions (e.g., asthma).

For exposures to lead, the neurological system is particularly sensitive accounting for the greater susceptibility of young children to lead's effects on their rapidly developing nervous systems. At high levels, lead exposure may also lead to anemia due to decreased hemoglobin production and destruction of red blood cells.

Characteristic changes in the skin are considered the earliest observable sign of overexposure to ingested arsenic, although gastrointestinal symptoms (e.g., nausea, diarrhea, vomiting) have been reported with short-term, high-level exposures and longer-term lower level exposures as well. As with lead, chronic arsenic exposure may also result in anemia. Arsenic is also classified as a known human carcinogen based on occupational studies of worker exposures to arsenic in air and epidemiological studies of populations chronically exposed to high levels of arsenic in drinking water.

Irreversible damage to the kidney resulting in impaired renal functioning is the primary effect of exposure to cadmium. In iron-deficient individuals, chronic oral exposure to cadmium may also contribute to anemia. Exposure to cadmium in air may result in decreased lung function, emphysema, and impairment of one's ability to smell. Increased risk of lung and prostate cancers have also been reported with inhalation exposure to cadmium.

For antimony, high doses have been shown to affect the respiratory and hematological systems, but gastrointestinal and dermal effects have also been reported. High doses of thallium have been reported to cause neurological effects, hematological effects, and hair loss.

RISK CHARACTERIZATION

Health risks may be characterized in different ways. In this risk assessment sulfur dioxide and particulate exposures were evaluated by comparing exposure point concentrations to health-based air quality standards and guidelines. For lead predicted blood lead levels for children and adults were compared to acceptable blood lead levels established by health and regulatory agencies. For metals other than lead, quantitative

estimates of exposure and toxicity were combined to yield numerical estimates of potential health risk. Risks for these chemicals are described below.

Risks from Exposure to Sulfur Dioxide and Airborne Particulates

The sulfur dioxide air concentrations reported in La Oroya exceeded the current Peruvian air quality standards, and indicate a potential for adverse respiratory effects. These effects are likely to be the result of short-term exposures to elevated sulfur dioxide concentrations during mid-morning to early afternoon hours. Individuals such as asthmatics and children are more likely to experience adverse health effects from elevated sulfur dioxide exposures.

Adverse respiratory effects from sulfur dioxide exposure typically end within hours of the time when the elevated exposure ceases. The elevated particulate matter concentrations in the same communities could increase the risk of adverse health effects from sulfur dioxide exposures. This is especially true for metal oxide particles that convert sulfur dioxide to the more potent sulfuric acid. These particles are carried deeper into the respiratory tract where health effects are greater than in the upper respiratory system.

In the future, the reduction of stack and fugitive sulfur dioxide emissions planned for the Complex will reduce the potential for adverse health effects in the nearby communities. The emission control projects planned for 2007 will not significantly reduce sulfur dioxide concentrations, which will still substantially exceed the health-based 24-hour or annual standards. In 2011 the annual average sulfur dioxide concentrations are predicted to be reduced by between 70 percent and 82 percent in the four communities evaluated.[2] As a result of these reductions, it is likely that sulfur dioxide air concentrations in Marcavalle and Chucchis will meet the Peruvian health-based standards. The sulfur dioxide air concentrations in La Oroya Nueva and La Oroya Antigua will slightly exceed the standards, but the magnitude of the emissions reductions will mean a much lower frequency of hours where sulfur dioxide concentrations could induce respiratory effects, as shown in Figure ES-5.

Based on the air model, the predicted reductions in lead emissions will result in concentrations of lead in air that comply with the Peruvian air quality standard of 1.5 $\mu g/m^3$ by 2007 in all of the communities evaluated.

[2] Doe Run Perú estimates that by the end of 2008, equipment installed in the lead circuit will reduce the sulfur dioxide about 30 percent from the 2007 levels. This earlier reduction in emissions is not considered in this risk assessment.

Risks from Exposures to Lead

Consistent with the blood lead levels observed in the 2004 DIGESA study of children in La Oroya the ISE model predicted that all of the children will have blood leads that exceed 10 μg/dL. This is the blood lead level at which the U.S. Centers for Disease Control and Prevention (CDC) in the U.S. recommends further evaluation in the form of additional blood lead monitoring and education on ways to reduce lead exposures. Most of the children residing in La Oroya Antigua fall in the range of blood lead levels (i.e., 20 μg/dL to 44 μg/dL) at which the CDC recommends an environmental hazard evaluation and more active medical monitoring.

High altitude populations are expected to have altered blood lead levels in response to lead exposures compared to low altitude populations. Lead in blood is primarily in red blood cells. High altitude populations have more red blood cells. Thus, high altitude populations may have a less lead in their bodies and less health risk than low altitude populations with similar blood lead levels. Conversely, people with anemia and lower red blood cell counts may have more lead in their bodies and greater risk than nonanemic people with comparable blood lead levels. The role of these factors in La Oroya needs to be carefully considered in predicting health risks from lead. CDC guidance for actions to take at various blood lead levels is based on studies of low altitude populations. High altitude populations, such as residents of La Oroya, may not experience the same health effects until blood lead levels are 20 percent greater than levels of concern identified by CDC.

Most of the children in La Oroya are at risk for neurobehavioral effects and effects on the synthesis heme, a critical component of red blood cells. Effects on heme synthesis may cause or worsen anemia. Children with the highest blood lead levels may also be at risk for effects on the heart, kidneys, bone and vitamin D metabolism. Many of these effects are subtle and cannot be easily attributed to lead exposures when examining an individual child. Health evaluations conducted to date have been observational in nature and do not support statistical analysis.

In addition to the difficultly of identifying effects of lead in an individual child, many of the same effects caused by lead also may be caused by other factors such as iron deficiency induced anemia or neurobehavioral effects. Due to these factors and the increases in hemoglobin of high altitude populations that cause higher blood lead levels relative to body burden, it is important that any future studies of the occurrence of specific adverse effects in the children of La Oroya be designed to include control populations that are properly matched for altitude, socioeconomic and nutritional status and urbanization. Without proper controls, the results of such studies could be misleading.

Blood lead levels for children in all of the communities are predicted to fall significantly in both 2007 and 2011; however, it is not predicted that any of the communities will meet the risk target of no more than a 5 percent probability of exceeding a blood lead level of 10 μg/dL. Nevertheless, the predicted reductions in blood lead levels are expected to substantially reduce health impacts of lead in the children of La Oroya (Figure ES-6).

To better understand the relative contributions to exposures from lead in outdoor dust, indoor dust, soil, diet, air and drinking water, the mean absorbed doses from each of these pathways were compared. The dominant exposure pathway for all of the communities was ingestion of outdoor dust. Indoor dust was the second greatest contributor to exposures in La Oroya Antigua, while in the other communities; diet was the second largest contributor. The contribution of diet is likely to be overestimated in these other communities because data on lead in the diet was only available for La Oroya Antigua and those data were also used for the other communities. It is noteworthy that inhalation of lead in air is a relatively minor exposure pathway (Figure ES-7).

Exposure sources were also evaluated for 2007 and 2011. As smelter emissions are reduced, the percent contribution of outdoor dust to combined exposures declines, while the percent contributions from soil and diet increase. This prediction suggests that eventually, additional actions may be needed to reduce exposures to lead in soil.

Blood lead levels in women of child-bearing age in La Oroya are much lower than blood lead levels in children. In La Oroya Antigua there is an 86 percent chance that fetal blood lead levels will exceed 10 μg/dL. In other communities evaluated, the probability is lower than in La Oroya Antigua, but still greater than 50 percent.

Reductions in future lead emissions are predicted to reduce adult and fetal blood lead levels to meet the target risk levels by 2011 in La Oroya Nueva and Marcavalle, and to reduce blood lead levels to close to the target risk levels in La Oroya Antigua and Chucchis. Due to limitations in the design of the adult lead model, predictions of future adult blood lead levels are associated with a greater degree of uncertainty than the predictions for children (Figure ES-6).

Risks from Exposures to Non-Lead Metals

In addition to lead, other metals evaluated in this risk assessment include arsenic,[3] cadmium, antimony, and thallium. Cancer risks for non-lead metals included in this risk assessment were estimated for ingestion of arsenic in soil, dust, and drinking water and for inhalation of arsenic and cadmium in the air in La Oroya. Ingestion of cadmium,

[3] Technically arsenic is a metalloid rather than a true metal.

antimony, and thallium does not present a cancer risk. Risks for health effects other than cancer were also evaluated. In each case, risks associated with typical exposures and risks associated with upper end exposures were both calculated. Risks were calculated for both current exposures and predicted exposures following implementation of planned emissions reduction strategies at the Complex.

Cancer Risks

Cancer risk estimates represent the incremental probability that an individual will develop cancer during his or her lifetime due to exposure to site-related chemicals. "Incremental probability" refers to the additional or excess chance of developing cancer that is above a background or baseline probability expected in the absence of the site-related exposures. An excess upper-bound lifetime risk range of one in ten thousand to one in one million is considered by USEPA to represent an acceptable range of cancer risks.

This incremental risk should be considered in light of high background cancer rates that range from 1 in 3 to 1 in 4 in many populations. For example, a 1 in 4 cancer risk is a probability of 25 percent of getting cancer in a lifetime.

Current Exposure Conditions: For current residents of La Oroya Antigua, cancer risk estimates for ingestion of arsenic in outdoor dust, indoor dust and soil were 2 in one thousand for typical exposures and 6 in one thousand for upper end exposures (i.e., exposures intended to represent individuals who may be more highly exposed than most residents). Risks were approximately three-fold lower in the other communities; however, all risk estimates exceed USEPA's acceptable risk range. Inhalation of arsenic and cadmium in La Oroya Antigua under current conditions has predicted cancer risks of 5 in one thousand for typical exposures and 2 in one hundred for upper end exposures. Risks were only slightly lower in the other communities and all risks exceed USEPA's acceptable risk range. Risks contributed by inhalation of arsenic are generally about one hundred times greater than those contributed by inhalation of cadmium. In fact, for typical exposures, risks due to inhalation of cadmium alone fall within the USEPA acceptable risk range for all of the communities evaluated.

Future Exposure Conditions: By the year 2011, cancer risks for ingestion of arsenic in dust and soil are expected to decrease approximately 67 to 80 percent compared to current conditions. Risks in La Oroya Antigua are predicted to fall to 6 in ten thousand for typical exposures and 2 in one thousand for upper end exposures. For both typical and upper end exposures, the predicted contribution of outdoor and indoor dust to total risk in 2011 remains higher than that for soil. However, the magnitude of difference between these exposure media (i.e., dust vs. soil) is not as great as under current conditions (Figure ES-8).

Future risks for inhalation of arsenic for all communities remain above USEPA's acceptable range of cancer risks, but for La Oroya Antigua fall to one in one thousand for typical exposures and 4 in one thousand for upper end exposures. Compared to current conditions, these results indicate a reduction of about 75 to 80 percent in cancer risk by the year 2011. As with the evaluation of current conditions, risks associated with inhalation of cadmium were much less than risks associated with arsenic inhalation (Figure ES-9).

These findings are consistent with the anticipated effect of Doe Run Peru's implementation of emission reduction plan, which is expected to significantly reduce arsenic emissions. Reductions in air emissions are expected to have a more significant and immediate effect on concentrations of metals in dusts relative to soils, which reflect more long-term deposition of metals from the Complex.

Noncancer Risks

Noncancer risks are characterized as the increased likelihood that an individual will suffer adverse health effects as a result of long term or chronic exposure to a chemical. An individual who is exposed to a chemical at a level that is less than or equal to an acceptable reference level (reference dose), is not expected to experience adverse health effects related to that exposure. Exposures above the reference dose do not mean that adverse human health effects will occur, but rather that further evaluation is required (USEPA 1989). Risks were evaluated for both typical exposures and for upper end exposures.

Noncancer risks for ingestion of arsenic, cadmium, antimony, and thallium in indoor and outdoor dust and surface soil were estimated in La Oroya communities where current (year 2005) concentrations of the metals exceeded risk-based screening levels. Current noncancer risks were also estimated for inhalation of cadmium in air in La Oroya. Predicted future noncancer risks were also estimated for arsenic and cadmium based on concentrations predicted in the year 2011 following implementation of all planned emissions reduction strategies. Although risks for the year 2007 were not estimated, it is anticipated that most of the predicted reductions in arsenic and cadmium concentrations would occur by the end of 2007.

Current Conditions: Based on current exposure conditions, noncancer risk estimates due to ingestion of metals were highest in La Oroya Antigua and greatest for exposure to arsenic (i.e., estimates were 10 to 30 times greater than the arsenic reference dose in La Oroya Antigua). Arsenic exposures corresponded to the highest noncancer risks in the other communities as well, though to a lesser degree (e.g., estimates were 3 to 10 times greater than the arsenic reference dose in the other communities studied). In all cases, exposure to outdoor dusts contributed the greatest impact to noncancer risk estimates for the ingestion pathways. Risk estimates also indicated possible concerns related to

exposures to antimony under current operating conditions in the communities of La Oroya Antigua and La Oroya Nueva.

Due to the magnitude of arsenic risks estimated for long term or chronic exposure, risks for shorter exposures, referred to as "subchronic exposures" during early childhood (birth to age 6) were also evaluated. The results of this evaluation indicate that exposures to children in La Oroya Antigua and La Oroya Nueva, respectively, are approximately 5 and 2 times higher than the subchronic reference dose for arsenic, indicating possible health concerns for shorter exposure times for children, in addition to risks from long term exposures for residents of these communities.

Estimated noncancer risk due to inhalation of cadmium was highest for upper end exposures, ranging from 10 to 20 times the inhalation reference dose in the communities evaluated. Estimates for typical exposures also indicated possible concerns at 3 to 6 times the reference dose.

Future Conditions: Noncancer risk estimates for the year 2011 are predicted to decrease from current estimates by 70 to 80 percent for ingestion of arsenic and cadmium in the communities evaluated. However, in some communities, exposures may still represent a concern based on future risk estimates that are 2 to 8 times the current chronic oral reference dose (Figure ES-10). For inhalation of cadmium, slightly greater reductions are expected than predicted for the ingestion pathways, however, risk estimates corresponding to upper end exposures to cadmium continue to indicate possible concerns for residents of all communities in 2011 (Figure ES-11).

UNCERTAINTIES

As described above, risk assessments predict the likelihood of health effects in a population, but do not directly measure the occurrence of health effects. The predicted risks are based on many assumptions about the ways that people come into contact with chemicals in the environment. Many of these assumptions are based on general scientific studies or on data collected at the site, but some uncertainty still exists regarding how well the available data reflect the ways in which residents are actually exposed to chemicals. The degree of confidence in the results of a risk assessment depend on how well the data and assumptions used represent actual conditions.

The degree of confidence in a risk assessment is described in an uncertainty evaluation. The uncertainty evaluation includes a list of critical assumptions and data, and an evaluation of the possibility that the assumptions and data used in the risk assessment may over-predict risk or under-predict risk. Overall, the availability of site-specific data from La Oroya increases the level of confidence in the risk assessment compared to risk

assessments conducted at sites in the U.S. because most U.S. risk assessments do not have as much site-specific information.

Prediction of current risks from inhaling chemicals in La Oroya is greatly strengthened by the availability of air monitoring data for sulfur dioxide, particulates, lead, arsenic, and cadmium. The exposure assessment for inhalation of these chemicals is expected to be more accurate than is the case in most risk assessments. Inhalation rates are well documented and fewer assumptions are required to estimate inhalation exposures than for other exposure pathways. There are some uncertainties in the emissions estimates and the air modeling study, but the available information is of good quality so confidence in the predicted future inhalation risks is also high.

For lead exposures, confidence in this risk assessment is greatly increased by the availability of high quality blood lead data for the population. The blood lead data allowed Integral scientists to confirm that the overall blood lead exposure predictions of the risk assessment are reliable. There is uncertainty in the relative contribution of some of the sources, especially with regard to the relative contribution of exposures to lead in outdoor dust, indoor dust and soil, but the sum of these exposures is judged to be accurate. Confidence in predictions of future lead exposures is mainly dependent on the accuracy of the air model deposition estimates for lead emitted from the Complex. The deposition estimates are judged to be adequate to support the risk estimates.

For oral exposures to metals other than lead, predicted risks are less certain than for other components of the risk assessment. This is because more assumptions were needed in the exposure estimates for ingested metals. Nevertheless, confidence in the assessment of these metals was increased by the reliance on some of the assumptions developed for estimating lead exposures. Thus, these exposure estimates are expected to be more reliable than those of typical U.S. risk assessments.

CONCLUSIONS

This risk assessment confirms previous studies that have identified lead exposures as the primary health risk factor for the population of La Oroya due to emissions from the Complex, with virtually all children residing in La Oroya Antigua at risk for neurobehavioral effects. Many adults in La Oroya Antigua and residents of other nearby communities are also at risk. Sulfur dioxide and sulfate releases also cause health effects that affect a majority of the population of all the communities. The pulmonary irritation induced by these chemicals is usually transient; however, there is also a risk of nonspecific increases in morbidity and mortality (i.e., illnesses and deaths from a variety of causes) associated with elevated exposures.

Due to the urgency of reducing lead exposures in children, many of our recommendations focus on lead exposures. Exposures to inhaled arsenic and cadmium and ingested arsenic are also associated with increased health risks in La Oroya, but can be addressed in a longer time frame because the health effects generally develop only after long periods of exposure. Additionally, many of the actions recommended to reduce lead exposures also will have the effect of reducing exposures to arsenic and cadmium. Reductions of sulfur dioxide and sulfate emissions also are addressed because they have a great impact on both quality of life and health in La Oroya.

Many actions have already been undertaken by the community, the Ministry of Health and by Doe Run Perú to reduce both lead exposures and releases of sulfur dioxide. Many additional actions are planned for the future. The results of this risk assessment indicate that implementation of the planned technological changes to reduce fugitive emissions and stack emissions will reduce sulfur dioxide concentrations to levels that will greatly reduce health effects. While lead emissions will also be greatly reduced, blood lead levels are still predicted to exceed health-based goals in 2011. This is due to the fact that dust and soil in La Oroya will still have high residual concentrations of lead from historical emissions. For that reason, Integral recommends continuing and expanding many of the community-based programs that help to reduce lead exposures and the associated health burden.

RECOMMENDATIONS

The CDC's recent report on La Oroya (CDC 2005) recommends that all stakeholders in La Oroya collaborate in a coordinated program to reduce emissions, reduce exposures and to eventually remediate historic contamination. Due to the diversity of issues facing La Oroya, Integral strongly support's the CDC's recommendation and further recommend that a stakeholder advisory group be formed that includes representatives of local governments, community organizations (including local religious representatives), the Convenio, MEM, DIGESA, and Doe Run Perú. A similar stakeholder group was very effective in guiding actions in Trail, British Columbia, Canada where an active lead and zinc smelter is located.

This stakeholder group should review proposals for additional collaborative studies in La Oroya. It is important that any studies conducted fully utilize available information and are coordinated with the needs identified by the stakeholders in the community.

In addition to this one general recommendation of forming a stakeholders group, recommendations are also provided below for specific actions related to facility operation, exposure assessment and environmental monitoring, community interventions, and dietary studies and interventions.

Facility Operations

Air emissions of sulfur dioxide and metal particulates from the Complex are the principal focus of this risk assessment. These emissions include both fugitive emissions from buildings and ducts and stack emissions from the main stack and the sinter plant scrubber stack. These emissions are affected by the specific metals produced, i.e., copper, zinc or lead, and by production volumes, as well as by operating conditions and emissions controls. Some technological changes have already been implemented to reduce emissions. In addition, Complex operations have been modified to reduce sulfur dioxide emissions by temporarily shutting down the smelter whenever an inversion is predicted.

Integral has two principal recommendations related to Complex operations:

- Based on the analysis by McVehil-Monnett showing that the majority of lead emissions impacts from the Complex (near the plant) are in the form of fugitive emissions that are released close to the ground surface, it is recommended that priority be given to reduction of fugitive emission sources of lead. Although reduction of fugitive emissions of lead and the sinter plant scrubber stack emissions were not identified as a goal in the PAMA, reduction of these emissions sources should be the highest priority at the Complex.

- Because of the extended time period needed to bring sulfur dioxide concentrations down to the air quality standards, it is recommended that the policy to reduce or suspend operations when inversions are predicted be continued. Based on the air modeling results, the supplemental control scenario produced a reduction (relative to normal 24-hour per day operation) of 25 to 50 percent in highest short-term morning sulfur dioxide concentrations, and approximately 25 percent in 24-hour average concentrations. The model results therefore confirm that a procedure for emission reductions in pre-dawn hours has a significant effect in reducing maximum pollutant concentrations during the following day.

Exposure Assessment and Environmental Monitoring

Environmental monitoring programs in La Oroya are important for several reasons. Continuing collection of data on chemical concentrations in air, dust, and soil are needed to understand how exposures might be changing over time. These data also are needed to determine if the actions undertaken to reduce emissions from the Complex are effective in reducing chemical concentrations in the environmental media to which people are exposed. The following sections provide recommendations for continued air monitoring and regular monitoring of dustfall.

Air Monitoring and Modeling

The air monitoring network currently operated by Doe Run Perú should be continued. Data from the air monitoring network are used directly in assessing health risks and also are needed to support more accurate air modeling and prediction of impacts of changes in Complex operations. Continued monitoring of sulfur dioxide, particulates as PM_{10}, lead, arsenic and cadmium is recommended. Ensuring high quality monitoring data is important.

Regular calibration of the monitoring equipment should be performed and quality assurance/quality control (QA/QC) procedures should be improved to assure that meteorological and air quality monitoring data are accurate. Implementation of data quality oversight program would be an excellent topic for consideration by a stakeholder group. For example, the monitoring program could be expanded to include collection and analysis of split samples by a third party. This would provide transparency in the environmental monitoring program, increase confidence in analytical results, and support QA/QC program objectives.

Additional air monitoring stations for metals may be needed to better track exposures and emissions reductions, including a station in Chucchis and possibly another station within La Oroya Nueva. The location of the Cushurupampa monitoring station should also be reviewed to determine if it would be technically appropriate to move both metal and sulfur dioxide monitors to a lower elevation within the residential areas (currently these monitors are located high on the hillside). Supplemental air modeling may also be needed in the future to guide emissions reduction efforts. Detailed recommendations related to air monitoring and air modeling are provided in the report.

Monitoring of Metals in Dustfall and Outdoor Dust

The air model predicted deposition rates for lead, arsenic and cadmium. Deposition is a measure of the rate at which particulates emitted from the Complex fall to the ground and settle on paved surfaces and soil. Deposition of airborne dust can be measured directly by setting out open top containers on surfaces in various locations. The amount of dust or of specific metals in a container with a known surface area provides a measure of dustfall (usually reported in mg/m^2). Dustfall measures can be used to determine if deposition rates of particulates from the Complex are being reduced as emissions are reduced.

Trends in dustfall rates also can be compared to trends in outdoor dust metal concentrations or metal loading in dust to see if reduced deposition may result in exposures to metals in the outdoor dust. It is recommended that the stakeholder group establish a program to monitor trends of lead, arsenic and cadmium in dustfall or other

environmental indicators that are deemed useful in assessing effectiveness of emissions reductions and in predicting exposures.

Community Interventions

Current activities conducted by both Doe Run Perú and the Convenio de Cooperación between the Ministry of Health and Doe Run Perú have addressed hygiene education at the community and individual level. These activities range from regular street cleaning and waste disposal to provision of shower facilities and public dining rooms. While visiting homes during the field sampling effort, Integral staff learned that educational programs provided by the Convenio de Cooperación are appreciated greatly and utilized by the community. Many residents commented that they received useful information regarding home cleaning practices, personal hygiene, food preparation practices, and nutrition.

Continuation of community education programs in La Oroya Antigua is recommended to further instruct residents on reducing exposures in the home. In addition, to the extent that program personnel working in La Oroya Antigua have time available, educational outreach programs should be expanded to the communities of La Oroya Nueva, Marcavalle, and Chucchis. Examples of programs that are recommended for support include:

- Due to the importance of personal hygiene (e.g., hand washing) in reducing exposures, particularly for children, the personal hygiene training program in schools should be continued and the program to make structural improvements to public sanitation facilities should be continued.
- Continued cleaning of streets and sidewalks is recommended to remove outdoor dust from Complex emissions. Additional cleaning of paved play areas, including school courtyards, plazas, and playfields (soccer and basketball) is particularly important. Expanding the areas cleaned on a regular basis will help to reduce dust accumulation in areas where children are likely to touch it. In addition, it may be helpful to increase the frequency of street and sidewalk cleaning in areas with heaviest child recreational activity and those areas impacted by other sources of lead dust (i.e., high traffic streets).
- It is important that annual blood lead studies continue to be conducted by DIGESA/Convenio de Cooperación. Through regular blood lead monitoring, the efficacy of reductions in Complex emissions and intervention programs may be assessed. With the continuation of blood lead monitoring of children in La Oroya, children with blood lead levels exceeding 45 μg/dL may be identified and targeted for educational (e.g., hygiene, nutrition) and clinical (nutritional supplements,

medical testing) interventions that are tailored to the child's home environment and economic means.

In addition to continuing existing community education and intervention programs, it is recommended that other actions be considered to further reduce environmental exposures within the population:

- Given the available information, it was not possible to correlate child blood lead levels with the presence of paved or unpaved walkways outside homes. However, it is possible that paving dirt roads and walkways will facilitate cleaning and reduce the generation of windblown dust that enters homes. It is recommended that the program to pave roads and walkways with exposed soil particularly those areas outside homes be continued.
- Empty lots used by children for recreation should also be evaluated to identify ways to reduce exposures. The program to grow grass on exposed soils and to plant trees is an important contribution to reducing windblown dust in La Oroya and should be continued. One approach to reducing exposure to lead in soil may be to treat the soil with phosphates that reduce the bioavailability of lead. Studies at sites with elevated levels of lead in soil have shown that phosphate treatment of soils has resulted in the reduction of the bioavailability of lead, and also may stabilize cadmium and zinc in soil (Martin and Ruby 2004). Martin and Ruby (2003) reported success in reducing the bioavailability of both lead and arsenic in soil through amending soil with a mixture of phosphate and iron-based chemicals.
- In other smelter communities, door mats composed of a material that traps dirt have been shown to be an effective means of reducing the amount of contaminated dirt and dust that is tracked into a home. It is recommended that the stakeholder group or the Convenio investigate the feasibility of using such mats in La Oroya Antigua.
- Many homes in La Oroya are constructed of adobe that is not covered with plaster and some have dirt floors. An unknown number of homes have roofs/ceilings constructed of corrugated metal sheets or adobe. It is possible for dust to enter these homes through cracks in combination roofs/ceilings constructed of corrugated metal. It is recommended that a program be developed to improve homes constructed of adobe with exposed dirt and roofs of corrugated metal sheets to reduce generation of indoor dust, particularly in those homes located closest to the Complex.
- The highest lead concentrations detected in outdoor dust were found at an elementary school in La Oroya Antigua. The elevated lead concentration is likely due to the proximity of the school to the Complex. Because children are likely to

contact dust while at school, both classrooms and outdoor play areas should be cleaned more frequently.

- It is recommended that the community and DIGESA take action to ensure that leaded gasoline is not being sold in the La Oroya region. Although sales of leaded gasoline were banned after December 2004, Integral scientists have been told that some leaded gasoline is still being offered for sale. Consistent with Perú's Decreto Supremo No. 019-98-MTC,[4] the sale and use of leaded gasoline should be prevented to further reduce lead emissions.

Dietary Studies and Interventions

As described above, the pilot dietary study conducted in La Oroya Antigua by the IIN found increased intakes of lead in the diets of women and young children. Iron intakes were found to be inadequate, and calcium intakes were highly variable. Vitamin C intakes were adequate. The CDC (2002) identifies ensuring adequate intakes of iron, calcium, and vitamin C as important factors that may affect lead absorption and toxicity. Insufficient evidence was found by the CDC to indicate the need for other dietary interventions. In particular, the CDC does not recommend low fat diets or zinc supplementation.

Based on the preliminary findings of the IIN study, additional study and dietary interventions are recommended for La Oroya. Further study is needed to confirm the means by which lead is being transferred to prepared foods, followed by the development of actions and an education program to reduce lead concentrations in food. The second focus of additional studies and interventions should be development of a program to ensure that residents have adequate iron and calcium intakes. Adequate iron intakes are particularly important because both low iron intake and high lead intake cause neurobehavioral disorders and anemia. Attention should also be given to ensuring the adequacy of calcium intakes.

Hemoglobin data from the DIGESA blood lead monitoring studies should be used to assess the occurrence of anemia in the children of La Oroya. When testing for anemia in La Oroya, it will be necessary to consider the expected hemoglobin and hematocrit values for each age group at the elevation of 3,700 meters. Residents of La Oroya may be anemic even when hematocrit and hemoglobin levels are comparable to those of populations residing at sea level.

[4] Decreto Supremo No. 019-98-MTC: Disponen eliminar el Mercado la oferta de Gasolina 95 RON con plomo y reducir el límite máximo de contenido de plomo en la Gasolina 84 RON.

A program to increase iron intakes among young children and women of child-bearing age should be developed by IIN and the Convenio. The CDC (2002) recommends encouraging caregivers to provide children with an adequate intake of iron by:

- Introducing them to iron-fortified cereals and pureed meats at their appropriate developmental stages.
- Providing one serving of lean red meat per day to older children.

CDC does not recommend giving children iron supplements except under the supervision of a physician or nutritionist and only when iron deficiency or anemia is documented. The effectiveness of efforts to increase iron intakes should be evaluated by tracking both hemoglobin levels and blood lead levels in the study participants. It should be remembered that blood lead levels will be an uncertain indicator of lead body burden in iron studies because 99 percent of lead in blood is in red blood cells, so any intervention that causes a significant increase in the hemoglobin concentration will also cause blood lead levels to increase (CDC 2002).

Increased attention should also be given by the Convenio to assessing calcium intakes. The CDC (2002) recommends encouraging caregivers to see that children with elevated blood lead levels receive an adequate amount of calcium (500 mg/day for 1 to 3 years of age; 800 mg/day for 4 to 8 years pf age), by:

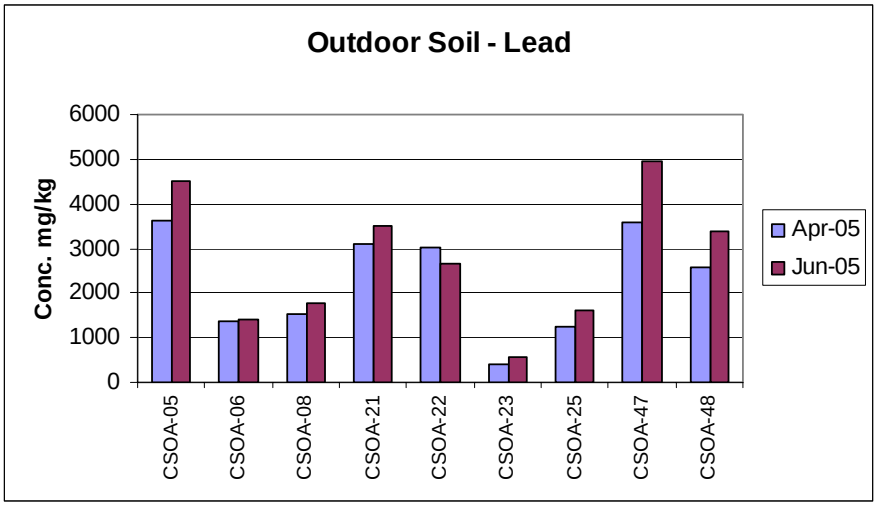
- Providing them with two servings of dairy products per day, unless they are lactase deficient.
- Providing lactase-deficient children with sufficient dietary calcium from other sources (e.g., broccoli, greens, kidney beans, and calcium-fortified juices).

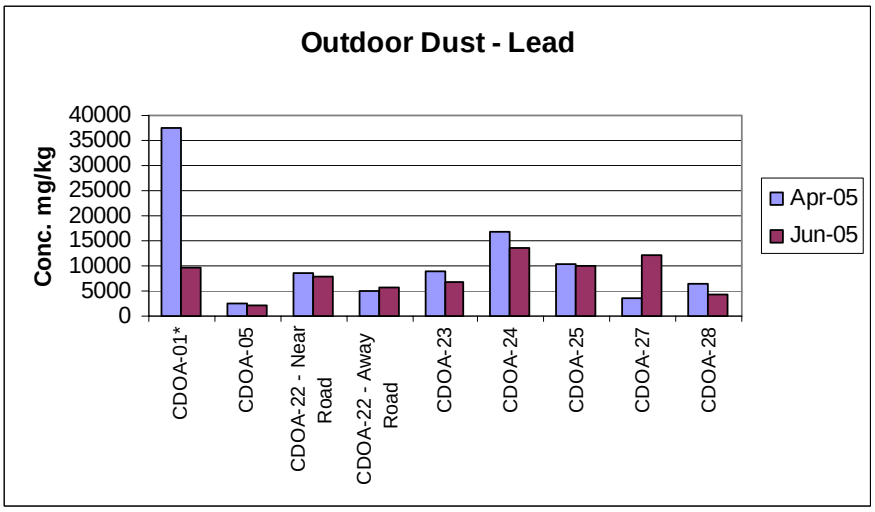
The CDC does not recommend giving children calcium supplements except under the supervision of a physician or nutritionist. The CDC also does not recommend supplementation in children with elevated blood lead levels beyond the recommended adequate calcium intake levels.

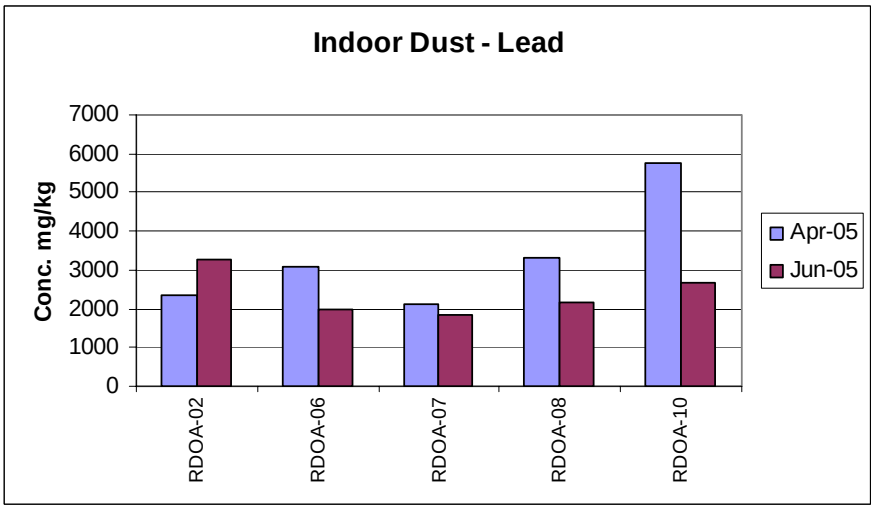
In order to better understand the ways in which lead enters the foods, it is recommended that representative samples of different foods be analyzed in order to identify foods that are higher lead contamination. It is also recommended that samples of food from the food supply chain be analyzed in order to determine the time when lead contamination occurs (i.e., before foodstuffs enter the market, in the market place, during the handling of foodstuffs at home, food prepared and sold by street vendors, etc.), as well as where the contamination is higher (types of markets, their location) in order to find spots and strategies to reduce lead contamination through food.

Reducing blood lead levels through the kinds of interventions recommended takes dedicated and continuing effort. This is why a stakeholder group should be established to oversee the programs being undertaken.

Figure ES-1.Exposure Pathways for Emissions from the Complex







* Outdoor dust sample collected at station CDOA-01 during March/April 2005 sampling event identified as outlier concentration.

Figure ES-2. Comparison of Lead Concentrations in Soil and Dust Samples Collected In La Oroya Antigua During March/April and June 2005 Sampling Events

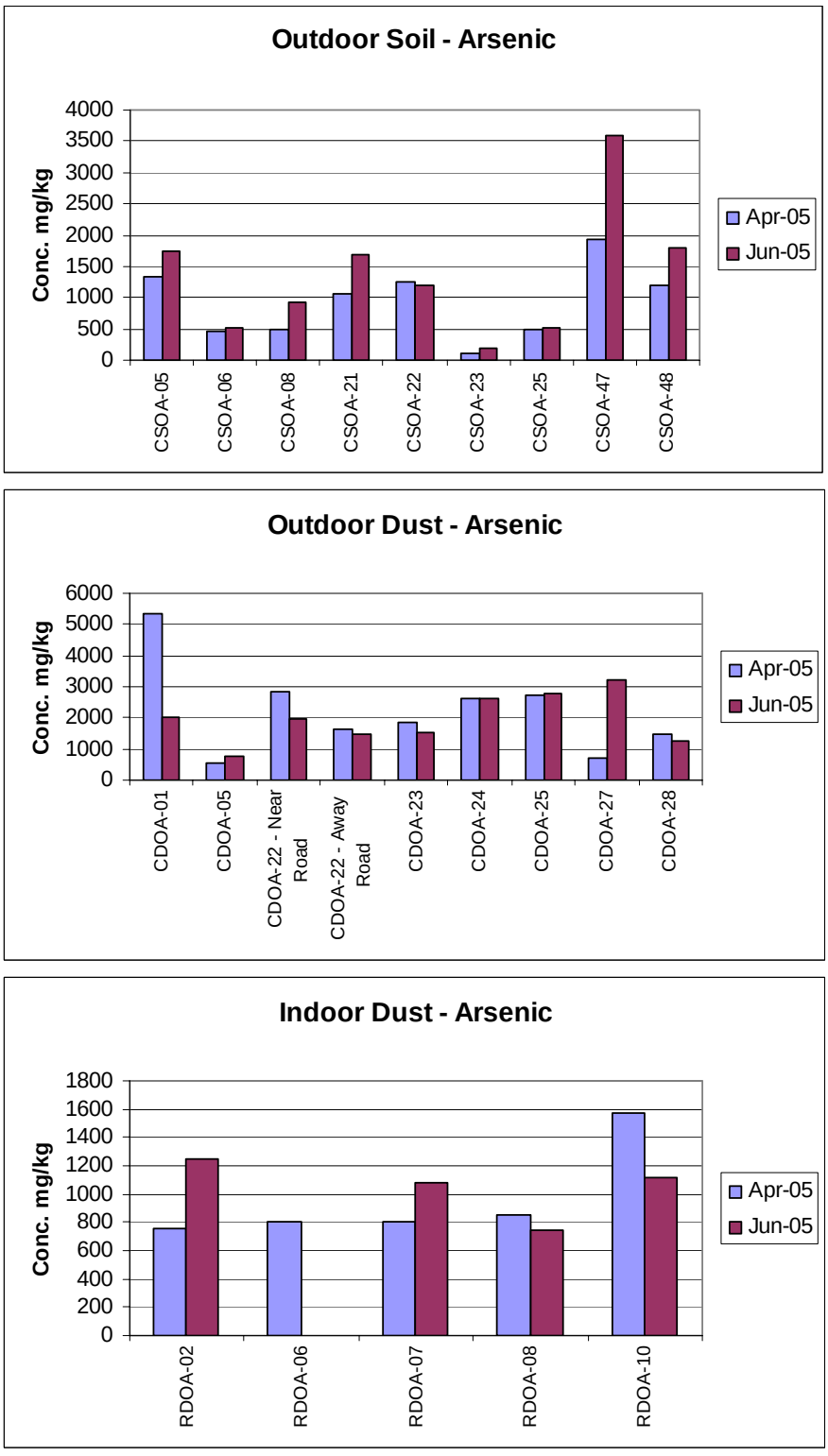


Figure ES-3. Comparison of Arsenic Concentrations in Soil and Dust Samples Collected In La Oroya Antigua During March/April and June 2005 Sampling Events

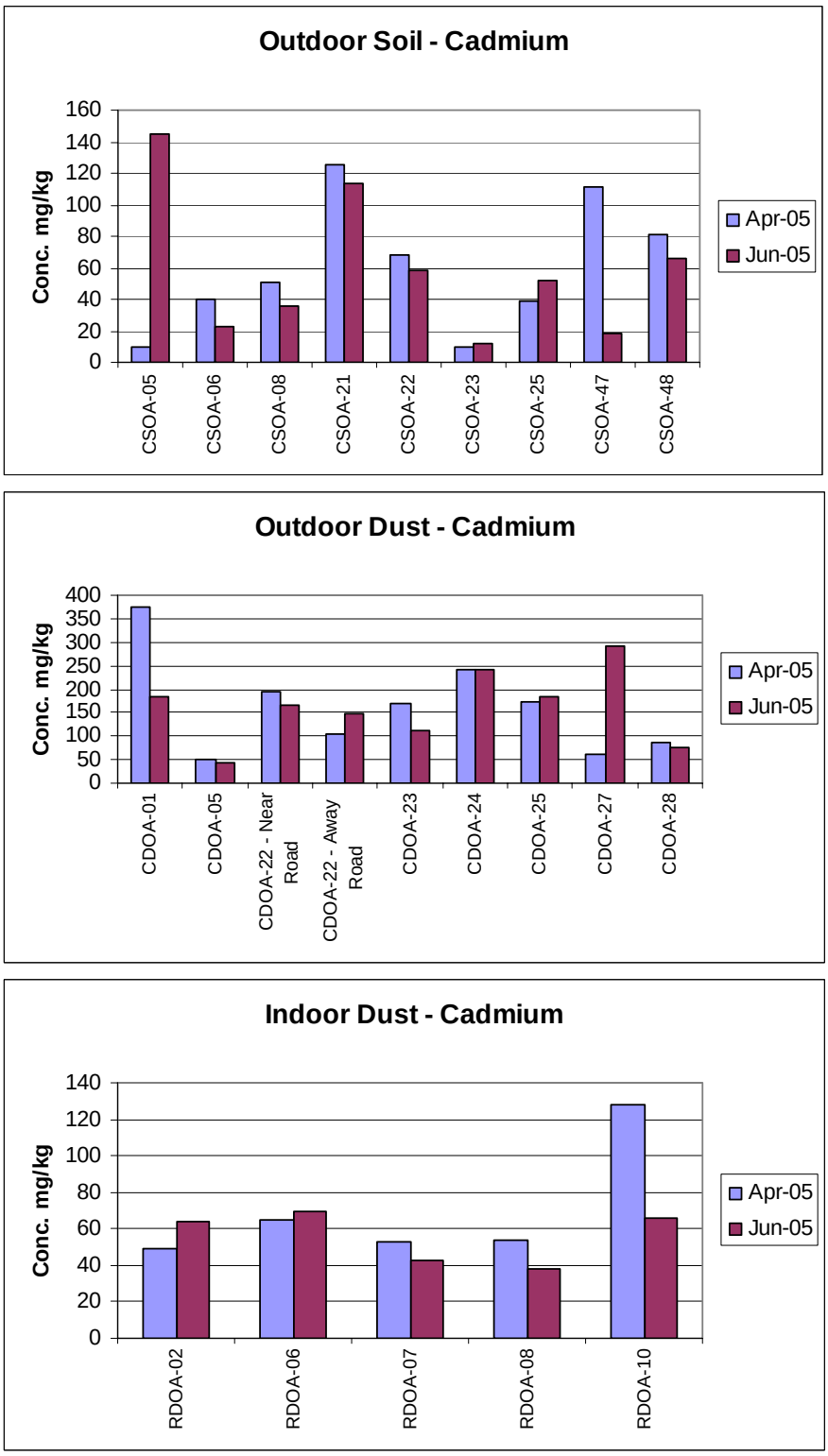


Figure ES-4. Comparison of Cadmium Concentrations in Soil and Dust Samples Collected In La Oroya Antigua During March/April and June 2005 Sampling Events

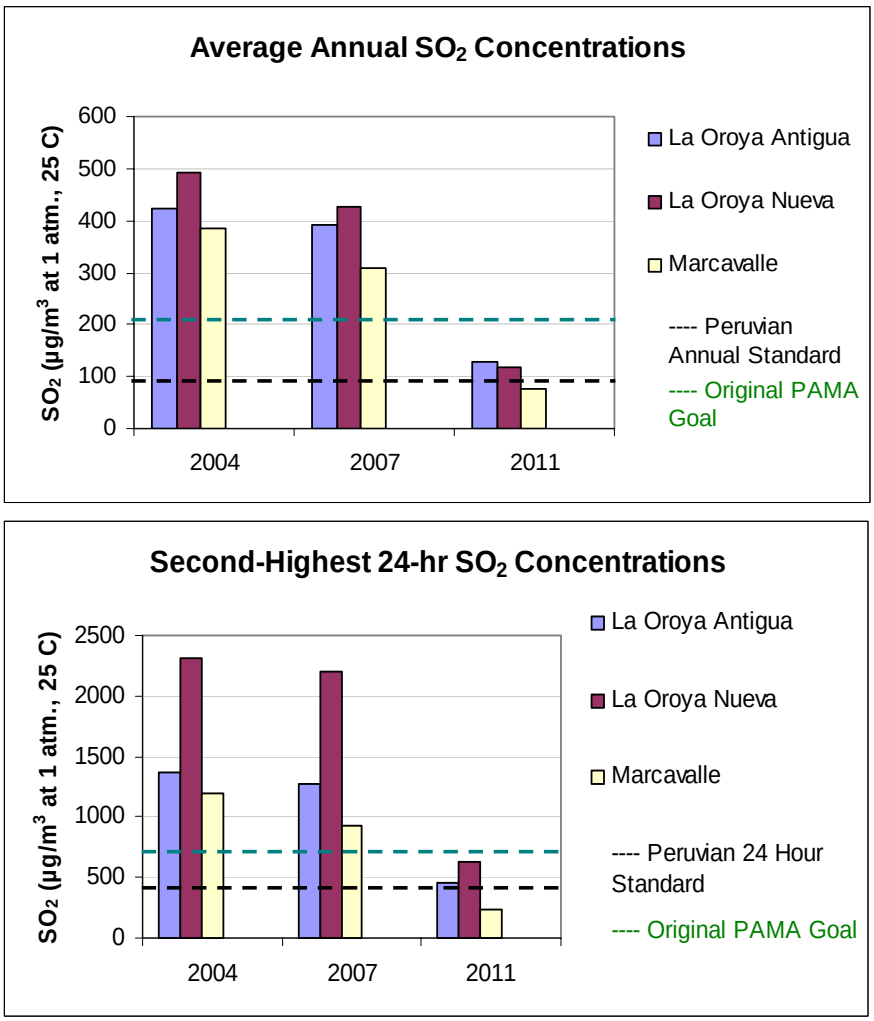


Figure ES-5. Average Annual and Second Highest 24-hour Sulfur Dioxide Concentrations for Years 2004, 2007, and 2011 Compared to Peruvian Air Quality Standards and PAMA Goals

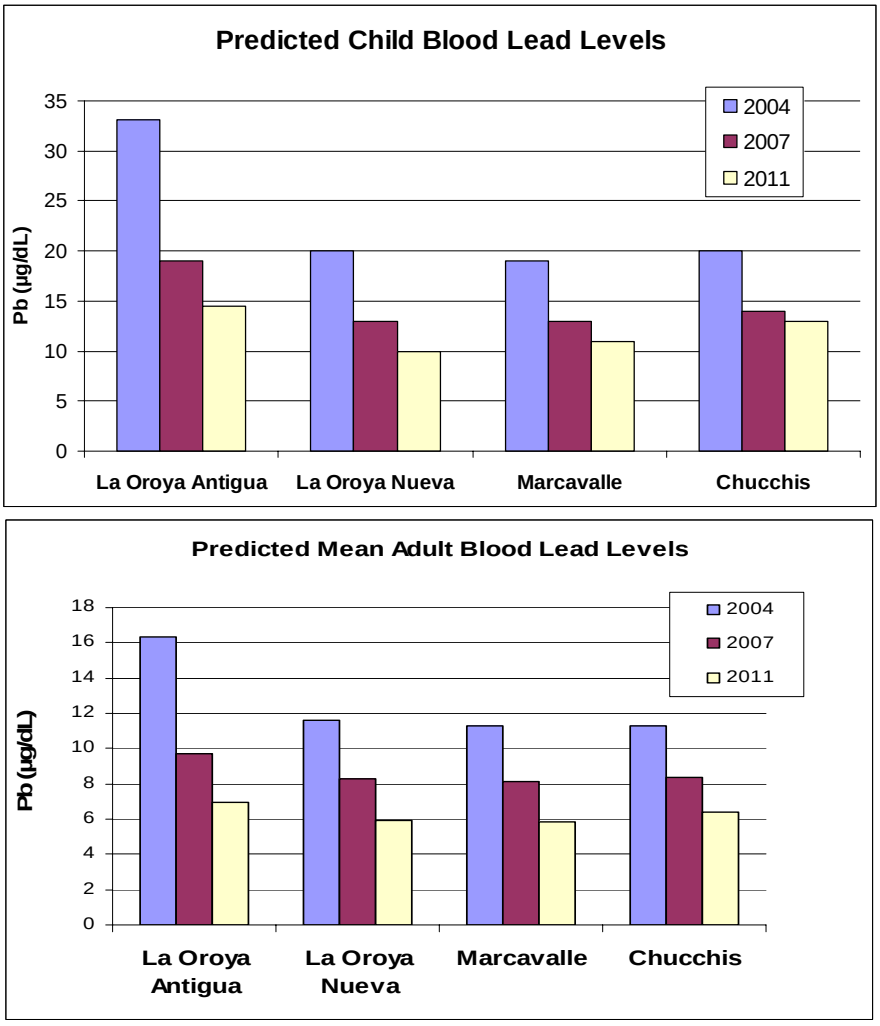


Figure ES-6. Predicted Mean Child and Adult Blood Lead Levels for Years 2004, 2007, and 2011

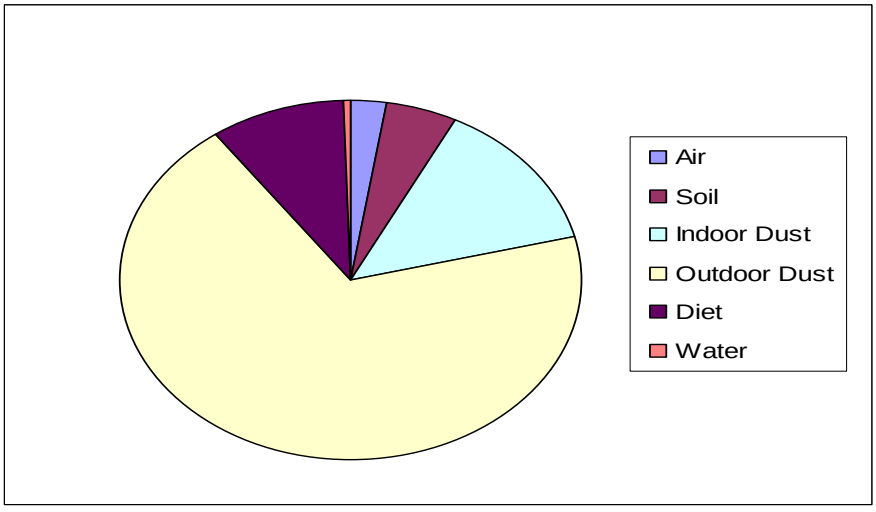


Figure ES-7. Contribution of Different Lead Sources to 2004 Child Blood Lead Model – La Oroya Antigua

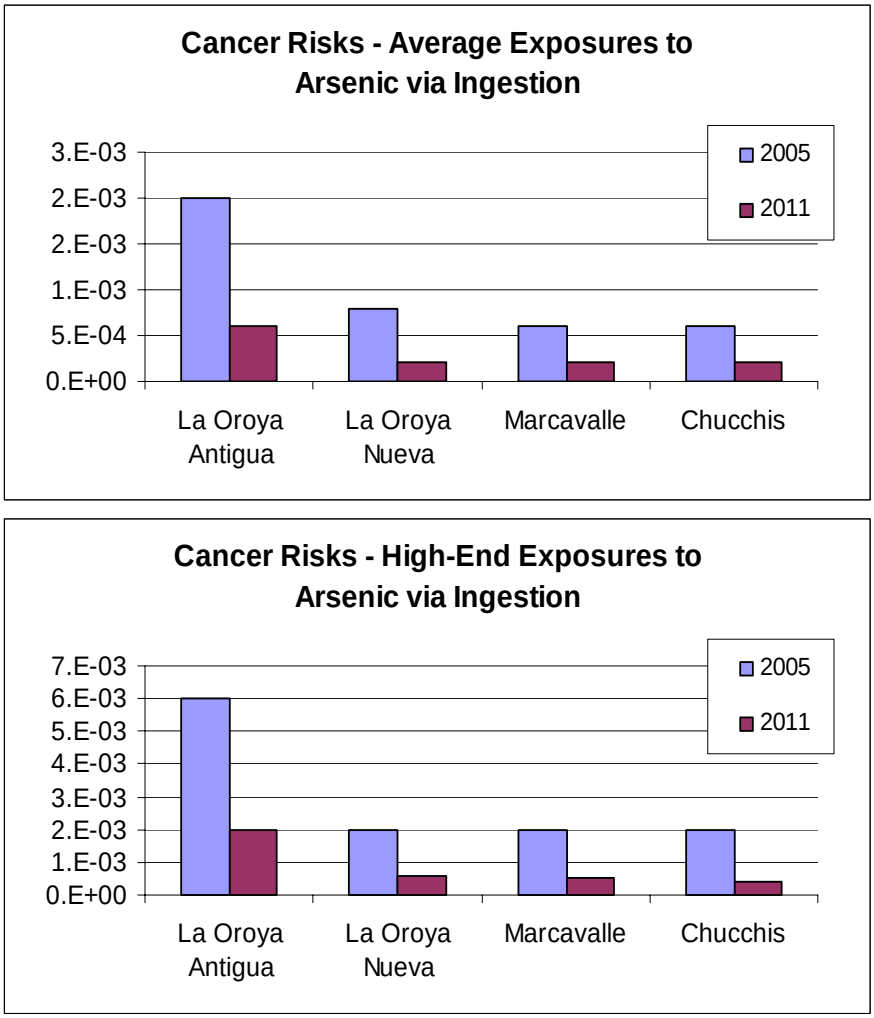


Figure ES-8. Current and Future Cancer Risks for Ingestion of Arsenic in Soil and Dust for Average and High-End Exposures

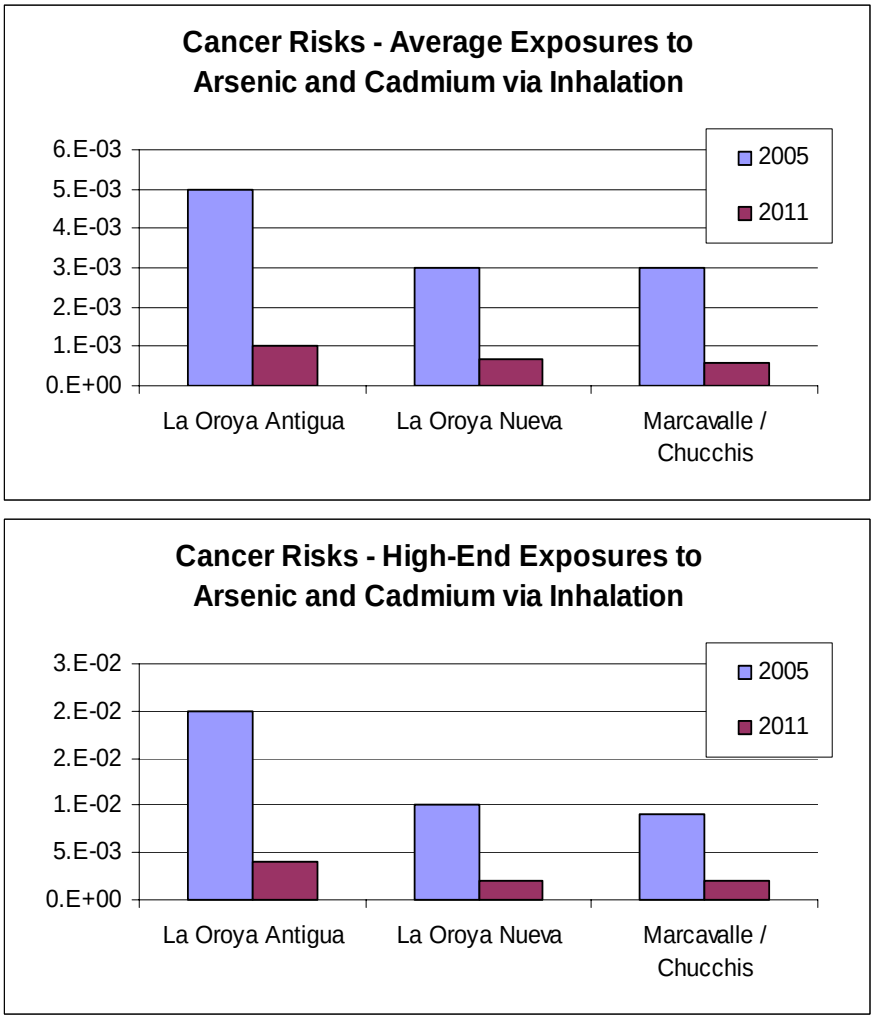


Figure ES-9. Current and Future Cancer Risks for Inhalation of Arsenic and Cadmium in Air for Average and High-End Exposures

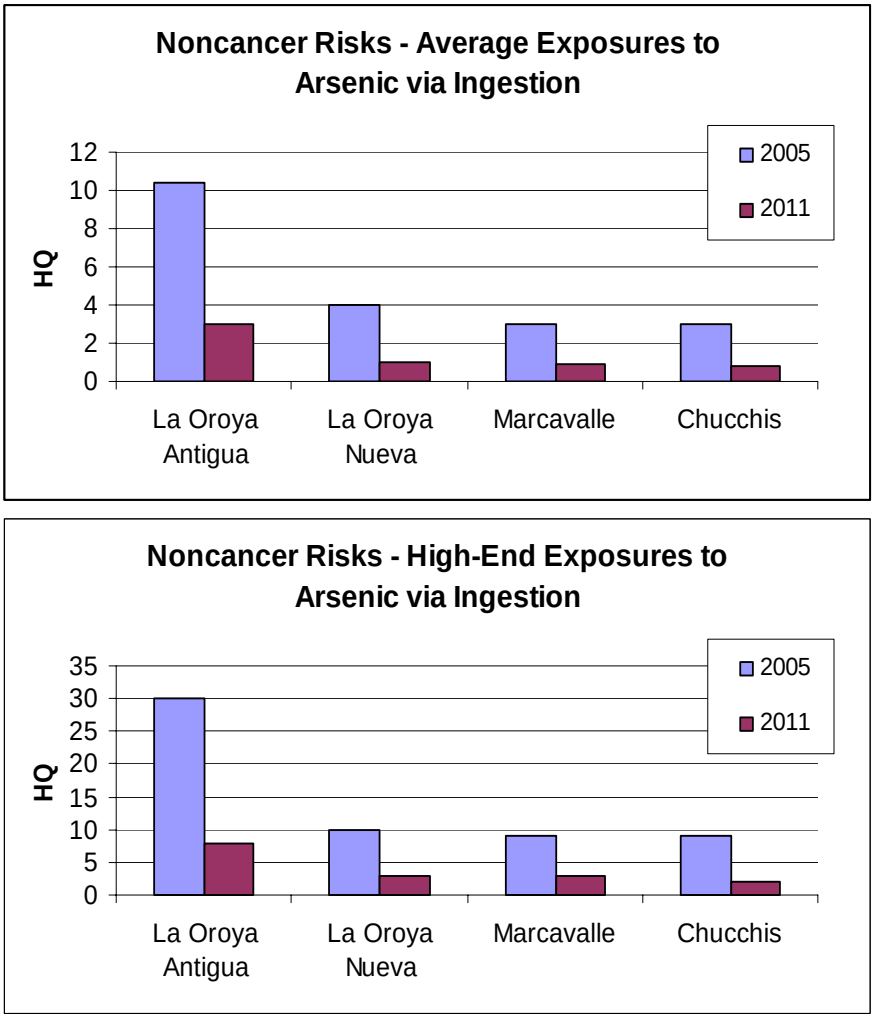


Figure ES-10. Current and Future Noncancer Hazard Quotients (HQ) for Ingestion of Arsenic in Soil and Dust for Average and High-End Exposures

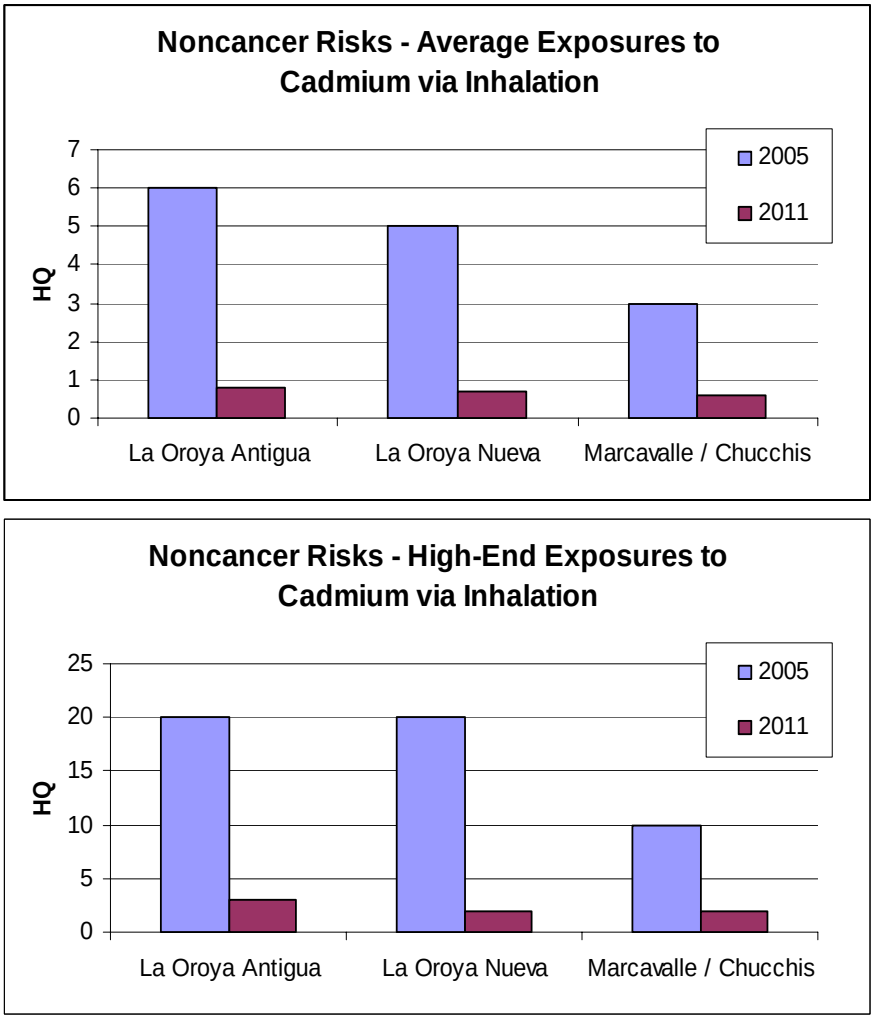


Figure ES-11 Current and Future Noncancer Hazard Quotients (HQ) for Inhalation of Cadmium in Air for Average and High-End Exposures

1 INTRODUCTION

This report presents the results of the human health risk assessment conducted by Integral Consulting Inc. (Integral) to assess emissions from the Doe Run Perú Metallurgical Complex (Complex) in La Oroya, Perú. Integral was retained by the Doe Run Perú Company to perform this risk assessment in order to comply with the Supreme Decree of the Peruvian Ministry of Energy and Mines (MEM). This risk assessment was conducted in accordance with guidance from the U.S. Environmental Protection Agency (USEPA) and other international standards for human health risk assessment.

A human health risk assessment is a quantitative evaluation of the risk posed to human health by the actual or potential presence or release of chemicals in the environment. Thus, a risk assessment predicts the likelihood of health effects in a population, but does not directly measure the occurrence of health effects. Therefore, a risk assessment is very different from an epidemiology study that reports the incidence of specific health effects or a biomonitoring study that reports the concentrations of chemicals in people's bodies. The value of a risk assessment is that it is a tool that may be used to predict conditions in the future. Risk assessment is needed for La Oroya to predict future health risks as emissions from the Complex are reduced.

The human health risk assessment process as defined by USEPA (1989) contains four major steps. The first step is to characterize the site and the chemicals associated with the site. This step includes many activities, including review of sources that release chemicals to the environment, the identification of the chemicals released, evaluation of the available data, and an assessment of how people in the community might contact the chemicals. The result of this step is the creation of an exposure pathway model, or a road map of how and where people might come into contact with the chemicals associated with the site. In this risk assessment, the site characterization and data evaluation sections comprise the first step of the process.

The second step is to evaluate the potential exposure of people to the chemicals being evaluated. This portion of the risk assessment process looks in detail at how people may come into contact with the chemicals. As part of this step, potential doses or intakes of chemicals from air, dust, soil, water or other media are quantified.

The third step is the toxicological evaluation. The toxicological evaluation looks at the potential toxicity of the chemicals being evaluated and identifies doses that may cause toxicity and doses that are not expected to cause health effects. In this risk assessment, the highest safe doses are called toxicity values.

The fourth step is the risk characterization. The risk characterization combines the results of the exposure assessment and the toxicological evaluation to describe potential risks to human health associated from site-related chemicals. The doses of chemicals to which people may be exposed are compared to the toxicity values to determine the risk of health effects. This step provides results that can be used to help decide if actions need to be taken to reduce chemical exposures at the site.

This human health risk assessment has two primary goals. The first goal is to evaluate current human health risks from the Complex and to characterize the ways in which people are currently exposed to chemicals released from the Complex. The second goal is to use predicted future changes in emissions from the smelter to predict health risks after the implementation of various changes in smelter operations.

Requirements imposed by MEM as well as additional actions proposed by Doe Run Perú form the basis for the predicted changes in emissions. In 1997 Doe Run Perú entered into an agreement with MEM called the Programa de Adecuación y Manejo Ambiental (PAMA). The agreement outlines monitoring and emissions reduction requirements. An amendment to PAMA in 1999 provided for increased spending by Doe Run Perú to update engineering controls at the Complex. The main goal of the PAMA projects is to reduce Complex stack emissions of sulfur dioxide, particulates, lead and arsenic to below maximum permissible emission levels identified by MEM.

Meanwhile, Doe Run Perú is performing additional actions to reduce environmental impacts, including (DRP 2002b):

- Reduce particulate matter emissions from the main stack;
- Reduce the environmental impact of sulfur dioxide gas emissions, and reduce environmental impacts of emissions;
- Improve the efficiency of the bag houses used to capture particulate matter; and
- Control fugitive emissions from areas of the Complex other than the main stack.

In accordance with the PAMA objectives, the human health risk assessment focuses on characterizing risks to nearby residents from chemicals released to the air during current operations of the Complex. Gases such as sulfur dioxide that are released to the air will mainly affect people by inhalation. However, many other chemicals are released from the smelter as particulates. These particulates fall to the ground as "dustfall" or are washed out of the air by rain. Once the particles are on the ground they may work their way into soil or be tracked into houses. Dust particles originally released to the air may also enter rivers or lakes. Dust on surfaces outside may get onto food in outdoor displays. Dust inside homes may get onto food as meals are being prepared. Thus, in this risk

assessment we consider the many different pathways by which people may be exposed to chemicals released from the Complex.

According to the PAMA and the transfer agreement, Centromin backed by the government of Perú is responsible for chemical contamination from historical operation of the Complex and continuing emissions through the period of the PAMA. The exceptions are the slag pile and ferrites for which Doe Run Perú agreed to take back the historical liability. Soil and dust in La Oroya may be affected both by current operations of the Complex and continuing emissions through the period of the PAMA and by historical operations. For that reason this risk assessment does not strictly distinguish between current and future chemical releases, but the focus is on air and dust because these are the exposure media that are most affected by current operations. Due to the focus on current operations of the Complex, this risk assessment also does not provide an assessment of the full extent of environmental contamination due to the operation of the Complex in La Oroya since 1922.

This risk assessment also provides information regarding future risks to the communities. Integral relied upon the results of air quality dispersion modeling, conducted by another independent company, to assess how planned reductions in Complex emissions would impact health risks in the future. Air modeling was conducted by McVehil-Monnett, a consulting company based in Denver, Colorado, USA. McVehil-Monnett have over a decade of experience conducting air modeling of emissions in La Oroya. Air modeling results used by Integral in this risk assessment included emissions from both the stack and fugitive sources at the Complex.

Based on these goals this risk assessment includes the following steps:

- Identifying the chemicals that should be included in the risk assessment.
- Identifying ways in which residents living near the Complex are currently exposed to chemicals.
- Calculating exposures to chemicals in air, soil, dust, and diet now and estimating future exposures.
- Evaluating and selecting toxicological values for chemicals included in the risk assessment.
- Calculating risks for predicted chemical exposures.
- Evaluating uncertainties and limitations associated with the risk calculations.

In addition, this risk assessment provides information that is important to identifying the most important sources of exposure within the communities impacted by the Complex. This information was used to develop recommendations for actions, in addition to the

planned operational changes already planned by Doe Run Perú that might be taken to further reduce health impacts in nearby residents.

Organization of this human health risk assessment report is as follows:

- Section 2, Site Characterization, provides a description of the Complex, including chemicals likely to be emitted, and the residents living near the Complex. The likely exposure pathways are also discussed in this section along with a summary of prior risk assessment studies.
- Section 3, Data Evaluation, summarizes existing data considered in development of the risk assessment and presents additional data (environmental field studies, a duplicate diet study, air modeling activities) relied upon in the report. This section of the report also details the screening process used to update the list of chemicals for quantitative risk evaluation and presents the final list of chemicals to be evaluated.
- Section 4, Exposure Assessment, summarizes the methods used to estimate human exposures in the risk assessment, and presents the results of the exposure evaluation.
- Section 5, Toxicological Evaluation, summarizes the toxicity values used in the risk assessment and describes potential health effects associated with chemicals evaluated.
- Section 6, Risk Characterization, describes the calculation of the risks from chemical exposures and provides a qualitative evaluation of uncertainties associated with these results.
- Section 7, Conclusions and Recommendations, delineates recommendations for future actions to further assess and/or reduce exposures in La Oroya.
- Section 8, References, lists the documents cited in this risk assessment.

2 SITE CHARACTERIZATION

The site characterization is a critical step in ensuring that the risk assessment properly assesses the potential risks to the affected communities, and that required data are available. Integral staff visited La Oroya three times to assess the nature of potential exposures, obtain available data, and collect additional samples. Contacts at the Doe Run Perú Metallurgical Complex (Complex) in La Oroya, Perú, the Ministry of Energy and Mines (MEM), and the Ministry of Health assisted with these efforts by providing documents and information about the smelter and the population of La Oroya. Two key outcomes of the site characterization process include identification of chemicals of potential concern and development of a conceptual site model. A discussion of each of these is provided below, following a description of the Complex and its operations, the local population, and the environmental setting.

2.1 DESCRIPTION OF THE COMPLEX AND ITS OPERATIONS

The Complex is located approximately 175 kilometers northeast of Lima, Perú in the Andes Mountain Range, at an altitude of 3,745 meters. It is situated in the Mantaro River Valley at the confluence of the Mantaro and Yauli Rivers. North of the Complex, across the Mantaro River is the town of La Oroya Antigua. The communities of La Oroya Nueva, Marcavalle, Chucchis, and Curipata are located upstream, along the Mantaro River, west-southwest of the Complex. The surrounding environs are dry, rugged, limestone mountains with sparse vegetation consisting of bunch grasses. Ground-level winds are predominantly from the west-southwest and the northeast.

The Complex was built by American Cerro de Pasco Copper Corporation and began smelting copper in 1922. Lead production began in 1928 and zinc production began in 1952. Recovery of precious metals began in 1950. The government-owned company, Centromin, operated the Complex from 1974 until 1997, when it was purchased by the Doe Run Company. The Complex is an operating smelter that processes approximately 600,000 metric tons of concentrate annually. Approximately 450,000 tons of the concentrate contain multiple metals including precious metals, and 150,000 tons are zinc concentrates. A total of eleven metals, most importantly lead, zinc, copper, silver, and gold, and eight byproducts are produced from the concentrate.

A main stack, rising 167.5 meters above ground level, emits gases and particulate matter produced during smelter operation. In addition, fugitive gases and particulate emissions escape from various areas of the facility that are not enclosed by buildings. The emissions from the main stack and fugitive emissions contain heavy metal dusts and sulfur dioxide gas that migrate to the surrounding communities.

Particulates and sulfur dioxide emitted from the main stack of the Complex are monitored by Doe Run Perú. Particulate matter and sulfur dioxide emissions have decreased since 1985. Mean particulate matter emissions from the main stack were reported as 14 tons per day (tons/day) for 1985 and have decreased to 6.95 tons/day in 2004. Mean sulfur dioxide emissions from the main stack were reported as 1,037 tons/day in 1985 and decreased to 911 tons/day in 2004.

Particulates emitted from the main stack are analyzed for lead, arsenic, and cadmium concentrations by Doe Run Perú. As with sulfur dioxide, metals concentrations also have decreased since 1985. Lead decreased from 4,255 Kilotons per day (Ktons/day) in 1985 to 1,702 Ktons/day in 2004. Arsenic decreased from 2,279 Ktons/day to 840 Ktons/day and cadmium decreased from 107 Ktons/day to 81 Ktons/day over the same time period. Thus, historical exposures to these chemicals may have been substantially greater than current exposures.

In addition to reducing stack emissions since purchasing the Complex in 1997, Doe Run Perú has introduced programs to reduce chemical exposures of workers and community residents (DRP 2001b). Additional programs have contributed to improving nutrition and living conditions for residents.

To improve worker hygiene, Doe Run Perú has improved change houses where chemically exposed workers are required to change out of their work clothes and take a shower at the end of their shift, before leaving the site and going home. The worker hygiene program is credited with contributing to a 31 percent reduction of blood lead levels in workers since 1997.

Community programs implemented by Doe Run Perú include:

- Conducting the first-ever community-wide blood lead level survey using protocols developed by the United States Center for Disease Control and Prevention;
- Entering into an agreement with the Peruvian Ministry of Health to reduce blood lead levels in children under the age of 6 who live in La Oroya Antigua;
- Constructing a medical clinic and government dining establishment that serves 800 low-income residents;
- Implementing water-collection systems in parts of La Oroya that enable treatment of storm water and sewage;
- Remodeling more than one dozen public schools;
- Introducing a breeding program for sheep and llamas and donating offspring to surrounding communities;

- Providing seminars on animal husbandry and pasture improvements;
- Providing small business practices training for nearly 4,000 local women, resulting in 25 new businesses;
- Developing a recreational center that includes soccer fields, artificial lakes, wildlife, and barbecue areas; and
- Introducing a community education program to address the issue of blood lead levels in young children.

2.2 CHEMICALS RELEASED FROM THE COMPLEX

Lead and sulfur dioxide, known to be released from the Complex at levels capable of causing health effects, were considered the primary focus of this risk assessment. Although lead is a naturally-occurring element, it is also emitted from the Complex. Ambient air monitoring data indicate that the lead is transported by wind to the surrounding communities. Recent studies by Doe Run Perú (2001a) and other organizations (UNES 1999; DIGESA 1999) demonstrate that blood lead levels in children and women of childbearing age exceed international health standards. Although sulfur dioxide emissions from the Complex have decreased over the previous five years, ambient air monitoring data indicate that sulfur dioxide levels frequently exceed international health-based standards.

Based on a description of the Complex operations and a review of available stack and fugitive emissions data, other chemicals of potential concern that were initially considered in this risk assessment were antimony, arsenic, cadmium, copper, mercury, selenium, silver, thallium, and zinc. In addition to being emitted from the Complex, these metals have been detected in dust and soil samples collected from various locations in La Oroya. In particular, the presence of arsenic and cadmium in soil and dust samples was of primary focus given that both are chemicals that can cause cancer. Only those chemicals that are likely to contribute the greatest overall health risk for residents of La Oroya were selected for further quantitative evaluation in this risk assessment. The process used to select these chemicals is described in Section 4.1.

In addition to sulfur dioxide gas, particulate matter is released through stack and fugitive emissions from the Complex. Particulate matter, which may contain a complex mixture of chemicals, is measured through Doe Run Perú's ambient monitoring program. Measured particulate matter concentrations in air were also considered in this risk assessment.

2.3 DESCRIPTION OF STUDY POPULATION

There are several communities located within the vicinity of the Complex. Nearest the Complex is La Oroya Antigua, which has a population of approximately 12,000. Other study area communities are La Oroya Nueva, Marcavalle, and Chucchis. Although Curipata is located near the District of La Oroya, it was not evaluated in the human health risk assessment due to its distance from the Complex and likelihood for reduced risks compared to other, closer communities.

Doe Run Perú conducted a socioeconomic study in the community of La Oroya in coordination with the Ministry of Health and the National Institute of Statistics and Data Processing (DRP 2002a). Demographic information was obtained for 18,308 residents of La Oroya, slightly more than one-half of the estimated population.

Heads of households were asked to report how long they have lived in La Oroya. Of those interviewed, 40 percent had been living in La Oroya less than 20 years, 21 percent had been living in La Oroya for 20 to 29 years, 22 percent had been living in La Oroya for 30 to 39 years, and 17 percent had been living in La Oroya for more than 40 years. Over the past decades, people migrated to La Oroya to seek economic opportunities. However, the migration of people to La Oroya dramatically decreased around the year 1999 compared to previous years since 1910. Even though only 40 percent of the population had lived in La Oroya for less than 20 years, anecdotal evidence suggests that a substantial subset of the population is highly mobile and moves frequently (IIN 2005). Much of this movement may be among communities within the study area. This mobility is an important factor affecting the interpretation of community exposure studies.

The population within the study area is generally young, with about a third of the people less than 15 years old (DRP 2002a). Only three percent of the population is greater than 64 years of age, while six percent are less than four years old. The majority of the population is of working age, 12 to 63 years old.

Women of child-bearing age represent 38 percent of the total district population. Of these, 38 percent have children. For those women who are mothers, 17 percent have only one child, 25 percent have two children, 21 percent have three children, and 24 percent have four to five children. Mothers with six or more children represent 13 percent of the mothers.

The educational status of females age 12 and over is generally low within the district. Eleven percent of women have no education and 24 percent have a primary school education only. Less than half (46 percent) of this subpopulation received secondary

school education. For this group, ten percent have college level training and eight percent have graduate school education.

Thirty-seven percent of the population earns less than 500 nuevo soles per month and 20 percent of the study population earns between 501 and 1000 nuevo soles. The majority of earnings go toward food (52 percent). Principal foods consumed by households include cereals (wheat, oats, barley, corn, etc.), potatoes, rice, milk, fruit, and vegetables. Foods also are obtained from social programs. Although 55 percent of the residents are familiar with the "Vaso de Leche" program, only 23 percent are program participants. Similarly, 24 percent are familiar with the "Comedor Popular" program but only two percent are participants.[5]

Residents of La Oroya also participate in public health programs. Some 45 percent of the residents participate in child development programs, 41 percent use family planning services, 40 percent participate in immunization programs, and 27 percent of the residents participate in tuberculosis prevention programs.

Within the district, 93 percent of the houses have electricity, 64 percent are served by public water supply inside the home, and 79 percent have bathrooms. Only about half of the houses have trash collection services. According to the study, other means of trash disposal include leaving trash in bags on the street (24 percent), throwing it into the river (6 percent), and throwing it in the street (1 percent).

2.4 EXPOSURE PATHWAYS

The way by which people are exposed to chemicals in the environment is called an *exposure pathway*. This pathway must be complete in order for an exposure to occur. An exposure pathway is complete if it includes all of the elements described below:

- Source – this includes sources, releases, types, and locations of chemicals and includes how a chemical can be transported from the source (e.g., by moisture or wind) to other areas or how it can be changed into some other form (e.g., a chemical that is more or less toxic)
- Exposure point – this is the location where a person can be exposed to the chemical (e.g., a child playing in dirt)

[5] The "Vaso de Leche," or "Glass of Milk" and "Comedor Popular" programs are sponsored by the Provincial Governor and Ministry of Health, respectively. The programs aim to improve nutrition for area residents by providing either a can of milk per day to women and children or meals to families.

- Exposure route – this is the way that a chemical enters the body (e.g., eating, drinking, or breathing)
- Individuals – people who are present at the exposure point and are eating, drinking or breathing the chemical.

If any one of these elements is missing, the pathway is not considered complete. For example, if the activities and/or location of individuals would not allow them to have contact with a chemical at the exposure point, then the exposure pathway for those people is not complete. Unless the chemical has contact with the person and then gets into the person's body, exposure has not occurred. A person who is not exposed to a chemical is not at risk of adverse health effects from that chemical.

In risk assessment, an exposure pathways diagram is developed to help identify the exposure pathways, or ways in which people might contact chemicals from a particular source. An exposure pathways diagram illustrates the relationships that exist between the elements of a complete exposure pathway within the study area.

An exposure pathways diagram that identifies the main principal exposure pathways for people within the study area is presented in Figure 2-1. As shown in this figure, chemicals are emitted from the Complex into the air may be inhaled (as vapors, such as sulfur dioxide, or in particulate matter). The particles also may settle out onto soil and paved surfaces, and later be ingested in soil or dust. Soil and dust may then be ingested. Chemicals in soil or dust in outdoor areas also may be transferred to indoor areas, such as floors and furniture, and ingested or inhaled if dust is disturbed and becomes airborne again. Airborne dust also may re-deposit onto food sources, including food stored in the home or food in open markets, or meal preparation areas where it then may be ingested along with the food.

This risk assessment focuses on chemicals that are known to be released from the Complex via stack and fugitive emissions. Surface water and groundwater that might be affected by releases from the Complex are not used by residents for drinking water, so water sources were not examined in detail. Also, releases from wastes stored in piles (e.g., slag) or impoundments were not characterized. Both historic and current operations may have contributed to metals concentrations in soil, dust, and other sampled media used to assess risks in this report. However, contributions from historic operations could not be distinguished from current operations in this risk assessment.

A variety of sources of lead that are not related to the Complex may contribute to its presence within the study area. The results of blood lead studies conducted on populations within La Oroya and other areas of Perú indicate that exposures to lead may reflect the influence of multiple sources. Given the potential for a variety of sources to contribute to levels of lead in blood within the study population, Figure 2-2 presents a

more detailed exposure pathways diagram for exposures to lead from the Complex and other potentially relevant sources within the study area.

As depicted in Figure 2-2, other potential sources of lead exposure within the study area include the following:

- Manufacturing and mineral processing operations other than the Complex
- Automobile emissions (Perú has banned leaded gasoline as of December 31, 2004, but old leaded gas supplies are still being used. It is not known how long it will take for the influence of prior use to dissipate.) This source would, however, have affected the base line blood lead study in 1999.
- Plumbing in potable water supplies (lead pipes, lead solder, and brass fittings)
- Lead-based paint
- Lead solder in cans
- Lead glazes on clay pottery
- Pencils and toys decorated with lead-based paints.

With the exception of continuing automobile emissions, our evaluation indicates that other sources are not major contributors to lead exposure in La Oroya.

Lead accumulated in the body is stored in bone, and may be released to the blood during pregnancy, as children grow and in people with osteoporosis. Thus, as noted in Figure 2-2, bone represents a source of lead in the body that contributes to blood lead levels in individuals with past exposure to lead.

2.5 PRIOR RISK ASSESSMENT STUDIES

A preliminary risk assessment was conducted by Gradient Corporation in 2004. This risk assessment focused on current risks from lead and sulfur dioxide, but also evaluated arsenic and cadmium. The methods used were consistent with guidance from the U.S. Environmental Protection Agency (USEPA). Exposure assumptions for U.S. residents were modified where possible to more accurately reflect conditions in La Oroya.

Risks from exposure to lead were evaluated using the Integrated Exposure Uptake Biokinetic Model (IEUBK), a model that estimates blood-lead levels that would be expected in children ages 0 to 7 based on specific levels of exposure to lead in dust, soil, food, water, and air. This model was used because lead exposures are typically evaluated by comparing blood lead levels to levels known to be associated with adverse health effects (see Section 5.3). When blood lead levels exceed 10 micrograms per deciliter

(μg/dL), various actions are typically recommended to monitor and reduce lead exposures.

Default USEPA assumptions were used for all inputs to the model except the ratio of the indoor air concentration to the outdoor air concentration, daily intake of lead in the diet, and the total daily intake of soil and dust. The model was run using various soil ingestion rates until mean blood lead levels predicted by the model were consistent with those observed in children of La Oroya as measured in the year 2000 (DRP 2001a). The resulting mean soil ingestion rate that contributed to a mean blood lead level of 35.0 μg/dL was 236 milligrams per day (mg/day) (range of 170 to 260 mg/day). Based on the model, Gradient concluded that 99.5 percent of the children of La Oroya were expected to have a blood lead level greater than 10 μg/dL.

Cancer and noncancer risks for exposure to cadmium and arsenic were estimated using a dose-based approach. Standard default exposure parameters were assumed for an adult and child resident of La Oroya except in the case of soil ingestion, where the mean soil ingestion rate developed using the IEUBK model was used for the child scenario (236 mg/day). Adults normally ingest less soil than children. Therefore, it was assumed that the adult soil ingestion rate was equal to one-half that of the child, resulting in a value of 118 mg/day. In addition, an adjustment of 80 percent for arsenic due to its lower bioavailability was used. USEPA-recommended toxicity values were applied to the intake estimates. The resulting risk characterization indicated that ingestion of arsenic and cadmium in soil by children and ingestion of arsenic in soil by adults may result in adverse noncancer health effects. The excess lifetime cancer risk estimated by Gradient for the resident of La Oroya, 7×10^{-3}. This value exceeds a risk level of 1×10^{-4}, a level above which USEPA recommends actions be taken to reduce exposures. Gradient concluded that soil ingestion contributed the greatest overall risk to children while the inhalation exposure pathway contributed to the greatest overall risk to adults.

Inhalation of sulfur dioxide was evaluated by comparing air monitoring data from the Sindicato station in La Oroya Antigua with health-based air quality criteria. Gradient found that for the year 2003, daily maximum 1-hour and annual sulfur dioxide levels frequently exceeded international and Peruvian government health-based standards. Based on these exceedances, Gradient concluded there is a potential for respiratory health effects due to short-term peaks in sulfur dioxide levels and that these effects may be intensified by simultaneous exposure to particulate matter. Long-term exposure to sulfur dioxide concentrations also was identified as a potential health risk. Inhalation of sulfur dioxide gas may present a greater risk to sensitive subpopulations, such as those with pre-existing respiratory illness, asthma, children, and the elderly.

Pathways that were not evaluated by Gradient but recommended for future study included:

- Ingestion of locally-grown produce and livestock
- Ingestion of surface water as drinking water
- Ingestion of unwashed food obtained from an open-air market
- Inhalation and/or ingestion of dust from vehicular traffic.

Additional uncertainties described by Gradient included a lack of chemical concentration data for soil, diet, and drinking water and the relative importance of contact with outdoor soil versus indoor and outdoor dust. Also, further investigation into site-specific soil ingestion rates and inhalation rates appropriate for a high-altitude population was recommended.

3 DATA EVALUATION

This section presents a summary of existing data and data analyses associated with the Doe Run Perú Metallurgical Complex (Complex) in La Oroya, Perú Complex and the study area, including soil, dust, drinking water, air monitoring, and blood lead data, and air modeling activities. Based on the review of existing data and previous analyses, it was determined that supplemental data collection at the Complex was necessary to adequately characterize current human health risks related to the Complex.

Additional data collection for completion of this risk assessment included sampling outdoor dust and soil, indoor dust and soil, and potable water sources by Integral scientists, and a diet study conducted by the Instituto de Investigación Nutricional (IIN) from Lima. Doe Run Perú also supported an updated air modeling study using new estimates of fugitive emissions and additional air monitoring data. This study was conducted by McVehil-Monnett of Denver, Colorado. Existing data, newly collected data and new studies are described below, followed by an updated evaluation of chemicals to be included in this risk assessment.

3.1 SUMMARY OF EXISTING DATA

This section includes summaries of data relevant to assessing exposures to chemicals in La Oroya that were collected prior to the beginning of this risk assessment study. Available data include air monitoring data, and soil, dust, and drinking water data, as well as blood lead concentration data.

3.1.1 Air Monitoring Data

In compliance with Ministry Resolution 315-96-EM/VMM, Doe Run Perú conducts air quality monitoring in communities near the Complex. Monitoring is conducted at five air quality and basic meteorological monitoring stations and one other station that also provides climatological data. The five ambient air monitoring stations monitor ambient air concentrations of sulfur dioxide, particulate matter less than 10 microns in diameter (PM_{10}), arsenic, cadmium and lead, in addition to several meteorological parameters.

3.1.1.1 Air Monitoring Locations

The locations of the air monitoring stations were selected by Centromin Perú while conducting a Preliminary Environmental Evaluation with the Japan International Cooperation Agency from 1994 to 1995 in compliance with Supreme Directive 016-93-EM. The location selection was approved by the Ministry of Energy and Mines (MEM) (DRP 2002b). The five locations are Sindicato de Obreros, Hotel Inca, Cushurupampa,

Casaracra, and Huanchán. The Huanchán monitoring station is located immediately downwind of the facility, in an industrial area where there is no residential population. The Sindicato de Obreros monitoring station is located in the community of La Oroya Antigua. This community is the closest community to the Doe Run Perú facility. The Cushurupampa and Hotel Inca monitoring stations are located in the communities of Marcavalle and La Oroya Nueva, respectively, further from the Doe Run Perú facility. The Casaracra monitoring station is located in an area expected to receive minimal impact from the facility.

3.1.1.2 Air Monitoring Data Collection

Centromin Perú initiated the air quality monitoring with older equipment borrowed from the Catholic University of Perú. Doe Run Perú initiated the modernization process for the monitoring stations in 1999 and finished with this process in 2000. Hourly ambient air concentrations of sulfur dioxide are monitored at all five stations using a Horiba Model APSA 360 ultraviolet fluorescence gas analyzer. This instrument provides both high sensitivity and stability and is designated by the U.S. Environmental Protection Agency (USEPA) as an appropriate ambient sulfur dioxide monitor for measuring compliance with U.S. National Ambient Air Quality Standards (NAAQS) (USEPA 2005d). The sulfur dioxide monitor is certified to USEPA reference method EQSA-0197-114.

Ambient air PM_{10} concentrations are monitored at all five stations by two different instruments. Hourly measurements are collected using a Met One Model BAM 1020 PM_{10} beta attenuation monitor (USEPA reference method EQPM-0798-122). Three day measurements are collected using a Graseby (Sierra-Andersen) Model 1200 High-Volume Air Sampler system with a size-selective inlet of 10 microns and less (USEPA reference method RFPS-1287-063). The particulate matter collected every 3 days with the Graseby Model 1200 sampler was also analyzed for lead, arsenic and cadmium concentrations. Both of these PM_{10} monitoring instruments are also designated by USEPA as appropriate for measuring compliance with NAAQS for PM_{10}. A comparison of the two methods of collection indicates that the two methods obtain comparable results. Table 3-1 compares the monthly averages of the hourly PM_{10} data from the Met One beta attenuation monitor to monthly averages of the 3-day PM_{10} data from the Graseby high-volume sampler. As shown in the table, there is close correlation between the monthly average concentrations collected from the two different methods.

At each of the monitoring stations, Doe Run Perú has collected hourly monitoring data of sulfur dioxide and PM_{10} from January 2001 to the current date. For the purposes of this risk assessment, sulfur dioxide and PM_{10} data from 2004 were used to estimate exposure under baseline conditions. The monitoring data were provided to Integral Consulting Inc. by Doe Run Perú for hourly and daily averaging times. At each of the monitoring stations, Doe Run Perú has also collected 24-hour samples every third day of arsenic,

cadmium, and lead concentrations. Copies of the monitoring data as provided by Doe Run Perú are contained in Appendix A (on a CD-ROM).

3.1.1.3 Air Monitoring Data Quality

As shown in Tables 3-2 and 3-3, there is a comprehensive body of data for sulfur dioxide and PM_{10} from each monitoring station. The percent completeness presented in Tables 3-2 and 3-3 indicates the percentage of hours over the monitoring period where usable data were collected. At every station, there were occasions when measurements were not recorded, usually due to a loss of electrical power. In some cases, measurements of sulfur dioxide with a zero value were reported. In those cases, the measurements were treated as unusable (missing) data. During 2004, all three of the sulfur dioxide monitors provided results for more than 98 percent of the hours in the year. Therefore, substitution of a surrogate value for the reported zero values was deemed unnecessary.

Table 3-2 also presents the total number of measurements and minimum and maximum detected concentrations of sulfur dioxide for each monitoring station by year of interest. Table 3-3 presents the total number of measurements, percent completeness of monitoring data, minimum and maximum detected concentrations of PM_{10} for each monitoring station by year. Only a very few measurements of PM_{10} with a zero value were reported across all monitoring stations. Zero value measurements of PM_{10} were treated as unusable (missing) data.

It is important to consider how the high altitude in La Oroya affects measurement of gases and particulates. The complex is located at an elevation of approximately 3,700 meters above sea level. The density of the atmosphere deceases with elevation above sea level. As a result there is less air in a cubic meter at La Oroya than at sea level. The lower air density causes a decrease in the atmospheric pressure. The density of air is also affected by temperature. As the temperature increase the air expands and becomes less dense and leads to less air in a unit volume.

When air concentrations of chemicals and particulates are expressed in units of mass per unit volume (i.e., micrograms per cubic meter, "$\mu g/m^3$") they are related to a particular temperature and atmospheric pressure. This is because the amount of air in a cubic meter depends on the temperature and pressure of the atmosphere. According to Doe Run Perú facility staff, hourly measurements of sulfur dioxide were recorded in parts per billion (ppb) and converted to $\mu g/m^3$ using standard temperature and pressure assumptions (that is 0°C and 1 atmosphere pressure). Tables 3-2 and 3-3 show minimum and maximum detected concentrations both in units of $\mu g/m^3$ at standard temperature and pressure as reported by Doe Run Perú, and in $\mu g/m^3$ converted to normal temperature and pressure as used for this risk assessment. Similarly, PM_{10} monitors were calibrated to standard

temperature and pressure and measurements were reported in units of μg/m^3 at standard temperature and pressure.

The air quality criteria used in this risk assessment (see Section 5.2) were reported in units of μg/m^3 but at the normal temperature and pressure of 25°C and 1 atmosphere. The atmospheric pressure is the same for both standard and normal conditions but the temperature is 25°C higher for normal conditions. The higher temperature at normal conditions leads to an air density that is 8 percent lower than at standard conditions. Therefore, all air monitoring data from Doe Run Perú were multiplied by a factor of 0.92 to adjust the air density from standard to normal temperature and pressure. All ambient air concentrations expressed in units of mass per unit volume in this document will be expressed at normal temperature and pressure.

The three community monitors used to characterize sulfur dioxide ambient air concentrations for this risk assessment have an upper threshold limit of 6,000 μg/m^3 (at normal temperature and pressure). A limited amount of sulfur dioxide ambient air monitoring data is available from another monitor in Sindicato that does not have this upper threshold. Sulfur dioxide concentrations collected at this monitor, identified as Sindicato 2, indicate that ambient air concentrations of sulfur dioxide can exceed 6,000 μg/m^3 for brief periods. Thus the upper limit on the sulfur dioxide monitors is likely to result in an underestimate of the average concentrations at the site.

As the averaging time increases from 1-hour to 24-hour to annual average, the impact of the monitor's upper threshold on the accuracy of the concentration estimate will diminish. This is because the number of hours that could have exceeded the threshold decreases with the increasing averaging time. For example, at all three of the monitors used in this risk assessment, approximately 95 percent of the hourly average concentrations were a factor of three less than the upper threshold of 6,000 μg/m^3. More than 80 percent of the hourly average ambient air concentrations were 10 times less than threshold. Additional discussion of the potential impacts of short-term peaks of sulfur dioxide air concentrations measured at the Sindicato 2 monitor is presented in Section 6.1. The hourly PM_{10} was not restricted by any known upper threshold limit.

As part of the transfer of technology from the Doe Run Company to Doe Run Perú, a Program of Internal Quality Assurance and Quality Control (QA/QC) program was established for the air monitoring systems. The QA/QC program followed USEPA guidance. U.S. Doe Run Company personnel trained Doe Run Perú personnel in the implementation of the QA/QC program (DRP 2002b).

In addition to the internal QA/QC program, the Directorate for Environmental Health, part of the Ministry of Health (DIGESA) has occasionally analyzed splits of Doe Run Perú's samples. Doe Run Perú's analytical results were compared to results from the

DIGESA laboratory analyses. DIGESA reported that the Doe Run Perú results were valid and were similar to the results obtained by the DIGESA laboratory (DRP 2002b).

Doe Run Perú has conducted at least one external audit of the air quality monitoring equipment. The sulfur dioxide monitoring system was audited during March 19-21, 2002, by CK Environmental of Canton, Massachusetts. CK conducted the audit according to USEPA Quality Assurance Handbook for Air Pollution Measurement Systems (Vol. II: Part 1, "Ambient Air Quality Monitoring Program System Development") guidelines. The monitoring equipment was considered satisfactory by CK scientists/auditors, Kathleen Holmes and David Mackintosh. The final results of the audit were positive. The auditors found that the sulfur dioxide monitoring equipment measured concentrations with a +/-0.23 percent margin of error, a value well below the USEPA recommended value of 2 percent (DRP 2002b).

3.1.2 Surface Soil Data

During Integral's site visit to La Oroya in January 2005, Doe Run Perú provided analytical results from two soil sampling events. Samples were collected during January, February, and March 2000 and again in March 2003. The samples were collected by Doe Run Perú staff and analyzed at the Complex laboratory.

Fourteen subsurface soil samples were collected throughout La Oroya between January and March 2000 from depths of 10 to 20 cm below ground surface (bgs). These samples were analyzed for lead, arsenic, cadmium, sulfate, calcium oxide, nitrate, zinc, and iron. Results for the first three metals included:

- A lead concentration range from 400 to 5,200 mg/kg, with a mean concentration of 2,750 mg/kg.
- An arsenic concentration range from 200 to 1,400 mg/kg, with a mean concentration of 814 mg/kg.
- Cadmium was detected at a concentration of 100 mg/kg in four of fourteen samples. Cadmium was not detected in the remaining eleven samples at concentrations greater than 100 mg/kg.

Fourteen surface soil samples were collected from unique locations throughout La Oroya in March 2003 from a depth of 0 to 10 cm bgs. The samples were analyzed for arsenic and lead, and found to have higher metal concentrations than the previously collected subsurface samples.

- Lead concentrations ranged from 400 to 41,000 mg/kg, with a mean concentration of 13,900 mg/kg.

- Arsenic concentrations ranged from 500 to 38,000 mg/kg, with a mean concentration of 5,786 mg/kg.

Due to the lack of detailed documentation of sample collection, analytical methods and quality assurance procedures, the previously collected soil data were not used in this risk assessment.

3.1.3 Dust Data

Analytical results for dust samples are available from two sources. A study of indoor dust concentrations was published by the Asociación Civil Labor and CooperAcción of Lima and Occupational Knowledge International of San Francisco (Cornejo and Gottesfeld 2004). More recently, Doe Run Perú collected outdoor surface dust samples for analysis in February 2005. Results of these two studies are described below.

The indoor dust collection study (Cornejo and Gottesfeld 2004) was conducted in mid-October 2003 by representatives of CooperAcción and Asociación Civil Labor. A total of 80 dust wipe samples were collected from 35 residences, three stores, and one school in La Oroya Antigua, La Oroya Nueva, and Curipata. The wipe samples were collected primarily from floors in the bedroom, kitchen, and dining room of homes as well as exterior surfaces.

The wipe samples were submitted to a lab in Perú and a lab in the U.S. and were analyzed for lead using both the USEPA and National Institute of Occupational Safety and Health (NIOSH) preparation and analytical methods. All of the wipe samples collected in residences in La Oroya Antigua contained lead at levels exceeding the USEPA standard of 40 $\mu g/ft^2$ for lead in dust on floors (mean of 314.6 $\mu g/ft^2$). Lead levels in approximately 70 percent of the wipe samples collected in La Oroya Nueva residences exceeded the USEPA standard (mean of 148.4 $\mu g/ft^2$). Lead levels found in dust in a Curipata residence, a community located 11.5 km (7 miles) away from La Oroya, were below the USEPA standard for lead in dust (33.2 $\mu g/ft^2$).

In February 2005, Doe Run Perú collected 21 dust samples by brushing from outdoor locations throughout La Oroya, including La Oroya Antigua, La Oroya Nueva, and Marcavalle. Samples were analyzed for arsenic, cadmium, copper, lead, and zinc. Samples were split following collection and one aliquot was analyzed by the Doe Run Perú laboratory at the Complex and the other aliquot was analyzed by EnviroLab in Lima. Analytical results from the Doe Run Perú laboratory were consistently higher than those from EnviroLab, which used USEPA digestion and analysis methods. The Doe Run Perú laboratory may use different sample digestion methods. Based on the EnviroLab results, the mean lead level in dust collected in La Oroya Antigua was 24,028 mg/kg, with lower levels found in La Oroya Nueva (5,642 mg/kg) and Marcavalle (1,876 mg/kg). Mean levels of arsenic, cadmium, copper, and zinc showed similar trends with the highest levels

found in La Oroya Antigua and lower concentrations in communities located farther from the Complex.

Due to the lack of detailed documentation of sample collection, analytical methods and quality assurance procedures, the previously collected dust data were not used in this risk assessment.

3.1.4 Drinking Water Data

Drinking water in La Oroya is obtained from many sources and is managed by Doe Run Perú, community-based organizations, and a municipal organization, EMSAPA. EMSAPA conducts periodic testing of its water supplies, including analysis of fecal coliform bacteria, hardness, turbidity, chlorine, sulfates, nitrates, and limited metals testing (copper, magnesium, chromium, calcium, iron, manganese, and zinc). No data for lead, arsenic and cadmium were available to Integral.

3.1.5 Blood Lead Data

Several studies of blood lead levels have been conducted in La Oroya (DIGESA 1999; UNES 1999; DRP 2001a; DIGESA 2005), summarized in Table 3-4. All studies have reported that most residents have blood lead levels exceeding the U.S. Centers for Disease Control and Prevention (CDC) standard of 10 μg/dL. The Union for Sustainable Development (UNES) (1999) reports developmental deficiencies in children of La Oroya based on standardized testing, but notes that the cause is malnutrition, and other factors related to the socioeconomic status of area residents.

Study of Adult Blood Lead Levels in La Oroya – Ramirez et al. (1997)

Scientists with Centromin Perú's Department of Occupational Health (Departamento de Salud Ocupacional Centromin Perú), National Institute of Neurological Sciences (Instituto Nacional de Ciencias Neurológicas), and Unidad Básica de Salud analyzed blood lead levels in 80 adult residents of La Oroya in 1997. The objective of the study was to compare blood lead levels in adults in four Peruvian cities with varying levels of industrialization. The mean blood lead level for adult (mean age of 23 years) La Oroya residents was 35 μg/dL. This level was higher than that found in three other cities, Lima (27 μg/dL), Huancayo (22 μg/dL), and Yaupi (14 μg/dL).

Blood Lead Levels in Children and Adults – DIGESA (1999)

DIGESA conducted a blood lead study in 1999 to meet two objectives. The first objective was to establish a baseline database of blood lead concentrations to be used in comparison with future blood lead monitoring data. The second objective was to identify the socioeconomic and behavioral factors that influence blood lead levels. A total of 346 children and 199 adolescents and adults were recruited from the communities of La

Oroya Antigua, La Oroya Nueva, and Santa Rosa de Sacco to participate in the study. For children ages three to ten years old, blood lead levels ranged from 15 μg/dL to 80 μg/dL, with a mean of 44 μg/dL. For residents aged ten years and older, the mean blood lead concentration was 29 μg/dL, with a range of 8 μg/dL to 83 μg/dL. Behaviors reported in children included eating soil, sucking on crayons, pencils, books, and magazines, chewing crayons and toys, eating paint, and putting hands in their mouths; however, the study stated that these behaviors did not appear to be correlated with blood lead levels. For this study, samples were taken by the method called Lead Care™ which was later found to have significant deficiencies in highland environments and must be used with caution (Taylor et al. 2004).

Blood Lead Levels and Exposure Factors in Pregnant Women and Children Under Three Years of Age in the City of La Oroya – UNES (1999)

In 1999, UNES conducted a much smaller study on exposure factors and blood lead levels for residents of La Oroya with the intent of developing recommendations for the improvement of health conditions, particularly of sensitive subpopulations. A total of 48 pregnant women living in La Oroya Antigua, Marcavalle, and Santa Rosa were recruited for the study. The reported mean blood lead level in pregnant women was 40 μg/dL, with a range of 20 μg/dL to 44 μg/dL. A total of 30 children under the age of three years participated in the UNES study. The mean blood lead level reported for the toddlers was 42 μg/dL, with a range of 16 μg/dL to 64 μg/dL.

Blood Lead Levels Children and Adults – Doe Run Perú (2001a)

In 2000, Doe Run Perú conducted a study to determine the levels of lead and hemoglobin in the population of La Oroya (DRP 2001a). In addition, a study of the medical and social welfare of those children found to have blood lead levels greater than 45 μg/dL was conducted.

Blood lead levels were measured in 5,062 residents of different age groups and residential locations, which was approximately ten percent of the population of the District of La Oroya (n = 50,268). This sample size was judged to provide an estimate of blood lead levels for the total population with a margin of error of one to two percent of the 95 percent confidence interval. Blood samples were analyzed in La Oroya's General Hospital of Chulec using established NIOSH methods for analysis of lead in blood. Results were grouped according to the age of the study participants, less than one to three years of age, four to six years, seven to 15 years, and 16 years and older. In addition, results were grouped by geographic region, Alto Perú/Calle Lima, Santa Rosa de Sacco, Chulec, Club Inca/Horacio Zeballos, Buenos Aires/Huaymanta, Marcavalle, La Oroya Antigua, Curipata, Comunidades, Pacha, and "other" communities. Information also was obtained regarding academic performance of first-grade students, physical development, and psychomotor development.

Children from less than one to three years old had the highest blood lead levels (mean = 26 μg/dL). Median blood lead levels for children between the ages of four and 15 ranged from 19 μg/dL to 22 μg/dL. A total of 69 residents, all under the age of 15 years, had blood lead levels exceeding 45 μg/dL. Most of these children were born in and live in La Oroya Antigua. According to the report, the mean blood lead level for children between the ages of less than one to three years old living in La Oroya Antigua was 37 μg/dL and 33 μg/dL for children between the ages of four and six. In Marcavalle, mean blood lead levels in children less than one to three years old and four to six are reported to be 22 and 21 μg/dL, respectively.

In residents over the age of 16, the reported median blood lead level was 14 μg/dL for all communities. In Marcavalle, the mean blood lead level for adult residents was 13 μg/dL, whereas the reported mean blood lead level for adults in La Oroya Antigua was 18 μg/dL.

Blood Lead Levels in Children in La Oroya Antigua – DIGESA (2005)

In November 2004, DIGESA conducted blood lead sampling of children under the age of 6 living in La Oroya Antigua (n = 758). Some children living in La Oroya Nueva also were included in the sampling effort (n = 23). The mean blood lead levels for children living in La Oroya Antigua from the ages of less than one to three and four to six were 34 μg/dL and 31 μg/dL, respectively. The mean blood lead level of children from less than one to six years old living in La Oroya Nueva was 25 μg/dL.

3.2 RECENT DATA COLLECTION ACTIVITIES

Integral conducted a field study between March and June 2005 that was designed to characterize potential exposure sources for residents of La Oroya. This field study included the collection and analysis of samples from environmental media, including drinking water, surface soil, indoor dust, and outdoor dust. In addition, a dietary study was conducted to assess the metal and nutrient intake for residents of La Oroya. The environmental and dietary studies are summarized below.

3.2.1 Environmental Field Studies

A detailed discussion of sample collection is provided in the Sampling and Analysis Plan (Integral 2005b) and the Quality Assurance Project Plan (Integral 2005a). Integral scientists conducted two sampling events in La Oroya with observers from the Ministry of Health and Doe Run Perú. The first sampling event occurred from March 28 to April 13, 2005 during the rainy season in La Oroya. The second sampling event occurred from June 1 to June 10, 2005 during the dry season in La Oroya.

Integral scientists collected drinking water, soil, and dust samples from the communities of La Oroya Antigua, La Oroya Nueva, Marcavalle, and Chucchis as described in the Sampling and Analysis Plan (Integral 2005b). Drinking water samples were collected from faucets where people obtain their drinking water. Dust samples were collected from the floor of residences and from paved outdoor plazas and playfields. Soil samples were collected the surface at depths of 0 to 2 cm and from the subsurface at depths of 2 to 10 cm from play areas with no groundcover. An effort was made to collect samples from locations at various distances from the smelter where Integral staff observed children playing. In addition, a soil sample was collected from the inside wall of one adobe house. Duplicate samples, rinse water from equipment, and known concentration samples were collected for quality control purposes.

Table 3-5 provides the number and type of samples collected in each community during the March/April and June 2005 field events. Sample collection locations are identified in Figures 3-1 through 3-4. The following sampling name codes appear at the beginning of each location name:

- CD: community (outdoor) dust
- CS: community surface soil locations
- RD: residential (indoor) dust
- RS: residential soil
- W: water samples.

Samples were submitted to EnviroLab, the Peruvian Institute for the Defense of Competition and Protection of Intellectual Property (INDECOPI)-certified laboratory located in Lima. EnviroLab used USEPA sample preparation and analytical methods for all analyses, as described in the Quality Assurance Project Plan (Integral 2005a). Drinking water samples were analyzed for arsenic, cadmium, copper, lead, and zinc. Soil and dust samples were analyzed for arsenic, cadmium, copper, lead, zinc, antimony, selenium, thallium, silver, and mercury.

Following receipt of the analytical results from the laboratory, Integral chemists validated the data to make sure it met the project goals. The precision, accuracy, representativeness, and comparability of the data were assessed during data validation. Completeness was calculated by comparing the total number of acceptable data (non-rejected data) to the total number of data points generated. Completeness for the March/April 2005 and June 2005 data was 100 percent, which exceeded the completeness goal of 90 percent in the Quality Assurance Project Plan (Integral 2005a). All sampling data met the project data quality objectives and are usable for all project purposes. The data validation reports for both sampling events are provided as Appendix B of this report.

Results for drinking water, dust, and soil samples collected during the March/April 2005 and June 2005 field event are provided in Appendix B. These data were used to estimate exposure point concentrations, as described in Section 4.1. Metals concentrations varied between the first and second sampling events at each sampling location, although the difference in mean concentrations of each dataset was not statistically significant. Figures 3-5 to 3-7 demonstrate differences in lead concentrations detected during the first and second sampling events in outdoor surface soil, outdoor dust, and indoor dust, respectively. Similar figures for arsenic and cadmium are also provided (Figures 3-8 to 3-13).

3.2.2 Duplicate Diet Study

In April 2005 Dr. Rosalind Schoof of Integral Consulting Inc. requested that the IIN in Lima design a dietary study to be conducted in La Oroya. In May 2005 the IIN initiated a pilot study in La Oroya Antigua to evaluate the dietary intake of iron, calcium, zinc, and lead by mothers with children between the ages of 12 and 35 months and their children. The IIN final report for this study, including recommendations for future actions, is provided as Appendix C of this report, and the methods and results are summarized below.

3.2.2.1 Study Methods

Representatives of IIN recruited 15 qualifying families to participate in the study with the assistance of the Ministry of Health and Doe Run Perú. Among the participating families, there were eight children between 12 and 23 months of age, seven children between 24 and 35 months of age, and 11 mothers. For each study participant, the IIN representatives recorded weight and height. Socioeconomic information and places where food is purchased were also recorded. The IIN representatives conducted the study by staying with each family for 12 hours per day for two consecutive days.

During the 12 hours in each home the IIN representatives weighed each meal ingredient and each prepared food item. Individual servings for each family member also were weighed and after mealtime the uneaten portions of food on each plate were weighed to determine the amount of each food consumed. Other foods and beverages consumed outside of family meals also were weighed. In addition, IIN representatives recorded every food item consumed by study participants, including food items consumed outside the 12-hour time period when the IIN representative was with the family. The weight of breast milk consumed by children was determined by weighing the child before and after feeding.

To estimate the metals content of foods consumed by the participating families, a portion of every food item consumed by the mothers and children was collected and submitted to

the IIN laboratory. Breast milk also was collected from mothers and submitted to the IIN laboratory. The food and breast milk samples were homogenized at the IIN laboratory and have been submitted to an accredited third-party laboratory for metals analysis. Analytical results for the concentrations of iron, calcium, zinc and lead in food and breast milk were used to estimate dietary intakes.

For lead, all breast milk samples and some other foods had lead concentrations below the analytical limit of detection.[6] This limitation is also frequently encountered in dietary studies conducted in the U.S. (Bolger et al. 1996; Gunderson et al. 1995). Thus, IIN followed the same procedure used in the U.S., of calculating lead intakes in two ways when the lead concentrations were below the detection limit. In one way the value of the detection limit was used as the concentration. In the other way, the value of zero was used as the concentration for that food. Lead intake estimates are presented in the IIN report for both methods.

For calcium, iron and zinc intakes were estimated in two ways. In the first approach, the concentration of minerals in the daily food samples was multiplied by the weight of food ingested to derive daily intakes. In the second approach, the weights of individual kinds of foods consumed were multiplied by the concentrations of the nutrients reported in Peruvian food composition tables. In both cases, the intakes of each participant were averaged during the two days of study.

3.2.2.2 Results for Lead

Lead intakes for mothers and children in terms of μg/day are summarized in Table 3-6. Two estimates of the mean intake are shown. For the eleven mothers, mean intake was 92 μg/day when nondetected values were treated as zero. When nondetected values were treated as having the concentration of the detection limit, the mean intake was 163 μg/day. For children 12 to 23 months old, the means were 60 μg/day (for nondetects treated as zero) and 71 μg/day (for nondetects assumed equal to the detection limit). For children 24 to 35 months old, the means were 48 μg/day (for nondetects treated as zero) and 78 μg/day (for nondetects assumed equal to the detection limit). The results for children were used as the basis for estimating lead intake from the diet in the risk assessment for lead, as described in Section 4.3.

The IIN also reported lead intakes in terms of μg/kg body weight/week so that the results of this study could be compared with the maximum permissible intake limit recommended by the Food and Agriculture Organization of the United Nations (FAO)/the World Health Organization (WHO) (25 μg/kg/week). Results show that both the average and the median lead intake from food eaten by children were above the FAO/WHO maximum permissible intake limit. Variability among individual children

[6] The detection limit for lead in breast milk was 0.05 mg/kg.

was high. Using the lower estimates of lead concentration in the diet, 67 percent of the children had a total daily lead intake above the recommended value, while by assuming the higher estimates of lead concentration, 87 percent of the children would be eating diets with levels above permissible limits. The largest source of lead in the diet of breastfed children is apparently the food and not the maternal milk.

The average lead intake in mothers was below the FAO/WHO maximum permissible limit, although some of the surveyed mothers had intake levels above the limit. Three individual mothers had intakes above permissible limits when a concentration of zero was assumed for nondetected values. The number exceeding the limit increased to four mothers when the detection limit concentration value was used for nondetected values.

3.2.2.3 Results for Nutrients

Results from this pilot study show that in general the intake of calcium, iron, and zinc is very variable among participating families, but in all of the groups there are mothers and children with inadequate intake and much below the recommended daily intake (Table 3-7, Table 3-8, Table 3-9). The high variability in minerals intake found in this survey can be explained to a great extent by the small size of the sample and the short period of the survey. Despite the small sample size, the study has several strengths: a) it was carried out in two days and the results represent the average 2-day ingestion by each person; and b) the direct weighing method was used. Both of these elements give higher precision to the data corresponding to each individual.

The iron intake calculated from the laboratory data is low, both in mothers and children. On the whole, the average percentage of coverage of the recommended daily intake is below 50 percent in children and below 20 percent in mothers. These results are similar to those obtained in other studies carried out in Perú.

The laboratory results show that the average daily zinc intake in mothers and children is near the recommended level (assuming low and medium zinc bioavailability in the diet of mothers and children, respectively). However, it is worth noting that due to the type of diet, it could be expected that zinc intake both in mothers and children would be much lower than the levels found. More so, taking into account that the main sources of iron are also sources of zinc and as the iron intake is low a similar pattern could be expected for zinc. Therefore, it is possible that zinc intake is near recommended levels owing to environmental pollution.

Calcium intake, estimated based on the food composition table, shows levels much below recommended levels, both in mothers and in the children. These levels are similar to the results of other studies carried out in Perú. Nevertheless, results obtained from the food composition table are lower than those obtained from chemical analyses carried out in the

laboratory. The difference may result from errors in the estimation of the content of nutrients, which are normally found in food composition tables.

Iron intake, as estimated based on the food composition table, is generally low in all groups, even though it was found that a few children had an acceptable iron intake. Furthermore, the ingestion of food rich in heminic iron, highly bioavailable, which comes from meat, fish and poultry is low (CPA iron). In children with high iron intake, the main sources of iron are chicken liver, evaporated milk fortified with iron and wheat products made with flour fortified with iron. In previous IIN surveys, it was found that not all wheat flours are fortified according to regulations. This could be one reason why the iron intake estimated based on the table calculations shows lower levels than lab analyses levels. As discussed in the case of calcium, the difference may result from estimation errors in the food composition table.

Zinc intake levels calculated based on the food composition table are low and much below those found through the chemical analyses carried out in the laboratory. It is possible that levels found in the chemical analyses may be higher due to contamination of food.

The food composition analysis also indicates that average intakes of both protein and vitamin C are adequate.

IIN cautions that the sample size for this pilot study was too small to provide a reliable profile of nutritional status for iron, calcium and zinc and of dietary lead exposures in the population of La Oroya. Nevertheless, the finding of inadequate iron intakes is consistent with studies in other Peruvian residents of the Andes. Additionally, the methods used in this study are much more rigorous than those typically used in dietary studies in North America and Europe. Such studies often rely on 24 hour recall of foods eaten by study participants, rather than collecting duplicate portions of food consumed. The additional assessment of nutrient intake based on food composition tables provides an extra level of support unusual in such a small pilot study. Recommendations for future studies and actions are provided in Section 7.

3.3 AIR MODELING ACTIVITIES

The air modeling to support this risk assessment was conducted by McVehil-Monnett of Englewood, Colorado, USA. Their report is included as Appendix D, and their results are summarized below.

Computer modeling of air pollution impacts of the Complex was carried out to provide estimates of future air quality after the implementation of emissions reduction programs. These programs include multiple projects to reduce fugitive emission by the end of 2007

and acid scrubbing controls on the main stack by the end of 2011. Model predictions for sulfur dioxide concentrations and for concentrations and deposition rates for particulates, lead, arsenic, and cadmium were generated for the populated areas being studied in the assessment.

Modeling utilized the CALPUFF model, an air quality simulation model recommended by the USEPA for application in areas of complex winds, terrain, and meteorology. The model accounts for the effects of time – and space-varying winds, atmospheric dispersion, chemical transformations, and surface deposition of pollutants.

Input data for the CALPUFF application included measured pollutant emissions from the Smelter main stack and estimated emissions from fugitive sources, all on an annual average basis for the year 2002. Other input data were measured hourly meteorological conditions at the six ground-level monitoring stations operated by Doe Run Perú. No site-specific weather observations from above ground level were available; therefore upper air winds and temperatures were estimated from six-hourly global weather analyses prepared by the U.S. National Weather Service.

The modeling of 2002 emissions and weather conditions provided model-predicted impacts that were compared to measured concentrations at Doe Run Perú monitoring stations, and also provided a "base case" against which to compare predictions for later years. Subsequent modeling, for projection of future trends, utilized the same 2002 meteorological data with estimates of later year emissions. Doe Run Perú provided estimates of pollutant emissions for 2005, 2007, and 2011 based on implementation of planned projects as described in the proposed revisions to the Programa de Adecuación y Manejo Ambiental (PAMA). Fugitive metal emission reductions were not targeted or emphasized in the original PAMA.

Performance of the model in simulating La Oroya air quality was tested by comparing predicted 2002 concentrations of sulfur dioxide, lead, arsenic, and Cadmium to measurements obtained during the same time period at Doe Run Perú monitoring stations. Emphasis in the evaluation was given to the populated areas being addressed in this risk assessment. These areas are best represented by the Sindicato, Hotel Inca, and Cushurupampa monitoring stations.

The model performance evaluation produced the following conclusions:

- Model predictions reflect the general magnitude of observed concentrations, with predicted concentrations ranging from almost complete agreement with observed values to agreement within a factor of 2 or 3.

- Sulfur dioxide concentration predictions of highest short-term and annual average values show good agreement with observations for the Sindicato and Hotel Inca monitors
- Sulfur dioxide predictions tend to be higher than measurements at Cushurupampa, and lower than measurements at Huanchán
- Hourly sulfur dioxide concentration predictions reproduce with good accuracy the timing and magnitude of observed morning pollution peaks
- Model predictions often reproduce the observed day-to-day changes in air quality caused by changing weather conditions
- Prediction of lead concentrations are higher than measured long-term concentrations by an average of 35 percent
- Arsenic and cadmium concentrations predictions are, on average, close to observations, but tend to be high at Cushurupampa, and low at Sindicato
- Model performance is better during daylight hours than at night, and appears to be better in the immediate area of La Oroya than up the Yauli River further from the Complex.

It is concluded that the model properly simulates basic dispersion processes in the region of the Complex, and provides realistic estimates of maximum short-term and average long-term impacts in that area. The model results also imply that the characterization of emission sources and average emission rates that were used reflect reality with reasonably accuracy. On the basis of these conclusions, projections of future air quality impacts, with modified sources and reduced emissions, are expected to be realistic and appropriate for risk assessment.

The projection of future ambient air concentrations and deposition rates indicates that the planned Smelter improvement projects will result in marked reduction in impacts for all pollutants addressed. The decrease in short and long-term concentrations and deposition rates from 2002 to 2011 is predicted to range from 60 to 85 percent. The greatest decrease in metals impacts will occur by 2007, with further decrease for metals and a major decrease for sulfur dioxide between 2007 and 2011. The projections of air quality levels for future years have been utilized in this risk assessment to quantify changes in population exposure.

The model results confirm and extend prior findings on the relative impact of main stack and fugitive sources for ground-level impacts. Fugitive sources, despite having smaller emissions than the main stack, are responsible for the major portion of local impacts, especially in La Oroya Antigua and La Oroya Nueva. The relative importance of main stack emissions increases with increasing distance from the Complex. The future trend analysis demonstrates that the greatest improvement in ambient air quality will occur as

projects are implemented to reduce or eliminate fugitive emissions. This result is true for all of the study areas, but especially for those near the Complex.

In addition, model results (as well as monitoring records) indicate that the Doe Run Perú supplemental control strategy (emission curtailments at times of anticipated poor air quality) is effective in mitigating high short-term pollution levels during morning air pollution episodes. Based on the air modeling results, the supplemental control scenario produced a reduction (relative to normal 24-hour per day operation) of 25 to 50 percent in highest short-term morning sulfur dioxide concentrations, and approximately 25 percent in 24-hour average concentrations. The model results therefore confirm that a procedure for emission reductions in pre-dawn hours has a significant effect in reducing maximum pollutant concentrations during the following day. This strategy, if continued, will contribute to additional improvement in air quality beyond that projected by the air modeling analysis. Recommendations from McVehil for improved performance of future air modeling efforts are provided in Section 7.

3.4 CHEMICALS TO BE EVALUATED

Chemicals identified in Section 2.2 that are not likely to contribute significantly to overall risks related to the Complex were eliminated from further consideration in this risk assessment. As described in Section 2, the Complex produces eleven metals, including lead, zinc, copper, silver, and gold. It is likely that all of these metals, plus additional contaminants are released from the Complex. USEPA (1989) provides the following criteria for eliminating chemicals from further quantitative evaluation in risk assessment:

- Low frequency of detection in a given exposure medium
- Evidence that the chemical is not associated with the operations at the site
- Classification as essential nutrients (e.g., iron, calcium)
- Chemical concentrations below applicable risk-based screening criteria.

The chemicals that pose the greatest health risk at copper, lead, and zinc smelters have been identified in previous risk assessments in the U.S., Canada, and La Oroya as lead, arsenic, cadmium, sulfur dioxide and particulates in air. These chemicals are all included in this risk assessment. Additional chemicals associated with Complex activities considered in the initial screening included antimony, copper, selenium, silver, thallium, zinc, and mercury.

The available data for metals in air, water, outdoor dust, indoor dust, and surface soil were grouped by community and then evaluated to determine the appropriate statistical distribution using ProUCL software issued by the USEPA (Version 3.0). ProUCL was

used to calculate the upper 95th percentile confidence limit of the mean based on the appropriate statistical distribution. The summary statistics, including upper confidence limit of the mean, for each chemical are provided in Tables 3-10 through 3-14. The output files from ProUCL are provided in Appendix B.

The lower of either the maximum detected concentration or the upper confidence limit of the mean for each metal was compared to its corresponding risk-based criteria. This comparison was conducted for each metal in all media, by community (i.e., La Oroya Antigua, La Oroya Nueva, Marcavalle, and Chucchis). Risk-based screening criteria correspond to a target risk or hazard quotient for a single metal in a single medium, under standard default exposure assumptions that are intended to represent high exposure conditions.

Chemicals can be eliminated from further quantitative risk assessment if they are present at levels that are below the risk-based screening criteria because sample concentrations below screening criteria are not expected to result in unacceptable risks. Chemical screening criteria are provided in Table 3-15. Elimination of chemicals from this risk assessment depends on the adequacy of the available data. As described below, data are limited for some metals in La Oroya.

3.4.1 Chemicals in Air

As described above, inhalation of sulfur dioxide, particulates, lead, arsenic and cadmium was evaluated in this risk assessment. Data were not available for other metals in air. The implications of this data limitation are described in the Uncertainty Evaluation in Section 6.5. The screening process for arsenic and cadmium is described below.

The upper confidence limit of the mean concentrations of non-lead metals in air were screened against risk-based criteria developed by USEPA (2005b), shown in Table 3-10. The air monitoring data were provided by Doe Run Perú and consist of cadmium and arsenic concentrations in PM_{10} samples (i.e., samples of particles less than 10 microns in diameter) that were collected every three days from the Sindicato de Obreros, Hotel Inca, Huanchán, Cushurupampa, and Casaracra monitoring stations during the year 2004 and from January to April 2005. The screening criteria for arsenic and cadmium are unit risk factors selected from the USEPA's Integrated Risk Information System (IRIS) (2005b) and correspond to a cancer risk level of 1×10^{-6} for an adult with a mean body weight of 70 kg and inhalation rate of 20 m^3/day.

The screening criteria for arsenic and cadmium, 2×10^{-4} $\mu g/m^3$ and 6×10^{-4} $\mu g/m^3$ respectively, were exceeded at all five stations, Sindicato de Obreros, Hotel Inca, Huanchán, Cushurupampa, and Casaracra. For this risk assessment, it is assumed that the Sindicato de Obreros monitoring station represents the community of La Oroya

Antigua, Hotel Inca represents La Oroya Nueva, and Cushurupampa represents Marcavalle and Chucchis. Huanchán and Casaracara are not located in residential areas; screening information for these stations is provided only for descriptive information regarding other areas surrounding the Complex. It is understood that these air monitoring stations are not precise representations of breathing zone concentrations, but serve to provide an approximation of the breathing zone. Based on this screening, both arsenic and cadmium were retained in the human health risk assessment as chemicals of potential concern.

3.4.2 Chemicals in Surface Soil

Surface soil samples collected by Integral were used to identify chemicals for evaluation in this risk assessment. These samples were analyzed for arsenic, cadmium, copper, lead, zinc, antimony, selenium, thallium, sliver, and mercury.

The upper confidence limit of the mean metal concentrations and risk-based screening criteria for surface soil (0-2 cm in depth) are provided in Table 3-13. Risk-based screening criteria for metals other than lead were obtained from USEPA guidance (2002b) and are based on exposure to chemicals in soil and dust that is ingested unintentionally. These criteria do not consider intentional ingestion of large quantities of soil (referred to as pica for soil). This issue is addressed in the Uncertainty Evaluation in Section 6.5. The screening criteria correspond to either a hazard quotient of 1 for noncarcinogens or risk level of 1×10^{-6} for carcinogens. A risk-based screening criterion for lead was obtained from USEPA Region 9 Preliminary Remediation Goals spreadsheet (USEPA 2004).

A reliable screening criterion was not available for copper. Oral toxicity data for copper are not currently available and so USEPA Region 9 has converted the current U.S. drinking water standard to an oral reference dose that can be used generate a risk-based screening criterion for incidental ingestion of copper in soil. The drinking water standard for copper is based on the occurrence of transient stomach irritation, and is not directly applicable to exposure to copper in media other than water. Due to the low toxicity of copper and the uncertainty associated with use of a soil screening criterion based on a drinking water standard, copper was not retained as a chemical of potential concern but is discussed as an uncertainty in this risk assessment, Section 6.5.

A total of three metals exceeded risk-based screening criteria for the communities of interest. In La Oroya Antigua, arsenic, cadmium, and lead were retained for evaluation in this risk assessment. Thallium, antimony, silver, mercury, and selenium were eliminated. In the remaining communities of La Oroya Nueva, Marcavalle, and Chucchis, only arsenic and lead were retained.

3.4.3 Chemicals in Outdoor Dust

Outdoor dust samples collected by Integral were used to identify chemicals for evaluation in this risk assessment. These samples were analyzed for arsenic, cadmium, copper, lead, zinc, antimony, selenium, thallium, sliver, and mercury.

The upper confidence limit of the mean metal concentrations and risk-based screening criteria for outdoor dust are provided in Table 3-11. Risk-based screening criteria for metals other than lead were obtained from USEPA guidance (2002b) and are based on exposure to chemicals in soil and dust that is ingested unintentionally. The screening criteria correspond to either a hazard quotient of 1 for noncarcinogens or risk level of 1×10^{-6} for carcinogens. A risk-based screening criterion for lead was obtained from USEPA Region 9 Preliminary Remediation Goals spreadsheet (USEPA 2004). As discussed in Section 3.4.2, a screening criterion was not available for copper and is discussed as an uncertainty in this risk assessment, Section 6.5.

As noted in Table 3-11, two data points were identified as outliers using Dixon's Extreme Value Test and the Discordance Test (USEPA 2000c). In La Oroya Antigua, the lead concentration detected in sample DRP-CDOA-01 (37,410 mg/kg wet weight) was removed from the dataset. In Marcavalle, the cadmium concentration detected in sample DRP2-CDTA-36 (907.2 mg/kg wet weight) was removed from the dataset. There is no known explanation for these extreme values, but their removal from the datasets reduces uncertainty in the datasets and improves the calculation of representative UCLM concentrations.

A total of five metals exceeded risk-based screening criteria in the communities of interest. In La Oroya Antigua, five metals were retained for evaluation in this risk assessment, including antimony, arsenic, cadmium, lead, and thallium. Silver, mercury and selenium were eliminated as risk factors. Antimony, arsenic, and lead were retained for evaluation for the community of La Oroya Nueva. In Marcavalle and Chucchis, antimony, arsenic, lead and thallium were retained for evaluation in the risk assessment.

3.4.4 Chemicals in Indoor Dust

Indoor dust samples collected by Integral were used to identify chemicals for evaluation in this risk assessment. These samples were analyzed for arsenic, cadmium, copper, lead, zinc, antimony, selenium, thallium, sliver, and mercury.

The upper confidence limit of the mean metal concentrations and risk-based screening criteria for indoor dust are provided in Table 3-12. Risk-based screening criteria for

metals other than lead were obtained from USEPA guidance (2002b) and are based on exposure to chemicals in soil and dust that is ingested unintentionally. The screening criteria correspond to either a hazard quotient of 1 for noncarcinogens or risk level of 1×10^{-6} for carcinogens. A risk-based screening criterion for lead was obtained from USEPA Region 9 Preliminary Remediation Goals spreadsheet (USEPA 2004). A screening criterion was not available for copper and is discussed as an uncertainty in this risk assessment, Section 6.5.

A total of four metals exceeded risk-based screening criteria for the communities of interest. In La Oroya Antigua, antimony, arsenic, cadmium, and lead were retained for evaluation in this risk assessment. Antimony, arsenic, and lead were retained for evaluation for the communities of La Oroya Nueva and Marcavalle. In Chucchis, arsenic, cadmium, and lead were retained for evaluation in this risk assessment.

3.4.5 Chemicals in Water

Water samples collected by Integral were used to determine if chemicals are present in drinking water. These samples were analyzed for arsenic, cadmium, copper, lead, and zinc.

The upper confidence limit of the mean (UCLM) metal concentrations and risk-based screening criteria for drinking water are provided in Table 3-14. One half of the detection limit was used when calculating UCLM concentrations for datasets containing non-detect values. As with other media, the lower of either the maximum detected concentration or UCLM was compared to the risk-based screening criteria.

U.S. federal drinking water maximum contaminant levels (MCLs) were used to screen all metals except antimony (USEPA 2005c). The MCLs are based on the assumption that exposure to metals in drinking water occurs via ingestion and dermal contact. The MCL for arsenic of 0.01 mg/L is a provisional value that will become effective in January 2006 and is consistent with the WHO guideline value. The Peruvian drinking water standard for arsenic is 0.1 mg/L. There is a proposal to reduce the value to 0.05 mg/L. A screening criterion was not available for antimony. Due to a lack of toxicity criteria and risk-based screening level for antimony, antimony was not screened.

Arsenic exceeded its criterion of 0.01 mg/L in three of the communities of interest, La Oroya Antigua, La Oroya Nueva, and Marcavalle. No other metals exceeded their respective risk-based concentrations. Although arsenic exceeded the Maximum Contaminant Level, arsenic will not be evaluated in this risk assessment because drinking water in La Oroya comes from sources that are not thought to be affected by releases from the Complex.

4 EXPOSURE ASSESSMENT

The exposure assessment includes calculation of exposures to chemicals for adult and child residents by all the exposure pathways identified as being important for current and future releases from the Doe Run Perú Metallurgical Complex (Complex) in La Oroya, Perú. Chemical exposures quantified include inhalation of sulfur dioxide, airborne particulates, lead, arsenic and cadmium, ingestion of metals in soil, outdoor dust, indoor dust, and drinking water, and ingestion of lead in food.

For each chemical and exposure medium exposure concentrations were estimated. For oral exposures, intake doses were calculated. Approaches to estimating exposures and risks are different for sulfur dioxide, airborne particulates, and lead than for other chemicals evaluated in this risk assessment. General exposure assessment methods are described below, followed by descriptions of the specific approaches used for sulfur dioxide and particulates, lead and other metals.

4.1 EXPOSURE ASSESSMENT APPROACHES

The approach used to identify exposure pathways for this risk assessment is described Section 4.1.1 below, followed by an explanation of the calculation of exposure point concentrations in Section 4.1.2. Inhalation exposures are often assessed by direct comparison of exposure point concentrations in air with air quality criteria or health-protective reference concentrations (RfC). When health risks are assessed by comparison of concentrations there is no need to calculate a dose or intake of the chemical. Oral exposures are typically assessed by estimating the average daily dose or intake of a chemical in terms of mg/kg body weight. The approach used to calculate doses or intakes is described in Section 4.1.3.

4.1.1 Exposure Pathways

Exposure pathways to be evaluated in this risk assessment were identified based on review of available data and on the results of supplemental data collection events (sampling and modeling activities). According to the U.S. Environmental Protection Agency (USEPA) (1989), exposure pathways may be eliminated from further consideration in a risk assessment based on any of the following reasons:

- "the exposure resulting from the pathway is much less than that from another pathway involving the same medium at the same exposure point;
- the potential magnitude of exposure from a pathway is low; or

- the probability of the exposure occurring is very low and the risks associated with the occurrence are not high."

Each of the potential exposure pathways identified in the preliminary review (see Section 2.4) was evaluated using these criteria. Inhalation exposure was confirmed to be a pathway of concern for sulfur dioxide and airborne particulates. Ingestion of dust on outdoor and indoor surfaces is the primary exposure pathway of concern for exposure to metals. Children, especially, spend a significant amount of time outdoors playing in plazas, playfields, and open spaces where dust may accumulate on surfaces between rain and cleaning events. Dust may adhere to a child's skin surface (i.e., hands) while playing, which then may be ingested unintentionally when they touch their faces and mouths or eat without first washing their hands.

Metals are also present in elevated concentrations in soil and air, so ingestion of metals in soil and inhalation of metals in air are confirmed as exposure pathways that need to be included in this risk assessment. Drinking water does not appear to be affected by releases from the Complex and was not included in the exposure assessment. Diet was confirmed to be an exposure pathway for lead. Intakes were not estimated for metals other than lead in diet because site-specific data were not available. Dermal absorption of metal particles on the skin was not evaluated because metals have only very limited absorption through the skin. The omission of these exposure pathways is discussed in the Uncertainty Evaluation in Section 6.5.

4.1.2 Exposure Point Concentrations

For most risk assessments, sample data for each exposure medium are subjected to a statistical evaluation to identify a concentration of each chemical that will be representative of exposures in each community. These concentrations are referred to as the exposure point concentrations.

Exposure point concentrations are the amounts of a chemical that will be contacted by people over the period of exposure being evaluated. Exposure point concentrations are usually estimated from air, dust or water sample results and from station monitoring data or by using chemical dispersion and deposition models to predict concentrations at locations where people will contact the chemical. For this risk assessment, monitoring and sampling data were used to estimate exposure point concentrations for current exposures and dispersion and deposition model outputs were used to predict exposure point concentrations for future exposures.

4.1.3 Estimating Doses and Intakes

Intake refers to the amount of a chemical that enters the mouth or lungs, or contacts the skin. Chemical-specific intakes for each exposure pathway are estimated using equations that incorporate five factors in addition to the exposure concentration previously described. These factors or "variables" are described below:

- Contact rate—the amount of water, food, dust, or air that a person may take into their body (i.e., drink, eat, breath, or contact with skin) over a specified time
- Exposure frequency—how often a person could be exposed to the chemical
- Exposure duration—how long a person could be exposed to the chemical
- Body weight—the typical mass (in kilograms) for each age group of people who may be exposed
- Exposure averaging time—the time (in days) over which exposure is averaged.

Intake is estimated using each of these variables and the exposure concentration in the following equation:

$$\text{Intake}\,(\text{mg/kg}\cdot\text{day}) = \frac{\text{C}\times\text{CR}\times\text{EF}\times\text{ED}}{\text{BW}\times\text{AT}}$$

where,

	C	=	chemical-specific exposure point concentration (mg/kg)
	CR	=	contact rate (mg/day, m^3/day, etc)
	EF	=	exposure frequency (days per year)
	ED	=	exposure duration (year)
	BW	=	body weight (kg)
	AT	=	averaging time (days)

The combination of specific values selected for use in this equation were selected based on statistics, professional judgment, and risk assessment guidance to produce estimates of average exposures termed the "central tendency exposure" and the "reasonable maximum exposure." The central tendency exposure (CTE) represents typical exposures for a given population. The reasonable maximum exposure (RME) is an estimate of the highest exposure that is reasonably expected to occur.

The reasonable maximum exposure is considered protective of sensitive subpopulations within the community. Typically, higher values are used in the calculation of the contact rate and exposure duration in combination with average body weights to protect the majority of people within a population. This avoids an overestimation of risk based on

the unreasonable assumption that the greatest intake will occur for the smallest individual.

4.2 ASSESSING EXPOSURES TO SULFUR DIOXIDE AND PARTICULATES

Air monitoring data were used to predict exposure point concentrations for assessing current exposures to sulfur dioxide and particulates in ambient air. Exposure point concentrations for short-term exposures to sulfur dioxide and particulates are based on the second highest 24-hour concentration reported during 2004 at each monitoring station. Exposure point concentrations for chronic exposures were based on annual average air concentrations for sulfur dioxide and particulates. Results of the air modeling analysis were used to predict how the concentrations of sulfur dioxide and particulates would change in 2007 and 2011 as operational changes were implemented at the Complex.

4.2.1 Selection of Data for Use in this Risk Assessment

Sulfur dioxide and PM_{10} data from three of the monitoring stations operated by Doe Run Perú were used in the analysis of current conditions: Sindicato, Hotel Inca, and Cushurupampa. Each of these monitoring stations was selected to represent a particular community near the Complex. The monitor had to be close to a community to be considered representative of current conditions in that community. Figure 4-1 shows the location of the communities evaluated in this risk assessment and the nearest Doe Run Perú monitoring stations. The station names correspond to the data summaries provided by Doe Run Perú.

Data from the Sindicato monitoring station were used to represent exposures in the La Oroya Antigua community. This station is located to the north of the Complex, just across the Mantaro River. Because the Sindicato sulfur dioxide monitor is located very close to the Complex, it typically records the highest sulfur dioxide air concentrations observed among the Doe Run Perú monitors. Much of the community of La Oroya Antigua is located farther north of the Sindicato station and farther from the Complex. Air concentrations decrease with distance away from the Complex when going north through La Oroya Antigua. Therefore, the Sindicato monitor should provide an indication of the highest air concentrations likely to be seen in La Oroya Antigua and tend to over-predict impacts in the more northerly sections of the community.

Data from the Hotel Inca monitoring station were used to represent exposures in the La Oroya Nueva community. This monitoring station is located to the west of the facility and near where the Yauli and Mantaro Rivers meet. Although located farther from the Complex than the Sindicato station, it is still one of the closest monitoring stations operated by Doe Run Perú. The community of La Oroya Nueva lies to the south of the

Hotel Inca station along the Yauli River. Some portions of the La Oroya Nueva community may actually be closer to the Complex than the Hotel Inca station. However much of the community is located farther south down the Yauli River valley.

It is difficult to say with certainty that the observations at the Hotel Inca sulfur dioxide monitor will always be as high as or higher than conditions anywhere in La Oroya Nueva. This should be the case for the portions of the community located farther south of the Complex where the Yauli River valley is broader and less steep. The northern portions of the community are located closer to the Complex where the river valley is narrow and steep. In general, the Hotel Inca monitor should provide a reasonable estimate of the 24-hour and annual average conditions expected in La Oroya Nueva. There should be a tendency to overestimate the conditions in the areas of the community where the Yauli River valley broadens and the pollutants can spread out more, leading to increased dilution.

Data from the Cushurupampa monitoring station were used to evaluate exposures for the Marcavalle community. This station is located to the southwest of the Complex in the Yauli River valley. The Cushurupampa station is closer to the Complex than Marcavalle which is located farther south along the Yauli River valley. The station is located on the eastern side of the valley where the terrain is steeper. The air dispersion modeling results indicated that higher concentrations of sulfur dioxide were found on the eastern side of the valley, most likely due to the steeper terrain. Because the monitor is located closer to the Complex, but in the same direction as Marcavalle, it will likely tend to overestimate conditions in the community.

No monitoring station was sufficiently close enough to establish current exposures for the Chucchis community, which is located south of Marcavalle along the Yauli River. The Cushurupampa monitoring station is the nearest site and was judged to be too far to accurately represent conditions in Chucchis. Because the Cushurupampa station is located much closer to the Complex but in the same direction as the community of Chucchis it would likely significantly overestimate the conditions in Chucchis.

4.2.2 Summary of Monitoring Results

To characterize risk, two averaging times were evaluated: a one year period and a 24-hour period. Therefore, an annual average concentration of sulfur dioxide was calculated from the air monitoring data at each station to evaluate potential long term exposure. A maximum daily average concentration was calculated from the air monitoring data for each station to evaluate potential acute exposure. Table 4-1 presents the 2004 annual average and maximum daily average concentrations of sulfur dioxide for each of the three monitoring stations evaluated in this risk assessment. These values were used to characterize potential risk under current conditions (see Section 6.1).

For comparison purposes, Table 4-1 also presents annual and maximum daily average concentrations of sulfur dioxide for the years 2002 and 2003, and maximum daily average concentrations for the first quarter of 2005. Although use of these data was not appropriate for evaluation of current conditions, they do provide a context for evaluation of the 2004 data. As shown in Table 4-1, in 2004, the greatest average concentrations of sulfur dioxide were measured at Hotel Inca (La Oroya Nueva). This is in contrast to previous years (2002 and 2003), when sulfur dioxide concentrations tended to be very similar at Hotel Inca (La Oroya Nueva) and at Sindicato (La Oroya Antigua), which is actually closer to the Complex. This change may be associated with changes in operations at the facility or with weather patterns. Such differences across years underscore the need for continued monitoring.

A review of the average concentrations of sulfur dioxide collected at each hour of the day (24-hour clock) during 2004 revealed daily trends. All three monitors (Sindicato, Hotel Inca, and Cushurupampa) show that concentrations of sulfur dioxide are the highest during the morning and early afternoon, from approximately 8 am to 1 pm. A graphical representation of the consistency of this daily peak in sulfur dioxide ambient air concentrations is shown in Figures 4-2 through 4-4. The figures present the average hourly concentration for each month of the year at one of the three community monitors used in the risk characterization. Although some months clearly show higher peaks than others, no seasonal trend was distinguished based on a limited analysis of trends in the monitoring data. A similar trend was observed for PM_{10} at Sindicato, but average hourly PM_{10} concentrations at Hotel Inca and Cushurupampa tend to be more variable and daily trends are not as marked as those for sulfur dioxide.

Figures 4-2 though 4-4 also demonstrate that the Hotel Inca monitor, shown on Figure 4-3, has the highest monthly average hourly concentration of the three monitors evaluated. This maximum occurred in November of 2004. The remaining months at Hotel Inca show peaks that are similar in magnitude to the Sindicato monitor shown in Figure 4-2. The annual average concentration for the Hotel Inca monitor was approximately 16 percent higher than for the Sindicato monitor. The Cushurupampa monitor had the lowest peak month of the three monitors and the lowest annual average. This is to be expected as it is located farther from the Complex than the other two monitors. No attempt was made to evaluate any potential temporal or spatial correlations between monitor sites as it was beyond the needs of the current risk assessment.

Although the data were insufficient to accurately evaluate seasonal trends, a review of Figures 4-2 through 4-4 shows that peak concentrations for the summer and fall months (November–July) were consistently greater than during the winter and spring months (May–December), particularly at Hotel Inca and Cushurupampa. The initial assumption was that greater concentrations would be seen in the winter, due to a greater incidence of

local atmospheric inversion conditions. In contrast to expectations, the peak sulfur dioxide concentrations at Hotel Inca and Cushurupampa actually decreased during the winter. According to Doe Run Perú facility staff, one potential explanation for this observation is the Intermittent Control Program implemented by the facility during the winter months of 2003–2004. The Intermittent Control Program includes provisions for curtailing operations that produce sulfur dioxide emissions during meteorological conditions exist that could adversely impact air quality in the area.

4.3 ASSESSING EXPOSURES TO LEAD

Health risks associated with lead exposures in a study population are assessed by comparison of the observed or predicted blood lead concentrations in that population with concentrations associated with adverse health effects in other populations previously studied. As described above, a number of blood lead studies have been conducted in La Oroya, and there are plans to continue monitoring blood lead levels in the future. These studies can be used to characterize the magnitude of current and ongoing exposures to lead and to predict health risks.

There are limitations based on existing information to understand the relative contribution of different sources of exposure. Toxicokinetic models have been developed that allow for pathway specific evaluations. These models rely on estimates of lead intake from environmental media such as air, soil and dust, and other sources such as drinking water, diet, and lead-containing consumer products. Concentration data from samples of community air, soil, dust, drinking water and diet may be combined with estimates of inhalation rates and ingestion rates to calculate intakes. Toxicokinetic parameters, including estimates lead absorption from each medium, are then used to predict blood lead levels.

The USEPA has issued several toxicokinetic models that may be applied to predict the distribution of lead concentrations in populations of children or adults. These models include many default assumptions for model parameters that are expected to be representative of the U.S. population. For a number of reasons, these default parameters may not be representative of the population of Perú or of La Oroya. Consequently, this risk assessment has required considerable effort to identify assumptions that will be more representative. The correctness of the selected parameters has been assessed by comparison of the model predictions of blood lead concentrations with the blood lead concentrations reported in previous studies. The blood lead concentrations used for this study are provided in Appendix E.

The following sections document to development of lead exposure models for children and for adults.

4.3.1 Exposure Models for Children

USEPA has developed two models for predicting blood lead concentrations in children. The integrated exposure uptake biokinetic (IEUBK) model is designed to predict blood lead levels in children (0-7 years old). The IEUBK was calibrated against blood lead study results during its development, and is the principal model used by USEPA. This model uses point estimates of average values for input parameters and lead concentrations in environmental media to calculate an average blood lead concentration. Then an estimate of geometric standard deviation is applied to create a log normal distribution of blood lead concentrations.

The second model, called the integrated stochastic model (ISE), uses distributions of input parameters and lead concentrations to generate the predicted distribution of blood lead concentrations using a Monte Carlo approach. Otherwise, the IEUBK model and the ISE model rely on the same toxicokinetic model to predict blood lead concentrations from absorbed lead doses. The intended use of the ISE model is for conducting uncertainty analyses of childhood lead exposures to identify important modeling assumptions and sources of variability and uncertainty.

An underlying premise of the IEUBK model is the assumption that lead exposures at contaminated sites will be dominated by exposure to lead ingested from soil. Smaller contributions are assumed from exposure to lead ingested from indoor dust, with minimal exposure due to inhaled lead in air. These assumptions do not apply to sites with ongoing air emissions of lead, such as smelters (Hilts 2003). As described in Section 2.4 and Section 4.1.1, the smelter in La Oroya releases lead to the air in the form of particulates. While some of the airborne lead may be inhaled, much of the airborne particulate load settles out onto pavement, soil and other outdoor surfaces. This outdoor dust contains much higher concentrations of lead than does the underlying soil. Because children playing outdoors may ingest this dust after getting it on their hands, it is important to include outdoor dust as a separate exposure medium in lead exposure models.

The ISE model includes a similar underlying premise that ingested soil is the principal exposure medium of concern, and that indoor dust concentrations are due to soil tracked into homes; however, it was found to be possible to modify the ISE model to allow the outdoor dust to be treated as a separate exposure medium. A similar modification could not easily be accomplished with the IEUBK model. Additionally, the IEUBK model was designed with an underlying assumption that blood lead levels are lognormally distributed among exposed children. In La Oroya the blood lead levels of young children were generally normally distributed.

The ISE model utilizes the same basic toxicokinetic model and exposure pathways that are used in the IEUBK model, but the ISE model uses Monte Carlo analysis to propagate variability and uncertainty through the exposure and uptake modules. Thus, the ISE model has greater flexibility to reflect conditions in La Oroya. Consequently, the ISE model was selected for use in predicting childhood lead exposures in La Oroya.

An important reason for selecting the ISE model is that statistical analysis of the 2004 blood lead data for children in La Oroya show that the best fit distributions are either normal or gamma distributions (see Table 4-2). Gamma distributions are similar to normal distributions. Only one group (the 2-3 year old group) demonstrates a lognormal distribution. However, this group of data also follows a gamma distribution, and the correlation of gamma distribution is stronger than that for the lognormal distribution. Blood lead data collected in 2000 also have distributions that are not log normal (see Table 4-2). Because the ISE model accepts distribution inputs for parameters such as lead concentrations in different media (e.g., soil, dust, water, diet), it can more readily produce a distribution of blood lead estimates that matches the distributions observed in the population.

This phase of the project used the one-dimensional module of the ISE model, which allows for variation of the values and distributions for major input variables to generate distributions of blood lead concentrations for children that are consistent with the sampling data collected from each of the communities. The ISE model also includes a two-dimensional modeling feature that allows identification of important modeling assumptions and sources of variability and uncertainty in predicting blood lead concentrations. Consequently, the input values and distributions can be adjusted to generate the blood lead modeling results that are supported by the site-specific sampling data. This feature was not used in this risk assessment.

As described above, an underlying assumption of the ISE model is that the presence of lead in indoor dust is due to soil being tracked into homes. Under this assumption, the ISE model combines the ingestion of outdoor soil and indoor dust as one input variable, and applies a factor to characterize the soil portion of the ingestion. This underlying assumption is not consistent with the exposure pathways in La Oroya which are dominated by high lead concentrations in outdoor dust. Because of the high lead concentrations and mobility of outdoor dust, the lead concentrations in indoor dust are more influenced by tracked in outdoor dust than by tracked in soil.

To address this site-specific characteristic, a modification was made in setting up the ISE model in which the parameter called soil was substituted by outdoor dust, and the ingestion of both indoor and outdoor dust was reflected in one intake rate. A factor was applied to represent the fraction of total dust ingestion due to outdoor dust. The contribution of lead ingested in soil was then characterized using the "Other" module

within the ISE model. The "Other" module was designed to account for additional exposure pathways not specified in the ISE model. The details of these modifications are described below for each parameter and the input files used in the ISE model are provided in Appendix E.

The ISE model was first used to predict current blood lead levels by an iterative process in which input parameters and distributions were selected, and then the model output was compared to the blood lead distributions reported in the 2004 Ministry of Health's Environmental Health Directorate (DIGESA) study. Values for input parameters and their associated distributions were then modified and the model rerun until the predicted distribution provided a reasonable match to the distribution reported by DIGESA (2005). The calibrated model was then used to predict future blood lead concentrations in 2007 and 2011 after reductions in lead emissions from the smelter. The two following sections describe these modeling efforts.

4.3.1.1 Determination of ISE Model Inputs for Current Scenario

This section presents the ISE model development and inputs for the current exposure scenario. There are two types of input parameters used in the ISE model. The first type is general parameters that are applicable to all of the simulation modeling runs for the communities evaluated. The second type is site-specific parameters that are applicable to specific communities or time periods.

The parameters that were the same for each community include:

- Exposure frequency
- Average time
- Ingestion rate for dust and soil
- Age-dependent dust ingestion rate scale factor
- Age-dependent water ingestion rate scale factor
- Absorption factors for various media (e.g., dust, soil, water, diet)
- Age-dependent ventilation rates
- Time spent outdoors for each of the age groups
- Age-dependent lung absorption factor.

The input values and distributions, if applicable, for these parameters are presented in Table 4-3a. Values and distributions for each of these parameters were determined or selected based on one of the following sources or rationales:

- USEPA default assumption
- Site-specific sampling data
- Observation and interviews with local residents
- Best professional judgment or best model fitting.

The corresponding source or rationale for each of the parameter values is noted in Table 4-3a. Community-specific parameter values are presented in Table 4-3b (La Oroya Antigua), Table 4-3c (La Oroya Nueva), Table 4-3d (Marcavalle), and Table 4-3e (Chucchis). A discussion of the derivation of the input values for specific exposure pathways and other parameters follows. The process of identifying the best model fit for the input values is further described in Section 4.3.1.2.

- **Inputs for Outdoor and Indoor Dust Pathways**

Dust lead intake in μg/day is calculated based on three parameters:

- concentration of lead in dust in mg/kg,
- dust ingestion rate in mg/day, and
- percent of the dose that is absorbed (i.e., absorption).

For each community a distribution of lead concentrations in outdoor dust and indoor dust was derived based on data from samples collected by Integral. Details of sampling of outdoor dust (community dust) and indoor dust (residential dust) are presented in Section 3.2. Default soil and dust ingestion rates in the ISE model vary with age, with different ingestion rates every year from 0 to 7 years if age. Age-dependent dust ingestion rates were determined based on best professional judgment and best model fit. The default age-dependent soil ingestion rate scale factors were applied in calculating dust intakes for different age groups. The distribution of lead absorption from both outdoor dust and indoor dust was assumed to be a triangular distribution with a likeliest value of 40 percent, minimum value of 15 percent and maximum value of 65 percent. The likeliest value reflects the expectation that lead in dust will have higher bioavailability compared to lead in soil.

As described above, the ISE model does not include a parameter for outdoor dust. To adapt this model to better represent conditions inn La Oroya, input values for outdoor dust were entered under "Soil." Input values for indoor dust are presented under "Dust." The input values and the corresponding distributions are presented in Tables 4-3b through 4-3e.

- **Inputs for Soil Lead Pathway**

Soil lead intake in μg/day is calculated based on three parameters:

- concentration of lead in soil in mg/kg,
- soil ingestion rate in mg/day, and
- percent of the dose that is absorbed (i.e., absorption).

For each community a distribution of soil lead concentrations was derived based on data from the soil samples collected by Integral. Details of the soil sampling are presented in Section 3.2. Default soil ingestion rates in the ISE model vary with age, with different ingestion rates every year from 0 to 7 years of age. Without the consideration of the age scale factor, the default ingestion rate of both soil and dust is 135 mg/day. The age scale factors for different age groups are listed in Table 4-3a.

Soil lead ingestion rates were determined based on best professional judgment and best model fit, along with the consideration of the default ingestion scale factors. According to the best fit of ISE modeling, the soil ingestion rate was determined to be normally distributed. The mean ingestion rate was 20 mg/day, with a standard deviation of 8.3 mg/day. Then the default age-dependent soil ingestion rate scale factors were applied on the mean ingestion rate and standard deviation in calculating soil intakes for different age groups for this risk assessment.

The distribution of lead absorption from soil was assumed to be a triangular distribution with a likeliest value of 30 percent, minimum value of 10 percent and maximum value of 50 percent. The likeliest value is the same as the model default mean value, and reflects the expectation that lead in soil will have reduced bioavailability compared to lead in dust.

As discussed above, the age-dependent daily soil intake distributions in μg/day were entered as the "Other" pathway in the ISE model. For each community, the intake distribution was generated by entering the distributions for the three input parameters into a Monte Carlo program. The resulting distribution was then used in the ISE model.

- **Inputs for Air Pathway**

Exposure to lead in air is calculated based on three parameters:

- Annual average lead concentration in air in $\mu g/m^3$
- Ventilation rate in m^3/day, and

- Absorption of lead from the lung.

Based on air monitoring data collected by Doe Run Perú during 2004 (see Section 3.1.1), distributions of lead in air were identified for each community evaluated. As described in Section 3.1.1, Doe Run Perú reported air concentrations in terms of standard temperature and pressure (i.e., 0°C and 1 atmosphere). These data were converted to normal temperature and pressure (i.e., 25°C and 1 atmosphere). The USEPA default assumptions for ventilation rates were used. As discussed in Section 4.4.3, people living at high altitudes may have increased ventilation rates; however, because the lead concentrations used were reported at normal temperature and pressure, the ventilation rates were not increased. Absorption of lead from air was entered as a point estimate of 32 percent, the same value as the USEPA default value.

- **Input for Diet Pathway**

Dietary lead exposure is based on two parameters:

- Intake from the diet in μg/day, and
- Absorption of lead from the diet.

Based on site-specific data on lead intake in the diet from the study conducted in La Oroya Antigua (see Section 3.2.2 and Appendix C), a distribution for age-dependent diet intakes of lead was determined. These values and distributions were applied to all the communities. It is possible that because the study was conducted in La Oroya Antigua, the values used may be higher than the actual dietary lead intakes in the other communities.

Because the dietary intake data were only collected from two age groups among the children, 12-23 months and 24-35 months, age-dependent intake values and distributions were determined for the age 1-2 and age 2-3. The overall average value and distribution were applied to the rest of the five age groups. This assumption may have overestimated lead intakes in infants less than one year old, and could underestimate the dietary lead intake in older children. The values selected are presented in Tables 4-3b through 4-3e.

- **Input for Drinking Water Pathway**

Exposure to lead in drinking water is calculated based on three parameters:

- Lead concentration in drinking water in μg/L
- Water ingestion rate in L/day, and
- Absorption of lead from drinking water.

Based on drinking water samples collected by Integral (see Section 3.2.1), point estimates or distributions of lead in water were identified for each community evaluated. The USEPA default assumptions for water ingestion rates were used. Absorption of lead from water was entered as a triangular distribution with a most likely value of 50 percent, a minimum value of 30 percent and a maximum value of 70 percent. The most likely value is the same as the USEPA default mean value.

- **Input for Maternal Blood Lead Concentration**

Maternal blood lead concentration will determine the blood lead concentration of infants at birth, and will continue to have a diminishing influence on blood lead levels as children grow. Consequently, it was important to use data for women of child bearing age from La Oroya for this parameter. Average maternal blood lead concentrations were derived from a study conducted in 2000 by Doe Run Perú (DRP 2001a, see description in Section 3.1.5). A point value for maternal blood lead concentration for each of the communities evaluated was determined based on the mean blood lead level in women 16 to 35 years old (see Table 4-4). Table 4-4 also lists the statistical distributions, the 10th, 20th, 50th, 80th, and 90th percentile values of the blood data for women age group of 16 to 35 in each of the communities. The point values used in ISE modeling for all the communities are listed in Tables 4-3b through 4-3e.

4.3.1.2 Calibration of ISE Model and Determination of Dust and Soil Ingestion Rates and Distributions

By using the general and site-specific input values and distributions, as described above, as well as the blood lead sampling data collected in La Oroya by DIGESA in November and December of 2004 (DIGESA 2005), a calibration analysis was conducted for the ISE model. The calibration analysis was performed through an iterative approach.

First, statistical analyses were conducted for the collected blood lead data. The distribution pattern of the blood lead data collected in 2001 and 2004 for each of the age groups was identified. Various statistical values, such as the mean, 10th percentile, 25th percentile, 50th percentile, 75th percentile, and 90th percentile of the blood lead data, were calculated. The results of the statistical analysis for each of the communities are listed in Tables 4-2 and Table 4-5, as well as in Tables 4-6a and Table 4-6b.

Second, general and site-specific values and distributions for the model parameters were input into the model. Initial statistical values (e.g., mean, standard deviation) and distributions for ingestion rate of outdoor and indoor dusts (listed as "soil" and "dust" in the model, respectively) and soil lead intake (listed as "other" in the model) were assigned, and a point value was given to the factor representing the fraction of intake that was outdoor dust.

Third, an initial ISE modeling run was conducted with the selected number of Monte Carlo iteration, and the mean blood lead concentration as well as the 10th, 25th, 50th, 75th, and 90th percentile values were predicted.

Fourth, the modeled blood lead values for the mean, 10th, 25th, 50th, 75th, and 90th percentiles were compared against the statistical results of blood lead sampling data from each of the communities in La Oroya. After examining the deviations of the modeled blood lead results from the sampling results, new statistical values and distributions were assigned to the distributions for dust and soil ingestion rates and absorption, and then a new ISE modeling was performed.

Finally, the procedures described in the third and forth steps were repeated until the ISE modeling results for the mean and the various percentile values were sufficiently close to the blood sampling results, and then the calibration process was completed. The final ISE modeling results were compared with the blood lead sampling data from each of the communities in La Oroya. The comparison results are listed in Tables 4-6a and 4-6b.

4.3.1.3 Determination of ISE Model Inputs for Future Scenarios

As described in Section 3.3, expected future reductions in lead emissions from the smelter were used in the air dispersion model to predict changes in concentrations of lead in air, as well as changes in lead deposition rates for future years. In La Oroya Antigua, the concentrations of lead in air are predicted to fall by 80 percent in 2007 and by 85 percent in 2011. Lead deposition rates were predicted to fall by 72 percent in 2007 and by 83 percent in 2011. Somewhat smaller percent reductions were predicted for the other communities. These predicted percent reductions in air lead concentration and deposition rates were used to predict the future air concentrations and deposition rates. These values are shown in Tables 4-7a through 4-7d. For example, as shown in Table 4-7a the 2004 lead annual average air concentration in La Oroya Antigua was 2.87 $\mu g/m^3$. Because an 80 percent reduction in this value is predicted for 2007, the 2007 air concentration was determined by multiplying 2.87 by a factor of (1 - 0.8) or 0.2. This yielded a predicted 2007 air lead concentration of 0.57 $\mu g/m^3$.

The projected percentage reductions of lead deposition rates were also used to predict reductions of lead concentrations in outdoor dust, indoor dust, soil and diet. At another smelter site in Trail, British Columbia, Canada, lead concentrations were measured in air, outdoor dustfall (a measure of deposition rates), street dust, house dust and soil both before and after installation of a new smelter (Table 4-8, Hilts 2003). In Trail it was found that the percent reduction in lead concentrations in street dust was almost as great as the percent reduction of lead dustfall rates (i.e., by a factor of 0.9 compared to dustfall). Indoor dust concentrations were reduced to a lesser extent (i.e., a factor of 0.5 compared

to dustfall). Soil lead concentrations were not significantly reduced (i.e., a factor of 0.1 compared to dustfall).

We used the findings from Trail as the basis to predict reductions in lead concentrations for various media in La Oroya. It was assumed that lead concentrations in the outdoor dust would be reduced to the same extent as the reductions in lead deposition (i.e., by a factor of 1.0 relative to deposition reductions). The reduction of lead concentrations in indoor dust was predicted to be a factor of 0.8 compared to the reduction in lead deposition. This is a greater reduction than was observed in Trail (where the indoor dust was reduced by a factor of 0.5 compared to dustfall), but reflects the fact that most homes in La Oroya are not as tightly sealed as homes in Trail. The reductions in lead concentrations in soil compared to deposition reductions were assumed to be a factor of 0.1 in 2007 and a factor of 0.3 in 2011. Dietary lead intake was predicted to be reduced by a factor of 0.6 relative to the reduction in lead deposition rates. The factor of 0.6 was judged to be a reasonable estimate of the contribution of lead deposition to the total lead concentrations in food.

These factors form the basis for the percentage reductions predicted for each exposure source in Tables 4-7a through 4-7d, i.e., the projected percent change in lead deposition for 2007 and 2011 for outdoor dust, indoor dust, soil and diet for each community were multiplied by the factors described above to yield the listed projected percent change.

As described above, the ISE model includes an input for the maternal contribution to child blood lead levels. The predicted reductions in concentrations of lead in air, dust, soil, and diet are expected to result in reductions of maternal blood lead levels by 2007 and 2011. As described below, blood lead levels in women of child bearing age were predicted for the years 2007 and 2011. The, predicted maternal blood lead levels for the years 2007 and 2011 for each community were incorporated into ISE to more accurately predict children's future blood lead levels.

Input parameters for the ISE model for future scenarios (years 2007 and 2011) are summarized in Tables 4-3b through 4-3e. The input parameters for future scenarios were applied in ISE modeling runs for predicting future blood lead concentrations and characterizing health risks among the children. The predicted risk results and discussions are presented in Section 6.2.1.

4.3.2 Adult Lead Exposure Model

USEPA (2003b) recommends use of a toxicokinetic model called the adult lead model (ALM) model to assess exposures of adults to lead. Similar to the IEUBK model and the ISE model, the ALM model is based on the assumption that soil is the main source of lead exposures at contaminated sites. Because outdoor dust, rather than soil, is thought to be

the primary source of lead exposures in La Oroya, the model inputs were modified to better reflect conditions in La Oroya. The ALM model version from USEPA is a much simpler model than the IEUBK and ISE models, and does not include the option of entering site-specific values for outdoor dust, water, air and diet. As described below, we used outdoor dust data instead of soil data in the model, and accounted for site-related exposures to lead in soil, diet and air by means of an elevated baseline blood lead value.

The ALM model includes a module to predict fetal blood lead levels to support estimates of exposures that are protective of a "fetus of a worker who develops a body burden as a result of non-residential exposure to lead." According to USEPA (2003b), protection of the fetus is the most health-sensitive endpoint for adults. Similar to the IEUBK model for residential exposure, the ALM model target risk level is no more than a 5 percent probability that a fetus exposed to lead will exceed a blood lead level of 10 μg/dL (USEPA 2003b).

The ALM model uses a technical approach described by Bowers et al. (1994) that predicts the blood lead level in an adult with a site-related lead exposure by summing the "baseline" blood lead level (PbB_0) (i.e., that which would occur in the absence of any site-related exposures) with the increment in blood lead concentration that is expected as a result of increased exposure due to contact with lead-contaminated soil. The latter is estimated by multiplying the average daily absorbed dose of lead from soil by a "biokinetic slope factor" (BKSF). Thus, the basic equation for exposure to lead in soil is:

$$PbB = PbB_0 + BKSF \times \left(\frac{PbS \times IR_s \times AF_s \times EF_s}{365} \right)$$

Where:

PbB = Geometric mean blood lead concentration (μg/dL) in women of child-bearing age that are exposed at the site

PbB_0 = "Background" geometric mean blood lead concentration (μg/dL) in women of child-bearing age in the absence of exposures to site soil

BKSF = Biokinetic slope factor (μg/dL blood lead increase per μg/day lead absorbed)

PbS = Soil lead concentration (μg/g)

IR_s = Intake rate of soil, including both outdoor soil and indoor soil-derived dust (g/day)

AF_s = Absolute gastrointestinal absorption fraction for lead in soil and dust (dimensionless). The value of AF_s is given by:

$$AF_s = AF_{food} \times RBA_{soil}$$

EF_s = Exposure frequency for contact with site soils and dusts (days per year)

RBA = Relative bioavailability adjustment

If a factor K_{SD} (which represents a mass fraction of soil in dust) and a weighting factor W_s (which represents the fraction of IR_s ingested as outdoor soil) are introduced to the basic equation for exposure to lead in soil, the basic equation can be rearranged as (USEPA 2003b):

$$PbB = PbB_0 + BKSF \times PbS \times \frac{\left[\left(IR_s \times AF_s \times EF_s \times W_s\right) + \left(K_{SD} \times IR_s \times \left(1 - W_s\right) \times AF_s \times EF_s\right)\right]}{365}$$

Where:

K_{SD} = Mass fraction of soil in dust (dimensionless)

W_s = Fraction of IR_s ingested as outdoor soil (dimensionless)

This rearranged equation was used for adult blood lead modeling for this study.

Once the geometric mean blood lead value is calculated, the full distribution of likely blood lead values in the population of exposed people can then be estimated by assuming the distribution is lognormal with a specified individual geometric standard deviation (GSD_i). The 95th percentile of the predicted distribution is given by the following equation from Aitchison and Brown (1957):

$$95^{th}\ percentile = GM \times GSD_i^{1.645}$$

Where:

GM = Geometric mean

GSD_i = Individual geometric standard deviation

The ALM model also uses the following equations to calculate the mean and 95th percentile of fetal blood concentrations:

$$PbB_{fetal} = R_{fetal-maternal} \times PbB_{adult}$$

$$PbB_{fetal,0.95} = R_{fetal/maternal} \times PbB_{adult,central} \times GSD_{i,adult}^{1.645}$$

Where:

PbB_{fetal} = Fetal blood lead concentration (μg/dL) (which, like PbBadult, is a variable quantity having the specified probability distribution).

$R_{fetal/maternal}$ = Constant of proportionality between fetal and maternal blood lead concentrations.

PbB_{adult} = Adult blood lead concentration (μg/dL), estimated with parameters appropriate to women of child bearing age.

$PbB_{fetal,0.95}$ = Fetal blood lead concentration (μg/dL) among fetus born to women having exposure to the specified site.

There is evidence that fetal blood lead concentrations are consistently lower than maternal blood lead concentrations by a factor of 0.9. Consequently, for this study the ALM default value, 0.9, for $R_{fetal/maternal}$ was used. The use of a point estimate for this value implies a deterministic (non-random) relationship between maternal and fetal blood lead concentrations. This assumption omits a source of variability (varying individual-specific ratios of fetal to maternal blood lead) that would tend to increase the variance of fetal blood lead concentrations (USEPA 2003b).

Additional model assumptions are described below, followed by a comparison of predicted blood lead values with blood lead data from a study conducted in 2000. The ALM files used in this HHRA are provided in Appendix E.

4.3.2.1 Summary of Input Parameters

Input parameters for modeling of current and future conditions are listed in Table 4-9 and are described below.

- **Lead Concentrations in Outdoor Dust**

The mean outdoor dust lead concentration in each community was derived based on samples collected by Integral in March and June 2005. Details of sampling and analysis of outdoor dust (community dust) and indoor dust (residential dust) are presented in Section 3.2. Reductions in future outdoor dust lead concentration were based on changes in lead deposition rates predicted by the air dispersion models for 2007 and 2011. It was assumed that the reduced lead deposition rates for 2007 and 2011 will be directly reflected

in the reductions of lead in outdoor dust. The predicted reduced lead concentrations in outdoor dust for 2007 and 2011 are summarized in Table 4-9.

- **Mass Fraction of Outdoor Dust in Indoor Dust and Weighting Factor**

The ALM model includes an assumption that indoor dust lead concentrations are due to tracking in lead-containing soil into homes. In La Oroya, outdoor dust is thought to be the major contributor to indoor dust. It is assumed that women of childbearing age ingest lead in both outdoor dust and indoor dust. A weighting factor, W_s, was used to apportion the dust ingestion rate between outdoor dust and indoor dust. It was assumed that 40 percent of the dust ingested is from outdoor dust (i.e., a weighting factor of 0.4).

The ALM model also includes a term to predict the indoor dust concentration from soil concentrations. This term, represented by K_{SD}, is called "mass fraction of soil in indoor dust." For La Oroya, we used this term to predict the contribution of outdoor dust to indoor dust lead concentrations. Site-specific indoor dust concentration data was available for each community evaluated, so the ratio of mean indoor dust concentration to mean outdoor dust concentrations in each community was used as a measure of the mass fraction of outdoor dust.

- **Biokinetic Slope Factor**

The original Bowers model, on which the USEPA ALM model was based, was developed using a biokinetic slope factor of 0.375 μg/dL per μg/day (Bowers and Cohen 1998), compared to the value of 0.4 μg/dL per μg/day that USEPA used as the default BKSF in the ALM model. Because the Bowers adult lead model has been demonstrated to predict blood lead levels accurately using the lower BKSF, the lower biokinetic value of 0.375 μg/dL per μg/day is used in this study.

- **Baseline Blood Level**

The baseline blood lead concentration is intended to represent the best estimate of a reasonable central value of blood concentration in women of child-bearing age that are not exposed to lead-contaminated soil in the study area (AGEISS 1996). The ALM default background geometric mean value of 1.5 μg/dL (for homogeneous populations) is based on studies in the U.S. In the lowland areas of Perú, the baseline blood lead level in women of child-bearing age is estimated to be approximately 6.5 μg/dL based on a study conducted by DIGESA in Lima in 1999 (DIGESA 1999). Baseline blood lead levels in La Oroya are expected to be higher due to the effects of altitude to increase hematocrit, and therefore, the lead carrying capacity of the blood (see Section 5.3).

It would be difficult to reliably determine a baseline blood lead level that is truly independent of effects of the smelter in La Oroya due to the pervasiveness of exposures to

lead from the smelter. In addition, it was necessary to modify the role of the baseline blood lead level in the model for La Oroya to account for the contribution of other site-related sources to lead exposures. While outdoor dust and indoor dust exposures were assessed based on site-specific data, exposures to lead in soil and diet were assessed indirectly by using a higher baseline blood lead level.

Based on the 2005 IIN diet study (see Section 3.2.2 and Appendix C), the mean dietary intake of lead for mothers in La Oroya ranges from 92 to 163 μg/day (Table 3-6). Using the methodology presented at the beginning of Section 4.3.2, a biokinetic slope factor of 0.375 μg/dL per μg/day, and an absorption factor of 8 percent (see discussion below), the mean contribution of dietary lead intake to baseline blood lead level can be estimated to range from 3 to 5 μg/dL.

To account for the contribution to baseline blood lead via soil ingestion, a soil ingestion rate range of 0.02–0.05 g/day was used. This range was determined based on the best fit of the ISE model (see Table 4–10) and professional judgment, as well as the consideration of the default soil ingestion rate recommended by USEPA (2003a). Assuming the biokinetic slope factor and the absorption factor for soil ingestion are the same as for dietary ingestion (i.e., 0.375 μg/dL per μg/day and 8 percent, respectively), the baseline blood lead level contribution from soil ingestion in La Oroya Antigua will be 1–4 μg/dL.

When the contributions from both soil ingestion and dietary intake are combined, the mean increment in the baseline blood level from these sources is predicted to be between 4 and 9 μg/dL. Considering that the baseline blood lead level without the influence of smelter emissions may be as high as 6.5 μg/dL without these site-specific influences, a baseline blood lead level of 9 μg/dL was selected to represent the current conditions, including smelter influence on dietary lead intake and exposures to lead in soil. Future baseline blood lead levels were assumed to be reduced as lead emissions from the Complex are reduced. The baseline blood lead levels used are presented in Table 4-9. The same baseline blood lead concentration was used in all four communities, with reductions predicted to occur in 2007 and 2011 selected based on professional judgment.

- **Soil and Dust Ingestion Rate**

For ALM modeling for this study, the default soil and dust ingestion rate of 0.05 g/day (or 50 mg/day) was used to represent combined ingestion of outdoor dust and indoor dust.

- **Absorption Fraction for Dust**

Based on the ALM model guidance (USEPA 2003b), USEPA assumes that the absorption fraction for soluble lead in water or diet is 0.2, and that lead absorption fraction from soil is 0.12. However, a validated lead pharmacokinetic model developed by O'Flaherty (1993) used an adult lead absorption value of 0.08 (8 percent) for water and diet. This

value more accurately predicts adult lead exposures than the default value selected by USEPA. The absorption of lead from dust is La Oroya is expected to similar to the absorption of lead from diet and water. Therefore, a lead absorption fraction of 0.08 for dust was selected (see Table 4-9).

- **Exposure Frequency**

The default ALM exposure frequency is 250 days/year for indoor workers. Since we are predicting blood lead concentrations for adult residents of La Oroya, exposure frequency was assumed to be 365 days per year. While some residents may spend a week or more away from home during the year, it is assumed that most residents do not have the means to travel away from the area.

- **Geometric Standard Deviation**

The default value for GSD in the ALM model is 2.1. However, USEPA acknowledged that a GSD of 1.8 was calculated among adult women in Leadville, Colorado (USEPA 2003b). USEPA further pointed out that low GSD (1.6-1.8) is consistent with an analysis of blood concentration measured in populations in mining communities (USEPA 1992) in the U.S. and Canada. The lowest values of GSD are expected among homogeneous populations.

This same pattern of higher GSDs in heterogeneous urban populations and lower GSDs in more homogeneous populations is also observed in Perú. Data from the 1999 DIGESA study in Lima yield GSD values of 1.93 and 2.01 for women aged 20-24 years old and 25-29 years old, respectively (DIGESA 1999), and the GSD value for all women of child-bearing age in Lima is 1.81 (see Table 4-11).

In contrast, calculations of GSD from data from the 2000 DIGESA study in La Oroya yielded a GSD value of 1.43 for women 16-35 years old (see Table 4-11). For women 16 years and older in all the communities, the GSD value was 1.44. Since the focus of the ALM modeling is to predict the blood lead concentration in women of childbearing age, a GSD value of 1.43 was selected for this study.

4.3.2.2 Comparison of Modeled Blood Lead Concentrations with Sampling Data

The input parameter values described above were used in the ALM model to predict the distribution of blood lead concentrations for women from each community (Table 4-4). The predicted distributions were compared with blood lead concentration distributions for women between the ages of 16-35 from the study conducted in 2000 (DRP 2001a).

The ALM model results matched well with the sampling data for the geometric mean and 50th percentile for all four communities; however, the model predicted values generally underestimated the 90th percentile values reported in the 2000 study. This

underestimation is likely due to the use of a high baseline blood lead value to represent contributions to blood lead levels from other site-related sources such as soil and diet. Since these other sources will be variable, the use of a point estimate to represent them will reduce the upper percentile values. Nevertheless, the consistency between the geometric means of the modeled results and the blood sampling data supports the use of the model to predict future mean blood levels. Predictions of upper percentile blood lead concentrations should be interpreted more cautiously.

Discussion of the modeling outcomes and the characterization of lead health risks for adults are presented in Section 6.2.3.

4.4 ASSESSING EXPOSURES TO METALS OTHER THAN LEAD

Metals other than lead are evaluated by calculating a daily average dose or intake in mg/kg body weight. Equations and input parameters used to calculate intake of ingested soil and dust, intakes inhaled from the air, and intake ingested from water are described below following a discussion of input parameters that are used in all of the exposure pathways.

4.4.1 Exposure Assumptions for All Pathways

Four parameters have the same values for all of the exposure pathways, including exposure frequency, exposure duration, averaging time and body weight. The selection of the values for these input parameters was based on risk assessment guidance and literature sources. Further explanation of each parameter and values selected to estimate intake are provided below.

4.4.1.1 Exposure Frequency

The exposure frequency exposure parameter represents the number of days per year that someone contacts the air, water, dust, or soil containing the chemicals being evaluated. This value varies for each person depending on the amount of time they spend within the exposure area, La Oroya. Peruvian law requires that employers provide one month of paid vacation per year, however, many residents of La Oroya do not have full-time jobs. Therefore, the CTE exposure frequency value was selected to represent people who leave La Oroya for a portion of their non-working days each year, and the RME exposure value was selected to represent people who stay in La Oroya every day. The exposure frequency for the CTE adult and child scenarios is 335 days per year, assuming 30 days each year are spent outside La Oroya. The exposure frequency for the RME adult and child scenarios is 365 days per year, assuming no time is spent outside of La Oroya.

4.4.1.2 Exposure Duration

The exposure duration parameter represents the total number of years that someone is in contact with the exposure media in La Oroya. Separate values for children and adults were selected for the exposure duration. In accordance with USEPA human health risk assessment guidance (USEPA 1989), exposures to children are evaluated for the first six years of life, after which time exposures are evaluated under the adult scenario. Therefore, the exposure duration for children is 6 years.

In 2001, Doe Run Perú, the Ministry of Health and the National Institute of Statistics and Information published a compilation of socioeconomic information for La Oroya. Doe Run Perú (DRP 2001a) reported that 40 percent of the residents have lived in La Oroya for less than 20 years, 21 percent have lived in La Oroya for 20 to 30 years, 22 percent have lived in La Oroya for 30 to 40 years, and 17 percent have lived in La Oroya for more than 40 years. Discussions with local public health representatives support these statistics, stating that many people move to or leave La Oroya seeking new employment opportunities.

CTE and RME values for the exposure duration parameter were selected to represent the greater portion of the population that live in La Oroya for only a portion of their lifetime and also those people who live their entire lives in La Oroya. The exposure duration for the CTE adult scenario is 30 years, representing approximately 60 percent of the population. The exposure duration for the RME adult scenario is 70 years, representing the life expectancy at birth for Peruvians (PAHO 2001). Subtracting the childhood exposure durations from the full CTE and RME adult exposure durations of 30 years and 70 years results in adult exposure durations of 24 years and 64 years, respectively.

4.4.1.3 Averaging Time

The averaging time is the time period over which an exposure is averaged. The averaging time for evaluating cancer risk is different than for evaluating noncancer health effects. Chemical intakes are averaged over the full 70-year lifetime (25,550 days) when evaluating cancer risk (USEPA 1989). When evaluating noncancer health effects, on the other hand, chemical intakes are averaged over the exposure duration (USEPA 1989). For noncancer health effects, the exposure duration is converted to days and is used as the averaging time. For example, the averaging time for evaluating noncancer health effects in children is six years (2,190 days). The averaging time for evaluating noncancer health effects in adults is 8,760 days and 23,360 days for the CTE and RME scenarios, respectively.

4.4.1.4 Body Weight

Body weight data for La Oroya residents is limited and body weight data for the United States are not likely to be representative of residents of La Oroya. However, body weight information is available for 788 children under the age of 6 years who participated in the recent November 2004 blood sampling event conducted by the Ministry of Health. The mean body weight for these children is 13 kg and will be used to represent the body weight for all children in La Oroya. This value is slightly lower than the reported mean child body weight for the United States of 15 kg (USEPA 1989).

A body weight was calculated for La Oroya adults based on the mean adult body weight reported for the United States of 70 kg (USEPA 1989) because adult body weight data are not available for La Oroya. A body weight value of 63 kg was calculated by multiplying the United States adult body weight (70 kg) by 0.893, the ratio of La Oroya child body weight (13.4 kg) to United States child body weight (15 kg). The 63-kg adult body weight represents both female and male residents.

The calculated body weight of 63 kg for La Oroya is similar to body weights reported by Lawrence et al. (1952) in a physiological study of an Andean population. Lawrence et al. (1952) report a mean adult male body weight of 59.4 kg (range of 52.3 to 75.0 kg) for 14 university students in Lima, Perú and a mean adult body weight of 62.8 kg (range of 54.1 to 68.2 kg) for 15 indigenous men in Morococha, Perú. More recently, Tarazona-Santos et al. (2000) reported a mean adult body weight of 60.0 kg (range of 41.8 to 74 kg) for 77 indigenous men in Huancavelica, Perú. In addition, body weights for 11 females between ages 21 and 46 years are available from a recent dietary study conducted in La Oroya (IIN 2005, Appendix C). The mean female body weight for study participants was 52.2 kg (range of 37.4 kg to 69.1 kg).

4.4.2 Soil and Dust Ingestion Intakes

The equation used to estimate exposure intakes for assessing effects other than cancer ingestion of metals in soil and dust is shown below. The following equation accounts for lifetime exposure, combining both the adult and child exposures into one intake calculation:

$$Intake = \left(\frac{C \times EF \times RAF}{AT \times CF} \right) \times \left(\frac{ED_{child} \times IR_{child}}{BW_{child}} + \frac{\left(ED_{adult} - ED_{child} \right) \times IR_{adult}}{BW_{adult}} \right)$$

Where,

Intake	=	Intake from incidental ingestion of soil and/or dust (mg/kg-day)

C	=	Concentration of metal in soil or dust (mg/kg)
IR	=	Ingestion rate (mg/day)
EF	=	Exposure frequency (day/year)
ED	=	Exposure duration (year)
AT	=	Averaging time (day)
BW	=	Body weight (kg)
CF	=	Units conversion factor (1E+06 mg/kg)
RAF	=	Relative absorption factor (unitless)

Exposure parameter values selected to estimate intake of metals in soil and dust for adult and child residents in La Oroya are presented in Table 4-10. A discussion of each value presented in Table 4-10 also is provided. Intake estimates for dust and soil ingestion are provided in Tables 4-12 to 4-14 for current exposures, and 4-15 to 4-17 for future exposures.

4.4.2.1 Soil/Dust Exposure Point Concentrations

Sampling data were used to estimate exposure point concentrations for current exposures to adult and child residents in the communities of La Oroya Antigua, La Oroya Nueva, Marcavalle, and Chucchis. Analytical results from the March/April and June 2005 field sampling events conducted by Integral were used to estimate current exposure concentrations for soil and dust ingestion exposure pathways. The data for metals other than lead were grouped by community and then evaluated to determine the appropriate statistical distribution using ProUCL (Version 3.0). ProUCL then was used to calculate the upper 95th percentile confidence limit of the mean (UCLM) based on the appropriate statistical distribution (see Appendix B). The lower of either the maximum detected concentration or the UCLM for each metal was selected as the exposure point concentration. The summary statistics, including UCLM, for each metal in indoor dust, outdoor dust, and surface soil were shown previously in Tables 3-11 through 3-13.

Future concentrations of metals in soil and dust in 2011 were predicted based on the changes in deposition of metals calculated from the air modeling study (see Section 3.3). Tables 4-18a-d and 4-19a-d provide expected reductions in arsenic and cadmium deposition and expected reductions in metals concentrations in dust and soil.

It was assumed that the reduction in emissions deposition will result in a direct reduction in metals concentrations in outdoor dust (e.g., 75 percent reduction in emissions depositions for 2011 = 75 percent reduction in outdoor dust concentrations from 2005). However, it was assumed that reduction in metals concentrations in indoor dust and surface soil would not be equivalent to the reduction in emissions depositions. Metals concentrations in indoor dust reflect 80 percent of the reduction in deposition and concentrations in surface soil reflect 30 percent of the reduction in deposition (e.g.,

75 percent reduction in deposition for 2011 = (75 percent x 80 percent) reduction in indoor dust concentrations from 2005, or 68 percent reduction in indoor dust concentrations from 2005). These estimates of reductions in media concentrations are based on professional experience working at other smelter facilities.

4.4.2.2 Soil/Dust Ingestion Rate

Incidental soil ingestion rates for direct exposures to soil and dust vary based on several factors including the following:

- Frequency of an individual's hand-to-mouth behaviors
- Seasonal climate conditions that affect availability of soil and dust (e.g., rainfall)
- Type of groundcover at the exposure location (e.g., grass or pavement vs. bare ground)
- Amount and type of outdoor activity
- Individual personal hygiene practices (e.g., frequency of hand washing, house cleaning, street cleaning).

Of these, the frequency of an individual's hand-to-mouth behaviors is considered a primary determinant of soil intake. Frequent mouthing behaviors typical of early childhood, particularly under the age of six years old, increase the potential for exposure to contaminants in soil and dust. Although fewer studies of adult soil ingestion have been published, hand-to-mouth activities in adults are considered much less frequent than in children. For this reason, risk assessment guidance typically recommends soil ingestion rates that are higher for children than for adults.

The exposure factor values selected to represent the residential child soil / dust ingestion rates were derived from the ISE model during the evaluation of exposures to lead As described in Section 4.3, the child CTE and RME ingestion rates for combined soil and dust is 110 mg/day and 206 mg/day, respectively. Of the 110 mg/day ingested by the CTE child, 20 mg/day are assumed to be surface soil, 36 mg/day are assumed to be indoor dust, and 54 mg/day are assumed to be outdoor dust. For the RME ingestion rate of 206 mg/day, 31 mg/day are assumed to be surface soil, 70 mg/day are assumed to be indoor dust, and 105 mg/day are assumed to be outdoor dust.

USEPA (2002b) recommends 100 mg/day of soil and dust as the best estimate, and 400 mg/day of soil and dust as an upper percentile estimate, of the mean soil ingestion rate for children under 6 years of age. The USEPA values are based on short-term population surveys conducted over 3 to 7 days, and USEPA (1997a, 2002b) notes that they do not represent usual intakes over longer time periods. One of these studies included a pica child, who ate dirt intentionally. Including soil ingestion rates for a pica child causes

overestimation of soil intakes for typical child behaviors (USEPA 1997a). It is possible that some children in La Oroya exhibit pica behavior, which may significantly affect blood lead levels. In a blood lead study in Callao, for example, 12 percent of children participants who were reported by their parents to eat soil also exhibited an excess 3.7 μg/dL of lead in their blood compared to other children in Callao (EHP 1999).

Adult ingestion rates for soil and dust were developed through calibration of the ALM model and professional judgment. The adult CTE ingestion rate for combined soil and dust is 70 mg/day, including a soil ingestion rate of 20 mg/day, outdoor dust ingestion rate of 20 mg/day, and indoor dust ingestion rate of 30 mg/day. The adult RME ingestion rate for combined soil and dust is 110 mg/day, including a soil ingestion rate of 32 mg/day, outdoor dust ingestion rate of 35 mg/day, and indoor dust ingestion rate of 43 mg/day.

Very few quantitative studies have assessed adult soil ingestion rates, and the available data are of limited reliability (USEPA 1997a). In the past, USEPA has recommended RME adult soil ingestion rates of 50 mg/day for industrial settings and 100 mg/day for residential and agricultural scenarios (USEPA 1997a). The Canadian Council of Ministers of the Environment (CCME) (2000), in accordance with CCME protocol, recommends an adult soil ingestion rate of 20 mg/day. Mid-range estimates of adult soil ingestion include 10 mg/day, 65 mg/day (Calabrese et al. 1990), and 6 mg/day (Stanek et al. 1997). High-end estimates of adult soil ingestion include 100 mg/day (Calabrese et al. 1990) and 331 mg/day (Stanek et al. 1997), which are based on a short-term survey not representative of chronic ingestion rates.

4.4.2.3 Relative Absorption Factors

For estimation of non-lead metals intake from soil and dust, the relative absorption factor (RAF, unitless) is an adjustment factor that accounts for the relative absorption of a chemical from the medium of interest (i.e., soil) compared to absorption from the exposure medium in the toxicity study used to derive the toxicity value. It is used for evaluating soil and dust ingestion, because there are typically differences in bioavailability between soil/dust and the dosing formulations used in the toxicity studies (usually water, food, or oil). The absorption of a metal from soil or dust depends on many factors, including species of the metal, soil mineralogy, nutritional status of the population, weathering, and more (Kelley et al. 2002).

Relative absorption varies among metals. In the case of arsenic, oral toxicity values for inorganic arsenic are based on studies of human populations exposed to dissolved arsenic naturally present in drinking water. Arsenic dissolved in water is almost completely absorbed (ATSDR 2000). Arsenic is soil is typically one tenth to one half as bioavailable as arsenic dissolved in water (that is, the RAF would range from 0.1 to 0.5) (Kelley et al.

2002). At a former smelter site in Anaconda, Montana arsenic in soil was reported to have an RAF of 0.20, while indoor dust had an RAF of 0.28 (Freeman et al. 1995).

Absorption of cadmium from water or food is very low, in the range of one to 7 percent (ATSDR 1999a). The relative bioavailability of cadmium in soil from a former zinc smelter site was 33 percent, that is an RAF of 0.33 (Schoof and Freeman 1995). Additional bioavailability studies for cadmium in soil yielded RAFs ranging from 0.2 to 0.9 (Schoof et al. in prep; Schroder et al. 2003). No bioavailability data were available for antimony or thallium.

Based on this review of available bioavailability studies, RAFs of 0.50 and 0.80 were selected for evaluation of arsenic in soil and dust, respectively. RAFs of 1.0 were used for other metals.

4.4.3 Inhalation Intakes

The equation used to estimate exposure intakes for inhalation of particulate matter and sulfur dioxide gas by residents of La Oroya is shown below: The following equation accounts for lifetime exposure, combining both the adult and child exposures into one intake calculation:

$$Intake = \left(\frac{C \times EF \times RAF}{AT \times CF} \right) \times \left(\frac{ED_{child} \times InhR_{child}}{BW_{child}} + \frac{\left(ED_{adult} - ED_{child}\right) \times InhR_{adult}}{BW_{adult}} \right)$$

Where,

Intake	=	Intake of chemicals from inhalation of vapors and particulates (mg/kg-day)
C	=	Concentration of chemical in air (mg/m^3)
InhR	=	Inhalation rate (m^3/day)
EF	=	Exposure frequency (day/year)
ED	=	Exposure duration (year)
AT	=	Averaging time (day)
BW	=	Body weight (kg)
CF	=	Units conversion factor (1E+03 mg/μg)

Exposure parameter values selected to estimate intake of metals in air for adult and child residents in La Oroya are presented in Table 4-10. A discussion of each value presented in Table 4-10 also is provided. Estimates for chemical intake via inhalation are provided in Table 4-20 for current exposures and Table 4-21 for future exposures.

4.4.3.1 Inhalation Exposure Point Concentrations

Exposure point concentrations for inhalation exposure pathways for the current adult and child residents were derived from ambient air monitoring data collected during 2004 and January to April 2005. These data were provided by Doe Run Perú and consist of cadmium and arsenic in PM_{10} samples that were collected once every three days from the Sindicato de Obreros, Hotel Inca, Huanchán, Cushurupampa, and Casaracra monitoring stations. Only those data collected at Sindicato de Obreros, Hotel Inca, and Cushurupampa are used in the human health risk assessment.

Arsenic and cadmium data collected during 2004 and the first quarter of 2005 from the Sindicato de Obreros (representing La Oroya Antigua), Hotel Inca (representing La Oroya Nueva), and Cushurupampa (representing Marcavalle and Chucchis) monitors were used to characterize exposures under current conditions. No air data were available for antimony and thallium. ProUCL was used to calculate the UCLM based on the appropriate statistical distribution for the monitoring data. The lower of either the maximum detected concentration or the UCLM for each metal was selected as the exposure point concentration. The summary statistics, including UCLM, for each metal in ambient air were shown previously in Table 3-10. Summaries of arsenic and cadmium data used in this risk assessment are provided in Appendix A.

Concentrations of arsenic and cadmium in air for the year 2011 were estimated based on the results of the air modeling study (see Section 3.3). The annual average concentrations of arsenic and cadmium in air that were used in this risk assessment are shown in Tables 4-18a-d and 4-19a-d.

4.4.3.2 Inhalation Rate

Exposure to metals or other chemicals in ambient air is a function of the concentration of a particular chemical in ambient air and the amount of air inhaled by an individual (USEPA 1989). The internal dose of chemical that an individual receives from inhaled air also is a function of absorption across the lungs. Once the intake of a chemical is estimated, it is compared to health-protective values, which are based on estimates of a population inhalation rate and absorption.

Populations living at high altitudes (3000 meters and above) exhibit physiological adaptations to the hypoxic (low oxygen) environment (Beall et al. 1997; Chiodi 1957; Frisancho 1969; Lawrence et al. 1952; Tarazona-Santos et al. 2000; de Meer et al. 1995; Mortola et al. 1990). These adaptations include smaller stature, increased lung volume, and increased oxygen absorption efficiency. When compared to various populations living at lower altitudes, the native Quechuas of Perú exhibit increased ventilation that is associated with increased pulmonary tidal volume and increased oxygen delivery due to

an increased pulmonary diffusion capacity (de Meer et al. 1995). There is evidence that the increased pulmonary diffusion capacity of the Quechua highlander population is due to increased size and number of alveoli in the lungs, associated with larger chest and lung volumes (de Meer et al. 1995). In addition, Quechua highlanders have been found to have increased red blood cell mass, resulting in increased blood viscosity (de Meer et al. 1995). These adaptations allow Quechua highlanders to obtain adequate oxygen at high altitudes and to operate more efficiently in their environment.

These adaptations mean that Quechua highlanders have higher inhalation rates than those assumed in the studies of lowlanders. USEPA has compiled several studies of inhalation rates for various U.S. sample populations. Mean resting daily inhalation rates obtained from these studies range from 0.45 – 0.7 m^3/hour for adult U.S. males (USEPA 1997a). In contrast, one study of Aymara highlanders of Bolivia found a mean resting ventilation rate of 0.78 m^3/hour (Beall et al. 1997). Although specific resting ventilation rates for a mixed Peruvian highlander population were not obtained, it is likely that average lung function of a Quechua or highlander Peruvian population is much more similar to the Aymara population than to the average U.S. population, since the Aymara and Quechua populations are similar in other high-altitude adaptations (Beall et al. 1997; Tarazona-Santos et al. 2000).

Because all air concentration data were corrected to represent normal temperature and pressure inhalation rates recommended by USEPA were selected to evaluate exposures via inhalation. USEPA (1997a) recommends daily inhalation rates of 11.3 and 15.2 m^3/day for women and men, respectively. The average of these rates is 13.2 m^3/day. USEPA (1997a) does not provide a high-end recommendation. In guidance for evaluating exposures to combustor emissions, USEPA (1998) recommends a rate of 19.9 m^3/day. Considering the range of values in USEPA guidance, 13 and 20 m^3/day are proposed for the CTE and RME inhalation rates, respectively, for adult residents in La Oroya.

USEPA (1997a) recommends daily inhalation rates of 4.5, 6.8, and 8.3 m^3/day for children less than one, 1-2, and three to five years old, respectively. The weighted average of these values is 7.2 m^3/day. In the combustor emissions guidance, USEPA (1998) recommends a rate of 10.1 m^3/day, based on metabolic rates. Considering the range of values in USEPA guidance, 7 and 10 m^3/hour are proposed for the CTE and RME inhalation rates, respectively, for child residents in La Oroya.

5 TOXICOLOGICAL EVALUATION

The purpose of a toxicity evaluation is to summarize adverse health effects that may be associated with exposure to the chemicals included in this risk assessment and to identify the doses that may be associated with those effects. The dose-response assessment then forms the basis for the identification of toxicity values that may be used to predict the risk of adverse health effects from chemical exposures. Chemicals being evaluated in this risk assessment include inhaled sulfur dioxide and particulates, and lead, arsenic, cadmium, antimony, and thallium.

5.1 OVERVIEW OF TOXICOLOGICAL EVALUATION PROCESS

A toxicological evaluation is conducted by reviewing relevant toxicity information for each chemical from governmental health authorities and in peer-reviewed publications. Toxicity values for carcinogenic and noncarcinogenic health effects have been developed for many chemicals by government agencies, including the U.S. Environmental Protection Agency (USEPA), the U.S. Agency for Toxic Substances and Disease Registry (ATSDR), Health Canada, and the World Health Organization (WHO). These toxicity values are numerical expressions of chemical dose and response, and vary based on factors such as the route of exposure (e.g., oral or inhalation) and duration of exposure.

Duration of exposure is an important factor because the exposure levels that cause toxic effects are usually lower when exposures continue for a longer period of time. For example, with continuous exposure to a chemical for many years (typically referred to as chronic exposures), much lower levels of a chemical could induce toxic effects, compared with levels that would cause toxic effects in a person who is only exposed to a chemical for one day (referred to as an acute exposure). Intermediate duration exposures (referred to as subchronic exposures) would induce toxic effects at intermediate doses.

Oral and inhalation cancer slope factors (CSFs) are upper-bound estimates of the carcinogenic potency of chemicals. CSFs are used to estimate the incremental risk of developing cancer, corresponding to a lifetime of exposure at the levels noted in the exposure assessment. In standard risk assessment procedures, estimates of carcinogenic potency reflect the conservative assumption that no threshold exists for carcinogenic effects, i.e., that any exposure to a carcinogenic chemical will contribute an incremental amount to an individual's overall risk of developing cancer. The slope factor values recommended by USEPA are conservative upper-bound estimates of potential risk. As a result, the "true" cancer risk is unlikely to exceed the estimated risk calculated using the cancer slope factors.

Another component of assessing carcinogenicity of chemicals is a qualitative evaluation of the strength of study data indicating that a chemical may be a human carcinogen. Data obtained from both human and animal studies may be considered to evaluate a chemical's carcinogenicity. Chemicals having adequate human data indicating carcinogencity are categorized as "known human carcinogens" while other chemicals with various levels of supporting data may be classified as "probable human carcinogens" or "possible human carcinogens." If data are inadequate for determining carcinogenicity, the chemical is considered "not classifiable as to human carcinogenicity." The chemical is classified as "Evidence of non-carcinogenicity in humans" when studies provide information that the chemical lacks carcinogenicity (USEPA 2005d).[7]

The potential for noncancer health effects from long duration or chronic exposures (i.e., greater than 7 years) is evaluated by comparing the estimated daily intake with a chronic oral or inhalation reference dose (RfD). These toxicity values represent average daily exposure levels at which no adverse health effects are expected to occur with chronic exposures. Subchronic RfDs are applied when exposures are less than 7 years, as is the case with children (i.e., 0 to 6 years). RfDs reflect the underlying assumption that systemic toxicity occurs as a result of processes that have a threshold. That is, that a safe level of exposure exists and that toxic effects will not be observed until this level has been exceeded.

The RfDs for many noncarcinogenic effects are generally derived based on laboratory animal studies or epidemiological studies in humans. In such studies, the RfD is typically calculated by first identifying the highest concentration or dose that does not cause observable adverse effects (the no-observed-adverse-effect level or NOAEL) in the study subject. If a NOAEL can not be identified from the study, a lowest-observed-adverse-effect Level (LOAEL) may be used. This dose or concentration is then divided by uncertainty factors to calculate a reference dose.

The uncertainty factors are applied to account for limitations of the underlying data and are intended to ensure that the toxicity value calculated based on the data will be unlikely to result in adverse health effects in exposed human populations. For example, an uncertainty factor of 10 is used to account for interspecies differences (if animal studies were used as the basis for the calculation), and another factor of 10 is used to address the potential that human subpopulations such as children or the elderly may have increased sensitivity to the chemical's adverse effects. Thus, variations in the strength of the underlying data are reflected in the uncertainty factors used to calculate the toxicity values and in the low, medium, or high confidence ratings assigned to those values (USEPA 2005d).

[7] The weight of evidence (WOE) categories described in the final *Guidelines for Carcinogen Risk Assessment* (USEPA 2005a) as "standard hazard descriptors" differ from and may eventually supersede those used in IRIS (USEPA 2005b). These descriptors include "carcinogenic to humans," "likely to be carcinogenic to humans," "suggestive evidence of carcinogenic potential," "inadequate information to assess carcinogenic potential," and "not likely to be carcinogenic to humans."

For each chemical evaluated in this risk assessment, the toxicological evaluation was conducted following standard procedures outlined by the USEPA (1989, 2003b) to identify and assess toxicity factors and other relevant toxicity information. Accordingly, the primary source consulted for toxicity values was USEPA's Integrated Risk Information System (IRIS). If toxicity values were not available from IRIS, then USEPA's Provisional Peer Reviewed Toxicity Values (PPRTVs) from the National Center for Environmental Assessment/Superfund Health Risk Technical Support Center (STSC) were consulted. If PPRTVs were not available, toxicity values were obtained from other documented sources, such as California Environmental Protection Agency (Cal EPA), ATSDR, Oak Ridge National Laboratory (ORNL), and USEPA's Health Effects Assessment Summary Tables (HEAST).

The toxicity values selected from these sources for each chemical are summarized in Tables 5-1 and 5-2. The uncertainties and limitations associated with the toxicity values are discussed in the risk characterization section of this report. A summary of key health effects information concerning sulfur dioxide and particulates, lead, arsenic, cadmium, antimony, and thallium is provided below.

5.2 HEALTH EFFECTS OF SULFUR DIOXIDE AND PARTICULATES

The Complex releases large quantities of sulfur dioxide and particulate matter to the air. The toxicity of inhaled sulfur dioxide and particulates will vary depending on the exact composition of the mixture being inhaled. The particulate matter includes metal compounds and may include sulfuric acid droplets. In addition, very small metal oxide particles may be coated with sulfuric acid. The air in La Oroya is also affected by gases and particles released from vehicle exhaust and other combustion sources, and by soil and dust particles resuspended by vehicle traffic, and by windblown soil and dust. Sulfur dioxide released to the air by the smelter can also be converted to sulfate particles over time.

Particulate matter represents a broad mixture of solid and liquid particles suspended in the atmosphere. The suspended material is divided into primary and secondary particles depending on how they were formed. Primary particles exist in the same form released into the atmosphere. Secondary particles are formed by chemical reactions in the atmosphere. Sulfates are a secondary particle in the atmosphere formed by the oxidation of sulfur dioxide. Because sulfates are formed from reactions in the atmosphere, it is difficult to relate ambient concentrations at a location to the original emission sources from which the sulfur dioxide originated.

Much of the recent epidemiological evidence on the health impacts of particulate matter has examined the role of sulfates as a specific component of particulate matter. The air

quality standards for particulate matter described below include consideration of sulfates and sulfuric acid (40 CFR § 50, 1996). Due to the influence of the smelter it is anticipated that particulates in the air of La Oroya will include a high proportion of sulfuric acid and sulfates.

As discussed in Section 3.1.1, the high altitude of La Oroya affects the measurement of gases and particulates. The lower atmospheric pressure in La Oroya relative to sea level values leads to a decrease in the air density. As a result there is less air in a cubic meter at La Oroya than at sea level. Temperature also affects air density with the air expanding and becoming less dense as temperature increases. The monitoring data at La Oroya, reported in units of $\mu g/m^3$, are converted from site temperature and pressure conditions to a standard reference of 1 atmosphere and 0°C. However, the air quality standards discussed in this section were provided in units of $\mu g/m^3$ at normal conditions of 1 atmosphere and 25°C. Because the concentrations are expressed in terms of the mass per volume of air, it is necessary to use the same temperature and pressure conditions to ensure that the volume of air per cubic meter is the same. All concentrations discussed in this section are in units of $\mu g/m^3$ at normal temperature and pressure. Monitoring data from Doe Run Perú have been converted from standard to normal conditions for comparison to the toxicity criteria presented here. Section 3.1.1 provides additional details on the rationale and methodology for this conversion.

The high elevation of La Oroya also affects how people breathe. It has been well documented that native populations living at high altitudes (3000 meters and above) exhibit physiological adaptations to the hypoxic (low oxygen) environment (Beall et al. 1997; Chiodi 1957; Frisancho 1969; Lawrence et al. 1952; Tarazona-Santos et al. 2000; de Meer et al. 1995; Mortola et al. 1990). These adaptations include smaller stature, increased lung volume and increased oxygen absorption efficiency. When compared to various populations living at lower altitudes, the native Quechuas of Perú exhibit increased ventilation that is associated with increased pulmonary tidal volume and increased oxygen delivery associated with increased pulmonary diffusion capacity (de Meer et al. 1995). These adaptations allow Quechua highlanders to obtain adequate oxygen at high altitudes and to operate more efficiently in their environment.

5.2.1 Health Effects of Sulfur Dioxide and Sulfuric Acid

Sulfur dioxide is a colorless gas that has a strong pungent odor. Sulfur dioxide in the atmosphere is converted to sulfuric acid through oxidation. Sulfur dioxide and sulfuric acid both act as lung irritants. Sulfur dioxide is highly soluble and is absorbed in the mucous membranes of the nose and the upper respiratory tract. Sulfuric acid exists as a liquid aerosol or is adsorbed on to the surface of particles. When the particles are very small, this allows sulfuric acid to penetrate deeper into the respiratory tract than sulfur dioxide. The high acidity of sulfuric acid results in greater irritation than sulfur dioxide at

the same concentration. The irritation effect of sulfuric acid is related to the pH and not the sulfate. Therefore, ammonia in the body can neutralize the sulfuric acid and lessen or even stop the effect from occurring.

Exposures to sulfur dioxide can lead to constriction of the airways. This results in difficulty in breathing, wheezing, and tightness in the chest. However, the sensitivity to sulfur dioxide is highly variable, with some individuals unaffected by concentrations that induce severe bronchoconstriction in others (WHO 2000). Studies with human volunteers indicate that most people will experience an irritation effect at sulfur dioxide concentrations of 13,000 $\mu g/m^3$ (Klassen 1996). The effects are reversible and generally will disappear within hours after the exposure ends. Data from studies on human asthmatic volunteers suggests that sulfur dioxide induced bronchoconstriction occurs within 10 minutes and increases minimally or is reduced beyond 10 minutes of exposure (NRC 2004).

Children and adults with asthma have been shown to be more sensitive to the effects of exposures to sulfur dioxide. The USEPA (1994) estimates that people with asthma may be up to 10 times more sensitive to sulfur dioxide than non-asthmatic individuals. For adolescents and the elderly, susceptibility to sulfur dioxide is determined primarily by respiratory health status and not age (ATSDR 1998).

The nature of the sulfur dioxide exposure has an effect on the magnitude of the impact or the concentration needed to induce a response. The penetration of sulfur dioxide into the lungs is greater during mouth breathing. This can increase the airway constriction relative to nose breathing as these regions of the airway have less protection than the nasal passage with its thicker mucus blanket. Studies have shown that exercise can intensify the reaction to sulfur dioxide exposure. Exercising asthmatics are more sensitive; however, the responses to sulfur dioxide are variable among individuals in this group. The USEPA (1994) estimates that approximately 10 to 20 percent of mild to moderate asthmatics exposed to sulfur dioxide at levels of 500 to 1,300 $\mu g/m^3$ during exercise would experience substantial respiratory effects. The most sensitive individuals could likely experience an incapacitating effect. Individuals without asthma who are mouth breathing or exercising are also more susceptible to sulfur dioxide exposures. These activities can lower the concentration required for a response from 13,000 $\mu g/m^3$ to a range of 2,620 $\mu g/m^3$ to 7,860 $\mu g/m^3$ (Klassen 1996). Exposure to sulfur dioxide in cold or dry air can also intensify the respiratory reaction, presumably due to a reduction in airway surface fluids, resulting in decreased absorption of the sulfur dioxide (Graham 1999).

As mentioned earlier sulfuric acid will also cause irritation effects leading to bronchoconstriction when inhaled, but at lower concentrations than required for a similar response from sulfur dioxide. The sulfuric acid enters the respiratory system as a liquid

aerosol or on the surface of particles in the atmosphere. The liquid aerosols can grow in size by absorbing water from the humid respiratory tract. If the particles have already penetrated deep into the lung, this growth in particle size can lead to a longer retention in the respiratory tract as the particles grow too large move back up the small passages in the deeper regions of the respiratory tract. The longer retention increases the time required for recovery after exposure to sulfuric acid aerosols. The deeper regions of the respiratory tract have less mucus protection and a higher density of sensitive areas than the upper airway. Thus as sulfuric acid enters the deeper regions of the respiratory tract the irritation effect can increase relative to exposures in the upper regions like the nasal passage.

The small particles composed of metal oxides released from the Complex can cause the conversion of sulfur dioxide to sulfuric acid. The sulfur dioxide adsorbs onto the surface of these particles and oxidation creates sulfuric acid. Studies have shown that as the size of particles decrease from 7 μm to less than 1 μm less sulfuric acid was needed to induce irritation in the airway (Klassen 1996). With large particles a concentration of 30,000 $\mu g/m^3$ did not cause airway constriction in guinea pigs. In contrast, a concentration of less than 1,000 $\mu g/m^3$ was sufficient to cause airway constriction when adsorbed on particles with a diameter of 0.3 μm. Guinea pigs exhibit sensitivity to sulfur dioxide and sulfates that is similar to asthmatics.

Other aspects of the way a person is exposed to sulfuric acid can influence the magnitude of the response. Breathing through the mouth or at higher rates, as would be the case during exercise, will allow the sulfuric acid to penetrate deeper into the respiratory tract than breathing through the nose at lower activity levels. The deeper penetration brings the sulfuric acid into contact with more sensitive and less protected areas of the airway than in the nasal passage. As a result the adverse effect on the respiratory system is increased relative to nasal breathing at rest. In addition, the effects take less time to start in the deeper regions than in the upper airway.

An extensive review of the scientific literature conducted as part of this risk assessment did not identify studies specifically evaluating the responses to sulfur dioxide for populations living at high altitudes. Increased pulmonary tidal volume in Andean populations could serve to increase the penetration of sulfur dioxide and sulfuric acid into the lung. As discussed above, the deeper penetration could increase the effect compared to exposures in the upper regions of the respiratory tract.

5.2.2 Sulfur Dioxide Health-Based Criteria

Health-based standards for ambient air concentrations of sulfur dioxide have been established by governmental and non-governmental organizations. The criteria established by the Peruvian Government, the WHO, and agencies in the U.S. were

considered relevant for this risk assessment and are presented and discussed below. The discussion is divided into two main sections, acute exposures that last for 24-hours or less and long-term exposures that reflect annual average conditions.

5.2.2.1 Acute Inhalation Exposure Criteria for Sulfur Dioxide

The acute exposure criteria for sulfur dioxide cover exposures ranging from minutes to 24-hours. The Government of Perú (2001) has established a health-based ambient air quality standard of 365 μg/m^3 for an averaging time of 24-hours. This standard is not to be exceeded more than once per year at a location. This is the same air concentration adopted by the USEPA (40 CFR § 50, 1996) as the ambient air quality standard for sulfur dioxide exposures averaged over 24-hours (USEPA 1986a). The USEPA also allows this value to be exceeded once per year at a location. The WHO (2000) recommends a 24-hour guideline air concentration of 115 μg/m^3.

The 24-hour standard established by the USEPA for sulfur dioxide was based on epidemiological studies of mortality and bronchitis in London. Using the London mortality studies and reanalyzes, the USEPA concluded that a significant risk of increased mortality exists for exposures to sulfur dioxide above 500 μg/m^3. The bronchitis study had also suggested a minimum sulfur dioxide air concentration leading to a significant response of 500 μg/m^3 (USEPA 1982). Both the mortality and bronchitis studies represent population groups among the most sensitive to pollutant effects (USEPA 1982). The 24-hour standard was set at 365 μg/m^3 to provide an adequate margin of safety for inhalation effects from sulfur dioxide. In 1996 the USEPA reviewed the 24-hour standard and concluded a revision was not required.

The WHO also used epidemiological studies to establish their 24-hour air quality guideline for sulfur dioxide. However, they only considered studies published after 1985 in an attempt to avoid older studies that assessed the effects of the historical air pollution mixtures that existed when coal combustion was a primary contributor of particulates to urban air (WHO 2000). They concluded that the mortality and morbidity studies did not indicate a consistent threshold for sulfur dioxide. The air quality guideline was set at 115 μg/m^3 after applying an uncertainty factor of two to the lowest observed adverse effect level for sensitive patients who experienced exacerbated symptoms when exposed to sulfur dioxide and particulate matter.

The primary response of acute exposures to low-levels of sulfur dioxide is associated with respiratory effects. These effects generally occur in the first 10 minutes of the exposure and increase minimally or even decrease with continued exposure. To evaluate the potential human health impacts from peak short-term exposures additional criteria were used. The WHO recommends a 10-minute ambient air concentration of 460 μg/m^3. This value is based on studies with exercising asthmatics that indicate some individuals

experience changes in pulmonary function and respiratory symptoms after exposures as short as 10 minutes (WHO 2000).

Another set of acute exposure criteria for sulfur dioxide are available from the National Research Council (NRC 2004) in the United States. The National Research Council establishes acute exposure guideline levels (AEGLs) that represent threshold exposure limits for the general public for chemical exposures ranging from 10 minutes to 8 hours. The AEGLs represent a three-tiered approach that reflects the severity of the response. The level one AEGL is the airborne concentration at which even sensitive individuals would experience only mild and reversible health effects. The level two AEGL is the concentration at which sensitive individuals would experience temporary health effects that would be considered moderate to severe. The level three AEGL is the air concentration above which the general public, including sensitive individuals could experience life-threatening health effects or death.

The AEGLs for sulfur dioxide provide a means to assess the severity of possible health effects when the ambient air concentrations in communities around the Complex exceed the Peruvian and USEPA air quality criteria. Like the ambient air quality standards, the sulfur dioxide AEGLs are developed to protect sensitive individuals from adverse health effects.

The level one and two AEGLs for sulfur dioxide were based on human studies of exercising adults. The level one AEGL value of 524 $\mu g/m^3$ is expected to result in temporary and reversible respiratory effects for asthmatics and have no effect on healthy individuals. The level two AEGL value of 1,965 $\mu g/m^3$ is the threshold for moderate to severe, but reversible, respiratory response in exercising asthmatics. The level one and two AEGL values apply for averaging times from 10 minutes to 8 hours due to the finding that the effects of sulfur dioxide generally occur in the first 10 minutes of the exposure and increase minimally or even decrease with continued exposure.

The level three AEGL value is for life threatening or lethal exposures for averaging times from 10 minutes to 8 hours. The level three values were based on a rat study of lethality (NRC 2004). The threshold was set based on the lethal concentration for 1 percent of the rats exposed to 1,500 mg/m^3 continuously for four hours. An uncertainty factor of 30 was applied to convert from animal to human exposures and account for variability in the study group. For the shortest exposure duration of 10 minutes, a value of 109,000 $\mu g/m^3$ has been established. For a thirty minute averaging time a value of 86,000 $\mu g/m^3$ has been established. The eight-hour air concentration threshold was set at 44,000 $\mu g/m^3$. For comparison, the National Institute of Occupational Safety and Health in the United States has set a threshold sulfur dioxide air concentration of 262,000 $\mu g/m^3$ as immediately dangerous to life and health (NIOSH 2005). This value is more appropriate for healthy workers rather than the general public.

For the risk characterization of inhalation exposures to sulfur dioxide lasting 24-hours or less, the Peruvian 24-hour ambient air quality standard of 365 μg/m^3 for sulfur dioxide will be used. The basis for the standard is the protection of human health for sensitive populations in the general public, and is therefore relevant for the populations evaluated in this risk assessment. The WHO 24-hour air quality guideline value will also be discussed in the risk characterization as a means to address uncertainty in defining the appropriate risk threshold. The AEGL values will be used to evaluate the potential magnitude of health effects when the 24 hour criteria are exceeded. The acute inhalation toxicity criteria selected for use in the risk characterization are summarized in Table 5-1.

5.2.2.2 Chronic Inhalation Exposure Criteria for Sulfur Dioxide

The Peruvian Government (2001) has established an annual average sulfur dioxide ambient air standard of 80 μg/m^3, which represents an arithmetic mean value for the year. This is the same value used by the USEPA (40 CFR § 50, 1996) as the ambient air quality standard for sulfur dioxide. In setting this standard, the USEPA observed that there was little quantitative data useful in developing long-term concentration-response relationships for sulfur dioxide.

The WHO has also developed an annual average guideline value of 46 μg/m^3 for sulfur dioxide (WHO 2000). Like the USEPA, the WHO notes the difficulty in estimating the long-term potential impacts for sulfur dioxide from available studies. Based on studies examining morbidity effects for exposures to sulfur dioxide and particulate matter, WHO judged the lowest-observed-adverse-effect-level to be 92 μg/m^3. An uncertainty factor of two was applied to yield the recommended annual average sulfur dioxide guideline value of 46 μg/m^3.

For the risk characterization of chronic exposures, the annual average standard of 80 μg/m^3 established by the Peruvian government will be compared to annual average air concentration for sulfur dioxide from monitor results and model predictions. The annual average air quality guideline value for sulfur dioxide recommended by the WHO will also be discussed as a means to address uncertainty.

5.2.3 Particulate Matter Health Effects and Criteria

Particles are typically described by their aerodynamic diameter. This is a useful metric as the diameter will dictate the effects of dispersion and removal from the atmosphere and the behavior in the respiratory system after inhalation. Coarse particles are typically defined as having an aerodynamic diameter greater than 2.5 μm, known as $PM_{2.5}$. They are typically generated from mechanical processes such as grinding and crushing or from suspension of dusts and biological material such as pollen or mold. Coarse particles are subject to gravitational effects and typically travel only short distances over a period of

hours. When inhaled, the coarse particles tend to stay in the upper reaches of the respiratory tract. They are most closely associated with aggravation of existing respiratory conditions such as asthma.

Fine particles are typically described as particles with aerodynamic diameters from 0.1 to 2.5 μm. Fine particles are primarily generated from high temperature combustion or smelting processes, vapor condensation or secondary reactions like the formation of sulfates from sulfur dioxide. These fine particles remain suspended in the atmosphere for much longer periods than coarse particles and travel much greater distances from their point of origin. Inhalation exposures to fine particles are associated with morbidity effects such as aggravation of existing respiratory and cardiovascular disease, changes in lung function and premature mortality in sensitive individuals.

Early studies of the health effects of particulates focused on the total suspended particles, which included particles up to 40 μm in diameter. The focus then changed to smaller size fractions that can migrate through the thoracic region of the respiratory system. As discussed earlier, as particles migrate deeper into the respiratory system they tend to have a greater impact on health. This led the USEPA in 1987 to establish a particulate standard based on particles having a mean aerodynamic diameter of 10 μm or less, known as PM_{10}. The PM_{10} standards issued by the USEPA were for 24-hour and annual averaging times (see Table 5-3). These standards were designed to be protective for premature mortality and aggravation of bronchitis (40 CFR § 50, 1987). They are also meant to be protective of exposure to sulfates including sulfuric acid.

In a review of the PM_{10} standard initiated by USEPA in 1994 new studies were found to indicate that the existing standards were not always protective of human health (USEPA 1997b). There was evidence that indicated mortality and morbidity effects in sensitive populations for exposures in areas or times where the existing PM_{10} standard was being met. The increase in relative risk was low for the most serious outcomes, but USEPA acted to protect sensitive individuals. Comparison of health effects between fine (i.e., < 2.5 μm) and coarse (i.e., between 2.5 and 10 μm) particle fractions indicated that the fine fraction was a better indicator for the mortality and morbidity effects seen at air concentrations below the PM_{10} standard.

Thus, the particulate matter standards were revised in 1997 to include a 24-hour and annual average standard for $PM_{2.5}$. The annual average concentration for $PM_{2.5}$ was set at 15 $\mu g/m^3$, which is less than one-third the 50 $\mu g/m^3$ annual average value used for PM_{10}. The 24-hour average concentration for $PM_{2.5}$ was set at 65 $\mu g/m^3$, which is slightly less than half the 150 $\mu g/m^3$ used for the PM_{10} 24-hour standard. The PM_{10} standards already in place were retained as a means to protect against aggravation of asthma and respiratory infection, which were plausibly linked to short and long-term exposures to PM_{10}.

The USEPA is currently conducting a review of the particulate matter standards with the goal of producing a final decision in the latter part of 2006. Analyses conducted to support the review process have upheld the association between fine particles (i.e., $PM_{2.5}$) and mortality from cardiopulmonary diseases and morbidity effects related to the respiratory system (USEPA 2005d). The analysis also cites studies indicating mortality and morbidity health effects below the existing $PM_{2.5}$ 24-hour standard that have led to proposals for lowering the standard to provide increased health protection.

The WHO does not have a recommended air quality guideline for particulate matter in ambient air (WHO 2000). WHO states that the weight-of-evidence points clearly and consistently to associations between concentrations of particulate matter and adverse health effects. The position of the WHO was that these effects are seen at low levels of exposure commonly encountered in developed countries. WHO concluded that the day-to-day variations in particulate matter correlate well with variations in health effects, however, the data are insufficient to identify a concentration without adverse effects. For long-term effects the analysis by WHO concluded that there was greater uncertainty. As a result of the lack of evidence for a no effect level, the WHO has not proposed acute or long-term air quality guidelines for particulate matter.

The particulate matter in the ambient air of communities surrounding the Complex reflects a mixture from a variety of sources both natural and man-made. The particulate matter released from the Complex includes primary metal particles such as lead, arsenic and cadmium, as well as secondary particles such as sulfates. The particulate matter standards established by the USEPA were designed to protect against health effects associated with sulfuric acid and sulfates, which are the primary atmospheric transformation products of sulfur dioxide. Inhalation of $PM_{2.5}$ rich in metals such as copper, zinc, lead and nickel was observed to cause lung inflammation in human volunteers (Ghio and Devlin 2001). This may increase the magnitude of health effects relative to particles that do not cause inflammation. The role of the chemical composition of the particulate matter continues to be a research topic of interest for the USEPA (2004). For now, the particle size and mass continues to be the metric used to relate health effects to ambient air concentrations of particulate matter.

5.2.3.1 Acute Inhalation Exposure Criteria for Particulate Matter

The Peruvian Government (2001) has established a 24-hour average air quality standard for particulate matter of 150 $\mu g/m^3$ for PM_{10}. This standard may be exceeded up to three times per year at a location. This is the same standard currently used by the USEPA (1997b) for PM_{10} concentrations in ambient air. When the USEPA adopted this standard in 1987, it was designed to provide a margin of safety for sensitive individuals. The standard was set at an air concentration value below which there was scientific consensus

that particulate matter would not cause premature mortality and aggravation of bronchitis (40 CFR § 50, 1987). In setting the value, USEPA noted that the 24-hour standard was in the lower portion of the range where sensitive and reversible physiological responses of uncertain health significance are possibly but not definitely observed in children.

As discussed in Section 3.1.1, Doe Run Perú collects PM_{10} using equipment and techniques that conform to requirements of the Peruvian and USEPA PM_{10} standard. The 24-hour PM_{10} standard will be compared to 24-hour average PM_{10} air concentrations observed in the Doe Run Perú monitors. Doe Run Perú does not have a program that would comply with the $PM_{2.5}$ standard established by the USEPA. The PM_{10} monitors will capture this smaller fraction of particles as part of the PM_{10} sampling. However it is not clear what fraction of the Doe Run Perú PM_{10} monitor results would be the fine particles below 2.5 μm in diameter. The potential risk from the fine particle size will be discussed in the Uncertainty Evaluation.

5.2.3.2 Chronic Inhalation Exposure Criteria for Particulate Matter

The Peruvian Government (2001) has established a health-based annual average air quality standard for particulate matter of 50 $\mu g/m^3$ for PM_{10}. This is the same standard established by the USEPA (40 CFR § 50, 1987) for PM_{10} concentrations in ambient air. The Doe Run Perú air monitors have recorded PM_{10} as defined in the air quality standard from 1994 to the present. The annual average PM_{10} air concentration from monitors located in communities near the Complex will be compared to the Peruvian standard.

5.3 LEAD

Lead occurs naturally in the environment as a bluish-gray metal. In its natural form, lead is present in small amounts within the earth's crust. Lead may combine with other chemicals to form lead salts and organic lead compounds. These forms of lead are also present in the environment, largely as a result of human activities. Lead released to the environment may be present in air, soil, water, dust, plants, and animals.

Different forms of lead have different properties, which contribute to how they behave within the environment. For example, metallic lead does not dissolve in water or burn, whereas lead salts may dissolve in water, and some organic lead compounds (e.g., tetraethyl lead used in gasoline) can burn. The size of lead particles, the ease with which lead compounds evaporate, and meteorological conditions will all affect the extent to which lead released to air will move away from the source or be deposited onto the ground or a body of water. Once deposited onto soil, the movement of lead is generally limited but varies with the type of lead salt or compound as well as different soil characteristics. Lead in soil and dust may result not only from air deposition, but also

from erosion of mineral deposits and weathering of lead-containing materials (e.g., lead-based paints) used on buildings or in other materials. Resuspension of lead in windblown soil may also contribute to lead in dust.

Health risks associated with lead exposures are assessed by determining the potential to exceed an absorbed dose of lead, measured as a blood lead concentration, that is associated with increased potential for adverse health effects (CDC 1997, 2002; USEPA 1998). As a result of numerous studies of occupationally exposed groups and the general population, much dose-effect data for lead has been published. In the U.S., the Centers for Disease Control and Prevention (CDC) (1991, 2002) has identified a blood lead level of 10 μg/dL as the concentration above which further evaluation may be warranted for an individual child. The 10-μg/dL blood lead level was selected based on studies indicating that exposures resulting in blood lead levels at or above this concentration may present an increased health risk to children (CDC 1991, 1997, 2002; USEPA 1998).

High altitude populations are expected to have altered blood lead levels in response to lead exposures compared to low altitude populations. As described below, lead in blood is primarily in red blood cells. High altitude populations have more red blood cells as shown by higher hematocrit and hemoglobin values (Ramirez-Cardich et al. 2004; Beall et al. 1998). Thus, high altitude populations may have a lower body burden and less health risk than low altitude populations with similar blood lead levels. Conversely, people with anemia and low hematocrits may have higher body burdens and greater risk than nonanemic people with comparable blood lead levels (CDC 2002). The role of these factors in LaOroya is discussed in the Risk Characterization, Section 6. References to the occurrence of toxic effects at various blood lead levels in the following sections are for low altitude populations. High altitude populations, such as residents of La Oroya, may experience the same effects at blood lead levels 20 percent greater than those listed.

As shown in Figure 5-1, the 10 μg/dL blood lead level of concern is considerably lower than earlier levels selected by the CDC since the 1960s. The trend toward lower blood lead levels of concern over time reflects the continued identification of new information concerning lower doses at which adverse effects related to lead could occur.

Since the 10 μg/dL level was selected, additional studies have been published examining the effects of low levels of lead on children's health. The CDC (2004) reviewed these studies and recently decided to retain the 10-μg/dL blood lead level of concern for three reasons:

- "No effective clinical interventions are known to lower blood lead levels for children with levels less than 10 μg/dL or to reduce the risks for adverse developmental effects.

- Children cannot be accurately classified as having blood lead levels above or below 10 μg/dL because of the inaccuracy inherent in laboratory testing.
- Finally, there is no evidence of a threshold below which adverse effects are not experienced. Thus, any decision to establish a new level of concern would be arbitrary and provide uncertain benefits."

Because children are more susceptible to lead exposures and effects than adults, the CDC's blood lead level of concern in children is also considered health-protective of adults. Specifically, early childhood (ages 0 to 6 years) represents a period of rapid neurological development that is particularly sensitive to critical effects caused by lead exposure (ATSDR 1999b). Children also engage in hand-to-mouth activities more frequently than adults. Such behavior increases their potential for ingestion of lead. In addition, young children also tend to spend more time on ground surfaces where lead deposits are likely to be present. Nursing infants may also be exposed via breast milk from mothers with prior or ongoing lead exposures.

5.3.1 Lead Toxicokinetics

The absorption of lead into the body is influenced by the exposure route, chemical form, and type of exposure medium (e.g., paint, soil, dust). The age and physiological state of the exposed individual (e.g., fasting, nutritional calcium and iron status) also influences lead absorption. Lead absorption occurs primarily within the gastrointestinal and respiratory tracts. Following absorption, lead is widely distributed to blood plasma and soft tissues. Lead is then redistributed in the body by exchanges of lead between blood plasma and bone surfaces, as well as in the kidney and intestines. The exchange of lead between blood and bone results in the accumulation of lead in bone. Lead that is not retained in the body is excreted primarily in the feces and urine. Organic lead, when inhaled, is also excreted in exhaled air. Studies of suckling mice and rats suggest that transfers of as much as one-third of the maternal dose of lead to mother's milk during lactation may occur. Thus, for nursing mothers, lead may also be excreted in breast milk.

Lead accumulated in bone represents a significant potential reservoir of lead within the body. Lead deposited in bone during bone growth and remodeling may be released from bone stores and contribute to blood lead concentrations during bone resorption. Life stages such as pregnancy, menopause, and advanced age, as well as disease states, such as osteoporosis or prolonged periods of immobilization, may result in greater release of lead from bone, increasing lead concentrations in blood.

The exchange of lead between blood plasma and bone surfaces is also influenced by how well lead is absorbed by the gastrointestinal system and how well it is excreted from the body (ATSDR 1999b). In infants and young children, gastrointestinal absorption and excretion efficiencies are higher than in adults (Klaassen 1996). The combination of these

factors with increased bone turnover rates in children results in greater transfers of bone lead to blood in children. Conversely, reduced bone turnover rates in adults results in increased retention of absorbed lead in bone. This accounts for the lower percentage of bone lead to total body burden in children (73 percent) compared with adults (94 percent) (ATSDR 1999b).

Releases of lead from bone that occur after an exposure has stopped may make it difficult to interpret blood lead effects that are observed in different populations with similar blood lead concentrations. This is because the effects observed at current blood lead levels may not account for the level and duration of past exposures to lead. For instance, ATSDR (1999b) reports that some occupational exposure studies have detected a number of neurobehavioral endpoints associated with current blood lead levels between 40 and 80 μg/dL in workers, but that measures of cumulative exposure may better predict impaired performance in workers with current blood lead levels less than 40 μg/dL.

Similarly, lead accumulated in the mother's bone may also be transferred to the fetus during pregnancy and to the newborn via breast milk, even in the absence of recent maternal exposures to lead. Thus, exposure to lead during fetal and newborn development will reflect both past and current lead exposures of the mother.

Because blood lead concentrations may reflect past and recent exposures if the individual's exposure history includes multiple or prolonged exposures to lead over time and from different sources, interpretation of blood lead data must be considered in the context of the individual's past history of exposure.

5.3.2 Lead Health Effects

Proposed mechanisms of lead toxicity are believed to involve fundamental biochemical processes, such as changes in cell membrane cation transport systems and interference with heme biosynthesis. These processes can affect almost every organ and system in the body. The neurological system is particularly sensitive to the effects of lead, especially in young children. The kinds of effects caused by lead are the same at comparable doses whether lead is inhaled or ingested.

Many of lead's health effects may occur without overt signs of toxicity. For instance, effects on heme[8] metabolism such as inhibition of the activity of δ-aminolevulinic acid dehydratase (ALAD), an enzyme involved in heme biosynthesis, can be detected at blood lead levels below 10 μg/dL in all ages. With prolonged exposures to much higher levels, clinically significant effects on heme synthesis may occur. These effects include decreased hemoglobin production and destruction of red blood cells. In occupationally exposed

[8] Heme is the iron-containing component of hemoglobin in red blood cells. Hemoglobin is responsible for carrying oxygen from the lungs to other tissues in the body.

adults, USEPA estimates the threshold blood lead level for a decrease in hemoglobin to be 50 μg/dL. In children, a blood lead threshold of about 40 μg/dL has been suggested for decreased hemoglobin levels (ATSDR 1999b).

Effects on neurobehavioral function such as decreased performance on IQ tests and other measures have been reported at blood lead levels below 10 μg/dL in children (ATSDR 1999; Lanphear et al. 2005; Canfield et al. 2003). However, at levels from 10-15 μg/dL, permanent effects on neurobehavioral performance were not observed in children based on findings of several studies (ATSDR 1999b). Inconsistent findings of effects on fetuses of low-level lead exposures have been reported. However, shortened gestational length and lower birth weights have been reported at maternal blood lead levels lower than 15 μg/dL in some epidemiological studies (ATSDR 1999b). It is noteworthy that these low-level effects of lead are only apparent in studies comparing populations of children with different blood lead levels. These effects would not be detectable in an individual child.

More pronounced effects of exposure to lead may occur in the blood lead range of 15-30 μg/dL. This is particularly apparent in children. For example, cardiovascular effects such as degenerative changes in myocardium and electrocardiogram abnormalities have been reported in studies of children with blood lead levels ranging from 6-20 μg/dL. Anemia (defined as a hematocrit less than 35 percent in populations living at sea level) has also been reported in young children at 25 μg/dL blood lead (ATSDR 1999b).

At blood lead levels exceeding 30 μg/dL in infants and children, kidney changes and growth retardation have been reported in association with exposure to lead (ATSDR 1999b). In the blood lead range of 33-120 μg/dL, impairment of vitamin D metabolism may also occur, particularly in cases of chronically high lead exposures of children who are nutritionally deficient in calcium, phosphorous, and vitamin D. At blood lead levels greater than 30 μg/dL, more overt neurological impairment may also become apparent (ATSDR 1999b).

Reduced sperm count and other effects on the male reproductive system have been observed in adult occupational studies at blood lead levels of 40-50 μg/dL. In adult occupational exposure studies (primarily via inhalation), blood lead levels in the range of 40-60 μg/dL have been associated with neurological symptoms including weakness of extensor muscles and upper limbs, loss of appetite, lower limb numbness and tingling, cognitive impairment, visual-motor coordination effects, and impaired verbal reasoning ability. Some adult worker studies also report colic at blood leads in this range, however, such gastrointestinal effects more typically occur at much higher levels (i.e., 100-200 μg/dL).

In children, ingestion of large amounts of lead may result in colic (60-100 μg/dL); irritability, lethargy, and behavioral problems (60-450 μg/dL); and encephalopathy (>80-800 μg/dL) (ATSDR 1999b).

The range of effects associated with blood lead levels in adults and children are depicted in Figure 5-2.

Dietary insufficiencies may contribute to increased absorption of lead in children. An inverse relationship has been observed between dietary intake of calcium and blood lead concentration in children as well as adults (ATSDR 1999b). A similar relationship has been reported for nutritional status related to iron. Comparisons of blood lead concentrations in iron deficient children with those in iron replete children suggest that such deficiency may result in higher lead absorption or that iron sufficiency may alter lead biokinetics in a way that contributes to lower blood lead levels in iron replete children (ATSDR 1999b).

Some of the mechanisms contributing to lead-calcium and lead-iron interactions in humans have also been suggested for lead interactions with copper, cadmium, magnesium, and zinc (ATSDR 1999b). For instance, some studies suggest that dietary copper may be antagonistic to certain adverse effects of lead (e.g., on the hematopoietic system, growth depression, and tissue hypertrophy) (ATSDR 1999b).

Lead also impairs the activity of zinc-requiring enzymes in the heme biosynthesis pathway. Thus, insufficient levels of zinc in the diet could contribute further to the effects of lead exposure. Conversely, nutritionally adequate dietary intakes of zinc may help to reduce the risks of lead toxicity due to the protection offered by zinc against lead-induced inhibition of zinc-dependent enzymes (ATSDR 1999b).

5.3.3 Lead Carcinogenicity

The USEPA (2005a) has determined that lead is a probable human carcinogen based on sufficient evidence of carcinogenicity in animals. Specifically, bioassays in rats and mice reported statistically significant increases in renal tumors with dietary and subcutaneous exposure to several soluble lead salts. The animal assays provided reproducible results in several laboratories, in multiple rat strains, and with some evidence of multiple tumor sites. Short-term studies indicated that lead affects gene expression. Evidence of lead carcinogenicity in human studies was found to be inadequate. Despite the finding that lead is a probable human carcinogen, USEPA has determined that noncancer effects of lead provide a more sensitive toxicity endpoint than cancer effects, and no toxicity values have been derived for cancer endpoints.

5.4 ARSENIC

Arsenic is a natural element that is widely distributed in much of the earth's crust. Volcanic eruptions have contributed to the ubiquitous nature of arsenic in the environment. Human activities, including mining of ores associated with arsenic (e.g., copper and lead) and burning of arsenic-containing coal and other waste products in coal-fired power plants or for incineration, also contribute to arsenic present in the environment. Arsenic that is present in soil and minerals may enter the air, water, and land from wind-blown dust. Arsenic may also enter water due to leaching or runoff from arsenic in soil.

The predominant forms of inorganic arsenic compounds in soils are trivalent and pentavalent. The solubility of inorganic arsenic compounds in water varies widely. Sodium arsenate and arsenic trioxide represent highly water-soluble forms, while less soluble forms include sulfide minerals, complex oxides, and arsenic present in iron, manganese, and phosphate mineral species. Ionic forms of inorganic arsenic may adsorb (stick to) to soil constituents. The presence of less soluble mineral phases and ionic forms that are strongly adsorbed to soil particles or coprecipitated with other elements in soil are thought to contribute to the reduced bioavailability of arsenic in soil.

For most populations, the primary source of exposure to inorganic arsenic is from the diet, especially drinking water. Globally, drinking water is the main source of excessive arsenic exposure and poisoning, with many Asian populations exposed to concentrations in excess of 100 micrograms per liter (μg/L) in drinking water. Consumption of fish and seafood also represents a significant source of total dietary arsenic intake for many people. However, arsenic in seafood is largely in nontoxic organic forms, such as arsenobetaine.

In addition to typical sources of arsenic exposure in diet and drinking water, individuals may have habits that cause additional exposures. For example, in a Danish study, the mean concentrations of arsenic in white and red wine were 11 and 9 μg/L, respectively, and the mean concentration in beer was 7 μg/L (Pedersen et al. 1994). At these concentrations, a 200-ml glass of wine yields approximately 2 μg arsenic. Thus, a person who routinely drinks wine or beer may have greater than normal dietary intakes.

Arsenic is present in tobacco smoke (inhaled directly or indirectly) so smokers and their families may have increased exposures to arsenic. In a study of employees at a semiconductor fabrication facility, hair arsenic levels were found to be correlated with smoking status and not with occupational exposures to arsenic (de Peyster and Silvers 1995). Chiba and Maseroni (1992) found a positive association between urinary arsenic

levels in children and parental smoking habits. In contrast, a study of people living in a mining area in Germany found no correlation between smoking status and arsenic content in either hair or urine (Gebel et al. 1998). Another German study of lung tissues of deceased people found no difference in arsenic levels between smokers and nonsmokers (Kraus et al. 2000). The amount of arsenic in cigarettes may vary with growing conditions for tobacco crops, and this variability may contribute to the variation in findings of the studies described above.

Arsenic has also been detected in homeopathic medicines (Kerr and Saryan 1986), Chinese proprietary medicines manufactured in Asia (Chan 1994), and leaf samples from medicinal plants (Reddy and Reddy 1997). Cases of acute arsenic poisoning have been found in children and adults using Chinese proprietary medicines (Chan 1994). While rare, these could be sources of excessive exposure in some individuals.

5.4.1 Arsenic Toxicokinetics

Water-soluble forms of inorganic arsenic are almost completely absorbed by both the oral and inhalation routes. For inhalation of arsenic in air, absorption across the lung involves deposition of particulate matter containing arsenic onto the lung, followed by absorption of arsenic from the deposited matter. Absorption of less soluble forms of inorganic arsenic is lower whether ingested or inhaled. Gastrointestinal absorption of inorganic arsenic in soil is also much lower than that of water-soluble arsenic forms (Freeman et al. 1993; Freeman et al. 1995; Groen et al. 1994; Casteel et al. 1997; Rodriguez et al. 1999). Dermal absorption of arsenic is low compared to other routes of exposure (ATSDR 2000).

Following absorption, widespread distribution of arsenic throughout the body occurs. Oxidation of arsenite forms to arsenates and reduction of arsenates to arsenites results in a mixture of arsenite and arsenate forms in the blood. Enzymic methylation of arsenite forms occurring in tissues, primarily in the liver, yields organic arsenic forms, monomethyl arsonic acid (MMA) and dimethyl arsenic acid (DMA). Methylated forms of arsenic do not convert back to inorganic arsenic. The extent to which methylation occurs varies with arsenic species as well as body tissue type. Decreased methylation may result in the retention of arsenic in some tissues. However, most arsenic (as arsenite, arsenate, MMA, and DMA) is rapidly excreted in the urine (i.e., greater than 75 percent of the absorbed dose). To a lesser extent, absorbed arsenic is also eliminated in feces (ATSDR 2000).

5.4.2 Arsenic Health Effects

A summary of primary health effects associated with arsenic exposure is provided below.

5.4.2.1 Acute

Acute exposures to arsenic (0.005 mg/kg-day) causes gastrointestinal symptoms in humans including nausea, vomiting, and diarrhea. These gastrointestinal effects tend to disappear following cessation of such oral or inhaled exposures (ATSDR 2000). At increased doses (8 mg/kg-day), hematemesis, hemoperitoneum, gastrointestinal hemorrhage, and necrosis have been reported (ATSDR 2000).

Evidence of liver toxicity in acute poisoning cases has been reported at doses of 2 mg/kg-day. However, a higher dose (19 mg/kg-day) exposure of an infant did not produce any hepatic effects (ATSDR 2000).

Neurological effects including headache, lethargy, mental confusion, hallucination, seizures, and coma have been reported for acute, high-dose oral exposures to arsenic (2 mg/kg-day or above).

5.4.2.2 Chronic

Long-term exposure to low doses of arsenic (less than 0.01 mg/kg-day) is generally not associated with gastrointestinal symptoms described with acute poisoning. However, the more severe gastrointestinal symptoms associated with acute, high-dose exposures have also been reported for chronic exposures to arsenic used in medicinal preparations at doses of 0.03-0.05 mg/kg-day.

Decreased production of red and white blood cells (anemia and leukopenia) has been reported for chronic oral, but not inhalation exposures to arsenic, at doses as low as 0.05 mg/kg-day. Repeated exposures to arsenic at 0.01-0.1 mg/kg-day has been associated with effects on the liver including swelling, tenderness, and elevation of liver enzymes.

Cough, sputum, rhinorrhea, and sore throat, have been reported in a few studies of people with repeated oral exposure to 0.03–0.05 mg/kg-day. Inhalation of arsenic in dusts may also cause nose, throat, and lung irritation, but is not reported to result in chronic impairment of respiratory functioning in workers exposed to high levels of arsenic in air (NOAEL 0.63 mg/m^3).

Arsenic-induced hypertension has also been reported in various studies (Chen et al. 1995; Rahman et al. 1999; Lee et al. 2003). Specifically, one study in Bangladesh (Rahman et al. 1999) reported as statistically significant increase in risk for hypertension with ingestion of arsenic in drinking water at time-weighted exposure concentrations ranging from <0.5 mg/L to >1.0 mg/L. The association of arsenic exposure in drinking water as a risk factor for diabetes mellitus is also suggested for this range based on an earlier study in Bangladesh (Rahman et al. 1998). More recent studies in Taiwan (Tseng et al. 2000; Wang et al. 2003) provide additional support of this association.

Both acute and chronic exposure to arsenic may also cause abnormal heart rhythms in humans (Glazener et al. 1968; Little et al. 1990; as cited in ATSDR 2000). Arsenic doses of 0.02–0.06 mg/kg-day in drinking water have been associated with increased incidence of Raynaud's disease and of cyanosis of fingers and toes based on studies in Chile (Borgono and Greiber 1972; Zaldivar 1974, 1977; Zaldivar and Guillier 1977, as cited in ATSDR 2000).

Neurological effects associated with oral exposure to arsenic include both peripheral and/or central neuropathy at doses as low as 0.03-0.1 mg/kg-day. These symptoms have also been observed in worker exposures to arsenic in air. An early sign of the peripheral neuropathy is numbness in the hands and feet. With increased exposure, symptoms may progress to a painful sensation of "pins and needles" followed by weakness, loss of reflexes, and wrist-drop or ankle-drop in more advanced cases (ATSDR 2000). Neurological effects may slowly diminish with cessation of exposure although complete recovery is not common (ATSDR 2000).

Characteristic changes in the skin are the primary effect on which USEPA (2005a) has based a chronic oral RfD of 3×10^{-4} mg/kg-day. These skin changes are noted to be the earliest observable sign of chronic arsenic overexposure via ingestion. The changes include thickening of the skin and formation of small "corns" or "warts," particularly on the palms and soles, as well as development of darkened areas of the skin interspersed with light spots.

Based on occupational studies of exposures to arsenic in dusts, direct contact with skin may cause mild irritation and dermatitis symptoms. Dermal contact rates in humans were not reported in these studies, however similar effects have been reported at 4 mg/kg-day in mice exposed for 30 weeks. Such symptoms usually heal without treatment upon cessation of exposure. Similar effects are not reported in studies of dermal exposures to arsenic in water or in soil (ATSDR 2000).

In animal studies, high exposure levels that elicited toxic effects or death in the pregnant female also resulted in reduced birth weights, fetal malformations, and fetal mortality indicating that arsenic is a developmental toxicant. However, as noted by ATSDR (2000), the exposure levels required to cause these fetal effects produced significant maternal toxicity or even death. There was no evidence of developmental effects in more recent animal studies applying exposure levels at which no maternal toxicity was observed (ATSDR 2000). Based on these findings, ATSDR (2000) has concluded: "the developing fetus is not especially susceptible, and teratogenicity or fetotoxicity are unlikely to be of concern except at doses that are also toxic to the pregnant female." Nonetheless, the earlier studies form the basis for an inhalation reference level of 0.03 micrograms per

cubic meter ($\mu g/m^3$) published by California's Office of Environmental Health and Hazard Assessment (OEHHA 2005) for chronic exposure to arsenic in air.

5.4.3 Arsenic Carcinogenicity

The USEPA (2005a) has classified arsenic as a known human carcinogen. This classification is based on increased lung cancer mortality observed in multiple studies of inhalation exposures to arsenic by smelter workers (Enterline and Marsh 1982; Lee-Feldstein 1983; Axelson et al. 1978; Tokudome and Kuratsune 1976; Rencher et al. 1977) and pesticide manufacturing workers (Ott et al. 1974; Mabuchi et al. 1979) in occupational settings. Further support for excess lung cancer risk associated with arsenic inhalation was derived from a single study of residents living near a pesticide manufacturing plant (Matanoski et al. 1981).

Based on some of these studies, USEPA derived a unit risk estimate for arsenic exposure in air of $4.3x10^{-3}$ per $\mu g/m^3$ (USEPA 2005a). The unit cancer risk represents the excess lifetime risk of lung cancer due to a continuous, constant lifetime exposure to one unit of carcinogenic arsenic concentration in air. This unit air risk for arsenic corresponds to an inhalation CSF of 15 per mg/kg-day (USEPA 1995).

For oral exposures, the carcinogenic classification is based largely on increased mortality from multiple internal organ cancers (liver, kidney, lung, and bladder) and an increased incidence of skin cancer in epidemiological studies of Taiwanese populations consuming high levels of arsenic (several hundred micrograms per day) in drinking water (Tseng et al. 1968; Tseng 1977). Based on these studies, USEPA derived an oral cancer slope factor (CSF) of 1.5 per mg/kg-day for arsenic and a drinking water unit risk of 5×10^{-5} L/µg.

Numerous weaknesses have been identified regarding the studies underlying the USEPA CSF and drinking water unit risk values. For example, information contained in the Taiwan studies included arsenic well concentrations in groups (villages) that often vary over a wide range within the same village, as well as over time. Thus, exposure estimates derived from the studies have been criticized as being highly uncertain. Other weaknesses identified include inadequate consideration of differences in genetic, nutritional, cultural, social, economic, and lifestyle characteristics between the Taiwanese study population and populations outside this region.

More recent epidemiology studies in Chile and Argentina are cited in support of findings of the Taiwan studies (Hopenhayn-Rich et al. 1996, 1998; Smith et al. 1998). However, these studies have been similarly criticized as providing inadequate information for estimating the magnitude of risk at specific arsenic concentrations (Brown and Beck 1996).

Conversely, increased incidence of skin cancer is not indicated based on studies of U.S. populations consuming relatively high arsenic concentrations (~0.1-0.2 mg/L) in drinking water (Goldsmith et al. 1972; Harrington et al. 1978; Morton et al. 1976; Southwick et al. 1981). Limitations of these studies include small numbers of exposed individuals.

Furthermore, estimates of incremental cancer risk that are based on linear extrapolation from observed effects at high doses are inaccurate. There is now substantial mode of action evidence that the dose response for induction of cancer by arsenic is nonlinear (e.g., Germolec et al. 1996; Zhao et al. 1997; Shimizu et al. 1998; Barchowsky et al. 1999; Kaltreider et al. 1999; Kirkpatrick et al. 2000; Menzel et al. 2000; Trouba et al. 2000; Andrew et al. 2003; Kitchin and Ahmad 2003). Specifically, arsenic carcinogenesis is postulated to involve indirect, rather than direct, interactions with DNA. Because arsenic would have to be present at a sufficiently high level for a sufficient duration to induce these types of indirect effects, postulated modes of action of arsenic carcinogenesis would be expected to have a non-linear dose-response relationship. In other words, low doses of arsenic are likely to be relatively less effective than higher doses, and may, in fact, be associated with zero risk.

In addition, there is biochemical and cellular evidence that sub-toxic levels of arsenic are protective or induce cellular protective mechanisms (Moore et al. 1993; Lee et al. 1985; Lee et al. 1986; Liu et al. 1994; Wang et al. 1994; Germolec et al. 1996; Barchowsky et al. 1999; Snow et al. 1999; Pott et al. 2000; Romach et al. 2000; Snow et al. 2000; Trouba et al. 2000). Evidence that arsenic can induce cellular protective responses at low doses provides further support that the effects of low doses of arsenic can not be accurately predicted by linear extrapolation from high doses.

5.5 CADMIUM

Cadmium, in pure form, is a soft, silver-white metal. In the environment, cadmium typically occurs as a mineral combined with other elements. Complexes with oxides, sulfides, and carbonates in zinc, lead, and copper ores are most common, while complexes with chlorides and sulfates occur to a lesser extent (ATSDR 1999b; NTP 2005).

Cadmium releases into the environment occur as a result of both natural and human activities. Weathering of cadmium minerals contained in rocks is a significant source of these releases to water in rivers and the ocean. Natural releases to air are contributed by forest fires and volcanoes. Mining activities, burning of fossil fuels and of household wastes, application of fertilizers to crops, and industrial sources may also contribute to cadmium levels in the environment.

The type of cadmium compound influences the solubility of cadmium in water. In general, cadmium chlorides and sulfates are more water soluble than other forms. In soil,

cadmium solubility also varies with form ranging from slightly soluble (sulfides) to moderately soluble (sulfates) to highly soluble (carbonates) (Kelley et al. 2002). In air, cadmium compounds are typically found in or attached to small particles. While the form of cadmium present in the environment may change under different conditions, the cadmium metal itself does not disappear from the environment.

For the general population, exposures to cadmium may occur with consumption of cadmium in food and drinking water, inhalation of cadmium-containing particles in ambient air or cigarette smoke, and ingestion of cadmium in soil or dust. The relative contribution of these sources to cadmium intakes by the general population varies considerably depending upon the smoking status of the exposed individual. For instance, in the U.S., food is the primary source of cadmium exposure to nonsmokers, while tobacco smokers may be exposed to an estimated 1.7 μg of cadmium per cigarette (NTP 2005). Primary food sources of cadmium include grain cereal products, potatoes, and other vegetables. Within the general U.S. population of nonsmoking adults, these food sources are thought to account for the largest contribution of cadmium to total daily intake, which is estimated at approximately 30 μg/day (NTP 2005).

Occupational exposures to cadmium are contributed primarily by the inhalation of dusts and fumes. Other exposure routes include incidental ingestion of cadmium-containing dusts on hands, cigarettes, or food.

5.5.1 Cadmium Toxicokinetics

Absorption of cadmium into the body may occur with oral or inhalation exposures. However, a much greater proportion of inhaled cadmium is retained by the body than when cadmium is ingested. For oral exposures, the source of cadmium intake influences absorption making intake source an important factor in evaluating cadmium toxicity contributed by the diet. In addition, other nutritional factors can increase cadmium absorption. Such factors include deficits in nutritional status related to iron (e.g., anemia), calcium, and protein, as well as increased levels of fat in the diet. With cadmium inhalation, absorption and distribution within the body appears to be affected by the chemical form, particle size of inhaled material, and solubility in biological fluids (ATSDR 1999a).

Long-term exposures to cadmium, ingested or inhaled, may result in accumulation of cadmium in the body to levels that cause adverse effects. Increases in the body burden of cadmium occur due to the chemical's very long biological half-life in the body. Specifically, it takes approximately 30 years for half of the cadmium that is absorbed to be excreted from the body. The portion of cadmium that is retained accumulates to the greatest extent in the renal cortex of kidney.

5.5.2 Cadmium Health Effects

For both the general population and occupationally exposed populations, the kidney is the primary target organ for toxic effects of cadmium. An early sign of kidney impairment is the presence of excessive amounts of protein in the urine ("proteinuria"). In the early stages of cadmium-induced kidney damage, effects on the renal tubules result in decreased reabsorption of filtered low molecular weight proteins. With increased accumulation, due to higher exposure levels or longer exposure durations, more pronounced excretion of higher molecular weight proteins occurs. This type of proteinuria indicates more severe damage to the kidney is occurring. In addition to decreased reabsorption of proteins, glomerular and tubular damage also may result in decreased reabsorption of calcium, glucose, amino acids, enzymes, phosphorous, and copper and disruption of vitamin D metabolism (ATSDR 1999a).

USEPA has derived an oral RfD for cadmium based on the concentration of cadmium in the human renal cortex (200 μg cadmium/gram wet human renal cortex) that is not associated with significant proteinuria (USEPA 2005a). USEPA applied toxicokinetic modeling to determine the daily cadmium intake in food or water over a 50-year time period that would result in this level. For cadmium intake in food and water, USEPA determined a NOAEL of 0.005 and 0.01 mg/kg-day, respectively. The assumed absorption of cadmium from food and water, was 2.5 and 5 percent, respectively. Applying an uncertainty factor to account for inter-individual variability, USEPA calculated an oral RfD for cadmium in food of 0.0005 mg/kg-day and in water of 0.001.

5.5.2.1 Inhalation

In addition to renal health effects, lung function is affected by exposure to respirable cadmium. Based on both human and animal studies involving acute exposures to cadmium, destruction of lung epithelial cells with subsequent pulmonary edema, tracheobronchitis, and pneumonitis has been reported at concentrations above 5 mg/m^3 (ATSDR 1999a). Decreased lung function, emphysema, and damage to olfactory function have been associated with longer-term exposure to lower concentrations. Based on information provided in some human and animal studies, development of tolerance to cadmium-induced lung irritation and recovery of respiratory function following exposure cessation may occur (ATSDR 1999a).

In a study by Cortona et al. (1992, as cited in ATSDR 1999a) that controlled for smoking, factory workers exposed over a period of several years to cadmium fumes at concentrations of 0.008-l.53 mg/m^3 revealed no significant differences in Forced Expiratory Volume (FEV), Forced Vital Capacity (FVC), Transfer Factor by the carbon monoxide method (TLCO), and Transfer Coefficient (KCO) relative to measurements in unexposed individuals.

The ATSDR (1999a) notes that ending exposure to cadmium does not necessarily decrease proteinuria as noted in workers who experienced continued kidney damage following an inhalation exposure to cadmium. ATSDR (1999a) reports that Roels et al. (1997) examined the reversibility of kidney damage in a worker population with varying body burdens of cadmium. For workers with mild proteinuria, kidney damage (e.g., tubule dysfunction) showed signs of reversibility. However, workers with greater body burdens and more severe cases of proteinuria showed continued tubule dysfunction after ending exposure to cadmium.

5.5.2.2 Ingestion

Oral exposure to high levels of cadmium has been shown to irritate the gastrointestinal epithelium in both human and animal studies. Nausea, vomiting, salivation, diarrhea, cramps, and abdominal pain are reported in children exposed via ingestion of cadmium in beverages and food at doses of about 70 μg/kg (ATSDR 1999).

Chronic oral exposure to cadmium in individuals with low iron intake may contribute to anemia, a finding supported by animal studies (ATSDR 1999a).

Cadmium-induced interference with metabolism of vitamin D in the kidney is thought to result in imbalances in calcium absorption and excretion. Increased calcium excretion secondary to cadmium-induced renal damage is suggested as a risk factor for osteoporosis, particularly in post-menopausal women. Some subchronic- and chronic-duration animal exposure studies are supportive of skeletal effects related to cadmium exposure. Specifically, studies in rats report decreased bone calcium and increased urinary calcium excretion with exposure in the 2-8 mg cadmium/kg-day range (ATSDR 1999a). Such findings are supportive of the association between cadmium exposure and painful bone disorders (e.g., osteomalacia) and spontaneous bone fractures (e.g., "Itai-Itai" disease) that have been reported for populations in cadmium contaminated areas of Japan (ATSDR 1999a). Such associations must, however, be considered in light of contributory risk factors for bone changes, such as nutritional calcium deficiencies, age at exposure (bone turnover rates), and multiple rounds of gestation and lactation.

Cessation of oral cadmium exposures does not result in decreases in proteinuria. Further, the severity of effects on renal tubular dysfunction and reduced glomerular filtration have been reported to increase after environmental exposures have ceased (ATSDR 1999a).

Little information is available regarding the reproductive, developmental, and genototoxic effects of inhaled and ingested cadmium in humans. Based on studies in animals, however, neurobehavioral effects appear to be the most sensitive indicator of developmental toxicity. For example, in a study of the offspring of female rats orally

exposed to cadmium at a dose of 0.04 mg/kg-day before and during gestation, decreased locomotor activity was reported (ATSDR 1999a).

The toxicity of cadmium is influenced by the nutritional status of the exposed individual. As mentioned previously, low levels of dietary iron, zinc, calcium, vitamin D, and protein result in increased absorption of cadmium. Increased cadmium absorption then may contribute to decreased absorption or metabolism of calcium and vitamin D, amplifying the effects of cadmium exposures on the skeletal system. The implications of this are magnified when considering other environmental exposures contributing to osteoporosis, such as alcohol and lead.

Numerous studies have demonstrated an antagonistic relationship between the intake of cadmium and zinc. Intake of sufficient quantities of zinc is protective of health effects, such as proteinuria, caused by exposure to cadmium. A potential mechanism for this effect is zinc's ability to induce metallothionein, which in turn binds cadmium. The interactions between cadmium and zinc are particularly important to consider for smelter sites because zinc is typically emitted in high levels from lead and zinc smelters that also emit cadmium. Magnesium also is reported to induce metallothionein synthesis, which may contribute to decreased cadmium toxicity (ATSDR 1999a).

5.5.3 Cadmium Carcinogenicity

Human and animal studies do not indicate that oral exposure to cadmium is associated with increased cancer rates (ATSDR 1999a; USEPA 2005b).

Increased incidence of lung cancers have been reported in occupationally-exposed populations with inhalation exposures to cadmium including workers from various manufacturing or processing facilities involving cadmium in England, Sweden, and the U.S. However, findings reported are confounded in these studies by various factors such as the presence of other metals in the exposure media and cigarette smoking behavior within the study population. The ATSDR (1999a) reports that these studies are not supportive of an association between inhalation exposure to cadmium and lung cancer.

In contrast, with regard to the U.S. cohort studied, the USEPA (2005b) concluded that investigators adequately controlled for confounding factors (co-exposure to other metals; cigarette smoking) in studies of workers exposed to cadmium dusts. Based on the findings of this study, as well as limited findings of cadmium carcinogenicity in humans reported in other similar studies and supporting animal studies, the USEPA classified cadmium as a probable human carcinogen via inhalation exposure. Information from the U.S. cohort studied provides the basis for USEPA's derivation of an inhalation unit risk, 1.8E-03 $m^3/\mu g$ for lifetime exposure cadmium (USEPA 2005b). This unit air risk for cadmium corresponds to an inhalation CSF of 6.3 per mg/kg-day.

USEPA's assessment of cadmium carcinogenicity is supported by laboratory studies involving chronic inhalation exposures of rats to cadmium dusts and fumes. Increased lung nodules and tumors were observed with increased dose in rats exposed for 18 months in two separate studies. However, tumor incidence was not observed in controlled studies involving mice and hamsters (ATSDR 1999a). More recently, cadmium exposure in rats has been shown to cause tumors in the pituitary gland (DHHS 2005).

The U.S. National Toxicology Program (DHHS 2005) has also concluded that cadmium and cadmium compounds are carcinogenic in their recent *Report on Carcinogens*, citing follow-up epidemiological studies that show a positive relationship between exposure to cadmium and lung cancer. In addition, the NIOSH has classified cadmium as a human carcinogen via the inhalation exposure route due to increased risk of lung and prostate cancer (NIOSH 2000).

5.6 ANTIMONY

Antimony is a metal naturally found in the earth's crust in small amounts. It occurs naturally as uncombined metals, oxides, or in combination with sulfur, lead, copper and silver (Elinder and Friberg 1986). Antimony enters the environment during mining and processing of its ores, as well as in the production of antimony metal, alloys, antimony oxide and combinations of antimony with other substances. Antimony in the environment can be present in air, soil, water, dust, plants and animals.

Most antimony in the environment will collect in the soil or sediment, where it attaches strongly to particles that contain iron, manganese, or aluminum (ATSDR 1992a). Antimony metal does not exist in significant amounts as an airborne particulate in the environment. It is quickly transformed into antimony oxides if it becomes airborne. (Newton et al. 1994). In water, dissolved antimony is found mostly as hydroxides in the trivalent and pentavalent states. (Mok and Wai 1990).

5.6.1 Antimony Toxicokinetics

The absorption of antimony into the body depends on the exposure route, chemical species, and type of exposure medium (e.g., soil, dust, air). Particle size, solubility, as well as the age and diet of the exposed individual also affect antimony absorption. Limited quantitative information regarding absorption of antimony suggests that less than 10 percent of ingested antimony is absorbed. Background exposures to antimony occur through intake of food, drinking water, and air. Absorption of antimony takes place primarily through the gastrointestinal and respiratory tracts, and is distributed mostly to the liver, lungs, intestines, and spleen. Antimony is mostly excreted in the urine and feces (ATSDR 1992a).

A study of antimony distribution in pregnant mice after oral exposure shows that while pregnancy results in a higher antimony body burden, transport across the placenta appears limited. Exposure of mice to antimony during lactation results in high antimony levels in newborns, suggesting that for nursing mothers, antimony may also be excreted in breast milk (ATSDR 1992a).

5.6.2 Antimony Health Effects

As with other metals, the toxic effects of antimony are related to its chemical form. For example, the acute toxicity of pentavalent antimony compounds is much less than that of the trivalent compounds. The mechanism of toxicity of antimony compounds is not well-understood. It is thought to be related to the high affinity of the metal for sulfhydryl groups, which could affect the structure and function of proteins (de Wolff 1995).

The chemical and toxicity characteristics of antimony resemble those of arsenic. Both elements are often found together as environmental contaminants, resulting in exposure of populations to both at the same time. Trivalent antimony has been shown to alter the genotoxicity of trivalent arsenic in an *in vitro* study (DeBoeck et al. 2003), which suggests an impact of antimony co-exposure on arsenic genotoxicity and carcinogenicity in humans. Studies showing inhaled antimony compounds causing lung tumors in both rodents and smelter workers have been reported. However, both in experimental systems and in workers, simultaneous exposure to other carcinogenic compounds, such as arsenic, cannot be ruled out.

The primary effects seen in a lifetime low-level antimony toxicity study in rats were decreased lifespan, decreased blood glucose and altered serum cholesterol levels. These effects were observed by Schroeder et al. (1970), who exposed rats to 5 ppm (i.e., 5 mg/L) potassium antimony tartrate, a trivalent antimony compound, in water, equivalent to 0.35 mg/kg-day. In 1991, USEPA selected this dose as the basis for their oral reference dose, applying an uncertainty factor of 1,000 to account for intraspecies differences, exposure of sensitive subpopulations, and conversion of the LOAEL to a NOAEL. Confidence in the resulting RfD of 0.0004 mg/kg-day is rated as low due to limitations in the supporting study and toxicity database (USEPA 2005a). In addition, potassium antimony tartrate is soluble in water, which makes the antimony relatively more bioavailable and more toxic than the undissolved antimony compounds in environmental exposure media such as soil and dust.

In a subchronic (13-week dose length) toxicity study in rats given 0.5-500 ppm potassium antimony tartrate in drinking water (equivalent to approximately 0.06-46 mg/kg-day), Poon et al. (1998) observed decreased blood glucose in female rats, hematologic effects, increased liver enzyme activity, and mild adaptive histological changes in several tissues.

In a 1999 provisional assessment, USEPA's National Center for Environmental Assessment selected this dose as the basis for their oral reference dose, and released a revised subchronic RfD of 0.0002 mg/kg-day (USEPA 2002a).

The primary effects seen in a subchronic (13 week dose length, 0-23.46 mg/m^3) antimony trioxide inhalation study in rats were corneal irregularities, cataracts, and microscopic changes in the lungs consistent with interstitial inflammation, granulomatous inflammation/granulomas and fibrosis (Newton et al. 1994). The primary effects of the chronic portion of this study (12 months, 0-4.5 mg/m^3 antimony trioxide) were cataracts and microscopic changes in the lungs consistent with interstitial inflammation, granulomatous inflammation/granulomas and fibrosis. No evidence of antimony trioxide carcinogenicity was seen. Based on this study, the National Center for Environmental Assessment developed a provisional subchronic inhalation reference concentration (RfC) for antimony of 0.0004 mg/m^3 in 1999 (USEPA 2002a).

Toxic effects of antimony compounds in humans above the RfD or RfC have been seen in two main populations: patients treated with antimonial antileishmaniasis agents and workers occupationally exposed to dusts and fumes containing antimony. Antimony poisoning affects several organ systems and symptoms include myocarditis, liver necrosis, nephritis, thrombocytopenia and pancreatitis. Reported side effects of sodium stibogluconate used to treat leishmaniasis include renal tubular acidosis, thrombocytopenia, and pancreatitis (deWolff 1995).

Studies of workers exposed to antimony trioxide via inhalation report a variety of respiratory ailments. Investigators concluded the health effects were largely due to the lung's physiological response to the accumulation of dust, inflammation and irritation. Respiratory effects of exposure include bronchospasm, airway obstruction, chronic bronchitis, chronic emphysema, and pleural adhesion (ATSDR 1992a). Workers with pneumoconiosis (inflammation and irritation of the lung) exhibited symptoms such as wheezing and coughing (ATSDR 1992a).

Respiratory effects similar to those reported for workers exposed to airborne antimony trioxide also have been observed in animal studies. As with humans, macrophage proliferation is a typical inflammation response to accumulation of dust in the lungs of laboratory animals. With continued exposure, macrophage proliferation is thought to contribute to development of fibrosis of the lung. In some cases, the inflammatory response continues after exposure has ceased (ATSDR 1992a). For example, rats exposed to 70 μg/m^3 antimony trioxide for one year showed continued macrophage production one year after exposures were halted (ATSDR 1992a). Interstitial fibrosis and lipoid pneumonia were reported in rats following one year of exposure to 1.6 to 83.6 mg/m^3 antimony trisulfide or antimony trioxide (ATSDR 1992a).

Workers exhibited increased blood pressure following inhalation of antimony, but these effects were not seen following oral exposures. In one study, exposure to 2.15 mg/m^3 antimony trisulfide for periods less than two years resulted in both increased blood pressure and altered EKG readings (ATSDR 1992a). Intravenous injection of trivalent antimony in humans to treat parasitic disease resulted in altered EKG readings, which returned to normal six weeks following exposure. Similar effects were seen in rats, rabbits, and dogs exposed to antimony trioxide via inhalation.

Reports of gastrointestinal illness in workers have not been confirmed to be a direct result of inhalation exposure to antimony. However, accidental poisoning via ingestion of lemonade containing antimony (approximately 530 μg per 70-kg male) caused workers to vomit (ATSDR 1992a).

In an early study of women factory workers, increased incidence of spontaneous abortion and altered menstrual cycles were reported following inhalation exposure to antimony trioxide, antimony pentasulfide, and metallic antimony (ATSDR 1992a). However, uncertainties associated with the study diminish confidence in the significance of these effects.

Airborne antimony trioxide was found to cause dermatitis upon mixing with sweat and penetrating the skin via the sweat glands in adults working in high temperature environments. Skin irritation and rash in exposed workers cleared 3 to 14 days following the exposure (ATSDR 1992a).

5.6.3 Antimony Carcinogenicity

Antimony trioxide has been reported as an animal carcinogen (Watt 1983; Groth et al. 1986), and based on the available research is classified as carcinogenic in laboratory animals (IARC 1989). There is limited evidence for carcinogenicity of antimony trisulfide in laboratory animals (IARC 1989). USEPA concluded based on the existing data that antimony compounds are not classifiable for cancer effects in humans (ATSDR 1992a). The International Agency for Research on Cancer (IARC) classifies antimony trioxide as possibly carcinogenic to humans and antimony trisulfide as not classifiable as to its carcinogenicity in humans. The existing human carcinogenicity studies of antimony compounds, such as epidemiological studies of art glass industry workers exposed to powdered antimony and a mortality study of workers in an antimony smelter plant, are difficult to evaluate given the frequency of co-exposure to arsenic and the existence of other co-exposures and confounders (DeBoeck et al. 2003).

5.7 THALLIUM

Pure thallium is a soft, bluish-white metal that is widely distributed in trace amounts in the earth's crust. It occurs naturally in the pure form or mixed with other metals in the form of alloys. It can also be found in the form of salts of bromine, chlorine, fluorine and iodine. Thallium is very stable in the environment, and is neither transformed nor biodegraded (ATSDR 1992b).

Thallium exists in two states, monovalent and trivalent. The monovalent state is more stable, and therefore is more common and likely to be present in the environment. Thallium is present in air, water, and soil (ATSDR 1992b). One way it gets into the environment is through discharge into the air from smelting operations. It then binds to soil and sediments, which can result in human exposure when the soil is inhaled, ingested or touched by people. Consumption of agricultural products grown in thallium-contaminated soil may be a significant route of exposure, because thallium can be taken up by plants via their roots. Very little data exist concerning how much thallium is in specific foods grown or eaten. Compounds of thallium are generally soluble in water. (ATSDR 1992b).

One primary source of human thallium exposure unrelated to industrial processes may be via cigarette smoking. People who smoke cigarettes have been shown to excrete about twice as much thallium in their urine as nonsmokers (ATSDR 1992b).

5.7.1 Thallium Toxicokinetics

The absorption of thallium compounds into the body depends on the exposure route, chemical species, and type of exposure medium (e.g., soil, dust, air). Particle size, solubility, as well as the age and diet of the exposed individual also affect antimony absorption.

In humans and animals it is thought that nearly 100 percent of ingested thallium is absorbed and distributed throughout the body. Quantitative information regarding absorption and distribution of thallium following inhalation exposures is not available. Once ingested, thallium rapidly distributes to various parts of the body, concentrating in the kidneys and liver. It is cleared from the body slowly, mostly in urine and a smaller amount in feces (ATSDR 1992b).

In a mouse study, thallium injected as thallous sulfate was shown to cross the placenta and reach the fetus. The concentration of thallium in the fetus was substantially lower than that in maternal tissues (ATSDR 1992b).

5.7.2 Thallium Health Effects

Thallium is reported to elicit adverse health effects with inhalation and oral exposures (USEPA 2005b). The toxic effects of thallium are related to its chemical form. The mechanism by which thallium exerts its toxic effects is not clear. Studies in animals suggest that toxicity may be attributable in part to the depletion or inhibition of critical enzyme systems (ATSDR 1992b).

ATSDR (1992b) suggests that neurological effects may be a primary effect following exposure to thallium, however dose-response data are not available for that effect. As the basis for its oral RfD, in 1986 USEPA (1986b) used a 90-day sub-chronic study in which rats were exposed to various concentrations of thallium sulfate. While the study found apparent dose-related increases in hair loss, tear-shedding and protrusion of eyeballs, as well as moderate dose-related changes in several blood chemistry parameters, these were not considered adverse effects. Therefore, the highest dose from the study, 0.25 mg/kg-day, was considered a NOAEL. An uncertainty factor of 3,000 was applied to the NOAEL to account for the sub-chronic study duration, intraspecies differences, sensitive subpopulations, and a lack of chronic and reproductive data, resulting in an RfD of 0.00008 mg/kg-day. USEPA's confidence in the RfD is rated as low due to low confidence in the toxicity database and supporting toxicity study (USEPA 2005b).

After conducting a screening-level literature review in 2002 to look for new relevant studies, EPA determined there was no need to update the RfD for thallium sulfate.

Toxic effects of thallium compounds in humans above the reference dose have been seen in two main populations: workers in industries producing or using thallium-containing materials and metal smelter workers (ATSDR 1992b). Oral exposure to high doses of thallium in humans (54 to 110 mg/kg) was reported to elicit adverse effects in the respiratory, gastrointestinal, and cardiovascular systems as well as the kidney and liver, although information regarding these effects is very limited (ATSDR 1992b). High and intermediate dose oral exposures to thallium are also reported to elicit neurological effects, including cranial and peripheral neuropathy (ATSDR 1992b). Examination of the peripheral nerves in fatal human poisoning cases revealed axonal degeneration. Gastrointestinal illness was also reported in a population of Chinese who consumed thallium-contaminated cabbage for a period of 17 years (ATSDR 1992b). Health effects in the exposed population included gastroenteritis, diarrhea or constipation, vomiting, and abdominal pain.

Hair loss was reported in humans after thallium ingestion (ATSDR 1992b). Hair loss has included body, scalp, and beard hair but the loss was temporary. Exposure of rats to 1.8 mg/kg-day thallium resulted in hair loss due to atrophy of hair follicles and decrease in size of sebaceous glands (ATSDR 1992b).

Workers in cement production who were exposed to airborne thallium for up to 44 years exhibited neurological damage, including paresthesia, numbness of the digits, and muscle cramps (ATSDR 1992b). Limitations of the study, such as pre-existing illness and lack of a control study population, contribute to uncertainty regarding the significance of these findings. No other reports of health effects following inhalation exposures were encountered.

5.7.3 Thallium Carcinogenicity

USEPA has determined that thallium is not classifiable as to human carcinogenicity due to a lack of human and animal carcinogenicity data (USEPA 2005b). No studies were found on whether thallium can cause cancer in humans or animals.

5.8 HEALTH EFFECTS OF MIXTURES

The toxicity assessment generally presents the toxic effects of exposure to individual chemicals. However, residents at most sites have exposures to mixtures chemicals. This is certainly true in La Oroya, where people are exposed to mixtures of metals. The nature of interactions that may occur from exposures to mixtures may result in increases or decreases in the health risks. The possibility of interactions among chemicals is greatest when chemicals in the mixture have the same kind of health effects. For example, both lead and cadmium may affect bone density. Other examples relevant to La Oroya is the fact that lead, cadmium and arsenic may all cause anemia, and that both lead and arsenic may contribute to increased risk of hypertension.

Sometimes the effects of multiple chemicals are simply additive, that is the total health risk may be estimated by adding the predicted risk for the two chemicals. In other cases, the actual health risks may be greater than the sum of expected effects of the two chemicals. Sometimes, health risks are reduced if one chemical interferes with the effects of another chemical. A recent review by Borgert et al. (2004) provides a good description of the mechanisms by which such interactions may occur and the finding that the occurrence of interactions depends on the level of exposures. Borgert et al. (2004) also describe critical issues in assessing health effects of mixtures and summarize U.S. guidance on risk assessment for mixtures (ATSDR 2001a and 2001b; USEPA 1988, 1989, 1999, 2000a, 2000b, 2001).

6 RISK CHARACTERIZATION

Health risks may be characterized in different ways. In this risk assessment sulfur dioxide and particulate exposures were evaluated by comparing exposure point concentrations to health-based air quality standards and guidelines. For lead predicted blood lead levels for children and adults were compared to acceptable blood lead levels established by health and regulatory agencies. For metals other than lead, quantitative estimates of exposure and toxicity were combined to yield numerical estimates of potential health risk. A discussion of the approaches used to characterize risks for each of the chemicals included in this risk assessment is provided in the following sections. The results of the risk characterization process are also provided, followed by a qualitative evaluation of uncertainties associated with the risk estimates and interpretation.

6.1 SULFUR DIOXIDE AND PARTICULATE MATTER HEALTH RISKS

The risk characterization for sulfur dioxide evaluated health risks from inhalation exposures for both current concentrations and concentrations predicted for the future after implementation of emissions control projects. The risk characterization for particulates evaluated only current health risks because future reductions in air concentrations for particulates were not available. The basis for current exposures was the ambient air monitoring data collected for the year 2004.

The Peruvian ambient air quality standards were used in the risk characterization. These standards are expressed as $\mu g/m^3$ in terms of normal temperature and pressure (i.e., 1 atmosphere and 25^o C). The monitoring data from Doe Run Perú was provided to Integral as $\mu g/m^3$ in terms of standard temperature and pressure (i.e., 1 atmosphere and 0^oC). For the risk characterization, all monitoring data from Doe Run Perú was multiplied by a factor of 0.92 for conversion to normal temperature and pressure prior to comparing to the Peruvian standards. In addition, all other air concentrations and health-based air quality criteria discussed in this section are expressed in terms of normal temperature and pressure. Section 3.1.1 provides more details on the rationale for this scaling procedure.

As discussed in Section 4.2, three air monitors operated by Doe Run Perú were used in the analysis of current conditions. Figure 4-1 shows the location of the communities evaluated in this risk assessment and the nearest Doe Run Perú monitors. Monitors selected to represent current conditions for each community evaluated were those closest to that community. Thus, the Sindicato monitor was used to represent exposures in the La Oroya Antigua community. The Hotel Inca monitor was used to represent exposures in the La Oroya Nueva community. The Cushurupampa monitor results were used to evaluate exposures for the Marcavalle community. No air monitor was sufficiently close enough to establish current exposures for the Chucchis community, which is located

south of Marcavalle along the Yauli River. A discussion of how the conditions at the selected monitoring locations relates to expected conditions in the communities is provided in Section 4.2.1.

6.1.1 Sulfur Dioxide Risk Characterization

As discussed in Section 5.2**,** the potential risks from inhalation of sulfur dioxide were evaluated by comparison of current and predicted ambient air concentrations with the annual average and 24-hour air quality standards established by the Peruvian Government. As noted in Table 6-1, the Peruvian annual average standard is 80 μg/m^{3}and the Peruvian 24-hour standard is 365 μg/m^3. These standards are equivalent to ambient air quality standards established by USEPA for sulfur dioxide.

The potential impacts from exposures to short-term peak concentrations of sulfur dioxide in ambient air were also evaluated by comparisons to acute exposure guideline levels (AEGLs) developed by the U.S. National Academy of Sciences (NAS). These values represent threshold exposure limits designed to protect the general public from emergency exposure periods ranging from 10 minutes to eight hours.

The following discussion presents details of the risk characterization for annual average and 24-hour exposure periods followed by the evaluation of exposures for acute exposures lasting less than 24 hours.

6.1.1.1 Current Annual Average Sulfur Dioxide Concentrations

Annual average sulfur dioxide concentrations were calculated based on 2004 monitoring data for the three air monitoring stations and compared to the Peruvian health-based standard to evaluate long-term health risks from inhalation exposures to sulfur dioxide under current conditions. The annual average concentrations at all three monitors exceed the annual average ambient air quality standard established by the Government of Perú for sulfur dioxide. The Hotel Inca monitor had the highest sulfur dioxide annual average concentration of 492 μg/m^3. This value is six times higher than the corresponding Peruvian standard. The Sindicato monitor had the next highest annual average sulfur dioxide concentration at 423 μg/m^3. This value is approximately five times greater than the Peruvian standard. Finally, the Cushurupampa monitor had the lowest annual average sulfur dioxide concentration at 384 μg/m^3. This value is nearly five times greater than the Peruvian standard.

As discussed in Section 5.2, there is little quantitative evidence that can be used to assess the long-term concentration-response relationship for sulfur dioxide. Therefore, it is difficult to determine the health consequences of chronic exposures to the elevated sulfur dioxide concentrations in La Oroya. All of the annual average monitoring values for 2004 were below 500 μg/m^3, a value identified as a threshold for increased mortality and

bronchitis by USEPA (1982). However, this threshold was noted for exposures on the order of 24 hours. Elevated sulfur dioxide concentrations combined with the particulate emissions from the Complex are likely to have an adverse impact on lung function for residents in the neighboring communities. This impact will likely be greater for people with existing respiratory conditions such as asthma.

6.1.1.2 Current 24-Hour Sulfur Dioxide Concentrations

Information on the daily average sulfur dioxide concentration during 2004 was compiled for each monitor. The values for each day of the year were compared to the 24-hour health-based standard established by the Government of Perú. This comparison allowed for a better understanding of the magnitude and frequency with which health-based standards were exceeded at each monitor in 2004. The evaluation was used to evaluate the potential for adverse health effects within each community studied.

Figure 6-1 shows the number of times each month the 24-hour concentration at each of the three monitors exceeded the Peruvian 24-hour standard of 365 $\mu g/m^3$ for sulfur dioxide. As shown in this figure, the standard was exceeded at each monitor during some portion of every month in 2004. At the Sindicato station, the standard was exceeded on 201 days during the year. At Hotel Inca, the standard was exceeded on 196 days during the year and at Cushurupampa, the standard was exceeded on 167 days.

At the Sindicato monitor, the highest 24-hour sulfur dioxide concentration in 2004 was 1,371 $\mu g/m^3$. This value is almost four times higher than the Peruvian 24-hour standard for sulfur dioxide (365 $\mu g/m^3$). The month with the least number of days exceeding the standard was August of 2004. Typically this month would be among the worst in the year for dispersion conditions which should result in some of the highest sulfur dioxide concentrations for the year. As discussed in Section 4.2.2, the Complex has initiated the intermittent control strategy that curtails operations that produce sulfur dioxide emissions during early morning hours. This strategy is used on days when dispersion will be at a minimum due to meteorological conditions. The use of this program may explain why August 2004 had so few exceedances of the 24-hour sulfur dioxide standard.

A more detailed view of the 24-hour sulfur dioxide concentrations at the Sindicato monitor is provided in Figure 6-2. This figure shows the daily sulfur dioxide concentration at the Sindicato monitor for each day in 2004. A dashed line on the figure indicates the concentration for the 24-hour Peruvian standard. The standard is exceeded consistently throughout the year. It is clear from this figure that the standard is exceeded less frequently during the winter months of June, July and August. However, this portion of the year has some of the highest daily concentrations

As noted in Figure 6-1, at the Hotel Inca station, the winter months of June, July, and August have the least number of days with exceedances of the 24-hour standard. This trend is similar to what is observed for the Sindicato monitor. Again this may be due to the intermittent control strategy used at the Complex during winter months. Figure 6-3 presents a more detailed view of the 24-hour sulfur dioxide concentrations at the Hotel Inca monitor. This figure shows the daily average sulfur dioxide concentrations at the monitor for 2004. The highest daily concentration occurs during the winter months, even though the frequency of exceeding the 24-hour standard decreases. The months of October, November and December had the greatest number of exceedances and some of the highest daily concentrations.

The Hotel Inca and Sindicato monitors had a similar number of days in excess of the 24-hour Peruvian standard; however the Hotel Inca monitor had the highest exceedances. The Sindicato monitor never had a daily average concentration in excess of 1,500 $\mu g/m^3$ while the Hotel Inca monitor detected 8 days above 1,500 $\mu g/m^3$. The significantly higher impacts at Hotel Inca relative to the Sindicato monitor is unexpected given that the Sindicato monitor is located much closer to the Complex. As discussed in Section 4.2.2, sulfur dioxide concentrations observed at the Hotel Inca monitor appear to have been unusually high in 2004. The Sindicato monitor experienced greater 24-hour sulfur dioxide concentrations than Hotel Inca for the years 2002 and 2003. It is not possible to tell if this is an anomaly or a new trend based on the current monitoring data available.

As shown in Figure 6-1, analysis of the Cushurupampa monitor results indicates, once again, the lowest number of days with exceedances came during the winter months. Figure 6-4 shows the daily average concentration at the Cushurupampa monitor for 2004 with a dashed line for the Peruvian 24-hour standard. The winter months have fewer exceedances of the standard, but still show some of the highest 24-hour average concentrations seen for the year, as was the case for the other two monitors. Again, this may indicate that the intermittent control strategy is reducing the number of exceedances during the winter months when dispersion is at a minimum in the region. Clearly, the Cushurupampa monitor is the least impacted of the three monitors based on the frequency and magnitude of the exceedances of the 24-hour standard (Figures 6-1 and 6-4).

The significant number of days in excess of the Peruvian 24-hour standard at all three monitors indicates the potential for increased respiratory problems in La Oroya due to sulfur dioxide concentrations in air. All of the monitors detected sulfur dioxide concentrations above 500 $\mu g/m^3$, the threshold USEPA identified for increased mortality and morbidity effects. However, the exact nature of the adverse health impacts is difficult to determine. Evaluation is further complicated because inhalation exposures to elevated sulfur dioxide concentrations are typically part of a mixture with particulates and other

chemicals also at levels that could cause adverse health effects. This is the case with sulfur dioxide exposures in La Oroya.

Studies of inhaled sulfur dioxide exposures have identified associations between exposures and morbidity (other than pulmonary irritation) and mortality effects, but not causal links. Based on the irritant nature of the sulfur dioxide, it can be expected that respiratory constriction will occur with exposure, especially for sensitive individuals such as asthmatics. The conversion of sulfur dioxide to sulfates, especially sulfuric acid will exacerbate the irritation effects that individuals could experience. The irritation of the respiratory system associated with the sulfur dioxide and sulfuric acid exposures are observed to be temporary and will cease after the air concentrations fall to levels below which such effects occur. Because of the lack of causal links and dose-response data, the potential for excess mortality associated with the current sulfur dioxide exposures at La Oroya could not be determined.

6.1.1.3 Current Hourly Sulfur Dioxide Concentrations

An analysis of the hourly concentrations at the monitors was conducted to gain additional insights into the potential severity of human health impacts from sulfur dioxide exposures. There are no Peruvian ambient air quality standards for sulfur dioxide at averaging times less than 24-hours. As discussed in Section 5.2, the AEGLs developed by the NAS represent threshold exposure limits for three levels of severity of health effects.

The AEGL-1 and AEGL-2 values are the same for all exposure times evaluated (ranging from 10 minutes to 8 hours). The AEGL-1 value of 524 $\mu g/m^3$ is based on the threshold at which exercising asthmatics develop temporary and mild respiratory effects. The AEGL-2 value of 1,965 $\mu g/m^3$ is the threshold at which exercising asthmatics experience temporary moderate to severe respiratory effects. Exercising asthmatics are expected to have more severe reactions to sulfur dioxide and sulfuric acid exposures than other people. These levels are not expected to have an effect on healthy individuals. The AEGL-3 values vary with exposure times (ranging from 10 minutes to 8 hours), and are protective for life threatening effects.

AEGL-1 Comparison:
The Sindicato, Hotel Inca, and Cushurupampa monitor data for 2004 all contain significant numbers of hours in excess of the AEGL-1 values. Figure 6-5 shows the number of hours for each day of the year when the hourly concentrations exceeded the AEGL-1 at the Sindicato monitor. Figures 6-6 and 6-7 show the same information for the Hotel Inca and Cushurupampa monitors, respectively. During 2004, the Hotel Inca monitor had the greatest number of hours exceeding the AEGL-1 (1,765 hours), followed by the Sindicato monitor with a total of 1,533 hours exceeding the AEGL-1. The air monitoring results from the Cushurupampa site included slightly lower impacts with a

total 1,340 hours above the AEGl-1 value. Once again, Hotel Inca was the most impacted location. Comparison of these figures reveals that the Hotel Inca monitor had the maximum number of hours in a given day above the AEGL-1 and a higher frequency of days with more than 12 hours above the AEGL-1.

The AEGL-1 value was exceeded during all seasons of the year for all three monitoring sites. The winter months once again show a decrease in the number of days with exceedances. This is consistent with the trend seen in the comparison of the daily average concentrations to the Peruvian 24-hour standard. The winter months do have some of the highest impact days in terms of the number of hours in excess of the AEGL-1 concentration. During the months of October, November and December the Hotel Inca and Sindicato monitors experienced more frequent and prolonged exceedances of the threshold than at any other time in the year (Figures 6-5 and 6-6).

As discussed earlier in Section 4.2.2, the sulfur dioxide ambient air concentrations tend to build during the morning, peak in the mid to late morning, and then decrease substantially during the afternoon and evenings. This pattern is clearly observed in Figures 6-8 (Sindicato), 6-9 (Hotel Inca), and 6-10 (Cushurupampa), which show the time of day when hourly monitor concentrations exceeded the AEGL-1 value during 2004. For all three monitors threshold exceedances occur at all times of the day but are most common between the hours of 9 am to 1 pm (represented as hours 9 to 13 in the figures).

AEGL-2 Comparison:
The comparison of the hourly sulfur dioxide results for 2004 versus the AEGL-2 value showed similar results as seen for the AEGL-1. Figure 6-11 shows the number of hours per day when the hourly monitor concentrations were above the AEGL-2 concentrations. Figures 6-12 and 6-13 show the same information for the Hotel Inca and Cushurupampa monitors, respectively. The results show that the Hotel Inca monitor experienced the greatest impacts during the year. The Sindicato monitor never had a day with more than six hours above the AEGL-2, and there were only two such days at Cushurupampa, while there were more than 15 such days at Hotel Inca. In total there were 714 hours above the AEGL-2 at the Hotel Inca monitor, 614 at the Sindicato monitor and a total of 400 hours at the Cushurupampa monitor. The AEGL-2 was exceeded throughout the year, however, the winter months show lower impacts in terms of the number of days with exceedances and the number of hours per day in excess of the AEGL-2 threshold.

The daily pattern of exceedances seen for the AEGL-1 comparison described previously was even more evident for the AEGL-2 comparison as shown in Figures 6-14 (Sindicato), 6-15 (Hotel Inca), and 6-16 (Cushurupampa). For all three monitoring sites the peak exceedances occur during the hours from 9am to 1pm (hours 9 to 13).

The exceedances of the AEGL-1 and AEGL-2 values indicate a potential for short-term respiratory health effects. The AEGL-1 and 2 values are designed to protect the most sensitive individuals from adverse health effects (i.e., exercising asthmatics). Thus, it is likely that the AEGL-1 and 2 values are protective of the majority of the population in La Oroya. However, the frequency and magnitude of the exceedances of the AEGL-1 and 2 values indicates that all individuals would likely experience temporary respiratory irritation. The daily pattern of sulfur dioxide concentrations indicates that these effects would occur during the mid-morning and early afternoon periods.

The three monitors used to establish the current conditions were unable to detect sulfur dioxide concentrations at levels greater than 6,000 $\mu g/m^3$. The presence of this threshold means that some of the elevated hourly average concentrations from these monitors may be underestimated. Doe Run Perú does operate one sulfur dioxide monitor, identified as Sindicato 2, which does not have this upper threshold. A limited set of data was available for this monitor. Sulfur dioxide data for Sindicato 2 with 15-minute averaging times provides a good indication of the variability in the 1-hour average concentrations from the standard monitors. The highest 15-minute average air concentration of 33,501 $\mu g/m^3$ occurred at 10:15 am local on March 12, 2005. Figure 6-17 shows that the sulfur dioxide concentrations on this day followed the typical pattern of concentrations rapidly building to a peak at mid-morning and then dropping significantly.

On March 12th there were 20 observations or approximately five hours when the sulfur dioxide concentration was in excess of the AEGL-2 value. These short-term peaks indicate a potential for moderate to severe respiratory problems for sensitive individuals. Individuals without preexisting respiratory conditions like asthma would also experience mild to moderate respiratory irritation based on the 13,000 $\mu g/m^3$ threshold for the general population discussed in Section 5.2. Strenuous activities such as exercise would increase the likelihood of respiratory irritation for all individuals. All of the observations for this day were above the AEGL-1 value indicating a potential for mild respiratory impacts in more sensitive individuals. In all cases, the health effects are expected to be temporary and would end soon after sulfur dioxide levels decreased below the guideline value.

AEGL-3 Comparisons:
The sulfur dioxide monitor values from Sindicato 2 for the maximum impact day of March 12th were also compared to the AEGL–3 values designed to be a threshold to protect the general population from lethal or life threatening effects. AEGL- 3 values have been established for 10 minute and 30 minute averaging times, but not the 15-minute averaging time used for the Sindicato 2 monitor results. The comparison to the 10 minute average is most relevant as it more closely matches the 15 minute averaging time of the Sindicato 2. Figure 6-18 shows a comparison of the 15 minute average concentrations at Sindicato 2 for March 12, 2005 along with the 10 minute AEGL-3 value of 109,000 $\mu g/m^3$

and the 30 minute AEGL-3 value of 86,000 μg/m^3. The highest 15 minute average sulfur dioxide concentration at Sindicato 2 of 33,501 μg/m^3 was approximately 31 percent of the 10 minute AEGL-3 value.

A maximum 30 minute average concentration for the Sindicato 2 monitor was calculated using the 15 minute averages for 10:00 am (25,133 μg/m^3 at the National Toxicology Program [NTP]) and 10:15 am (33,501 μg/m^3 at NTP), which represents the second highest and highest values for the day, respectively. The calculated 30 minute average of 29,317 μg/m^3 is approximately one-third the AEGL-3 value for 30 minutes.

Comparison to AEGL-3 values shows that lethal or life threatening effects are not likely based on the acute exposures to sulfur dioxide released from the Complex. It is expected that data from the Sindicato monitors represent some of the highest or highest impacts in the La Oroya area. The 2004 results do show that in some instance greater impacts were seen at the Hotel Inca monitor. However, it is very unlikely that the short-term concentrations anywhere in the area would exceed the AEGL-3 values.

In summary, for the year 2004 the sulfur dioxide ambient air concentrations at the three monitors exceeded health-based values throughout the year. As discussed in Section 5.2, it is not clear what the long-term implications on human health would be for exposures to elevated sulfur dioxide concentrations. The short-term exposures to concentrations in excess of the acute exposure guideline values would result in temporary respiratory effects such as wheezing, tightness of the chest, and coughing. The results from the unlimited sulfur dioxide monitor indicates that concentrations would be sufficient to induce respiratory effects, but are well below the levels at which lethal or life threatening effects could occur.

6.1.1.4 Future Sulfur Dioxide Health Risks

Risk characterization for future exposures was based on predicted emissions reductions to be achieved in 2007 and 2011 (see Section 3.3 and Appendix D). As described in Section 3.3, the CALPUFF air dispersion model was used to predict the percent reductions in sulfur dioxide air concentrations in the communities due to decreases in emissions at the Complex. The main stack at the Complex is the primary source of sulfur dioxide emissions. The remainder of the sulfur dioxide emissions is released as fugitive emissions that come from vents, open buildings and other uncontrolled sources.

In the year 2007 the sulfur dioxide stack emissions were projected to decrease by 25 percent compared to baseline conditions. By the year 2011 the stack emissions are projected to decrease by approximately 84 percent compared to baseline conditions. The fugitive emission rates of sulfur dioxide at the Complex are unchanged by the proposed programs until the year 2011. In the year 2011 the fugitive emission rate of sulfur dioxide

from the Complex decreases by almost 68 percent. We understand that Doe Run Perú is developing plans to construct some of the sulfur dioxide reduction equipment by 2008, but those plans are not considered in this risk assessment. Doe Run Perú estimates that by the end of 2008, equipment installed in the lead circuit will reduce the sulfur dioxide about 30 percent from the 2007 levels.

The reduced sulfur dioxide emission rates were used in the CALPUFF air dispersion model to predict the percent reduction in sulfur dioxide air concentrations in the years 2007 and 2011 relative to current conditions. The percent reductions were then used to scale the current conditions, indicated by the 2004 monitoring results, to evaluate the health impacts for reduced sulfur dioxide emissions in the years 2007 and 2011.

The model results can be used to reliably indicate the change in air concentrations from emission reductions, and the relative impact of point versus fugitive sources. The model does reproduce the pattern of elevated concentrations during the morning and early afternoon hours that was seen in the monitoring data for 2004. A comparison of the model predictions to monitoring data for 2002 showed that while the model was in good agreement overall, there were areas of over- and under-prediction of the actual conditions. Therefore, the model results cannot be used to predict the air concentration at a particular location and hour of the day with a high degree of accuracy.

Due to uncertainty in the emissions estimates and meteorological conditions, predicted 1-hour results are highly uncertain. The currently available site emissions and meteorological data are not adequate to support more accurate modeling for time intervals shorter than 24 hours. Therefore, modeling results will not be used to evaluate inhalation risks for periods less than 24-hours and potential future risks will be discussed qualitatively.

Based on the estimated sulfur dioxide emission reductions for the years 2007 and 2011, the CALPUFF air dispersion model was used to predict the reductions in air concentrations in each of the four communities evaluated in this risk assessment. The CALPUFF model did not include the effects of wet deposition, which would remove the highly soluble sulfur dioxide from the atmosphere during rain events. Not including wet deposition in the modeling will tend to overestimate the sulfur dioxide air concentrations.

Based on comparisons with monitoring data for Cushurupampa, the CALPUFF results for La Oroya Nueva, Marcavalle and Chucchis are over-predictions of sulfur dioxide concentrations for these communities. The reasons for this over-prediction are likely due in part to the inability to accurately characterize the inversion conditions in the area with the meteorological data available. The results for the La Oroya Antigua area are considered to be realistic.

The air model predicted results at many locations within each of the communities. The highest and lowest values within a community were averaged to provide an estimate of the typical sulfur dioxide air concentrations in each community. The average concentrations for 2007 and 2011 were compared to the baseline modeling to provide an estimate of the percent reduction. The model predicted percent reductions were then used to scale the 2004 monitoring results discussed earlier to provide an indication of future impacts. The annual average and 24-hour results were used for this analysis. The second highest 24-hour average predictions by the model were used to conform to the Peruvian 24-hour standard for sulfur dioxide which allows for one exceedance of the standard per year.

Table 6-1 provides a summary of the 24-hour and annual sulfur dioxide percent reductions for emissions reductions in 2007 and 2011. The table also includes the 24-hour and annual average health-based standards established by the government of Perú. All concentrations have been converted to normal temperature and pressure conditions (i.e., NTP). For each of the four communities, the sulfur dioxide impacts are predicted to decrease over time. The reduction in 2007compared to current conditions ranges from 7 to 22 percent. In 2011, the reductions range from approximately 70 to 82 percent.

The reductions in sulfur dioxide emissions appear to have the greatest impact in Chucchis and Marcavalle. However, these are also the areas where the model accuracy is expected to be lower as discussed earlier. In 2007, a 25 percent reduction in sulfur dioxide stack emissions yields a reduction of approximately 20 percent in the air concentration. This reduction is seen for both the 24-hour and annual average concentrations. In the communities of La Oroya Neueva and La Oroya Antigua, the year 2007 reductions in sulfur dioxide emissions have a smaller impact on the air concentrations. These communities are closer to the Complex where fugitive emissions provide a much greater contribution to the air concentrations predicted by the CALPUFF model. Despite these reductions, sulfur dioxide concentrations are predicted to remain above the annual average and 24-hour average ambient air quality standards in 2007.

The predicted reductions in sulfur dioxide concentrations in 2007 are in the range of 20 percent for both the 24-hour and annual average for Marcavalle and Chucchis. As a result, it is likely that the number of days in excess of the 24-hour standard and the number of hours in excess of the acute exposure guideline values will decrease in both locations. However there will still be a substantial number of exceedances throughout the year at all locations. The impacts are expected to be associated with elevated short-term sulfur dioxide air concentrations that typically occur in mid-morning and early afternoon periods. The most obvious health impacts will be temporary respiratory effects with a greater potential for such adverse health impacts in sensitive individuals such as asthmatics and children. Increased activity levels from exercise or strenuous labor could

increase the potential for adverse health effects from exposures to elevated sulfur dioxide air concentrations.

The reductions in the fugitive emissions estimated for 2011 have a significant impact in all four communities. Predicted percent reductions in sulfur dioxide concentrations range from 70 percent in La Oroya Antigua to 82 percent in Chucchis. The air concentrations in Marcavalle are likely to be at or below the Peruvian health-based standards for sulfur dioxide in 2011. This will also be the case in Chucchis. Few if any exceedances of the 24-hour standard are expected in 2011. Without better model predictions of hourly sulfur dioxide ambient air concentrations, it is not possible to say definitively if there would be exceedances of the AEGL-1 or AEGL- 2 values. It is possible to say that the frequency and magnitude of exceedances will decrease. As a result, individuals will experience far fewer episodes of respiratory discomfort.

The ambient sulfur dioxide air concentrations in La Oroya Nueva and La Oroya Antigua are predicted to be markedly reduced, but will still exceed the 24-hour and annual average standards in 2011. The significant reductions predicted by the CALPUFF model for these two areas would results in far fewer days in excess of the 24-hour standard and the AEGL-1 and 2 values. The impacts are expected to be associated with elevated short-term sulfur dioxide air concentrations that typically occur in mid-morning and early afternoon periods. The most obvious health impacts will be temporary respiratory effects with a greater potential for such adverse health impacts in sensitive individuals such as asthmatics and children. Increased activity levels from exercise or strenuous labor could increase the potential for adverse health effects from exposures to elevated sulfur dioxide air concentrations.

6.1.2 Particulate Matter Risk Characterization

Particulate matter concentrations were provided by Doe Run Perú for five stations in the area of the Complex. The monitors are designed to collect particulate matter with a diameter less than or equal to 10 microns, known as PM_{10}. Particles in this size range and smaller have been associated with adverse effects on human health. The Complex is likely to be a significant source of the airborne particulate detected by these monitors. Other significant sources in the area would include vehicle exhaust and dust introduced into air from traffic. As discussed in Section 5.2, the emissions from the Complex will include a number of other air toxics together with particulate matter that have been associated with adverse health effects. The toxicity of the particulate matter will vary depending on the nature of the mixture, including the particle sizes found in the mixture.

PM_{10} data were used for the Sindicato, Hotel Inca and Cushurupampa monitoring locations. These monitor locations were used to represent the communities of La Oroya Antigua (Sindicato monitor), La Oroya Nueva (Hotel Inca monitor) and Marcavalle

(Cushurupampa monitor). The hourly results for these monitors were provided by Doe Run Perú in the form of hourly concentrations in $\mu g/m^3$ at standard temperature and pressure. The potential impact from inhalation of PM_{10} was determined from a comparison with the health-based ambient air quality standards established by the Peruvian Government. Two PM_{10} standards were available: a 24-hour standard of 150 $\mu g/m^3$, not to be exceeded more than three times per year and an annual average of 50 $\mu g/m^3$. As was the case for sulfur dioxide, the PM_{10} monitoring results were converted to normal temperature and pressure for comparison to the Peruvian standards.

As expected, the highest 24-hour and annual average PM_{10} concentrations were detected at the Sindicato monitor and the lowest concentrations were at the Cushurupampa monitor. For the Sindicato monitor, the annual average concentration of 93 $\mu g/m^3$ was approximately twice the air quality standard. There were five 24-hour average concentrations at the Sindicato monitor that exceeded the 24-hour standard, which is two more exceedances than allowed for compliance with the standard. The highest 24-hour PM_{10} air concentration at Sindicato of 214 $\mu g/m^3$ was approximately 43 percent higher than the standard. The remaining exceedances ranged from 3 percent to 15 percent greater than the 24-hour standard of 150 $\mu g/m^3$.

For the Hotel Inca monitor the PM_{10} annual average concentration was approximately 70 $\mu g/m^3$. This value is 40 percent higher than the annual average standard. There were four days in the year when the 24-hour standard was exceeded at the Hotel Inca monitor, which is one more day of exceedances than allowed for the 24-hour standard. The magnitude of the exceedances of the 24-hour standard ranged from 2 percent to 13 percent for the year 2004.

At the Cushurupampa monitor the annual average PM_{10} concentration of 60 $\mu g/m^3$. This value is approximately 20 percent higher than the standard. Only one 24-hour PM_{10} air concentration exceeded the Peruvian standard. This indicates compliance with the standard because three exceedances are allowed.

The PM_{10} concentrations observed for 2004 indicate the potential for adverse health effects in La Oroya. The nature and magnitude of the health impacts is difficult to determine. USEPA (1997b) identified epidemiological studies that indicated increased mortality and morbidity associated with particulate matter exposures at ambient concentrations below the PM_{10} standard. This observation was the motivation behind the USEPA's establishment of a $PM_{2.5}$ standard as it was believed to be a better indicator of the potential for the observed increase in health effects.

The air modeling effort conducted for this risk assessment did not address the changes in PM_{10} concentrations in the future. The controls on emissions of metals and sulfur dioxide will reduce the ambient air particulate concentrations, but it was not possible to quantify

the expected reduction in ambient air concentrations. The Complex is a significant source of particulate matter. The smelting operations and sulfur dioxide emissions are associated with the production of fine particles in the range of $PM_{2.5}$ and below. The proposed emissions reductions will result in reductions of the fine particle air concentrations and the associated health effects.

6.2 LEAD HEALTH RISKS

As described in Section 3.1.5, a series of blood lead studies have demonstrated that children and adults in La Oroya have elevated lead exposures that put them at risk for a variety of adverse effects. This health risk assessment has two primary goals. The first goal is to evaluate current human health risks from the Complex and to characterize the ways in which people are currently exposed to chemicals released from the Complex. The second goal is to use predicted future changes in emissions from the smelter to predict health risks after the implementation of various changes in smelter operations.

In accordance with these goals, this section describes health risks for children and adults from current lead exposures, the relative contributions to exposures from the exposure pathways evaluated, and predicted changes in exposures in 2007 and 2011.

The health effects of lead are described in Section 5.3. As is the case for all chemicals, the occurrence of health effects and the severity of health effects are dependent on dose or levels of exposures. Typically, the risk of adverse health effects from lead is stated in terms of blood lead levels. Blood lead level is primarily an indicator recent exposure, but is also influenced by previous exposure if lead stored in bone is being released to the blood.

6.2.1 Influence of Altitude and Anemia on Blood Lead Levels

Lead in the blood is primarily in red blood cells, so blood lead concentrations may also be modified by factors that affect hematocrit or hemoglobin levels. Interpretation of blood lead levels in La Oroya is complicated by the occurrence of two factors that may alter hematocrit and hemoglobin levels. As described in Section 5.3, high altitude populations such as those in La Oroya may have hematocrits approximately 20 percent higher than those of people living close to sea level. On the other hand, many people in La Oroya have low iron intakes and may have reduced hematocrits due to iron deficiency anemia.

These two factors complicate the prediction of adverse health effects in this population. Toxicokinetic modeling has confirmed that lead body burdens are not increased as blood lead increases with altitude (DEHUC 1997). Thus, People in La Oroya who are not anemic may not experience adverse health effects until their blood lead levels are about 20 percent higher than blood lead levels at which sea level residents experience effects.

People in La Oroya who are anemic may experience adverse health effects at blood lead levels similar to levels inducing effects in sea levels residents who are not anemic. It is also possible that treatment of anemia may cause increases in blood lead levels as hematocrit levels increase.

6.2.2 Lead Health Risks in Children

Due to the factors described above, prediction of health effects at blood lead levels observed in La Oroya is complicated. Nevertheless, there is no doubt that significant health effects are to be expected from lead exposures in La Oroya.

6.2.2.1 Current Risks for Children

The predicted blood lead levels for children in different communities are summarized in Table 6-2. Table 6-2 also presents the predicted health risk results, expressed in terms of the probability of a random child exceeding a blood lead value of 10 μg/dL (which is referred to as "P10"in the table) for children in different communities. The risk target for children is to have no more than a 5 percent probability of exceeding a blood lead level of 10 μg/dL within a group of similarly exposed children. As can be seen from this table, all of the children are predicted to exceed the 10 μg/dL level at which the Centers for Disease Control and Prevention (CDC) in the U.S. recommends further evaluation in the form of additional blood lead monitoring and education on ways to reduce lead exposures. Most of the children residing in La Oroya Antigua fall in the range of blood lead levels (i.e., 20 μg/dL to 44 μg/dL) at which the CDC recommends an environmental hazard evaluation and more active medical monitoring.

As described in Section 5.3, the number of different health effects from lead exposure increases with dose, and so does the severity of effects. Most of the children in La Oroya are at risk for neurobehavioral effects and effects on heme biosynthesis. Effects on heme biosynthesis may cause or worsen anemia. Children with the highest blood lead levels may also be at risk for effects on the heart, kidneys, bone and vitamin D metabolism. Many of these effects are subtle and cannot be easily attributed to lead exposures when examining an individual child.

Health evaluations conducted to date have been observational in nature and do not support statistical analysis. For example, in the study conducted in 2000 by Doe Run Perú, those children with blood lead levels greater than 45 μg/dL were recruited for additional developmental evaluation. The evaluation included physical, psychomotor, and educational development. The height, weight, and age of 60 children recruited for the physical evaluation were evaluated. Based on the growth measurements, the clinicians determined that approximately 53 percent of the children had some degree of malnutrition and 47 percent were found to have normal growth.

Following psychomotor testing of 45 children, the clinicians determined that 73 percent of the children had normal psychomotor development. This is in agreement with a study conducted by DIGESA (1999), which concluded that there were no symptoms of chronic lead poisoning among children tested in La Oroya. However, 12 cases of slight to marked delays in psychomotor development were noted by clinicians.

In addition, the educational progress of children with blood lead levels greater than 45 μg/dL was evaluated by reviewing the marks received by these children from their teachers. It was found that 77 percent of the children received high marks, 19 percent received average marks, and only 4 percent of the children received low marks. The clinicians concluded that the blood lead levels found in these children had not affected their educational success.

As described above, many of the effects of lead are too subtle to be detected in an individual child. In addition many of the same effects caused by lead may also be caused by other factors such as iron deficiency induced anemia or neurobehavioral effects. Due to these factors and the increases in hemoglobin of high altitude populations that cause higher blood lead levels relative to body burden, it is important that any future studies of the occurrence of specific adverse effects in the children of La Oroya be designed to include control populations that are properly matched for altitude, socioeconomic status and urbanization. If a suitable control community cannot be identified, it may be possible to design a study that compares children who live in La Oroya communities located at different distances from the Complex. Without proper controls, the results of such studies could be misleading.

6.2.2.2 Future Reductions in Children's Lead Exposures

Predicted blood lead levels in 2007 and 2011 for children are also shown in Table 6-2. All of the blood lead levels are predicted to fall significantly in both 2007 and 2011; however, it is not predicted that any of the communities evaluated will meet the risk target of no more than a 5 percent probability exceeding a blood lead level of 10 μg/dL. Nevertheless, the predicted reductions in blood lead levels are expected to substantially reduce health impacts of lead in the children of La Oroya.

6.2.2.3 Exposure Pathway Contributions to Lead Exposures in Children

To better understand the relative contributions to exposures from lead in outdoor dust, indoor dust, soil, diet, air and drinking water, the mean absorbed doses from each of these pathways were compared. The results for 2004 are summarized in Table 6-3a. The dominant exposure pathway for all of the communities was ingestion of outdoor dust. The highest contribution from the outdoor dust ingestion to the blood lead concentration occurred in La Oroya Antigua, representing 69 percent of the total, followed by Chucchis (50 percent), Marcavalle (46 percent), and La Oroya Nueva (43 percent).

Indoor dust was the second greatest contributor to exposures in La Oroya Antigua, while in the other communities; diet was the second largest contributor. The contribution of diet is likely to be overestimated in these other communities because data on lead in the diet was only available for La Oroya Antigua and those data were also used for the other communities. It is noteworthy that inhalation of lead in air is a relatively minor exposure pathway.

Exposure sources were also evaluated for 2007 and 2011 (see Tables 6-3b and 6-3c). As smelter emissions are reduced, the percent contribution of outdoor dust to combined exposures declines, while the percent contributions from soil and diet increase. This prediction suggests that eventually, additional actions may be needed to reduce exposures to lead in soil.

6.2.3 Lead Health Risks for Adults

As described in Section 5.3, maternal blood lead levels lower than 15 μg/dL have been associated with lower birth weights and shortened gestational time in some epidemiological studies. Other adverse health effects in adults are generally associated with higher blood lead levels, so the adult lead model is designed to predict risks of adverse effects to the fetus in pregnant women. As described in Section 4.3.2, fetal blood lead levels are lower than the blood lead concentrations in the pregnant woman, so both values are predicted by the model. The health protection goal is to have no more than a 5 percent probability that fetal blood lead levels will exceed 10 μg/dL.

6.2.3.1 Current Risks for Adults

As shown in Table 4-4, blood lead levels in women of child-bearing age in La Oroya are much lower than blood lead levels in children. The predicted adult and fetal blood lead levels are summarized in Table 6-4. The results are expressed as geometric mean of blood lead concentrations for adult women, as well as geometric mean and 95th percentile of blood lead concentrations among fetuses. In La Oroya Antigua there is an 86 percent chance that fetal blood lead levels will exceed 10 μg/dL. In other communities evaluated, the probability is lower than in La Oroya Antigua, but still greater than 50 percent.

6.2.3.2 Future Reductions in Adult Lead Exposures

Predicted future blood lead levels in 2007 and 2011 for adults are also shown in Table 6-4. Reductions in future lead emissions are predicted to reduce adult and fetal blood lead levels to meet the target risk levels by 2011 in La Oroya Nueva and Marcavalle, and to reduce blood lead levels to close to the target risk levels in La Oroya Antigua and Chucchis. Due to limitations in the design of the adult lead model, predictions of future

adult blood lead levels are associated with a greater degree of uncertainty than the predictions for children.

6.3 RISKS FOR METALS OTHER THAN LEAD

In addition to lead, other metals evaluated in this risk assessment include arsenic, cadmium, antimony, and thallium. As described in the toxicological evaluations for these metals (Section 5), a range of potential health effects have been reported in association with elevated exposures to these metals. These health effects may include cancer effects or effects other than cancer depending on the specific metal and route of exposure by the body. As discussed in Section 5.1, potential cancer risks are characterized differently than potential risks of health effects other than cancer.

Specifically, cancer risk estimates represent the incremental probability that an individual will develop cancer during his or her lifetime due to exposure to site-related chemicals. "Incremental probability" refers to the additional or excess chance of developing cancer that is above a background or baseline probability expected in the absence of the site-related exposures. An excess upper-bound lifetime risk range of one in ten thousand (i.e., 1×10^{-4}) to one in one million (i.e., 1×10^{-6}) is considered by USEPA to represent an acceptable range of cancer risks.

This incremental risk should be considered in light of high background cancer rates that range from 1 in 3 to 1 in 4 in many populations. For example, a 1 in 4 cancer risk is a probability of 0.25 of getting cancer in a lifetime. An incremental risk of one in ten thousand means that the background cancer risk would be increased from 0.2500 to 0.2501.

For health effects other than cancer, site-related exposure is represented as a dose estimate and compared to a toxicity value that represents the doses of a chemical that will not cause adverse health effects in any members of a population. This dose is called the "reference dose".

In both cases, risk characterization involves combining quantitative estimates of exposure (described in Section 4.4) and toxicity (Tables 5-1 and 5-2) to yield numerical estimates of potential health risk. The methods used to characterize risks due to exposures to site-related metals other than lead are described below. Quantitative estimates of cancer risks and risks for health effects other than cancer are also presented.

6.3.1 Characterization of Cancer Risks for Exposures to Arsenic and Cadmium

Cancer risks for non-lead metals included in this risk assessment were estimated for ingestion of arsenic in soil, dust, and drinking water and for inhalation of arsenic and cadmium in the air in La Oroya. Ingestion of cadmium, antimony, and thallium does not present a cancer risk. Risks were calculated for both current exposures and predicted exposures in the year 2011 following implementation of planned emissions reduction strategies.

6.3.1.1 Calculation of Cancer Risks

Excess (incremental) lifetime cancer risks for the oral and inhalation exposure pathways were calculated using pathway-specific intake estimates and corresponding cancer slope factors according to one of two equations depending upon the relative magnitude of risk predicted (USEPA 1989). The first equation is valid only when the intake is relatively low (i.e., corresponding to a risk level lower than 0.01 or 1 x 10^{-2}). It is based on the linear portion of the multistage model dose-response curve (USEPA 1989):

$$Cancer\ Risk = Intake\left(\frac{mg}{kg \cdot day}\right) \times CancerSlopeFactor\left(\frac{mg}{kg \cdot day}\right)^{-1}$$

The second equation, called the "one-hit equation," is used when the intake is high, corresponding to a risk level greater than 0.01 or 1 x 10^{-2} (USEPA 1989):

$$CancerRisk = 1 - EXP\left[Intake\left(\frac{mg}{kg \cdot day}\right) \times CancerSlopeFactor\left(\frac{mg}{kg \cdot day}\right)^{-1}\right]$$

When the product of intake x cancer slope factor is small, the two equations are equivalent mathematically. In this risk assessment, the first equation was used to calculate cancer risks for oral exposure to arsenic and inhalation exposure to arsenic and cadmium. Due to the high concentrations of arsenic in air, the second equation was used to estimate cancer risks due to inhalation exposure to arsenic when cancer risks were greater than 0.01.

In risk assessment, cancer risks are generally assumed to be additive (USEPA 1989). Based on this assumption, cancer risk estimates for arsenic and cadmium in air were added together for each community to produce a total risk estimate for the inhalation

exposure pathway for typical and high end exposure conditions. Similarly, for ingestion of arsenic, total cancer risks for typical and upper end exposures at each community include contributions from ingestion of indoor dust, outdoor dust, and surface soil.

Cancer risk estimates were developed using exposure concentration information for operation of the Complex under current conditions and predicted conditions for 2011 based on implementation of Doe Run Peru's emission reduction plan. Many of these reductions are actually expected to be in place by the end of 2007; however, no air modeling was conducted to predict concentrations and deposition of arsenic and cadmium in 2007. A discussion of these risk estimates is provided below.

6.3.1.2 Cancer Risk Estimates for Current Exposures

The methods and assumptions used to estimate current exposure intakes for ingestion of arsenic in dust and soil and inhalation of arsenic and cadmium in air, were previously described in Section 4.4. Cancer risk estimates for ingestion of arsenic in indoor dust, outdoor dust, and surface soil by residents of each community under current conditions are presented in Table 6-5a. Cancer risk estimates for inhalation of arsenic and cadmium in air under current conditions are presented in Table 6-5b.

Summary of Current Cancer Risks Due to Ingestion of Metals Other than Lead

Combined cancer risks for incidental ingestion of arsenic in indoor and outdoor dust and soil are summarized in Table 6-5a. The highest risk estimate, two in one thousand (2×10^{-3}), was for the community of La Oroya Antigua. In the communities of La Oroya Nueva, Marcavalle, and Chucchis, risk estimates for typical exposures were lower, ranging from six in ten thousand (6×10^{-4}) to eight in ten thousand (8×10^{-4}). For upper end exposures, the highest risk estimate, six in one thousand (6×10^{-3}), was for the community of La Oroya Antigua. Risk estimates for the three other communities were slightly lower at two in one thousand (2×10^{-3}).

These risk estimates are above the excess upper-bound lifetime risk range of one in ten thousand (i.e., 1×10^{-4}) to one in one million (i.e., 1×10^{-6}) that is considered by USEPA to represent an acceptable range of cancer risks. In all of the communities, the highest contribution to total cancer risk for oral exposure came from incidental ingestion of arsenic contained in outdoor dust. Indoor dust contributions to total cancer risks for this pathway were lower than outdoor dust, but higher than the contribution by surface soil in all communities. As noted in Table 6-5a, the cancer risk estimates due to incidental ingestion of outdoor dust were generally about ten times higher than corresponding estimates for surface soil.

Summary of Current Cancer Risks Due to Inhalation of Metals Other than Lead

Combined cancer risks for inhalation of arsenic and cadmium in air are summarized in Table 6-5b. For typical exposures the highest risk estimate, five in one thousand (5×10^{-3}), was for the community of La Oroya Antigua. In the other communities, risk estimates for typical exposures were slightly lower, at three in one thousand (3×10^{-3}). For upper end exposures, the highest risk estimate, two in one hundred (2×10^{-2}), was for the community of La Oroya Antigua. Risk estimates for the other communities were slightly lower, but still above USEPA's acceptable risk range.

Both typical and upper end exposures exceed USEPA's acceptable risk range in all communities due to combined inhalation of cadmium and arsenic in air. Risks contributed by inhalation of arsenic are generally about one hundred times greater than those contributed by inhalation of cadmium (Table 6-5b). In fact, for typical exposures, risks due to inhalation of cadmium alone fall within the USEPA acceptable risk range for all of the communities evaluated.

6.3.1.3 Cancer Risk Estimates for Future Exposures

As noted above, cancer risk estimates for predicted future exposures were developed using exposure concentration information for operation of the Complex under current conditions and predicted conditions for 2011 based on implementation of Doe Run Peru's emission reduction plan. Many of these reductions are actually expected to be in place by the end of 2007; however, no air modeling was conducted to predict concentrations and deposition of arsenic and cadmium in 2007.

Summary of Future Cancer Risks Due to Ingestion of Metals Other than Lead

Combined cancer risks for incidental ingestion of arsenic in indoor and outdoor dust and soil are summarized in Table 6-5c. The highest risk estimate, six in ten thousand (6×10^{-4}), was for the community of La Oroya Antigua. In the other communities, typical exposure risk estimates were slightly lower, at two in ten thousand (2×10^{-4}). For upper end exposures, the highest risk estimate, two in one thousand (2×10^{-3}), was for the community of La Oroya Antigua. In the communities of La Oroya Nueva, Marcavalle, and Chucchis, risk estimates for upper end exposures were lower, ranging from four in ten thousand (4×10^{-4}) to six in ten thousand (6×10^{-4}). These risk estimates are above USEPA's acceptable range of cancer risks. These results indicate that, by the year 2011, cancer risk estimates for intake of arsenic via incidental ingestion of dust and soil are expected to decrease approximately 67 to 80 percent compared to estimates for current conditions.

For both typical and upper end exposures, the predicted contribution of outdoor and indoor dust to total risk in 2011 remains higher than that for soil. However, the results in Table 6-5c indicate that the magnitude of difference between these exposure media (i.e., dust vs. soil) is not as great as under current conditions (Table 6-5a). This finding is consistent with the anticipated effect of Doe Run Peru's implementation of emission control strategies, which are expected to significantly reduce emissions of arsenic to air. Reductions in air emissions are expected to have a more significant and immediate effect on concentrations of metals in dusts relative to soils, which reflect historical deposition of metals from the Complex.

Summary of Future Cancer Risks Due to Inhalation of Metals Other than Lead

Combined future cancer risks for inhalation of arsenic and cadmium in air are summarized in Table 6-5d. The highest risk estimate, one in one thousand (1×10^{-3}), was for the community of La Oroya Antigua. In the other communities, risk estimates for typical exposures were slightly lower, ranging from six in ten thousand (6×10^{-4}) to seven in ten thousand (7×10^{-4}). For upper end exposures, the highest risk estimate, four in one thousand (4×10^{-3}), was for the community of La Oroya Antigua. In the other communities, total inhalation risk estimates were two in one thousand (2×10^{-3}). Risk estimates for all communities are above USEPA's acceptable range of cancer risks. Compared to current conditions, however, these results indicate a reduction of about 75 to 80 percent total cancer risk due to inhalation of arsenic and cadmium in air by the year 2011. As with the evaluation of current conditions, arsenic remains the primary contributor to total cancer risk via inhalation in 2011.

6.3.2 Characterization of Noncancer Risks for Exposures to Arsenic, Cadmium, Antimony, and Thallium

Noncancer risks for metals other than lead included in this risk assessment were estimated for ingestion of arsenic, cadmium, antimony, and thallium in indoor and outdoor dust and surface soil in those communities where these metals exceeded screening levels as described in Section 3.4. Specifically, evaluation of noncancer risks included the following:

For incidental ingestion of surface soil --

- arsenic and cadmium in La Oroya Antigua
- arsenic in La Oroya Nueva, Marcavalle, and Chucchis

For incidental ingestion of outdoor dust --

- antimony, arsenic, cadmium, and thallium in La Oroya Antigua
- antimony and arsenic in La Oroya Nueva
- antimony, arsenic, and thallium in Marcavalle and Chucchis

For incidental ingestion of indoor dusts --

- antimony, arsenic, and cadmium in La Oroya Antigua
- antimony and arsenic in La Oroya Nueva and Marcavalle
- arsenic and cadmium in Chucchis.

Noncancer risk estimates were also estimated for inhalation of cadmium in air in La Oroya.

Noncancer health risk estimates for all pathways were calculated for both current exposures and predicted exposures in the year 2011 following implementation of planned emissions reduction strategies.

6.3.2.1 Calculation of Noncancer Risks

Noncancer health risks are characterized as the increased likelihood that an individual will suffer adverse health effects as a result of exposure to a chemical. An individual that is exposed to a chemical at a level that is less than or equal to an acceptable reference levels (reference dose), is not expected to experience adverse health effects related to that exposure. Exposures above the reference dose do not mean that adverse human health effects will occur, but rather that further evaluation is required (USEPA 1989).

To evaluate noncancer risks, the ratio of the average daily intake to the reference dose is calculated. This ratio is referred to as the hazard quotient. If the calculated value of hazard quotient is less than 1.0, no adverse health effects are expected. If the calculated value of the hazard quotient is greater than 1.0, then further risk evaluation is needed.

For the ingestion and inhalation pathways, the hazard quotient was calculated using the following equation:

$$HQ = \frac{Intake}{RfD}$$

Where,

HQ	=	Hazard quotient associated with exposure to the chemical *via* the specified route of exposure (dimensionless)
Intake	=	Estimated average daily intake of the chemical *via* the specified exposure route (mg/kg-day)
RfD	=	Reference dose or appropriate substitute toxicity value identified for the chemical of concern (mg/kg-day)

To evaluate the effect of exposure to multiple chemicals that act on the body in a similar manner, the hazard quotients for each exposure pathway for individual chemicals are typically summed to determine a noncancer hazard index using the following formula:

$$HazardIndex = \frac{I_1}{RfD_1} + \frac{I_2}{RfD_2} + ... + \frac{I_i}{RfD_i}$$

Where,

I_i	=	Intake for chemical *i* (mg/kg-day)
RfD_i	=	Reference dose or concentration for the i^{th} chemical (mg/kg-day)

Hazard indices for multiple chemicals are generally not summed if the reference doses for the chemicals are based on effects on different target organs. This is because the noncancer health risks associated with chemicals that affect different target organs are unlikely to be additive. As summarized in Table 5-1, the reference doses for antimony, arsenic, cadmium, and thallium are based on effects on different organs or systems within the body (e.g., cadmium is based on kidney effects and arsenic is based on skin effects). Based on these differences, hazard quotients for different chemicals were not summed in this risk assessment. However, given the levels of exposures to these metals in La Oroya, it is possible that interactions between the chemicals could result in increased effects on some organs or systems in the body. The kinds of interactions that are expected to be most significant in La Oroya are discussed in Section 6.4.

6.3.2.2 Noncancer Risk Estimates for Current Exposures

The methods and assumptions used to estimate current exposure intakes for the pathways and metals included for evaluation of noncancer risks were previously described in Section 4.4. Noncancer risk estimates for ingestion of metals in indoor dust, outdoor dust, and surface soil by a person residing in each community under current conditions are presented in Table 6-7a. Noncancer risk estimates for inhalation by individuals of cadmium in air under current conditions are presented in Table 6-7b.

Summary of Current Noncancer Risks Due to Ingestion of Metals Other than Lead

Noncancer risk estimates were highest in La Oroya Antigua. In this community, estimated noncancer risks for both typical (HQ = 10) and upper end (HQ = 30) exposures to arsenic via combined incidental ingestion of indoor dust, outdoor dust, and surface soil greatly exceeded the chronic oral reference dose for arsenic. Risk estimates for the other communities were also elevated for arsenic (HQs from 3 to 4 for typical exposures and 9 to 10 for upper end exposures).

In addition to arsenic, noncancer risk estimates for upper end exposures to antimony were also elevated in La Oroya Antigua (HQ = 3) and La Oroya Nueva (HQ = 2). Antimony risk estimates for typical exposure conditions in these communities did not indicate a concern for noncancer health risks.

Given the magnitude of arsenic risks associated with chronic exposure to arsenic within these communities, risks associated with shorter-term (i.e., subchronic) exposures may also be elevated. The potential for elevated risks due to shorter exposure periods is particularly relevant for children who may be more sensitive than adults to the effects of exposure during the period of early childhood from birth to age 6 years. To estimate the magnitude of potential risk for this sensitive subpopulation, exposures to children age 0 to 6 years from incidental ingestion of outdoor dust, indoor dust, and surface soil were compared to a subchronic reference dose for arsenic of 5×10^{-3} mg/kg-day. Based on this comparison, upper end exposure of a child resident in La Oroya Antigua is expected to be approximately 5 times higher than the subchronic reference dose for arsenic (HQ = 5). Childhood exposures to arsenic in La Oroya Nueva are expected to be approximately 2 times higher than the subchronic reference dose (HQ = 2) indicating a possible concern in that community as well. In Marcavalle and Chucchis, such exposures are expected not to exceed the subchronic reference dose (HQ = 1), indicating that noncancer risks due to arsenic in these communities are not of concern.

Summary of Current Noncancer Risks Due to Inhalation of Metals Other than Lead

Noncancer risk estimates for inhalation of cadmium in air are summarized in Table 6-7b. Estimated noncancer risk due to inhalation of cadmium was highest for upper end exposures in La Oroya Antigua and La Oroya Nueva (HQs = 20), but was also elevated for exposures in Marcavalle/Chucchis (HQ = 10). Typical exposure conditions resulted in risk estimates that also indicated possible concerns at 3 to 6 times the inhalation reference dose for cadmium.

6.3.2.3 Noncancer Risk Estimates for Future Exposures

Estimates of concentrations of antimony and thallium in dust and soil for the year 2011 were not available; therefore, noncancer risks were calculated for exposure to arsenic and cadmium only. Noncancer risk estimates are provided in Tables 6-7a for incidental ingestion of outdoor dust, indoor dust, and surface soil. Table 6-7b summarizes noncancer risk estimates for inhalation of cadmium in 2011.

Summary of Current Noncancer Risks Due to Ingestion of Metals Other than Lead

In La Oroya Antigua, predicted noncancer risks for incidental ingestion of arsenic in surface soil, indoor dust, and outdoor dust decrease by approximately 70 percent for both

typical and upper end exposures. However, risk estimates in this community continue to be elevated, at approximately 3 to 8 times the current reference dose.

Reductions of between 70 and 80 percent in noncancer risk due to arsenic are also predicted for the other communities evaluated. In addition, in 2011, possible concerns for noncancer health risks are indicated in these communities only for upper end exposures to arsenic (HQs ranging from 2 to 3). Risk estimates for typical exposures in these communities do not exceed the arsenic reference dose.

For cadmium, slightly greater reductions (75 to 80 percent) are predicted for residents of La Oroya Antigua in 2011. Noncancer risk estimates for incidental ingestion of cadmium via these pathways in all of the communities remains well-below the reference dose in 2011.

Summary of Current Noncancer Risks Due to Inhalation of Metals Other than Lead

For inhalation of cadmium in air in 2011, risk reductions ranging from 80 to 90 percent are predicted. Risk estimates corresponding to upper end exposures to cadmium continue to indicate possible concerns for residents of all communities in 2011 (HQs ranging from 2 to 3). However, typical exposures predicted in 2011 do not exceed the cadmium inhalation reference dose.

6.4 EVALUATION OF RISKS FROM MULTIPLE CHEMICAL EXPOSURES

As described in Section 5.8, mixtures of chemicals that cause similar kinds of health effects may have interactions that either increase or decrease the overall health effects. For mixtures of carcinogenic chemicals, standard risk assessment practice is to assume that risks are additive (USEPA 1989). Assessment of mixtures is a developing area of toxicology that is not fully understood, and the USEPA guidance for risk assessment of mixtures does not yet provide consistent methods for quantitative analysis of effects other than cancer (Borgert et al. 2004).

The potential for significant interactions among chemicals in La Oroya is great because of the high levels of exposure and the potential for more than one chemical to cause the same kinds of effects. While we cannot quantify the interactions that might occur among chemicals in La Oroya, it is very important that the multiple factors that may contribute to the primary health effects in La Oroya be understood and be accounted for in any future health studies that are conducted. In the sections below we review the principal expected health effects and the factors that may contribute to these health effects in the population.

6.4.1 Effects on the Lung

The air in La Oroya contains a mixture of particulate matter and sulfur dioxide. The nature of this mixture has an impact on the nature and magnitude of the resulting pulmonary effects. The air contains particulate matter and sulfur dioxide above health-based standards, each of which alone would indicate the potential for adverse effects on the lung. As discussed earlier, the metal oxides in ultra fine particulates released from the Complex are effective at converting sulfur dioxide to the more potent sulfuric acid. Inhalation exposures to sulfuric acid can alter the ability of the body to clear particles from the lungs which would compromise a significant defense mechanism in the body (Klaassen 1996). Long-term exposures to elevated concentrations of sulfuric acid can lead to chronic bronchitis. This can lead to increased deposition of particles in the respiratory system. The chronic bronchitis results in a thickened mucus layer which increases the potential for impaction of particles.

The mixture of gases and particles found in the air at La Oroya may work in synergy to increase the magnitude of the effects on the lung. The magnitude of this synergy cannot be directly quantified in this risk assessment; however, a degree of protection exists because the air quality standards were also derived from studies of mixtures that may have included many of the chemicals present in the air in La Oroya.

6.4.2 Neurological Effects

As described previously, neurological effects are a primary consideration with exposure to lead. In addition to effects on neurobehavioral function reported at lower blood lead levels in children, higher blood lead levels have been associated with neurological symptoms including muscle weakness and numbness and tingling in the extremities (ATSDR 1999b). Some similar neurological effects (e.g., numbness of hands and feet; "pins and needles" feeling in extremities, and weakness) have also been reported with chronic exposure to arsenic (ATSDR 2000). In addition, neurobehavioral effects have been identified as the most sensitive indicator of developmental toxicity associated with cadmium exposure based on some studies in animals (ATSDR 1999a)

For neurological effects, potential mechanisms of interactions between lead and arsenic, as well as between lead and cadmium have been suggested. In some animal studies, arsenic and lead have been shown to affect each other's concentrations in the brain when administered as a pair, but cadmium and lead did not (ATSDR 2004). All three chemicals have been reported to affect neurotransmitter levels in the brain. However, the mechanisms by which two or more of these chemicals may interact to affect neurological systems is not clear due, in part, to the underlying complexity of effect mechanisms pertinent to any one of the chemicals on its own (ATSDR 2004).

6.4.3 Anemia

The potential for interactive effects on the hematological system by simultaneous exposures to lead with arsenic and lead with cadmium has been proposed (ATSDR 2004). As noted in Section 5, exposure to each of these chemicals has been associated with anemia. For lead, alteration of heme synthesis may result in decreased hemoglobin production and destruction of red blood cells leading to anemia. With arsenic, decreased production of red blood cells may also result with ingestion of chronically high levels. In individuals with low iron intake, cadmium decreases absorption of iron from the gastrointestinal tract, indirectly inhibiting heme synthesis, which may further contribute to anemia.

Dietary deficiencies in iron may also contribute to increased absorption of lead. As noted previously, comparisons of blood lead concentrations in iron deficient children with those in iron replete children suggest that such deficiency may result in higher lead absorption or that iron sufficiency may alter lead biokinetics in a way that contributes to lower blood lead levels in iron replete children (ATSDR 1999). Counter to this effect, some studies in animals indicate the impact of cadmium on the gastrointestinal tract may result in decreased absorption of lead, producing decreased blood lead levels in individuals exposed to lead with cadmium (ATSDR 2004).

6.4.4 Effects on Bone

Skeletal system effects, such as osteoporosis, may occur due to the combination of poor nutritional status and exposure-induced interferences on key biochemical pathways in the body. For example, nutritional deficiencies in iron, zinc, calcium, vitamin D, and protein, may result in increased absorption of cadmium, which may further decrease absorption or metabolism of calcium and vitamin D (ATSDR 1999b). Impairment of vitamin D may also occur at high blood lead levels (range of 33-120 μg/dL). This is particularly evident in cases of chronically high lead exposures of children who are nutritionally deficient in calcium, phosphorous, and vitamin D (ATSDR 1999b). Other external factors, such as alcohol use, may further contribute to effects on the skeletal system.

6.5 UNCERTAINTY EVALUATION

As described above, risk assessments predict the likelihood of health effects in a population, but do not directly measure the occurrence of health effects. The predicted risks are based on many assumptions about the ways that people come into contact with chemicals in the environment. Many of these assumptions are based on general scientific studies or on data collected at the site, but some uncertainty still exists regarding how well the available data reflect the ways residents are actually exposed to chemicals. The

degree of confidence in the results of a risk assessment depend on how well the data and assumptions used represent actual conditions.

The degree of confidence in a risk assessment is described in an uncertainty evaluation. The uncertainty evaluation includes a list of critical assumptions and data, and an evaluation of the possibility that the assumptions and data used in the risk assessment may over-predict risk or under-predict risk. Overall, the availability of site-specific data from La Oroya increases the level of confidence in the risk assessment compared to risk assessments conducted at sites in the U.S. because most U.S. risk assessments do not have as much site-specific information.

6.5.1 Risk Assessment Scope

It is important that the uncertainty be evaluated in the context of the intended scope of the risk assessment. The goals of this risk assessment were to evaluate current human health risks in the community due to air emissions from the Complex and to predict changes in health risks in the future as smelter operations are changed to reduce emissions. Because of these goals, the risk assessment did not consider risks associated with releases to water or from depositing wastes on land. Risks to workers at the Complex were not evaluated, nor were ecological risks evaluated.

Evaluation of current health risks was focused on characterizing the ways people are exposed to Complex air emissions and the relative contribution of various exposure pathways to total exposures. No effort was made to determine the land area affected by historical Complex emissions because this was outside the scope of this risk assessment.

Only those communities between La Oroya Antigua and Chucchis were evaluated in the risk assessment because they are expected to have the greatest impacts from Complex emissions. Communities located farther from the Complex receive lower deposition and air concentrations from the Complex than communities located nearby and will have lower health risks. Results of this risk assessment will be useful in understanding possible exposure pathways at more distant communities.

These factors related to the scope of the risk assessment are not sources of uncertainty in the results, but are described to explain the risk assessment focus.

6.5.2 Confidence in the Risk Assessment

Prediction of current risks from inhaling chemicals in La Oroya is greatly strengthened by the availability of air monitoring data for sulfur dioxide, particulates, lead, arsenic, and cadmium. The exposure assessment for inhalation of these chemicals is expected to be more accurate than is the case in most risk assessments. Inhalation rates are well

documented and fewer assumptions are required to estimate inhalation exposures than for other exposure pathways. There are some uncertainties in the emissions estimates and the air modeling study, but the available information is of good quality so confidence in the predicted future inhalation risks is also high.

For lead exposures, confidence in this risk assessment is greatly increased by the availability of high quality blood lead data for the population. The blood lead data allowed Integral scientists to confirm that the overall blood lead exposure predictions of the risk assessment are reliable. There is uncertainty in the relative contribution of some of the sources, especially with regard to the relative contribution of exposures to lead in outdoor dust, indoor dust and soil, but the sum of these exposures is judged to be accurate. Confidence in predictions of future lead exposures is mainly dependent on the accuracy of the air model deposition estimates for lead emitted from the Complex. The deposition estimates are judged to be adequate to support the risk estimates.

For oral exposures to metals other than lead, predicted risks are less certain than for other components of the risk assessment. This is because more assumptions were needed in the exposure estimates for ingested metals. Nevertheless, confidence in the assessment of these metals was increased by the reliance on some of the assumptions developed for estimating lead exposures. Thus, these exposure estimates are expected to be more reliable than those of typical U.S. risk assessments.

The uncertainty evaluation puts the risk estimates into context. To accomplish this goal, factors that may tend to over- or underestimate risks were identified and the relative magnitude of the uncertainty for each factor was evaluated so that the level of confidence associated with the risk estimates is clear. In general, where uncertainties exist, a conservative approach was used in selecting parameters, assumptions, and methodologies, to enhance the likelihood that potential exposures and risks were not underestimated. Specific sources of uncertainty in various steps of the risk assessment are described in Table 6-8.

7 CONCLUSIONS AND RECOMMENDATIONS

This risk assessment has confirmed previous studies that have identified lead exposures as the primary health risk factor for the population of La Oroya due to emissions from the Doe Run Perú Metallurgical Complex (Complex), with virtually all children residing in La Oroya Antigua at risk for neurobehavioral effects. Many adults in La Oroya Antigua and residents of other nearby communities are also at risk. Sulfur dioxide and sulfuric acid releases also cause effects that place a burden on a majority of the population of all the communities. The pulmonary irritation induced by these chemicals is usually transient; however, there is also a risk of nonspecific increases in morbidity and mortality associated with elevated exposures.

Due to the urgency of reducing lead exposures in children, many of our recommendations focus on lead exposures. Exposures to inhaled arsenic and cadmium and ingested arsenic are also high enough to impose a health burden in La Oroya, but in our judgment can be addressed in a longer time frame. Additionally, many of the actions recommended to reduce lead exposures also will have the effect of reducing exposures to arsenic and cadmium. Reductions of sulfur dioxide and sulfate emissions also are addressed because they have a great impact on both quality of life and health in La Oroya.

Many actions have already been undertaken by the community, the Ministry of Health and by Doe Run Perú to reduce both lead exposures and releases of sulfur dioxide. Many additional actions are planned for the future. The results of this risk assessment indicate that implementation of the planned technological changes to reduce fugitive emissions and stack emissions will reduce sulfur dioxide concentrations to levels that will not pose a major health burden. While lead emissions will also be greatly reduced, blood lead levels are still predicted to exceed health-based goals in 2011. This is due to the fact that dust and soil in La Oroya will still have high residual concentrations of lead from historical emissions. For that reason, we recommend continuing and expanding many of the community-based programs that help to reduce lead exposures and the associated health burden.

The U.S. Centers for Disease Control and Prevention's (CDC) recent report on La Oroya (CDC 2005) recommends that all stakeholders in La Oroya collaborate in a coordinated program to reduce emissions, reduce exposures and to eventually remediate historic contamination. Due to the diversity of issues facing La Oroya, we strongly support the CDC's recommendation and further recommend that a stakeholder advisory group be formed that includes representatives of local governments, community organizations (including local religious representatives), the Convenio, Peruvian Ministry of Energy and Mines (MEM), Ministry of Health's Environmental Health Directorate (DIGESA), and Doe

Run Perú. A similar stakeholder group was very effective in guiding actions in Trail, British Columbia, Canada were an active lead and zinc smelter is located.

This stakeholder group should review proposals for additional studies in La Oroya. Independent studies are not likely to be as effective as studies that fully utilize available information and are coordinated with the needs identified by the stakeholders in the community.

In addition to this one general recommendation of forming a stakeholders group, we also provide recommendations for specific actions related to facility operation, exposure assessment and environmental monitoring, community interventions, and dietary studies and interventions.

7.1 FACILITY OPERATIONS

Air emissions of sulfur dioxide and metal particulates from the Complex are the principal focus of this risk assessment. These emissions include both fugitive emissions from buildings and ducts and stack emissions from the main stack and the sinter plant scrubber stack. These emissions are affected by the specific metals produced, i.e., copper, zinc or lead, and by production volumes, as well as by operating conditions and emissions controls. Some technological changes have already been implemented to reduce emissions. In addition, Complex operations have been modified to reduce sulfur dioxide emissions by temporarily shutting down the smelter whenever an inversion is predicted.

We have two principal recommendations related to Complex operations:

- Based on the analysis by McVehil-Monnett showing that the majority of lead emissions impacts from the Complex (near the plant) are in the form of fugitive emissions, we recommend that priority be given to reduction of fugitive emission sources of lead. Although reduction of fugitive emissions of lead was not identified as a goal in the Programa de Adecuación y Manejo Ambiental (PAMA), we believe that reduction of these fugitive emissions should be the highest priority at the Complex.

- Due to the long time period before sulfur dioxide concentrations are expected to be reduced down toward the air quality criteria concentrations, it is recommended that the policy to reduce or suspend operations when inversions are predicted be continued. Based on the air modeling results, the supplemental control scenario produced a reduction (relative to normal 24-hour per day operation) of 25 to 50 percent in highest short-term morning sulfur dioxide concentrations, and approximately 25 percent in 24-hour average concentrations. The model results therefore confirm that a procedure for emission reductions in pre-dawn hours has

a significant effect in reducing maximum pollutant concentrations during the following day.

7.2 EXPOSURE ASSESSMENT AND ENVIRONMENTAL MONITORING

Environmental monitoring programs in La Oroya are important for several reasons. Continuing collection of data on chemical concentrations in air, dust, and soil are needed to understand how exposures might be changing over time. These data also are needed to determine if the actions undertaken to reduce emissions from the Complex are effective in reducing chemical concentrations in the environmental media to which people are exposed. The following sections provide recommendations for continued air monitoring and regular monitoring of dustfall and outdoor dust and soil.

7.2.1 Air Monitoring

The air monitoring network currently operated by Doe Run Perú should be continued. Data from the air monitoring network are used directly in assessing health risks and also are needed to support more accurate air modeling and prediction of impacts of changes in Complex operations. Continued monitoring of sulfur dioxide, particulates as PM_{10}, lead, arsenic and cadmium is recommended for assessing health impacts. Ensuring high quality monitoring data that can be utilized for improved air quality model application in the future also is important.

Regular calibration of the monitoring equipment should be performed and quality assurance/quality control (QA/QC) procedures should be improved to assure that meteorological and air quality monitoring data are accurate. Implementation of data quality oversight program would be an excellent topic for consideration by a stakeholder group. For example, the monitoring program could be expanded to include collection and analysis of split samples by a third party. This would provide transparency in the environmental monitoring program, increase confidence in analytical results, and support QA/QC program objectives.

Additional air monitoring stations for metals may be needed to better track exposures and emissions reductions, including a station in Chucchis and possibly another station within La Oroya Nueva. The location of the Cushurupampa monitoring station should also be reviewed to determine if it would be technically appropriate to move both metal and sulfur dioxide monitors to a lower elevation within the residential areas (currently these monitors are located high on the hillside). Supplemental air modeling may also be needed in the future to guide emissions reductions efforts. Detailed recommendations related to air monitoring are provided below:

- Surface meteorological stations that collect wind speed and direction information should be routinely calibrated. The complexity of the terrain surrounding the Complex requires high quality data be used in the CALPUFF model.
- The doppler acoustic sounder monitoring should be continued and improved so that high quality upper air data will be recorded on a consistent basis over extended time periods.
- The routine sulfur dioxide monitoring equipment should be examined to see if the upper limit on concentration can be removed or extended. In the short-term the Sindicato 2 station could be used to provide a more realistic assessment of short-term air concentrations. However, the data from the Sindicato 2 monitor are likely to be more relevant to communities near the Complex, and not more distant communities like Chucchis or even Marcavalle. No one resides in the area of Huanchan.

7.2.2 Air Modeling

Computer modeling of air pollution impacts of the Complex was carried out by McVehil-Monnett to provide estimates of future air quality after the implementation of emissions reduction programs. It was concluded that the model properly simulated basic dispersion processes in the region of the Complex, and provided realistic estimates of maximum short-term and average long-term impacts. The model results also imply that the characterization of emission sources and average emission rates that were used reflect reality with reasonable accuracy. On the basis of these conclusions, projections of future air quality impacts, with modified sources and reduced emissions, were judged to be realistic and appropriate for risk assessment. Nevertheless, if future air modeling is needed for other purposes, the following observations may be useful.

Analysis of the air model results for sulfur dioxide on an hour by hour, day by day, and site by site basis with the available monitoring data suggests that the lack of site-specific meteorological data for altitudes above ground level limits model performance. It is expected that future air modeling, using acoustic sounder data for above-ground wind and temperature (now in progress at the Complex), inclusion of revised emissions during curtailment periods, and possibly additional fugitive emissions monitoring data, will be able to demonstrate improved model capability. An improved model could be used to identify impacts of specific sources within the smelter complex and of physical processes that did not need to be evaluated for this risk assessment. The following actions could be considered for improved air quality model application in the future:

- Continue to collect site-specific upper air data that could be used in the CALPUFF model. This will reduce a significant source of uncertainty in modeling the transport and dispersion of emissions from the Complex.

- Run the CALPUFF model again in about a year when sufficient high quality surface and upper air meteorological data are obtained.
- If the accuracy of the short-term CALPUFF model increases, then conduct modeling to evaluate the elevated acute sulfur dioxide exposures and examine the effectiveness of proposed sulfur dioxide source reductions on reduction of acute exposures. These exposures are related to brief peaks of minutes to hours that are seen in the mid-morning to early afternoon hours.
- As recommended in Section 7.2.1, consider additional air monitoring up the Yauli River and/or relocation of the Cushurupampa monitor to provide representative data for model validation.

7.2.3 Monitoring of Metals in Dustfall and Outdoor Dust

The air model predicted deposition rates for lead, arsenic and cadmium. Deposition is a measure of the rate at which particulates emitted from the Complex fall to the ground and settle on paved surfaces and soil. Deposition of airborne dust can be measured directly by setting out open top containers on surfaces in various locations. The amount of dust or of specific metals in a container with a known surface area provides a measure of dustfall (usually reported in mg/m^2). Dustfall measures can be used to determine if deposition rates of particulates from the Complex are being reduced as emissions are reduced.

Trends in dustfall rates also can be compared to trends in outdoor dust metal concentrations or metal loading in dust to see if reduced deposition may result in exposures to metals in the outdoor dust. We recommend that the stakeholder group establish a program to monitor trends of lead, arsenic and cadmium in dustfall or other environmental indicators that are deemed useful in assessing effectiveness of emissions reductions and in predicting exposures.

7.3 COMMUNITY INTERVENTIONS

Current activities conducted by both Doe Run Perú and the Convenio de Cooperación between the Ministry of Health and Doe Run Perú have addressed hygiene education at the community and individual level. These activities range from regular street cleaning and waste disposal to provision of shower facilities and public dining rooms. While visiting homes during the field sampling effort, Integral staff learned that educational programs provided by the Convenio de Cooperación are appreciated greatly and utilized by the community. Many residents commented that they received useful information regarding home cleaning practices, personal hygiene, food preparation practices, and nutrition.

Continuation of community education programs in La Oroya Antigua is recommended to further instruct residents on reducing exposures within the home. In addition, to the extent that program personnel working in La Oroya Antigua have time available, educational outreach programs should be expanded to the communities of La Oroya Nueva, Marcavalle, and Chucchis. Examples of programs that are recommended for support include:

- Due to the importance of personal hygiene (e.g., hand washing) in reducing exposures, particularly for children, the personal hygiene training program in schools should be continued and the program to make structural improvements to public sanitation facilities should be continued.
- Continued cleaning of streets and sidewalks is recommended to remove deposited dustfall from Complex emissions. Additional cleaning of paved play areas, including school courtyards, plazas, and playfields (soccer and basketball) is particularly important. Expanding the areas cleaned on a regular basis will help to reduce dust accumulation in areas where children are likely to contact dust. In addition, it may be helpful to increase the frequency of street and sidewalk cleaning in areas with heaviest child recreational activity and those areas impacted by other sources of lead dust (i.e., high traffic streets).
- It is important that annual blood lead studies continue to be conducted by DIGESA/Convenio de Cooperación. Through regular blood lead monitoring, the efficacy of reductions in Complex emissions and intervention programs may be assessed. With the continuation of blood lead monitoring of children in La Oroya, children with blood lead levels exceeding 45 μg/dL may be identified and targeted for educational (e.g., hygiene, nutrition) and clinical (nutritional supplements, medical testing) interventions that are tailored to the child's home environment and economic means.

In addition to continuing existing community education and intervention programs, it is recommended that other actions be considered to further reduce environmental exposures within the population:

- Given the available information, it was not possible to correlate child blood lead levels with the presence of paved or unpaved walkways outside homes. However, it is possible that paving dirt roads and walkways will facilitate cleaning and reduce the generation of windblown dust that enters homes. We recommend continuation of the program to pave roads and walkways with exposed soil particularly those areas outside homes.
- Empty lots used by children for recreation should also be evaluated to identify ways to reduce exposures. The program to grow grass on exposed soils and to plant trees is an important contribution to reducing windblown dust in La Oroya and should be continued. One approach to reducing exposure to lead in soil may

be to treat the soil with phosphates that reduce the bioavailability of lead. Studies at sites with elevated levels of lead in soil have shown that phosphate treatment of soils has resulted in the reduction of the bioavailability of lead, and also may stabilize cadmium and zinc in soil (Martin and Ruby 2004). Martin and Ruby (2003) reported success in reducing the bioavailability of both lead and arsenic in soil through amending soil with a mixture of phosphate and iron-based chemicals.

- In other smelter communities, door mats composed of a material that traps dirt have been shown to be an effective means of reducing the amount of contaminated dirt and dust that is tracked into a home. We recommend that the stakeholder group or the Convenio investigate the feasibility of using such mats in La Oroya Antigua.
- According to a 2001 census (DRP 2002a), approximately 40 percent of homes in La Oroya are constructed of adobe, six percent have dirt floors, and an unknown number of homes have roofs/ceilings constructed of corrugated metal sheets or adobe. The walls and ceilings of many adobe homes are covered with plaster, which prevents the sloughing off of dirt into homes. For those homes with walls that are not plastered or covered with other material, there is a possibility that elevated levels of lead and other metals may be present.[9] In addition, it is possible for dustfall to enter homes through cracks in combination roofs/ceilings constructed of corrugated metal. We recommend development of a program of improving homes constructed of adobe with exposed dirt and roofs of corrugated metal sheets to reduce generation of indoor dust, particularly in those homes located closest to the Complex.
- The highest lead concentrations detected in outdoor dust were found at an elementary school in La Oroya Antigua. The elevated lead concentration is likely due to the proximity of the school to the Complex. Because children are likely to contact dust while at school, both classrooms and outdoor play areas should be cleaned more frequently.
- Studies at sites with elevated levels of lead in soil have shown that phosphate treatment of soils has resulted in the reduction of the bioaccessibility of lead, and also may stabilize cadmium and zinc in soil (Martin and Ruby 2004). Martin and Ruby (2003) reported success in reducing the bioavailability of both lead and arsenic in soil through amending soil with a mixture of phosphate and iron-based chemicals. Based on this and other field studies successful in reducing metals bioaccessibility, we recommend using phosphate or other amendment to reduce the bioaccessibility of lead in soil and possibly in the streets.

[9] One dirt sample collected from bare, adobe-walled home (RSOA-08) yielded a lead concentration of 712 mg/kg, wet weight. [USEPA Region 9 risk-based Preliminary Remediation Goal for lead in residential soil is 400 mg/kg, dry weight.]

- It is recommended that the community and DIGESA take action to ensure that leaded gasoline is not being sold in the La Oroya region. Although sales of leaded gasoline were banned after December 2004, we have had reports that some leaded gasoline is still being offered for sale. Consistent with Perú's Decreto Supremo No. 019-98-MTC,[10] the sale and use of leaded gasoline should be prevented to further reduce lead emissions.

7.4 DIETARY STUDIES AND INTERVENTIONS

The pilot dietary study conducted in La Oroya Antigua by the IIN examined intakes of several nutrients that have the potential to affect lead exposure and health effects. The importance of nutritional factors as modulators of lead exposure and toxicity has been reviewed by the CDC (2002).

The CDC identifies ensuring adequate intakes of iron, calcium, and vitamin C as important, noting that "Nutritional measures have not yet been proven to have a clinically important impact on elevated blood lead levels in children. However, children with elevated blood lead levels are often at risk for poor nutrition, and their caregivers should receive nutritional counseling to help these children obtain a well-balanced and age-appropriate diet." Insufficient evidence was found by the CDC to indicate the need for other dietary interventions. In particular, the CDC does not recommend low fat diets or zinc supplementation.

The pilot dietary study conducted by the IIN with a small number of participants from La Oroya Antigua confirmed that iron intakes by women and young children in La Oroya are inadequate. Confidence in this finding is supported by the knowledge that iron intakes are typically inadequate in populations residing in the Peruvian Andes. The pilot dietary study also found that calcium intakes were highly variable, and that many mothers and some children had inadequate intakes of calcium. While not a specific goal of this study, the IIN noted that review of the foods consumed by the study population and food composition tables indicated that vitamin C intake is adequate in La Oroya.

The IIN study also identified food as a significant source of exposure to lead. Although the means by which lead entered the prepared foods was not determined in the study, it is likely that much of the lead was transferred to the foods in the form of settled dust while they were for sale in markets or during contact with settled dust during cooking.

Based on these preliminary findings, additional study and dietary interventions are recommended for La Oroya. Further study is needed to confirm the means by which lead

[10] Decreto Supremo No. 019-98-MTC: Disponen eliminar el Mercado la oferta de Gasolina 95 RON con plomo y reducir el límite máximo de contenido de plomo en la Gasolina 84 RON.

is being transferred to prepared foods, followed by the development of actions and an education program to reduce lead concentrations in food. The second focus of additional studies and interventions should be development of a program to ensure that residents have adequate iron intakes. Adequate iron intakes are particularly important because both low iron intake and high lead intake cause neurobehavioral disorders and anemia. Attention should also be given to ensuring the adequacy of calcium intakes.

Specific recommendations from the CDC for anemia screening, and ensuring adequate iron and calcium intakes are described below, followed by a summary of site-specific recommendations from the IIN.

Iron deficiency screening: The CDC (2002) recommends testing those at risk for anemia (e.g., those from low-income) at the following ages:

- Initially between ages 9 and 12 months
- Six months later
- Annually from ages 2 to 5 years.

When testing for anemia in La Oroya, it will be necessary to consider the expected hemoglobin and hematocrit values for each age group at the elevation of 3,700 meters. Residents of La Oroya may be anemic even when hematocrit and hemoglobin levels are comparable to those of populations residing at sea level.

Iron intake: The CDC (2002) recommends encouraging caregivers to provide children with an adequate intake of iron by:

- Introducing them to iron-fortified cereals and pureed meats at their appropriate developmental stages.
- Providing one serving of lean red meat per day to older children.

The CDC does not recommend giving children iron supplements except under the supervision of a physician or nutritionist and only when iron deficiency or anemia is documented. It also should be remembered that blood lead levels will be an uncertain indicator of lead body burden in iron studies because 99 percent of lead in blood is in red blood cells, so any intervention that causes a significant increase in the hemoglobin concentration will also cause blood lead levels to increase (CDC 2002).

Calcium intake: The CDC (2002) recommends encouraging caregivers to see that children with elevated blood lead levels receive an adequate amount of calcium (500 mg/day for 1 to 3 years of age; 800 mg/day for 4 to 8 years pf age), by:

- Providing them with two servings of dairy products per day, unless they are lactase deficient.
- Providing lactase-deficient children with sufficient dietary calcium from other sources (e.g., broccoli, greens, kidney beans, and calcium-fortified juices).

The CDC does not recommend giving children calcium supplements except under the supervision of a physician or nutritionist. The CDC also does not recommend supplementation in children with elevated blood lead levels beyond the recommended adequate calcium intake levels.

IIN recommendations for dietary studies in La Oroya: The IIN recommends that nutritional interventions be focused on pregnant women and young children. Due to the small size of the pilot study, the IIN recommends that a study with a sample of a greater size be designed and conducted over a longer period and at different times of the year, in order to obtain results that will be representative of the population and to better understand the variability found in this pilot study. The new study is recommended to have the same objectives included in the pilot study, but is proposed to include new elements to answer questions that emerged from the results of the pilot study. Specifically,

- It is recommended that representative samples of different foods be analyzed in order to identify foods that are higher lead contamination.
- It is also recommended that samples of food from the food supply chain be analyzed in order to determine the time when lead contamination occurs (i.e., before foodstuffs enter the market, in the market place, during the handling of foodstuffs at home, food prepared and sold by street vendors, etc.), as well as where the contamination is higher (types of markets, their location) in order to find spots and strategies to reduce lead contamination through food.

The results of these analyses could provide the information needed to design an educational program to help residents reduce intake of lead in the diet.

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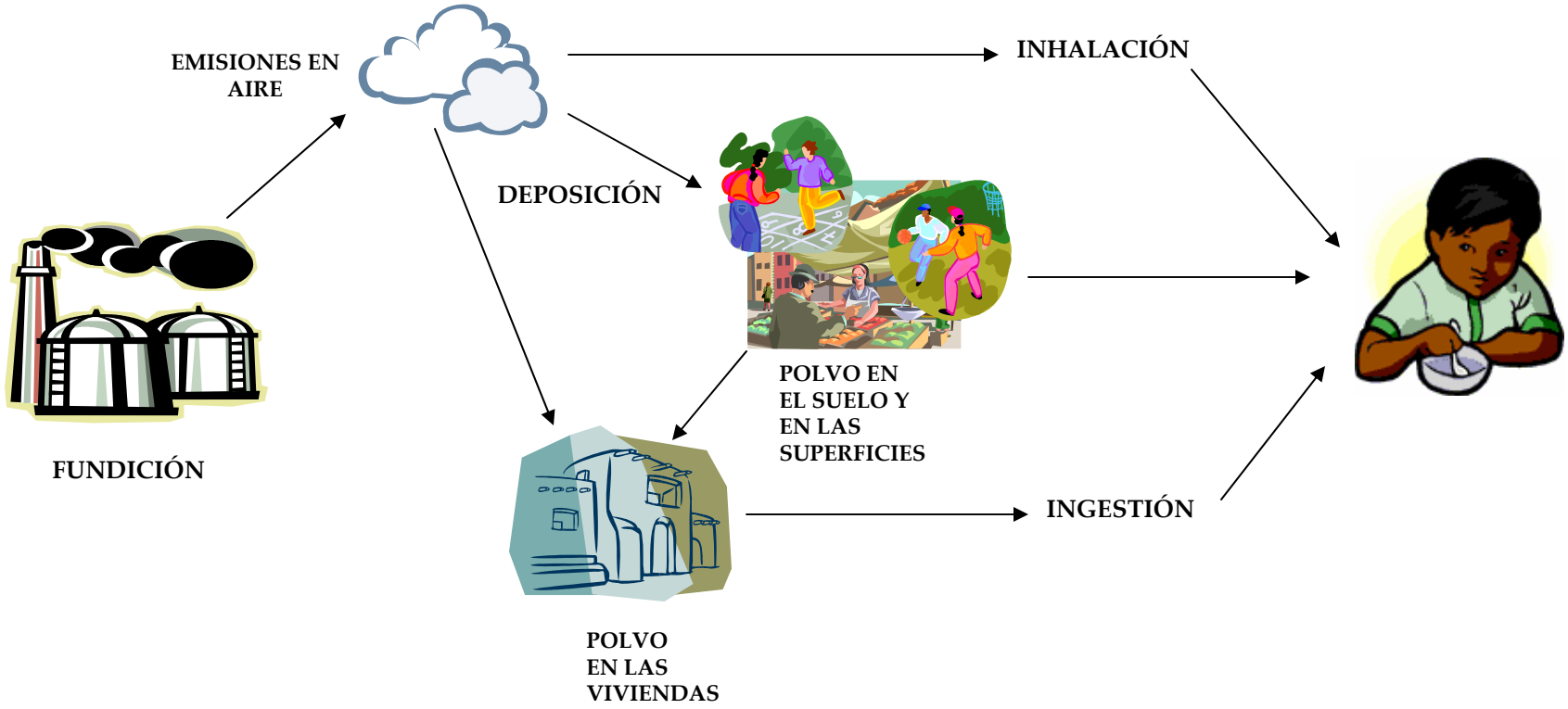

Figure 2-1. Exposure Pathways for Emissions from the Complex (Fuentes de Exposición a Emisiones)

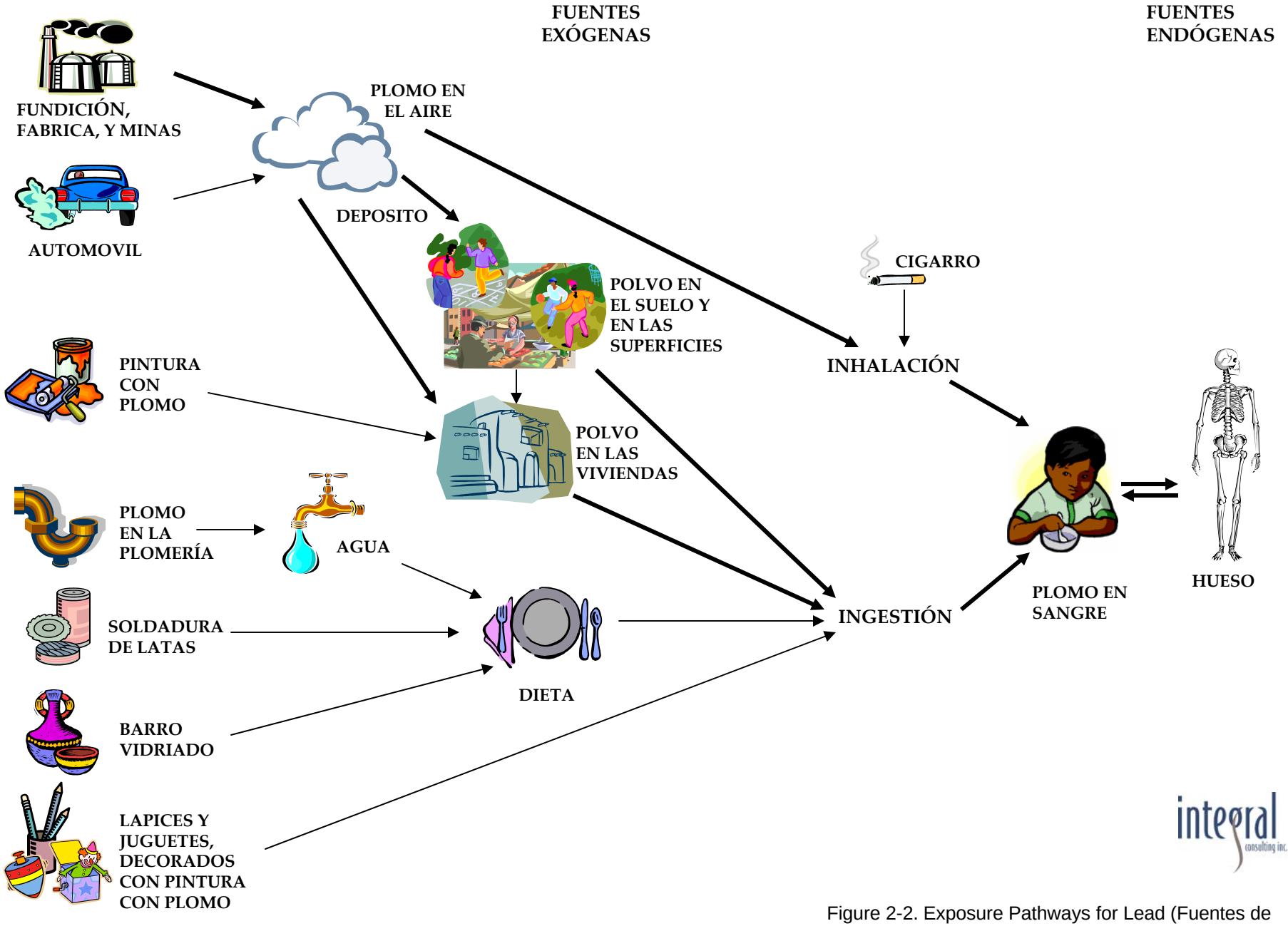

Figure 2-2. Exposure Pathways for Lead (Fuentes de Exposición a Plomo)

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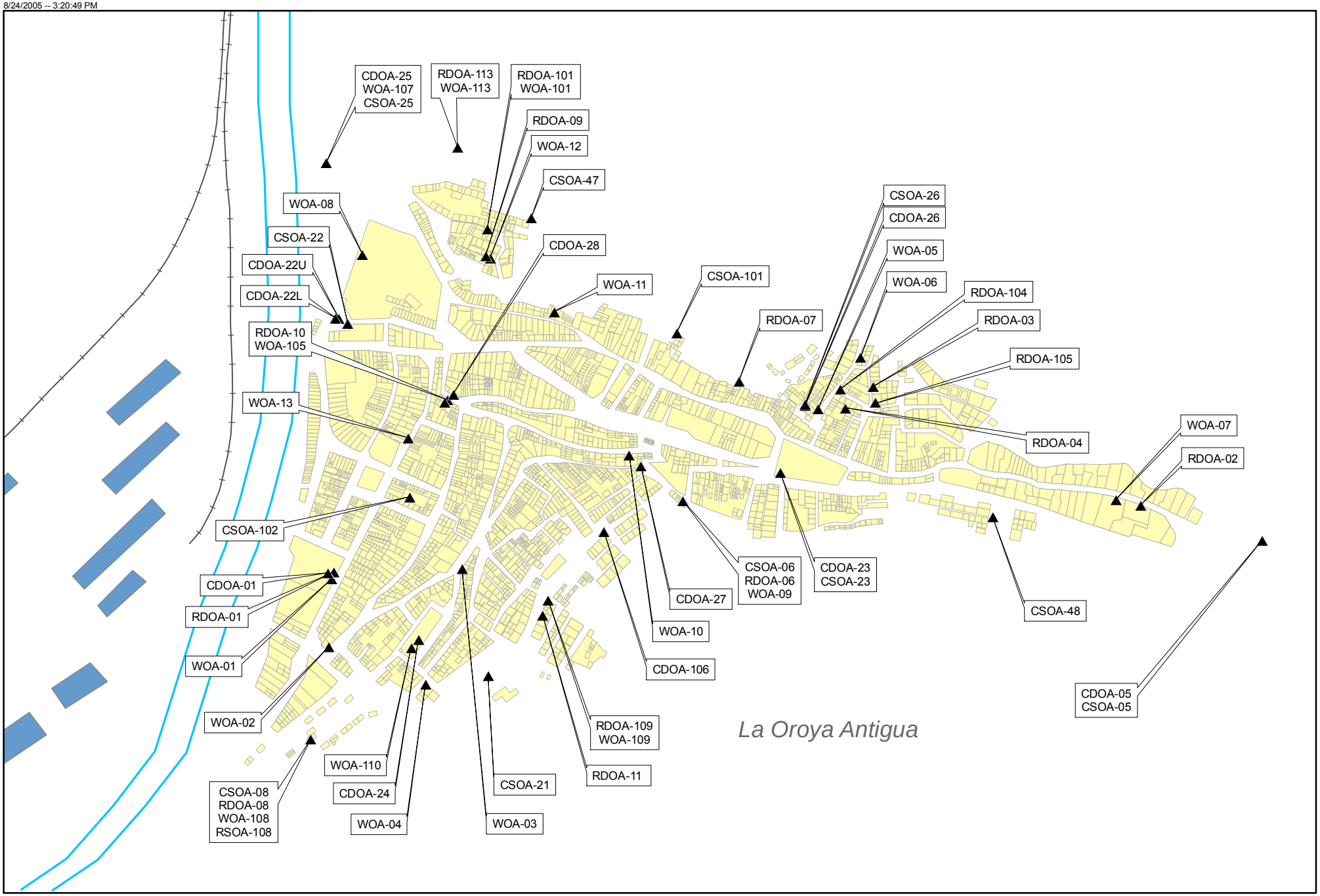

Leyenda:

- ▲ Ubicación de Muestra
  - RDXX-XX = Polvo de Vivienda
  - RSXX-XX = Suelo de Vivienda
  - CSXX-XX = Suelo de Comunidad
  - CDXX-XX = Polvo de Comunidad
  - WXX-XX = Agua Domestica
- Ferrocarril
- Fundición
- Edificios

0 20 40 Meters

Figura 3-1.
Ubicaciones de Muestras de Polvo, Suelo, y Agua
La Oroya Antigua

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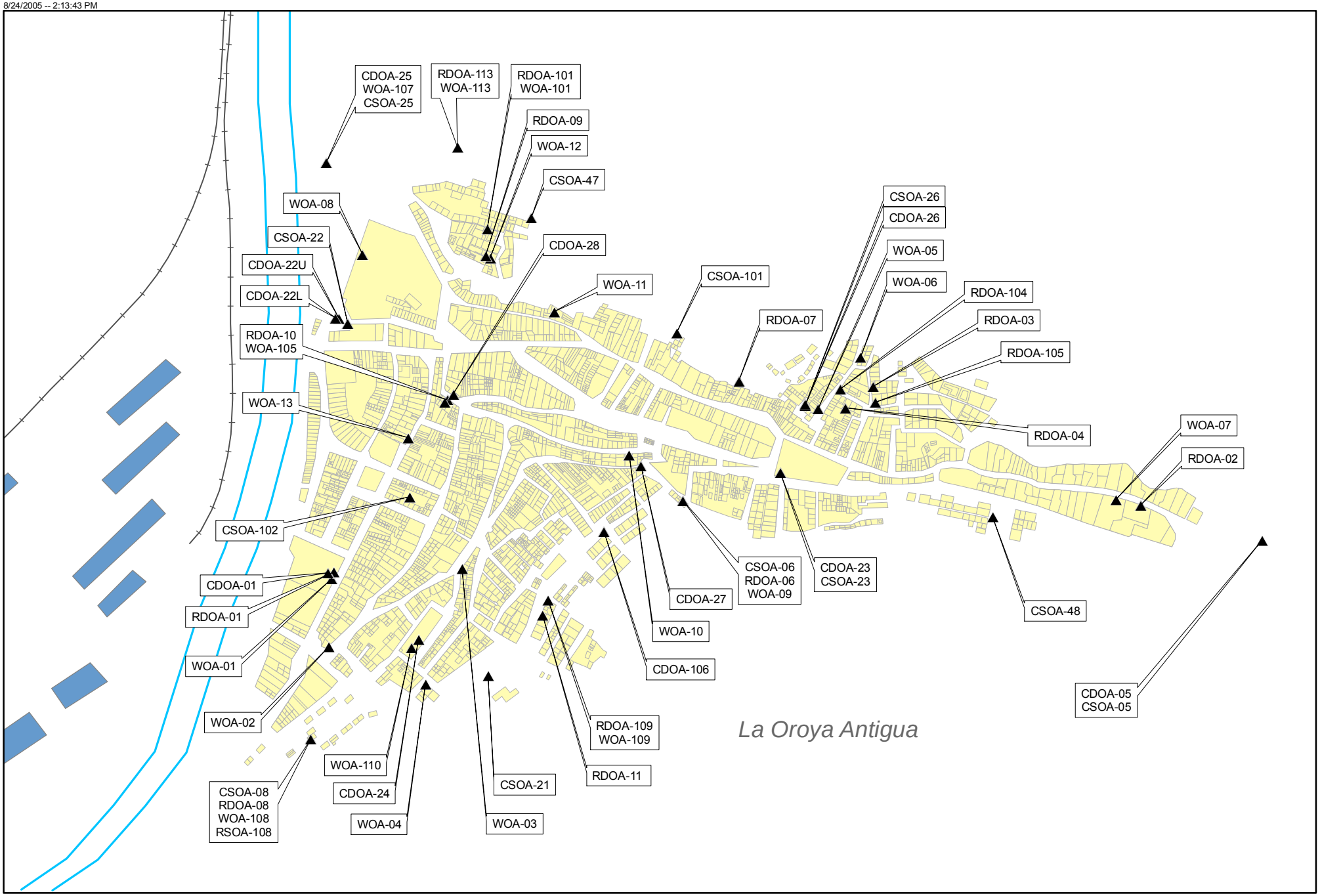

integral consulting inc.

Legend:

- Sample Collection Location
  - RDXX-XX = Residential Dust
  - RSXX-XX = Residential Soil
  - CSXX-XX = Community Soil
  - CDXX-XX = Community Dust
  - WXX-XX = Drinking Water
- Railroad
- Smelter
- Buildings

0 20 40 Meters

Figure 3-1.
Sample Collection Locations for Dust, Soil, Water
La Oroya Antigua

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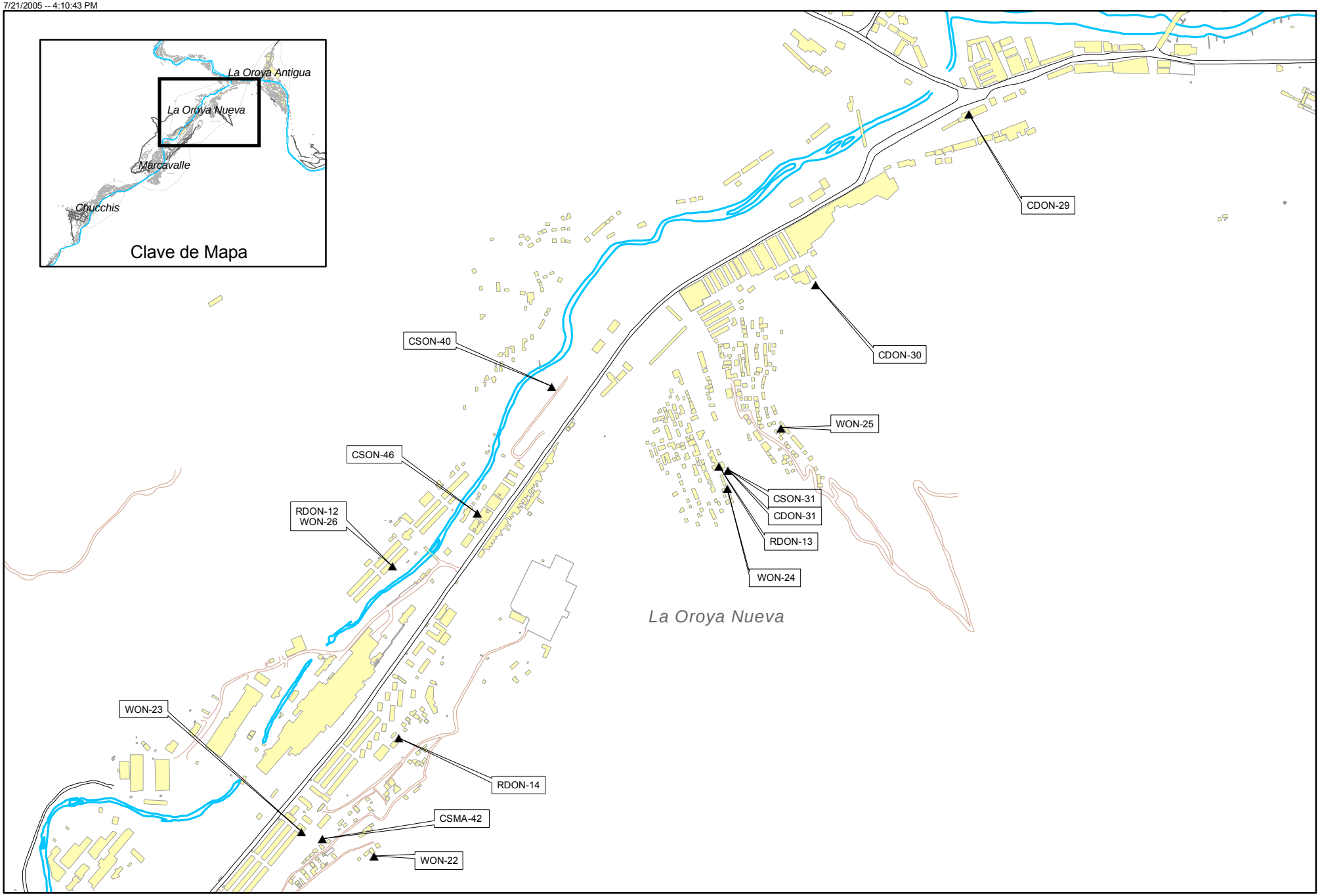

Leyenda:

▲ Ubicación de Muestra
RDXX-XX = Polvo de Vivienda
RSXX-XX = Suelo de Vivienda
CSXX-XX = Suelo de Comunidad
CDXX-XX = Polvo de Comunidad
WXX-XX = Agua Domestica

Carretera
Estructuras
Edificios

N

0 20 40 Metros

Figura 3-2.
Ubicaciones de Muestras de Polvo, Suelo, y Agua
La Oroya Nueva

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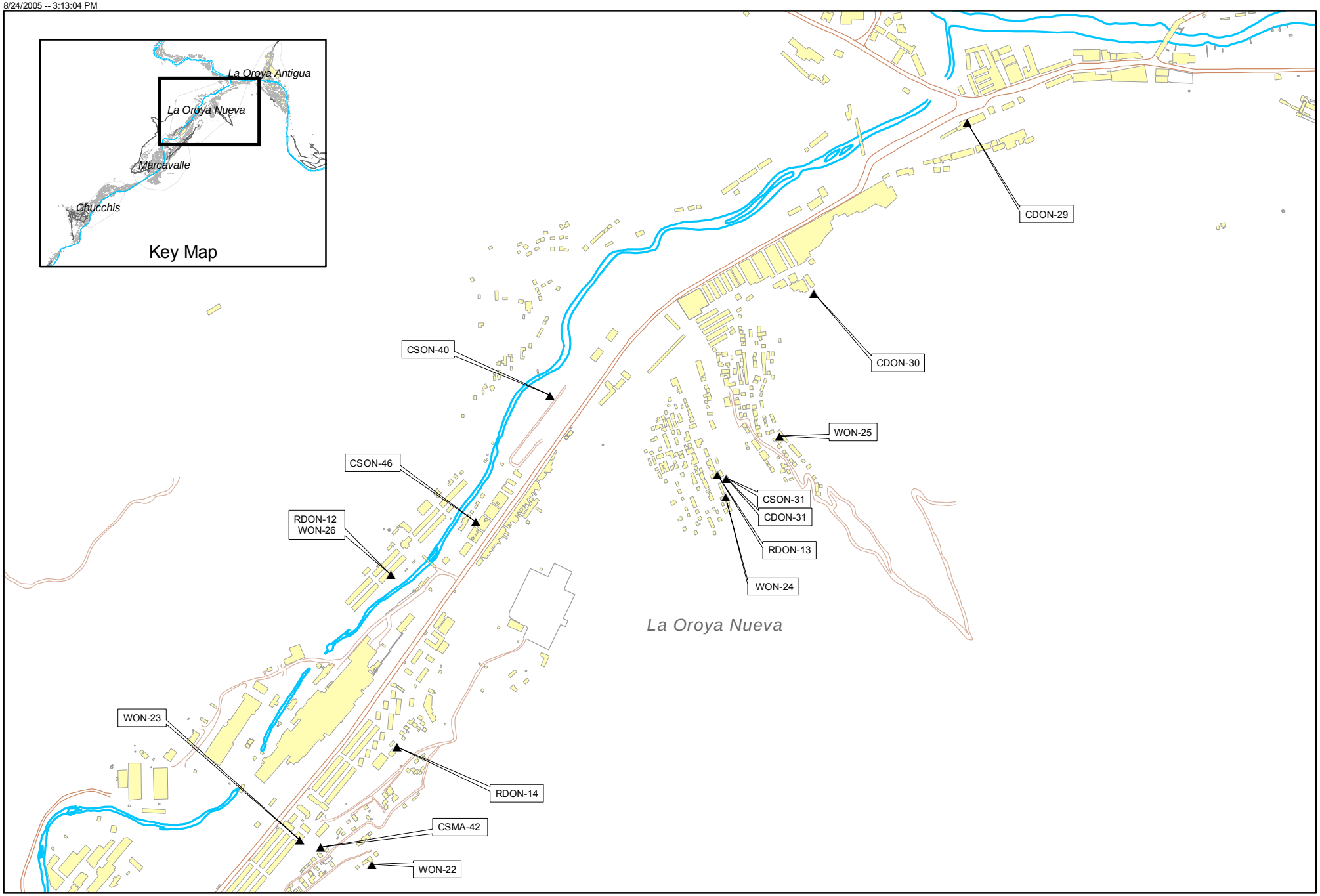

Legend:

- ▲ Sample Collection Location
  - RDXX-XX = Residential Dust
  - RSXX-XX = Residential Soil
  - CSXX-XX = Community Soil
  - CDXX-XX = Community Dust
  - WXX-XX = Drinking Water
- Roads
- Structures
- Buildings

N

0 20 40 Meters

Figure 3-2.
Sample Collection Locations for Dust, Soil, Water
La Oroya Nueva

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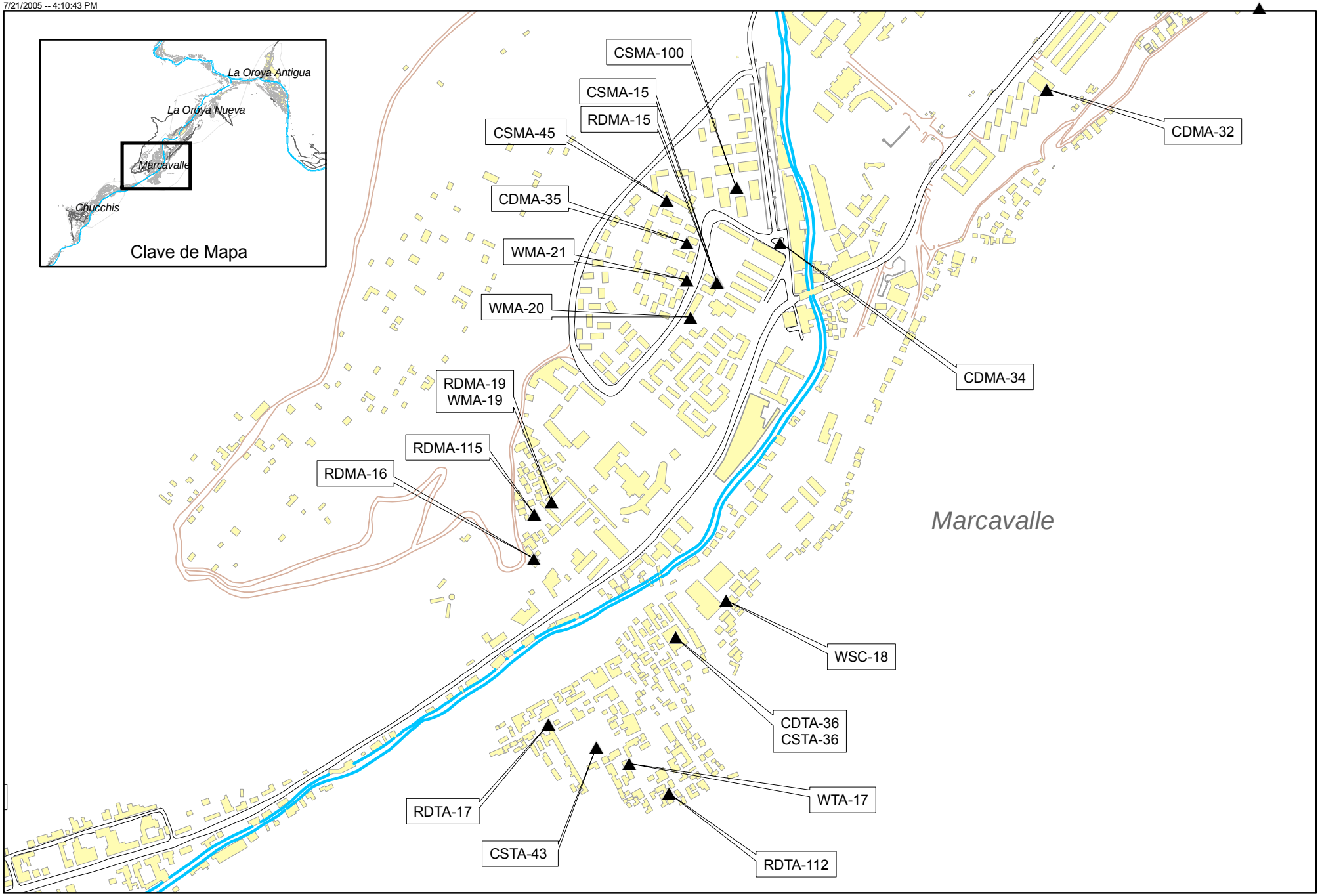

Leyenda:

▲ Ubicación de Muestra
RDXX-XX = Polvo de Vivienda
RSXX-XX = Suelo de Vivienda
CSXX-XX = Suelo de Comunidad
CDXX-XX = Polvo de Comunidad
WXX-XX = Agua Domestica

Carretera
Estructuras
Edificios

N

0 20 40 Metros

Figura 3-3.
Ubicaciones de Muestras de Polvo, Suelo, y Agua
Marcavalle

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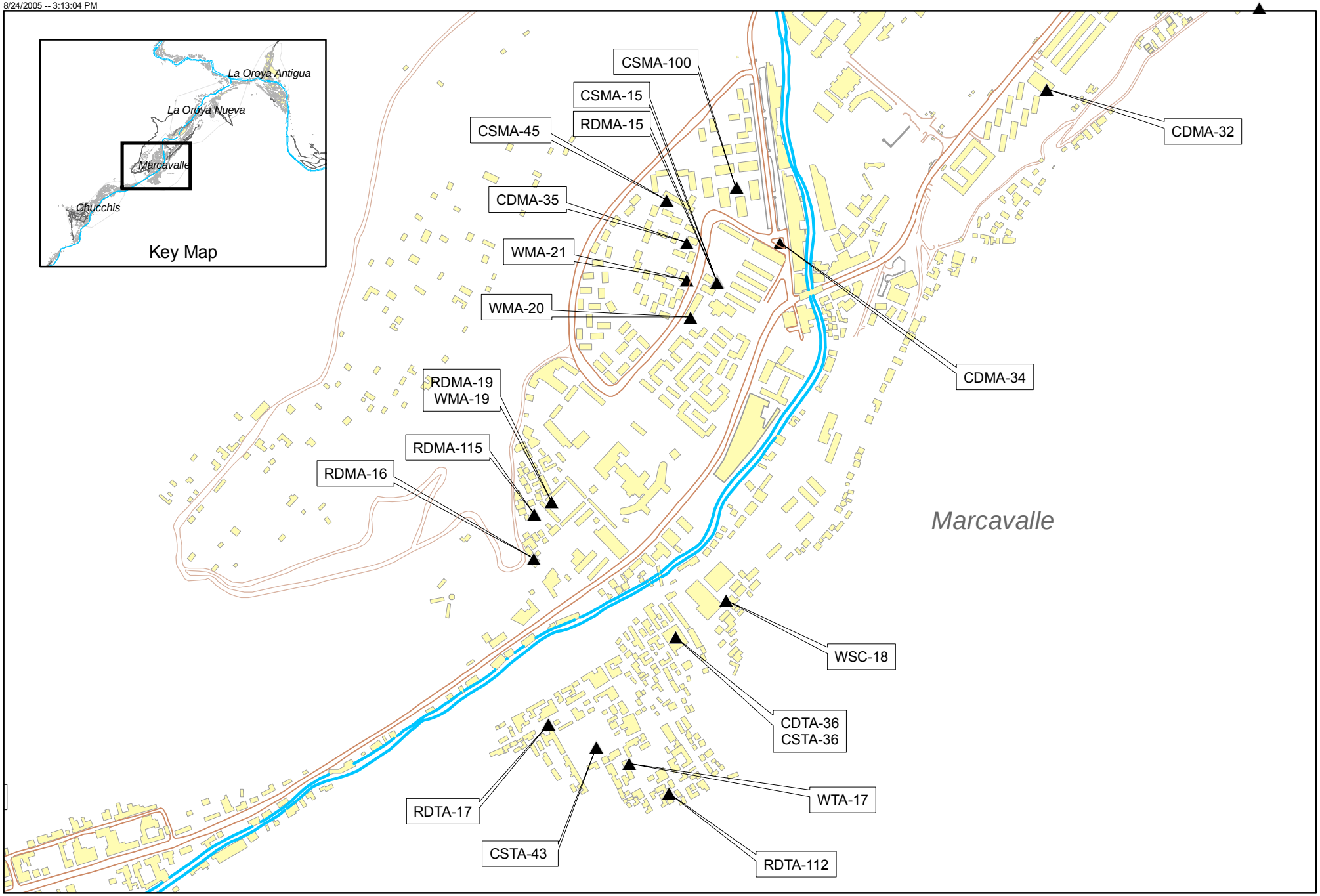

Legend:

- ▲ Sample Collection Location
  - RDXX-XX = Residential Dust
  - RSXX-XX = Residential Soil
  - CSXX-XX = Community Soil
  - CDXX-XX = Community Dust
  - WXX-XX = Drinking Water
- Roads
- Structures
- Buildings

N

0 20 40 Meters

Figure 3-3.
Sample Collection Locations for Dust, Soil, Water
Marcavalle

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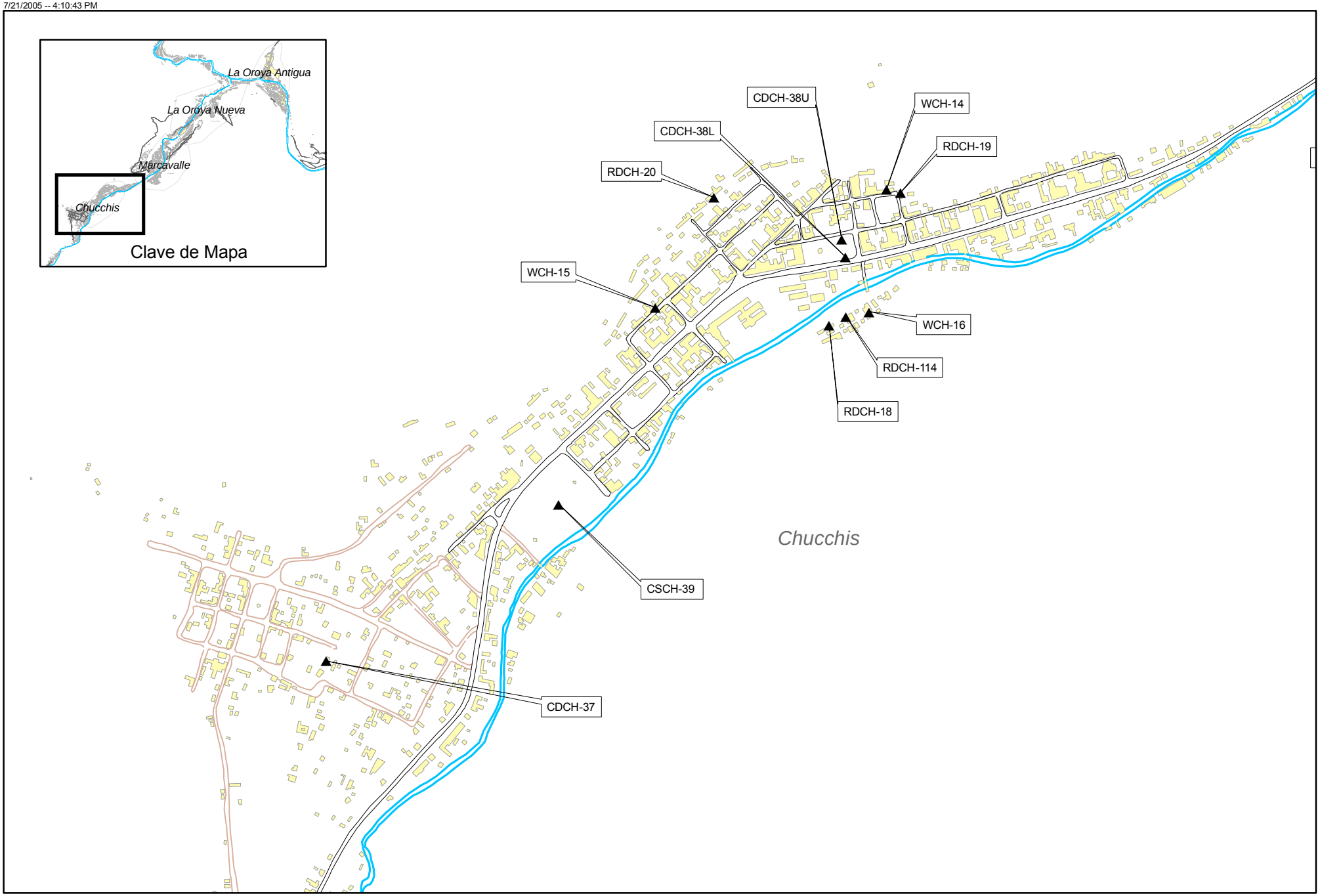

Leyenda:

▲ Ubicación de Muestra
RDXX-XX = Polvo de Vivienda
RSXX-XX = Suelo de Vivienda
CSXX-XX = Suelo de Comunidad
CDXX-XX = Polvo de Comunidad
WXX-XX = Agua Domestica

Carretera
Estructuras
Edificios

N

0 20 40 Metros

Figura 3-4.
Ubicaciones de Muestras de Polvo, Suelo, y Agua
Chucchis

Map Document: (C:\GIS\Projects\Doe_Run\Doe Run_Fig3_2-4.mxd)
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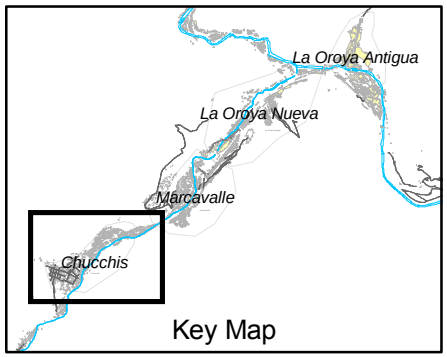

CDCH-38U
WCH-14
CDCH-38L
RDCH-19
RDCH-20
WCH-15
WCH-16
RDCH-114
RDCH-18
Chucchis
CSCH-39
CDCH-37

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Legend:

- ▲ Sample Collection Location
  - RDXX-XX = Residential Dust
  - RSXX-XX = Residential Soil
  - CSXX-XX = Community Soil
  - CDXX-XX = Community Dust
  - WXX-XX = Drinking Water
- Roads
- Structures
- Buildings

N

0 20 40 Meters

Figure 3-4.
Sample Collection Locations for Dust, Soil, Water
Chucchis

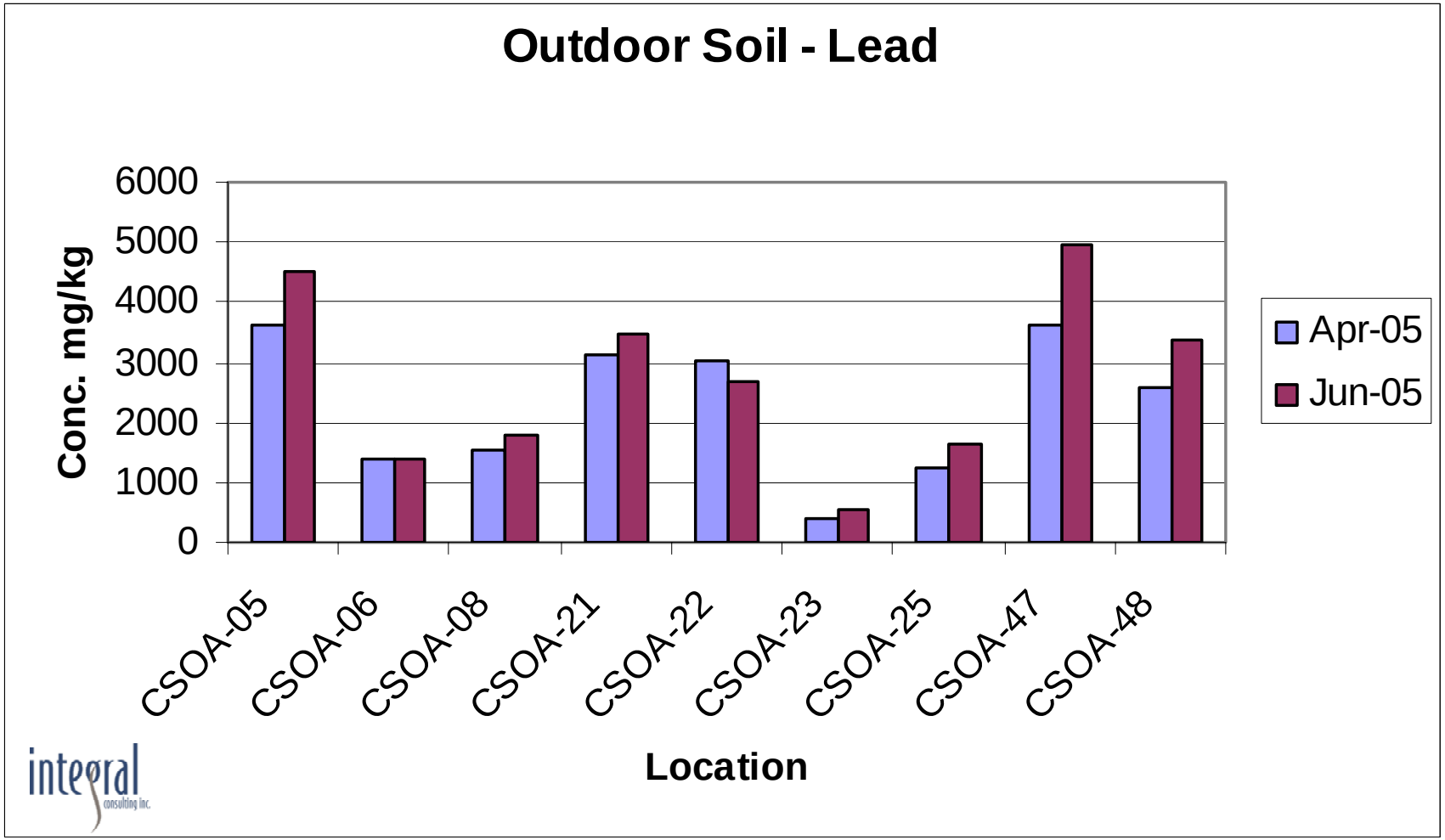

Figure 3-5. Lead In Outdoor Soil in La Oroya Antigua

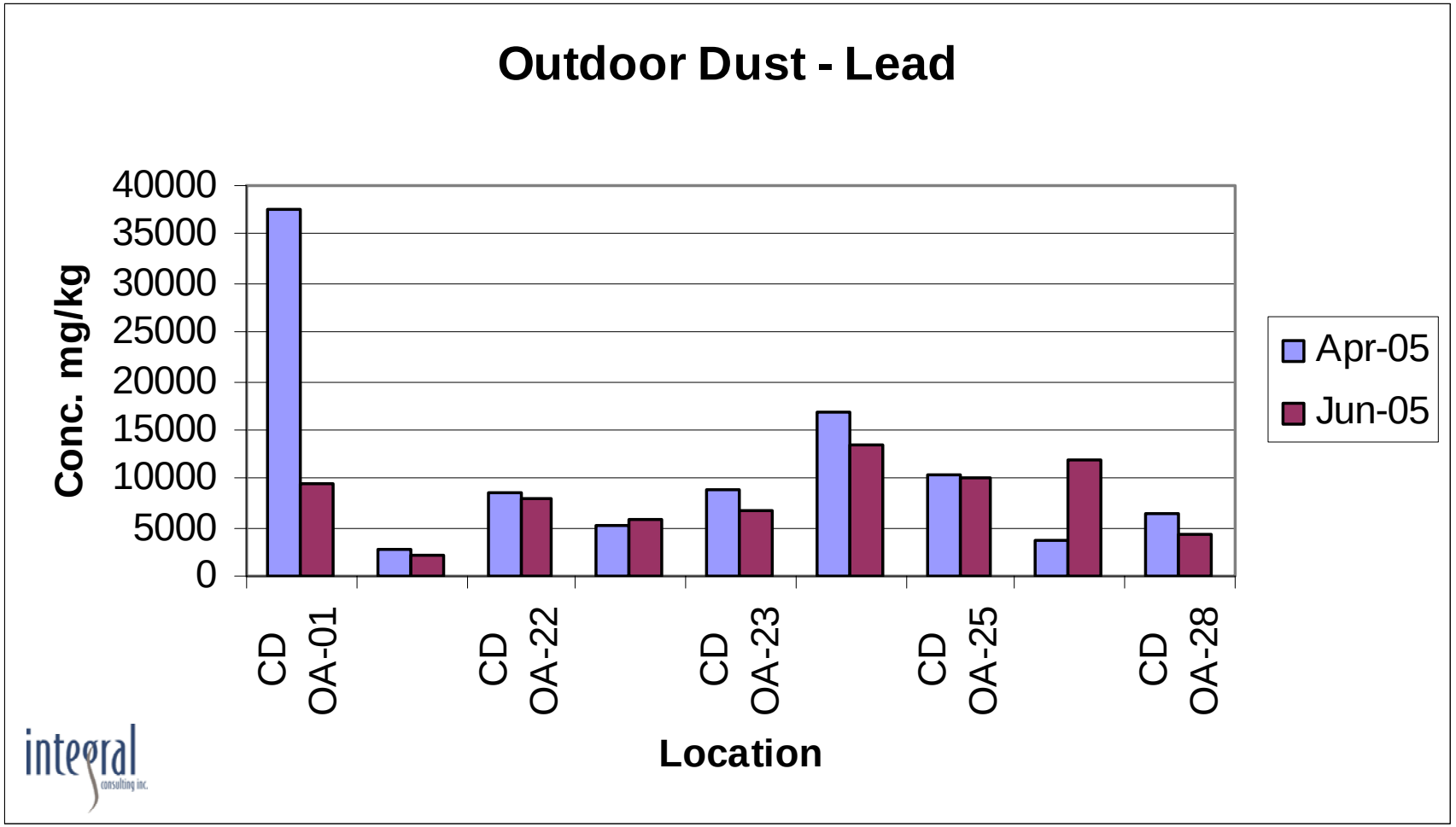

Figure 3-6. Lead in Outdoor Dust in La Oroya Antigua

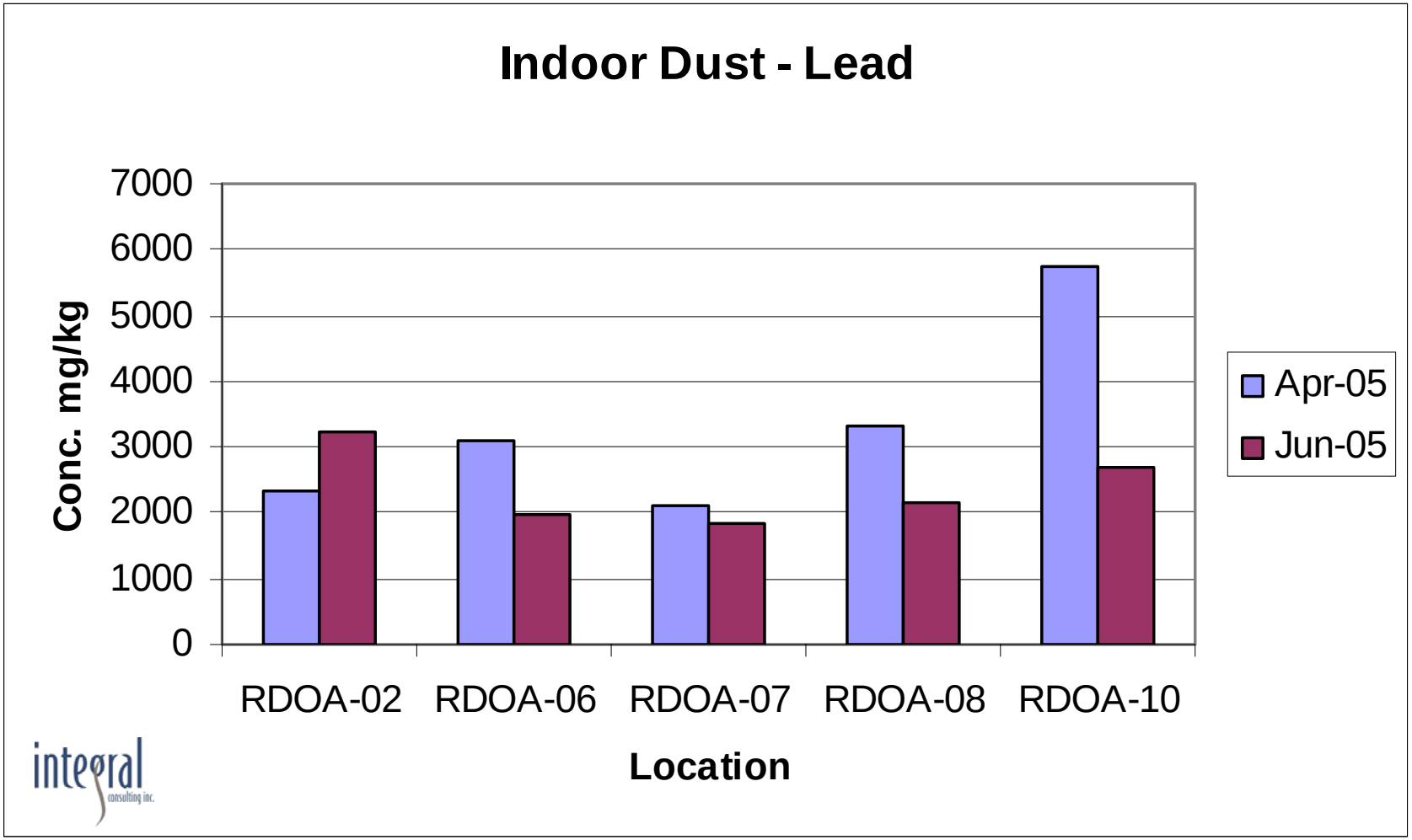

Figure 3-7. Lead in Indoor Dust in La Oroya Antigua

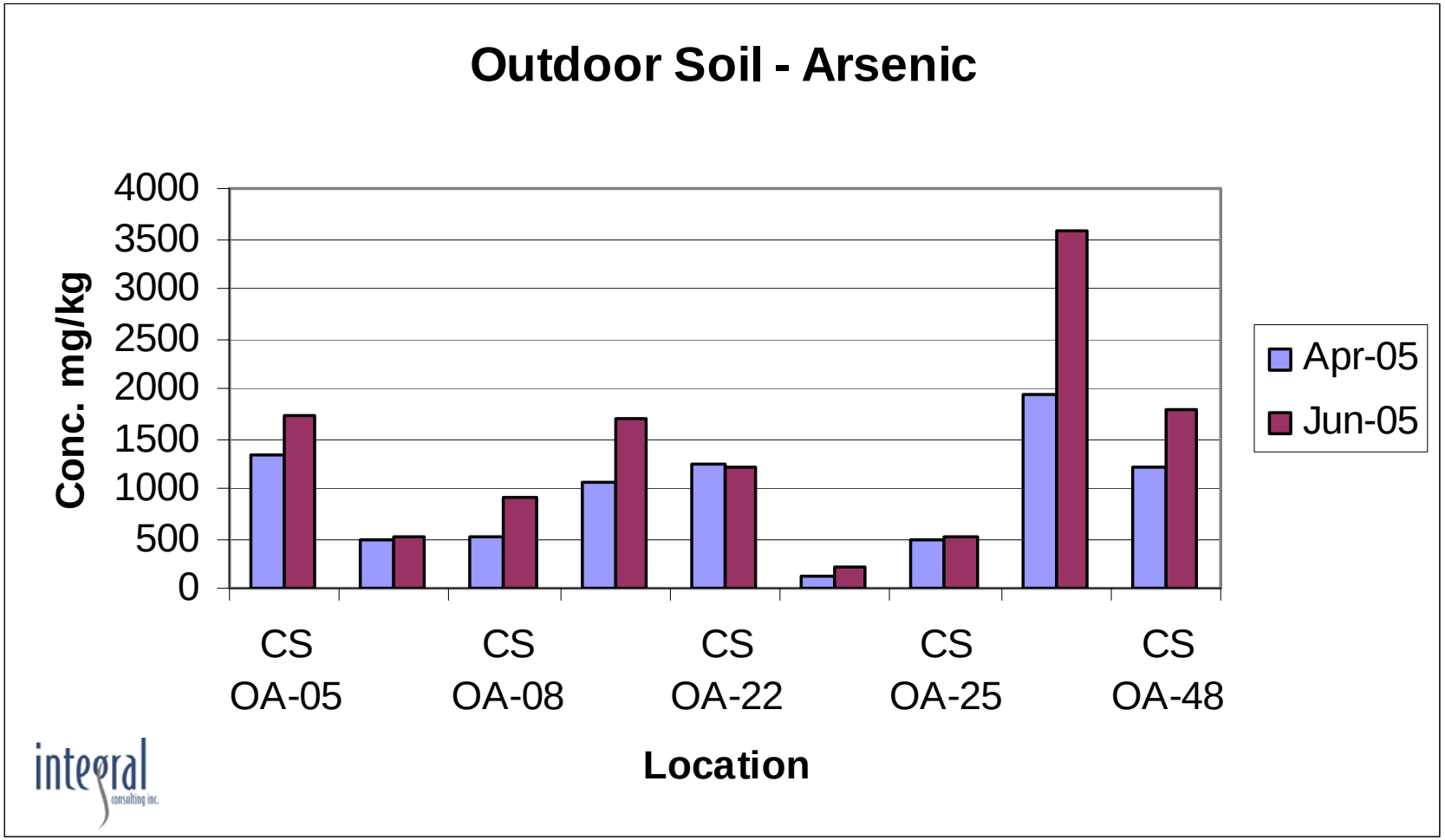

Figure 3-8. Arsenic in Outdoor Soil in La Oroya Antigua

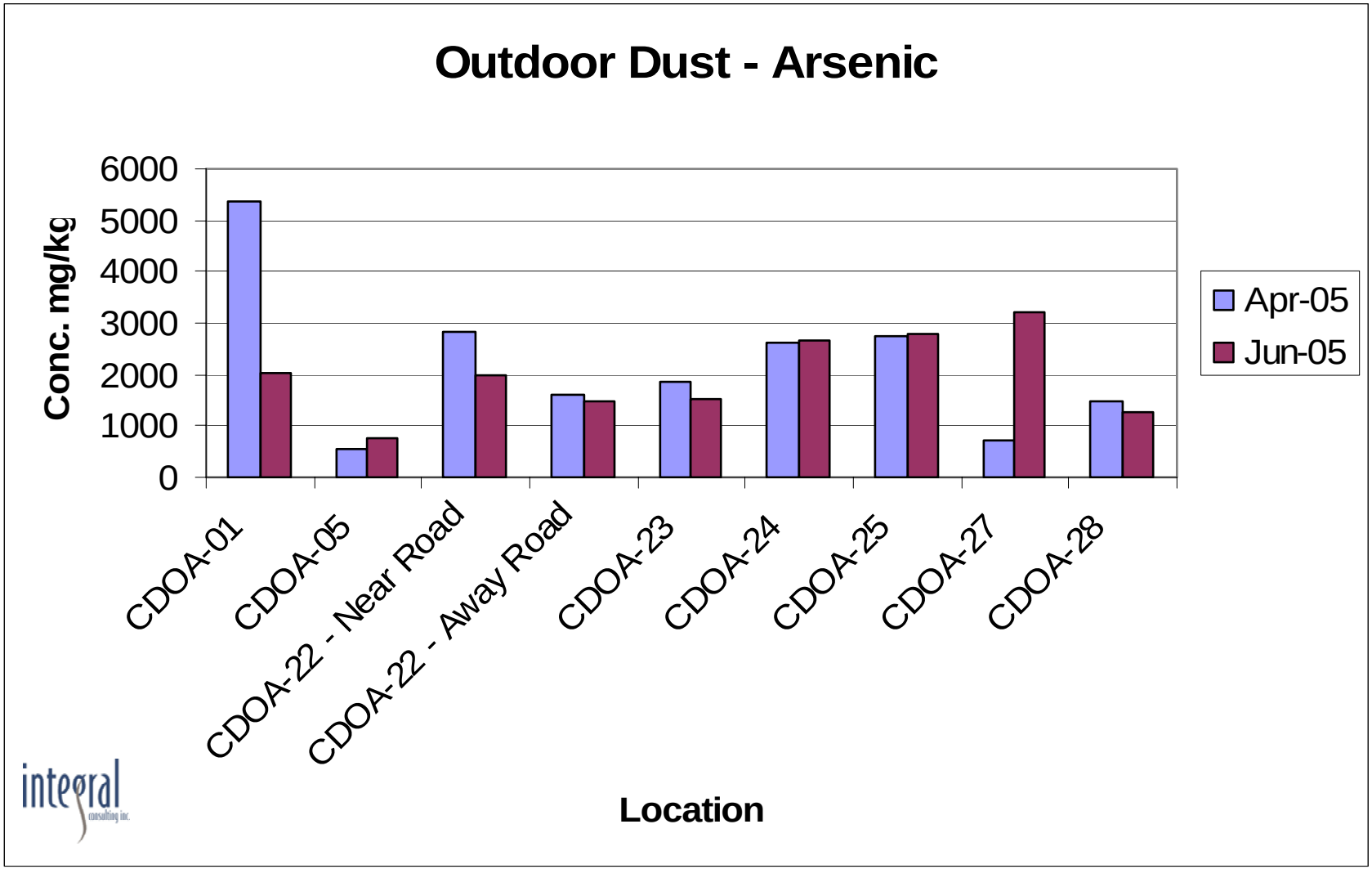

Figure 3-9. Arsenic in Outdoor Dust in La Oroya Antigua

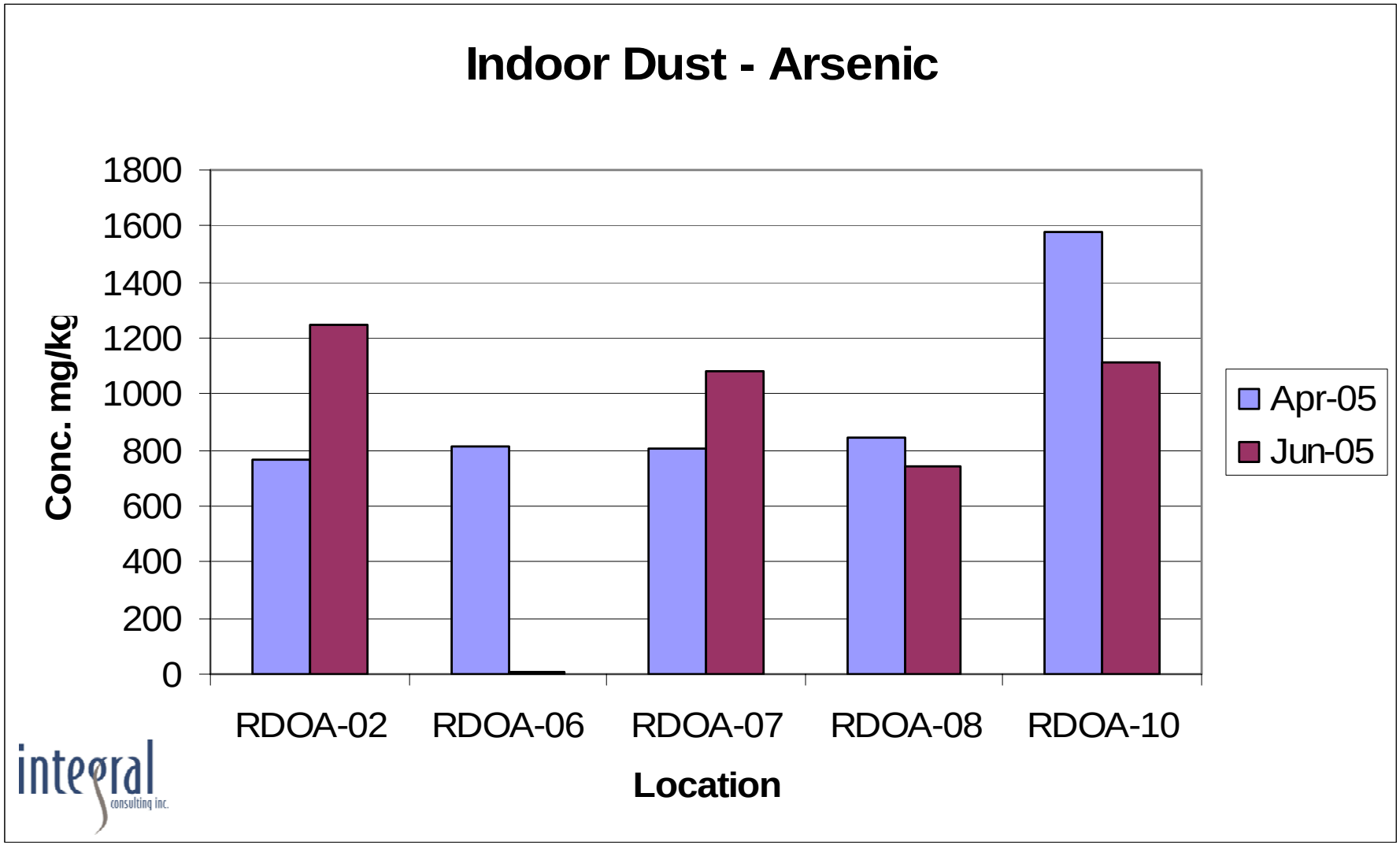

Figure 3-10. Arsenic in Indoor Dust in La Oroya Antigua

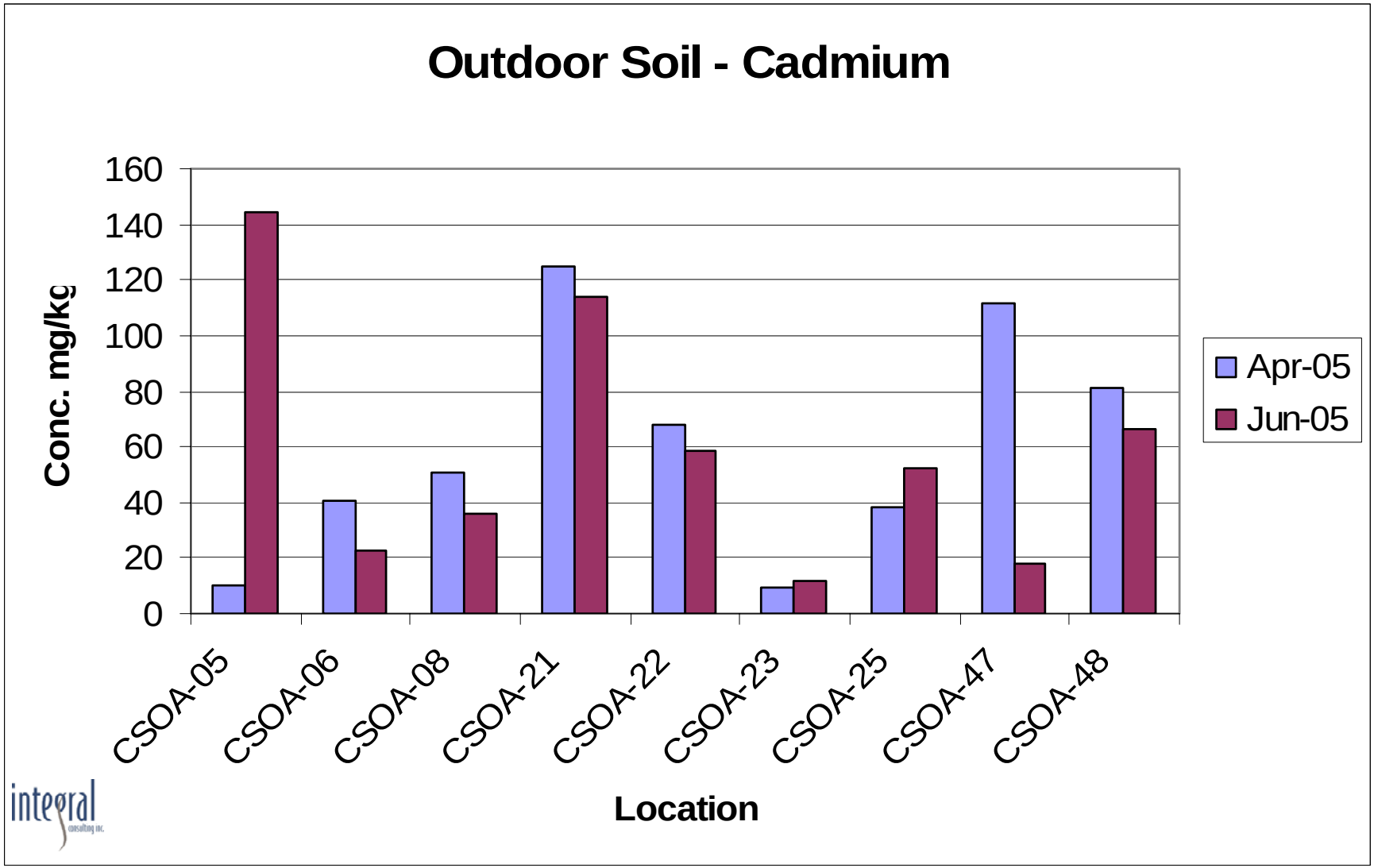

Figure 3-11. Cadmium in Outdoor Soil in La Oroya Antigua

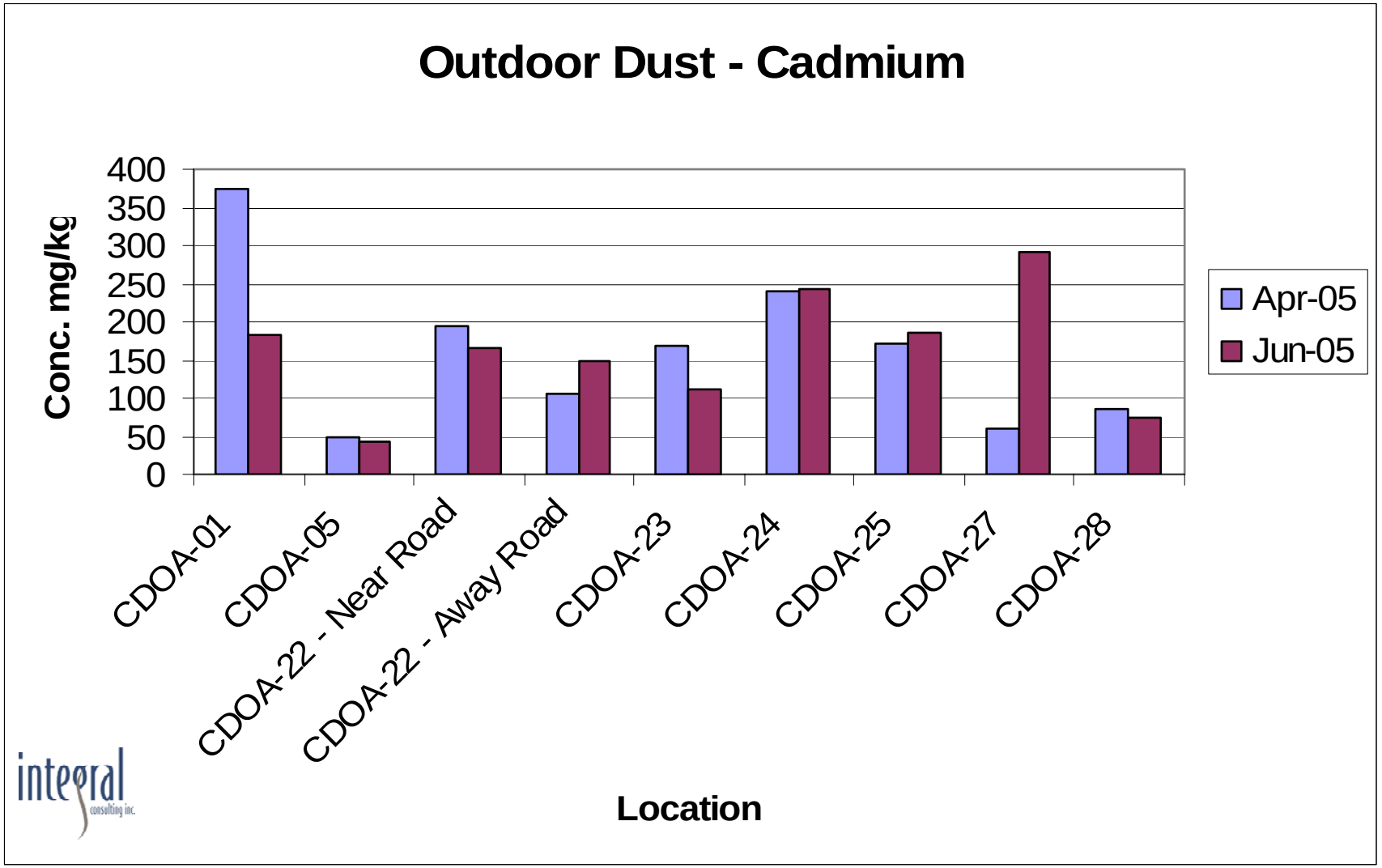

Figure 3-12. Cadmium in Outdoor Dust in La Oroya Antigua

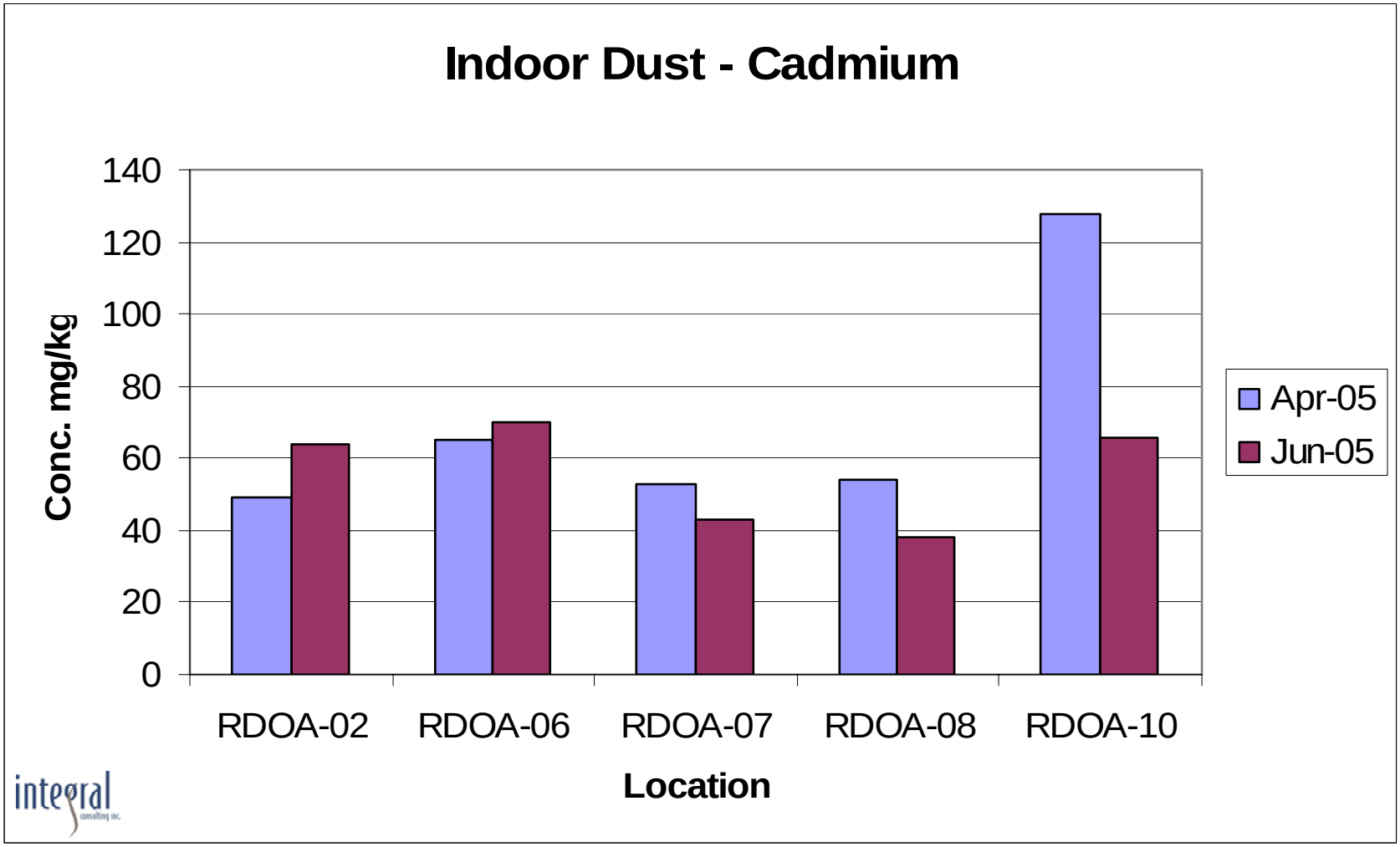

Figure 3-13. Cadmium in Indoor Dust in La Oroya Antigua

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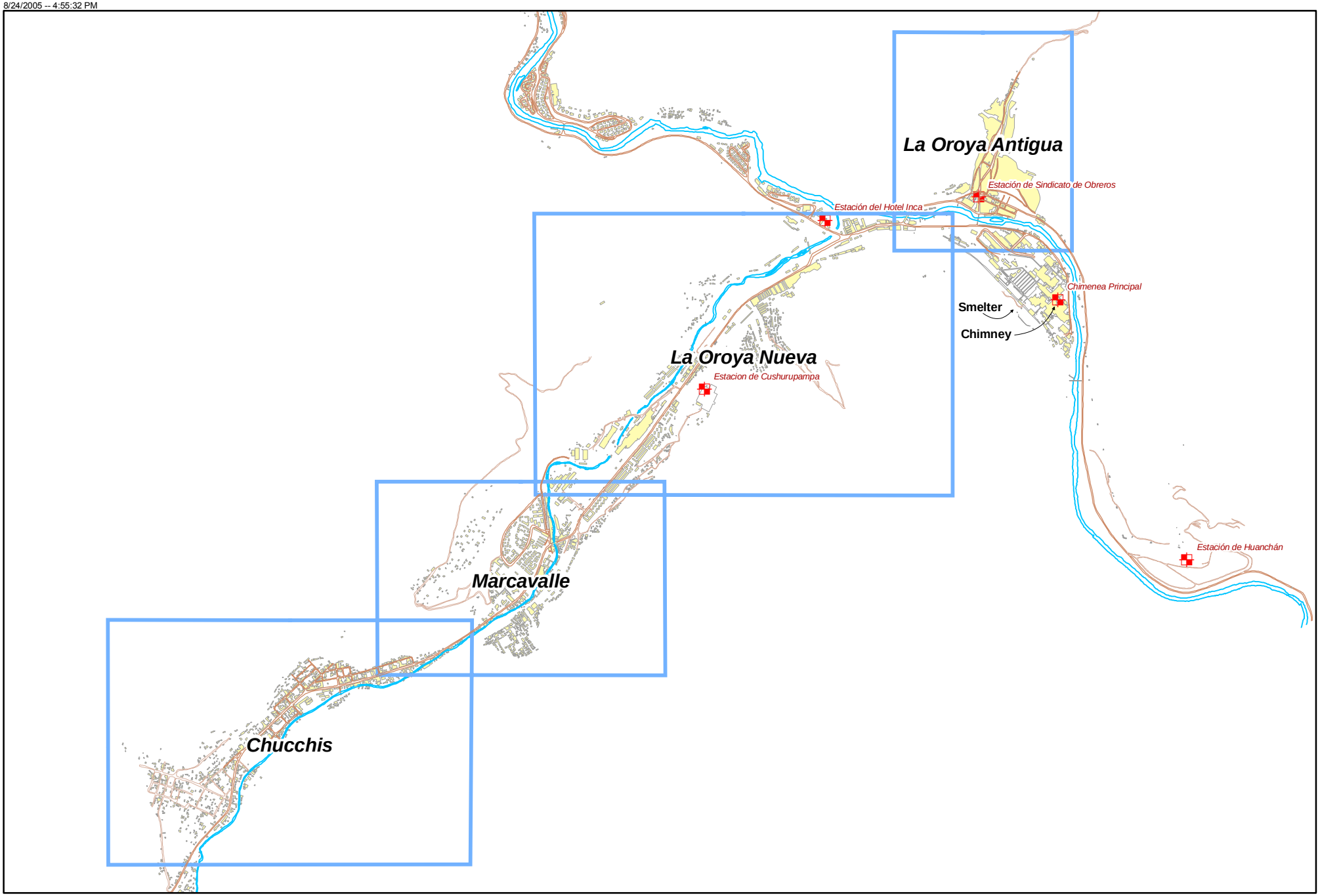
8/24/2005 -- 4:55:32 PM



integral consulting inc.

Legend:
- Air Monitoring Station
- Roads
- Structures
- Buildings
- Communities

N

0 100 200 Meters

Figure 4-1. Vicinity Map Communities and Monitoring Stations

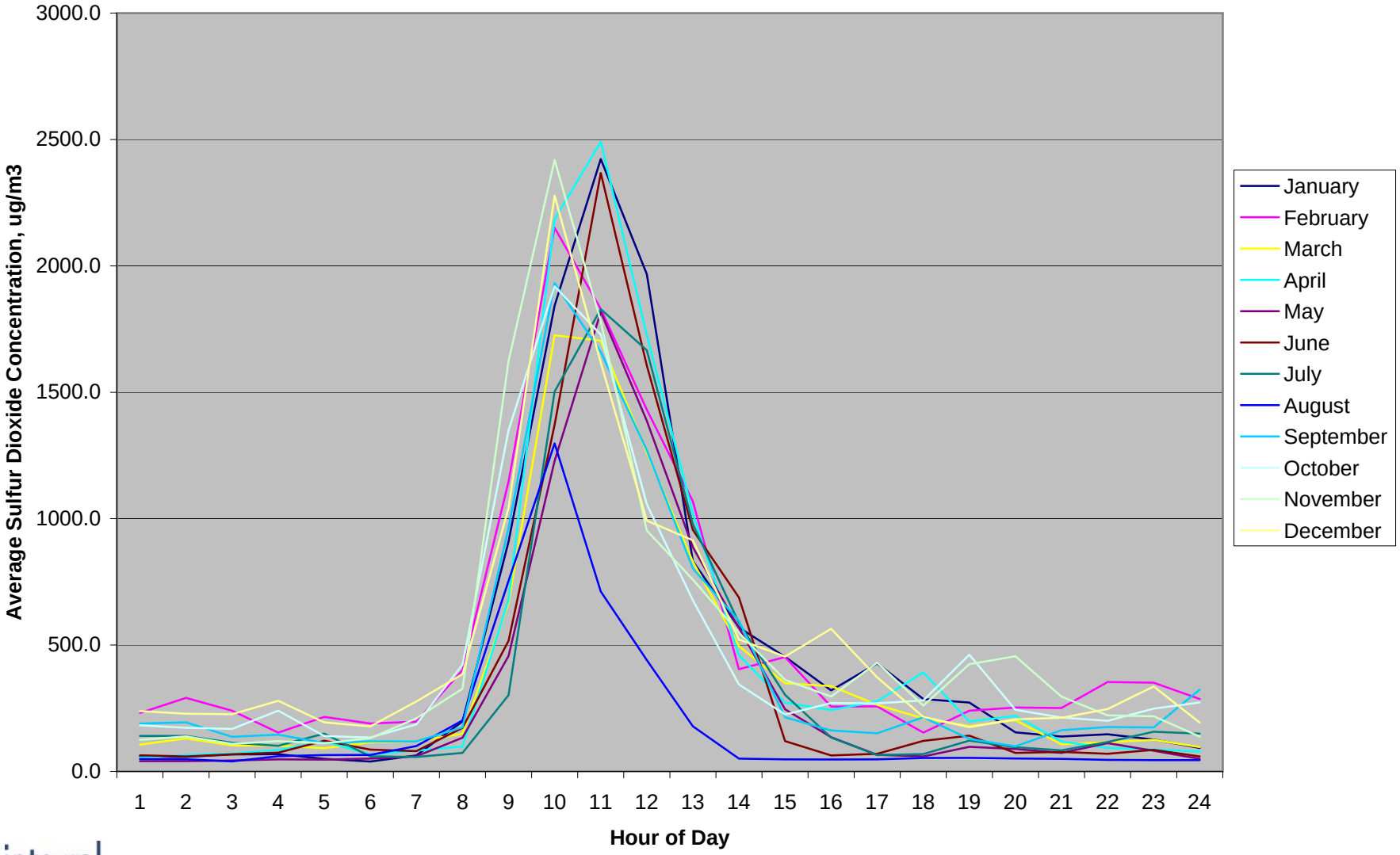


Figure 4-2. Average Hourly Sulfur Dioxide Concentration by Month, Sindicato Monitor.

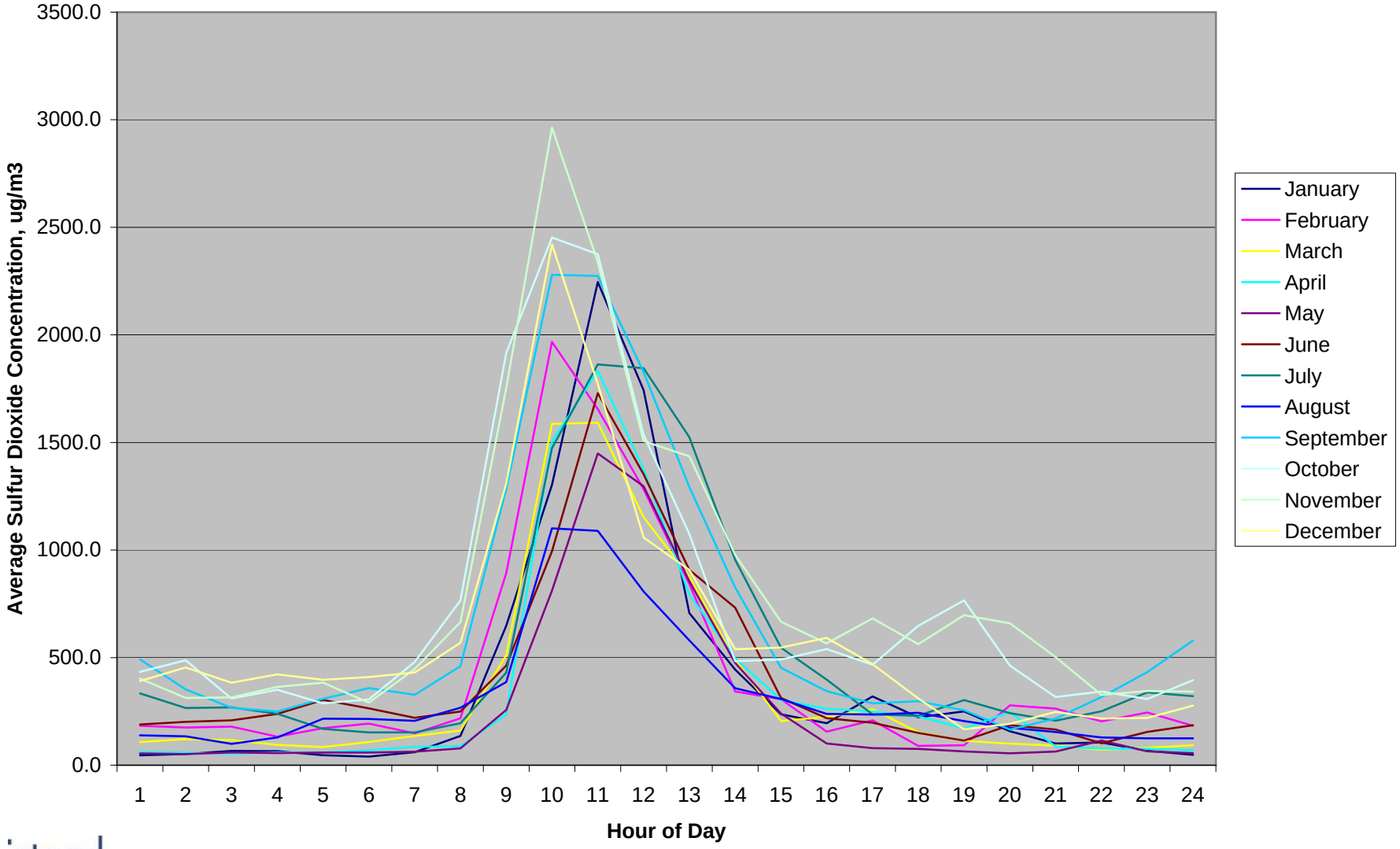


Figure 4-3. Average Hourly Sulfur Dioxide Concentration by Month, Hotel Inca Monitor.

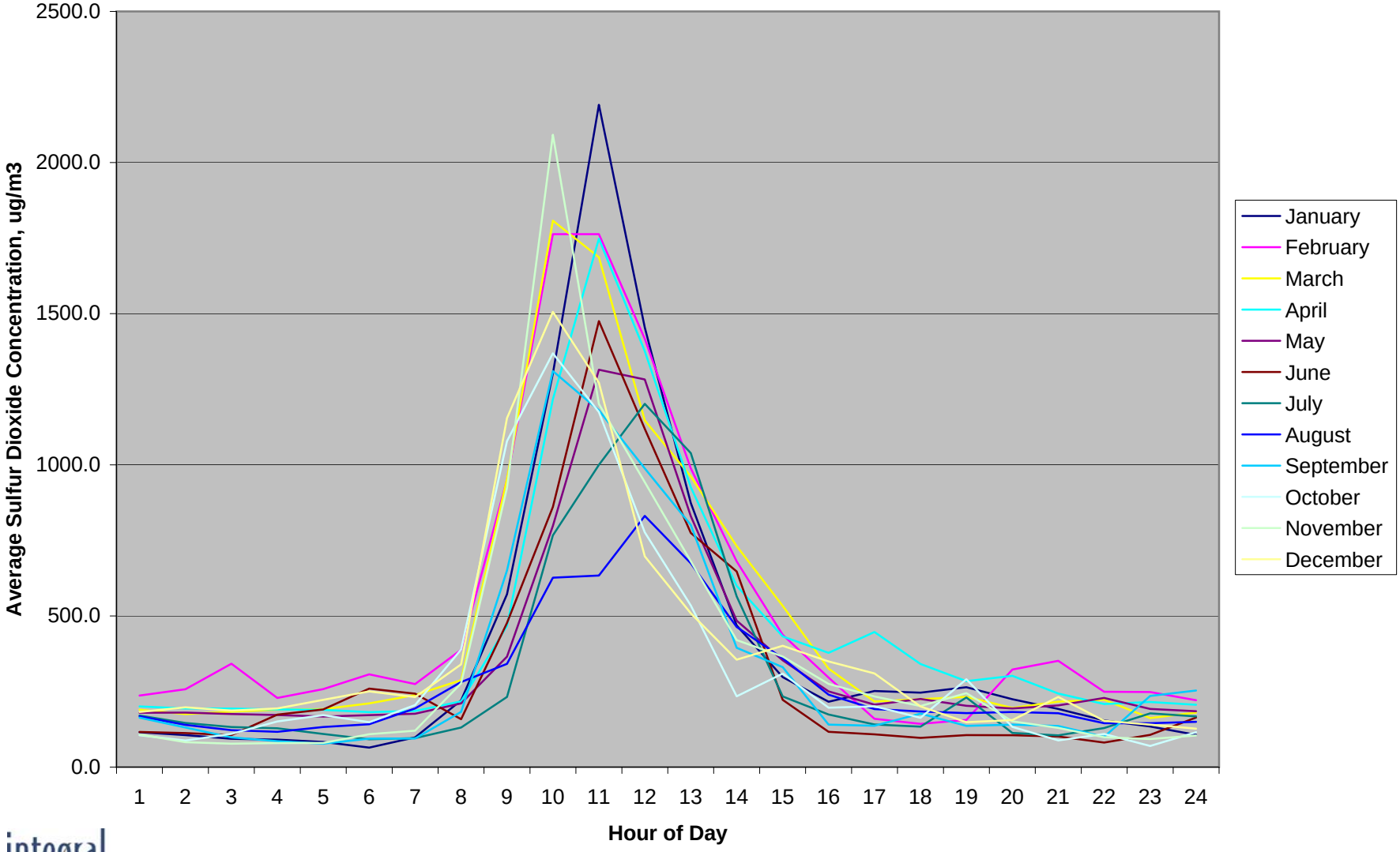


Figure 4-4. Average Hourly Sulfur Dioxide Concentration by Month, Cushurupampa Monitor.

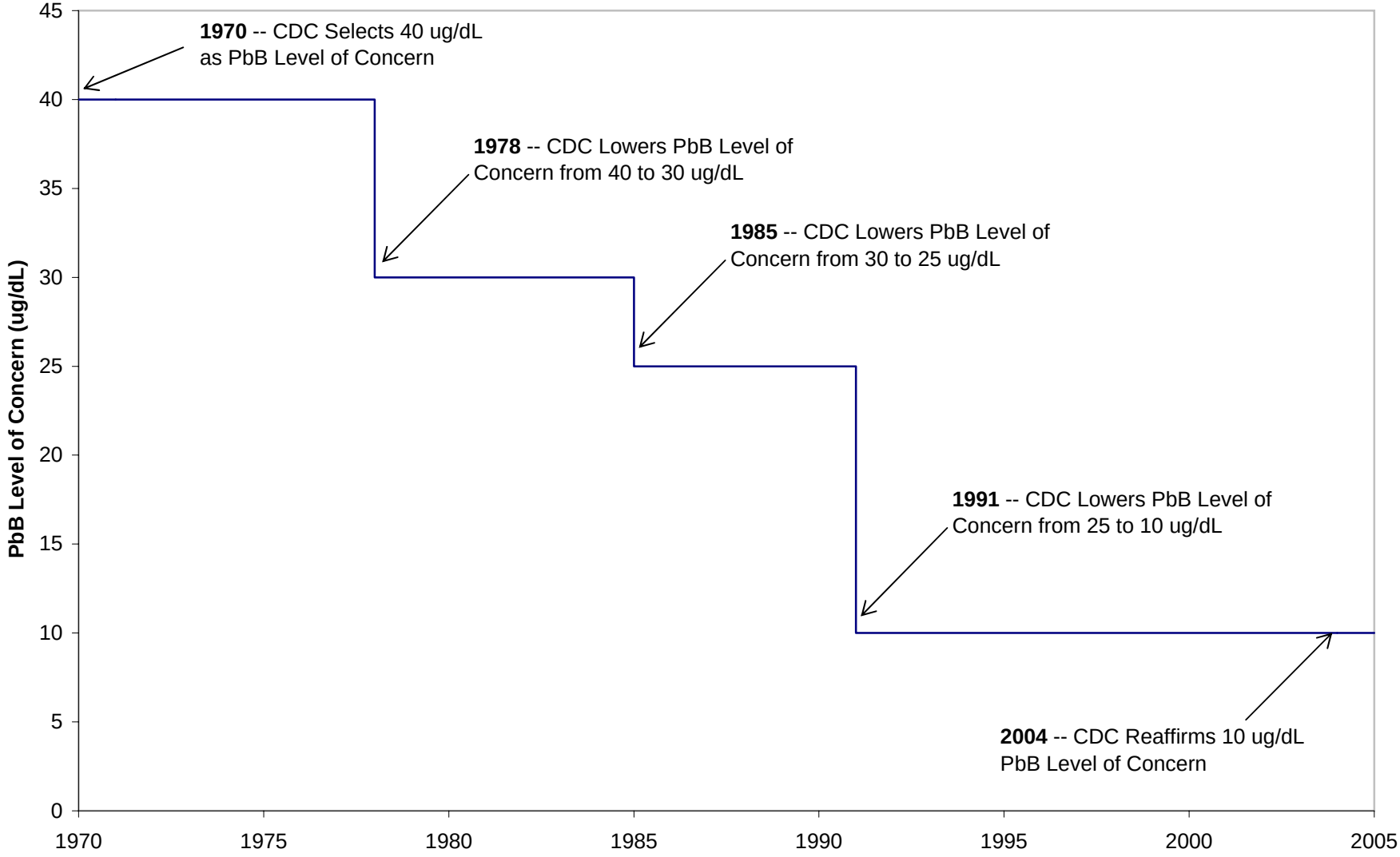


Figure 5-1. Historical Blood Lead Levels of Concern Selected by the CDC.

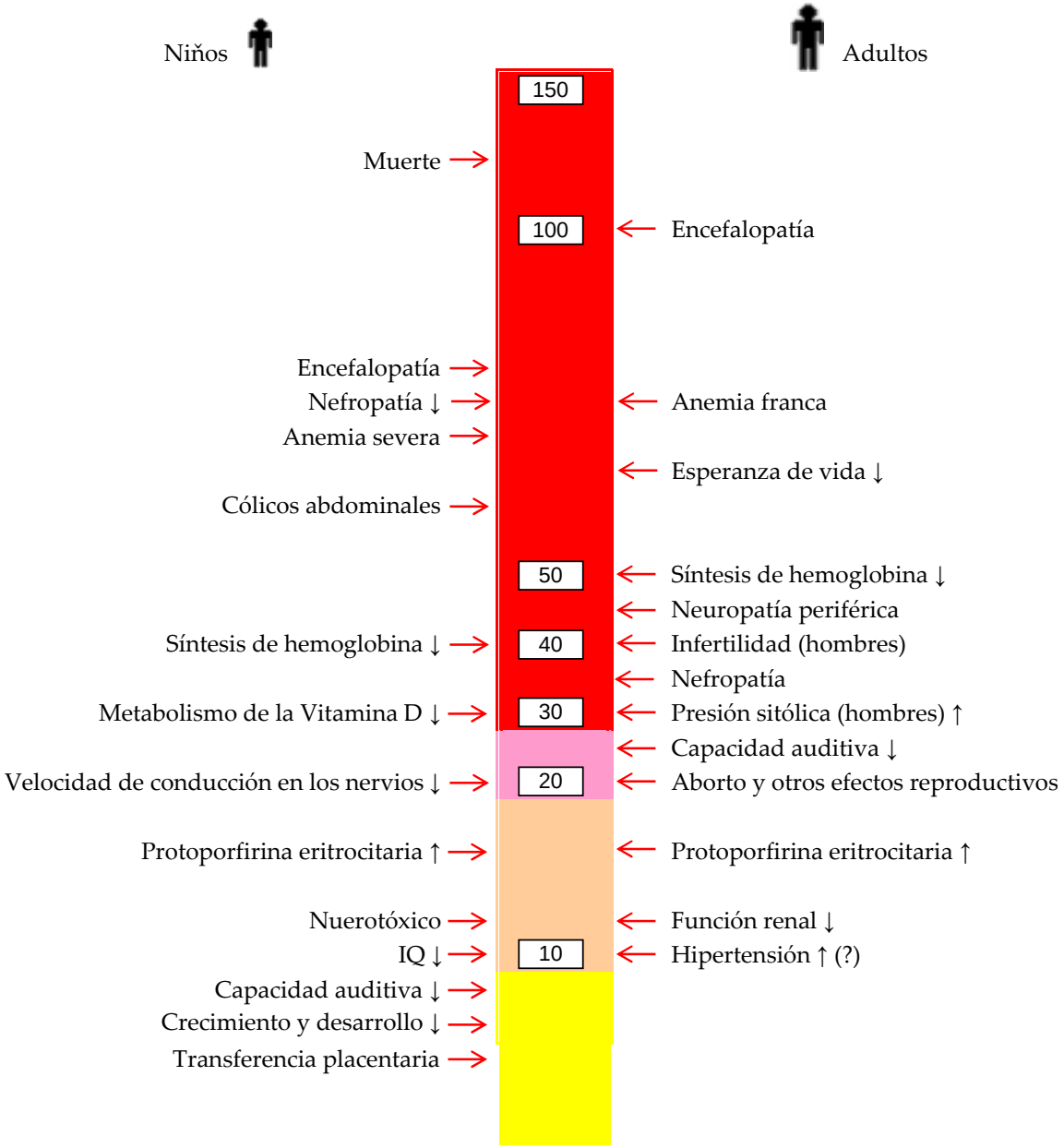


Figure 5-2. Concentración de Plomo en Sangre

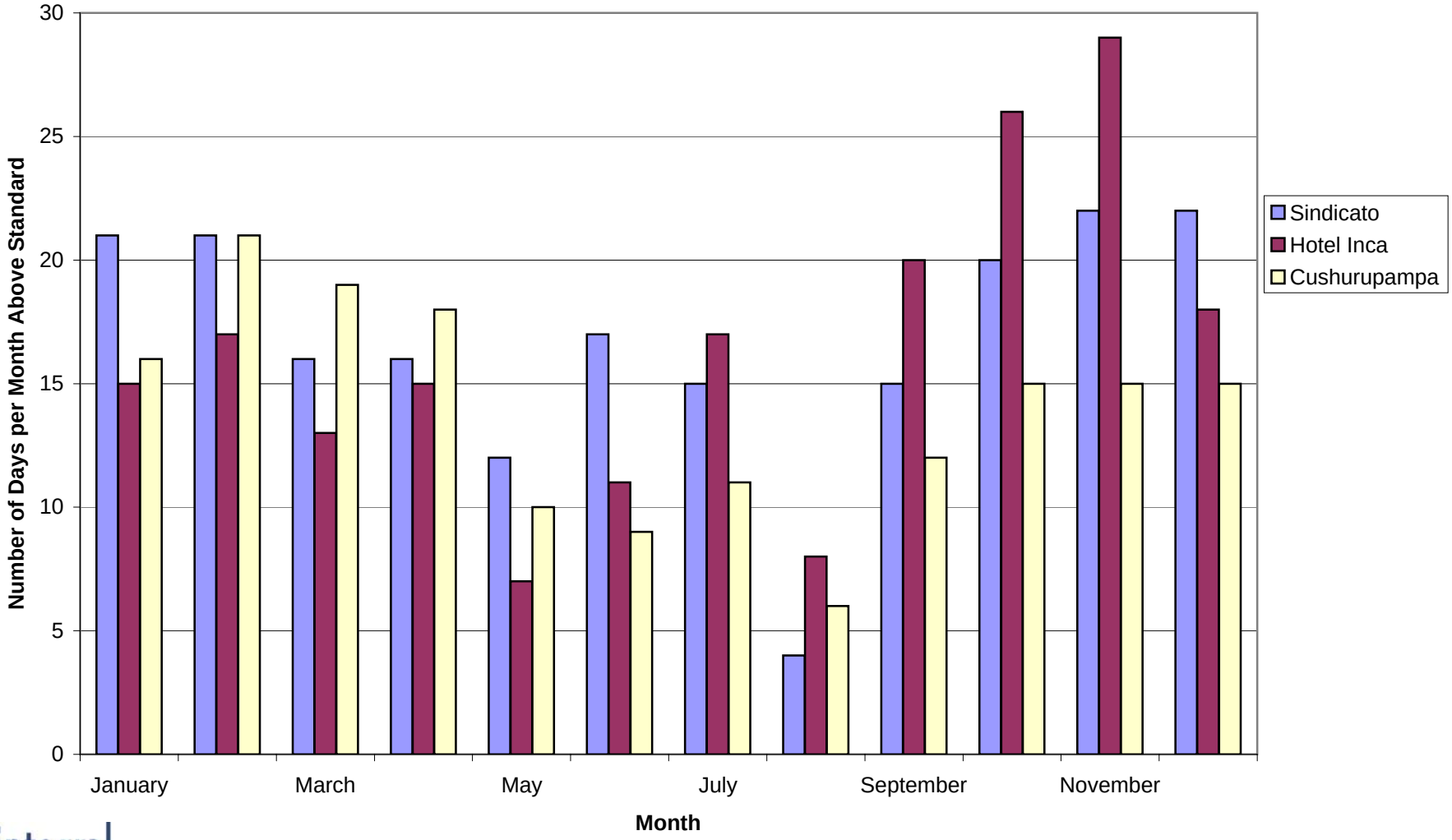


Figure 6-1. Number of Days per Month in 2004 with Daily Average Sulfur Dioxide Concentrations Greater than the Peruvian 24-hour National Ambient Air Quality Standard

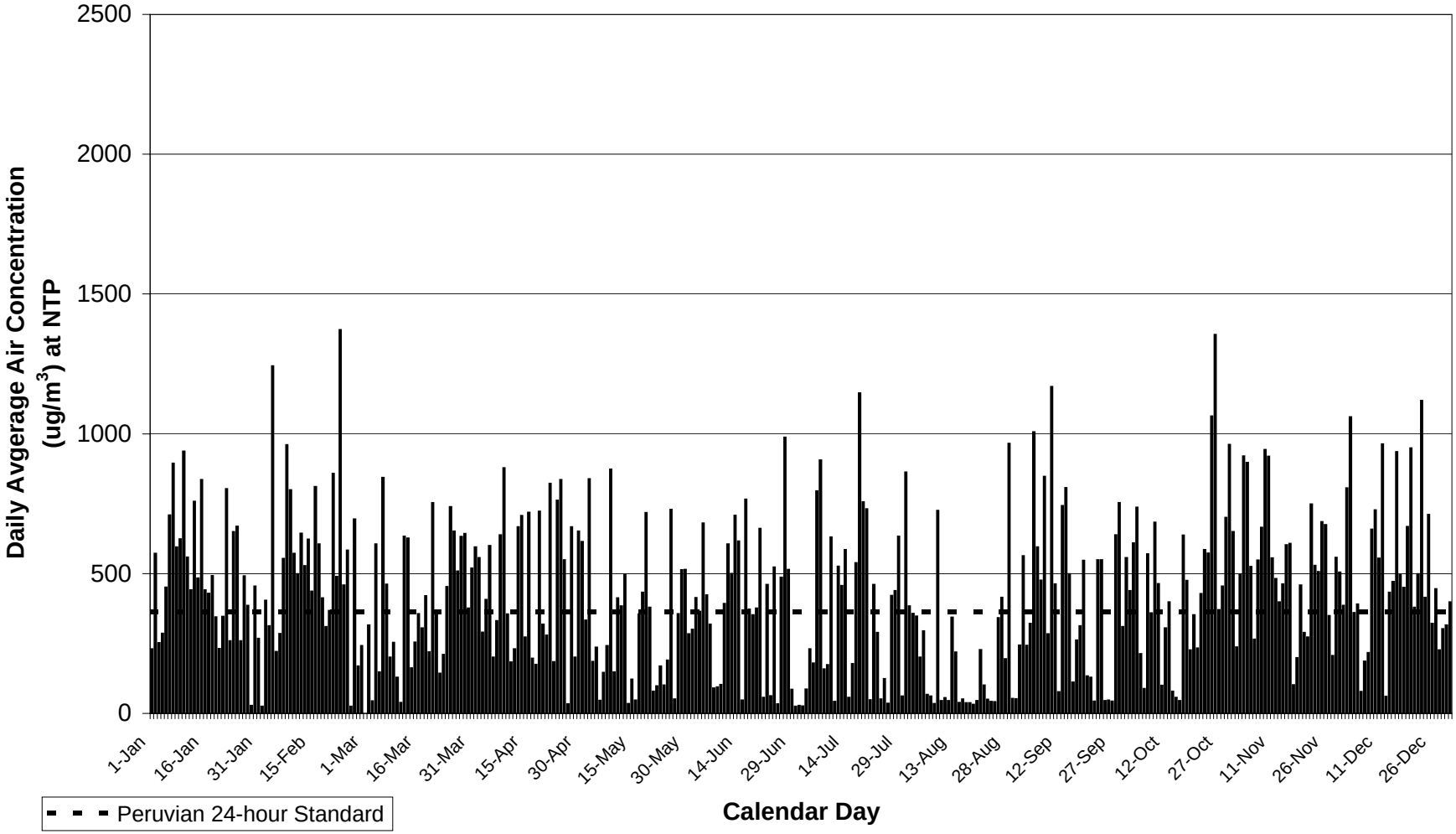


Figure 6-2. Daily Average 2004 Sulfur Dioxide Air Concentrations for the Sindicato Monitor versus the Peruvian 24-hour Air Quality Standard

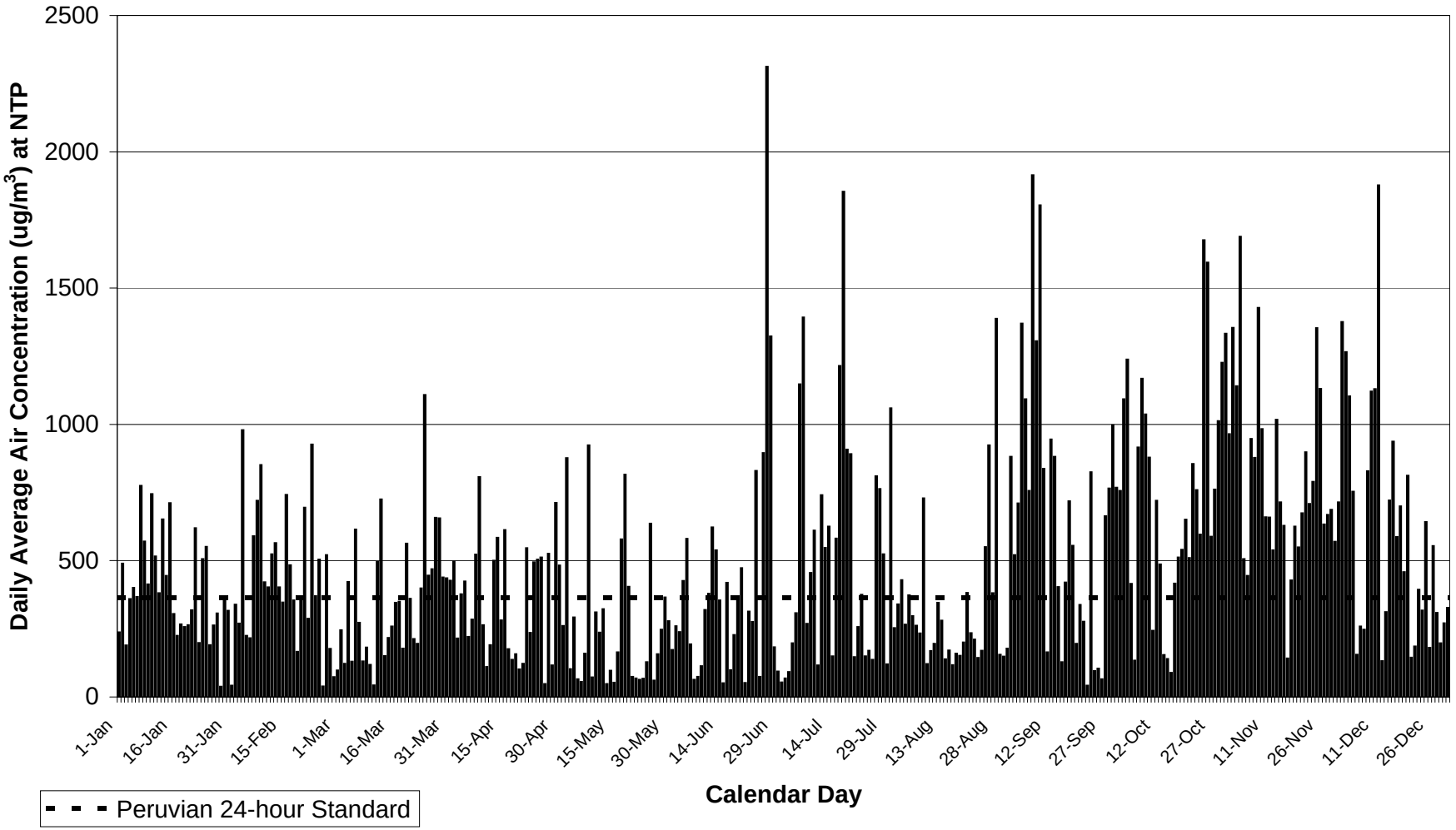


Figure 6-3. Daily Average 2004 Sulfur Dioxide Air Concentrations for the Hotel Inca Monitor versus the Peruvian 24-hour Air Quality Standard

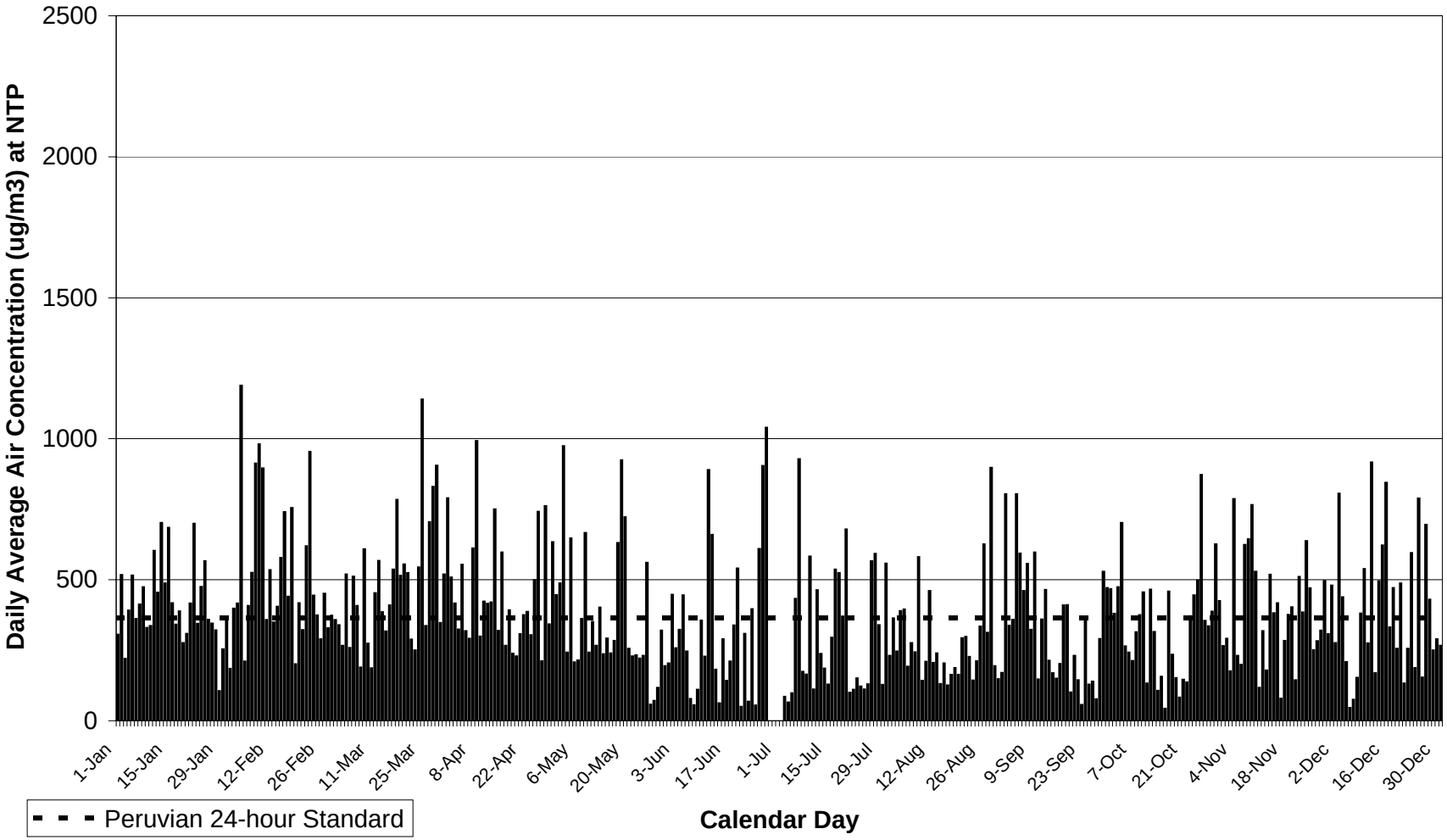


Figure 6-4. Daily Average 2004 Sulfur Dioxide Air Concentrations for the Cushurupampa Monitor versus the Peruvian 24-hour Air Quality Standard

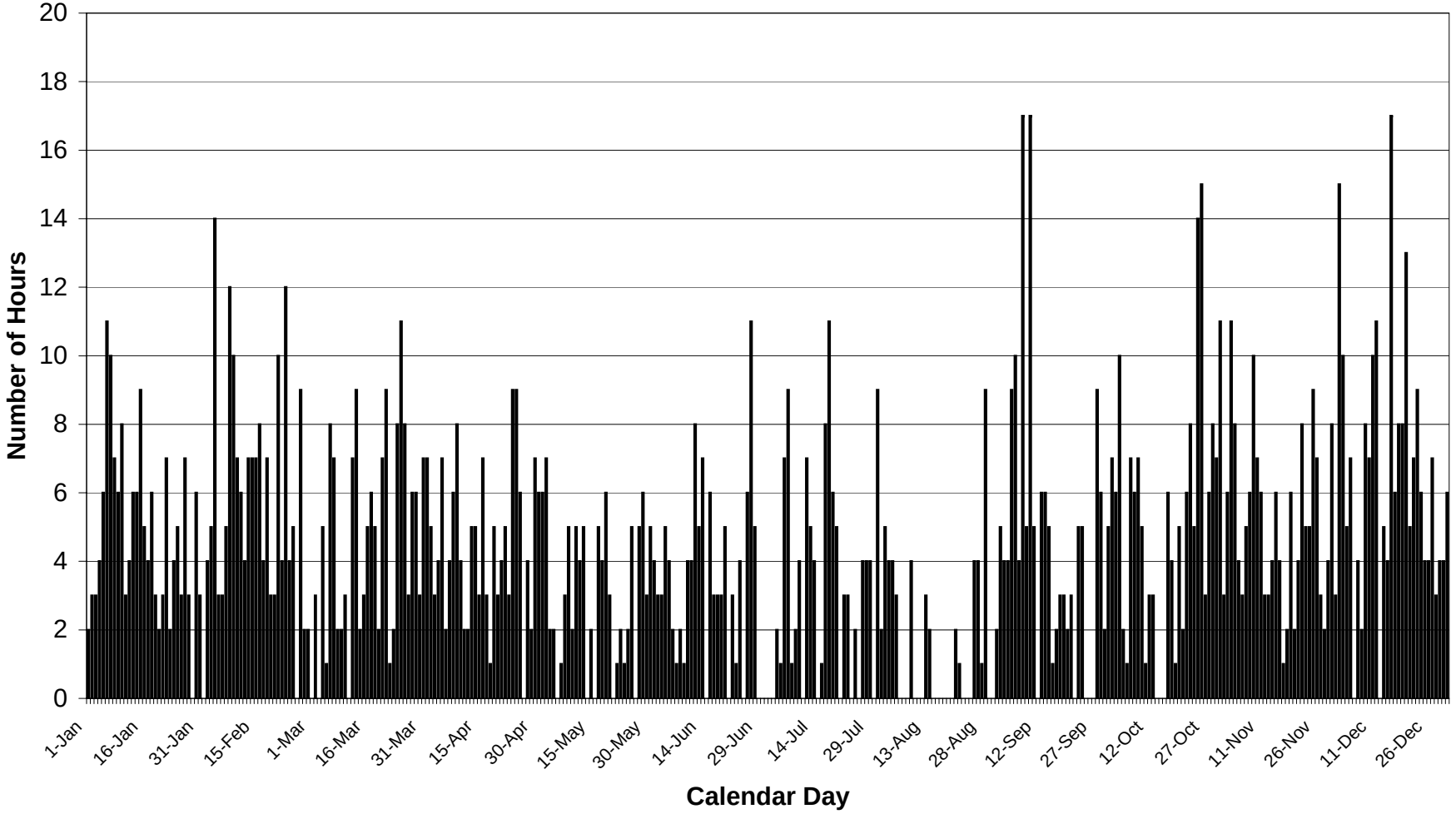


Figure 6-5. Number of Hours per Day in 2004 When Sulfur Dioxide Hourly Concentrations at the Sindicato Monitor Exceed the Threshold for Mild and Reversible Respiratory Effects in Sensitive Individuals (AEGL-1)

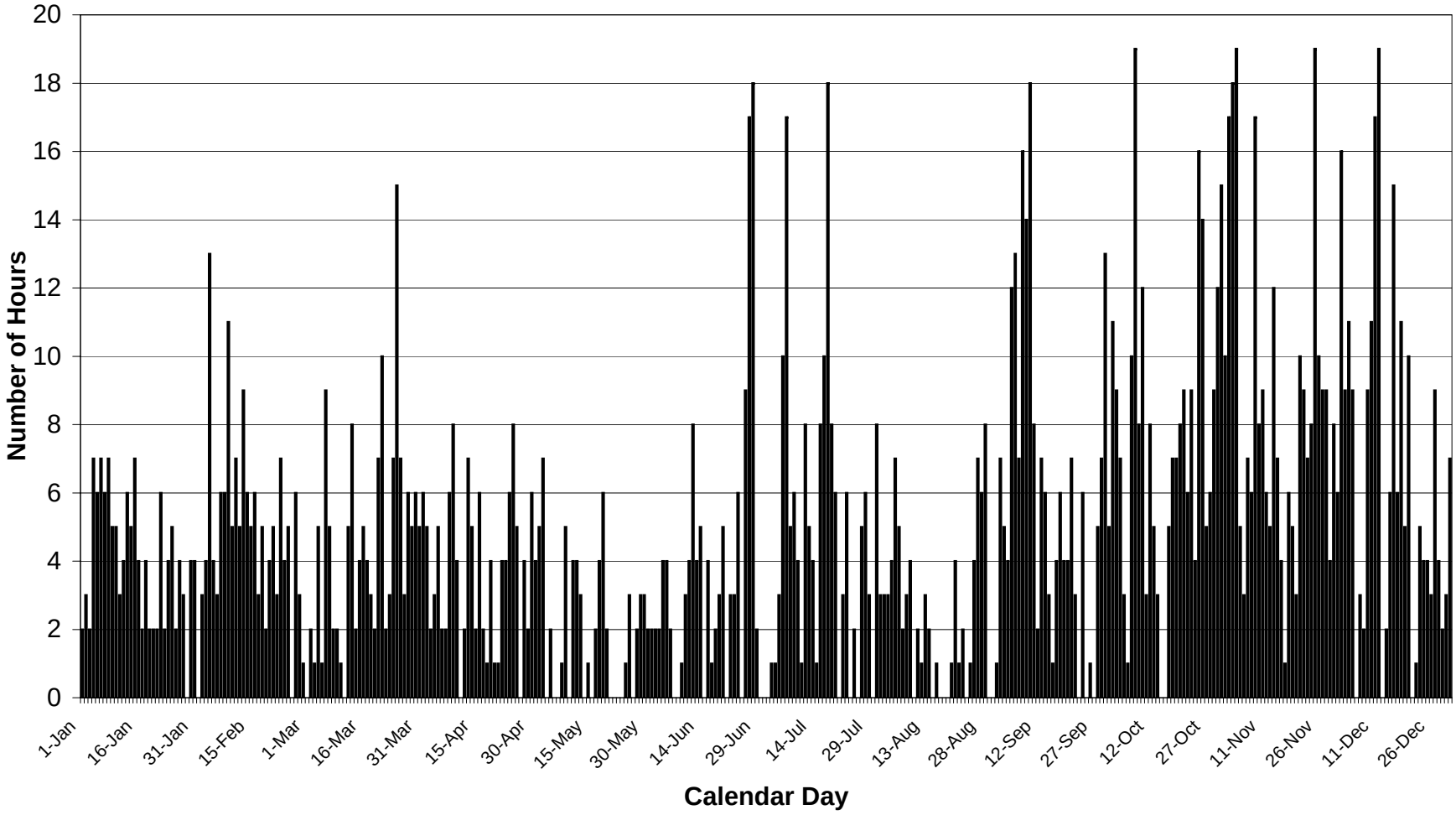


Figure 6-6. Number of Hours per Day in 2004 When Sulfur Dioxide Hourly Concentrations at the Hotel Inca Monitor Exceed the Threshold for Mild and Reversible Respiratory Effects in Sensitive Individuals (AEGL-1)

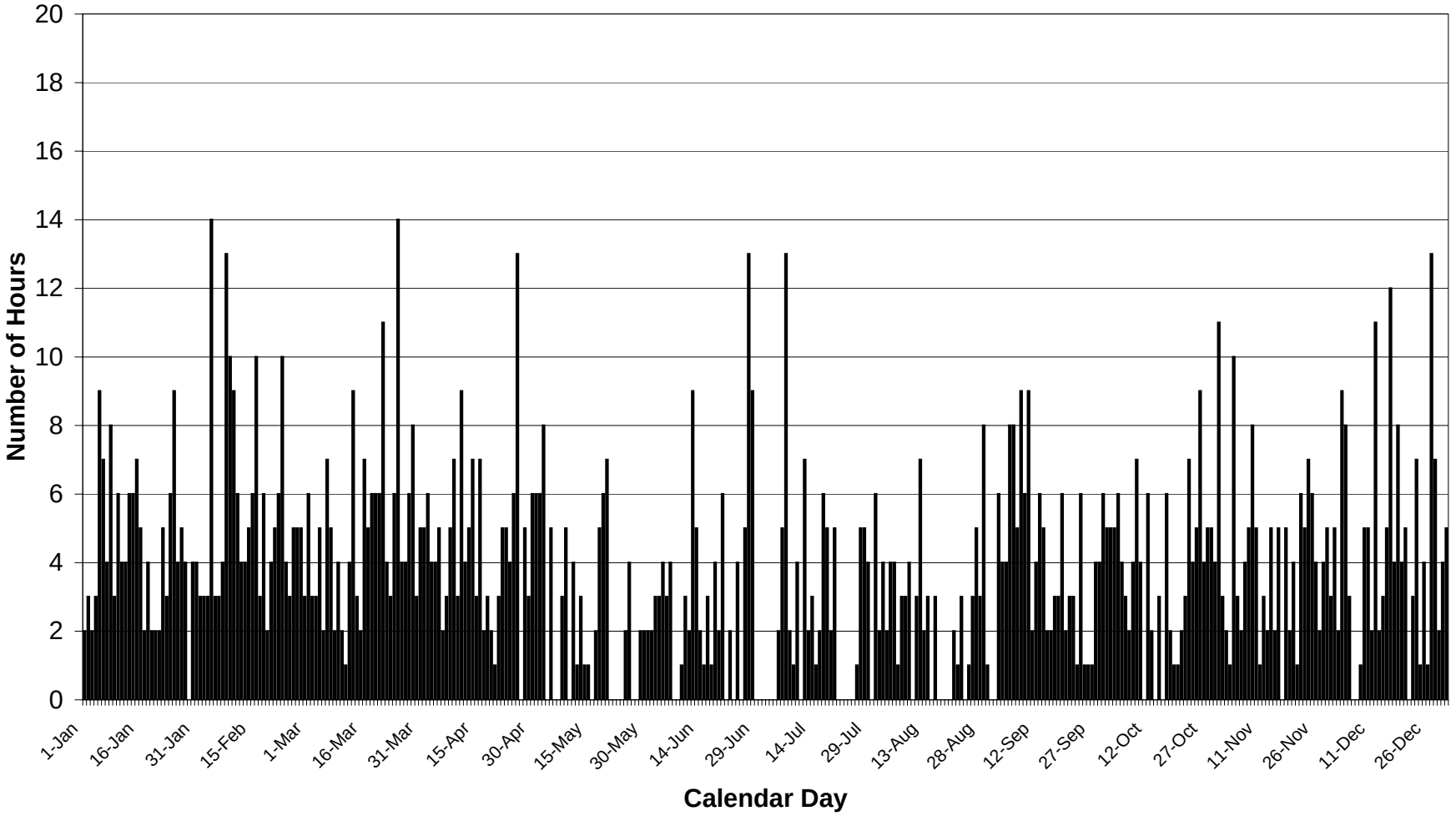


Figure 6-7. Number of Hours per Day in 2004 When Sulfur Dioxide Hourly Concentrations at the Cushurupampa Monitor Exceed the Threshold for Mild and Reversible Respiratory Effects in Sensitive Individuals (AEGL-1)

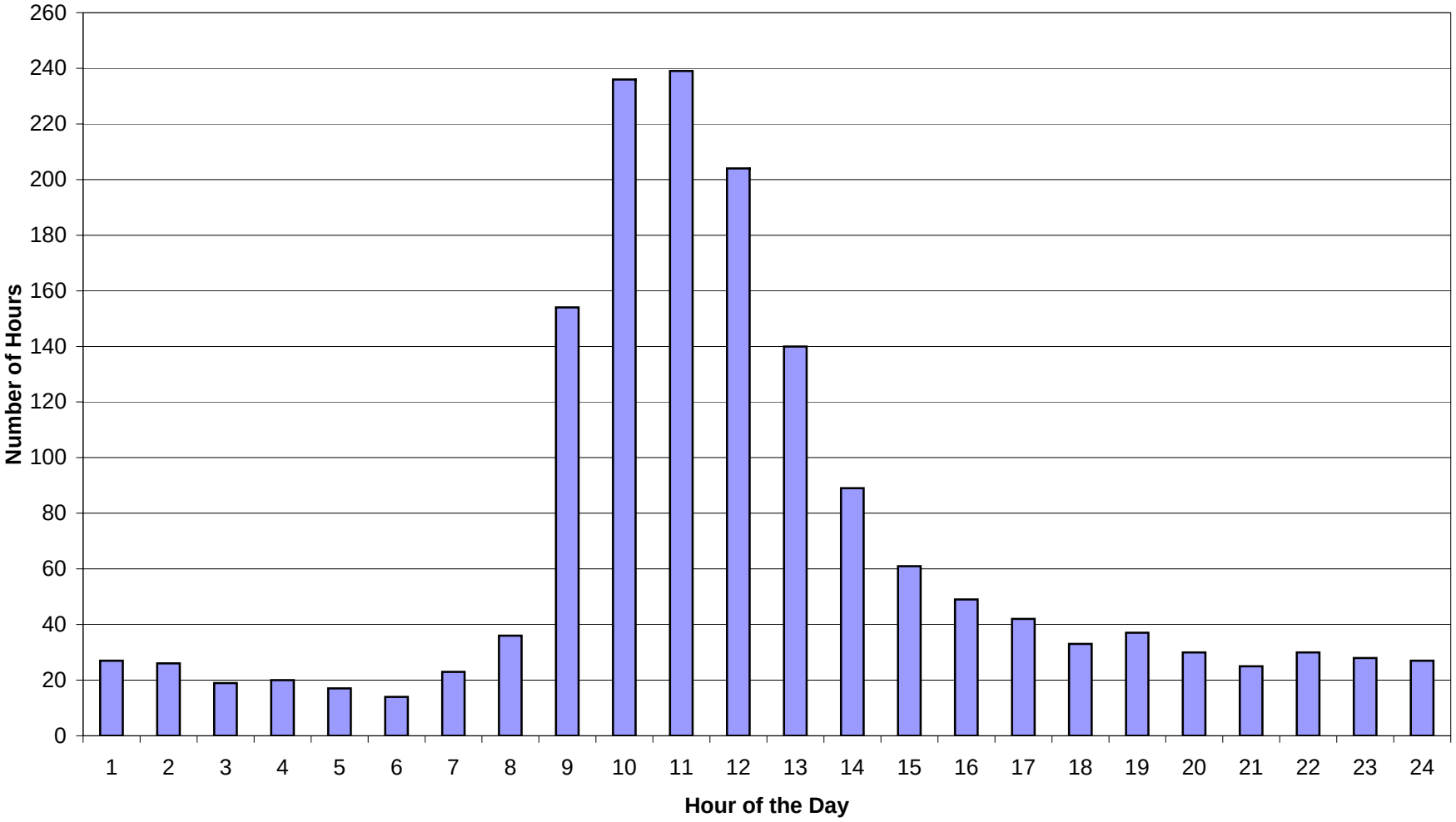


Figure 6-8. Total Number of Hours During the Day in 2004 When Sindicato Monitor Hourly Sulfur Dioxide Concentrations Exceed the Threshold for Mild and Reversible Respiratory Effects for Sensitive Individuals (AEGL-1)

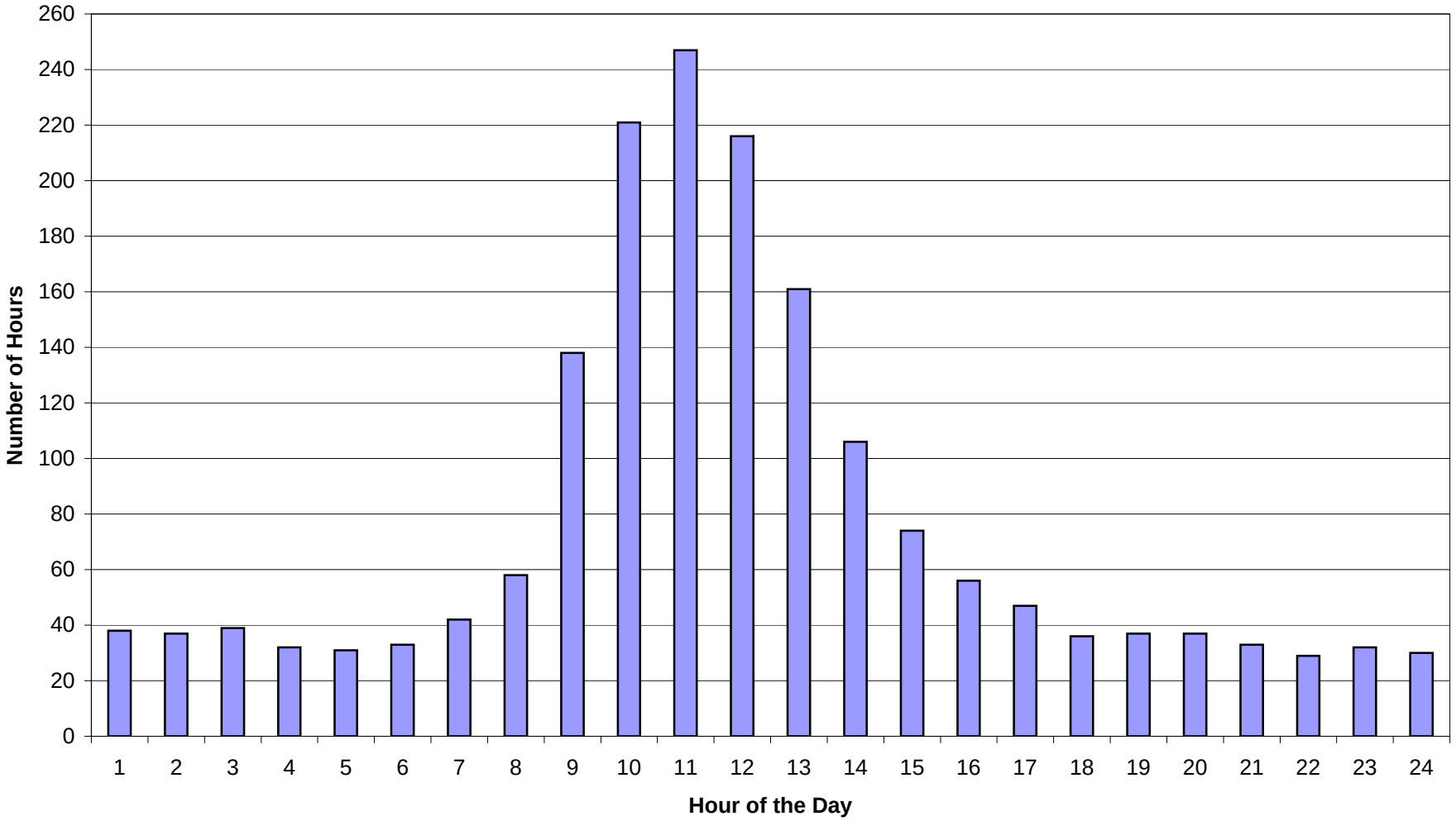


Figure 6-9. Total Number of Hours During the Day in 2004 When Hotel Inca Monitor Hourly Sulfur Dioxide Concentrations Exceed the Threshold for Mild and Reversible Respiratory Effects for Sensitive Individuals (AEGL-1)

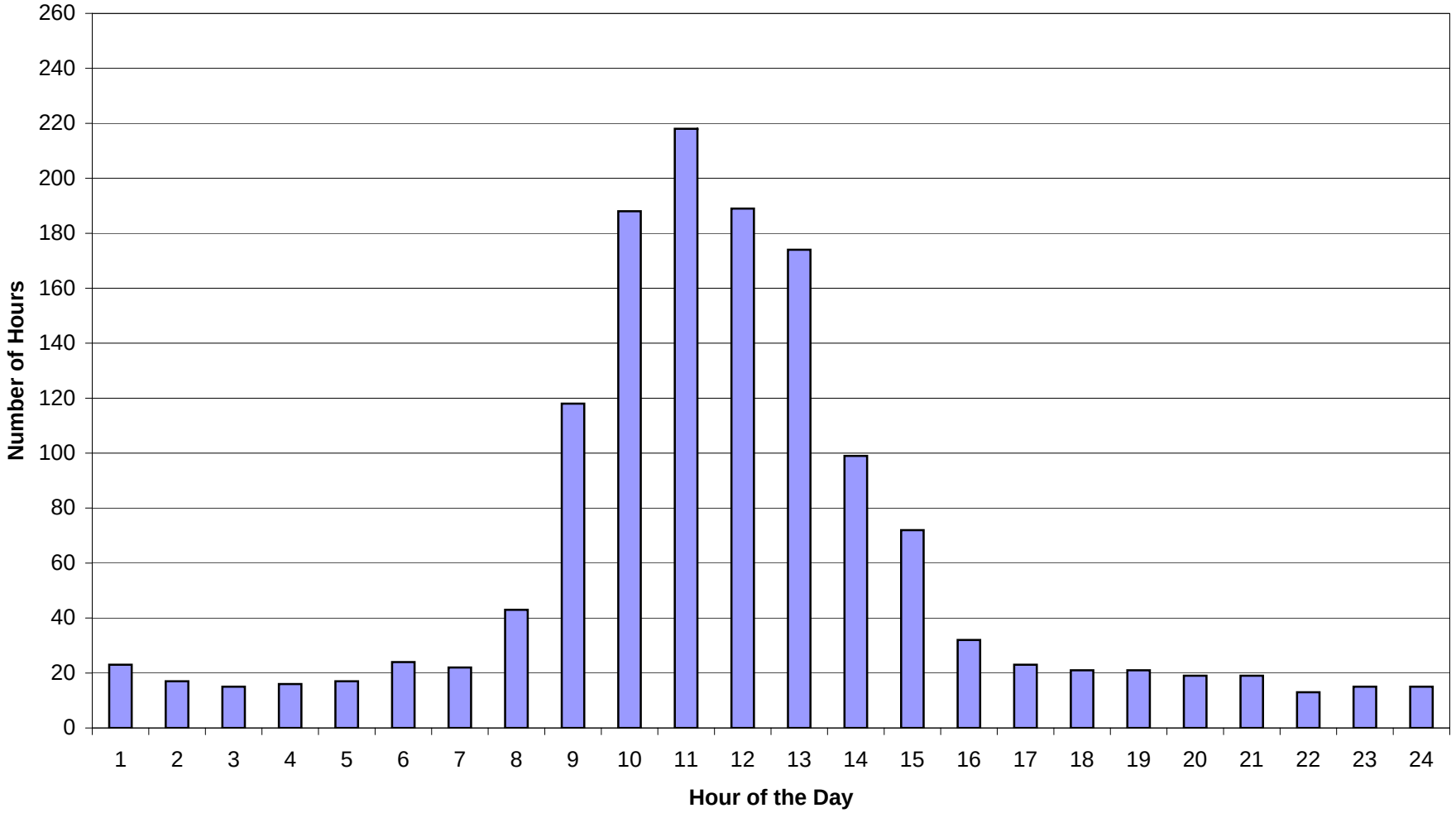


Figure 6-10. Total Number of Hours During the Day in 2004 When Cushurupampa Monitor Hourly Sulfur Dioxide Concentrations Exceed the Threshold for Mild and Reversible Respiratory Effects for Sensitive Individuals (AEGL-1)

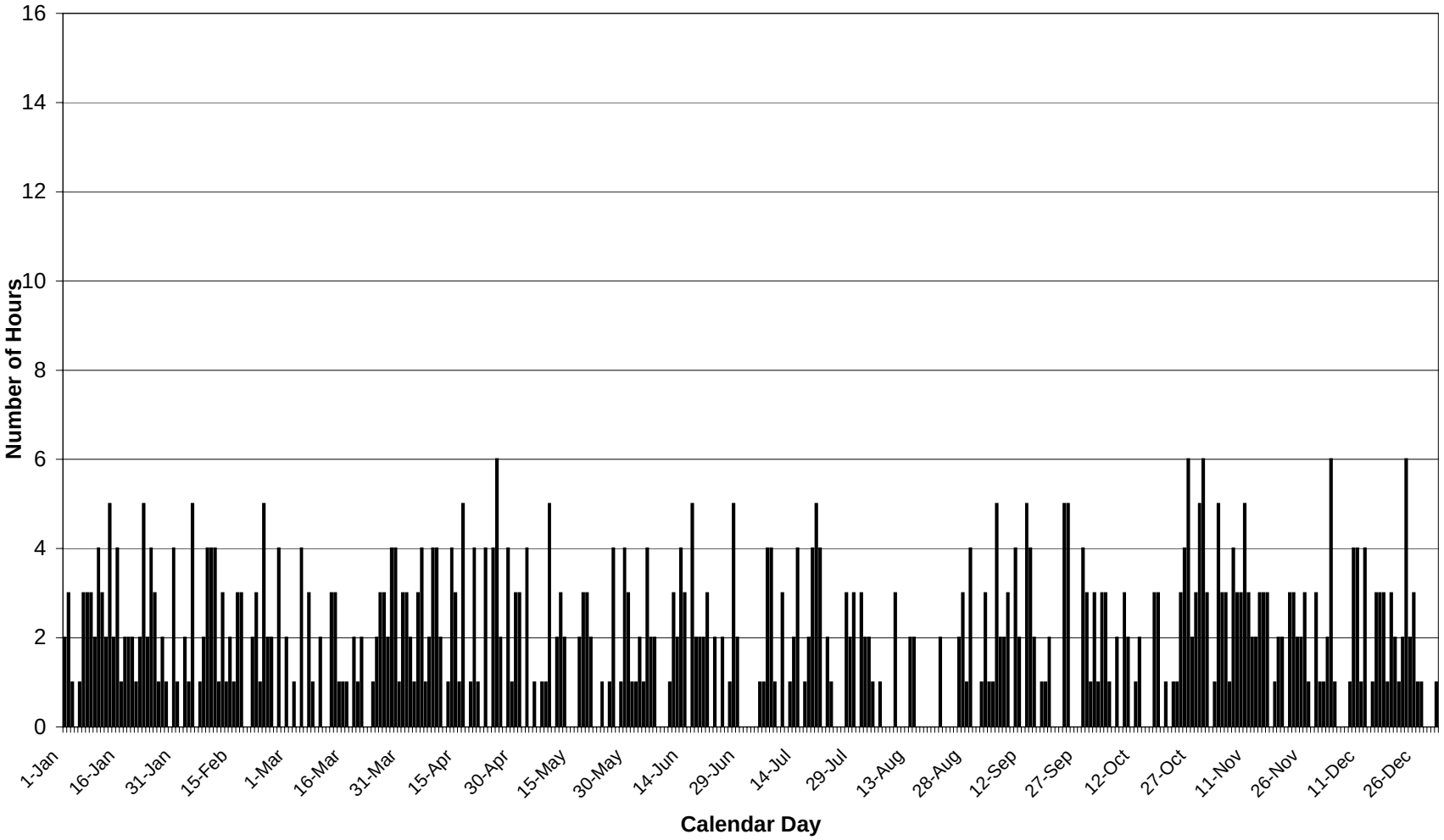


Figure 6-11. Number of Hours per Day in 2004 When Sulfur Dioxide Hourly Concentrations at the Sindicato Monitor Exceed the Threshold for Moderate to Severe but Reversible Respiratory Effects in Sensitive Individuals (AEGL-2)

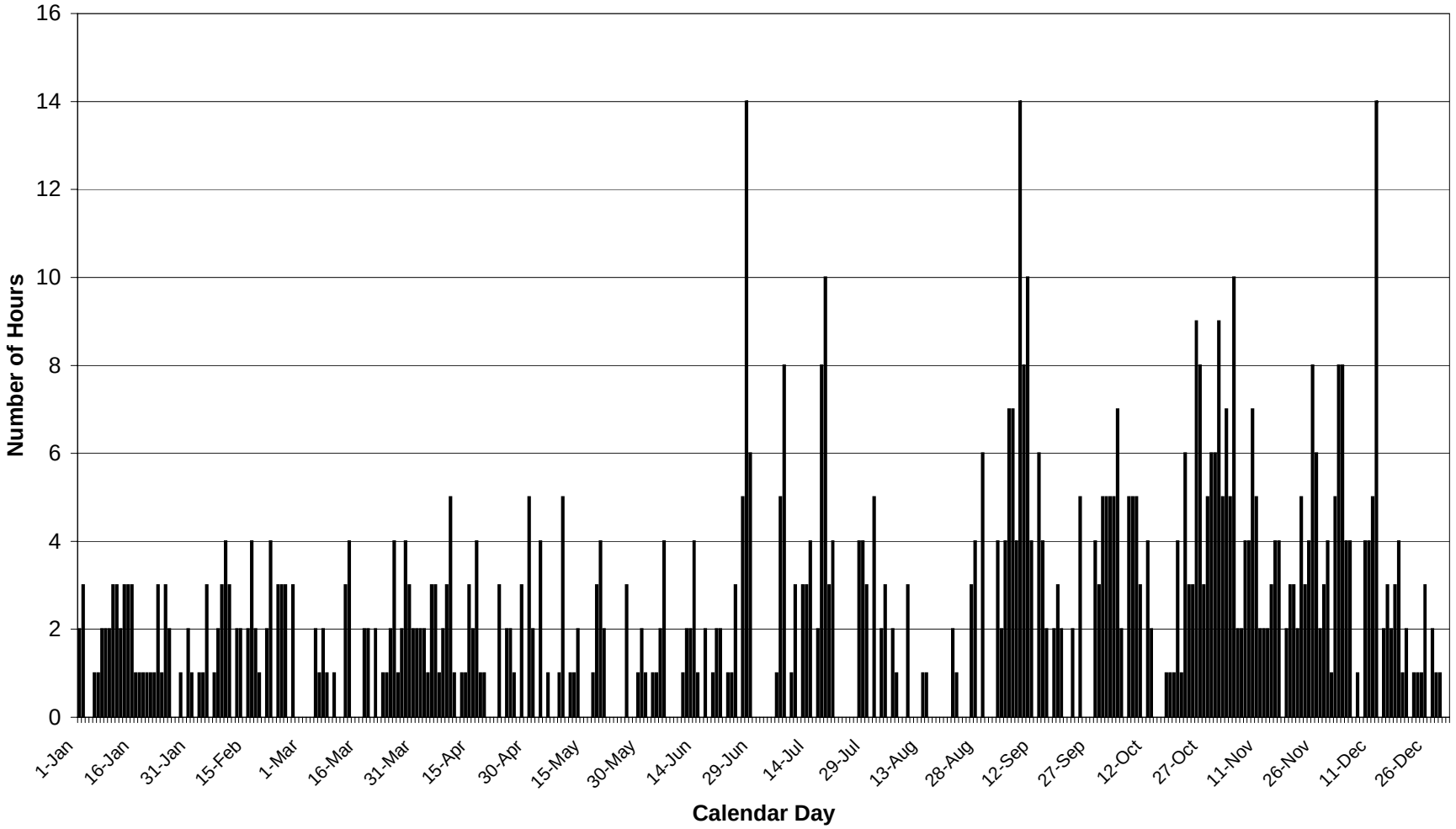


Figure 6-12. Number of Hours per Day in 2004 When Sulfur Dioxide Hourly Concentrations at the Hotel Inca Monitor Exceed the Threshold for Moderate to Severe but Reversible Respiratory Effects in Sensitive Individuals (AEGL-2)

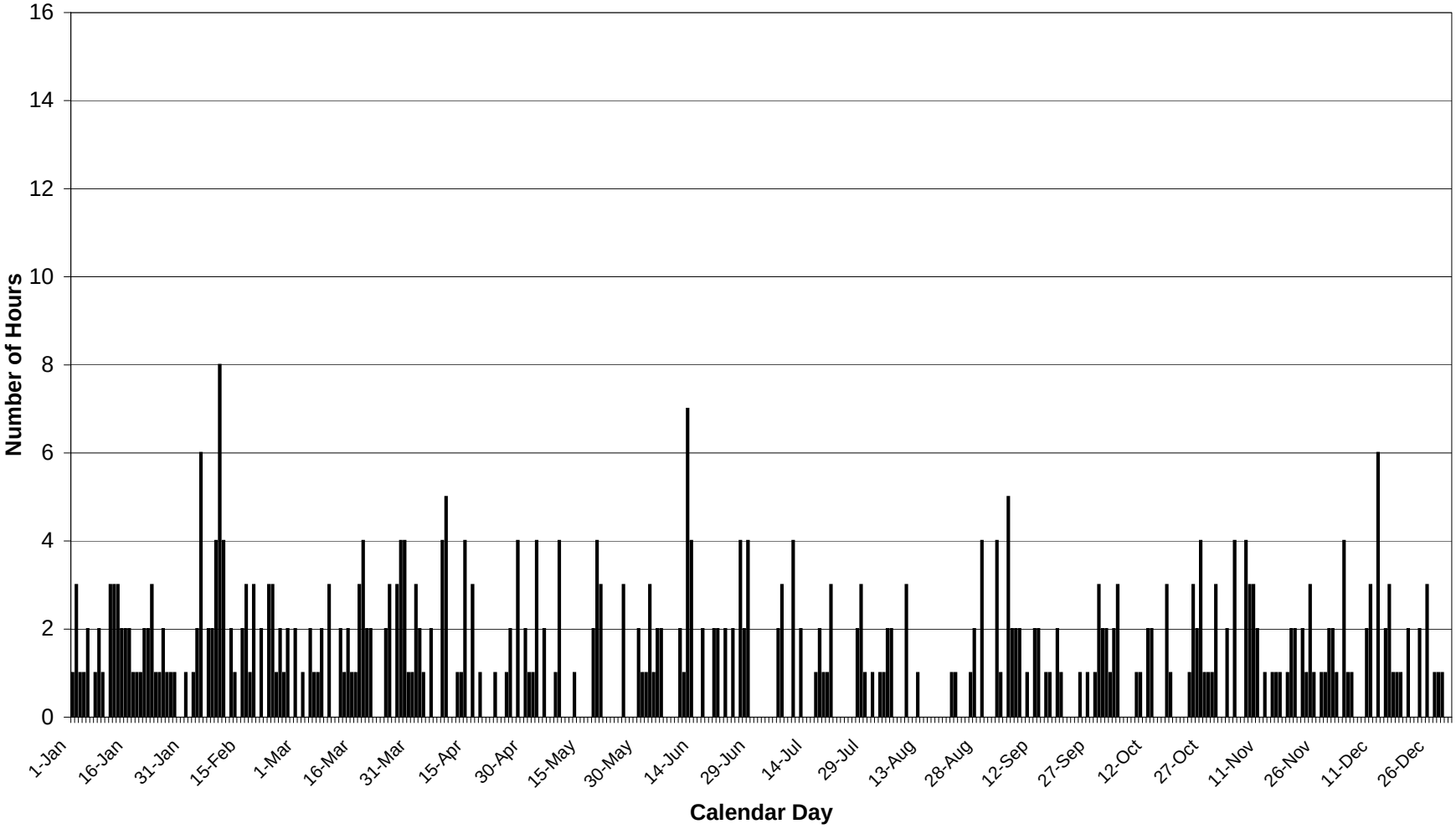


Figure 6-13. Number of Hours per Day in 2004 When Sulfur Dioxide Hourly Concentrations at the Cushurupampa Monitor Exceed the Threshold for Moderate to Severe but Reversible Respiratory Effects in Sensitive Individuals (AEGL-2)

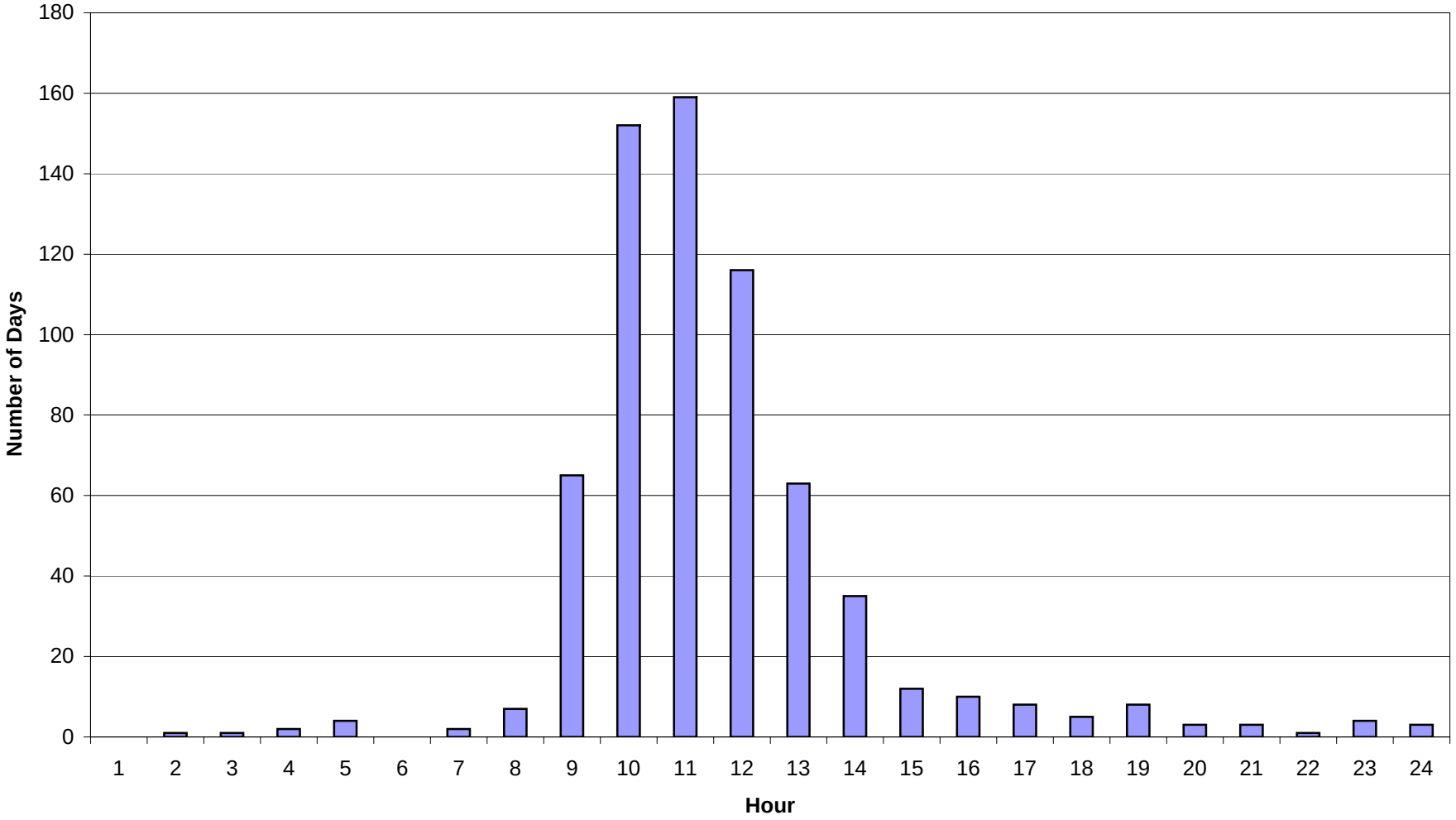


Figure 6-14. Total Number of Hours during the Day in 2004 when Sindicato Monitor Sulfur Dioxide Concentrations Exceed the Threshold for Moderate to Severe but Reversible Respiratory Effects in Sensitive Individuals (AEGL-2)

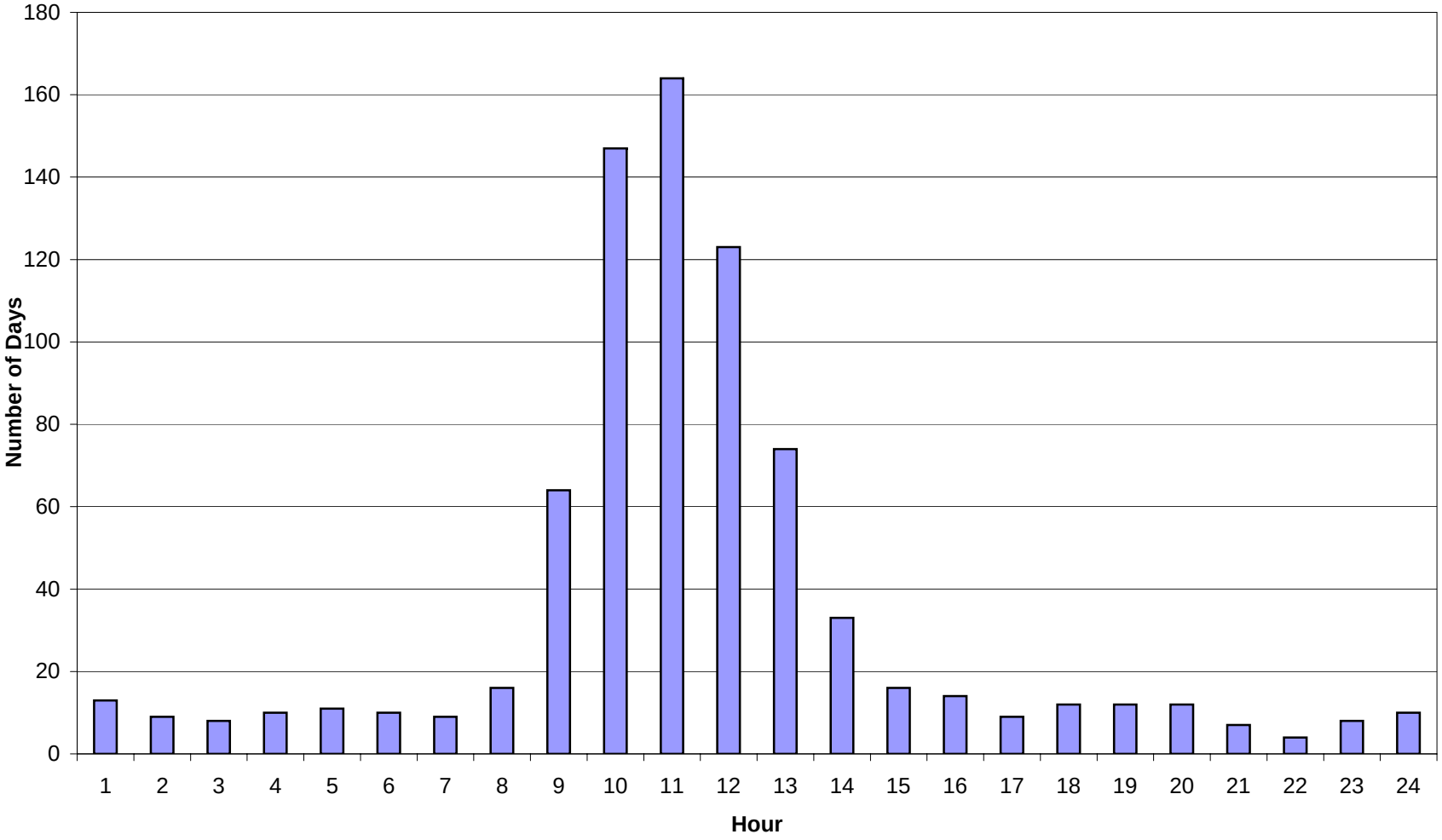


Figure 6-15. Total Number of Hours during the Day in 2004 when Hotel Inca Monitor Sulfur Dioxide Concentrations Exceed the Threshold for Moderate to Severe but Reversible Respiratory Effects in Sensitive Individuals (AEGL-2)

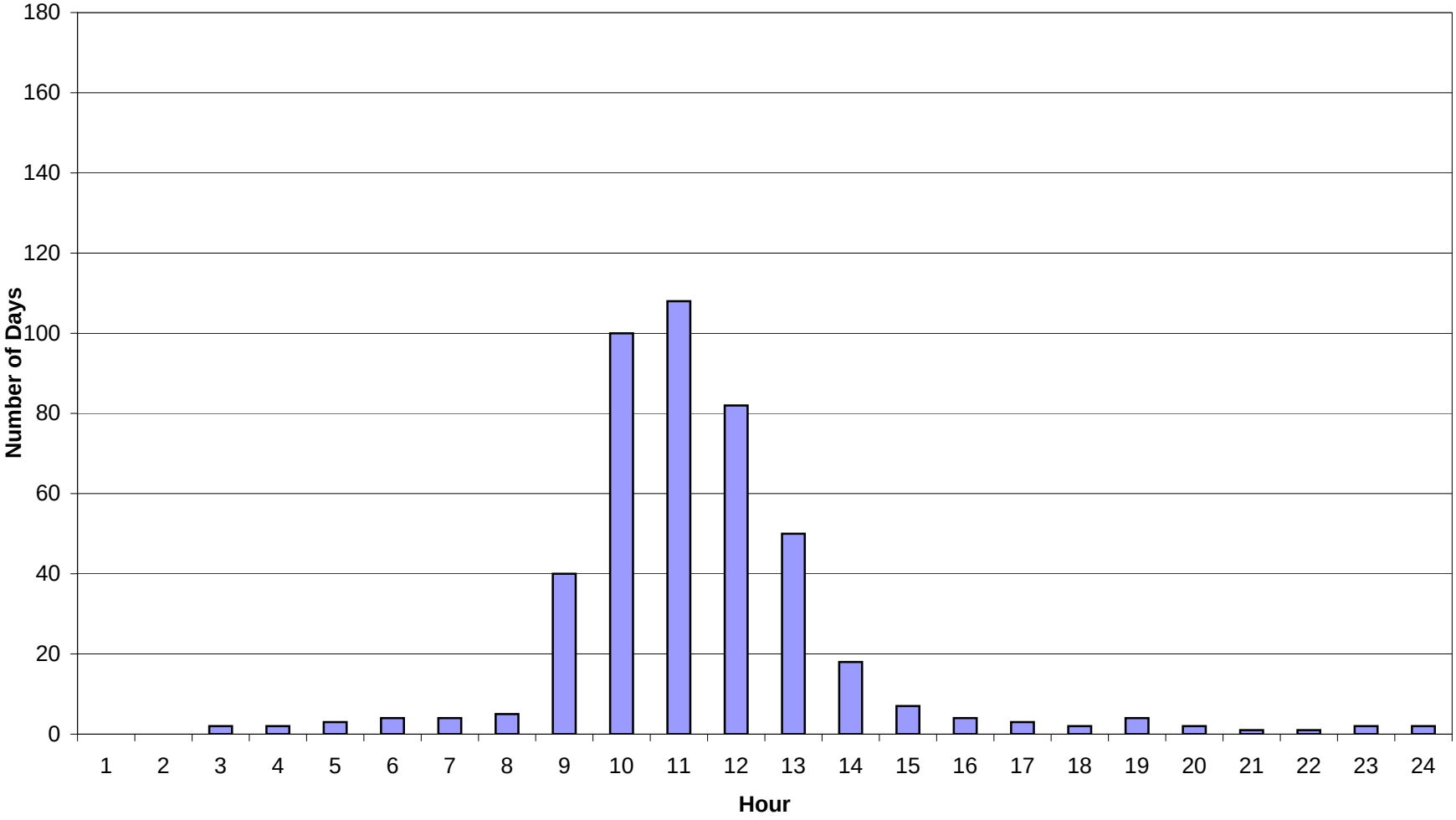


Figure 6-16. Total Number of Hours during the Day in 2004 when Cushurupampa Monitor Sulfur Dioxide Concentrations Exceed the Threshold for Moderate to Severe but Reversible Respiratory Effects in Sensitive Individuals (AEGL-2)

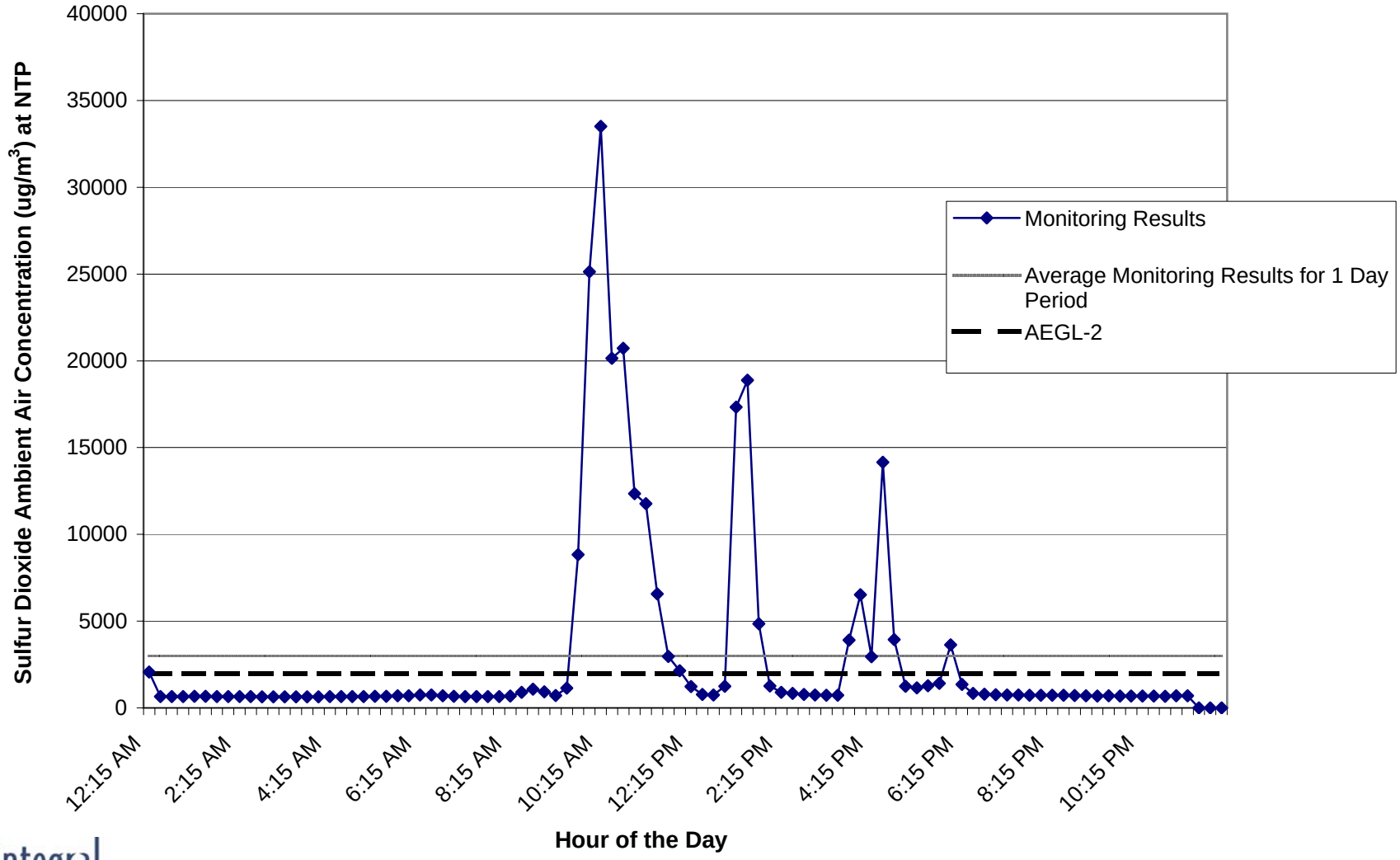


Figure 6-17. Sulfur Dioxide Air Concentrations at the Sindicato 2 Monitor on 12 March 2005 Compared to Acute Standards for Temporary and Reversible Respiratory Effects

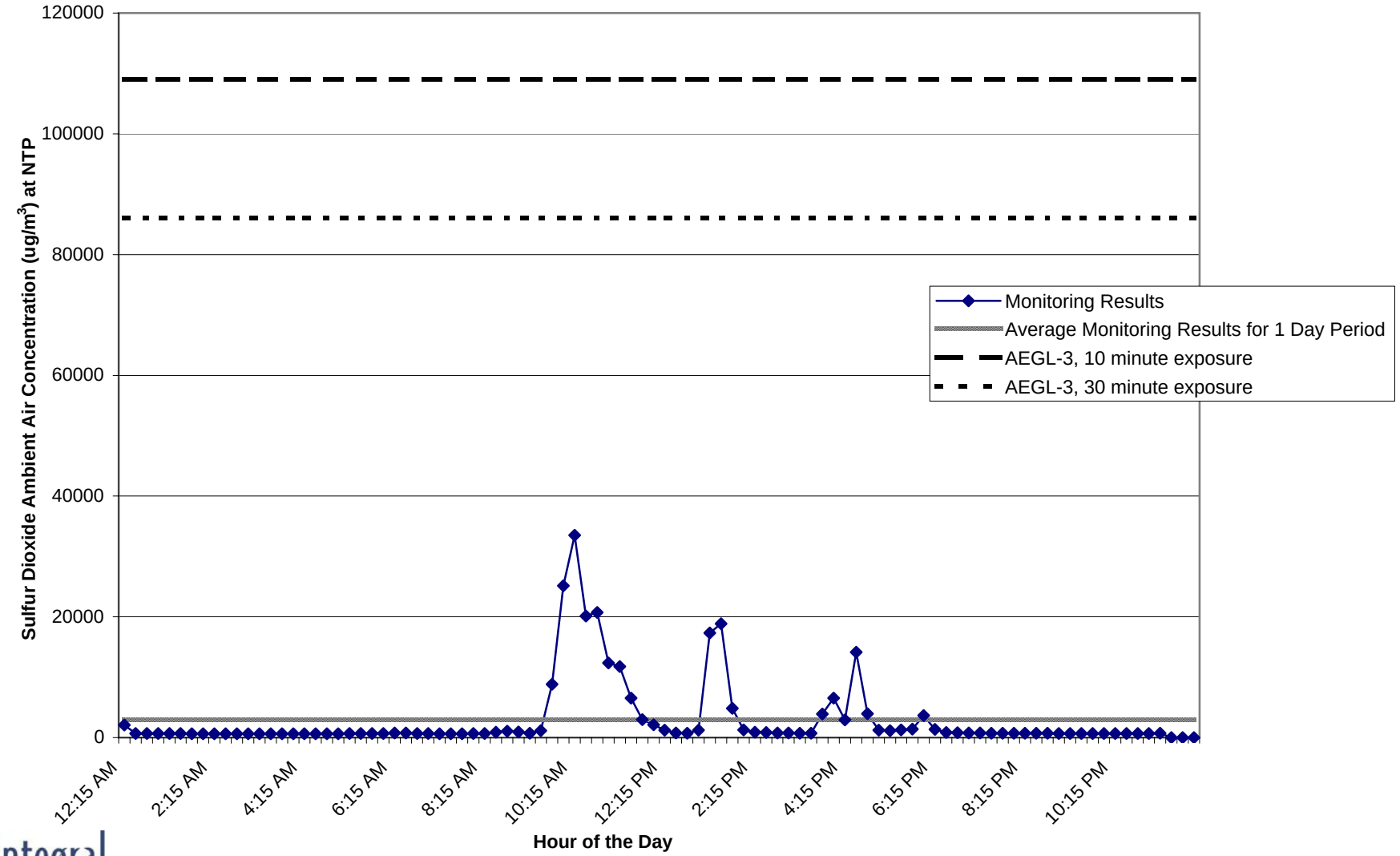


Figure 6-18. Sulfur Dioxide Air Concentrations at the Sindicato 2 Monitor on 12 March 2005 Compared to Acute Standards to Protect from Life Threatening or Lethal Effects

Table 3-1. Comparison of Monthly Average Concentrations of Suspended Particulate Matter (PM_{10}) from Two Different Monitoring Instruments ($\mu g/m^3$).

Year	Month	Sindicato		Cushurupampa		Hotel Inca	
		Met One BAM 1020 Measurement	Graseby 1200 Hi-Vol Sampler	Met One BAM 1020 Measurement	Graseby 1200 Hi-Vol Sampler	Met One BAM 1020 Measurement	Graseby 1200 Hi-Vol Sampler
2004	January	96	96	75	75	88	88
	February	103	103	51	51	90	90
	March	93	93	52	48	75	75
	April	104	104	55	55	76	76
	May	100	100	70	70	67	67
	June	93	93	57	57	65	65
	July	108	108	75	76	78	78
	August	79	79	52	52	52	52
	September	105	105	70	70	72	72
	October	80	80	54	54	59	59
	November	77	77	58	58	61	61
	December	78	78	50	50	59	59
2005	January	72	72	51	51	57	57
	February	72	72	55	55	58	58
	March	81	81	54	54	63	63

Definitions: PM_{10} - suspended particulate matter of 10 microns or less.
$\mu g/m^3$ - micrograms per cubic meter.

Notes: All concentrations are shown as µg/m3 at normal temperature and pressure (25 degrees Celsius and 1 atmosphere).

Table 3-2. Summary of Ambient Air Sulfur Dioxide (SO_2) Monitoring Data for 2004 at Sindicato, Hotel Inca, and Cushurupampa.

			Detected SO_2 Concentration as Reported in STP				Detected SO_2 Concentration Converted to NTP			
Monitoring Station	**N**	**Percent Completeness**	**Minimum Detected Value**	**Units**	**Maximum Detected Value**	**Units**	**Minimum Detected Value**	**Units**	**Maximum Detected Value**	**Units**
Sindicato	8751	99.6	2.6	$\mu g/m^3$	6023.4	$\mu g/m^3$	2.4	$\mu g/m^3$	5541.5	$\mu g/m^3$
Cushuru	8664	98.6	0.4	$\mu g/m^3$	6022.6	$\mu g/m^3$	0.4	$\mu g/m^3$	5540.8	$\mu g/m^3$
Hotel Inca	8774	99.9	0.8	$\mu g/m^3$	6000	$\mu g/m^3$	0.7	$\mu g/m^3$	5520.0	$\mu g/m^3$

Definitions:
N number of measurements.
NTP normal temperature and pressure (25 degrees Celsius and 1 atmosphere)
STP standard temperature and pressure (0 degrees Celsius and 1 atmosphere)
$\mu g/m^3$ microgram per cubic meter.

Notes:
Measured values reported as 0.0 were treated as missing values.
Percent completeness is the percentage of hourly measurements collected over the monitoring period (1-year).

Table 3-3. Summary of Suspended Particulate Matter (PM_{10}) Monitoring Data for 2004 at Sindicato, Hotel Inca, and Cushurupampa.

			Detected PM_{10} Concentration as Reported in STP				Detected PM_{10} Concentration as Converted to NTP			
Monitoring Station	**N**	**Percent Completeness**	**Minimum Detected Value**	**Units**	**Maximum Detected Value**	**Units**	**Minimum Detected Value**	**Units**	**Maximum Detected Value**	**Units**
Sindicato	8758	99.7	2.3	$\mu g/m^3$	994.2	$\mu g/m^3$	2.1	$\mu g/m^3$	914.7	$\mu g/m^3$
Cushuru	8543	97.3	1	$\mu g/m^3$	998.4	$\mu g/m^3$	0.9	$\mu g/m^3$	918.5	$\mu g/m^3$
Hotel Inca	8781	99.9	1.9	$\mu g/m^3$	998.3	$\mu g/m^3$	1.7	$\mu g/m^3$	918.4	$\mu g/m^3$

Definitions:
N number of measurements
NTP normal temperature and pressure (25 degrees Celsius and 1 atmosphere)
ppb parts per billlion
STP standard temperature and pressure (0 degrees Celsius and 1 atmosphere)
$\mu g/m^3$ microgram per cubic meter

Notes:
Measured values reported as 0 were treated as missing values.
Percent completeness is the percentage of hourly measurements collected over the monitoring period (1-year).

Table 3-4. Summary of Blood Lead Studies Conducted in La Oroya.

Organization	Date	Population / Community	Age	No. Samples	Mean Blood Lead Level (µg/dL)
Ramirez et al.	1997	Women in La Oroya	mean = 23 yr	n = 40	33
DIGESA	1999	Women and children in La Oroya Antigua, La Oroya Nueva, Santa Rosa de Sacco	<10 yr. >10 yr.	n = 346 n = 199	44 29
UNES	1999	Pregnant women and children in La Oroya Antigua, Marcavalle, Santa Rosa de Sacco	Adults <3 yr.	n = 48 n = 30	40 42
Doe Run Peru	2000	Children and adults in La Oroya Antigua, Marcavalle, Santa Rosa de Sacco, Alto Peru/Calle Lima, Chulec, Club Inca/Horacio Zaballos, Buenos Aires/Huaymanta, Curipata, Comunidades, Pacha, other	All ages <3 yr. >16 yr.	n = 50,268 (total) n = 252 n = 2,449	-- 26 14
		La Oroya Antigua statistics	<3 yr. >16 yr.	n = 75 n = 400	37 18
DIGESA	2004	Children in La Oroya Antigua,	<3 yr. <6 yr.	n = 325 n = 756	34 32
		La Oroya Nueva	<6 yr.	n = 23	25

Table 3-5. Summary of Samples Collected in La Oroya during March/April and June 2005 Field Events.

Media	Community	No. of Samples March / April	No. of Samples June
Drinking Water	La Oroya Antigua	13	10
	La Oroya Nueva	5	
	Marcavalle	4	
	Tupac Amaru	1	
	Chucchis	3	
	Field Duplicate Samples	2	1
Total		28	11
Community Dust	La Oroya Antigua	11	10
	La Oroya Nueva	4	3
	Marcavalle	2	3
	Tupac Amaru	1	1
	Chucchis	3	3
	Field Duplicate Samples	1	1
	Reference Samples	0	1
Total		22	23
Community Soil (0-2 cm bgs)	La Oroya Antigua	9	12
	La Oroya Nueva	4	3
	Marcavalle	3	3
	Tupac Amaru	1	2
	Chucchis	1	1
	Field Duplicate Samples	1	3
	Reference Samples	0	2
Total		19	26
Community Soil (2-10 cm bgs)	La Oroya Antigua	5	7
	La Oroya Nueva	1	3
	Marcavalle	1	3
	Tupac Amaru	1	2
	Chucchis	1	1
	Field Duplicate Samples	0	1
	Reference Samples	0	2
Total		9	19
Residential Soil	La Oroya Antigua	0	1
Residential Dust	La Oroya Antigua	10	10
	La Oroya Nueva	3	2
	Marcavalle	2	3
	Tupac Amaru	1	1
	Chucchis	3	2
	Field Duplicate Samples	1	2
	Reference Samples	0	2
Total		20	22

bgs = below ground surface
cm = centimeters

Table 3-6. Total Dietary Lead Intake (µg/day).

	Mean[a]	Median[a]	Standard Deviation[a]
Mothers (N=11)	92-163	0-148	108-44
Children 12-23 months old (N=8)	60-71	71-71	35-19
Children 24-35 months old (N=7)	48-78	54-68	51-36

[a]The number on the left was calculated assuming values below the detection limit equal zero. The number on the left was calculated assuming values below the detection limit equal the detection limit.

Table 3-7. Dietary Intake of Calcium, Iron, and Zinc in the Mothers' Diet (N=11) and Percentage of Recommended Daily Intake (in parentheses).

	Total Food Intake (g)	Calcium (mg/day)	Iron (mg/day)	Zinc (mg/day)
Mean	2,138	835 (84%)	6.9 (18%)	13.2 (108%)
Standard deviation	269	207	2.2	6.7
Median	2,137	819 (82%)	7.0 (15%)	11.0 (78%)

Table 3-8. Dietary Intake of Calcium, Iron, and Zinc in the Diets of 12-23 Month Old Children (N=8) and Percentage of Recommended Daily Intake (in parentheses).

	Total Food Intake (g)	Calcium (mg/day)	Iron (mg/day)	Zinc (mg/day)
Mean	959	484 (97%)	2.2 (37%)	3.3 (80%)
Standard deviation	290	260	1.8	1.7
Median	871	438 (88%)	1.5 (25%)	3.1 (77%)

Table 3-9. Dietary Intake of Calcium, Iron, and Zinc in the Diets of 24-35 Month Old Children (N=7) and Percentage of Recommended Daily Intake (in parentheses).

	Total Food Intake (g)	Calcium (mg/day)	Iron (mg/day)	Zinc (mg/day)
Mean	1186	578 (116%)	3.6 (60%)	4.6 (113%)
Standard deviation	416	309	2.3	2.3
Median	1254	565 (113%)	2.4 (40%)	5.6 (136%)

Table 3-10. Summary Statistics and Selection of Chemicals for Air.

Air Monitoring Stations (µg/m^3)	Distribution	Min	Max	Mean	95% UCLM	Screening Criteria	Selected for analysis?	Rationale
Sindicato - La Oroya Antigua								
Arsénico	Gamma	0.106	20.501	2.67	2.967	0.0002	Yes	ASL
Cádmio	Gamma	0.011	0.651	0.12	0.133	0.0006	Yes	ASL
Huanchán								
Arsénico	Nonparametric	0.256	19.364	4.16	5.287	0.0002	Yes	ASL
Cádmio	Nonparametric	0.011	2.014	0.29	0.386	0.0006	Yes	ASL
Hotel Inca - La Oroya Nueva								
Arsénico	Nonparametric	0.112	5.698	1.70	2.130	0.0002	Yes	ASL
Cádmio	Nonparametric	0.005	0.328	0.082	0.105	0.0006	Yes	ASL
Cushurupampa - Marcavalle / Chucchis								
Arsénico	Nonparametric	0.051	6.852	1.24	1.579	0.0002	Yes	ASL
Cádmio	Nonparametric	0.005	0.281	0.059	0.075	0.0006	Yes	ASL
Casaracra								
Arsénico	Nonparametric	0.051	2.617	0.503	0.695	0.0002	Yes	ASL
Cádmio	Nonparametric	0.005	0.168	0.022	0.032	0.0006	Yes	ASL

Notes:
ASL = concentration is above the screening level
UCLM = 95th upper confidence limit of the mean
µg/m^3 = micrograms per cubic meter

Table 3-11. Summary Statistics and Selection of Chemicals for Outdoor Dust.

Outdoor Dust (mg/kg, ww)	Frequency of Detection	Distribution	Min	Max	Mean	95% UCLM	Screening Level	Selected for analysis?	Rationale
La Oroya Antigua									
Antimonio	20 / 20	Gamma	2.8	810.5	195.9	311	31	Yes	ASL
Arsénico	20 / 20	Gamma	570	5354	1950	2490	0.4	Yes	ASL
Cádmio	20 / 20	Normal	40.8	373.1	151.1	187	70	Yes	ASL
Cobre	20 / 20	Gamma	760	17900	4935	6875	--	--	NSL
Plomo[a]	19 / 19	Normal	2077	16880	7684	9272	400	Yes	ASL
Selenio	20 / 20	Gamma	6.84	182.80	39.57	57	390	No	BSL
Tálio	20 / 20	Gamma	2.38	24.93	11.45	15	6	Yes	ASL
Zinc	20 / 20	Gamma	1275	14560	4824	6201	23000	No	BSL
Plata	20 / 20	Gamma	7.13	289.40	65.54	100	390	No	BSL
Mercurio	20 / 20	Gamma	0.2225	1.944	0.677	0.860	23	No	BSL
La Oroya Nueva									
Antimonio	6 / 6	Gamma	7.7	196.3	50.3	173	31	Yes	ASL
Arsénico	6 / 6	Normal	134	1179	602	887	0.4	Yes	ASL
Cádmio	6 / 6	Normal	13.2	56.2	35.2	47	70	No	BSL
Cobre	6 / 6	Normal	177	1584	1062	1464	--	--	NSL
Plomo	6 / 6	Normal	971	3730	2159	3169	400	Yes	ASL
Selenio	5 / 6	Normal	0.03	7.23	4.99	7	390	No	BSL
Tálio	6 / 6	Normal	1.97	3.46	2.42	3	6	No	BSL
Zinc	6 / 6	Normal	891	7465	3237	5348	23000	No	BSL
Plata	6 / 6	Normal	6.91	39.19	20.83	31	390	No	BSL
Mercurio	6 / 6	Normal	0.137	0.353	0.214	0.281	23	No	BSL
Marcavalle (includes Tupac Amaru)									
Antimonio	8 / 8	Normal	14.0	77.2	34.0	49	31	Yes	ASL
Arsénico	8 / 8	Normal	289	851	514	654	0.4	Yes	ASL
Cádmio[b]	7 / 7	Normal	16.6	94	44.6	66	70	No	BSL
Cobre	8 / 8	Normal	397	1248	946	1128	--	--	NSL
Plomo	8 / 8	Normal	939	3684	2153	2792	400	Yes	ASL
Selenio	8 / 8	Normal	2.08	10.78	5.54	8	390	No	BSL
Tálio	8 / 8	Lognormal	1.74	6.67	3.64	6	6	Yes	ASL
Zinc	8 / 8	Normal	1760	3906	2628	3082	23000	No	BSL
Plata	8 / 8	Normal	7.10	34.93	16.28	22	390	No	BSL
Mercurio	8 / 8	Gamma	0.116	0.619	0.245	0.367	23	No	BSL
Chucchis									
Antimonio	6 / 6	Normal	9.2	62.3	37.6	55	31	Yes	ASL
Arsénico	6 / 6	Gamma	351	1069	536	818	0.4	Yes	ASL
Cádmio	6 / 6	Lognormal	24.5	77.3	39.4	61	70	No	BSL
Cobre	6 / 6	Normal	468	1470	988	1310	--	--	NSL
Plomo	6 / 6	Normal	1095	4707	2371	3480	400	Yes	ASL
Selenio	6 / 6	Normal	2.07	7.76	4.48	6	390	No	BSL
Tálio	6 / 6	Normal	1.73	14.16	5.73	9	6	Yes	ASL
Zinc	6 / 6	Normal	1604	7846	4808	6964	23000	No	BSL
Plata	6 / 6	Normal	3.26	28.17	17.54	25	390	No	BSL
Mercurio	6 / 6	Gamma	0.079	1.471	0.365	1.181	23	No	BSL

Notes:

'-- = screening level not available

ASL = concentration is above the screening level

BSL = concentration is below the screening level

mg/kg, ww = milligram per kilogram, wet weight

NSL = no screening level

UCLM = 95th upper confidence limit of the mean

a = One sample concentration (DRP-CDOA-01, 37410 mg/kg, ww) was determined to be an outlier and was removed from dataset. Mean and UCL concentrations including outlier value would have been 9381 mg/kg, ww and 12538 mg/kg, ww, respectively.

b = One sample concentration (DRP2-CDTA-36, 907.2 mg/kg, ww) was determined to be an outlier and was removed from dataset. Mean and UCL concentrations including outlier value would have been 153 mg/kg, ww and 624 mg/kg, ww, respectively.

Table 3-12. Summary Statistics and Selection of Chemicals for Indoor Dust.

Indoor Dust (mg/kg, ww)	Frequency of Detection	Distribution	Min	Max	Mean	95% UCLM	Screening Level	Selected for analysis?	Rationale
La Oroya Antigua									
Antimonio	20 / 20	Gamma	0.46	259.2	69.9	109	31	Yes	ASL
Arsénico	20 / 20	Normal	4	1575	933	1084	0.4	Yes	ASL
Cádmio	20 / 20	Normal	38.4	128.3	64.8	75	70	Yes	ASL
Cobre	20 / 20	Gamma	673	3514	1442	1706	--	--	NSL
Plomo	20 / 20	Gamma	1485	6140	2795	3248	400	Yes	ASL
Selenio	20 / 20	Gamma	1.02	35.72	11.45	15	390	No	BSL
Tálio	20 / 20	Normal	1.59	7.26	4.13	5	6	No	BSL
Zinc	20 / 20	Normal	1324	4951	2993	3409	23000	No	BSL
Plata	20 / 20	Gamma	3.28	60.25	18.97	25	390	No	BSL
Mercurio	20 / 20	Non-parametric	0.192	41.505	2.778	11.685	23	No	BSL
La Oroya Nueva									
Antimonio	5 / 5	Normal	5.9	203.7	63.7	146	31	Yes	ASL
Arsénico	5 / 5	Normal	4	801	348	650	0.4	Yes	ASL
Cádmio	5 / 5	Normal	10.3	17.6	14.5	17	70	No	BSL
Cobre	5 / 5	Normal	188	793	467	712	--	--	NSL
Plomo[a]	5 / 5	Normal	31	2335	1483	2471	400	Yes	ASL
Selenio	5 / 5	Normal	0.23	3.04	1.96	3	390	No	BSL
Tálio	5 / 5	Normal	0.93	2.87	1.67	2	6	No	BSL
Zinc	5 / 5	Normal	1050	7862	3661	6736	23000	No	BSL
Plata	5 / 5	Normal	0.68	7.03	4.93	7	390	No	BSL
Mercurio	5 / 5	Normal	0.110	0.811	0.468	0.767	23	No	BSL
Marcavalle (includes Tupac Amaru)									
Antimonio	7 / 7	Gamma	4.0	63.0	22.9	45	31	Yes	ASL
Arsénico	7 / 7	Gamma	157	708	303	465	0.4	Yes	ASL
Cádmio	7 / 7	Gamma	9.9	29.6	14.9	21	70	No	BSL
Cobre	7 / 7	Normal	197	1055	516	756	--	--	NSL
Plomo	7 / 7	Gamma	510	2370	1109	1657	400	Yes	ASL
Selenio	7 / 7	Gamma	1.01	4.37	1.95	3	390	No	BSL
Tálio	7 / 7	Normal	0.78	2.78	1.87	2	6	No	BSL
Zinc	7 / 7	Normal	950	4166	2391	3171	23000	No	BSL
Plata	7 / 7	Gamma	3.08	14.25	5.90	9	390	No	BSL
Mercurio	7 / 7	Normal	0.107	1.137	0.465	0.731	23	No	BSL
Chucchis									
Antimonio	5 / 5	Normal	2.9	13.7	7.7	12	31	No	BSL
Arsénico	5 / 5	Normal	122	414	261	391	0.4	Yes	ASL
Cádmio[a]	5 / 5	Gamma	7.7	128.8	36.0	156	70	Yes	ASL
Cobre	5 / 5	Normal	191	729	354	565	--	--	NSL
Plomo	5 / 5	Normal	456	2031	1004	1589	400	Yes	ASL
Selenio	5 / 5	Normal	0.57	2.40	1.38	2	390	No	BSL
Tálio	5 / 5	Normal	0.69	2.49	1.54	2	6	No	BSL
Zinc	5 / 5	Lognormal	1192	25280	6611	17280	23000	No	BSL
Plata	5 / 5	Normal	3.23	12.09	6.19	10	390	No	BSL
Mercurio	5 / 5	Gamma	0.097	0.703	0.261	0.692	23	No	BSL

Notes:

'-- = screening level not available

ASL = concentration is above the screening level

BSL = concentration is below the screening level

mg/kg, ww = milligram per kilogram, wet weight

NSL = no screening level

UCLM = 95th upper confidence limit of the mean

a = The maximum detected concentration was compared to the screening value when the UCLM exceeded the maximum concentration.

Table 3-13. Summary Statistics and Selection of Chemicals for Surface Soil.

Surface Soil (0-2 cm bgs) (mg/kg, ww)	Frequency of Detection	Distribution	Min	Max	Mean	95% UCLM	Screening Level	Selected for analysis?	Rationale
La Oroya Antigua									
Antimonio	22 / 22	Lognormal	0.3	84.7	10.3	26	31	No	BSL
Arsénico	22 / 22	Gamma	114	3579	1109	1476	0.4	Yes	ASL
Cádmio	22 / 22	Gamma	9.5	144.6	55.1	75	70	Yes	ASL
Cobre	22 / 22	Normal	156	2149	1005	1208	--	--	NSL
Plomo	22 / 22	Normal	418	4942	2407	2869	400	Yes	ASL
Selenio	22 / 22	Gamma	0.74	17.16	6.85	10	390	No	BSL
Tálio	22 / 22	Normal	0.58	7.16	3.64	4	6	No	BSL
Zinc	22 / 22	Normal	817	5286	2491	2908	23,000	No	BSL
Plata	22 / 22	Normal	3.07	29.08	16.32	19	390	No	BSL
Mercurio	22 / 22	Gamma	0.098	1	0.440	0.561	23	No	BSL
La Oroya Nueva									
Antimonio	7 / 7	Normal	0.2	2.7	1.5	2	31	No	BSL
Arsénico	7 / 7	Normal	156	711	386	546	0.4	Yes	ASL
Cádmio	7 / 7	Normal	10.1	27.2	15.6	20	70	No	BSL
Cobre	7 / 7	Normal	109	845	385	589	--	--	NSL
Plomo	7 / 7	Normal	293	2357	1039	1592	400	Yes	ASL
Selenio	7 / 7	Gamma	0.09	3.78	1.23	3	390	No	BSL
Tálio	7 / 7	Normal	0.69	2.23	1.42	2	6	No	BSL
Zinc	7 / 7	Gamma	514	5837	1753	3714	23,000	No	BSL
Plata	7 / 7	Lognormal	1.85	36.47	12.15	34	390	No	BSL
Mercurio	7 / 7	Normal	0.099	0.265	0.181	0.230	23	No	BSL
Marcavalle (includes Tupac Amaru)									
Antimonio	9 / 9	Gamma	0.2	3.0	1.2	2	31	No	BSL
Arsénico	9 / 9	Normal	86	512	262	354	0.4	Yes	ASL
Cádmio	9 / 9	Normal	4.5	45.6	21.9	30	70	No	BSL
Cobre	9 / 9	Normal	46	520	278	387	--	--	NSL
Plomo	9 / 9	Normal	211	2041	858	1233	400	Yes	ASL
Selenio	8 / 9	Normal	0.03	1.85	0.95	1	390	No	BSL
Tálio	9 / 9	Gamma	0.66	5.26	1.81	3	6	No	BSL
Zinc	9 / 9	Normal	255	1740	947	1283	23,000	No	BSL
Plata	9 / 9	Gamma	1.42	21.67	8.69	16	390	No	BSL
Mercurio	9 / 9	Normal	0.068	0.380	0.218	0.284	23	No	BSL
Chucchis									
Antimonio	2 / 2	--	0.3	1.4	0.9	--	31	No	BSL
Arsénico	2 / 2	--	69	201	135	--	0.4	Yes	ASL
Cádmio	2 / 2	--	4.0	21.9	13.0	--	70	No	BSL
Cobre	2 / 2	--	53	275	164	--	--	--	NSL
Plomo	2 / 2	--	176	870	523	--	400	Yes	ASL
Selenio	2 / 2	--	0.09	1.70	0.90	--	390	No	BSL
Tálio	2 / 2	--	0.58	1.20	0.89	--	6	No	BSL
Zinc	2 / 2	--	382	688	535	--	23,000	No	BSL
Plata	2 / 2	--	1.35	38.86	20.11	--	390	No	BSL
Mercurio	2 / 2	--	0.165	0.9	0.533	--	23	No	BSL

Notes:

-- = screening level not available or statistical analysis not possible due to small sample size

ASL = concentration is above the screening level

BSL = concentration is below the screening level

mg/kg, ww = milligram per kilogram, wet weight

NSL = no screening level

Table 3-14. Summary Statistics and Selection of Chemicals for Drinking Water.

Drinking Water (mg/L)	Frequency of Detection	Distribution	Min	Max	Mean	95% UCLM	Screening Level[a]	Exceed?
La Oroya Antigua								
Arsénico	23 / 23	Non-parametric	0.001	0.122	0.014	0.035	0.1 / 0.01	No / Yes
Cádmio	0 / 23	--	< 0.0002	< 0.003	< 0.003	--	0.005	No
Cobre	13 / 23	Non-parametric	0.007	0.050	0.028	0.046	1.3	No
Plomo	11 / 23	Non-parametric	0.003	0.031	0.007	0.013	0.015	No
Zinc	23 / 23	Lognormal	0.014	1.081	0.127	0.230	5	No
La Oroya Nueva								
Arsénico[b]	5 / 5	Non-parametric	0.001	0.008	0.005	0.011	0.1 / 0.01	No / No
Cádmio	0 / 5	--	< 0.003	< 0.003	< 0.003	--	0.005	No
Cobre	1 / 5	--	0.046	0.046	0.046	--	1.3	No
Plomo	0 / 5	--	< 0.010	< 0.010	< 0.010	--	0.015	No
Zinc	5 / 5	Gamma	0.021	1.611	0.438	1.89	5	No
Marcavalle (includes Tupac Amaru)								
Arsénico[b]	3 / 5	Gamma	0.001	0.036	0.013	0.267	0.1 / 0.01	No / Yes
Cádmio	0 / 5	--	< 0.003	< 0.003	< 0.003	--	0.005	No
Cobre	0 / 5	--	< 0.010	< 0.010	< 0.010	--	1.3	No
Plomo	1 / 5	--	0.016	0.016	0.016	--	0.015	No
Zinc	5 / 5	Gamma	0.026	0.059	0.036	0.052	5	No
Chucchis								
Arsénico	1 / 3	--	0.002	0.002	--	--	0.1 / 0.01	No / No
Cádmio	0 / 3	--	< 0.003	< 0.003	--	--	0.005	No
Cobre	1 / 3	--	0.019	0.019	--	--	1.3	No
Plomo	0 / 3	--	< 0.010	< 0.010	--	--	0.015	No
Zinc	3 / 3	--	0.025	0.042	0.031	--	5	No

Notes:

< = analyte not detected above detection limit

-- = statistical analysis not possible due to small sample size

ND = analyte not detected in any sample

mg/L = milligram per liter

UCLM = 95th upper confidence limit of the mean

a = The current Peruvian drinking water standard is 0.1 mg/L. There is a proposal to reduce the value to 0.05 mg/L. The U.S. drinking water standard is 0.01 mg/L.

b = The maximum detected concentration was compared to the screening value when the UCLM exceeded the maximum concentration.

Table 3-15. Chemical Screening Criteria.

Chemicals of Potential Concern	Ingestion of Soil/Dust (mg/kg)	Source	Inhalation of Fugitive Particulates from Soil/Dust (mg/kg)	Source	Ingestion of Drinking Water $(mg/L)^{-1}$	Source	Inhalation of Ambient Air $(ug/m3)^{-1}$	Source
Antimony	31[a]	USEPA 2002c	NA	--	Not Eval.	--	--	--
Arsenic	0.4[b,c]	USEPA 2002c	770[c]	USEPA 2002c	0.01[g]	USEPA 2005c	0.0043[k]	USEPA 2005b
Cadmium	70[a,b,d]	USEPA 2002c	1800[c]	USEPA 2002c	0.005[h]	USEPA 2005c	0.0018[k]	USEPA 2005b
Copper	NA	--	NA	--	1.3[i]	USEPA 2005c	--	--
Lead	NA	--	NA	--	0.015[i]	USEPA 2005c	1.5[l]	USEPA 2005d
Mercury	23[a,e]	USEPA 2002c	NA	--	--	--	--	--
Selenium	390[a]	USEPA 2002c	NA	--	--	--	--	--
Silver	390[a]	USEPA 2002c	NA	--	--	--	--	--
Thallium	6[a,f]	USEPA 2002c	NA	--	--	--	--	--
Zinc	23,000[a]	USEPA 2002c	NA	--	5[j]	USEPA 2005c	--	--

[a]Calculated value corresponds to a noncancer hazard quotient of 1. For exposure to multiple non-carcinogens, USEPA evaluates contaminants according to the critical effect listed as the basis for the RfD/RfC and where more than one chemical affects the same target organ or organ system, SSLs for those chemicals should be divided by the number of chemicals present in the group.

[b]Calculated based on combined exposure via ingestion and dermal contact.

[c]Calculated values correspond to a cancer risk of 1 in 1,000,000. For multiple carcinogens, USEPA believes values will accumulate to be within acceptable risk levels (i.e., 1E-06 to 1E-04).

[d]Based on dietary RfD for cadmium.

[e]Based on RfD for mercuric chloride.

[f]Based on RfD for thallium chloride.

[g]U.S. Safe Drinking Water Act Maximum Contaminant Level (MCL) for Arsenic that will be in effect as of 1/23/06. Also the provisional guideline value published by the World Health Organization (WHO).

[h]Current U.S. primary drinking water standard; MCL.

[i]Current U.S. primary drinking water standard; treatment action level.

[j]Current U.S. secondary drinking water standard.

[k]Air Unit Risk value published in USEPA's IRIS database.

[l]U.S. National Ambient Air Quality Standard for lead based on quarterly average monitoring.

NA - not available

Table 4-1. Annual Average and Maximum Daily Average Concentrations of Sulfur Dioxide (µg/m^3).

Averaging Time	Monitor (Location)	Monitor Ambient Air Concentration [a]			
		2002	2003 [b]	2004	2005 [c]
Annual	Sindicato (La Oroya Antigua)	383	345	423	NA
	Hotel Inca (La Oroya Nueva)	375	345	492	NA
	Cushurupampa (Marcavalle)	323	315	384	NA
24-hour	Sindicato (La Oroya Antigua)	1558	1728	1371	1405
	Hotel Inca (La Oroya Nueva)	1294	1463	2311	1103
	Cushurupampa (Marcavalle)	1501	1005	1188	1197

[a] All ambient air concentrations at normal temperature and pressure conditions.

[b] Year 2003 includes data from January through October only.

[c] First quarter monitoring results only.

NA - Not available. Monitoring for 2005 not yet completed.

µg/m^3 - Micrograms per cubic meter.

Table 4-2. Statistical Comparison of 2000 and 2004 Children Blood Lead Data, La Oroya Antigua.

Age Group	2004 Sampling Data								2000 Sampling Data							
	Number of PbB Samples	Statistical Distribution of PbB Samples	Mean (µg/dL)	10th Percentile (µg/dL)	25th Percentile (µg/dL)	50th Percentile (µg/dL)	75th Percentile (µg/dL)	90th Percentile (µg/dL)	Number of PbB Samples	Statistical Distribution of PbB Samples	Mean (µg/dL)	10th Percentile (µg/dL)	25th Percentile (µg/dL)	50th Percentile (µg/dL)	75th Percentile (µg/dL)	90th Percentile (µg/dL)
All	758	Non-parametric	32	20	26	33	37	45	756	Non-parametric	27	17	22	28	33	38
0-1	78	Normal	31	17	23	30	37	44	9	Normal	23	13	16	22	32	38
1-2	119	Normal	36	20	30	36	43	49	13	Non-parametric	29	7	25	31	35	40
2-3	128	Gamma	34	20	26	33	40	49	11	Normal	29	17	24	27	38	43
3-4	115	Gamma	33	20	27	31	37	44	23	Non-parametric	34	30	31	34	37	43
4-5	137	Normal	32	21	27	32	37	41	24	Normal	30	20	24	31	36	39
5-6	181	Non-parametric	30	20	23	30	36	41	35	Non-parametric	30	11	22	32	37	43
6-7									73	Normal	29	16	24	29	37	40
7-8									88	Non-parametric	30	20	25	31	35	38
8-9									77	Normal	29	18	25	30	35	38
9-10									94	Normal	28	19	23	28	33	37
10-11									122	Normal	26	16	21	26	29	34
11-12									87	Normal	25	15	20	25	29	34
12-13									38	Normal	24	16	19	24	29	32
13-14									22	Normal	26	18	22	25	30	35
14-15									22	Normal	22	11	19	22	27	31
15-16									18	Normal	21	7	14	21	28	32

Table 4-3a. ISE Input Parameters Used for All Simulations.

Parameter	Units	Distribution	Point Value / Mean / Min[a]	Standard Deviation / Likliest[a]	Maximum	Rationale / Source
Exposure Frequency	days/yr	Point	365			USEPA default assumption
Averaging Time	days/yr	Point	365			USEPA default assumption
Dust Ingestion Rate	mg/day	Lognormal	90	75		Best professional judgement, best model fit
Dust Ingestion Rate Scale Factor - Ages						
0-1		Point	0.6296			USEPA default assumption
1-2		Point	1			USEPA default assumption
2-3		Point	1			USEPA default assumption
3-4		Point	1			USEPA default assumption
4-5		Point	0.7407			USEPA default assumption
5-6		Point	0.6666			USEPA default assumption
6-7		Point	0.6296			USEPA default assumption
F (Fraction of intake that is outdoor dust)		Point	0.6			Observation & interviews with area residents
Water Ingestion Rate Scale Factor - Ages						
0-1	L/day	Point	0.2			USEPA default assumption
1-2	L/day	Point	0.5			USEPA default assumption
2-3	L/day	Point	0.52			USEPA default assumption
3-4	L/day	Point	0.53			USEPA default assumption
4-5	L/day	Point	0.55			USEPA default assumption
5-6	L/day	Point	0.58			USEPA default assumption
6-7	L/day	Point	0.56			USEPA default assumption
Absorption						
Outdoor Dust	%	Triangular	15	40	65	Best professional judgement, best model fit
Residential Dust	%	Triangular	15	40	65	Best professional judgement, best model fit
Water	%	Triangular	30	50	70	Best professional judgement, best model fit
Diet	%	Triangular	30	50	70	Best professional judgement, best model fit
Soil	%	Triangular	10	30	50	Best professional judgement, best model fit
Passive Fraction	%	Point	0.2			USEPA default assumption
Half Saturation Level	µg/day	Point	100			USEPA default assumption
Ventiliation Rate - Ages						
0-1	m^3/day	Point	2			USEPA default assumption
1-2	m^3/day	Point	3			USEPA default assumption
2-3	m^3/day	Point	5			USEPA default assumption
3-4	m^3/day	Point	5			USEPA default assumption
4-5	m^3/day	Point	5			USEPA default assumption
5-6	m^3/day	Point	7			USEPA default assumption
6-7	m^3/day	Point	7			USEPA default assumption
Indoor Concentration (% of Outdoor)	%	Point	30			USEPA default assumption
Time Spent Outdoors - Ages						
0-1	hr/day	Point	4			Observation & interviews with residents
1-2	hr/day	Point	8			Observation & interviews with residents
2-3	hr/day	Point	8			Observation & interviews with residents
3-4	hr/day	Point	8			Observation & interviews with residents
4-5	hr/day	Point	8			Observation & interviews with residents
5-6	hr/day	Point	6			Observation & interviews with residents
6-7	hr/day	Point	6			Observation & interviews with residents
Lung Absorption - Ages						
0-1	%	Point	32			USEPA default assumption
1-2	%	Point	32			USEPA default assumption
2-3	%	Point	32			USEPA default assumption
3-4	%	Point	32			USEPA default assumption
4-5	%	Point	32			USEPA default assumption
5-6	%	Point	32			USEPA default assumption
6-7	%	Point	32			USEPA default assumption

[a] The ISE model calls for input of arithmetic mean and arithmetic standard deviation for both log normal and normal distributions.

Table 4-3b. ISE Input Parameters That Vary With Time and/or Community - La Oroya Antigua.

Parameter	Units	Distribution	Point Value / Mean / Min[a]	Standard Deviation / Likliest[a]	Rationale / Source
La Oroya Antigua - 2004					
Soil Lead Intake - Ages (listed as "Other" in model)					
0-1	µg/day	Lognormal	30.2	12.6	Best professional judgement, best model fit
1-2	µg/day	Lognormal	48	20	Best professional judgement, best model fit
2-3	µg/day	Lognormal	48	20	Best professional judgement, best model fit
3-4	µg/day	Lognormal	48	20	Best professional judgement, best model fit
4-5	µg/day	Lognormal	35.5	14.8	Best professional judgement, best model fit
5-6	µg/day	Lognormal	32.2	13.4	Best professional judgement, best model fit
6-7	µg/day	Lognormal	30.2	12.6	Best professional judgement, best model fit
Air Concentration	$\mu g/m^3$	Lognormal	2.87	1.97	Based on site-specific sampling data
Community Dust Concentration (listed as "Soil" in model)	µg/g	Lognormal	7,684	3,991	Based on site-specific sampling data
Residential Dust Concentration (listed as "Dust" in model)	µg/g	Lognormal	2,795	1,199	Based on site-specific sampling data
Drinking Water Concentration - La Oroya Antigua	µg/L	Normal	7	6.6	Based on site-specific sampling data
Maternal Blood Lead Concentration	µg/dL	Point	17		Based on site-specific sampling data
Diet Intake - Ages					
0-1	µg/day	Normal	55	42	Based on site-specific sampling data
1-2	µg/day	Normal	60	35	Based on site-specific sampling data
2-3	µg/day	Normal	48	51	Based on site-specific sampling data
3-4	µg/day	Normal	55	42	Based on site-specific sampling data
4-5	µg/day	Normal	55	42	Based on site-specific sampling data
5-6	µg/day	Normal	55	42	Based on site-specific sampling data
6-7	µg/day	Normal	55	42	Based on site-specific sampling data
La Oroya Antigua - 2007					
Soil Lead Intake - Ages (listed as "Other" in model)					
0-1	µg/day	Lognormal	28.1	11.7	Best professional judgement, best model fit
1-2	µg/day	Lognormal	44.6	18.6	Best professional judgement, best model fit
2-3	µg/day	Lognormal	44.6	18.6	Best professional judgement, best model fit
3-4	µg/day	Lognormal	44.6	18.6	Best professional judgement, best model fit
4-5	µg/day	Lognormal	33	13.8	Best professional judgement, best model fit
5-6	µg/day	Lognormal	29.9	12.5	Best professional judgement, best model fit
6-7	µg/day	Lognormal	28.1	11.7	Best professional judgement, best model fit
Air Concentration	$\mu g/m^3$	Lognormal	0.57	0.39	Based on air model results
Community Dust Concentration (listed as "Soil" in model)	µg/g	Lognormal	2,627	2,168	Based on air model results
Residential Dust Concentration (listed as "Dust" in model)	µg/g	Lognormal	1,185	508	Based on air model results
Drinking Water Concentration - La Oroya Antigua	µg/L	Normal	7	6.6	Based on site-specific sampling data
Maternal Blood Lead Concentration	µg/dL	Point	10		Based on adult lead model results
Diet Intake - Ages					
0-1	µg/day	Normal	31.2	23.9	Based on air model results, judgement
1-2	µg/day	Normal	34.1	19.9	Based on air model results, judgement
2-3	µg/day	Normal	27.3	29	Based on air model results, judgement
3-4	µg/day	Normal	31.2	23.9	Based on air model results, judgement
4-5	µg/day	Normal	31.2	23.9	Based on air model results, judgement
5-6	µg/day	Normal	31.2	23.9	Based on air model results, judgement
6-7	µg/day	Normal	31.2	23.9	Based on air model results, judgement
La Oroya Antigua - 2011					
Soil Lead Intake - Ages (listed as "Other" in model)					
0-1	µg/day	Lognormal	22.7	9.5	Best professional judgement, best model fit
1-2	µg/day	Lognormal	36	15	Best professional judgement, best model fit
2-3	µg/day	Lognormal	36	15	Best professional judgement, best model fit
3-4	µg/day	Lognormal	36	15	Best professional judgement, best model fit
4-5	µg/day	Lognormal	26	11.1	Best professional judgement, best model fit
5-6	µg/day	Lognormal	24.1	10.1	Best professional judgement, best model fit
6-7	µg/day	Lognormal	22.7	9.5	Best professional judgement, best model fit
Air Concentration	$\mu g/m^3$	Lognormal	0.43	0.3	Based on air model results
Community Dust Concentration (listed as "Soil" in model)	µg/g	Lognormal	1,595	1,316	Based on air model results
Residential Dust Concentration (listed as "Dust" in model)	µg/g	Lognormal	950	408	Based on air model results
Drinking Water Concentration - La Oroya Antigua	µg/L	Normal	7	6.6	Based on site-specific sampling data
Maternal Blood Lead Concentration	µg/dL	Point	7		Based on adult lead model results
Diet Intake - Ages					
0-1	µg/day	Normal	27.5	21	Based on air model results, judgement
1-2	µg/day	Normal	30	17.5	Based on air model results, judgement
2-3	µg/day	Normal	24	25.5	Based on air model results, judgement
3-4	µg/day	Normal	27.5	21	Based on air model results, judgement
4-5	µg/day	Normal	27.5	21	Based on air model results, judgement
5-6	µg/day	Normal	27.5	21	Based on air model results, judgement
6-7	µg/day	Normal	27.5	21	Based on air model results, judgement

[a] The ISE model calls for input of arithmetic mean and arithmetic standard deviation for both log normal and normal distributions.

Table 4-3c. ISE Input Parameters That Vary With Time and Community - La Oroya Nueva.

Parameter	Units	Distribution	Point Value / Mean / Min[a]	Standard Deviation / Likliest[a]	Rationale / Source
La Oroya Nueva - 2004					
Soil Lead Intake - Ages (listed as "Other" in model)					
0-1	µg/day	Lognormal	13	7.7	Best professional judgement, best model fit
1-2	µg/day	Lognormal	20.7	12.3	Best professional judgement, best model fit
2-3	µg/day	Lognormal	20.7	12.3	Best professional judgement, best model fit
3-4	µg/day	Lognormal	20.7	12.3	Best professional judgement, best model fit
4-5	µg/day	Lognormal	15.3	9.1	Best professional judgement, best model fit
5-6	µg/day	Lognormal	13.9	8.2	Best professional judgement, best model fit
6-7	µg/day	Lognormal	13	7.7	Best professional judgement, best model fit
Air Concentration	µg/m^3	Lognormal	2.12	1.43	Based on site-specific sampling data
Community Dust Concentration (listed as "Soil" in model)	µg/g	Normal	2,159	1,228	Based on site-specific sampling data
Residential Dust Concentration (listed as "Dust" in model)	µg/g	Normal	1,483	1,037	Based on site-specific sampling data
Drinking Water Concentration - La Oroya Nueva	µg/L	Point	5		Based on site-specific sampling data
Maternal Blood Lead Concentration	µg/dL	Point	11		Based on site-specific sampling data
Diet Intake - Ages					
0-1	µg/day	Normal	55	42	Based on site-specific sampling data
1-2	µg/day	Normal	60	35	Based on site-specific sampling data
2-3	µg/day	Normal	48	51	Based on site-specific sampling data
3-4	µg/day	Normal	55	42	Based on site-specific sampling data
4-5	µg/day	Normal	55	42	Based on site-specific sampling data
5-6	µg/day	Normal	55	42	Based on site-specific sampling data
6-7	µg/day	Normal	55	42	Based on site-specific sampling data
La Oroya Nueva - 2007					
Soil Lead Intake - Ages (listed as "Other" in model)					
0-1	µg/day	Lognormal	12.2	7.2	Best professional judgement, best model fit
1-2	µg/day	Lognormal	19.5	11.6	Best professional judgement, best model fit
2-3	µg/day	Lognormal	19.5	11.6	Best professional judgement, best model fit
3-4	µg/day	Lognormal	19.5	11.6	Best professional judgement, best model fit
4-5	µg/day	Lognormal	14.3	8.6	Best professional judgement, best model fit
5-6	µg/day	Lognormal	13.1	7.7	Best professional judgement, best model fit
6-7	µg/day	Lognormal	12.2	7.2	Best professional judgement, best model fit
Air Concentration	µg/m^3	Lognormal	0.87	0.58	Based on air model results
Community Dust Concentration (listed as "Soil" in model)	µg/g	Normal	863.6	491.2	Based on air model results
Residential Dust Concentration (listed as "Dust" in model)	µg/g	Normal	771.2	539.2	Based on air model results
Drinking Water Concentration - La Oroya Nueva	µg/L	Point	5		Based on site-specific sampling data
Maternal Blood Lead Concentration	µg/dL	Point	8		Based on adult lead model results
Diet Intake - Ages					
0-1	µg/day	Normal	35.2	26.9	Based on air model results, judgement
1-2	µg/day	Normal	38.4	22.4	Based on air model results, judgement
2-3	µg/day	Normal	30.7	32.6	Based on air model results, judgement
3-4	µg/day	Normal	35.2	26.9	Based on air model results, judgement
4-5	µg/day	Normal	35.2	26.9	Based on air model results, judgement
5-6	µg/day	Normal	35.2	26.9	Based on air model results, judgement
6-7	µg/day	Normal	35.2	26.9	Based on air model results, judgement
La Oroya Nueva - 2011					
Soil Lead Intake - Ages (listed as "Other" in model)					
0-1	µg/day	Lognormal	9.9	5.9	Best professional judgement, best model fit
1-2	µg/day	Lognormal	15.7	9.3	Best professional judgement, best model fit
2-3	µg/day	Lognormal	15.7	9.3	Best professional judgement, best model fit
3-4	µg/day	Lognormal	15.7	9.3	Best professional judgement, best model fit
4-5	µg/day	Lognormal	11.6	6.9	Best professional judgement, best model fit
5-6	µg/day	Lognormal	10.6	6.2	Best professional judgement, best model fit
6-7	µg/day	Lognormal	9.9	5.9	Best professional judgement, best model fit
Air Concentration	µg/m^3	Lognormal	0.45	0.3	Based on air model results
Community Dust Concentration (listed as "Soil" in model)	µg/g	Normal	431.8	245.6	Based on air model results
Residential Dust Concentration (listed as "Dust" in model)	µg/g	Normal	533.9	373.3	Based on air model results
Drinking Water Concentration - La Oroya Nueva	µg/L	Point	5		Based on site-specific sampling data
Maternal Blood Lead Concentration	µg/dL	Point	6		Based on adult lead model results
Diet Intake - Ages					
0-1	µg/day	Normal	28.3	21.6	Based on air model results, judgement
1-2	µg/day	Normal	30.8	18.0	Based on air model results, judgement
2-3	µg/day	Normal	24.7	26.2	Based on air model results, judgement
3-4	µg/day	Normal	28.3	21.6	Based on air model results, judgement
4-5	µg/day	Normal	28.3	21.6	Based on air model results, judgement
5-6	µg/day	Normal	28.3	21.6	Based on air model results, judgement
6-7	µg/day	Normal	28.3	21.6	Based on air model results, judgement

[a] The ISE model calls for input of arithmetic mean and arithmetic standard deviation for both log normal and normal distributions.

Table 4-3d. ISE Input Parameters That Vary With Time and Community - Marcavalle.

Parameter	Units	Distribution	Point Value / Mean / Min[a]	Standard Deviation / Likliest[a]	Rationale / Source
Marcavalle - 2004					
Soil Lead Intake - Ages (listed as "Other" in model)					
0-1	µg/day	Lognormal	10.7	6.2	Best professional judgement, best model fit
1-2	µg/day	Lognormal	17.1	9.9	Best professional judgement, best model fit
2-3	µg/day	Lognormal	17.1	9.9	Best professional judgement, best model fit
3-4	µg/day	Lognormal	17.1	9.9	Best professional judgement, best model fit
4-5	µg/day	Lognormal	12.6	7.3	Best professional judgement, best model fit
5-6	µg/day	Lognormal	11.5	6.6	Best professional judgement, best model fit
6-7	µg/day	Lognormal	10.7	6.2	Best professional judgement, best model fit
Air Concentration	µg/m^3	Lognormal	1.44	1.15	Based on site-specific sampling data
Community Dust Concentration (listed as "Soil" in model)	µg/g	Normal	2,153	955	Based on site-specific sampling data
Residential Dust Concentration (listed as "Dust" in model)	µg/g	Normal	1,109	597	Based on site-specific sampling data
Drinking Water Concentration - Marcavalle	µg/L	Normal	7.2	4.9	Based on site-specific sampling data
Maternal Blood Lead Concentration	µg/dL	Point	12		Based on site-specific sampling data
Diet Intake - Ages					
0-1	µg/day	Normal	55	42	Based on site-specific sampling data
1-2	µg/day	Normal	60	35	Based on site-specific sampling data
2-3	µg/day	Normal	48	51	Based on site-specific sampling data
3-4	µg/day	Normal	55	42	Based on site-specific sampling data
4-5	µg/day	Normal	55	42	Based on site-specific sampling data
5-6	µg/day	Normal	55	42	Based on site-specific sampling data
6-7	µg/day	Normal	55	42	Based on site-specific sampling data
Marcavalle - 2007					
Soil Lead Intake - Ages (listed as "Other" in model)					
0-1	µg/day	Lognormal	10.1	5.8	Best professional judgement, best model fit
1-2	µg/day	Lognormal	16.6	9.3	Best professional judgement, best model fit
2-3	µg/day	Lognormal	16.6	9.3	Best professional judgement, best model fit
3-4	µg/day	Lognormal	16.6	9.3	Best professional judgement, best model fit
4-5	µg/day	Lognormal	11.8	6.8	Best professional judgement, best model fit
5-6	µg/day	Lognormal	10.8	6.2	Best professional judgement, best model fit
6-7	µg/day	Lognormal	10.1	5.8	Best professional judgement, best model fit
Air Concentration	µg/m^3	Lognormal	0.68	0.54	Based on air model results
Community Dust Concentration (listed as "Soil" in model)	µg/g	Normal	904.3	401	Based on air model results
Residential Dust Concentration (listed as "Dust" in model)	µg/g	Normal	594.4	319.9	Based on air model results
Drinking Water Concentration - Marcavalle	µg/L	Normal	7.2	4.9	Based on site-specific sampling data
Maternal Blood Lead Concentration	µg/dL	Point	8		Based on adult lead model results
Diet Intake - Ages					
0-1	µg/day	Normal	35.9	27.4	Based on air model results, judgement
1-2	µg/day	Normal	39.1	22.8	Based on air model results, judgement
2-3	µg/day	Normal	31.3	33.3	Based on air model results, judgement
3-4	µg/day	Normal	35.9	27.4	Based on air model results, judgement
4-5	µg/day	Normal	35.9	27.4	Based on air model results, judgement
5-6	µg/day	Normal	35.9	27.4	Based on air model results, judgement
6-7	µg/day	Normal	35.9	27.4	Based on air model results, judgement
Marcavalle - 2011					
Soil Lead Intake - Ages (listed as "Other" in model)					
0-1	µg/day	Lognormal	8.6	3.7	Best professional judgement, best model fit
1-2	µg/day	Lognormal	13.8	7.9	Best professional judgement, best model fit
2-3	µg/day	Lognormal	13.8	7.9	Best professional judgement, best model fit
3-4	µg/day	Lognormal	13.8	7.9	Best professional judgement, best model fit
4-5	µg/day	Lognormal	10.1	5.9	Best professional judgement, best model fit
5-6	µg/day	Lognormal	9.2	5.3	Best professional judgement, best model fit
6-7	µg/day	Lognormal	8.6	5.0	Best professional judgement, best model fit
Air Concentration	µg/m^3	Lognormal	0.49	0.39	Based on air model results
Community Dust Concentration (listed as "Soil" in model)	µg/g	Normal	732.0	324.7	Based on air model results
Residential Dust Concentration (listed as "Dust" in model)	µg/g	Normal	523.5	281.8	Based on air model results
Drinking Water Concentration - Marcavalle	µg/L	Normal	7.2	4.9	Based on site-specific sampling data
Maternal Blood Lead Concentration	µg/dL	Point	6		Based on adult lead model results
Diet Intake - Ages					
0-1	µg/day	Normal	33.2	25.3	Based on air model results, judgement
1-2	µg/day	Normal	36.2	21.1	Based on air model results, judgement
2-3	µg/day	Normal	29.0	30.8	Based on air model results, judgement
3-4	µg/day	Normal	33.2	25.3	Based on air model results, judgement
4-5	µg/day	Normal	33.2	25.3	Based on air model results, judgement
5-6	µg/day	Normal	33.2	25.3	Based on air model results, judgement
6-7	µg/day	Normal	33.2	25.3	Based on air model results, judgement

[a] The ISE model calls for input of arithmetic mean and arithmetic standard deviation for both log normal and normal distributions.

Table 4-3e. ISE Input Parameters That Vary With Time and Community - Chucchis.

Parameter	Units	Distribution	Point Value / Mean / Min[a]	Standard Deviation / Likliest[a]	Rationale / Source
Chucchis - 2004					
Soil Lead Intake - Ages (listed as "Other" in model)					
0-1	µg/day	Lognormal	10.7	6.2	Best professional judgement, best model fit
1-2	µg/day	Lognormal	17.1	9.9	Best professional judgement, best model fit
2-3	µg/day	Lognormal	17.1	9.9	Best professional judgement, best model fit
3-4	µg/day	Lognormal	17.1	9.9	Best professional judgement, best model fit
4-5	µg/day	Lognormal	12.6	7.3	Best professional judgement, best model fit
5-6	µg/day	Lognormal	11.5	6.6	Best professional judgement, best model fit
6-7	µg/day	Lognormal	10.7	6.2	Best professional judgement, best model fit
Air Concentration	µg/m^3	Lognormal	1.44	1.15	Based on site-specific sampling data
Community Dust Concentration (listed as "Soil" in model)	µg/g	Normal	2,371	1,348	Based on site-specific sampling data
Residential Dust Concentration (listed as "Dust" in model)	µg/g	Normal	1,004	613	Based on site-specific sampling data
Drinking Water Concentration - Chucchis	µg/L	Point	5		Based on site-specific sampling data
Maternal Blood Lead Concentration	µg/dL	Point	12		Based on site-specific sampling data
Diet Intake - Ages					
0-1	µg/day	Normal	55	42	Based on site-specific sampling data
1-2	µg/day	Normal	60	35	Based on site-specific sampling data
2-3	µg/day	Normal	48	51	Based on site-specific sampling data
3-4	µg/day	Normal	55	42	Based on site-specific sampling data
4-5	µg/day	Normal	55	42	Based on site-specific sampling data
5-6	µg/day	Normal	55	42	Based on site-specific sampling data
6-7	µg/day	Normal	55	42	Based on site-specific sampling data
Chucchis - 2007					
Soil Lead Intake - Ages (listed as "Other" in model)					
0-1	µg/day	Lognormal	10.2	5.9	Best professional judgement, best model fit
1-2	µg/day	Lognormal	16.2	9.4	Best professional judgement, best model fit
2-3	µg/day	Lognormal	16.2	9.4	Best professional judgement, best model fit
3-4	µg/day	Lognormal	16.2	9.4	Best professional judgement, best model fit
4-5	µg/day	Lognormal	12	6.9	Best professional judgement, best model fit
5-6	µg/day	Lognormal	10.9	6.3	Best professional judgement, best model fit
6-7	µg/day	Lognormal	10.2	5.9	Best professional judgement, best model fit
Air Concentration	µg/m^3	Lognormal	0.72	0.58	Based on air model results
Community Dust Concentration (listed as "Soil" in model)	µg/g	Normal	1,186	674	Based on air model results
Residential Dust Concentration (listed as "Dust" in model)	µg/g	Normal	602.4	367.8	Based on air model results
Drinking Water Concentration - Chucchis	µg/L	Point	5		Based on site-specific sampling data
Maternal Blood Lead Concentration	µg/dL	Point	8		Based on adult lead model results
Diet Intake - Ages					
0-1	µg/day	Normal	38.5	29.4	Based on air model results, judgement
1-2	µg/day	Normal	42	24.5	Based on air model results, judgement
2-3	µg/day	Normal	48	35.7	Based on air model results, judgement
3-4	µg/day	Normal	38.5	29.4	Based on air model results, judgement
4-5	µg/day	Normal	38.5	29.4	Based on air model results, judgement
5-6	µg/day	Normal	38.5	29.4	Based on air model results, judgement
6-7	µg/day	Normal	38.5	29.4	Based on air model results, judgement
Chucchis - 2011					
Soil Lead Intake - Ages (listed as "Other" in model)					
0-1	µg/day	Lognormal	8.9	5.1	Best professional judgement, best model fit
1-2	µg/day	Lognormal	14.2	8.2	Best professional judgement, best model fit
2-3	µg/day	Lognormal	14.2	8.2	Best professional judgement, best model fit
3-4	µg/day	Lognormal	14.2	8.2	Best professional judgement, best model fit
4-5	µg/day	Lognormal	10.4	6.1	Best professional judgement, best model fit
5-6	µg/day	Lognormal	9.5	5.5	Best professional judgement, best model fit
6-7	µg/day	Lognormal	8.9	5.1	Best professional judgement, best model fit
Air Concentration	µg/m^3	Lognormal	0.58	0.46	Based on air model results
Community Dust Concentration (listed as "Soil" in model)	µg/g	Normal	1,020	579.6	Based on air model results
Residential Dust Concentration (listed as "Dust" in model)	µg/g	Normal	546.2	339.6	Based on air model results
Drinking Water Concentration - Chucchis	µg/L	Point	5		Based on site-specific sampling data
Maternal Blood Lead Concentration	µg/dL	Point	6		Based on adult lead model results
Diet Intake - Ages					
0-1	µg/day	Normal	36.2	27.6	Based on air model results, judgement
1-2	µg/day	Normal	39.5	23	Based on air model results, judgement
2-3	µg/day	Normal	31.6	33.6	Based on air model results, judgement
3-4	µg/day	Normal	36.2	27.6	Based on air model results, judgement
4-5	µg/day	Normal	36.2	27.6	Based on air model results, judgement
5-6	µg/day	Normal	36.2	27.6	Based on air model results, judgement
6-7	µg/day	Normal	36.2	27.6	Based on air model results, judgement

[a] The ISE model calls for input of arithmetic mean and arithmetic standard deviation for both log normal and normal distributions.

Table 4-4. Adult Blood Lead Data from 2000 and Predicted Value for 2004.

Age Group	Number of Samples	Statistical Distribution of Samples	Geometric Mean	10th Percentile	20th Percentile	50th Percentile	80th Percentile	90th Percentile
			(µg/dL)	(µg/dL)	(µg/dL)	(µg/dL)	(µg/dL)	(µg/dL)
La Oroya Antigua								
2000 Sampling Data								
16 - 35	236	Gamma	16	11	13	17	20	23
Predicted Values								
Adult Female		Lognormal	16	15	15	16	18	18
La Oroya Nueva[a]								
2000 Sampling Data								
16 - 35	221	Nonparametric	11	8	8	11	14	17
Predicted Values								
Adult Female		Lognormal	12	10	10	12	13	13
Marcavalle								
2000 Sampling Data								
16 - 35	182	Normal	12	8	10	13	17	18
Predicted Values								
Adult Female		Lognormal	11	10	10	11	12	13
Chucchis[b]								
2000 Sampling Data								
16 - 35	134	Nonparametric	12	8	10	11	15	18
Predicted Values								
Adult Female		Lognormal	11	10	10	11	12	13

Notes:

[a] Blood sampling data for residents from Club Inca and Buenos Aires used in comparison.

[b] Blood sampling data for residents from Santa Rosa de Sacco used in comparison.

Table 4-5. Statistical Comparison of 2001 and 2004 Children Blood Lead Data, La Oroya Nueva.

Age Group	2004 Sampling Data								2001 Sampling Data							
	Number of PbB Samples	Statistical Distribution of PbB Samples	Mean (µg/dL)	10th Percentile (µg/dL)	25th Percentile (µg/dL)	50th Percentile (µg/dL)	75th Percentile (µg/dL)	90th Percentile (µg/dL)	Number of PbB Samples	Statistical Distribution of PbB Samples	Mean (µg/dL)	10th Percentile (µg/dL)	25th Percentile (µg/dL)	50th Percentile (µg/dL)	75th Percentile (µg/dL)	90th Percentile (µg/dL)
All	23[a]	Normal	25	20	20	26	30	33	1670[b]	Non-parametric	18	10	13	17	22	27
0 - 6	23	Normal	25	20	20	26	30	33	470	Normal	21	11	15	20	25	32

Notes:
[a] Children ages 0 to 6 years old. Dataset includes three samples from locations outside La Oroya Nueva (Curipata, Marcavalle).
[b] Children ages 0 to 16 years old.

Table 4-6a. Comparison of 2004 Children Blood Lead Data and Predicted Blood Lead Levels, La Oroya Antigua and La Oroya Nueva (Children Ages 0 to 6).

Mean (µg/dL)	25th Percentile (µg/dL)	50th Percentile (µg/dL)	75th Percentile (µg/dL)	90th Percentile (µg/dL)	95th Percentile (µg/dL)
La Oroya Antigua					
2004 Sampling Data					
32	26	33	37	45	50
2004 Predicted Concentrations					
33	29	33	36	39	42
La Oroya Nueva					
2004 Sampling Data					
25	20	26	30	33	36
2004 Predicted Concentrations					
20	18	20	22	23	24

Table 4-6b. Comparison of 2000 Children Blood Lead Data and Predicted Blood Lead Levels, Marcavalle, Chucchis (Children Ages 0 to 6).

Mean (µg/dL)
Marcavalle
2000 Sampling Data
21
2004 Predicted Concentrations
19
Chucchis
2000 Sampling Data
22
2004 Predicted Concentrations
20

Note: 2000 Sampling data from DRP 2001.
Data for Marcavalle from Anexo.
Data for Chucchis from pg. 41, Santa Rose de Sacco.

Table 4-7a. Summary of Input Values for ISE Modeling for La Oroya Antigua.

Varible	Unit	2004	2007			2011		
			Projected % change	Conversion Factor	Input Value	Projected % change	Conversion Factor	Input Value
Pb Concentration in Air	$\mu g/m^3$	2.87	-80.0%	0.200	0.57	-85.0%	0.150	0.43
Pb Deposition	$g/m^2/year$	0.017	-72.0%	0.280	0.005	-83.0%	0.170	0.003
Mean Pb Conc. in Community Dust	mg/kg	7684	-72.0%	0.280	2151.52	-83.0%	0.170	1306.28
Mean Pb Conc. in Residential Dust	mg/kg	2795	-57.6%	0.424	1185.08	-66.4%	0.336	939.12
Mean Pb Conc. in Soil	mg/kg	2407	-7.2%	0.928	2233.70	-24.9%	0.751	1807.66
Mean Pb Diet Intake	µg/day	55	-43.2%	0.568	31.24	-49.8%	0.502	27.61
Mean Pb Conc. in Water	µg/L	7	0.0%	1.0	7.00	0.0%	1.0	7.00

Notes:

1. Pb air concentration for 2004 was determined based on monitoring results.
2. Pb deposition rate for 2004 was determined based on air quality modeling.
3. The projected percent changes for air concentration and deposition were based on air quality modeling report.
4. 2004 air concentration was derived from the monitoring results from the Sindicato de Obreros station.

Table 4-7b. Summary of Input Values for ISE Modeling for La Oroya Nueva.

Varible	Unit	2004	2007			2011		
			Projected % change	Conversion Factor	Input Value	Projected % change	Conversion Factor	Input Value
Pb Concentration in Air	$\mu g/m^3$	2.12	-59.0%	0.410	0.87	-79.0%	0.210	0.45
Pb Deposition	$g/m^2/year$	0.060	-60.0%	0.400	0.024	-81.0%	0.190	0.011
Mean Pb Conc. in Community Dust	mg/kg	2159.00	-60.0%	0.400	863.60	-81.0%	0.190	410.21
Mean Pb Conc. in Residential Dust	mg/kg	1483.00	-48.0%	0.520	771.16	-64.8%	0.352	522.02
Mean Pb Conc. in Soil	mg/kg	1038.50	-6.0%	0.940	976.19	-24.3%	0.757	786.14
Mean Pb Diet Intake	µg/day	55.00	-36.0%	0.640	35.20	-48.6%	0.514	28.27
Mean Pb Conc. in Water	µg/L	5.00	0.0%	1.0	5.00	0.0%	1.0	5.00

Note:

1. Pb air concentration for 2004 was determined based on monitoring results.
2. Pb deposition rate for 2004 was determined based on air quality modeling.
3. The projected percent changes for air concentration and deposition were based on air quality modeling report.
4. 2004 air concentration was derived from the monitoring results from the Hotel Inca station.

Table 4-7c. Summary of Input Values for ISE Modeling for Marcavalle.

Varible	Unit	2004	2007			2011		
			Projected % change	Conversion Factor	Input Value	Projected % change	Conversion Factor	Input Value
Pb Concentration in Air	$\mu g/m^3$	1.44	-53.0%	0.470	0.68	-66.0%	0.340	0.49
Pb Deposition	$g/m^2/year$	0.060	-58.0%	0.420	0.025	-66.0%	0.340	0.020
Mean Pb Conc. in Community Dust	mg/kg	2153.00	-58.0%	0.420	904.26	-66.0%	0.340	732.02
Mean Pb Conc. in Residential Dust	mg/kg	1109.00	-46.4%	0.536	594.42	-52.8%	0.472	523.45
Mean Pb Conc. in Soil	mg/kg	858.00	-5.8%	0.942	808.24	-19.8%	0.802	688.12
Mean Pb Diet Intake	µg/day	55.00	-34.8%	0.652	35.86	-39.6%	0.604	33.22
Mean Pb Conc. in Water	µg/L	7.20	0.0%	1.0	7.20	0.0%	1.0	7.20

Note:

1. Pb air concentration for 2004 was determined based on monitoring results.
2. Pb deposition rate for 2004 was determined based on air quality modeling.
3. The projected percent changes for air concentration and deposition were based on air quality modeling.
4. 2004 air concentration was derived from the monitoring results from the Cushurupampa station.

Table 4-7d. Summary of Input Values for ISE Modeling for Chucchis.

Varible	Unit	2004	2007			2011		
			Projected % change	Conversion Factor	Input Value	Projected % change	Conversion Factor	Input Value
Pb Concentration in Air	$\mu g/m^3$	1.44	-50.0%	0.500	0.72	-60.0%	0.400	0.58
Pb Deposition	$g/m^2/year$	0.007	-50.0%	0.500	0.004	-57.0%	0.430	0.003
Mean Pb Conc. in Community Dust	mg/kg	2371.00	-50.0%	0.500	1185.50	-57.0%	0.430	1019.53
Mean Pb Conc. in Residential Dust	mg/kg	1004.00	-40.0%	0.600	602.40	-45.6%	0.544	546.18
Mean Pb Conc. in Soil	mg/kg	858.00	-5.0%	0.950	815.10	-17.1%	0.829	711.28
Mean Pb Diet Intake	µg/day	55.00	-30.0%	0.700	38.50	-34.2%	0.658	36.19
Mean Pb Conc. in Water	µg/L	7.20	0.0%	1.0	7.20	0.0%	1.0	7.20

Note:

1. Pb air concentration for 2004 was determined based on monitoring results
2. Pb deposition rate for 2004 was determined based on air quality modeling
3. The projected percent changes for air concentration and deposition were based on air quality modeling
4. No site-specific data for soil at Chucchis; the data from Marcavalle were used instead.
5. 2004 air concentration was derived from the monitoring results from the Cushurupampa station

Table 4-8. Summary of Improvements in Geometric Mean Environmental Lead Levels after 1997.

Environmental Medium	Units	Before NLS (1994-96)	After NLS (1999)	Change (%)
Air (suspended particulate)	$\mu g/m^3$	1.1	0.3	73
Outdoor dustfall	mg/m^2 per day	61	31	50
Indoor dustfall	mg/m^2 per day	0.14	0.07	50
Street dust	mg/m^2	220	120	45
Soil	Ppm	844	756	10*
House dust	ppm	758	583	23*

NLS, new lead smelter – commenced operating in 1997.
*Not statistically significant at 0.05 level.

Table 4-9. Input Parameters for the ALM Model.

Variable	Unit	Definition	Proposed Input Value-Mothers
$R_{fetal/maternal}$	unitless	Fetal/maternal PbB ratio	0.9
BKSF	µg/dL per µg/day	Biokinetic Slope Factor	0.375
GSD_i	unitless	Geometric standard deviation PbB	1.43
IR_{S+D}	g/day	Soil ingestion rate (including soil-derived indoor dust)	0.05
W_s	unitless	Weighting Factor (fraction of IR ingested as outdoor dust)	0.4
$AF_{S,D}$	unitless	Absorption fraction	0.08
$EF_{S,D}$	days/yr	Exposure frequency (same for soil and dust)	365
$AT_{S,D}$	days/yr	Averaging time (same for soil and dust)	365
K_{SD}	unitless	Mass fraction of outdoor dust in indoor dust - La Oroya Antigua	0.40
K_{SD}	unitless	Mass fraction of outdoor dust in indoor dust - La Oroya Nueva	0.69
K_{SD}	unitless	Mass fraction of outdoor dust in indoor dust - Marcavalle	0.52
K_{SD}	unitless	Mass fraction of outdoor dust in indoor dust - Chucchis	0.42
PbB_0	µg/dL	Baseline blood Pb concentration - 2004	9.0
PbB_0	µg/dL	Baseline blood Pb concentration - 2007	7.2
PbB_0	µg/dL	Baseline blood Pb concentration - 2011	5.4
PBS	mg/kg	Community Dust Concentration - La Oroya Antigua 2004	7,684
PBS	mg/kg	Community Dust Concentration - La Oroya Antigua 2007	2,627
PBS	mg/kg	Community Dust Concentration - La Oroya Antigua 2011	1,595
PBS	mg/kg	Community Dust Concentration - La Oroya Nueva 2004	2,159
PBS	mg/kg	Community Dust Concentration - La Oroya Nueva 2007	864
PBS	mg/kg	Community Dust Concentration - La Oroya Nueva 2011	410
PBS	mg/kg	Community Dust Concentration - Marcavalle 2004	2,153
PBS	mg/kg	Community Dust Concentration - Marcavalle 2007	904
PBS	mg/kg	Community Dust Concentration - Marcavalle 2011	732
PBS	mg/kg	Community Dust Concentration - Chucchis 2004	2,371
PBS	mg/kg	Community Dust Concentration - Chucchis 2007	1,186
PBS	mg/kg	Community Dust Concentration - Chucchis 2011	1,020

Table 4-10. Exposure Parameters for Adult and Child Residents.

Parameter	Units	Child		Reference	Adult		Reference
		CTE	RME		CTE	RME	
EPC	mg/kg m^3/day mg/L	Chemical specific, see Tables 3-10 to 3-13			Chemical specific, see Tables 3-10 to 3-13		
InhR-chronic	m^3/day	7	10	USEPA 1997, USEPA 1998	13	20	USEPA 1997, USEPA 1998
EF	day/year	335	365	CTE assumes family leaves town for 30 days vacation per year	335	365	CTE assumes family leaves town for 30 days vacation per year
ED	years	6	6	USEPA 1989, Child ages 0 - 6 yrs.	24	64	CTE assumes total residence time of 30 years; RME assumes total residence time of 70 years
IR-soil	mg/day	20	31	Estimated from ISE modeling	20	32	Estimated from ALM, Professional judgement
IR-residential dust	mg/day	36	70	Estimated from ISE modeling	30	43	Estimated from ALM, Professional judgement
IR-comm. dust	mg/day	54	105	Estimated from ISE modeling	20	35	Estimated from ALM, Professional judgement
RAF-dust	unitless	0.8	0.8	Best professional judgement	0.8	0.8	Best professional judgement
RAF-soil	unitless	0.5	0.5	Best professional judgement	0.5	0.5	Best professional judgement
BW	kg	13	13	Mean for children in La Oroya who participated in blood lead sampling program	63	63	Adult body weight proportional to La Oroya child body weight
ATnc	days	2190	2190	AT = ED x 365 day/year	8760	23360	AT = ED x 365 day/year
ATc	days	25550	25550	AT = 70 years x 365 day/year	25550	25550	AT = 70 years x 365 day/year
CF	mg/µg	1.00E-03	1.00E-03	--	1.00E-03	1.00E-03	--
CF	mg/kg	1.00E+06	1.00E+06	--	1.00E+06	1.00E+06	--

Table 4-11a. Blood Lead Levels for Women of Child-bearing Age in Lima (1999).

Method:	GSD = EXP[(Ln(σ^2/μ^2 +1))^0.5] = EXP[(Ln(CV^2 + 1))^0.5]				
	CV = SD / AM				
	SD = Arithmetic standard deviation				
	AM = Arithmetic mean				
	CV = Coefficient of variation				
1999 PbB Sampling Results from Lima, Peru					
	For women in Lima				
	N =	383		GSD =	1.81
	Mean =	6.5	μg/dL		
	Std Dev =	4.2	μg/dL		

Table 4-11b. Calculation of Site-Specific GSD for La Oroya Using Blood Lead Sampling Data for Year 2000.

Method:	GSD = EXP[(Ln(σ^2/μ^2 +1))^0.5] = EXP[(Ln(CV^2 + 1))^0.5]			
	CV = SD / AM			
	SD = Arithmetic standard deviation			
	AM = Arithmetic mean			
	CV = Coefficient of variation			
2001 PbB Sampling Results at La Oroya				
	For entire community:			
	N =	2449	**GSD =**	**1.46**
	Mean =	13.7 μg/dL		
	Std Dev =	5.4 μg/dL		
	Median =	13 μg/dL		
	For women in entire community (> 16 years old):			
	N =	2096	**GSD =**	**1.44**
	Mean =	13.3 μg/dL		
	Std Dev =	5 μg/dL		
	Median =	12.3 μg/dL		
	***For women ages of 16-35 years in entire community:**			
	N =	**477**	**GSD =**	**1.43**
	Mean =	**13.4 μg/dL**		
	Std Dev =	**5 μg/dL**		
	Median =	**13 μg/dL**		
	For adults at La Oroya-Antigua:			
	N =	400	**GSD =**	**1.37**
	Mean =	18 μg/dL		
	Std Dev =	5.8 μg/dL		
	Median =	17 μg/dL		

* GSD for women age 16-35 from entire community used in ALM

Table 4-12. Calculation of Intake of Chemicals from Indoor Dust - Year 2005.

		NonCancer Evaluation		Cancer Evaluation	
		CTE Intake (mg/kg-day)	RME Intake (mg/kg-day)	CTE Intake (mg/kg-day)	RME Intake (mg/kg-day)
Chemical	Exposure Point Concentration (mg/kg ww)	Combined Child/Adult	Combined Child/Adult	Combined Child/Adult	Combined Child/Adult
La Oroya Antigua					
Antimonio	109	9.39E-05	2.77E-04	4.02E-05	1.19E-04
Arsénico	1084	7.44E-04	2.20E-03	3.19E-04	9.42E-04
Cádmio	75	6.43E-05	1.90E-04	2.75E-05	8.13E-05
La Oroya Nueva					
Antimonio	146	1.25E-04	3.70E-04	5.37E-05	1.59E-04
Arsénico	650	4.46E-04	1.32E-03	1.91E-04	5.65E-04
Marcavalle					
Antimonio	45	3.87E-05	1.14E-04	1.66E-05	4.90E-05
Arsénico	465	3.19E-04	9.42E-04	1.37E-04	4.04E-04
Chucchis					
Arsénico	391	2.69E-04	7.93E-04	1.15E-04	3.40E-04
Cádmio	129	1.11E-04	3.26E-04	4.74E-05	1.40E-04

CTE = central tendency exposure

mg/kg-day = milligram per kilogram per day

mg/kg ww = milligram per kilogram wet weight

RME = reasonable maximum exposure

Table 4-13. Calculation of Intake of Chemicals in Outdoor Dust - Year 2005.

		NonCancer Evaluation		Cancer Evaluation	
		CTE Intake (mg/kg-day)	RME Intake (mg/kg-day)	CTE Intake (mg/kg-day)	RME Intake (mg/kg-day)
Chemical	Exposure Point Concentration (mg/kg ww)	Combined Child/Adult	Combined Child/Adult	Combined Child/Adult	Combined Child/Adult
La Oroya Antigua					
Antimonio	311	3.10E-04	8.72E-04	1.33E-04	3.74E-04
Arsénico	2490	1.98E-03	5.58E-03	8.50E-04	2.39E-03
Cádmio	187	1.86E-04	5.22E-04	7.96E-05	2.24E-04
Tálio	15	1.49E-05	4.18E-05	6.37E-06	1.79E-05
La Oroya Nueva					
Antimonio	173	1.72E-04	4.84E-04	7.37E-05	2.07E-04
Arsénico	887	7.06E-04	1.99E-03	3.03E-04	8.52E-04
Marcavalle					
Antimonio	49	4.90E-05	1.38E-04	2.10E-05	5.91E-05
Arsénico	654	5.21E-04	1.46E-03	2.23E-04	6.28E-04
Tálio	6	6.03E-06	1.70E-05	2.58E-06	7.27E-06
Chucchis					
Antimonio	55	5.52E-05	1.55E-04	2.36E-05	6.65E-05
Arsénico	818	6.51E-04	1.83E-03	2.79E-04	7.85E-04
Tálio	9	9.37E-06	2.64E-05	4.02E-06	1.13E-05

CTE = central tendency exposure

mg/kg-day = milligram per kilogram per day

mg/kg ww = milligram per kilogram wet weight

RME = reasonable maximum exposure

Table 4-14. Calculation of Intake of Chemcials from Surface Soil - Year 2005.

		NonCancer Evaluation		Cancer Evaluation	
		CTE Intake (mg/kg-day)	RME Intake (mg/kg-day)	CTE Intake (mg/kg-day)	RME Intake (mg/kg-day)
Chemical	Exposure Point Concentration (mg/kg ww)	Combined Child/Adult	Combined Child/Adult	Combined Child/Adult	Combined Child/Adult
La Oroya Antigua					
Arsénico	1476	3.80E-04	1.15E-03	1.63E-04	4.94E-04
Cádmio	75	3.85E-05	1.17E-04	1.65E-05	5.00E-05
La Oroya Nueva					
Arsénico	546	1.41E-04	4.26E-04	6.04E-05	1.83E-04
Marcavalle					
Arsénico	354	9.12E-05	2.76E-04	3.91E-05	1.18E-04
Chucchis					
Arsénico	201	5.19E-05	1.57E-04	2.22E-05	6.73E-05

CTE = central tendency exposure
mg/kg-day = milligram per kilogram per day
mg/kg ww = milligram per kilogram wet weight
RME = reasonable maximum exposure

Table 4-15. Calculation of Intake of Chemicals from Indoor Dust - Year 2011.

		NonCancer Evaluation		Cancer Evaluation	
		CTE Intake (mg/kg-day)	RME Intake (mg/kg-day)	CTE Intake (mg/kg-day)	RME Intake (mg/kg-day)
Chemical	Exposure Point Concentration (mg/kg ww)	Combined Child/Adult	Combined Child/Adult	Combined Child/Adult	Combined Child/Adult
La Oroya Antigua					
Arsénico	373	2.56E-04	7.56E-04	1.10E-04	3.24E-04
Cádmio	21	1.78E-05	5.25E-05	7.63E-06	2.25E-05
La Oroya Nueva					
Arsénico	142	9.75E-05	2.88E-04	4.18E-05	1.23E-04
Cádmio	5	4.38E-06	1.29E-05	1.88E-06	5.54E-06
Marcavalle					
Arsénico	133	9.15E-05	2.70E-04	3.92E-05	1.16E-04
Chucchis					
Arsénico	117	8.02E-05	2.37E-04	3.44E-05	1.01E-04
Cádmio	15	1.26E-05	3.72E-05	5.40E-06	1.59E-05

CTE = central tendency exposure
mg/kg-day = milligram per kilogram per day
mg/kg ww = milligram per kilogram wet weight
RME = reasonable maximum exposure

Table 4-16. Calculation of Intake of Chemicals from Outdoor Dust - Year 2011.

		NonCancer Evaluation		Cancer Evaluation	
		CTE Intake (mg/kg-day)	RME Intake (mg/kg-day)	CTE Intake (mg/kg-day)	RME Intake (mg/kg-day)
Chemical	Exposure Point Concentration (mg/kg ww)	Combined Child/Adult	Combined Child/Adult	Combined Child/Adult	Combined Child/Adult
La Oroya Antigua					
Arsénico	488	3.88E-04	1.09E-03	1.66E-04	4.68E-04
Cádmio	23	2.25E-05	6.34E-05	9.66E-06	2.72E-05
La Oroya Nueva					
Arsénico	157	1.25E-04	3.51E-04	5.35E-05	1.50E-04
Marcavalle					
Arsénico	154	1.23E-04	3.45E-04	5.26E-05	1.48E-04
Cádmio	37	3.64E-05	1.03E-04	1.56E-05	4.39E-05
Chucchis					
Arsénico	166	1.32E-04	3.72E-04	5.67E-05	1.60E-04

CTE = central tendency exposure

mg/kg-day = milligram per kilogram per day

mg/kg ww = milligram per kilogram wet weight

RME = reasonable maximum exposure

Table 4-17. Calculation of Intake of Chemicals from Surface Soil - Year 2011.

		NonCancer Evaluation		Cancer Evaluation	
		CTE Intake (mg/kg-day)	RME Intake (mg/kg-day)	CTE Intake (mg/kg-day)	RME Intake (mg/kg-day)
Chemical	Exposure Point Concentration (mg/kg ww)	Combined Child/Adult	Combined Child/Adult	Combined Child/Adult	Combined Child/Adult
La Oroya Antigua					
Arsénico	859	2.22E-04	6.71E-04	9.49E-05	2.87E-04
Cádmio	41	2.12E-05	6.41E-05	9.07E-06	2.75E-05
La Oroya Nueva					
Arsénico	300	7.74E-05	2.34E-04	3.32E-05	1.00E-04
Marcavalle					
Arsénico	207	5.33E-05	1.61E-04	2.28E-05	6.91E-05
Chucchis					
Arsénico	107	2.76E-05	8.35E-05	1.18E-05	3.58E-05

CTE = central tendency exposure
mg/kg-day = milligram per kilogram per day
mg/kg ww = milligram per kilogram wet weight
RME = reasonable maximum exposure

Table 4-18a. Summary of Estimated Arsenic Concentrations for La Oroya Antigua.

Variable	Unit	2005	2011		
			Projected % change	Conversion Factor	Input Value
As Concentration in Air	µg/m^3	2.67	-74.0%	0.260	0.69
As Deposition	g/m^2/year	0.005	-75.0%	0.250	0.001
Mean As Conc. in Outdoor Dust	mg/kg	1,950	-75.0%	0.250	488
Mean As Conc. in Indoor Dust	mg/kg	933	-60.0%	0.400	373
Mean As Conc. in Soil	mg/kg	1,109	-22.5%	0.775	859

Note:
1. As air concentration for 2005 was determined based on monitoring results for Year 2004 and Jan-May 2005.
2. As deposition rate for 2005 was determined based on air quality modeling results for 2002.
3. The projected percent changes for air concentration and deposition were based on air quality modeling report.
4. 2005 air concentration was derived from the monitoring results from the Sindicato de Obreros station.
5. As concentrations in dust and soil were obtained from April and June 2005 sample efforts.

Table 4-18b. Summary of Estimated Arsenic Concentrations for La Oroya Nueva.

Variable	Unit	2005	2011		
			Projected % change	Conversion Factor	Input Value
As Concentration in Air	µg/m^3	1.70	-74.0%	0.260	0.44
As Deposition	g/m^2/year	0.026	-74.0%	0.260	0.007
Mean As Conc. in Outdoor Dust	mg/kg	603	-74.0%	0.260	157
Mean As Conc. in Indoor Dust	mg/kg	348	-59.2%	0.408	142
Mean As Conc. in Soil	mg/kg	386	-22.2%	0.778	300

Note:
1. As air concentration for 2005 was determined based on monitoring results for Year 2004 and Jan-May 2005.
2. As deposition rate for 2005 was determined based on air quality modeling results for 2002.
3. The projected percent changes for air concentration and deposition were based on air quality modeling report.
4. 2005 air concentration was derived from the monitoring results from the Hotel Inca station.
5. As concentrations in dust and soil were obtained from April and June 2005 sample efforts.

Table 4-18c. Summary of Estimated Arsenic Concentrations for Marcavalle.

Variable	Unit	2005	2011		
			Projected % change	Conversion Factor	Input Value
As Concentration in Air	µg/m^3	1.24	-71.0%	0.290	0.36
As Deposition	g/m^2/year	0.014	-70.0%	0.300	0.004
Mean As Conc. in Outdoor Dust	mg/kg	514	-70.0%	0.300	154
Mean As Conc. in Indoor Dust	mg/kg	303	-56.0%	0.440	133
Mean As Conc. in Soil	mg/kg	262	-21.0%	0.790	207

Note:
1. As air concentration for 2005 was determined based on monitoring results for Year 2004 and Jan-May 2005.
2. As deposition rate for 2005 was determined based on air quality modeling results for 2002.
3. The projected percent changes for air concentration and deposition were based on air quality modeling report.
4. 2005 air concentration was derived from the monitoring results from the Cushurupampa station.
5. As concentrations in dust and soil were obtained from April and June 2005 sample efforts.

Table 4-18d. Summary of Estimated Arsenic Concentrations for Chucchis.

Variable	Unit	2005	2011		
			Projected % change	Conversion Factor	Input Value
As Concentration in Air	µg/m^3	1.24	-69.0%	0.310	0.38
As Deposition	g/m^2/year	0.006	-69.0%	0.310	0.002
Mean As Conc. in Outdoor Dust	mg/kg	536	-69.0%	0.310	166
Mean As Conc. in Indoor Dust	mg/kg	261	-55.2%	0.448	117
Mean As Conc. in Soil	mg/kg	135	-20.7%	0.793	107

Note:
1. As air concentration for 2005 was determined based on monitoring results for Year 2004 and Jan-May 2005.
2. As deposition rate for 2005 was determined based on air quality modeling results for 2002.
3. The projected percent changes for air concentration and deposition were based on air quality modeling report.
4. 2005 air concentration was derived from the monitoring results from the Cushurupampa station.
5. As concentrations in dust and soil were obtained from April and June 2005 sample efforts.

Table 4-19a. Summary of Estimated Cadmium Concentrations for La Oroya Antigua.

Variable	Unit	2005	2011		
			Projected % change	Conversion Factor	Input Value
Cd Concentration in Air	$\mu g/m^3$	0.12	-84.0%	0.160	0.02
Cd Deposition	$g/m^2/year$	0.0006	-85.0%	0.150	0.0001
Mean Cd Conc. in Outdoor Dust	mg/kg	151	-85.0%	0.150	22.65
Mean Cd Conc. in Indoor Dust	mg/kg	64.8	-68.0%	0.320	20.74
Mean Cd Conc. in Soil	mg/kg	55.1	-25.5%	0.745	41.05

Note:
1. Cd air concentration for 2005 was determined based on monitoring results for Year 2004 and Jan-May 2005.
2. Cd deposition rate for 2005 was determined based on air quality modeling results for 2002.
3. The projected percent changes for air concentration and deposition were based on air quality modeling report.
4. 2004 air concentration was derived from the monitoring results from the Sindicato de Obreros station.
5. Cd concentrations in dust and soil were obtained from April and June 2005 sample efforts.

Table 4-19b. Summary of Estimated Cadmium Concentrations for La Oroya Nueva.

Variable	Unit	2005	2011		
			Projected % change	Conversion Factor	Input Value
Cd Concentration in Air	$\mu g/m^3$	0.082	-81.0%	0.190	0.02
Cd Deposition	$g/m^2/year$	0.0022	-81.0%	0.190	0.0004
Mean Cd Conc. in Outdoor Dust	mg/kg	35.2	-81.0%	0.190	6.69
Mean Cd Conc. in Indoor Dust	mg/kg	14.5	-64.8%	0.352	5.10
Mean Cd Conc. in Soil	mg/kg	15.6	-24.3%	0.757	11.81

Note:
1. Cd air concentration for 2005 was determined based on monitoring results for Year 2004 and Jan-May 2005.
2. Cd deposition rate for 2005 was determined based on air quality modeling results for 2002.
3. The projected percent changes for air concentration and deposition were based on air quality modeling report.
4. 2005 air concentration was derived from the monitoring results from the Hotel Inca station.
5. Cd concentrations in dust and soil were obtained from April and June 2005 sample efforts.

Table 4-19c. Summary of Estimated Cadmium Concentrations for Marcavalle.

Variable	Unit	2005	2011		
			Projected % change	Conversion Factor	Input Value
Cd Concentration in Air	$\mu g/m^3$	0.059	-75.0%	0.250	0.015
Cd Deposition	$g/m^2/year$	0.0012	-76.0%	0.240	0.0003
Mean Cd Conc. in Outdoor Dust	mg/kg	153	-76.0%	0.240	36.60
Mean Cd Conc. in Indoor Dust	mg/kg	14.9	-60.8%	0.392	5.84
Mean Cd Conc. in Soil	mg/kg	21.9	-22.8%	0.772	16.91

Note:
1. Cd air concentration for 2005 was determined based on monitoring results for Year 2004 and Jan-May 2005.
2. Cd deposition rate for 2005 was determined based on air quality modeling results for 2002.
3. The projected percent changes for air concentration and deposition were based on air quality modeling.
4. 2005 air concentration was derived from the monitoring results from the Cushurupampa station.
5. Cd concentrations in dust and soil were obtained from April and June 2005 sample efforts.

Table 4-19d. Summary of Estimated Cadmium Concentrations for Chucchis.

Variable	Unit	2005	2011		
			Projected % change	Conversion Factor	Input Value
Cd Concentration in Air	$\mu g/m^3$	0.059	-75.0%	0.250	0.015
Cd Deposition	$g/m^2/year$	0.0005	-74.0%	0.260	0.0001
Mean Cd Conc. in Outdoor Dust	mg/kg	39.4	-74.0%	0.260	10.24
Mean Cd Conc. in Indoor Dust	mg/kg	36.0	-59.2%	0.408	14.69
Mean Cd Conc. in Soil	mg/kg	13.0	-22.2%	0.778	10.11

Note:
1. Cd air concentration for 2005 was determined based on monitoring results for Year 2004 and Jan-May 2005.
2. Cd deposition rate for 2005 was determined based on air quality modeling results for 2002.
3. The projected percent changes for air concentration and deposition were based on air quality modeling.
4. 2005 air concentration was derived from the monitoring results from the Cushurupampa station.
5. Cd concentrations in dust and soil were obtained from April and June 2005 sample efforts.

Table 4-20. Calculation of Intake of Chemicals from Air - Year 2005.

		NonCancer Evaluation		Cancer Evaluation	
		CTE Intake (mg/kg-day)	RME Intake (mg/kg-day)	CTE Intake (mg/kg-day)	RME Intake (mg/kg-day)
Chemical	**Exposure Point Concentration (µg/m^3)**	**Combined Child/Adult**	**Combined Child/Adult**	**Combined Child/Adult**	**Combined Child/Adult**
La Oroya Antigua					
Arsénico	2.97	NA	NA	3.18E-04	1.06E-03
Cádmio	0.13	3.3E-05	1.1E-04	1.43E-05	4.74E-05
La Oroya Nueva					
Arsénico	2.13	NA	NA	2.29E-04	7.59E-04
Cádmio	0.10	2.6E-05	8.7E-05	1.12E-05	3.73E-05
Marcavalle / Chucchis					
Arsénico	1.58	NA	NA	1.69E-04	5.62E-04
Cádmio	0.075	1.9E-05	6.2E-05	8.06E-06	2.68E-05

CTE = central tendency exposure
mg/kg-day = milligram per kilogram per day
RME = reasonable maximum exposure
µg/m^3 = microgram per cubic meter

Table 4-21. Calculation of Intake of Chemicals from Air - Year 2011.

		NonCancer Evaluation		Cancer Evaluation	
		CTE Intake (mg/kg-day)	**RME Intake (mg/kg-day)**	**CTE Intake (mg/kg-day)**	**RME Intake (mg/kg-day)**
Chemical	**Exposure Point Concentration ($\mu g/m^3$)**	**Combined Child/Adult**	**Combined Child/Adult**	**Combined Child/Adult**	**Combined Child/Adult**
La Oroya Antigua					
Arsénico	0.69	NA	NA	7.45E-05	2.47E-04
Cádmio	0.02	4.8E-06	1.6E-05	2.06E-06	6.84E-06
La Oroya Nueva					
Arsénico	0.44	NA	NA	4.74E-05	1.57E-04
Cádmio	0.02	3.9E-06	1.3E-05	1.67E-06	5.55E-06
Marcavalle / Chucchis					
Arsénico	0.36	NA	NA	3.86E-05	1.28E-04
Cádmio	0.01	3.7E-06	1.2E-05	1.58E-06	5.25E-06

CTE = central tendency exposure
mg/kg-day = milligram per kilogram per day
RME = reasonable maximum exposure
$\mu g/m^3$ = microgram per cubic meter

Table 5-1. Toxicity Criteria - Inhalation Route.

Inhalation Route									
Chemicals	**Unit Risk (m^3/µg)**	**Source**	**WOE**	**Source**	**Chronic RfC (mg/m^3)**	**Critical Organ / Effect**	**Source**	**Inhalation CSF (mg/kg-day)**	**Source**
Metals									
Arsenic	4.3E-03	USEPA 2005b	A	USEPA 2005b	3E-05	Developmental Cardio Neurologic	OEHHA 2005	1.5E+01	USEPA 1995
Cadmium	1.8E-03	USEPA 2005b	B1	USEPA 2005b	2E-05	Renal Respiratory	OEHHA 2005	6.3E+00	USEPA 2005b
Lead	NA	--	D	USEPA 2005b	NA	--	--	NA	--

NA - not available
RfC - reference concentration
WOE - weight of evidence (see text for description)

Table 5-2. Toxicity Criteria - Oral Route.

	Oral Route									
Chemicals	**CSF_o (kg-day/mg)**	**Water Unit Risk Factor (L/µg)**	**Source**	**WOE**	**Source**	**Chronic RfD_o (mg/kg-day)**	**Critical Organ / Effect**	**Source**	**Subchronic RfD_o (mg/kg-day)**	**Source**
Metals										
Antimony	NA	NA	--	NA[a]	USEPA 2005b	4.0E-04	Longevity, blood glucose, cholesterol	USEPA 2005b	NA	--
Arsenic	1.5E+00	5.0E-05	USEPA 2005b	A	USEPA 2005b	3.0E-04	Hyperpigmentation, keratosis, possible vascular complications	USEPA 2005b	5.0E-03	USEPA 2002a
Cadmium (food)	NA	NA	--	B1	USEPA 2005b	1.0E-03	Significant proteinuria	USEPA 2005b	NA	--
Cadmium (water)	NA	NA	--	B1	USEPA 2005b	5.0E-04	Significant proteinuria	USEPA 2005b	NA	--
Copper	NA	NA	--	D	USEPA 2005b	4.0E-02[b]		USEPA 1997b	1.0E-02	ATSDR 2005
Lead	NA	NA	--	B2	USEPA 2005b	NA		USEPA 2005b	NA	--
Mercury	NA	NA	--	C	USEPA 2005b	3.0E-04	Autoimmune effects	USEPA 2005b	2.0E-03	ATSDR 2005
Selenium	NA	NA	--	D	USEPA 2005b	5.0E-03	Clinical selenosis	USEPA 2005b	5.0E-03	USEPA 1997b
Silver	NA	NA	--	D	USEPA 2005b	5.0E-03	Argyria	USEPA 2005b	5.0E-03	USEPA 1997b
Thallium	NA	NA	--	D	USEPA 2005b	8.0E-05	Increased levels of SGOT and LDH	USEPA 2005b	8.0E-04	USEPA 1997b
Zinc	NA	NA	--	D	USEPA 2005b	3.0E-01	Decreased ESOD	USEPA 2005b	3.0E-01	ATSDR 2005

[a] This substance/agent has not undergone a complete evaluation and determination under US EPA's IRIS program for evidence of human carcinogenic potential.

[b] Based on conversion of current U.S. primary drinking water standard (1.3 mg/L) to an RfD for chronic and subchronic oral exposure.

CSF - cancer slope factor

NA - not available

RfD - reference dose

WOE - weight of evidence (see text for description)

Table 5-3. Selected Health-based Ambient Air Criteria for Sulfur Dioxide and Particulate Matter.

Air Pollutant	Averaging Time	Criteria (µg/m^3) (NTP)	Description
Sulfur Dioxide	10 minutes to 8 hours	524	AEGL-1
	10 minutes to 8 hours	1,965	AEGL-2
	10 minutes	109,000	AEGL-3
	30 minutes	86,000	AEGL-3
	8 hours	44,000	AEGL-3
	24 hours	365	Peruvian ambient air quality standard; not to be exceeded more than once per year
	Annual	80	Peruvian ambient air quality standard
Particulate Matter	24 hour	150	Peruvian ambient air standard; not to be exceeded more than three times per year
	Annual	50	Peruvian ambient air standard

AEGL-1 – Acute Exposure Guideline Value expected to result in temporary and reversible respiratory effects for exercising asthmatics and have no effect on healthy individuals.
AEGL-2 – Acute Exposure Guideline Value established to reflect moderate to severe, but reversible, respiratory response in exercising asthmatics and have no effect on healthy individuals.
AEGL-3 – Acute Exposure Guideline Value with threshold safety margins to protect the general population from life threatening or lethal effects.
NTP – Normal temperature and pressure of 1 atmosphere and 25 degrees C.
PM_{10} – Particulate matter with a mean aerodynamic diameter of 10 microns.

Table 6-1. Predicted Sulfur Dioxide Concentration in Ambient Air (µg/m^3).

Averaging Time	Peruvian Air Quality Standard	Location	2004	2007		2011	
			Monitor Ambient Air Concentration[a]	CALPUFF Predicted Percent Reduction	Estimated Air Concentation (e)	CALPUFF Predicted Percent Reduction	Estimated Air Concentation (e)
Annual	80	La Oroya Antigua	423 [c]	7%	393	70%	127
		La Oroya Nueva	492 [d]	13%	428	76%	118
		Marcavalle	384 [e]	20%	307	80%	77
		Chucchis	ND	22%	NA	82%	NA
24-hour	365	La Oroya Antigua	1371 [c]	7.5%	1,268	67%	452
		La Oroya Nueva	2311 [d]	5%	2,195	73%	624
		Marcavalle	1188 [e]	22%	927	80%	238
		Chucchis	ND	21%	NA	82%	NA

[a] All ambient air concentrations at normal temperature and pressure conditions.

[b] Estimated concentrations based on adjusting 2004 monitor concentrations by reductions predicted by CALPUFF air model for population area.

[c] Sindicato sulfur dioxide monitoring data used for this location.

[d] Hotel Inca sulfur dixoide monitoring data used for this location.

[e] Cushurupampa sulfur dioxide monitoring data used for this location.

ND No data. No ambient air monitor close enough to location for this analysis.

NA Not analyzed due to lack of baseline monitor data.

Table 6-2. Predicted Child Blood Lead Levels for Each Community (µg/dL).

La Oroya Antigua	**2004**	**2007**	**2011**	**La Oroya Nueva**	**2004**	**2007**	**2011**
P10 Percent	100	100	100	P10 Percent	100	96	38
Mean Blood-Lead Concentration	33	19	15	Mean Blood-Lead Concentration	20	13	10
25th Percentile	29	17	13	25th Percentile	18	12	9
50th Percentile	33	19	15	50th Percentile	20	13	9
75th Percentile	36	21	16	75th Percentile	22	14	11
90th Percentile	39	23	18	90th Percentile	23	16	12
95th Percentile	42	24	19	95th Percentile	24	17	12
Marcavalle	**2004**	**2007**	**2011**	**Chucchis**	**2004**	**2007**	**2011**
P10 Percent	100	93	81	P10 Percent	100	99	93
Mean Blood-Lead Concentration	19	13	11	Mean Blood-Lead Concentration	20	14	13
25th Percentile	17	12	10	25th Percentile	18	12	11
50th Percentile	19	13	11	50th Percentile	19	14	13
75th Percentile	21	14	12	75th Percentile	22	15	14
90th Percentile	23	15	13	90th Percentile	23	17	16
95th Percentile	24	16	15	95th Percentile	25	18	16

Note:
P10 Percent is the percentage of the population predicted to have a blood lead level exceeding 10 µg/dL.

Table 6-3a. Relative Contributions from Different Media to Year 2004 Modeled Child Blood Lead Concentrations.

	Air (µg/day)	Soil (µg/day)	Indoor Dust (µg/day)	Outdoor Dust (µg/day)	Diet (µg/day)	Water (µg/day)	Total (µg/day)
La Oroya Antigua							
Intake Amount	7.65	48.00	100.62	506.57	55.00	3.71	721.56
% Contribution	**1.1**	**6.7**	**13.9**	**70.2**	**7.6**	**0.5**	100.0
Absorption Factor	1	0.3	0.4	0.4	0.5	0.5	
Absorbed Amount	7.65	14.40	40.25	202.63	27.50	1.86	294.29
Corrected % Contribution	***2.6***	***4.9***	***13.7***	***68.9***	***9.3***	***0.6***	100.0
La Oroya Nueva							
Intake Amount	5.65	21.00	53.39	116.59	55.00	2.65	254.28
% Contribution	**2.2**	**8.3**	**21.0**	**45.8**	**21.6**	**1.0**	100.0
Absorption Factor	1	0.3	0.4	0.4	0.5	0.5	
Absorbed Amount	5.65	6.30	21.36	46.63	27.50	1.33	108.77
Corrected % Contribution	***5.2***	***5.8***	***19.6***	***42.9***	***25.3***	***1.2***	100.0
Marcavalle							
Intake Amount	3.84	17.00	39.92	116.26	55.00	3.82	235.84
% Contribution	**1.6**	**7.2**	**16.9**	**49.3**	**23.3**	**1.6**	100.0
Absorption Factor	1	0.3	0.4	0.4	0.5	0.5	
Absorbed Amount	3.84	5.10	15.97	46.50	27.50	1.91	100.82
Corrected % Contribution	***3.8***	***5.1***	***15.8***	***46.1***	***27.3***	***1.9***	100.0
Chucchis							
Intake Amount	3.84	17.00	36.14	128.03	55.00	2.65	242.67
% Contribution	**1.6**	**7.0**	**14.9**	**52.8**	**22.7**	**1.1**	100.0
Absorption Factor	1	0.3	0.4	0.4	0.5	0.5	
Absorbed Amount	3.84	5.10	14.46	51.21	27.50	1.33	103.44
Corrected % Contribution	***3.7***	***4.9***	***14.0***	***49.5***	***26.6***	***1.3***	100.0

Note:
Calculations are based on mean concentrations from 2005 sampling data, central intake values, and mean absorption factors.

Table 6-3b. Relative Contributions from Different Media to Year 2007 Modeled Child Blood Lead Concentrations.

	Air (µg/day)	Soil (µg/day)	Indoor Dust (µg/day)	Outdoor Dust (µg/day)	Diet (µg/day)	Water (µg/day)	Total (µg/day)
La Oroya Antigua							
Intake Amount	1.52	44.6	42.66	141.86	31.2	3.71	265.55
% Contribution	**0.6**	**16.8**	**16.1**	**53.4**	**11.7**	**1.4**	100.0
Absorption Factor	1	0.3	0.4	0.4	0.5	0.5	
Absorbed Amount	1.52	13.38	17.06	56.74	15.60	1.86	106.16
Corrected % Contribution	***1.4***	***12.6***	***16.1***	***53.4***	***14.7***	***1.7***	100.0
La Oroya Nueva							
Intake Amount	2.32	19.5	27.76	46.63	35.2	2.65	134.06
% Contribution	**1.7**	**14.5**	**20.7**	**34.8**	**26.3**	**2.0**	100.0
Absorption Factor	1	0.3	0.4	0.4	0.5	0.5	
Absorbed Amount	2.32	5.85	11.10	18.65	17.60	1.33	56.85
Corrected % Contribution	***4.1***	***10.3***	***19.5***	***32.8***	***31.0***	***2.3***	100.0
Marcavalle							
Intake Amount	1.81	16.2	21.40	48.83	35.9	3.82	127.88
% Contribution	**1.4**	**12.6**	**16.7**	**38.2**	**28.0**	**3.0**	100.0
Absorption Factor	1	0.3	0.4	0.4	0.5	0.5	
Absorbed Amount	1.81	4.85	8.56	19.53	17.93	1.91	54.59
Corrected % Contribution	***3.3***	***8.9***	***15.7***	***35.8***	***32.8***	***3.5***	100.0
Chucchis							
Intake Amount	1.92	16.2	21.69	64.04	38.5	2.65	145.00
% Contribution	**1.3**	**11.2**	**15.0**	**44.2**	**26.6**	**1.8**	100.0
Absorption Factor	1	0.3	0.4	0.4	0.5	0.5	
Absorbed Amount	1.92	4.86	8.67	25.62	19.25	1.33	61.65
Corrected % Contribution	***3.1***	***7.9***	***14.1***	***41.6***	***31.2***	***2.1***	100.0

Note:
Calculations are based on mean concentrations from 2005 sampling data, central intake values, and mean absorption factors.

Table 6-3c. Relative Contributions from Different Media to Year 2011 Modeled Child Blood Lead Concentrations.

	Air (µg/day)	Soil (µg/day)	Indoor Dust (µg/day)	Outdoor Dust (µg/day)	Diet (µg/day)	Water (µg/day)	Total (µg/day)
La Oroya Antigua							
Intake Amount	1.15	36	34.20	86.13	27.5	3.71	188.69
% Contribution	**0.6**	**19.1**	**18.1**	**45.6**	**14.6**	**2.0**	100.0
Absorption Factor	1	0.3	0.4	0.4	0.5	0.5	
Absorbed Amount	1.15	10.80	13.68	34.45	13.75	1.86	75.68
Corrected % Contribution	***1.5***	***14.3***	***18.1***	***45.5***	***18.2***	***2.5***	100.0
La Oroya Nueva							
Intake Amount	1.20	15.7	18.79	22.15	28.3	2.65	88.76
% Contribution	**1.4**	**17.7**	**21.2**	**25.0**	**31.8**	**3.0**	100.0
Absorption Factor	1	0.3	0.4	0.4	0.5	0.5	
Absorbed Amount	1.20	4.71	7.52	8.86	14.14	1.33	37.75
Corrected % Contribution	***3.2***	***12.5***	***19.9***	***23.5***	***37.4***	***3.5***	100.0
Marcavalle							
Intake Amount	1.31	14	18.84	39.53	33.2	3.82	110.48
% Contribution	**1.2**	**12.5**	**17.1**	**35.8**	**30.1**	**3.5**	100.0
Absorption Factor	1	0.3	0.4	0.4	0.5	0.5	
Absorbed Amount	1.31	4.13	7.54	15.81	16.61	1.91	47.30
Corrected % Contribution	***2.8***	***8.7***	***15.9***	***33.4***	***35.1***	***4.0***	100.0
Chucchis							
Intake Amount	1.55	14.2	19.66	55.08	26.2	2.65	119.34
% Contribution	**1.3**	**11.9**	**16.5**	**46.2**	**22.0**	**2.2**	100.0
Absorption Factor	1	0.3	0.4	0.4	0.5	0.5	
Absorbed Amount	1.55	4.26	7.87	22.03	13.10	1.33	50.13
Corrected % Contribution	***3.1***	***8.5***	***15.7***	***44.0***	***26.1***	***2.6***	100.0

Note:
Calculations are based on mean concentrations from 2005 sampling data, central intake values, and mean absorption factors.

Table 6-4. Predicted Adult and Fetal Blood Lead Concentrations.

(Geometric mean values in µg/dL)							
La Oroya Antigua	**2004**	**2007**	**2011**	**La Oroya Nueva**	**2004**	**2007**	**2011**
PbB_{adult}	16	10	7	PbB_{adult}	12	8	6
PbB_{fetus}	15	9	6	PbB_{fetus}	10	7	5
$PbB_{fetal, 0.95}$	27	16	11	$PbB_{fetal, 0.95}$	19	13	10
P(PbBfetal > PbBt)	86%	35%	9%	P(PbBfetal > PbBt)	55%	20%	4%
Marcavalle	**2004**	**2007**	**2011**	**Chucchis**	**2004**	**2007**	**2011**
PbB_{adult}	11	8	6	PbB_{adult}	11	8	6
PbB_{fetus}	10	7	6	PbB_{fetus}	10	8	6
$PbB_{fetal, 0.95}$	18	13	10	$PbB_{fetal, 0.95}$	18	14	10
P(PbBfetal > PbBt)	52%	20%	5%	P(PbBfetal > PbBt)	52%	21%	6%

Note:

PbB_{adult} = Blood lead of female adults, geometric mean

PbB_{fetus} = Blood lead of fetus, geometric mean

$PbB_{fetal, 0.95}$ = 95th percentile blood lead among fetuses of adults

P(PbBfetal > PbBt) = Probability of fetal blood lead levels exceeding blood lead threshold of 10 µg/dL

Table 6-5a. Summary of Cancer Risks for Year 2005 - Ingestion Exposures.

	Cancer Risk - CTE	Cancer Risk - RME
	Arsénico	Arsénico
La Oroya Antigua		
Indoor Dust Ingestion	5.E-04	1.E-03
Outdoor Dust Ingestion	1.E-03	4.E-03
Surface Soil Ingestion	2.E-04	7.E-04
Total Cancer Risk	2.E-03	6.E-03
La Oroya Nueva		
Indoor Dust Ingestion	3.E-04	8.E-04
Outdoor Dust Ingestion	5.E-04	1.E-03
Surface Soil Ingestion	9.E-05	3.E-04
Total Cancer Risk	8.E-04	2.E-03
Marcavalle		
Indoor Dust Ingestion	2.E-04	6.E-04
Outdoor Dust Ingestion	3.E-04	9.E-04
Surface Soil Ingestion	6.E-05	2.E-04
Total Cancer Risk	6.E-04	2.E-03
Chucchis		
Indoor Dust Ingestion	2.E-04	5.E-04
Outdoor Dust Ingestion	4.E-04	1.E-03
Surface Soil Ingestion	3.E-05	1.E-04
Total Cancer Risk	6.E-04	2.E-03

Table 6-5b. Summary of Cancer Risks for Year 2005 - Inhalation Exposures.

	Cancer Evaluation	
	CTE Risk	RME Risk
La Oroya Antigua		
Arsénico	5E-03	2E-02
Cádmio	9E-05	3E-04
Total Cancer Risk	5E-03	2E-02
La Oroya Nueva		
Arsénico	3E-03	1E-02
Cádmio	7E-05	2E-04
Total Cancer Risk	3E-03	1E-02
Marcavalle / Chucchis		
Arsénico	3E-03	8E-03
Cádmio	5E-05	2E-04
Total Cancer Risk	3E-03	9E-03

Note:
Cancer risk was caluclated using the linear low-dose cancer risk equation when the risk is lower than 0.01.
Cancer risk was caluclated using the one-hit eqaution for high carcinogenic risk levels when the risk is higher than than 0.01 (USEPA 1989).

Table 6-5c. Summary of Cancer Risks for Year 2011 - Ingestion Exposures.

	Cancer Risk - CTE	Cancer Risk - RME
	Arsénico	Arsénico
La Oroya Antigua		
Indoor Dust Ingestion	2.E-04	5.E-04
Outdoor Dust Ingestion	2.E-04	7.E-04
Surface Soil Ingestion	1.E-04	4.E-04
Total Cancer Risk	6.E-04	2.E-03
La Oroya Nueva		
Indoor Dust Ingestion	6.E-05	2.E-04
Outdoor Dust Ingestion	8.E-05	2.E-04
Surface Soil Ingestion	5.E-05	2.E-04
Total Cancer Risk	2.E-04	6.E-04
Marcavalle		
Indoor Dust Ingestion	6.E-05	2.E-04
Outdoor Dust Ingestion	8.E-05	2.E-04
Surface Soil Ingestion	3.E-05	1.E-04
Total Cancer Risk	2.E-04	5.E-04
Chucchis		
Indoor Dust Ingestion	5.E-05	2.E-04
Outdoor Dust Ingestion	9.E-05	2.E-04
Surface Soil Ingestion	2.E-05	5.E-05
Total Cancer Risk	2.E-04	4.E-04

Table 6-5d. Summary of Cancer Risks for Year 2011 - Inhalation Exposures.

	Cancer Evaluation	
	CTE Risk	RME Risk
La Oroya Antigua		
Arsénico	1E-03	4E-03
Cádmio	1E-05	4E-05
Total Cancer Risk	1E-03	4E-03
La Oroya Nueva		
Arsénico	7E-04	2E-03
Cádmio	1E-05	3E-05
Total Cancer Risk	7E-04	2E-03
Marcavalle / Chucchis		
Arsénico	6E-04	2E-03
Cádmio	1E-05	3E-05
Total Cancer Risk	6E-04	2E-03

Note:
Cancer risk was calculated using the linear low-dose cancer risk equation when the risk is lower than 0.01.
Cancer risk was calculated using the one-hit eqaution for high carcinogenic risk levels when the risk is higher than than 0.01 (USEPA 1989).

Table 6-6a. Summary of Noncancer Risks for Year 2005 - Ingestion Exposures.

	Noncancer Evaluation - CTE Resident				Noncancer Evaluation - RME Resident			
	Antimonio	**Arsénico**	**Cádmio**	**Tálio**	**Antimonio**	**Arsénico**	**Cádmio**	**Tálio**
La Oroya Antigua								
Indoor Dust Ingestion	2.E-01	2.E+00	6.E-02	NA	7.E-01	7.E+00	2.E-01	NA
Outdoor Dust Ingestion	8.E-01	7.E+00	2.E-01	2.E-01	2.E+00	2.E+01	5.E-01	5.E-01
Surface Soil Ingestion	NA	1.E+00	4.E-02	NA	NA	4.E+00	1.E-01	NA
Hazard Quotient (by analyte)	1.E+00	1.E+01	3.E-01	2.E-01	3.E+00	3.E+01	8.E-01	5.E-01
La Oroya Nueva								
Indoor Dust Ingestion	3.E-01	1.E+00	NA	NA	9.E-01	4.E+00	NA	NA
Outdoor Dust Ingestion	4.E-01	2.E+00	NA	NA	1.E+00	7.E+00	NA	NA
Surface Soil Ingestion	NA	5.E-01	NA	NA	NA	1.E+00	NA	NA
Hazard Quotient (by analyte)	7.E-01	4.E+00	0.E+00	0.E+00	2.E+00	1.E+01	0.E+00	0.E+00
Marcavalle								
Indoor Dust Ingestion	1.E-01	1.E+00	NA	NA	3.E-01	3.E+00	NA	NA
Outdoor Dust Ingestion	1.E-01	2.E+00	NA	8.E-02	3.E-01	5.E+00	NA	2.E-01
Surface Soil Ingestion	NA	3.E-01	NA	NA	NA	9.E-01	NA	NA
Hazard Quotient (by analyte)	2.E-01	3.E+00	0.E+00	8.E-02	6.E-01	9.E+00	0.E+00	2.E-01
Chucchis								
Indoor Dust Ingestion	NA	9.E-01	1.E-01	NA	NA	3.E+00	3.E-01	NA
Outdoor Dust Ingestion	1.E-01	2.E+00	NA	1.E-01	4.E-01	6.E+00	NA	3.E-01
Surface Soil Ingestion	NA	2.E-01	NA	NA	NA	5.E-01	NA	NA
Hazard Quotient (by analyte)	1.E-01	3.E+00	1.E-01	1.E-01	4.E-01	9.E+00	3.E-01	3.E-01

NA = Not applicable

Table 6-6b. Summary of Noncancer Risks for Year 2005 - Inhalation Exposures.

	NonCancer Evaluation	
	CTE Resident	**RME Resident**
La Oroya Antigua		
Cádmio	6E+00	2E+01
La Oroya Nueva		
Cádmio	5E+00	2E+01
Marcavalle / Chucchis		
Cádmio	3E+00	1E+01

Table 6-7a. Summary of Noncancer Risks for Year 2011 - Ingestion Exposures.

	Noncancer Evaluation - CTE Resident		Noncancer Evaluation - RME Resident	
	Arsénico	**Cádmio**	**Arsénico**	**Cádmio**
La Oroya Antigua				
Indoor Dust Ingestion	9.E-01	2.E-02	3.E+00	5.E-02
Outdoor Dust Ingestion	1.E+00	2.E-02	4.E+00	6.E-02
Surface Soil Ingestion	7.E-01	2.E-02	2.E+00	6.E-02
Hazard Quotient (by analyte)	3.E+00	6.E-02	8.E+00	2.E-01
La Oroya Nueva				
Indoor Dust Ingestion	3.E-01	NA	1.E+00	NA
Outdoor Dust Ingestion	4.E-01	NA	1.E+00	NA
Surface Soil Ingestion	3.E-01	NA	8.E-01	NA
Hazard Quotient (by analyte)	1.E+00	NA	3.E+00	NA
Marcavalle				
Indoor Dust Ingestion	3.E-01	NA	9.E-01	NA
Outdoor Dust Ingestion	4.E-01	NA	1.E+00	NA
Surface Soil Ingestion	2.E-01	NA	5.E-01	NA
Hazard Quotient (by analyte)	9.E-01	NA	3.E+00	NA
Chucchis				
Indoor Dust Ingestion	3.E-01	1.E-02	8.E-01	4.E-02
Outdoor Dust Ingestion	4.E-01	NA	1.E+00	NA
Surface Soil Ingestion	9.E-02	NA	3.E-01	NA
Hazard Quotient (by analyte)	8.E-01	1.E-02	2.E+00	4.E-02

NA = Not applicable

Table 6-7b. Summary of Noncancer Risks for Year 2011 - Inhalation Exposures.

	NonCancer Evaluation	
	CTE Resident	**RME Resident**
La Oroya Antigua		
Cádmio	8E-01	3E+00
La Oroya Nueva		
Cádmio	7E-01	2E+00
Marcavalle / Chucchis		
Cádmio	6E-01	2E+00

Table 6-8. Key Uncertainties for the Human Health Risk Assessment.

Source of Uncertainty	Effect on Risk Estimates	Potential Magnitude of Effect	Explanation and Rationale for Assumptions
Air Quality Data			
Upper analytical detection limit for SO_2 in air limited maximum detected concentrations.	Underestimate	Low	The limitation in maximum reported concentrations biases the dataset toward a lower maximum 24 hour concentration. The effect is limited due to small time periods when the upper detection limit is exceeded. No effect is anticipated on annual average concentrations.
Air monitoring stations are not representative of all communities.	Over- or underestimate	Medium	The data obtained from air monitoring stations are not likely to provide exact estimates of breathing-zone chemical concentrations for residents in all communities. Use of data from the Cushurupampa station will overestimate exposure point concentrations for residents of Chucchis.
Air Modeling			
Site-specific upper air meteorological data were not available.	Over- or underestimate	Medium	The global weather analyses from the U.S. Weather Service were relied upon for upper air wind and temperature data. These analyses are appropriate to use when site-specific data are not available.
The air model did not account for wet deposition.	Over- or underestimate	Medium	The air model only included dry deposition. Wet deposition occurs when rain washes gases and particulates from the air. This factor could reduce concentrations of sulfur dioxide and metals at increasing distances from the smelter during the rainy season. Inclusion of wet deposition in the air model would likely increase the accuracy of predictions for both sulfur dioxide and metal concentrations at varying distances from the smelter.

Table 6-8. Key Uncertainties for the Human Health Risk Assessment (continued).

Source of Uncertainty	Effect on Risk Estimates	Potential Magnitude of Effect	Explanation and Rationale for Assumptions
The smelter was assumed to operate continuously regardless of weather conditions.	Overestimate	High	The intermittent control strategy implemented to reduce emissions when inversions are forecast was not taken into account in the model, which results in an overestimate of actual emissions. These shutdowns were predicted to reduce the maximum 24 hour sulfur dioxide concentrations by 25 percent.
Most reductions in sulfur dioxide emissions were assumed to occur during 2011.	Overestimate	High	There are apparently new plans to reduce sulfur dioxide emissions by 30 percent during 2008. This would cause exposures and risks to be reduced earlier than predicted in the risk assessment.
Fugitive emissions of metals were estimated based on comparison of operations in La Oroya to those of other similar smelters.	Over- or underestimate	Medium	Fugitive emissions are difficult to measure, so historical information from other smelters is the best available source of estimates.
Dust and Soil Data			
The number of samples collected was relatively small.	Over- or underestimate	Medium	Concentrations of metals were found to vary substantially both within communities and also between communities. The use of an upper bound estimate of the true mean concentrations for metals other than lead in a community may have resulted in overestimates of typical metal concentrations throughout the community.
Two sets of samples were collected several months apart in the wet season and the dry season, but seasonal changes were not clear.	Over- or underestimate	Low	Average concentrations did not vary greatly between wet and dry seasons, but some uncertainty remains due to the small sample size.
Analytical results for metals in dust and soil samples were provided in wet weight units.	Underestimate	Low	Reporting metal concentrations in wet weight units could have resulted in a slight underestimation of the metal concentrations in soil and outdoor dust, particularly for samples collected during the wetter months of March and April. During June the average moisture content of soil samples was less than 6 percent.

Table 6-8. Key Uncertainties for the Human Health Risk Assessment (continued).

Source of Uncertainty	Effect on Risk Estimates	Potential Magnitude of Effect	Explanation and Rationale for Assumptions
USEPA default screening values used to determine which chemicals should be included in the risk assessment.	Underestimate	Low	Risk-based screening levels may or may not be representative of exposures in La Oroya. The most toxic metals were included in the risk assessment, so exclusion of metals that were screened out is not likely to have had an impact on overall risk estimates.
Dietary Lead Data			
The diet study was a pilot study with a small number of samples.	Over- or underestimate	Medium	Small sample size results in large variability in analytical results.
The diet study only included residents of La Oroya Antigua. These data were used to estimate lead intakes for all communities.	Overestimate	Medium	The dietary lead intakes in communities farther from the smelter are expected to be less than intakes in La Oroya Antigua if dust from the smelter is assumed to be affecting lead concentrations in food.
The diet study did not include analysis of metals other than lead.	Underestimate	Low	Exposure to metals of concern other than lead, such as cadmium, antimony, thallium, and arsenic, could not be evaluated. Intake via food ingestion is likely to be low relative to other intake pathways (ingestion of dust, soil).
Lead Exposure Models			
The relative contribution of outdoor dust, indoor dust and soil to lead exposures was not known, but outdoor dust was assumed to be the primary source of exposure.	Over- or underestimate	Low	Studies in other smelter communities have demonstrated that outdoor dust is a primary factor controlling lead exposures. Risk estimates for current exposures will not be affected if this assumption is incorrect because the exposure models were fit to the data from site-specific blood lead studies for both children and adults. However, if outdoor dust is not as important as assumed in the models, the impact of future emissions reductions may be overestimated.

Table 6-8. Key Uncertainties for the Human Health Risk Assessment (continued).

Source of Uncertainty	Effect on Risk Estimates	Potential Magnitude of Effect	Explanation and Rationale for Assumptions
The distributions of intake rates of outdoor dust, indoor dust and soil by children were not known.	Over- or underestimate	Medium	The distributions used in the ISE lead exposure model were selected to produce overall lead exposures that best matched the observed blood lead distributions from the 2004 study in La Oroya Antigua. The match achieved was best in the range of 25th to 75th percentiles of the population. Despite the selection of lognormal distributions for dust and soil intake rates, the model underpredicted the upper percentile blood lead levels, suggesting that some children with extremely high exposures are not being accurately represented by the present model.
The relative bioavailability of lead in dust and soil was not measured, and the distribution of bioavailability is not known.	Overestimate	Medium	Because this is an active smelter site, the relative bioavailability of lead in dust and soil was assumed to be higher than typical default values. Triangular distributions were selected because of the likely existence of upper and lower bounds to lead absorption.
Dietary lead intake data were only available for children between the ages of 12 and 36 months old. The overall average and distribution of lead intakes for these children were applied to younger and older children in the ISE model.	Over- or underestimate	Low	Dietary lead intakes may be overestimated for children less than 12 months old and underestimated for children greater than 36 months old. The overall predicted distribution of blood lead levels is not expected to be much affected by this factor.
The impact of future lead emissions reductions on lead in outdoor dust, indoor dust, soil, and diet was estimated.	Over- or underestimate	Medium	Estimates were based, in part, on reductions measured in dust and soil in another smelter community after similar emissions reductions.
Blood lead data used to fit the exposure model did not include the time lived in the current residence.	Over- or underestimate	Low	If children and adults recently moved to La Oroya their blood lead levels may not yet accurately reflect current exposures. On the other hand, if they have moved from a community close to the smelter to one farther away, their blood lead levels may be higher than would be expected at their current location. These inconsistencies could affect the assumptions used for the lead exposure models.

Table 6-8. Key Uncertainties for the Human Health Risk Assessment (continued).

Source of Uncertainty	Effect on Risk Estimates	Potential Magnitude of Effect	Explanation and Rationale for Assumptions
For children, little to no blood sampling data from 2004 were available for communities outside of La Oroya Antigua.	Over- or underestimate	Low	This limitation affected the ability to assure the lead exposure model for children was accurately calibrated for communities other than La Oroya Antigua; however, the assumption that exposure patterns would be similar in all the communities was judged to be reasonable. This assumption was supported by comparison of model predictions with blood lead data from 2000 for the other communities.
The adult lead exposure model did not allow entry of separate inputs for all of the exposure pathways considered to be important in La Oroya. Consequently, all pathways other than outdoor dust were considered to contribute to the baseline blood lead level.	Over- or underestimate	Low	This model limitation did not affect the overall risk estimates because the model was fitted to site-specific blood lead data; however, the relative contribution of exposure pathways other than outdoor dust cannot be observed with the current model.
Exposure Assessment for Arsenic, Cadmium, Antimony and Thallium			
Exposure input parameters for other metals were estimated based on the outcome of the lead exposure models.	Over- or underestimate	Medium	Exposure pathways for these metals are expected to the same as those for lead, so reliance on the inputs developed for lead is a reasonable way to derive site-specific assumptions.
Dermal contact with chemicals was not included as an exposure pathway.	Underestimate	Low	Dermal absorption of metals is low and is not likely to have had an impact on overall risk estimates.
The relative bioavailability of metals in dust and soil was not measured.	Overestimate	Medium	Because this is an active smelter site, the relative bioavailability of metals in dust and soil was assumed to be higher than typical default values.
The impact of future metal emissions reductions on metals in outdoor dust, indoor dust, soil, and diet was estimated.	Over- or underestimate	Medium	Estimates were based, in part, on reductions measured in dust and soil in another smelter community after similar emissions reductions.

Table 6-8. Key Uncertainties for the Human Health Risk Assessment (continued).

Source of Uncertainty	Effect on Risk Estimates	Potential Magnitude of Effect	Explanation and Rationale for Assumptions
Toxicity Assessment for SO_2 and Particulates			
Epidemiological studies suggesting a link between elevated sulfur dioxide concentrations and increased morbidity and mortality are confounded by exposure to mixtures containing particulate matter.	Over- or underestimate	Medium	Due to this confounding, USEPA has not established air quality standards for sulfur dioxide that are based on the endpoints of general morbidity and mortality.
Morbidity and mortality associated with particulates is more closely correlated with the smallest particles, i.e., particles 2.5 microns or less in diameter or $PM_{2.5}$.	Underestimate	Medium	The La Oroya data for particulates is for air particles ten microns or less in diameter (i.e., PM_{10}). USEPA has set air quality standards for both $PM_{2.5}$ and for PM_{10}. These standards are currently under review. For now, comparison with the PM10 standards is adequate, but this might be a good issue to reconsider after completion of operational changes at the Complex.
Toxicity Assessment for Lead			
Populations living at high altitudes have increased hematocrits, making blood lead levels increase relative to body burden.	Overestimate	Medium	Blood lead levels associated with toxicity in epidemiology studies of sea level populations may overstate the toxicity of similar blood lead levels in high altitude populations such as that of La Oroya.
Anemia may lead to decreased blood lead levels relative to body burden.	Underestimate	Medium	Blood lead levels associated with toxicity in epidemiology studies of non-anemic populations may understate the toxicity of similar blood lead levels in a population with a high prevalence of anemia such as that of La Oroya.
Toxicity Assessment for Arsenic, Cadmium, Antimony and Thallium			
Cancer slope factors for arsenic and cadmium assume lack of a threshold for cancer induction.	Overestimate	High	This assumption may lead to high risk estimates when risks may actually be as low as zero. There is considerable evidence that the dose-response for ingested arsenic is nonlinear, with a possible threshold below which cancer risks are not increased.

Table 6-8. Key Uncertainties for the Human Health Risk Assessment (continued).

Source of Uncertainty	Effect on Risk Estimates	Potential Magnitude of Effect	Explanation and Rationale for Assumptions
The reference doses used to assess health effects other than cancer are designed to be health protective, *i.e.*, to minimize that chance that risks will be underestimated.	Overestimate	High	Standard procedures use multiple uncertainty factors to extrapolate toxicity estimates from animal studies to humans, to account for inter-individual variability, and to account for deficiencies in available toxicity data. The uncertainty factors are based on the upper bounds of observed differences in these factors for other chemicals and are likely to overestimate toxicity.
The toxicity database for antimony is limited.	Overestimate	Medium	Chemical and toxicity characteristics of antimony resemble those of arsenic, thus when exposure to both metals occurs simultaneously, the effects due to arsenic versus antimony may be difficult to delineate.
The toxicity database for thallium is limited.	Over- or underestimate	High	The mechanism by which thallium exerts its toxicity is unclear and there are many uncertainties in the toxicity database, such that USEPA has assigned a low confidence rating to the reference dose for thallium.
Risk Characterization for SO_2 and Particulates			
The intermittent control strategy and the proposed early partial reduction of sulfur dioxide emissions (i.e., in 2008) are not accounted for in the risk assessment.	Overestimate	High	The planned reduction of sulfur dioxide emissions in 2008 could reduce concentrations by about 30 percent three years earlier than assumed in the risk assessment. The intermittent control program to shut down prior to inversion events may also have reduced 24 hour average sulfur dioxide concentrations by about 25 percent.
The air model and available data did not permit prediction of future short-term sulfur dioxide concentrations for time periods much less than 24 hours.	Underestimate	Medium	Transient pulmonary irritation may occur due to short times with elevated sulfur dioxide concentrations. These short times with elevated concentrations may be missed when 24 hour averages are evaluated.

Table 6-8. Key Uncertainties for the Human Health Risk Assessment (continued).

Source of Uncertainty	Effect on Risk Estimates	Potential Magnitude of Effect	Explanation and Rationale for Assumptions
The composition and particle size distribution is not known for particulates, and neither is the contribution from sources other than the Complex. Predictions of future particle emission rates were also not available.	Over- or underestimate	Low	Predicted health risks from particulates were much lower than risks for sulfur dioxide. Consequently, the uncertainty associated with characterization of particulates is not likely to have a significant impact on the reliability of risk estimates. Prediction of future risks is also not a high priority.
Risk Characterization for Lead			
The blood lead exposure model may underestimate blood lead levels of children with the highest exposures.	Underestimate	Medium	A greater percentage of children than predicted by the model may exceed target blood lead levels.
Health risks based on sea level populations may overestimate health risks for the high altitude of La Oroya.	Overestimate	Medium	Blood lead levels associated with health risks may be approximately 20 percent higher in La Oroya than at sea level.
Health risks based on non-anemic populations may underestimate health risks for people with anemia.	Underestimate	Medium	A high prevalence of anemia is expected in La Oroya based both on the dietary study conducted in La Oroya Antigua and also on other studies of Peruvian Andean populations.
Risk Characterization for Arsenic, Cadmium, Antimony and Thallium			
Risks for multiple chemicals were not addressed quantitatively.	Over- or underestimate	Medium	Simultaneous exposure to multiple chemicals is typically assumed to result in additive risks; however, actual health risks may reflect synergistic or antagonistic interactions among chemicals. The potential for such interactions is thought to be dose dependent, and to vary for different exposure conditions. Although the potential impacts of interactions on health risks in La Oroya could not be quantified, a qualitative discussion of health effects that could be subject to such interactions is provided as a guide for any future health studies that might be conducted.

Table 6-8. Key Uncertainties for the Human Health Risk Assessment (continued).

Source of Uncertainty	Effect on Risk Estimates	Potential Magnitude of Effect	Explanation and Rationale for Assumptions
Risks for all chemicals are given equal weight regardless of confidence in the toxicity factor or severity of the health endpoint of concern	Over- or underestimate	Low	This approach is standard risk assessment practice, but does not account for the fact that some risk estimates are based on toxicity studies in humans, while others are extrapolated from animals. Similarly, risk estimates for some chemicals are based on severe health effects, while others are based on much less severe health effects. The impact of this factor is limited because of the small number of chemicals contributing to risk estimates in La Oroya, and the extensive amount of toxicity data available for the principal chemicals contributing to risks, i.e., arsenic and cadmium.

Exhibit C

Complementary Human Health Risk Assessment, La Oroya Metallurgical Complex. Prepared for Doe Run Peru. Integral Consulting Inc., Mercer Island, WA (2008).

COMPLEMENTARY HUMAN HEALTH RISK ASSESSMENT

La Oroya Metallurgical Complex

Prepared for

Doe Run Peru

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November 21, 2008

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ACRONYMS AND ABBREVIATIONS

AEGL	acute exposure guideline level
ALAD	δ-aminolevulinic acid dehydratase
ALM	adult lead exposure model
AQG	air quality guideline
ASTM	American Society for Testing and Materials
ATSDR	United States Agency for Toxic Substances and Disease Registry
Blufstein	Blufstein Clinical Laboratory S.A.
CCME	Canadian Council of Ministers of the Environment
CDC	United States Centers for Disease Control and Prevention
CENSOPAS	Centro Nacional de Salud Ocupacional y Protección del Ambiente para la Salud
CFR	Code of Federal Regulations
Complex	Doe Run Peru – La Oroya Metallurgical Complex
CONAM	Consejo Nacional del Ambiente
Convenio	Convenio de Cooperacion MINSA, Gobierno Regional Junin, Doe Run Peru
COPC	chemical of potential concern
CSF	cancer slope factor
CTE	central tendency exposure
DHHS	United States Department of Health & Human Services
DIGESA	Ministry of Health's Environmental Health Directorate (Direcciòn General de Salud Ambiental)
DRP	Doe Run Peru
EHP	Environmental Health Project
EKG	electrocardiogram
EPC	exposure point concentration
G6PD	glucose-6-phosphate dehydrogenase
GSD	geometric standard deviation
GSH	glutathione

GWI	Ground Water International
HQ	hazard quotient
IARC	International Agency for Research on Cancer
ICC	Indian childhood cirrhosis
IEUBK	Integrated exposure uptake biokinetic model
IIN	Instituto de Investigacion Nutricional
INEI	National Institute of Statistics and Information
Integral	Integral Consulting Inc.
IOM	Institute of Medicine
IPCS	International Programme on Chemical Safety
IRIS	Integrated Risk Information System
ISA	integrated science assessment
ISE	integrated stochastic exposure
LOAEL	lowest-observed-adverse-effects level
LOEL	lowest-observed-effect level
MEM	Peruvian Ministry of Energy and Mines
MINSA	Peruvian Ministry of Health
MM5	meso-scale model
MMA	McVehil-Monnett Associates, Inc.
MRL	minimum risk level
NAAQS	National Ambient Air Quality Standards
NAC	National Advisory Committee for Acute Exposure Guideline Levels
NAS	United States National Academy of Sciences
NCEH	National Center for Environmental Health
NIOSH	National Institute of Occupational Safety and Health
NOAEL	no-observed-adverse-effects level
NRC	National Research Council
NTP	National Toxicology Program
PAHO	Pan-American Health Organization
PAMA	Project of the Environmental and Management Program

PM_{10}	particulate matter with diameter smaller than 10 microns
$PM_{2.5}$	particulate matter with diameter smaller than 2.5 microns
QA/QC	quality assurance and quality control
RAF	relative absorption factor
RDA	recommended dietary allowance
RfC	reference concentration
RfD	reference dose
RME	reasonable maximum exposure
SO_2	sulfur dioxide
SUNASS	Superintendencia Nacional de Servicio de Saneamiento
TOR	terms of reference
UCDEH	University of Cincinnati Department of Environmental Health
UCLM	upper confidence limit of the mean
UL	upper intake level
USEPA	United States Environmental Protection Agency
WHO	World Health Organization
WOE	weight-of-evidence
ZPP	zinc protoporphyrin

GLOSSARY OF TERMS

Accuracy: The degree to which a measurement reflects the true quantitative value of a variable.

Acute: Having a sudden onset or lasting a short time. An acute stimulus is severe enough to induce a response rapidly. The word acute can be used to define either the exposure or the response to an exposure (effect).

Air Quality Criteria: Maximum legally allowable concentrations for air pollutants that are intended to protect public health, including "sensitive" populations such as asthmatics, children and the elderly.

Carcinogen: An agent capable of inducing cancer.

Chronic: Involving a stimulus that is lingering or continues for a long time; often signifies periods from several weeks to years, depending on the reproductive life cycle of the species. Chronic can be used to define either the exposure or the response to an exposure (effect). Chronic exposures typically induce a biological response of relatively slow progress and long duration.

Confidence Limit: Either of the two numbers that specify the endpoints of the confidence interval.

Deposition: The processes by which chemical constituents settle from the atmosphere to the earth's surface, which include precipitation (wet deposition, such as rain or cloud fog) and particle and gas deposition (dry deposition).

Exposure: The contact of people with chemicals.

Exposure Medium: The contaminated environmental medium to which an individual is exposed, such as soil, water, sediment and air.

Exposure Pathway: The path a chemical or physical agent takes from a source to an exposed organism. An exposure pathway describes a unique mechanism by which an individual or population is exposed to chemicals or physical agents at or originating from a site. Each exposure pathway includes a source or release from a source, an exposure point, and an exposure route. If the exposure point differs from the source, a transport/exposure medium (e.g. air) or media (in cases of intermedia transfer) also is included.

Exposure Pathway Model: A model in which potential pathways of exposure are identified for the selected receptor species.

Exposure Point: The potential contact between a person and a contaminant within an exposure medium.

Exposure Point Concentration: The value that represents a conservative estimate of the chemical concentration available from a particular medium or route of exposure.

Exposure Route: The mechanism for which a contaminant comes in contact with a person (e.g., by ingestion, inhalation, dermal contact).

Exposure Scenario: A set of assumptions concerning how an exposure takes place, including assumptions about the exposure setting, stressor characteristics, and activities of an organism that can lead to exposure.

Fugitive Emissions: Air emissions that do not pass through a stack, chimney, vent, or other functionally-equivalent opening.

Gamma Distribution: In probability theory and statistics, the gamma distribution is a continuous probability distribution. In a probability distribution, every interval of the real number is assigned a probability so that the probability axioms are satisfied.

Hazard Index: The ratio of an exposure level to a substance to a toxicity value selected for the risk assessment for that substance.

Lognormal Distribution: In probability theory and statistics, the lognormal distribution is the probability distribution of any random variable whose logarithm is normally distributed.

Mean: The average value of a set of numbers.

Media: Specific environmental components—air, water, soil—which are the subject of regulatory concern and activities.

Median: The middle value in an ordered set of numbers.

Noncancer Risk: Characterized as the increased likelihood that an individual will suffer adverse health effects as a result of exposure to a chemical.

Non-carcinogen: An agent not capable of inducing cancer.

Particulate Matter: Material suspended in the air in the form of minute solid particles or liquid droplets, especially when considered as an atmospheric pollutant

Precision: A measure of the closeness of agreement among individual measurements.

Risk Assessment: A qualitative or quantitative evaluation of the risk posed to human health and/or the environment by the actual or potential presence or release of hazardous substances, pollutants, or contaminants.

Risk Characterization: The integration of information on hazard, exposure, and dose-response to provide an estimate of the likelihood that any of the identified adverse effects will occur in exposed individuals.

Risk Evaluation: The evaluation of scientific information on the hazardous properties of environmental agents (hazard characterization), the dose-response relationship (dose-response assessment), and the extent of human exposure to those agents (exposure assessment). The product of the risk assessment is a statement regarding the probability that populations or individuals so exposed will be harmed and to what degree (risk characterization).

Screening Criteria: A risk-based concentration of a chemical in an environmental medium (e.g., soil, air, etc) that is considered protective of public health and can be used to compare to chemical data to determine if a chemical is present in the environmental medium at concentrations that may present a hazard to public health.

Stack Emissions: The particulate matter and vapors captured and released to the atmosphere through a stack, chimney, vent, flue, or other functionally-equivalent opening. **Toxicity Values:** A numerical expression of a substance's exposure-response relationship that is used in risk assessments

EXECUTIVE SUMMARY

This document presents a complementary human health risk assessment for the Doe Run Peru Metallurgical Complex (Complex) in La Oroya, Peru. It updates a risk assessment prepared by Integral Consulting Inc. (Integral) in 2005. The focus of the earlier risk assessment had been to characterize risks to nearby residents from chemicals released to the air during current and future operations of the Complex. In response to a request from the Ministry of Energy and Mines to update the 2005 risk assessment, Doe Run Peru contracted Integral to conduct the update. The same methods were used in both risk assessments; this update incorporates new data reflecting current conditions. Future scenarios were also predicted on the basis of planned changes at the Complex by Doe Run Peru.

STUDY AREA

The Complex is located approximately 175 kilometers northeast of Lima, Peru in the Andes Mountain Range, at an altitude of 3,745 meters. It is situated in the Mantaro River Valley at the confluence of the Mantaro and Yauli Rivers. This risk assessment presents estimates of health risks for the communities of La Oroya Antigua, La Oroya Nueva, Marcavalle, Chucchis, Santa Rosa de Sacco, Huaynacancha, Paccha, and Huari. Adjacent to and north of the Complex, across the Mantaro River, is the town of La Oroya Antigua. The communities of La Oroya Nueva, Marcavalle, Chucchis, Santa Rosa de Sacco, and Huaynacancha are located upstream, along the Yauli River, at increasing distances west-southwest of the Complex. Paccha is upstream along the Mantaro River, while Huari is downstream of the Complex.

The Complex was built by American Cerro de Pasco Copper Corporation and began smelting copper in 1922. Lead production began in 1928 and zinc production began in 1952. Recovery of precious metals began in 1950. The government-owned company, Centromin, operated the Complex from 1974 until 1997, when it was purchased by the Doe Run Company. The Complex is an operating smelter that processes approximately 600,000 metric tons of concentrate annually. Eleven metals, including lead, zinc, copper, silver, and gold, and eight by-products are produced from the concentrate.

A main stack rising 167.5 meters above ground level emits gases and particulate matter produced during smelter operation. There is also a much smaller stack called the sinter plant stack. In addition, gases and particulate emissions escape from various buildings, ductwork, and machinery at the Complex. These "fugitive" emissions and those from the main stack contain heavy metal dusts and sulfur dioxide gas that migrate to the surrounding communities at levels capable of causing adverse health effects.

RISK ASSESSMENT DEFINITION, 2005 RESULTS AND 2008 OBJECTIVES

A human health risk assessment is a quantitative evaluation of the risk posed to human health by the actual or potential presence or release of chemicals in the environment. It predicts the likelihood of health effects in a population, but does not directly measure their occurrence. In this way, a risk assessment is very different from an epidemiology study that reports the incidence of specific health effects or a biomonitoring study that reports the concentrations of chemicals in people's bodies. The value of a risk assessment is that it is a tool to better understand the factors contributing to chemical exposures and to predict conditions in the future.

The risk assessment conducted in 2005 concluded that the residents of La Oroya had elevated risks of adverse health effects from chemicals released by the Complex. Both sulfur dioxide and air particulates were found to exceed air quality criteria. As expected from available blood lead data for La Oroya residents, risks of adverse health effects due to lead exposures were markedly elevated. Cancer risks from inhalation of arsenic in air and from incidental ingestion of arsenic in dust and soil were found to be unacceptably high. The risks of adverse health effects other than cancer were also found to be elevated for inhalation of cadmium and arsenic in air and for ingestion of arsenic and antimony in dust and soil.

The 2005 risk assessment evaluated the potential that future risks could be lowered by operational changes to reduce stack and fugitive emissions. Factors that contribute to the elevated health risks were examined, and actions in the form of community and dietary interventions to reduce exposures and mitigate health impacts were recommended. This update of the risk assessment for La Oroya is needed to evaluate the progress of efforts to reduce emissions from the Complex and to predict future health risks as emissions are further reduced.

The complementary risk assessment includes the following key components:

- Updates to the site characterization and exposure pathway model based on the findings from the 2005 risk assessment and recent updates to the Complex
- A summary and evaluation of existing data and details of the process used to select chemicals of concern
- An exposure assessment based on new data and the updated air model
- An update of the toxicity assessment for chemicals included in the risk assessment
- Characterization of current and future risks and a discussion of uncertainty associated with the risk estimates
- Recommendations for future actions and assessments in La Oroya.

2008 RISK ASSESSMENT METHODS

This complementary risk assessment was conducted with the same methods used in 2005. Available data were compiled and the data adequacy to support the risk assessment was evaluated. Air monitoring data collected during 2007 at six air monitoring stations operated by Doe Run Peru were used to evaluate sulfur dioxide, particulate, and metal concentrations in air. Data from samples collected in June 2008 by Doe Run Peru were used to assess metals concentrations in surface soil and outdoor dust. Data from samples collected by the Convenio during 2007 and 2008 were used to assess metals in indoor dust. Drinking water data on metals also came from samples collected by the Convenio. Blood lead data for children and pregnant women used in the risk assessment were collected by the Blufstein Clinical Laboratory in November 2007. Additionally, a Convenio-sponsored study to evaluate the micronutrient and metals content in food, completed in April 2008, provided information on lead content in the diet. Thus, available data include chemical concentrations in air, soil, dust, drinking water, and food, as well as blood lead concentrations in children and pregnant women. A risk-based screening process was used to determine which chemicals associated with the Complex should be included in the risk assessment, and exposure pathways were identified.

Consistent with the 2005 risk assessment, different approaches were used to evaluate different chemicals. Inhalation of sulfur dioxide and air particulates was assessed by comparing annual average and 24-hour air concentrations during 2007 with Peruvian and United States air quality criteria. These comparisons were carried out using data from monitoring stations located in the following communities: La Oroya Antigua, La Oroya Nueva, Marcavalle (and Chucchis), Huaynacancha, Paccha, and Huari.

To assess health risks from lead exposures, an exposure model developed for the United States Environmental Protection Agency (USEPA) was modified to reflect conditions in La Oroya and then used to produce a distribution of blood lead concentrations. The validity of this model was assessed by comparing the model results with blood lead levels measured in the children of La Oroya during November 2007. Initially, the exposure parameters developed for the 2005 risk assessment were used along with new data for lead concentrations in air, soil, outdoor dust, indoor dust, drinking water, and food. A small number of exposure parameters were then modified to produce a better fit with the November 2007 blood lead data. A similar process was used to update the lead exposure model for adults. To characterize risks of other metals, quantitative estimates of exposure and toxicity were combined to yield numerical estimates of potential health risk. For carcinogens, USEPA's acceptable range of risks is an incremental lifetime risk of 1 in 10,000 to 1 in 1 million. The term "incremental" reflects the fact that the calculated risk associated with site-related exposure is in addition to the background risk of cancer experienced by all individuals in the course of daily life. Cancer risk estimates are expressed as unitless values reflecting the additional probability that an individual will develop cancer over a lifetime of exposure. Arsenic and cadmium are carcinogenic when inhaled, and

arsenic is carcinogenic if ingested at very high doses; accordingly, cancer risks were assessed for inhaled arsenic and cadmium, and for ingested arsenic.

Noncancer health risks of other metals, including arsenic, cadmium, antimony, and copper, were characterized as the increased likelihood that an individual will suffer adverse health effects as a result of exposure. For health effects other than cancer, estimated exposures were compared with toxicity values that represent doses of a chemical that will not cause adverse health effects in any members of a population (i.e., reference dose). This comparison yields a hazard index. If the hazard index does not exceed a value of 1.0, no adverse health effects are expected. Thus, consistent with USEPA guidance, the target risk for health effects other than cancer is a hazard index of 1.0.

Future health risks are anticipated to decline after completion of additional projects to reduce emissions from the Complex. Specifically, acid plants will be added to the zinc circuit (in September 2008) and copper circuit (in October 2009), significantly reducing stack emissions of sulfur dioxide and metals. The air dispersion model used for the 2005 risk assessment was updated by McVehil-Monnett Associates, Inc. to predict the reductions in air concentrations of sulfur dioxide and particulates and in deposition of metals in dust after 2009. The results of this model were used to predict future risks.

The complementary risk assessment also includes a review of and updates to the recommendations made in the 2005 risk assessment.

2008 RISK ASSESSMENT RESULTS

This complementary risk assessment confirms the continued existence of the health risks found in 2005. The magnitude of exposures to lead and other metals during 2007 has been substantially reduced compared with 2005; however, these risks remain elevated above acceptable levels. Risks related to sulfur dioxide exposure have slightly increased in many areas around the Complex.

SULFUR DIOXIDE AND PARTICULATES

The annual average sulfur dioxide concentrations at all six of the monitors exceeded the annual average ambient air quality standard of 80 $\mu g/m^3$ established by the government of Peru for sulfur dioxide, with concentrations ranging from 706 $\mu g/m^3$ for La Oroya Antigua to 110 $\mu g/m^3$ for Paccha. The Peruvian 24-hour standard (365 $\mu g/m^3$) was exceeded most frequently and by the greatest degree at the monitor in La Oroya Antigua. The standard was exceeded on 267 days, and the second highest 24-hour sulfur dioxide concentration was nearly 8 times the Peruvian standard. There were also frequent exceedances of the standard in La Oroya Nueva, Marcavalle/Chucchis, and Huari, with rare exceedances in Paccha and Huaynacancha.

An evaluation of short-term hourly sulfur dioxide concentrations (in comparison with acute exposure guideline values) predicted that some members of the population may experience temporary respiratory effects such as wheezing, tightness of the chest, and coughing, but concentrations were well below lethal or life-threatening levels. Individuals such as asthmatics and children are more likely to experience adverse health effects from elevated sulfur dioxide exposures. Adverse respiratory effects from sulfur dioxide exposure typically end within hours of the time when the elevated exposure ceases.

As a result of several technical modifications at the Complex, sulfur dioxide impacts are predicted to decrease dramatically after 2009. Annual average concentrations are predicted to decline by 78 to 82 percent and maximum 24-hour average concentrations are anticipated to be 60 to 66 percent lower. In addition to the planned changes to the Complex, an alternative scenario was constructed in which the main stack is located on Cerro Somi, producing an additional 100 meters of elevation to the stack. Based on this model, annual average concentrations are predicted to decrease by 75 to 93 percent and maximum 24-hour average concentration are estimated to be 78 to 81 percent lower. The Peruvian 24-hour sulfur dioxide standard will drop from 365 $\mu g/m^3$ at present (2008) to 80 $\mu g/m^3$ in 2009 and then to 20 $\mu g/m^3$ in 2014. It is assumed that these changes will render the annual standard irrelevant. Despite the marked reductions in sulfur dioxide emissions in both scenarios described above, air concentrations will remain well above the new Peruvian standard. However, the magnitude of the emissions reductions means that there will be many fewer hours when sulfur dioxide concentrations could induce respiratory effects.

For particulates, the highest annual average concentrations of PM_{10} (particles with diameter less than 10 microns) in 2007 were detected in La Oroya Antigua and the lowest concentrations were detected in Paccha. The annual average concentration in La Oroya Antigua was 64 $\mu g/m^3$, 28 percent higher than the Peruvian standard of 50 $\mu g/m^3$. The Peruvian standard was also exceeded at Marcavalle/Chucchis (52 $\mu g/m^3$) and Huaynacancha (64 $\mu g/m^3$), but not at La Oroya Nueva (equivalent to the standard). Values at both Huari (46 $\mu g/m^3$) and Casaracra (26 $\mu g/m^3$) fell below the standard.

The 24-hour average PM_{10} standard of 150 $\mu g/m^3$, not to be exceeded more than three times per year, was exceeded only once in La Oroya Antigua, and not at all at the other monitors. Because this standard allows three exceedances per year, all areas were in compliance. In the future, particulates are more likely to be evaluated by means of comparison with standards for fine particulate matter or $PM_{2.5}$ (diameter less than 2.5 microns). In 2007, maximum 24-hour values of $PM_{2.5}$ all fell below the current Peruvian standard of 65 $\mu g/m^3$. However, it has been proposed that the $PM_{2.5}$ standard be reduced to 50 $\mu g /m^3$ starting in 2010 and to 25 $\mu g/m^3$ in 2014. Particulate concentrations after 2009 were not predicted by the air dispersion model because of the numerous other sources of air particulates in La Oroya that have not been characterized. After 2009, contributions of the Complex to air particulates will be markedly

reduced, but the contributions from other sources may limit the observed reductions in PM_{10} and $PM_{2.5}$..

LEAD

Risks of adverse health effects from lead exposures in 2007 were reduced compared with those in 2005, but remain unacceptably elevated, particularly in children in La Oroya Antigua. Health risks associated with lead exposure are assessed by comparing the observed or predicted blood lead concentrations in a population with levels known to cause specific adverse health effects. The number and severity of health effects increases with dose. The United States Centers for Disease Control and Prevention (CDC) has identified 10 μg/dL as a level of concern and as the concentration above which additional monitoring is recommended. In 2007, the mean blood lead level for all children under age 6 in the area was 18 μg/dL, with a maximum value of 55 μg/dL. In La Oroya Antigua, the mean value was 21 μg/dL; this compares with a 2004 mean of 32 μg/dL. For 2007 the model predicts that 100 percent of children in La Oroya Antigua had blood lead levels greater than 10 μg/dL; however, risk that blood lead levels exceeded 10 μg/dL for other communities ranges from 36 percent in Paccha to 93 percent in La Oroya Nueva.

Predictions for after 2009, when planned operational changes will have been implemented, indicate further declines in children's blood lead levels. The operational changes are expected to cause lead emissions to decline by 91 percent. Due to limitations in air modeling, it was not possible to make future predictions for Paccha and Huari. There is some uncertainty regarding the extent of decline in soil and dust lead concentrations relative to the decline in air emissions. It is assumed that soil concentrations are heavily influenced by historical emissions and are not likely to decline dramatically in the short-term. It is also believed that declines in dust lead concentrations will be limited by soil concentrations, as windblown soil contributes to dust. Considering these limitations, the predicted annual mean concentration for La Oroya Antigua is 15μg/dL, with 98 percent of children there expected to have blood lead concentrations above 10 μg/dL. In La Oroya Nueva, blood lead levels in 39 percent of children are expected to remain above the CDC level of concern; the prediction for Marcavalle/Chucchis is 7 percent.

The USEPA risk target for lead exposure in children is 5 percent; in other words, the probability that a child's blood lead concentration would exceed 10 μg/dL should be no greater than 5 percent. Based on the ISE model, it is expected that all communities surrounding the Complex will continue to exceed this risk target, meaning that many of the children in the region are at risk for neurobehavioral changes and effects on the body's ability to make heme, a vital iron-carrying pigment in blood. Many of these effects are subtle and cannot be easily attributed to lead exposures in an individual child. The effects of lead may also be confounded by other factors such as poor nutrition and iron-deficiency anemia. The effects of altitude must also be considered when evaluating risk in this population. Natural increases in hemoglobin levels of high-altitude populations cause higher blood lead levels relative to body burden.

Blood lead levels in adults have also shown a marked decrease compared with the 2005 risk assessment. Data collected in 2007 from pregnant women showed a mean blood lead level of 7 µg/dL for La Oroya Antigua, compared with 17 µg/dL in 2004. Fetal blood lead levels can be calculated from maternal levels and compared with the CDC level of concern. In 2004, there was an 86 percent probability that a fetus' blood lead concentration would exceed 10 µg/dL in La Oroya Antigua. In 2007, the probability dropped to 18 percent. After 2009, it is predicted that the mean maternal blood lead level in La Oroya Antigua will be 5.4 µg/dL, with a 5 percent probability that a fetus' blood will exceed 10 µg/dL. Other communities show even lower levels for 2007 and 2009. Because of limitations in the design of the adult blood lead model, greater uncertainty is associated with predictions of future adult blood lead levels than with children's.

Relative contributions from different media (soil, dust, air, water, and diet) to total exposure were assessed using the children's blood lead model. Outdoor dust is currently the largest contributor to exposure in all communities, ranging from 38 percent in Paccha to 56 percent in La Oroya Antigua. As emissions from the smelter decline, the relative contribution is expected to shift so that soil becomes a larger contributor to overall exposure. This trend can be observed by comparing the 2004 modeling results to the 2007 results. In 2004, soil contributed 5 percent of exposure in La Oroya Antigua compared with 12 percent in 2007. After 2009, the percent contribution is expected to be 17 percent. As soil becomes a more prominent exposure pathway, future declines in blood lead levels will be limited by residual lead concentrations in soil.

CANCER RISK ESTIMATES

Cancer risks for non-lead metals included in this risk assessment were estimated for ingestion of arsenic in soil, dust, and drinking water, and for inhalation of arsenic and cadmium in the air. Arsenic was detected only infrequently in drinking water samples but exceeded regulatory limits established by the Superintendencia Nacional de Servicio de Saneamiento (SUNASS) in four samples from La Oroya Antigua.. Risk estimates calculated for these samples exceeded the USEPA acceptable cancer risk range, but were not added to other risk estimates because the origin of arsenic in these samples was not clear. Because of limitations in the air dispersion model, cancer risk estimates for predicted future exposures after 2009 were developed only for La Oroya Antigua, La Oroya Nueva, and Marcavalle/Chucchis.

Combined cancer risks for incidental ingestion of arsenic in indoor dust, outdoor dust, and soil are highest for La Oroya Antigua, with an upper-end exposure risk estimate of 5 in 1,000 (5×10^{3}), and a typical or central tendency exposure risk estimate of 2 in 1,000 (2×10^{-3}). In the other communities, risk estimates were lower, but still above USEPA's acceptable risk range. Many of these risk estimates have fallen slightly compared with those of the 2005 risk assessment. In all communities, the highest contribution to total cancer risk for oral exposure came from incidental ingestion of arsenic contained in outdoor dust. The contribution from indoor dust was lower than or in some cases equal to that from outdoor dust. The contribution from

incidental ingestion of arsenic in surface soil was generally lower than that from outdoor dust, although its relative contribution was greater in 2007 than in 2005.

After 2009, arsenic emissions from the Complex are expected to decline by 91 percent and cancer risk estimates for intake of arsenic via incidental ingestion of dust and soil are expected to decrease approximately 30 to 50 percent compared with current conditions. Except for risk estimates for typical exposures in La Oroya Nueva and Marcavalle/Chucchis, the future risk estimates remain above USEPA's range of acceptable cancer risks. For both typical and upper-end exposures, the predicted contribution of outdoor and indoor dust to total risk after 2009 remains higher than that for soil. However, consistent with the expected reductions in arsenic emissions and arsenic concentrations in dust, the magnitude of difference between these exposure media (i.e., dust vs. soil) is not as great as under current conditions. As emissions from the Complex are reduced, the residual soil arsenic concentrations from historical operations will come to dominate exposures.

Cancer risk estimates for inhalation of arsenic and cadmium in air under current conditions were greatest in La Oroya Antigua for both typical and reasonable maximum exposures. For La Oroya Antigua, the risk estimate for upper-end exposures was 4 in 1,000 (4×10^{-3}), while for typical exposures the risk estimate was 2 in 1,000 (2×10^{-3}). In the other communities, inhalation risk estimates were lower, but still above USEPA's acceptable risk range. All of these risk estimates have fallen compared with those from the 2005 risk assessment; in 2005 La Oroya Antigua had the highest risk estimate for both upper-end and typical exposures at 2 in 100 (2×10^{-2}) and 5 in 1,000 (5×10^{-3}), respectively. Risks contributed by inhalation of arsenic are generally about 100 times as great as those of cadmium.

Estimates of cancer risks for inhalation of arsenic and cadmium after 2009 are dramatically reduced from current conditions and most of them fall within the upper end of USEPA's acceptable cancer risk range. The highest risk estimate, 8 in 100,000 ($8x\ 10^{-5}$) is for upper-end exposures in La Oroya Antigua. Estimates of risk for typical exposures in these communities and both upper-end and typica exposures in Marcavalle/Chucchis are within USEPA's acceptable risk range.

CHARACTERIZATION OF NONCANCER RISKS

Noncancer health risk estimates for all communities were calculated for both current exposures and predicted exposures after 2009. Ingestion exposures were assessed for arsenic, cadmium, antimony, and copper in indoor dust, outdoor dust, and surface soil. Drinking water ingestion exposures were assessed for arsenic and antimony. Inhalation exposures were assessed for arsenic, antimony, and cadmium.

For drinking water, as described above, arsenic was detected in four samples from La Oroya Antigua, with a maximum arsenic concentration of 0.025 mg/L, 2.5 times the SUNASS limit.

There is no SUNASS limit for antimony, which was detected in only two samples at the detection limit of 0.01 mg/L. Hazard indices for arsenic in drinking water are 3 for the central tendency exposure and 7 for the upper-end exposure. For antimony, the comparable hazard indices are 0.9 and 2. These hazard indices were not added to those for dust and soil because the origin of the drinking water supplies and potential impacts from the Complex on the supplies are not clear.

Current noncancer risk estimates for ingestion of dust and soil combined were highest for arsenic, with hazard indices exceeding 1 in all communities. Hazard indices for typical exposures were 9 in La Oroya Antigua, and 1 to 3 in the other communities. Hazard indices for upper-end exposures were 20 in La Oroya Antigua, and 4 to 10 in the other communities. Noncancer risk estimates were below levels of concern for all other metals in all communities, with the exception of upper-end exposures to antimony in La Oroya Antigua (hazard index of 3).

Given the magnitude of risks associated with chronic exposure to arsenic within these communities, risks associated with shorter-term (i.e., subchronic) exposures were assessed for young children. Exposures of children 0 to 6 years old from incidental ingestion of outdoor dust, indoor dust, and surface soil were compared with an arsenic subchronic reference dose. Hazard indices for upper-end exposures were 4 for a child residing in La Oroya Antigua and 2 for a child residing in Marcavalle/Chucchis. In La Oroya Nueva, Santa Rose de Saco/Huaynacancha, Paccha and Huari, hazard indices were less than 1, indicating that subchronic noncancer risks due to arsenic in these communities are not of concern.

Noncancer ingestion risks are predicted to drop dramatically after 2009. Predictions were made for exposures to arsenic and cadmium in La Oroya Antigua, La Oroya Nueva, and Marcavalle/Chucchis. The predicted hazard index for upper-end exposures for arsenic in La Oroya Antigua is 5 (compared with 20 for current conditions). After 2009, soil (hazard index of 3) is predicted to make the greatest contribution to arsenic exposures. Hazard indices for arsenic in other communities were 2 or less. For cadmium, all predicted hazard indices are much less than 1.

Current noncancer risk estimates were also calculated for inhalation of arsenic, cadmium, and antimony. Arsenic yielded the highest risk estimates for current exposures. In La Oroya Nueva and La Oroya Antigua the hazard indices were 40 for the typical exposures and 60 for the upper-end exposures. In Marcavalle/Chucchis, the hazard indices were 20 for the typical exposures and 30 for the upper-end exposures. In Huari, Paccha, and Santa Rosa de Sacco/Huaynacancha, hazard indices ranged from 8 to 10 for typical exposure conditions and from 10 to 20 for upper-end exposures.

Hazard indices for cadmium were 2 or less in all communities, indicating very limited risks. Cadmium risks have declined significantly since the 2005 assessment. Antimony upper-end

exposure hazard indices ranged from 4 to 6 in La Oroya Nueva, La Oroya Antigua, and Marcavalle/Chucchis, and those for typical exposures from 2 to 4. In Huari, Paccha, and Santa Rosa de Sacco/Huaynacancha, antimony hazard indices were all 3 or less.

Future noncancer inhalation risks are predicted to drop dramatically after 2009. Predicted arsenic hazard indices range from 0.4 to 1 and cadmium hazard indices from 0.1 to 0.3.

CONSIDERATION OF MIXTURES OF CHEMICALS

Chemicals in mixtures can interact to either increase or decrease overall health effects. For mixtures of carcinogenic chemicals, standard risk assessment practice is to assume that risks are additive. Assessment of mixtures is a developing area of toxicology that is not fully understood, and the USEPA guidance for risk assessment of mixtures does not yet provide consistent methods for quantitative analysis of effects other than cancer.

The potential for significant interactions among chemicals in La Oroya is great because of the high levels of exposure and the similarity of potential effects. While possible interactions in La Oroya cannot be quantified, it is very important to understand the multiple factors that may contribute to the primary health effects and to account for them in any future health studies. To that end, the risk assessment includes a review the principal expected health effects and their contributing factors, including the impacts of mixtures of particulate matter and sulfur dioxide on the lung; possible interactions of lead, arsenic, cadmium and iron deficiency on anemia; and possible interactions among poor nutritional status, lead, cadmium, and alcohol on bone.

UNCERTAINTY EVALUATION

As described above, risk assessments predict the likelihood of health effects in a population, but do not directly measure the occurrence of health effects. The predicted risks are based on many assumptions about the ways that people come into contact with chemicals in the environment. Although many of these assumptions are based on scientific studies and site-specific data, uncertainty remains regarding how well the available data reflect the ways residents are actually exposed to chemicals. The degree of confidence in the results of a risk assessment depends on how closely the data and assumptions used match actual conditions. In general, where uncertainties existed, conservative parameters, assumptions, and methodologies were used to enhance the likelihood that potential exposures and risks would not be underestimated.

It is important that the uncertainty be evaluated in the context of the intended scope of the risk assessment. The goals of this risk assessment were to evaluate current human health risks in the community due to air emissions from the Complex and to predict changes in future health risks as smelter emissions are reduced. Evaluation of current health risks focused on characterizing the ways people are exposed to Complex air emissions and the relative

contribution of various exposure pathways to total exposure. No effort was made to determine the land area affected by historical Complex emissions because this was outside the scope of this risk assessment.

Uncertainties in current inhalation risks have been minimized by the availability of local air monitoring data for sulfur dioxide, particulates, lead, and other metals. The exposure assessment for inhalation of these chemicals is expected to be more accurate than is the case in most risk assessments. Inhalation rates are well documented and fewer assumptions were required to estimate inhalation exposures than for other exposure pathways. Despite some uncertainties in the emissions estimates and the air modeling study, the available information is of good quality. Confidence in the predicted future inhalation risks is also high.

Possible uncertainties for lead exposures have been greatly reduced by the availability of high-quality blood lead data for the population. Both the adult and child blood lead models have been shown to accurately predict mean and middle percentile blood lead concentrations in the population. Upper percentile risks are consistently underestimated by the model, and the predictions may not capture some individuals in the population who may have unusually high exposures. There is also uncertainty in the relative contribution of some of the sources (i.e., outdoor dust, indoor dust, and soil), but the sum of these exposures is judged to be accurate. Confidence in predictions of future lead exposures is dependent on the accuracy of the air model deposition estimates for lead emitted from the Complex. The deposition estimates are judged to be adequate to support the risk estimates. A sensitivity analysis demonstrated that the model predictions remain stable within a reasonable range of predicted soil and dust concentrations. For ingestion exposures to metals other than lead, predicted risks are relatively less certain because more assumptions were needed. Nevertheless, confidence in the assessment of these metals was enhanced by relying on some of the assumptions developed for lead. Oral exposure estimates for metals other than lead are expected to be more reliable than those of typical U.S. risk assessments.

RECOMMENDATIONS

Integral's 2005 report provided a series of recommendations intended to help the community reduce health risks. The recommendations included actions related to facility operation, environmental monitoring, community interventions, dietary studies, and nutritional training and supplementation. The complementary risk assessment reports the status of these activities and recommends additional actions to decrease exposure risk to the communities.

One general recommendation was the formation of a stakeholder advisory group constituting representatives of local government, community organizations (including local religious groups), the Convenio, Peruvian Ministry of Energy and Mines (MEM), Ministry of Health's Environmental Health Directorate (DIGESA), and Doe Run Peru. The group would meet

regularly to share information about the Complex operations and about community activities undertaken to reduce local health impacts. We continue to recommend that such a group be formed.

At the Complex, numerous technological and operational changes have already been implemented to reduce stack and fugitive emissions of sulfur dioxide and metals. Future planned changes include construction of sulfuric acid plants for the lead and copper circuits, to be completed in September 2008 and October of 2009, respectively. With the completion of these changes, our recommendations from 2005 for changes in facility operations will have been fully implemented. Additionally, Doe Run Peru has proposed moving the main stack to an adjacent hill, which would improve dispersion of emissions and substantially reduce exposures to the communities closest to the Complex.

The 2005 report recommended continuing collection of data on chemical concentrations in air, dust, and soil to show how exposures might be changing over time and whether actions to reduce emissions from the Complex are effectively lowering concentrations in the environmental media to which people are exposed. The 2005 report had recommended a dustfall monitoring program, along with continued collection of samples of soil, outdoor dust, and indoor dust. These samples have been collected by the Convenio (indoor and outdoor dust samples) and by Doe Run Peru (dustfall, soil, and outdoor dust), and the recommendation has been fulfilled.

The recommendations for changes in the air monitoring network, and data quality control efforts have been implemented. In addition to fulfilling the recommendation for continued air monitoring, Doe Run Peru initiated monitoring for fine particulate matter ($PM_{2.5}$), and also analysis for additional metals. In this way, Doe Run Peru has surpassed the recommendation. It was also recommended that the monitoring program be expanded to include collection and analysis of split samples by a third party to provide transparency in the environmental monitoring program. We continue to recommend this action. The 2005 risk assessment report also summarized recommendations for updating and improving the air dispersion model developed by McVehil-Monnett. The implementation of these recommendations and the resulting revised air dispersion model are described in the final air modeling report. For community interventions, ongoing activities are being conducted by Doe Run Peru and the Convenio to reduce exposures and improve health status of La Oroya residents. These activities including regular street cleaning, improvement of public hygiene facilities, a program to pave dirt streets and walkways, planting of grass and trees to reduce exposed soil, and efforts to improve the construction of houses with dirt walls and with roofs that do not keep dust out. Residents have also been provided with information regarding home cleaning practices, personal hygiene, food preparation practices, and nutrition. Homes of children considered to be most at risk have been identified and professional cleaning services have been employed to assist in keeping these homes clean. We recommend continuing support for these activities

with additional focus on cleaning and hygiene training programs in the schools. We also recommend the continuation of the annual blood lead monitoring program of the Convenio.

The diet study conducted in 2008 fulfilled the primary recommendation from the 2005 risk assessment for a series of actions to identify ways to reduce intakes of lead and other metals from the diet and to improve nutritional status. Because this study confirmed the finding of inadequate iron and calcium intake in both women and children, it is recommended that programs be developed to ensure adequate intakes of these nutrients. The 2008 study did not identify elevated intakes of lead or cadmium from the diet because concentrations in the food samples were all below analytical detection limits. Arsenic was detected in some of the food samples, but only total arsenic was reported, which includes nontoxic organic forms of arsenic that are naturally present in many foods, especially in fish and rice. Nevertheless, efforts to minimize intake of these metals in the diet is considered prudent.

To prevent metals in dust from contaminating food as it is prepared and eaten in the home, it is recommended that the community should determine the best way to ensure that all households have the necessary resources to store food, water, and utensils in closed containers. It is further recommended that all households are instructed in proper techniques for washing food, hands, and cooking surfaces before preparing and eating meals. Further study should be undertaken to investigate means outside the home (e.g., at outdoor markets) by which lead and other metals are transferred to food. Findings from such research should be used to develop programs to reduce this exposure.

1 INTRODUCTION

This document presents a complementary human health risk assessment for the Doe Run Peru Metallurgical Complex (Complex) in La Oroya, Peru. It updates a 2005 risk assessment conducted by Integral Consulting Inc. (Integral). Doe Run Peru (DRP) had commissioned the 2005 risk assessment to comply with the Supreme Decree of the Peruvian Ministry of Energy and Mines (MEM). The focus of the risk assessment was to characterize risks to nearby residents from chemicals released to the air during current and future operations of the Complex. As a part of the Project of the Environmental Adjustment and Management Program (PAMA), MEM has requested that Doe Run Peru carry out a "Complementary Risk Assessment" considering the implementation of the recommendations made by Integral in 2005 (MEM 2006); Doe Run Peru has contracted Integral for that purpose. The same methods have been used in both risk assessments; the later document incorporates new data. The approach and scope of the update are described below, followed by a summary of the 2005 risk assessment.

1.1 RISK ASSESSMENT APPROACH AND SCOPE

A human health risk assessment is a quantitative evaluation of the risk posed to human health by the actual or potential presence or release of chemicals in the environment. It predicts the likelihood of health effects in a population, but does not directly measure their occurrence. In this way, a risk assessment is very different from an epidemiology study reporting the incidence of specific health effects or a biomonitoring study documenting the concentrations of chemicals in people's bodies. This updated risk assessment is needed to evaluate the progress of recent efforts to reduce emissions from the Complex and to predict future health risks as emissions are further reduced.

The scope of the complementary risk assessment was defined by the Ministry of Energy and Mines in a document titled *Terms of Reference of the 2008 Update of the Risk Assessment in La Oroya* (referred to herein as TOR). As specified by the TOR, the risk assessment evaluates and quantifies the current risks to human health due to operations at the Complex. The current risks are compared with those that had been predicted for 2007 in the 2005 risk assessment. To the extent possible, the effects on future health risks of additional planned changes in Complex operations are assessed. Methods and structure of both reports are generally consistent, with any exceptions noted.

The human health risk assessment process as defined by the United States Environmental Protection Agency (USEPA 1989) contains four major steps. The first step is to characterize the site and the chemicals associated with it. This step involves many activities, including review of sources that release chemicals to the environment, identification of the chemicals released, evaluation of available data, and assessment of how people in the community might contact the

chemicals. The result of this first step is a "road map" showing how and where people might come into contact with the chemicals associated with the site. This description is known more formally as an exposure pathway model.

The second step is to examine the potential exposure, looking in detail at how and to what extent people may come into contact with the chemicals. As part of this step, potential doses, or intakes, of chemicals from air, dust, soil, water, and other media are quantified.

The third step is the toxicological evaluation, which includes a characterization of the kinds of adverse health effects a chemical may cause. Specific doses of each chemical that may cause toxicity are identified. "Safe" doses are also identified; more precisely, a "safe" dose is one that is not expected to cause adverse health effects. In this risk assessment, the highest "safe" doses are called toxicity values.

The fourth step is the risk characterization. Here, results of the exposure assessment and the toxicological evaluation are combined to describe potential risks to human health associated with site-related chemicals. The doses of chemicals to which people may be exposed are compared with the toxicity values to determine the risk of health effects. Results can guide decisions about actions to protect human health.

This complementary risk assessment includes the following key components:

- Updates to the original site characterization and exposure pathway model based on the findings from the 2005 risk assessment and recent changes at the Complex
- An exposure assessment based on new data and an updated air model
- An update of the toxicity assessment for chemicals included in the risk assessment
- Characterization of current and future risks and the associated uncertainty.

1.2 SUMMARY OF THE 2005 RISK ASSESSMENT

The *Human Health Risk Assessment Report: La Oroya Metallurgical Complex* (Integral 2005a) evaluated then-current and future risks from operations of the Complex. Based on a review of the chemicals released by the Complex and their health effects, the risk assessment focused on inhalation of airborne sulfur dioxide and particulate matter, and on inhalation and ingestion of lead, arsenic, cadmium, antimony, and thallium.

For sulfur dioxide and particulates, the exposure assessment used data for the year 2004 collected at three air monitoring stations maintained by Doe Run Peru in residential areas of La Oroya. Health risks were assessed by comparing reported concentrations with Peruvian and United States air quality criteria.

Air concentrations of sulfur dioxide exceeded (i.e., did not meet) the Peruvian air quality standards by a very large margin, for both the annual average concentrations and the 24-hour concentrations. Exceedance of the standards was greatest in La Oroya Antigua and indicated a potential for adverse respiratory effects, particularly for short-term exposures by asthmatics and children during mid-morning to early afternoon.

Air concentrations of sulfur dioxide were also higher than guidelines for acute exposure (i.e., for a few hours or less), developed by the National Academy of Sciences in the United States, to protect against temporary respiratory effects such as wheezing, tightness of the chest, and coughing. Acute exposure guidelines intended to protect against life-threatening effects were not exceeded.

Very small particles suspended in the air have the greatest potential to cause adverse health effects. In 2004, air monitoring data were available for particles less than 10 microns in diameter (termed PM_{10}). Two Peruvian PM_{10} standards were available: a 24-hour standard of 150 $\mu g/m^3$, not to be exceeded more than three times per year, and an annual average of 50 $\mu g/m^3$. The annual average PM_{10} concentration for La Oroya Antigua was approximately twice the air quality standard, with occasional exceedance of the 24-hour standard. In La Oroya Nueva and Marcavalle, air particulate concentrations also exceeded the standards but by a much smaller amount.

For lead, the exposure assessment used a model developed for USEPA and modified for conditions in La Oroya to generate a distribution of blood lead concentrations. Predicted concentrations in children were high enough to put them at risk for many adverse health effects. The model predictions were consistent with blood lead levels measured in the children of La Oroya. The exposure model helped to identify sources of exposure responsible for the observed blood lead levels; recommendations were then made to reduce exposure. A similar model was used to assess lead exposures in adults and to recommend corrective actions.

The exposure assumptions used in the lead exposure models were also used to predict risks for arsenic, cadmium, antimony, and thallium. Arsenic and cadmium are carcinogenic when inhaled. Based on the air monitoring data in La Oroya, arsenic was the primary cause of increased cancer risks. These risks were highest in La Oroya Antigua, but were unacceptably high in all areas. Inhaled cadmium also posed an unacceptable risk of adverse effects other than cancer.

Arsenic is also carcinogenic when ingested at high doses. Cancer risks for ingestion of arsenic were unacceptably elevated in La Oroya, with the greatest risk in La Oroya Antigua. Non-cancer risks for ingestion of arsenic were also unacceptable, with the greatest risk again in La Oroya Antigua. Health risks for ingested antimony were above targets in the areas closest to the Complex, but those for ingested cadmium were not. In all, the magnitude of risks was sufficient to cause concern about additional health impacts due to possible interactions among the metals.

The 2005 risk assessment focused on metals and other chemicals that might be released from the Complex via stack and fugitive emissions. Releases to surface water and groundwater had been judged as not significant exposure pathways for residents of La Oroya, and had been excluded from the risk assessment. Releases from wastes stored in piles (e.g., slag) or impoundments were similarly excluded. Historical contamination was not characterized in detail, although metal concentrations in soil, dust, and other media that had been sampled likely included contributions from both historical and ongoing operations.

Future exposures had been estimated on the basis of planned reductions in fugitive and stack emissions. Doe Run Peru provided estimates of current and future emissions to the air modeling consulting company McVehil-Monnett Associates Inc. After developing an air model that matched current concentrations of sulfur dioxide and metals, McVehil-Monnett used the estimated future fugitive and stack emissions rates to predict future air concentrations of sulfur dioxide, particulate matter, and metals, as well as deposition rates for the metals. Future health risks were then predicted from the modeled future air concentrations for sulfur dioxide. For metals, the percent changes in deposition rates were used to predict future concentrations of metals in outdoor dust, indoor dust, soil, and, in the case of lead, the diet.

The 2005 risk assessment had also recommended numerous changes in Complex operations to reduce emissions, as well as community and dietary interventions to reduce and mitigate the effects of exposures.

1.3 REPORT ORGANIZATION

Organization of this complementary human health risk assessment report is as follows:

- Section 2, Site Characterization, provides a description of the Complex, including chemicals likely to be emitted and demographic characteristics of the residents living near the Complex. The likely exposure pathways are also discussed.
- Section 3, Data Evaluation, summarizes existing data and presents additional data (i.e., environmental field studies, a duplicate diet study, and air modeling activities) considered in development of the risk assessment. It also details the screening process used to update the list of chemicals for quantitative risk evaluation and presents the final list of chemicals to be evaluated.
- Section 4, Exposure Assessment, summarizes the methods used to estimate human exposures in the risk assessment, and presents the results of the exposure evaluation.
- Section 5, Toxicological Evaluation, identifies the toxicity values used in the risk assessment and describes potential health effects associated with chemicals evaluated.

- Section 6, Risk Characterization, describes the calculation of the risks from chemical exposures and provides a qualitative evaluation of uncertainties associated with these results.
- Section 7, Conclusions and Recommendations, delineates recommendations for future actions.
- Section 8, References, lists the documents cited.

2 SITE CHARACTERIZATION

Since completion of the 2005 risk assessment, Doe Run Peru has made many changes in operations, undertaken regular air monitoring at six stations located in the communities surrounding the Complex, and promoted community development initiatives in the region. Additionally, monitoring of soil, dust, and water has contributed to a larger body of knowledge from which to estimate health risks to the population. This new information has been incorporated into the following site characterization.

In May 2008, Integral staff visited La Oroya to assess the current status of potential exposures, and to obtain available data relevant for the conduct of the complementary risk assessment. Contacts at the Doe Run Peru and the Convenio[1] assisted with these efforts by providing documents and information about the smelter and the population of La Oroya. Data obtained from these and other sources have been used to characterize the Complex, local population, and environmental setting.

2.1 DESCRIPTION OF THE COMPLEX AND ITS OPERATIONS

The Complex is an active smelting facility located approximately 175 kilometers northeast of Lima, Peru in the Andes Mountain Range, at an altitude of 3,745 meters. It is situated in the Mantaro River Valley at the confluence of the Mantaro and Yauli Rivers. North of the Complex, across the Mantaro River is the town of La Oroya Antigua. The communities of La Oroya Nueva, Marcavalle, Chucchis, Santa Rosa de Sacco, and Huaynacancha are located upstream, along the Yauli River, west-southwest of the Complex. The community of Paccha is located to the northwest along the Mantaro River and the community of Huari is located to the southwest, where the Rio Huayhuey meets the Rio Mantaro. The surrounding environs are dry, rugged limestone mountains sparsely vegetated with bunch grasses. Ground-level winds are predominantly from the west-southwest and the northeast.

The Complex was built by American Cerro de Pasco Copper Corporation and began smelting copper in 1922. Lead production began in 1928 and zinc production began in 1952. Recovery of precious metals began in 1950. The government-owned company Centromin operated the Complex from 1974 until 1997, when it was purchased by the Doe Run Company.

The Complex processes approximately 600,000 metric tons of concentrate annually. Approximately 450,000 tons of the concentrate contains multiple metals including precious metals, with the remaining 150,000 tons containing zinc concentrates. Eleven metals (most

[1] The Convenio is a cooperative agreement between the Ministry of Health, the regional government of Junin, and Doe Run Peru.

importantly lead, zinc, copper, silver, and gold) and eight by-products are produced from the concentrate.

A main stack rising 167.5 meters above ground level emits gases and particulate matter produced during smelter operation. In addition, gases and particulate emissions escape from various areas of the facility that are not enclosed by buildings. The main stack and fugitive emissions contain heavy metal dusts and sulfur dioxide gas that migrate to the surrounding communities

2.1.1 Updates to the Complex

In the last 3 years, Doe Run Peru has improved the efficiency of the smelter, reduced stack emissions, and increased industrial safety for its workers. The following specific emission reduction projects have been completed since 2005:

- Upgrade of the sulfuric acid plant for the zinc circuit
- Installation of baghouses for the lead furnaces, arsenic trioxide plant, and dross plant reverberatory furnace
- Enclosure of the lead blast furnace and dross plant buildings
- Upgrade of the ventilation systems of the lead sinter plant
- Partial enclosure and use of water sprays for the lead and copper preparation beds
- Expanded use of Central Cottrell for treatment of sinter plant gases, copper converter gases, and exit gases from the anodic residue plant
- Treatment of nitrous gases from the anodic residue plant
- Installation of a new ventilation system for the anodic residue plant
- Implementation of "Complementary Environmental Projects" such as paving of industrial areas, and use of street sweepers and tire washers
- Installation of three domestic and one industrial water treatment plants to control total liquid effluents.

Technology improvements at the Complex have led to notable declines in both stack and fugitive emissions, ultimately reducing concentrations of metals in the air and dust surrounding the smelter. Several projects have been planned for 2008 and 2009 that will further reduce emissions and exposure to the community. These include the following:

- Completion of a sulfuric acid plant for the lead circuit in September 2008.

- Construction of a sulfuric acid plant for the copper circuit to be completed in October 2009. This plant will render the copper roaster and copper reverberatory furnace obsolete.

- Installation of an Isasmelt furnace for the copper circuit.

- Installation of additional "Tuyere Control" systems for the lead furnaces, effectively reducing the amount of oxygen injected into the furnaces and providing better processing of emissions. Acquisition and use of additional street sweepers and industrial vacuums to keep areas around the complex dust-free.

2.1.2 Chemicals Released from the Complex

Chemicals considered in this complementary risk assessment were identified by evaluating the potential health effects of chemicals known to be emitted from the Complex. Chemicals identified in risk assessments of other smelters were also considered. Sulfur dioxide has long been identified as a pollutant in smelter stack emissions. Metal-containing fine particulate matter is also a frequent concern for both smelter stack and fugitive emissions. Metals released from smelters include both primary products, such as zinc, copper, and lead, and other metals associated with the ores being processed. The 11 metals produced the Complex are zinc, lead, copper, silver, gold, bismuth, cadmium, indium, tellurium, antimony, and selenium. Arsenic trioxide is produced as a by-product, and arsenic emissions have been of concern at other smelter sites. None of the other by-products (including sodium bisulfite, sulfuric acid, specific metal compounds, and oleum) were considered in the risk assessment.

A risk-based screening process was used to determine which chemicals associated with the Complex should be included in the risk assessment. As noted above, the 2005 risk assessment had included sulfur dioxide, air particulates, lead, arsenic, cadmium, antimony, and thallium. The selection of chemicals for inclusion in this complementary risk assessment is presented in Section 3.3.

2.2 COMMUNITY INTERVENTIONS

In addition to reducing stack emissions since purchasing the Complex in 1997, Doe Run Peru has introduced programs to reduce chemical exposures of workers and community residents (DRP 2001b). Additional programs have contributed to improving nutrition and living conditions for residents.

As reported in the 2005 risk assessment, Doe Run Peru improved the change houses where chemically exposed workers are required to remove their work clothes and shower before leaving the site at the end of their shift.

Several community programs had been implemented by Doe Run Peru prior to 2005:

- Conducting the first-ever community-wide blood lead level survey using protocols developed by the United States Center for Disease Control and Prevention
- Entering into an agreement with the Peruvian Ministry of Health to reduce blood lead levels in children under the age of 6 who live in La Oroya Antigua
- Constructing a medical clinic and government dining establishment to serve 800 low-income residents
- Implementing water-collection systems in parts of La Oroya that enable treatment of stormwater and sewage
- Remodeling more than 12 public schools
- Introducing a breeding program for sheep and llamas and donating offspring to surrounding communities
- Providing seminars on animal husbandry and pasture improvements
- Providing training in small business practices for nearly 4,000 local women, resulting in 25 new businesses
- Developing a recreational center that includes soccer fields, artificial lakes, wildlife areas, and barbecue areas
- Introducing a community education program to address the issue of blood lead levels in young children.

Since 2005, Doe Run Peru has continued to play a key role in promoting community development initiatives in the surrounding region. Some of the recent projects implemented by Doe Run Peru include the following:

- Developing, in conjunction with the Ministry of Health (MINSA), a neighborhood cleaning campaign, resulting in a significant increase in the frequency of street cleaning since 2006
- Providing supplemental food to 356 kindergarten and first grade students from La Oroya Antigua schools
- Constructing shower modules in six schools, serving approximately 900 children ages 4 to 12
- Training women in food production, textile manufacturing, handicrafts, and business management (in 2006, 622 women received training)
- Creating the "Basic Home Improvement Program," which helps residents make interior repairs to in La Oroya Antigua (in 2006, 24 homes were repaired)

- Paving areas of exposed dirt in La Oroya Antigua to reduce children's contact with soil (to date, 19 high traffic areas have been paved)
- Performing construction projects, repairs, and maintenance on community buildings and public areas
- Initiation of the program "Healthy Families and Homes," sponsored by the Convenio; in 2008, 647 families participated in the educational programs.

2.3 DESCRIPTION OF SURROUNDING POPULATION

Several communities are located within the vicinity of the Complex. Nearest the Complex is La Oroya Antigua, which has a population of approximately 12,000. Other communities within the study area for the risk assessment include La Oroya Nueva, Marcavalle, Chucchis, Santa Rosa de Saco, Huaynacancha, Huari, and Paccha, accounting for approximately 30,000 additional inhabitants.

In coordination with the Ministry of Health and the National Institute of Statistics and Data Processing (INEI), Doe Run Peru has conducted two socio-economic studies in the district of La Oroya (DRP 2002, 2006). In 2002, demographic information was obtained for 18,308 residents of LaOroya and in 2006, 16,806 residents were surveyed. The studies differed slightly with regard to the information gathered; data from both studies are presented in this section.

La Oroya has a considerable transient population. The majority of the residents (52 percent) have lived in the community for fewer than 10 years; 39 percent have lived in La Oroya for 10 to 39 years, and 9 percent have lived there for more than 40 years (DRP 2002). In the past, people have migrated to La Oroya to seek economic opportunities; however, there is some evidence that immigration to the region has slowed in recent years.

The 2006 study revealed a young population, with approximately one-third of the people under age 15 and nearly 13 percent under age 6. The majority of the population is of working age, 15 to 64 years old, with only 4 percent older than 65 years.

Women of child-bearing age (12-49 years old) represent 31 percent of the total population and 80 percent of the female population. The 2002 study showed that 17 percent of mothers have only one child, 25 percent have two children, 21 percent have three children, and 24 percent have four to five children. Women with six or more children represent 13 percent of all mothers (DRP 2002). Comparable data were not collected in 2006.

The educational status of heads of households is generally low. The more recent study (DRP 2006) reports that 4 percent have no education and 29 percent have some primary school education. Less than half (44 percent) received secondary school education. Approximately 10 percent have college level training and 12 percent have some technical education.

Nearly 80 percent of the surveyed population lives in their own home. Most of the remaining population (17 percent) lives in an apartment building, with the rest residing with other family members or in an improvised home (DRP 2006). Within the districts of La Oroya and Santa Rosa de Sacco, 80 percent of the houses have electricity, though many of those homes also use candles for illumination (DRP 2006). Most (70 percent) homes are serviced by public water supply inside the home; nearly all of the remaining homes have water outside of the home but within the property.

2.4 IDENTIFICATION OF EXPOSURE PATHWAYS

The site characterization provides the basis for developing an exposure pathways model. The 2005 risk assessment and the current update focus on chemicals known to be released from the Complex via stack and fugitive emissions. The exposure pathways model developed for the 2005 risk assessment (Figure 2-1) remains valid for the current exposures. As shown in the figure, chemicals emitted from the Complex into the air may be inhaled (as vapors, such as sulfur dioxide, or in particulate matter). The particles that settle out onto soil and paved surfaces may later be ingested in soil or dust. Chemicals in soil or dust outdoors may be transferred to indoor surfaces, such as floors and furniture. When people contact these indoor surfaces, the dust may adhere to their hands. From their hands, the dust can be ingested by direct transfer to the mouth or to objects placed in the mouth, such as toys or cigarettes. When disturbance makes the dust airborne again, these small particles can be inhaled. Airborne dust may then be redeposited directly onto food stored in the home, in open markets, or onto meal preparation areas where it then may be ingested along with the food.

According to USEPA (1989), exposure pathways may be eliminated from further consideration in a risk assessment for any one of the following reasons:

- The exposure resulting from the pathway is much less than that from another pathway involving the same medium at the same exposure point
- The potential magnitude of exposure from a pathway is low
- The probability of exposure is very low and the risks associated with the occurrence are not high.

Two potential exposure pathways were eliminated from consideration in both the 2005 risk assessment and the current complementary assessment: those involving release from slag piles and dermal contact with metals. Releases from waste stored in piles (e.g., slag) or impoundments in the industrial zone away from residential areas were considered unlikely to affect residents of La Oroya in the 2005 assessment; the same judgment has been made for the current update. Dermal absorption of metal particles on the skin was not evaluated because there is only very limited absorption of metals through the skin.

Drinking water pathways involving surface water directly affected by the smelter are assumed to be incomplete. Surface water and groundwater that might be affected by releases from the Complex are not used by residents for drinking water or other purposes. Drinking water for residents of La Oroya originates at higher elevations, in areas not affected by smelter emissions. Thus, drinking water exposures are assessed based on tap water samples from homes or community taps.

Existing concentrations of metals in soil, dust, and other sampled media represent cumulative effects of historical and present-day operations. Neither the 2005 nor the complementary risk assessment distinguish contributions from historical versus current operations.

Blood lead studies of populations elsewhere in Peru indicate that lead in the body may be influenced by multiple sources, such as automobile exhaust, paint, plumbing, tin cans, pottery, and toys. The exposure pathways diagram in Figure 2-2 reflects this wider variety of sources, each of which could contribute to elevated blood lead concentrations in some people within the study area.

3 DATA EVALUATION

This section presents a summary of existing data and data analyses associated with the Complex. Data applicable to the risk assessment have been generated by both Doe Run Peru and the Convenio. All available data have been evaluated for inclusion in the risk assessment and are discussed in Section 3.1. The Ministry of Energy and Mines has also requested an analysis of the Complex workers' morbidity concerns and causes of death. Although this is not a part of the complementary risk assessment, the data to support this analysis are described in this section. In addition to using data collected in 2007 and 2008 to evaluate current health risks, air modeling predictions have been used to assess future concentrations of chemicals in the air and subsequent health risks. Air modeling methods and approaches are discussed in Section 3.2. The application and robustness of the air model are also addressed. In Section 3.3, the selection of chemicals for inclusion in the risk assessment and the derivation of exposure point concentrations[2] for the exposures assessment are described.

3.1 SUMMARY OF EXISTING DATA

Since 2006, Doe Run Peru has undertaken regular environmental sampling in an effort to monitor the effect of smelter emissions on the region. At the request of Integral, additional soil and dust sampling was undertaken in June 2008 to meet the data needs of the complementary risk assessment. Doe Run Peru also sponsors annual blood lead sampling of children and pregnant women living in the surrounding communities. The Convenio has undertaken yearly household dust sampling as well as drinking water source monitoring. Additionally, a Convenio-sponsored study to evaluate the micronutrient and metals content in food was completed in April 2008. Thus, available data include chemical concentrations in air, soil, dust, drinking water, food, as well as blood lead concentrations in children and pregnant women. The quality and completeness of these data as well as how the data are used in the risk assessment are discussed below.

3.1.1 Air Monitoring Data

Doe Run Peru conducts air quality monitoring in the communities surrounding the Complex. Monitoring of sulfur dioxide, particulates, and metals is conducted at six stations in residential areas—Sindicato, Hotel Inca, Marcavalle, Huaynacancha, Casaraca, and Huari—and one station in an industrial area immediately downwind of the Complex—Huanchàn[3]. Doe Run Peru also maintains a meteorological monitoring station at Cerro Somi, located immediately south of the

[2] Exposure point concentration is the value that represents a conservative estimate of the chemical concentration available from a particular medium or route of exposure

[3] This location is not used for the risk assessment, but is an important component of the air modeling activities and provides a context for what is happening in the immediate vicinity of the Complex.

Complex. Data from each monitoring station located in a residential area were used to evaluate exposures in the communities closest to the station.

The following sections describe the location of the monitoring stations relative to the communities being evaluated in the risk assessment as well as the characteristics of the data collected. Summaries of the data and a description of how the data were used are provided in Section 4.

3.1.1.1 Air Monitor Locations

Sulfur dioxide and particulate matter data from six of the monitoring stations operated by Doe Run Peru were used in the analysis of current risk to health. Each of these monitoring stations was selected to represent a particular community near the Complex (see Figure 3-1). The communities and the corresponding monitoring stations are listed below.

Community	Monitoring Station
La Oroya Antigua	Sindicato
La Oroya Nueva	Hotel Inca
Marcavalle	Marcavalle
Chucchis	Marcavalle
Santa Rosa de Sacco	Huaynacancha
Huaynacancha	Huaynacancha
Paccha	Casaracra
Huari	Huari

Data from the Sindicato monitoring station were used to represent exposures in the La Oroya Antigua community. This station is located to the north of the Complex, just across the Mantaro River. Because the Sindicato monitor is located very close to the Complex, it typically records the highest air concentrations observed among the Doe Run Peru monitors. Much of the community of La Oroya Antigua is located farther north of the Sindicato station and farther from the Complex. Based on the air model contours established in 2005, air concentrations are expected to decrease with distance away from the Complex when going north through La Oroya Antigua. Therefore, data from the Sindicato monitor should indicate the highest air concentrations likely to be seen in La Oroya Antigua and tend to overpredict impacts in the more northerly sections of the community.

Data from the Hotel Inca monitoring station were used to represent exposures in the La Oroya Nueva community. This monitoring station is located to the west of the facility, near the confluence of the Yauli and Mantaro rivers. Although located farther from the Complex than the Sindicato station, it is still one of the closest monitoring stations operated by Doe Run Peru.

The community of La Oroya Nueva lies to the south of the Hotel Inca station along the Yauli River. For purposes of the risk assessment, the area to the west and northwest of the monitoring station has also been included in the analysis. Some portions of the La Oroya Nueva community along the Yauli River may actually be closer to the Complex than the Hotel Inca station. However, much of the community is located farther south down the Yauli River valley and the Hotel Inca monitor should provide a reasonable estimate of the 24-hour and annual average conditions expected in La Oroya Nueva.

In 2005, data from a monitoring station in Cushurupampa had been used to evaluate exposures for the Marcavalle community. This station had been located to the southwest of the Complex in the Yauli River valley, closer to the Complex than the community of Marcavalle. The station had been on the hillside on the eastern side of the valley where the terrain is steeper and where air modeling demonstrated higher concentrations than in the valley. In 2005, it was recommended that this station be relocated to a lower elevation more reflective of the residential area. In response to this recommendation, Doe Run Peru replaced the Cushurupampa station with the Marcavalle station in January 2007.

Data from the Marcavalle monitoring station were used to evaluate exposures for both Marcavalle and Chucchis. The new station is located closer to the communities of Marcavalle and Chucchis than the old station. However, since the monitor is closer to the smelter than the community of Chucchis, it is anticipated that reported air concentrations at the Marcavalle station will be slightly higher than those to which the people living in Chucchis are actually exposed.

Three additional air monitoring stations are located in outlying communities: Huaynacancha, Huari, and Casaracra. The Huaynacancha station, southwest of Marcavalle and Chucchis, began monitoring metals on April 1, 2007 and sulfur dioxide and particulates on May 12, 2007. Data from the Huaynacancha station were used to evaluate exposures in both Santa Rosa de Sacco and Huaynacancha.

The Huari station is located in the community of Huari, to the southeast of the smelter along the Mantaro River valley. This station began monitoring metals concentrations on February 16, 2007 and sulfur dioxide and particulate concentrations on March 1, 2007.

The Casaracra station has been in operation for several years. It is located several kilometers northwest of the smelter in the community of Paccha, where effects from the Complex are generally lowest.

3.1.1.2 Air Monitoring Data Summary

Monitoring data for all locations has been provided to Integral for the years 2005, 2006, 2007, and the first quarter of 2008. For the purposes of this risk assessment, data from 2007 were used to estimate exposure. Each monitoring station measures ambient air concentrations of sulfur

dioxide (SO_2), particulate matter equal to or less than 10 microns in diameter (PM_{10}), and particulate matter equal to or less than 2.5 microns in diameter ($PM_{2.5}$). Additionally, metals concentrations in PM_{10} are recorded for arsenic, cadmium, lead, thallium, antimony, and bismuth.

When air concentrations of chemicals are expressed in units of mass per unit volume (i.e., micrograms per cubic meter, $\mu g/m^3$), they are related to a particular temperature and atmospheric pressure. According to DRP staff, hourly measurements of sulfur dioxide and particulate matter are recorded in normal temperature and pressure (25°C and 1 atmosphere). Thus, all ambient air concentrations expressed in mass per unit volume, including future predictions, are expressed at normal temperature and pressure.

As part of the transfer from the Doe Run Company to DRP, a program of internal quality assurance and quality control (QA/QC) was established for the air monitoring systems. The QA/QC program follows USEPA guidance, and DRP personnel have been training in the implementation of the program (DRP 2002a). Currently, the sulfur dioxide monitors are calibrated once a year by an external lab and the calibration is verified monthly by DRP. The high-volume monitors used for metals in PM_{10} are calibrated by an external lab every 6 months and verified each month by DRP. The continuous PM_{10} monitors were calibrated for the first time in July 2008 (Gonzales Paredes 2008, pers. comm.).

3.1.1.3 Operations Curtailment Program

In 2003, Doe Run Peru implemented an operations curtailment program in an effort to control sulfur dioxide emissions during periods of unfavorable meteorological conditions. The operations curtailment program involves periodic suspension of various elements of the smelter operations to reduce sulfur dioxide emissions. The decision to curtail production is based on observations of specific environmental conditions identified by DRP as high, medium, and low risk.

High-risk conditions are defined as clear days with a minimum temperature of less than 3°C, a wind speed of less than 1.5 m/s, sulfur dioxide levels of greater than 2,000 $\mu g/m^3$ measured at the Huanchán station, and a plume that reaches La Oroya Antigua and beyond. On days when these conditions occur, the Complex reduces burning in the copper ovens and the Oxy Fuel stove and curtails the use of multiple copper converters. Agglomeration in the lead circuit may also be suspended.

Medium-risk conditions are defined as partly cloudy days with a minimum temperature between 3° and 6°C, a wind velocity of less than 2.5 m/s, sulfur dioxide levels of less than 2,000 $\mu g/m^3$ measured at the Huanchán station, and observations of the plume not reaching La Oroya Antigua.. On these days, one copper converter is shut down.

Only when conditions of low risk occur can all production lines of the Complex operate at full capacity. These are defined as cloudy days when the minimum temperature is greater than 6°C, wind speed is greater than 2.5 m/s, sulfur dioxide levels at the Huanchán station are measured as less than 500 μg/m^3, and the plume reaches the slag pile.

In the year 2007, total curtailment of the copper circuit converters was 3,221 hours (i.e., almost 37 percent of the time) and curtailment of the lead circuit agglomeration facility was 1,155 hours (i.e., approximately 13 percent of the time). Production line curtailments were more frequent from June through November, with the highest number of hours occurring in the month of June. However, no distinct seasonal trend can be discerned. Monthly closures are shown in Figure 3-2.

3.1.1.4 Data Quality and Completeness

All of the air monitoring data have been evaluated for quality and completeness, as described below.

Sulfur Dioxide

Each air monitoring station provides 15-minute, hourly, and daily averages of sulfur dioxide concentrations in the air. Table 3-1 shows the percentage of hours during the monitoring period (1 year) where usable data were collected (percent completeness). At every station, there were occasions when measurements were not recorded because of a mechanical failure or temporary lack of power. In some cases, zero values were recorded. These events have been treated as unusable (missing) data. Percent completeness calculations for Marcavalle, Huari, and Huaynacancha were adjusted to reflect the start of the monitoring period of each station. During 2007, all of the monitors provided results for more than 93 percent of the hours that they were in operation.

In 2005, all but one of the monitors had an upper threshold limit of 6,000 μg/m^3, resulting in a suspected underestimation of average concentrations. This limitation was remedied in 2006; the monitors at Sindicato, Hotel Inca, and Huanchán now have an upper threshold of 26,200 μg/m^3. The monitors at greater distance from the Complex have thresholds of 5,240 μg/m^3 (McVehil 2008a, pers. comm.).

Particulate Matter

Ambient air PM_{10} concentrations are monitored at all stations by two different instruments. Hourly measurements are collected using a Met One Model BAM 1020 beta attenuation monitor. Every third day, measurements are collected using a Graseby Model 1200 High-Volume Air Sampler system from which metals concentrations are recorded (discussed below). Hourly, daily, and annual averages were used in the risk assessment. Table 3-2 shows the hours of sampling data recorded the percent completeness of PM_{10} data. Percent completeness calculations for Marcavalle, Huari, and Huaynacancha were adjusted to reflect the start of the

monitoring period of each station. During 2007, all of the monitors provided results for more than 93 percent of the hours that they were in operation.

In June 2006, Doe Run Peru began monitoring $PM_{2.5}$. A 24-hour average of $PM_{2.5}$ concentration is recorded once a month at every monitoring station on different dates throughout the month.

Atmospheric Metals

As noted above, measurements of PM_{10} from a high-volume air sampler system located at each monitoring station are analyzed every third day for metals. Analysis is done by Inspectorate Services. The metals monitored include lead, arsenic, cadmium, antimony, bismuth, and thallium; the latter three metals have only been measured since February 2006. Table 3-3 shows the number of samples taken and the percent completeness of metals in PM_{10} data. Percent completeness calculations for Marcavalle, Huari, and Huaynacancha have been adjusted to reflect the start of the monitoring period of each station. During 2007, all of the monitors provided results for more than 98 percent of the hours that they were in operation. Detection limits for metals in PM_{10} vary by metal; samples in which no metal was detected were reported at the detection limit.

3.1.2 Soil Data

Small numbers of soil samples have been collected in La Oroya periodically since 2000. Data collected in 2000 and 2003 by Doe Run Peru (including 14 subsurface samples in 2000 and 14 surface samples in 2003) and in 2005 by Integral (40 surface samples and a smaller number of subsurface samples) were described in the 2005 risk assessment report (Integral 2005a).

Since March 2007, Doe Run Peru has collected soil samples every 3 months. During each sampling event, soil is collected at 24 individual locations in the communities surrounding the Complex. An area 1 meter square is measured and soil within this area is sampled from a depth of 3 to10 cm. Samples are sent to an external laboratory and analyzed for antimony, arsenic, bismuth, cadmium, lead, and thallium. In 2007, data were collected in March, October, and December. Mean values from the three sampling events, stratified by community, are provided in Table 3-4.

To obtain data more representative of surface soil to which residents will have the most direct contact, Doe Run Peru collected additional soil samples in June 2008 using the same procedures employed by Integral in 2005. A detailed explanation of sampling methods is provided in the Integral (2005b) sampling and analysis plan. Twenty-three locations were sampled from the communities surrounding the smelter. At each location, both surface and subsurface samples were collected. The surface samples were collected from a depth of 0 to 2 cm, and the subsurface samples were collected from a depth of 2 to 10 cm. These samples were analyzed for antimony, arsenic, bismuth, cadmium, copper, mercury, lead, selenium, silver, thallium, and zinc. A summary of these data are found in Tables 3-5 and 3-6.

All soil samples collected by Doe Run Peru in 2007 and 2008 were considered for inclusion in the risk assessment. These samples were also compared with the data collected in 2005 to assess changes in contaminant concentrations over time. A work plan prepared by Activos Mineros (GWI and Intrinsik 2007) indicates that additional soil samples were collected during 2008. However, the results of that sampling effort were not available for consideration in this complementary risk assessment.

3.1.3 Dust Data

Since 2003, dust samples have been collected in La Oroya by several parties. The 2005 risk assessment reviewed data collected through June 2005, including 40 outdoor dust samples and 37 indoor dust samples collected by Integral in 2005 (Integral 2005b). In contrast with soil concentrations, which are not expected to change much over time, dust concentrations rapidly reflect changes in deposition of dust particles from the air. Consequently, older dust data are not reflective of current conditions in La Oroya, and were not considered in this complementary risk assessment.

Analytical results for dust samples are available from several more recent studies in La Oroya. As described in the exposure pathway model, residents of La Oroya are expected to contact metals-laden dust on floors and surfaces inside their homes as well as outside surfaces including sidewalks, playgrounds, and other paved areas. Several approaches may be used to assess metals in dust:

- One method is to wipe a specified area with a cloth or gauze, and then measure the amount of metal on the fabric. Results for such wipe samples are reported in terms of loading or the amount of metal per unit of area (for example, μg metal/m^3).
- Another approach is to leave containers at an outside location for a specified time period, and then analyze the dust that has collected in the container. This approach provides information on the contribution of airborne particulates to metals in surface dust.
- A third approach is to outline an area on the floor or outdoor surface and use a brush to sweep the surface dust into a container. These results are reported as the concentration of the metal in the dust (for example mg metal/kg dust).

The third approach was used in both the 2005 risk assessment and the complementary risk assessment. Data from all three approaches are reviewed below.

As a part of ongoing monitoring efforts, the Convenio collected indoor and outdoor dust from selected homes and community areas in December 2006, May 2007, and March 2008. In 2006 and 2007, dust wipe samples were collected from 14 residences. In 2008, the study was expanded to 25 homes, 2 schools, and 2 market areas. Sampling methods were in adherence with American Society of Testing and Materials method ASTM E-1792-03, *Standard Specification*

for Wipe Sampling Materials for Lead in Surface Dust. Wipe samples of 1 square foot were collected from floors, walls, and windowsills of a room within the home. They were sent to the Inspectorate Services laboratory and analyzed for metal content using USEPA sample preparation and analytical methods. Additional samples were taken directly outside the home. Indoor data from May 2007 and March 2008 reported as metal concentration in dust were considered for use in the risk assessment. Data from the 2006 study were not included, as the sampling followed too soon after significant operational changes at Complex to have reflected the effects of emissions reductions.

Starting in January 2007[4], DRP has also collected a monthly dustfall sample using the method prescribed by the Pan American Health Organization. Small buckets (20 cm diameter x 25 cm height) are used to collect the 30-day dustfall, which is then washed, evaporated, and weighed. Samples are sent to an external laboratory for metals analysis by inductively coupled plasma–mass spectrometry. These data are useful in understanding changes in metals in dustfall over time, but are not representative of the surface dust to which residents are exposed. Consequently, these data were not used in the exposure assessment.

In order to maintain consistency with the data used previously, DRP collected 23 outdoor dust samples in June 2008 using the same procedures employed by Integral (Integral 2005b) in 2005. A summary of these data is found in Table 3-8.

3.1.4 Drinking Water Data

The drinking water for the communities surrounding the smelter comes from a variety of sources and is not thought to be a major pathway for exposure to heavy metals (Integral 2005a). Drinking water is monitored every 6 months by Doe Run Peru at 13 sampling sites. ENVIROLAB, an external company, collects data on standard water quality parameters such as pH, turbidity, and dissolved oxygen, as well as fecal coliform bacteria. Metals concentrations are measured at four water supply sources: Toma Rio Tishgo, Reservorio Chulec, Reservorio Cushurupampa, and Reservorio Rail Way. Data from these four sources were screened for inclusion in the risk assessment.

The Convenio also completed a study in October 2007 to monitor water quality and determine metals concentrations, comparing the results with maximum permissible limits established by the National Superintendent of Sanitation (SUNASS)[5]. Nineteen sites were selected to be tested for 29 metals by Inspectorate Services. These data were also screened for inclusion in the risk assessment. A data summary of the metals of concern is found in Table 3-9.

[4] Data were not collected in February 2007.
[5] SUNASS is the National Superintendent of Sanitation Services (Superintendencia Nacional de Servicios de Saneamiento) in Peru. SUNASS is the national regulator of water quality in Peru; standards established by the Superintendent are reflective of WHO guidelines.

3.1.5 Blood Lead Data

Since the last risk assessment was completed, regular blood lead monitoring has occurred in La Oroya. Samples have been collected each November from 1,000 to 2,000 children in the communities surrounding the Complex, with fewer children also sampled each May. These studies include children ranging in age from birth to 10 years old, though monitoring of children older than 6 years has occurred less frequently. Pregnant women are also included in the annual studies. Significant changes in children's blood lead levels have occurred since 2004. A comparison of annual mean blood lead levels by age group is shown in Figure 3-3. Table 3-10 summarizes the blood lead data from 2004 to 2007.

In November 2007, Doe Run Peru contracted Blufstein Clinical Laboratory S.A. (Blufstein) to conduct blood lead testing in the communities surrounding the Complex. In this study, blood was drawn from 1,877 children between the ages of 6 months and 10 years. One hundred and five pregnant women were also evaluated for blood lead at this time. Summary results for children from birth to 6 years are presented in Table 3-11. Only a small number of children over 6 were sampled in this study (71 total). Given the paucity of data for older children and the fact that the model used in this study is designed for children under age 7, these data were excluded from the quantitative analysis.

The Centro Nacional de Salud Ocupacional y Protección del Ambiente para la Salud (CENSOPAS) expressed concerns over the quality of the data generated by Blufstein. Integral has reviewed these concerns carefully and evaluated the data and documentation provided by Blufstein; it was determined that the data are of sufficient quality for use in risk assessment.

3.1.6 Food and Diet Data

In May 2005, the Instituto de Investigacion Nutricional (IIN) completed a preliminary diet study in La Oroya Antigua to evaluate the dietary intake of iron, calcium, zinc, and lead of 11 mothers and 15 children between the ages of 12 and 36 months. A follow-up study with a larger sample size was recommended to identify the mechanisms by which lead and other metals are transferred to prepared foods. The Convenio designed an expanded study (Diaz et al. 2007) that was conducted in April 2008. The primary goals were threefold:

- To confirm the critical nutritional issues that might affect the health status of the population also exposed to high levels of metals from the Complex
- To identify ways to reduce metals exposures via the diet
- To quantify lead, arsenic, and cadmium concentrations in duplicate diet samples from communities affected by smelter emissions.

The study included 1,200 children under 3 years and 204 pregnant women living in three districts around La Oroya (La Oroya, Santa Rosa de Sacco, and Paccha) (Vargas-Machuca 2008).

The methods are described in detail by Vargas-Machuca (2008). The results are summarized below.

3.1.6.1 Consumption of Nutrients

The 2008 study measured the dietary consumption of energy, protein, iron, zinc, calcium, and vitamin C. Iron intake was confirmed to be low in both women and children. Reported median intakes as a percentage of the recommended daily intake are approximately 50 percent for children and 21 percent for pregnant women (Figure 3-4). Inadequate intakes were also found in IIN's pilot study, as well as other studies carried out in Peru (IIN 2005). A higher recommended daily intake was used in this study compared with the pilot study (11.6 mg/day rather than 6 mg/day for children). This change was the result of assuming a dietary iron bioavailability of 5 percent rather than 10 percent. Consequently, the mean intakes as a percent of recommended values is lower than found previously (Figure 3-5). Iron intake is markedly low in pregnant women, even in the upper quartile; no woman had intake above 40 percent of the daily recommended value and approximately three-quarters of this group consumed 25 percent or less of the recommended intake (Figure 3-4). A few children were found to have acceptable intake (Figure 3-4). Additionally, intake of heminic iron, the highly bioavailable form found in meat, fish, and poultry, was low. Less than 20 percent of dietary iron was of animal origin. This percentage is about twice that found in the IIN pilot study.

Zinc intake was near the recommended values, although consumption was lower in children than in pregnant women (Figure 3-6). For these two groups, the median intake as a percentage of the recommended daily intake is approximately 80 percent for children and 95 percent for adults (Figure 3-7), assuming a moderate dietary zinc bioavailability for both groups. More than one-quarter of each group had acceptable zinc consumption. These results are consistent with the findings of the IIN study[6] although the median daily zinc intake for women was found to be much lower in the current study than in the pilot study (Figure 3-6). The pilot study also found that dietary zinc was higher than expected based on diet type, and suggested that environmental pollution may have contributed to zinc intake. The current study did not test this theory, although it did confirm aspects of the diet type in that both studies found approximately 40 percent of the zinc to be of animal origin. This is an important determinant of bioavailability, as zinc of animal origin is more readily absorbed into the body.

Although consumption frequency analysis indicates that about two-thirds of children and about one-third of pregnant women consume dairy products on a daily basis, calcium intake is moderate in children and low in pregnant women. The median intake as a percentage of the recommended daily intake is around 60 percent for children. Approximately 25 percent of children had sufficient calcium intake (Figure 3-8). For pregnant women, the median intake as a

[6] The 2007 study used a lower recommended daily intake zinc value for women because the dietary zinc bioavailability was assumed to be moderate rather than low, as was assumed by the pilot study.

percentage the daily recommended intake was much lower: approximately 30 percent. No women had an intake meeting the recommended daily value (Figure 3-8). These results are much lower than those of the IIN pilot study.[7] The median calcium intake in women is less than half of what was found in the pilot study and the median intake in children is approximately 35 percent lower than the previous results (Figure 3-9).

Consistent with IIN results, protein consumption was found to be adequate. This is especially true in children; few individuals had a daily intake below the recommended value (Figure 3-10). The median intake as a percentage of the recommended daily intake is around 90 percent for pregnant women.

Vitamin C intake is also generally acceptable, with a median intake as a percentage of the recommended daily intake of approximately 70 percent for both pregnant women and children. More than 25 percent of each group exceeded the recommended daily value (Figure 3-11). Again, this is consistent with the pilot study results.

3.1.6.2 Intake of Lead, Arsenic, and Cadmium

Lead, arsenic, and cadmium concentrations were determined in food samples representing all of the foods consumed during a single day by 99 pregnant women and children younger than age 3. These metals were also measured in 19 samples of maternal milk. In all samples, lead and cadmium concentrations were below the reported analytical detection limits of 0.039 mg/kg and 0.009 mg/kg, respectively. In comparison, the IIN study reported that lead was below a detection limit of 0.05 mg/kg in food samples from 6 of 11 mothers, 5 of 15 children, and all maternal milk samples. This comparison suggests that lead concentrations in food in La Oroya have been reduced since 2005. For 2008, using one-half the detection limit as the estimated concentration, mean lead intake was estimated to be 39 μg/day in pregnant women and less than 4 μg/day in young children. For cadmium, mean intake was estimated to be 9 μg/day in pregnant women and 16 μg/day in young children. Arsenic was present above its analytical detection limit in 28 food samples and 9 maternal milk samples. Mean arsenic intake was estimated to be 10 μg/day in pregnant women and 4 μg/day in young children.

It is important to note that the arsenic intakes represent total arsenic and only a small fraction of the total is likely to be inorganic arsenic. Much of the arsenic in foods is organic forms that have very low toxicity and are not included in this risk assessment.

3.1.6.3 Practices Contributing to the Ingestion of Metals

In order to identify the pathways that may contribute to increased ingestion of metals, this study examined in-home practices related to food consumption using a questionnaire and direct

[7] The current study did use a higher recommended daily intake value for women (1,200 mg/day rather than 1,000 mg/day) because, unlike the previous study, these women were pregnant.

observation. The findings identified inadequacies that may increase exposures in many households in storage of food, water, and utensils; washing of food, hands, and utensils; and floor and ceiling conditions.

Improperly stored water, food, and cooking utensils can accumulate contaminated dust, which can lead to ingestion of heavy metals when the food is consumed. Although most of the homes surveyed had access to a public water system either inside or outside the home, at least half of the households store water in buckets or other portable containers; up to a quarter of these containers were not protected from dust.

Storing cooking utensils in closed cupboards, drawers, or other containers protects them from contaminated dust. Approximately 15 percent of homes do not protect any of their kitchenware in this way, while half of homes have at least some items unprotected.

Foods that are not stored in covered containers are exposed to contaminated dust. This study found uncovered vegetables in at least 70 percent of homes and uncovered fruits and meats in approximately 40 percent of homes. When interviewed about food preparation, approximately 80 percent of women claim to wash vegetables while only a few wash fruits or meats. Prior to food preparation, less than 20 percent of women rewash cooking utensils and very few clean surfaces used for food preparation.

The study investigated hand-washing practices, as hand-washing is a good way to remove contaminated dust before it can be transferred to the mouth, nose, or food and subsequently ingested. According to the questionnaires, approximately 75 percent of women wash their hands prior to cooking, and about half wash their hands before feeding themselves or their children. Few women wash their hands after activities that expose them to high amounts of dust, such as handling garbage, cleaning, or shopping. Despite the fact that almost all mothers claimed to wash their children's hands before eating, only half of mothers in the direct observation subsample washed their children's hands during the 12-hour observation period. Few mothers reported washing children's hands after they play, when exposure to contaminated dust is high.

The study also observed floor and ceiling status, factors that affect the quantity of dust exposure inside the home with increased impact on uncovered food, dishes, and cooking surfaces. As dirt and unpolished cement floors collect dust and are difficult to clean, they are not considered protective of human health. Approximately 40 percent of homes did not have a suitable floor. Lack of a complete ceiling increased exposure of food preparation and eating areas to contamination in approximately 20 percent of homes.

Exposure to heavy metals can also occur through ingestion of animals raised in contaminated areas. This study found that one-third of homes surveyed raised small animals, mainly for self-

consumption. Of these homes, about half consume the animal viscera, which contain elevated concentrations of heavy metals.

In addition to the large-scale study described above, the Convenio conducted a study in September 2007 in which lead, cadmium, and arsenic were analyzed in 12 local food samples (Inspectorate 2007). These results are summarized in Table 3-12 and were considered in the risk assessment.

The results of these studies were used to estimate dietary intake of lead; diet data for arsenic and cadmium were considered qualitatively. The results of the diet study were also used to update recommendations regarding ways to moderate the health effects of lead and other metals by improving nutritional status. Finally, the results of the study provide a basis for recommendations regarding ways to reduce metals intake from the diet.

3.1.7 Worker Morbidity and Mortality Data

The Terms of Reference specifies that an assessment of worker morbidity and mortality be conducted. This assessment used the data described below and is provided in Appendix C.

Integral was provided with data for worker morbidity and mortality from several sources. Essalud, the government health service, provides medical services to Doe Run Peru workers who have health concerns. A list of the most common pathologies seen in the Essalud clinic has been provided. Because of confidentiality concerns, these data are tabulated by visit rather than by patient. Consequently, these data give only a general sense of common complaints among workers at the Complex, and do not provide a context for how many workers become ill or how illnesses might be distributed among job category.

The most useful source of morbidity information comes from the required annual physical examination of all workers conducted by Doe Run Peru. In 2007, 2,759 workers were evaluated. Of these, 678 were diagnosed with some form of illness or injury. The data from the annual examination have been used to describe trends in morbidity among workers. Mortality data from 2007 were also provided, as were summary data of blood lead, urinary arsenic, and urinary cadmium of exposed workers.

3.2 AIR MODELING ACTIVITIES

In 2005, McVehil-Monnett Associates, Inc. (MMA) performed air quality modeling analyses using the CALPUFF model to help Doe Run Peru identify and control air emissions and predict future air concentrations for use in the risk assessment (MMA 2005). The model was designed to simulate atmosphere transport and dispersion of smelter emissions in order to define ground-level pollutant concentrations on an hour-to-hour basis at monitoring stations and points of potential human exposure. In 2005, the report concluded that "the model has skill at

reproducing the complex meteorological and dispersion processes at La Oroya, but improvement is necessary if the model is to be of optimum use for future predictions of impacts within the modeled area" (MMA 2005). The 2005 modeling report made a number of recommendations for improvement of modeling capability:

- Use of the DRP Doppler Acoustic Sounder to acquire continuous measurement of winds and temperatures in the Mantaro Valley near La Oroya from ground level to above stack height
- Installation of additional ground-level meteorological and air quality monitoring stations
- Acquisition and use of measured precipitation and cloud data
- Expansion of the modeling domain (area) to distances of at least 20 km from La Oroya
- Improvement in the quantification of pollutant emissions from the La Oroya smelter and other local sources.

In addition, the TOR for the update of the air model called for the following enhancements:

- Utilization of meso-scale model (MM5) predictions to improve the specification of regional meteorological conditions for dispersion model (CALPUFF) input
- Expansion of the model domain to greater distances from La Oroya.

Although a Doppler Acoustic Sounder was installed by Doe Run Peru in 2005, the technology failed to provide reliable data despite continued efforts on the part of the supplier and other consultants. The failure may be related to the high elevation of La Oroya, as well as the noise-intensive environment of the smelter (MMA 2008b). Another attempt to obtain vertical sounding data was made with a tethersonde (an instrumented tethered balloon), but this effort also failed because strong downdrafts prevented the rise of the balloon to sufficient altitude. Finally, in September 2006 a meteorological monitoring station was installed at Cerro Somi at an elevation of 3,936 meters in an effort to obtain wind and air temperature measurements above the Mantaro Valley; however, these data did not prove adequate to model vertical motions and wind/temperature structure above the valley (MMA 2008a).

The MM5 model was acquired so that input data to CALPUFF could be more specific and subsequently provide more accurate predictions. However, MMA was not able to estimate weather conditions at a finer scale of resolution than the data provided by the U.S. National

Weather Service[8]. After a number of attempts, the supplier of the MM5 data informed MMA that available data for the La Oroya area were not adequate for MM5 modeling.

Because of these difficulties and poor predictions in the initial model simulations, MMA requested a time extension and conducted further model development. The following empirical model enhancements considerably improved the model performance (MMA 2008a):

- Application of a building wake model to account for the severe downwash associated with the steep terrain around the smelter
- A decrease in the assumed buoyancy of roof vent fugitive emissions
- Addition of a constant background concentration to reflect the pollutant trapping that occurs in the valley
- Application of a linear reduction in concentrations above the 95th percentile for the Sindicato, Hotel Inca, and Marcavalle monitors.

With these enhancements, excellent agreement was achieved for annual average concentrations of SO_2 at the four monitoring stations closest to the smelter. Day-to-day predictions were not judged to be as reliable as the annual average predictions. Predictions for the stations farther away (at Casaracra, Huaynacancha, and Huari) were also less accurate.

Future predictions of sulfur dioxide, lead, arsenic and cadmium air concentrations were developed using DRP estimates for smelter emissions for the time period after the completion of pollution control projects in November 2009. DRP plans to increase the stack height to 180 meters and install a nozzle, reducing the stack diameter to 10 meters. Additionally, it is expected that stack gas flow and temperature will be reduced in the future. These anticipated changes were incorporated into the predictive model. Due to limitations in the model, predictions provided by MMA were used to calculate future risks only for the communities in close proximity to the Complex (i.e., La Oroya Antigua, La Oroya Nueva, and Marcavalle/Chucchis).

The model capability varies with pollutant because of the differing characteristics of the contaminants of concern. For sulfur dioxide, the model provides predicted annual averages, 24-hour average highs, and 1-hour average highs for the time period after 2009. These results are found in Table 3-7. Predictions of lead concentrations have also been provided as an annual average, highest monthly average, and 24-hour high after November 2009. These predictions are shown in Table 3-13. Contributions to the ambient air from sources other than the smelter made it especially challenging to predict particulate matter concentrations and MMA was not able to provide predictions for particulates.

[8] The National Weather Service data were provided with a one-degree spacing of latitude and longitude.

3.3 CHEMICALS TO BE EVALUATED

As described in Section 2, the Complex produces 11 metals from concentrate. It is likely that all of these metals plus additional contaminants are released from the Complex. In this section, a risk-based screening process is used to identify chemicals present in sufficient concentrations to be included in the risk assessment. Following identification of these chemicals, exposure point concentrations were calculated for use in the exposure assessment (Section 4).

Available environmental data were evaluated to identify chemicals for inclusion in the risk assessment using the maximum detected concentration of each potential chemical of concern. Chemicals not likely to contribute significantly to overall risks related to the Complex were eliminated from further quantitative evaluation in this risk assessment using the following criteria (USEPA 1989):

- Low frequency of detection in a given exposure medium
- Evidence that the chemical is not associated with the operations at the site
- Classification as an essential nutrient (e.g., iron, calcium)
- Chemical concentrations below applicable risk-based screening criteria

The chemicals that pose the greatest health risk at copper, lead, and zinc smelters have been identified in previous risk assessments in the U.S., Canada, and La Oroya as lead, arsenic, cadmium, sulfur dioxide, and particulates in air. Additional chemicals associated with Complex activities considered in the initial screening included antimony, bismuth, copper, selenium, silver, thallium, zinc, and mercury.

The maximum detected concentration of each of these metals in air, water, outdoor dust, indoor dust, and surface soil samples collected in 2007 and/or 2008 was compared to its corresponding risk-based criterion. Risk-based screening criteria represent health protective concentrations based on exposure assumptions intended to represent high-exposure conditions. If the maximum detected concentration exceeded the risk-based criterion, available data for that metal and that medium were evaluated as part of this risk assessment. To better understand the relationships between exposures to metals in soil, indoor dust, and outdoor dust, any metal that exceeded its criterion in one of these media was also included in the evaluation of the other two media. For all media screened, this comparison was conducted using the maximum detected concentration of each metal for all community data without regard to individual communities (i.e., La Oroya Antigua, La Oroya Nueva, Marcavalle, Chucchis, Huaynacancha, Casaracra, and Huari).

Chemicals of Potential Concern (COPCs) were eliminated from further quantitative risk assessment if they were present at levels below the risk-based screening criteria. Sample concentrations below screening criteria are not expected to result in unacceptable risks. A

summary of metals screening results for each medium are provided in Tables 3-14 through 3-18. Chemical screening criteria for metals in all media are provided in Table 3-19.

Metals with a low frequency of detection were also eliminated from further evaluation if the detection limit was less than the corresponding screening criterion for that metal.

After the screening was completed, exposure point concentrations (EPCs) for each metal retained for each medium were derived for use in the quantitative risk evaluation. An exposure point concentration is the amount of a chemical that will be contacted by people over the period of exposure being evaluated. EPCs are usually estimated from air, soil, dust, or water sample results taken in locations where people will contact the chemical. EPCs may also be estimated by using chemical dispersion and deposition models to predict concentrations. For this risk assessment, monitoring and sampling data were used to estimate EPCs for current exposures, and outputs from the dispersion and deposition model were used to predict EPCs for future exposures.

Exposure point concentrations were derived for either all of the communities as a whole or for individual communities, depending on data adequacy. Where data were adequate, ProUCL software issued by the USEPA (Version 4.0) was used to calculate the upper 95th percentile confidence limit of the mean based on the appropriate statistical distribution. The lower of either the maximum detected concentration or the upper confidence limit of the mean for each metal was selected as the EPC for use in the quantitative risk assessment. If data were not adequate for distribution fitting, the maximum detected concentration for that neighborhood was used as the exposure point concentration. The summary statistics, including upper confidence limit of the mean, for each chemical are provided in Tables 3-14 through 3-18.

Details of the data screening and exposure point concentration derivation process and results for each medium are described below.

3.3.1 Chemicals in Air

Inhalation of sulfur dioxide, particulates, lead, arsenic, and cadmium was evaluated in the 2005 risk assessment. As described above, three additional metals—antimony, bismuth, and thallium—have been measured in air monitoring data since February 2006. In 2007, all of the monitors provided results for all six of these metals for more than 98 percent of the hours that they were in operation. The screening process for antimony, arsenic, bismuth, cadmium, lead, and thallium is described below.

The highest detected concentration in air reported for each metal among all six of the air monitoring stations evaluated was screened against risk-based criteria developed by USEPA (2005b), shown in Table 3-14. The air monitoring data, which were provided by Doe Run Peru, consist of antimony, arsenic, bismuth, cadmium, lead, and thallium concentrations in PM_{10}

samples (i.e., samples of particles less than 10 microns in diameter) that were collected every 3 days from the Sindicato de Obreros, Hotel Inca, Marcavalle, Casaracra, Huari, and Huaynacancha monitoring stations during the year 2007. For arsenic, cadmium, lead, bismuth, and thallium, the highest concentrations were reported for the Sindicato monitor. For antimony, the highest concentration was detected at the Marcavalle monitor. The screening criteria for antimony, arsenic, and cadmium are unit air concentrations selected from the USEPA's Integrated Risk Information System (IRIS) (2005a) that correspond to a cancer risk level of 1×10^{-6} for an adult with a mean body weight of 70 kg and inhalation rate of 20 m^3/day.

Risk-based screening criteria for bismuth and thallium were not available. However, in 2008, the Peruvian government proposed ambient quality standards for these metals and these proposed standards were used for screening purposes (CONAM 2008b). Based on these standards, thallium was retained as a chemical of potential concern for further evaluation in the risk assessment but bismuth was not. The ambient quality standards proposed also include values for arsenic (0.006 ug/m^3), cadmium (0.05 ug/m^3), and antimony (0.2 ug/m^3) (CONAM 2008b). The proposed standards for arsenic and cadmium are higher than the risk-based screening concentrations applied in this update, but were still exceeded by respective maximum detected concentrations in air at the site. The proposed standard for antimony is identical to the risk-based concentration used in this assessment.

The screening criteria for arsenic (2×10^{-4} μg/m^3) and cadmium (6×10^{-4} μg/m^3) were exceeded at all six stations. The screening criterion for antimony (0.2 μg/m^3) was exceeded at each station except Huaynacancha.

Upper confidence limits of the mean for each metal at each station were calculated based on data for that station. For all metals at all stations, the maximum detected concentration was greater than the calculated upper confidence limit of the mean. Therefore, the upper confidence limits of the mean were selected as the exposure point concentrations for use in the risk assessment.

3.3.2 Chemicals in Surface Soil

As described previously, new soil data were collected in March, October, and December 2007 and in June 2008 for the communities around the smelter. Maximum detected concentrations from each of these data sets were initially screened against risk-based criteria as summarized in Table 3-20. Risk-based screening criteria for metals in surface soil were obtained from USEPA regional screening level tables (2008) and are based on exposure to chemicals in soil and dust that is ingested unintentionally. These criteria do not consider intentional ingestion of large quantities of soil (referred to as pica for soil). This issue is addressed in the Uncertainty Evaluation in Section 6.5. The screening criteria correspond to either a hazard quotient of 1 for noncarcinogens or risk level of 1×10^{-6} for carcinogens. A reliable screening criterion was not available for bismuth. Oral toxicity data for bismuth are also currently not available, but

because toxicity is expected to be low, bismuth was not retained for further evaluation in this complementary risk assessment[9].

Antimony, arsenic, cadmium, and lead exceeded the respective risk-based criteria in all four sets of data. Copper also exceeded the criterion in the 2008 data, but was not reported in the 2007 data. The copper screening criterion for incidental ingestion of soil was derived by converting the U.S. drinking water standard to an oral reference dose. The drinking water standard for copper is based on the occurrence of transient stomach irritation, and is not directly applicable to exposure to copper in media other than water. Because of its low toxicity and the uncertainty associated with a soil screening criterion based on a drinking water standard, copper was retained as a chemical of potential concern but is discussed as an uncertainty in this risk assessment (Section 6.5).

Statistical comparisons (two-tailed t-tests) of the metal concentrations in the 2008 surface and subsurface samples for each sample location revealed no statistically significant differences between metal concentrations at each sample location for the two depth horizons (Table 3-20). Statistically significant differences were evident for cadmium between the 2007 data and the 2008 data as shown in Table 3-20. Despite the absence of statistically significant differences between the June 2008 surface (0-2 cm) and subsurface (2-20 cm) samples collected by Doe Run Peru, only the surface data were used in the quantitative risk assessment update. Data from recent surface soil samples were selected for use in the risk assessment because residents are expected to have the greatest contact with surface soils; however, the similarity in metal concentrations between surface and subsurface soil suggests that both are of reflective of long-term impacts from smelter emissions. The 2008 surface soil samples collected by Doe Run Peru in June 2008 used the same procedures employed by Integral in 2005. Data for antimony, arsenic, cadmium, copper, and lead from this data set were used in the quantitative risk assessment update.

The upper confidence limits of the mean metal concentrations for the five metals that exceeded risk-based screening criteria for surface soil (0-2 cm depth) are provided in Table 3-17. Summary statistics by community are also provided for each metal in this table. Sufficient data were available for La Oroya Antigua to calculate neighborhood-specific upper confidence limits of the mean metal concentrations. These values were used as the exposure point concentrations for this neighborhood. Elsewhere, sample sizes were too small to calculate neighborhood-specific upper confidence limits of the means; the maximum detected concentration for each metal in the neighborhood was selected instead as the exposure point concentration.

[9] Bismuth is widely used as a medicine including in preparations to treat diarrhea.

3.3.3 Chemicals in Outdoor Dust

Outdoor dust data used in the screening were collected by Doe Run Peru in June 2008 at the same locations where soil was sampled. As described above, the Convenio also collected indoor and outdoor dust samples in 2007 and 2008. Outdoor dust samples collected in May 2007 and March 2008 by the Convenio were also considered in initial screening; all chemicals of concern that would have been identified from this data set were identified from the Doe Run Peru outdoor dust data.

Review of the Convenio data revealed an inconsistency between the 2007 and 2008 results. In most studies of indoor and outdoor dust, the indoor dust metal concentrations are much lower than the outdoor values. This pattern was apparent in the 2007 Convenio dust data. As shown in Table 3-21, however, the 2008 Convenio dust data exhibit the opposite pattern, with indoor metals concentrations higher than outdoor concentrations. There is no apparent explanation for these differences, which creates some concern regarding data quality of the 2008 Convenio data. Because of the unexplained inconsistencies, screening and quantitative risk evaluation was limited to the outdoor dust data collected by Doe Run Peru in June 2008.

In the 2008 outdoor dust data, only antimony, arsenic, cadmium, copper, and lead exceeded risk-based criteria. Risk-based screening criteria applied to surface soil were also used for screening dust and the same limitations and uncertainties discussed for soil also apply to dust. The chemicals of potential concern for outdoor dust were identical to those screened in for surface soil.

The upper confidence limits of the mean concentrations for these five metals are provided in Table 3-15. Sufficient data were available for La Oroya Antigua to calculate neighborhood-specific upper confidence limits of the means. These values were used as the exposure point concentrations for this neighborhood. Elsewhere, sample sizes were too small to calculate neighborhood-specific upper confidence limits of the means; the maximum detected concentration for each metal in the neighborhood was selected instead as the exposure point concentration. Summary statistics for each of these metals are also provided in Table 3-15.

3.3.4 Chemicals in Indoor Dust

Household dust samples collected in May 2007 and March 2008 by the Convenio were used for screening chemicals of potential concern in indoor dust. No other indoor dust data were available. As described above, the March 2008 indoor dust data are higher than expected relative to the paired outdoor dust data (see Table 3-21). Nevertheless, to ensure adequate representation of the range of indoor dust metals concentrations, both the 2007 and 2008 data sets were used for screening and derivation of exposure point concentrations. Inclusion of the March 2008 indoor dust data is expected to cause a high bias in the indoor dust exposure

estimates, but this bias was judged to be preferable to relying solely on the small May 2007 data set.

As noted in Table 3-16, one sample in La Oroya Antigua—the March 2008 indoor dust sample from Escuela Antonio Encinas—was identified as an outlier for metals concentrations and removed from the data set. There is no known explanation for this extreme sample, but its removal reduces uncertainty in the data set and improves the representativeness of the calculated upper confidence limits of the mean concentrations.

Based on screening of maximum detected metal concentrations for all community data against the same risk-based criteria applied to surface soil and outdoor dust, five metals were retained for further quantitative evaluation in the risk assessment: antimony, arsenic, cadmium, copper, and lead. As noted for outdoor dust, the limitations and uncertainties of the soil screening criteria also apply to dust. The chemicals of potential concern for indoor dust were identical to those screened in for surface soil. The upper confidence limits of the mean metal concentrations for these five metals are provided in Table 3-16. Summary statistics by community are also provided for each metal. Sufficient data were available for La Oroya Antigua to calculate neighborhood-specific upper confidence limits of the mean metal concentrations. These values were used as the exposure point concentrations for this neighborhood. Data for all other communities were combined to derive summary statistics. Upper confidence limits of the mean for these "other communities" were applied in the quantitative risk assessment as exposure point concentrations for each individual neighborhood (other than La Oroya Antigua).

3.3.5 Chemicals in Water

Maximum concentrations of metals in water samples collected by the Convenio in 2007 and by Envirolab on behalf of Doe Run Peru in 2008 were compared to risk-based screening criteria for drinking water as summarized in Table 3-18. Available sample data from these two sources included antimony, arsenic, cadmium, copper, lead, mercury, selenium, thallium, and zinc. SUNASS[10] limits were used to screen arsenic, cadmium, copper, lead, mercury, and selenium. USEPA maximum contaminant levels were used to screen antimony and thallium. For zinc, the USEPA risk-based criterion in tap water was used. Only arsenic and antimony exceeded screening levels. Both chemicals were detected infrequently. All of the detected arsenic (4 of 19 samples) was found in samples from La Oroya Antigua, as were the two samples in which antimony was detected. However, the detection limit for antimony in all communities exceeded the screening level.

[10] Values for cadmium and mercury are from 1995 WHO guidelines. Values for copper, lead, arsenic, and selenium are from the Peruvian national law, "Reglamento de Requisitos Oficiales fisicos, quimicos, y bacteriologicos que deben reunir las aquas de medida para ser consideradas potables," 1946.

3.3.6 Chemicals in Diet

As described above, the diet study conducted by the Convenio included evaluation of lead, arsenic, and cadmium, but dietary intakes were quantified only for lead. Lead was not detected in any of the duplicate diet samples; as specified in the work plan (Diaz et al. 2007), one-half the detect limit was used to estimate intakes.

4 EXPOSURE ASSESSMENT

In this section, adult and child exposures to chemicals are calculated for all exposure pathways identified as important for current and future releases from the Complex. This exposure assessment relies on the exposure pathway analysis presented in Section 2 and the data evaluation conducted in Section 3. The data evaluation included a risk-based screening process that yielded lists of chemicals to be analyzed for each exposure medium. Once the chemicals were identified, exposure point concentrations were calculated. An EPC represents a conservative estimate of the chemical concentration available from a particular medium or route of exposure.

Inhalation exposures were quantified for sulfur dioxide, airborne particulates, lead, arsenic, cadmium, antimony, and thallium. Ingestion exposures were quantified for metals in soil, outdoor dust, indoor dust, drinking water, and food. Three approaches were used to estimate exposures and risks:

- For sulfur dioxide and airborne particulates, inhalation exposures were assessed by comparing concentrations in air directly with air quality criteria or health-protective reference concentrations. In this case there was no need to calculate a dose or intake of the chemical.
- Lead exposures and risks were assessed using toxicokinetic models in which lead concentrations in the blood are predicted from estimated doses of lead received from soil, dust, diet, drinking water, and air.
- Exposures for metals other than lead were assessed by estimating the average daily dose or intake in milligrams per kilogram of body weight. These doses were then compared with known toxic doses.

Intake or dose refers to the amount of a chemical that enters the body. Chemical-specific intakes for each exposure pathway were estimated using equations that incorporate five factors in addition to the EPC:

- Contact rate—the amount of water, food, dust, or air that a person may take into the body (i.e., drink, eat, breath, or contact with skin) over a specified time
- Exposure frequency—how often a person could be exposed to the chemical
- Exposure duration—how long a person could be exposed to the chemical
- Body weight—the typical mass (in kilograms) for each age group of people who may be exposed
- Exposure averaging time—the time (in days) over which exposure is averaged.

Intake is estimated by the following equation:

$$\text{Intake}\,(\text{mg/kg}\cdot\text{day}) = \frac{\text{C}\times\text{CR}\times\text{EF}\times\text{ED}}{\text{BW}\times\text{AT}}$$

Where:

C	=	chemical-specific exposure point concentration (mg/kg)
CR	=	contact rate (mg/day)
EF	=	exposure frequency (days per year)
ED	=	exposure duration (year)
BW	=	body weight (kg)
AT	=	averaging time (days)

One goal of the exposure assessment is to identify the range of exposures from typical to highest likely. As described in Section 5, for sulfur dioxide, particulates, and some metals, exposure factors were considered during the development of air quality standards expected to protect even the most sensitive members of the population. For lead, the range of exposures was assessed by models that generate a distribution of blood lead levels, whereas for other metals, the range was assessed by selecting several point estimates of exposure parameters.

The following sections describe the specific approaches used for sulfur dioxide and particulates, lead, and other metals.

4.1 ASSESSING EXPOSURES TO SULFUR DIOXIDE AND PARTICULATE MATTER

Air monitoring data were used to estimate exposure point concentrations from which to describe current exposures to sulfur dioxide and particulates in ambient air. The potential health effects of exposure to sulfur dioxide and particulates are assessed by comparing measured air concentrations with air quality standards. To be consistent with air quality standards, EPCs for short-term exposures to sulfur dioxide and particulates were based on the second highest 24-hour concentration reported during 2007 at each monitoring station, and EPCs for chronic exposures were based on annual average air concentrations. Results of the air modeling analysis (see Section 3.2) were used to predict changes in sulfur dioxide concentrations after 2009 as operational improvements are implemented at the Complex.

4.1.1 Sulfur Dioxide

The 2007 annual average and the second highest daily average concentration of sulfur dioxide for each of the six monitoring stations relevant for this risk assessment are summarized in Table 4-1. These values were used to characterize potential risk under current conditions. To provide a context for evaluation of the 2007 data, Table 4-1 presents comparable data for the years 2005, 2006, and 2008.

As shown in Table 4-1, the greatest average concentrations of sulfur dioxide in 2007 were measured at Sindicato and the lowest average concentrations were measured at Casaracra. Annual average sulfur dioxide levels have increased at four stations since 2005, and, as was the case in 2005, levels at all stations significantly exceeded the Peruvian and USEPA annual air quality standard of 80 $\mu g/m^3$. At Sindicato, the 2005 annual average was 492 $\mu g/m^3$ compared with 706 $\mu g/m^3$ in 2007. Hotel Inca measurements increased slightly from an annual average of 394 $\mu g/m^3$ in 2005 to 435 $\mu g/m^3$ in 2007. Concentrations at the Casaracra monitoring station increased significantly from 29 $\mu g/m^3$ in 2005 to 110 $\mu g/m^3$ in 2007. Although not strictly comparable, the 2005 annual average at Cushurupampa was 386 $\mu g/m^3$ and the 2007 average in Marcavalle was 374$\mu g/m^3$; the change in monitoring location occurred in January 2007. Annual average concentrations from Huari and Huaynacancha are available only for the year 2007: 346 $\mu g/m^3$ and 142 $\mu g/m^3$, respectively.

A review of the average hourly sulfur dioxide concentrations during 2007 reveals daily peaks during morning and early afternoon (from approximately 9 am to 1 pm) at the Sindicato, Hotel Inca, Marcavalle, and Huari locations (see Figures 4-1 through 4-4). The data from Casaracra and Huaynacancha do not display this trend.

Seasonal trends were also evaluated (Figures 4-1 through 4-4). Although some months clearly show higher peaks than others, there was no consistent seasonal trend across stations. Local atmospheric inversions, which are most common in the winter months, might have been expected to generate higher concentrations of sulfur dioxide at the monitoring stations, but this pattern was evident only at Huari, with peaks in May, June, and July. The lack of consistently high winter concentrations may be the result of the Operations Curtailment Program (discussed in Section 3.1.1.3) in which operations that produce sulfur dioxide are curtailed during poor meteorological conditions.

Figures 4-1 through 4-4 also show that the Sindicato monitor (Figure 4-1) had the highest average hourly concentrations of the six monitors: 5,193 $\mu g/m^3$. This maximum occurred in June 2007. The annual average concentration for the Sindicato monitor was approximately 62 percent higher than that for the Hotel Inca monitor. No attempt was made to evaluate temporal or spatial correlations between monitor sites, as it was beyond the needs of the current risk assessment.

4.1.2 Particulate Matter

The annual average and the second highest daily average concentration of PM_{10} for each of the six monitoring stations are summarized in Table 4-2. For comparison purposes, Table 4-2 also presents annual and second highest daily average concentrations for the years 2005, 2006, and 2008. In 2007, the greatest average annual concentration of particulate matter was measured at Sindicato (63 $\mu g/m^3$) and the lowest at Casaracra (26$\mu g/m^3$).

Annual average PM_{10} concentrations have been reduced at all stations since 2005. The annual average at the Sindicato station has decreased from 77 $\mu g/m^3$ to 64 $\mu g/m^3$, and concentrations at Hotel Inca have gone from 64 $\mu g/m^3$ to 50 $\mu g/m^3$. PM_{10} concentrations have remained relatively stable at Casaracra with a 2005 level of 28 $\mu g/m^3$ and a 2007 level of 26 $\mu g/m^3$. Concentrations of PM_{10} at Marcavalle (52 $\mu g/m^3$), Huaynacancha (64 $\mu g/m^3$), and Huari (46 $\mu g/m^3$) are not much lower than those closer to the smelter, possibly reflecting the prevalence of nonpoint PM_{10} sources throughout the region (e.g., vehicle exhaust, road dust entrainment, combustion of wood and fossil fuels, and construction activities).

Exposure point concentrations for acute exposures to particulates are based on 24-hour averages. EPCs are compared with both Peruvian and US health-based standards, which differ only in that the Peruvian standard states that the PM_{10} 24-hour standard should not be exceeded more than three times per year (CONAM 2001) while USEPA guidance states that the standard should not be exceeded more than once per year on average over 3 years (USEPA 2008e). EPCs for chronic exposures are based on annual average air concentrations.

In June 2006, Doe Run Peru began monitoring $PM_{2.5}$, particulate matter with a diameter less than or equal to 2.5 microns. A 24-hour average of $PM_{2.5}$ concentration is recorded once a month for every monitoring station on different dates throughout the month. The annual average and 24-hour maximum values for each station are summarized in Table 4-3. In accordance with the assessment method for PM_{10}, EPCs for acute exposure to $PM_{2.5}$ were determined using the 24-hour values and chronic exposures were evaluated using annual averages. These EPCs were compared with Peruvian and U.S. standards to evaluate potential health impact of exposure.

4.2 ASSESSING EXPOSURES TO LEAD

Health risks associated with lead exposures are assessed by determining the potential that a threshold concentration of lead in the blood will be exceeded. The United States Centers for Disease Control and Prevention (CDC 2002) and USEPA (1998) have adopted 10 micrograms of lead per deciliter of blood ($\mu g/dL$) as a threshold or risk management action level for children. This action level is based on studies indicating that exposures resulting in blood lead levels at or above this concentration may present an increased health risk to children.

Several toxicokinetic models have been developed to predict the distribution of blood lead concentrations in populations of adults and children. These models allow pathway-specific evaluations of lead concentrations, relying on estimates of lead intake from air, soil, dust, water, diet, and consumer products. However, the default parameters included in many widely used USEPA models are not appropriate for the population of La Oroya. In the prior risk assessment (Integral 2005), considerable effort was required to identify representative assumptions and an appropriate model to predict blood lead levels in the children who live near the Complex. The integrated stochastic exposure (ISE) model was selected for use in the 2005 risk assessment and has been used again in this update. The ISE model uses distributions of input parameters including environmental data, dietary intake, and maternal lead concentrations to generate a predicted distribution of blood lead concentrations in a population of children.

Assessing exposures of adults to lead requires a different set of assumptions from those used in the ISE model. USEPA recommends use of a toxicokinetic model called the adult lead exposure model (ALM) for this purpose. The ALM is based on the assumption that soil is the main source of lead exposure at contaminated sites. Because outdoor dust, rather than soil, is thought to be the primary source of lead exposure in La Oroya, the model inputs have been modified to more accurately reflect the relative contributions to lead exposure.

The following sections describe, in depth, the lead exposure models for children and for adults used in the complementary risk assessment. The parameters developed in the 2005 risk assessment provided a starting point for the update. Each model was run initially with new lead concentration data and the parameters developed in 2005. The results were then compared with the November 2007 blood lead data, and the models were adjusted as needed to improve the match between the model predictions and the 2007 data sets. The adjusted models were then used to predict blood lead levels after further reduction of lead emissions from the Complex in 2009.

4.2.1 Exposure Models for Children

USEPA has developed two models for predicting blood lead concentrations in children. The integrated exposure uptake biokinetic model (IEUBK) is designed to predict blood lead levels in children (0–7 years old). The IEUBK was calibrated against blood lead study results during its development, and is the principal model used by USEPA (1994). From point estimates of average values for input parameters and lead concentrations in environmental media, the model calculates an average blood lead concentration. Based on the mean value, an estimate of geometric standard deviation is applied to create a lognormal distribution of blood lead concentrations.

The integrated stochastic exposure model relies on the same toxicokinetic model as the IEUBK model to predict blood lead concentrations from absorbed lead doses. However, instead of using point estimates, the ISE uses probability distributions for exposure and uptake variables,

and an iterative Monte Carlo approach to quantify variability[11]. The intended use of the ISE model is for conducting uncertainty analyses of childhood lead exposures to identify important modeling assumptions and sources of variability and uncertainty.

An underlying premise of the IEUBK model is the assumption that lead exposures at contaminated sites will be dominated by exposure to lead ingested from soil. Smaller contributions are assumed from exposure to lead ingested from indoor dust, with minimal exposure due to inhaled lead in air. These assumptions do not apply to sites with ongoing air emissions of lead, such as smelters (Hilts 2003). The smelter in La Oroya releases lead to the air in the form of particulates. While some of the airborne lead may be inhaled, much of the airborne particulate load settles out onto pavement, soil, and other outdoor surfaces. This outdoor dust contains much higher concentrations of lead than does the underlying soil. Because children playing outdoors may ingest this dust after getting it on their hands, it is important to include outdoor dust as a separate exposure medium in the lead exposure model used for La Oroya.

The ISE model includes a similar underlying premise that ingested soil is the principal exposure medium of concern, and that indoor dust concentrations are due to soil tracked into homes. However, the ISE model can be modified to allow the treatment of outdoor dust as a separate exposure medium. A similar modification could not easily be accomplished with the IEUBK model. Thus, the ISE model has greater flexibility to reflect conditions in La Oroya. In addition, the IEUBK model was designed with an underlying assumption that blood lead levels are lognormally distributed among exposed children. Because the ISE model accepts distribution inputs for parameters such as lead concentrations in different media (e.g., soil, dust, water, diet), it can more readily produce a distribution of blood lead estimates that matches the distributions observed in a specific population. The ISE model has several simulation options enabling the user to select the most suitable parameters. The one-dimensional Monte Carlo module of the ISE model was used for this analysis. This module allows for variation of the values and distributions for major input variables that are consistent with the sampling data collected from each of the communities. Based on the selected input variables, the model then generates distributions of blood lead concentrations in children.

As described above, an underlying assumption of the ISE and IEUBK models is that the presence of lead in indoor dust is due to soil being tracked into homes. Under this assumption, the models derive estimates of indoor dust intake by means of an assumed relationship between soil and dust concentrations. The default assumption is that indoor dust concentrations are 70 percent of soil concentrations. Soil and dust ingestion is then assumed to be apportioned between the two media. This underlying assumption is not consistent with the exposure pathways in La Oroya, which are dominated by high lead concentrations in outdoor dust. Because of the high lead concentrations and mobility of outdoor dust, the lead concentrations in

[11] Monte Carlo methods are stochastic techniques based on the use of random numbers and probability statistics.

indoor dust are more influenced at present by tracked-in outdoor dust than by tracked-in soil. This relationship may change in the future as lead emissions from the Complex are reduced and outdoor dust lead concentrations approach those in underlying soil.

To address this site-specific characteristic, a modification was made in setting up the ISE model for the 2005 risk assessment in which the parameter called "soil" was replaced by outdoor dust, and the ingestion of both indoor and outdoor dust was reflected in a single intake rate. A factor was applied to represent the fraction of total dust ingestion due to outdoor dust. The contribution of lead ingested in soil was then characterized using the "other" module within the ISE model by combining the soil concentration and soil ingestion rates to obtain lead intake from soil in μg/day.[12]

The ISE model was first run using the general input parameters generated for the 2005 risk assessment, but with new exposure concentrations for air, soil, dust, diet, and water from data gathered in 2007 and 2008. These results were then compared with 2007 blood lead levels. An iterative process was used to modify the input parameters and distributions until the predicted distribution matched the blood lead data as closely as possible. The calibrated model was then used to predict future blood lead concentrations after 2009, when reductions in lead emissions from the smelter are expected to be significant. The two following sections describe parameters used in the ISE model.

4.2.1.1 Determination of ISE Model Inputs for the Current Scenario

Two types of input parameters are used in the ISE model. The first type is general parameters applicable to all simulation modeling runs for the communities evaluated. The second type is site-specific parameters applicable to only specific communities or time periods.

The following parameters are the same for each community:

- Exposure frequency
- Averaging time
- Ingestion rate for dust and soil
- Age-dependent dust ingestion rate scale factor
- Age-dependent water ingestion rate scale factor
- Absorption factors for various media (e.g., dust, soil, water, diet)
- Age-dependent ventilation rates

[12] The "other" module was designed to account for additional exposure pathways not already specified in the ISE model.

- Time spent outdoors for each of the age groups
- Age-dependent lung absorption factor.

The input values and distributions, if applicable, for these parameters are presented in Table 4-4. Values and distributions for each of these parameters were determined or selected on the basis of one of the following sources or rationales:

- USEPA default assumption
- Site-specific sampling data
- Observation and interviews with local residents
- Best professional judgment or best model fitting.

The corresponding source or rationale for each of the parameter values is also noted in Table 4-4. A discussion of the derivation of the input values for specific exposure pathways and other parameters follows. Input values specific to each community are summarized in Tables 4-5 through 4-9.

4.2.1.2 Input for Outdoor and Indoor Dust Pathways

Dust lead intake in micrograms per day (μg/day) is calculated from three parameters:

- Concentration of lead in dust in milligrams per kilogram (mg/kg)
- Dust ingestion rate in milligrams per kilogram (mg/day)
- Percent of the dose that is absorbed.

For each community, a distribution of lead concentrations in outdoor dust and indoor dust was derived using data from samples collected during 2007 and 2008. For outdoor dust, data from the June 2008 samples taken by Doe Run Peru were used to determine community-specific input values. As described in Section 3.1.1, 23 samples were collected from the communities surrounding the Complex during this sampling event. A lognormal distribution was generated for the entire data set and this same distribution was assumed for smaller subsets of the data for which it was not possible to generate a distribution. Default dust ingestion rates in the ISE model vary with age, with different ingestion rates for each year between 0 and 7 years of age. The default age-dependent soil ingestion rate scale factors were applied in calculating dust intakes for different age groups.

Indoor dust data used in the model were from the 2007 and 2008 Convenio household dust studies. The lognormal distribution generated for the entire data set was assumed for subsets of the data that did not have enough data points to reliably generate a distribution.

The distribution of lead absorption from both outdoor dust and indoor dust was assumed to be a triangular distribution with a likeliest value of 35 percent, minimum value of 15 percent, and

maximum value of 65 percent. The likeliest value reflects the expectation that lead in dust is more bioavailable than lead in soil (see discussion below).

4.2.1.3 Input for Soil Lead Pathway

Soil lead intake in micrograms per day (μg/day) is calculated based on three parameters:

- Concentration of lead in soil in milligrams per kilogram (mg/kg)
- Soil ingestion rate in milligrams per day (mg/day)
- Percent of the dose that is absorbed.

For each community, a distribution of soil lead concentrations was derived using data from the surface (0-2 cm depth) soil samples collected by Doe Run Peru during June 2008. A lognormal distribution was generated for the entire data set, and this same distribution was assumed for smaller subsets of the data for which it was not possible to generate a distribution. Default soil ingestion rates in the ISE model vary with age, with different ingestion rates every year from 0 to 7 years of age. The age scale factors for different age groups are listed in Table 4-4.

Soil ingestion rates were determined using best professional judgment and best model fit, with due consideration to the default ingestion scale factors. According to the best fit of ISE modeling, the soil ingestion rate was determined to be lognormally distributed. The mean ingestion rate was 20 mg/day, with a standard deviation of 8.3 mg/day. The mean ingestion rate was applied to the mean concentration of lead in soil calculated from the sampling data for each community. The default age-dependent soil ingestion rate scale factors were then applied to the base value to derive a soil intake for each age group.

The distribution of lead absorption from soil was assumed to be a triangular distribution with a likeliest value of 30 percent, minimum value of 10 percent, and maximum value of 50 percent. The likeliest value is the same as the model default mean value, and reflects the expectation that lead in soil is less bioavailable than lead in dust.

As discussed above, the age-dependent daily soil lead intake distributions, in micrograms per day (μg/day), were entered as the "other" pathway in the ISE model. For each community, the intake distribution was generated by entering the distributions for the three input parameters into a Monte Carlo program. The resulting distribution was then used in the ISE model.

4.2.1.4 Input for Air Pathway

Exposure to lead in air is calculated based on three parameters:

- Annual average lead concentration in air in micrograms per cubic meter ($\mu g/m^3$)
- Ventilation rate in cubic meters per day (m^3/day)

- Absorption of lead from the lung.

Based on air monitoring data collected by Doe Run Peru during 2007, distributions of lead in air were identified for each community evaluated. The USEPA default assumptions for ventilation rates were used. People living at high altitudes may have increased ventilation rates; however, because the lead concentrations used were reported at normal temperature and pressure, the ventilation rates were not increased. Absorption of lead from air was entered as a point estimate of 32 percent, the same value as the USEPA default value.

4.2.1.5 Input for Diet Pathway

Dietary lead exposure is based on two parameters:

- Intake from the diet in micrograms per day (μg/day)
- Absorption of lead from the diet.

Site-specific data on lead intake in the diet from the study conducted by the Convenio in 2008 were used to construct a distribution for age-dependent diet intakes of lead. Though lead was not detected in any of the samples, a conservative midpoint value was generated from the laboratory detection limit. The midpoint value for La Oroya Antigua was 18 μg/day with a standard deviation of 8 μg/day. An estimated value of 15 μg/day and 5 μg/day standard deviation was used for the remaining communities.

Because the 2008 dietary intake data were collected only from children under 3 years, there was no distribution between age groups. Consequently, the same value was used for all ages. This assumption may have overestimated lead intakes in infants less than 1 year old, and could underestimate the dietary lead intake in older children.

4.2.1.6 Input for Drinking Water Pathway

Exposure to lead in drinking water is calculated based on three parameters:

- Lead concentration in drinking water in micrograms per liter (μg/L)
- Water ingestion rate in liters per day (L/day)
- Absorption of lead from drinking water.

Of 19 drinking water samples collected during 2008, lead was detected in only one sample (from La Oroya Antigua). When four samples were retaken from this same site in August 2008, no lead was detected. Thus, a conservative point estimate of 5μg/L (one-half of the detection limit) was used for all communities. The USEPA default assumptions for water ingestion rates were used. Due to the generally low lead concentrations in drinking water, it was not necessary to determine a site-specific value for this parameter. Absorption of lead from water was entered as a triangular distribution with a most likely value of 50 percent, a minimum value of

30 percent, and a maximum value of 70 percent. The most likely value is the same as the USEPA default mean value.

4.2.1.7 Input for Maternal Blood Lead Concentration

Maternal blood lead concentration will determine the blood lead concentration of infants at birth, and with a diminishing influence on blood lead levels as children grow. Consequently, it is important to use data for women of child-bearing age from La Oroya for this parameter. The mean maternal blood lead concentrations were calculated from the 2007 blood lead data for pregnant women. The mean value for La Oroya Antigua was 8 μg/dL and 6 μg/dL for the rest of the communities. The results of the 2007 blood lead sample of pregnant women are found in Table 4-10.

4.2.1.8 Calibration of ISE Model and Determination of Dust Distributions

As discussed above, the ISE model was first run using data gathered in 2007 and 2008, but with the assumptions developed in 2005. These results were then compared to the blood lead data collected in 2007. An iterative process was then used to calibrate the model. First, statistical analyses were conducted for the collected blood lead data for all of the communities combined. The distribution pattern of the blood lead data for each of the age groups was identified. Various statistical values, such as the mean, 10^{th}, 25^{th}, 50^{th}, 75^{th}, and 90^{th} percentiles of the blood lead data, were also calculated. A summary of these data is presented in Table 4-11. For reference, the 2004 sampling data are also included in this table.

Second, general and site-specific values and distributions for the model parameters were entered into the model. Initial statistical values (e.g., mean, standard deviation) and distributions for ingestion rates of outdoor and indoor dusts (listed as "soil" and "dust" in the model, respectively) and soil lead intake (listed as "other" in the model) were assigned based on 2007 and 2008 sampling results. A point value was given to the factor representing the fraction of intake that is outdoor dust.

Third, an initial ISE modeling run using La Oroya Antigua data was conducted with 1,000 Monte Carlo iterations. From this process, the mean blood lead concentration as well as the 10^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 95^{th} percentile values were predicted.

Fourth, the modeled blood lead values for the mean, 10^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th} and 95^{th} percentiles were compared against the statistical results of blood lead sampling data from La Oroya Antigua. After examining the deviations of the modeled blood lead results from the sampling results, new statistical values were assigned to the distribution parameters for dust absorption and another run of the model was performed.

The procedures described in the third and fourth steps were repeated until the ISE modeling results for the mean and the various percentile values were sufficiently close to the blood

sampling results. Modeling runs were then performed for the other communities including La Oroya Nueva, Santa Rosa de Sacco, Paccha, and Huari. The final ISE modeling results were then compared with the blood lead sampling data from each of the communities in La Oroya.

4.2.1.9 Determination of ISE Model Inputs for Future Scenarios

Planned changes in Complex operations indicate significant reductions of lead emissions will occur at the end of 2009. Based on the expected emissions reductions in November 2009, predictions of percent reductions in ambient air lead concentrations were generated by McVehil-Monnett using the air dispersion model. In La Oroya Antigua, La Oroya Nueva, and Marcavalle, the concentrations are predicted to decrease by 95 percent. The projected percent reduction in lead deposition is assumed to be equal to the decrease in annual lead air concentrations (McVehil 2008b, pers. comm). Decreases in deposition of lead in particulate matter from smelter stack and fugitive emissions will reduce the amount of lead in outdoor dust and indoor dust. The degree of reduction is somewhat uncertain and will depend on how much other sources of dust (e.g. resuspended soil, road dust, or diesel emissions) contribute to the total dust load. The summary input values for future predictions are listed in Tables 4-12 through 4-14.

Reductions in air emissions and subsequent lead deposition are expected to have only a small effect on lead concentrations in soil. For post-2009, soil concentrations are assumed to be reduced by a factor of 0.2 relative to lead deposition for La Oroya Antigua and La Oroya Nueva. This factor was selected to yield average soil concentrations slightly below the values measured in 2005. The limited soil data available for the complementary risk assessment yielded higher lead concentrations for La Oroya Antigua and La Oroya Nueva compared with the 2005 data. We suspect that the apparent increase is an artifact of having a small number of samples. For that reason, we assume that after 2009, representative soil concentrations will be approximately 20 percent less than the soil concentrations measured in the limited dataset collected in 2008.

Using this factor, the mean future soil lead concentration input for La Oroya Antigua is 2,388 mg/kg and for La Oroya Nueva the lead concentration is assumed to be 1,148 mg/kg. Due to its increased distance from the Complex, the community of Marcavalle/Chucchis was assumed to have soil concentrations reduced by a smaller fraction. A factor of 0.1 relative to predicted declines in deposition was used, thus the soil lead concentration input is assumed to be ,752 mg/kg.

Concentrations of lead in outdoor and indoor dust are expected to decrease with the decrease in lead deposition; however, these reductions are expected to be limited by soil concentrations because windblown soil also contributes to dust. As the deposition of lead from smelter emissions declines, outdoor dust concentrations will increasingly be controlled by lead concentrations in surrounding soil. Thus, it is not expected that outdoor dust concentrations

will decline much below soil concentrations; input values selected for community dust concentrations for the future scenario are 20 percent less than those for soil in La Oroya Antigua and 10 percent less than those for soil in La Oroya Nueva and Marcavalle/Chucchis. Efforts to reduce the presence of exposed soil in La Oroya Antigua are anticipated to diminish the influence of soil lead concentrations on outdoor dust concentrations, thereby increasing the plausibility of more dramatic reductions in dust lead concentrations in this neighborhood. Indoor dust concentrations for the future scenarios were calculated as a percent of outdoor dust concentrations, based on the observed ratio of indoor to outdoor dust sampled in 2007. In all three communities, indoor dust has a lead concentration that is approximately 60 percent of the outdoor dust concentration.

Following the assumption used in 2005, dietary lead intake was predicted to be reduced by a factor of 0.6 relative to the reduction in lead deposition rates. The factor 0.6 was judged to be a reasonable estimate of the contribution of lead deposition to the total lead concentrations in food. This calculation resulted in a mean input value of 17 μg/day. Since the water source in La Oroya is not considered to be impacted by the Smelter operations, inputs for the water pathway remained the same (5 μg/L).

As described above, the ISE model includes an input for the maternal contribution to child blood lead levels. The predicted reductions in concentrations of lead in air, dust, soil, and diet are expected to result in some reductions of maternal blood lead levels. The Adult Lead Exposure model was used to predict blood lead levels for women after 2009. The predicted maternal blood lead levels were then incorporated into ISE to more accurately predict children's future blood lead levels. The predicted mean maternal blood lead levels were then incorporated into ISE model (6 μg/dL for La Oroya Antigua and 4.5 μg/dL for other communities).

Uncertainty regarding the extent of lead reductions in soil and dust is explored in a sensitivity analysis presented in section 6.5. The analysis examines several alternative scenarios to evaluate the sensitivity of the model to different assumptions regarding how a reduction in lead deposition will affect dust, food, and soil lead concentrations.

4.2.2 Adult Lead Exposure Model

USEPA (2003) recommends use of the toxicokinetic model ALM to assess exposures of adults to lead. Like the IEUBK and ISE models, the ALM is based on the assumption that soil is the main source of lead exposures at contaminated sites. Because outdoor dust is thought to be a significant contributor to lead exposures in La Oroya in addition to soil, the model inputs were modified to better reflect local conditions. The ALM model from USEPA is much simpler than the IEUBK and ISE models, and does not include the option of entering site-specific values for various exposure pathways. As described below, outdoor dust data replaced soil data in the

model. Site-related exposures in soil, diet, and air were accounted for by means of an elevated baseline blood lead value.

The ALM includes a module to predict fetal blood lead levels, results of which can be used to estimate exposures in pregnant women that are protective of the fetus. According to USEPA (2003), protection of the fetus is the most health-sensitive endpoint for adults. Like the IEUBK model for childhood exposure, the ALM target risk level is no more than a 5 percent probability that a fetus exposed to lead will exceed a blood lead level of 10 μg/dL (USEPA 2003).

The ALM uses a technical approach described by Bowers et al. (1994) that predicts site-related adult blood lead concentrations by summing the "baseline" blood lead level (i.e., that which would occur in the absence of site-related exposures) with the incremental increase expected from ingestion of lead-contaminated soil. The latter is estimated by multiplying the average daily absorbed dose of lead from soil by a biokinetic slope factor. As noted, outdoor dust was substituted for soil in the model as applied to La Oroya. Thus, the basic equation for exposure to lead in outdoor dust in La Oroya is:

$$PbB = PbB_0 + BKSF \times \left(\frac{PbDo \times IR_{sd} \times AF_s \times EF_s}{365} \right)$$

Where:

PbB = Geometric mean blood lead concentration (μg/dL) in women of child-bearing age who are exposed at the site

PbB_0 = Baseline geometric mean blood lead concentration (μg/dL) in women of child-bearing age in the absence of exposures to site soil

BKSF = Biokinetic slope factor (μg/dL blood lead increase per μg/day lead absorbed)

PbDo = Outdoor dust lead concentration (μg/g)

IR_{sd} = Intake rate outdoor soil and indoor soil-derived dust (g/day)

AF_s = Absolute gastrointestinal absorption fraction for lead in soil and dust (dimensionless). The value of AF_s is given by:

$$AF_s = AF_{food} \times RBA_{soil}$$

EF_s = Exposure frequency for contact with site soils and dusts (days per year)

The ALM includes an option to predict the contribution of soil, or in the case of La Oroya, outdoor dust, to indoor dust concentrations. It is assumed that indoor dust lead concentrations are the result of tracking in lead-containing outdoor dust. If a factor K_{SD} (which represents a mass fraction of outdoor dust in indoor dust) and a weighting factor W_s (which represents the

fraction of IR_{sd} ingested as outdoor dust) are introduced to the basic equation for exposure to lead in soil, the basic equation can be rearranged as (USEPA 2003b):

$$PbB = PbB_0 + BKSF \times PbDo \times \frac{\left[\left(IR_s \times AF_s \times EF_s \times W_s\right) + \left(K_{SD} \times IR_{sd} \times \left(1 - W_s\right) \times AF_s \times EF_s\right)\right]}{365}$$

Where:

K_{SD} = Mass fraction of outdoor dust in indoor dust (dimensionless)

W_s = Fraction of IR_{sd} ingested as outdoor dust (dimensionless)

To account for the relative contributions of indoor and outdoor dust, this expanded equation was used for adult blood lead modeling in the complementary risk assessment.

Once the geometric mean blood lead value is calculated, the full distribution of likely blood lead values in the population of exposed people can be estimated by assuming the distribution is lognormal with a specified individual geometric standard deviation (GSD_i). The 95th percentile of the predicted distribution is given by the following equation from Aitchison and Brown (1957):

$$95^{th}\ percentile = \mathrm{GM} \times GSD_i^{1.645}$$

Where:

GM = Geometric mean

GSD_i = Individual geometric standard deviation

The ALM also uses the following equations to calculate the mean and 95th percentile of fetal blood concentrations:

$$PbB_{fetal} = R_{fetal/maternal} \times PbB_{adult}$$

$$PbB_{fetal,0.95} = R_{fetal/maternal} \times PbB_{adult} \times GSD_{i,adult}^{1.645}$$

Where:

PbB_{fetal} = Fetal blood lead concentration (µg/dL) (which, like PbB_{adult}, is a variable quantity having the specified probability distribution)

$R_{fetal/maternal}$ = Constant of proportionality between fetal and maternal blood lead concentrations

PbB_{adult} = Adult blood lead concentration (µg/dL), estimated with parameters appropriate to women of child-bearing age

$PbB_{fetal,\ 0.95}$ = Fetal blood lead concentration (μg/dL) among fetuses born to women having exposure to the specified site

$GSD_{i,adult}$ = Geometric standard deviation of individual adult.

There is evidence that fetal blood lead concentrations are consistently lower than maternal blood lead concentrations by a factor of 0.1 (USEPA 2003). Consequently, for this study, the ALM default value of 0.9 was used for $R_{fetal/maternal}$. The use of a point estimate for this value implies a deterministic (non-random) relationship between maternal and fetal blood lead concentrations. This assumption omits a source of variability (individuals' actual ratios of fetal to maternal blood lead) that would tend to increase the variance of fetal blood lead concentrations.

4.2.2.1 Summary of Input Parameters

Input parameters for modeling of current and future conditions are listed in Table 4-15 and are described below.

Lead Concentrations in Outdoor Dust

The mean outdoor dust lead concentration in each community was derived using data from samples collected by Doe Run Peru in June 2008. Reductions in future outdoor dust lead concentration are based on changes in lead deposition rates predicted by the air dispersion models for after 2009. This is discussed in Section 4.2.2.3.

Weighting Factor and Mass Fraction of Outdoor Dust in Indoor Dust

In La Oroya, outdoor dust is thought to be the major contributor to indoor dust. It is assumed that women of child-bearing age ingest lead in both outdoor dust and indoor dust. A weighting factor, W_S, was used to apportion the dust ingestion rate between outdoor dust and indoor dust. It was assumed that 40 percent of the lead in dust is ingested from outdoor dust (i.e., a weighting factor of 0.4), and the remaining 60 percent from indoor dust.

The ALM also includes a term to predict the indoor dust concentration from soil concentrations. This term, represented by K_{SD}, is called "mass fraction of soil-derived particles in indoor dust." For La Oroya, this term was used to predict the contribution of outdoor dust to indoor dust lead concentrations. A mass fraction value of 0.5 was calculated as the mean of the individual ratios of indoor dust lead concentrations to outdoor dust lead concentrations reported in the 2007 Convenio household dust study (Convenio 2007). This value falls within the historical range of values found. As described in Section 3, the indoor dust concentrations from the 2008 study (Convenio 2008) were generally higher than the outdoor dust concentrations. Because this finding is inconsistent with the 2007 data and other studies of paired indoor and outdoor dust concentrations, data from the 2008 study were not considered when determining the ratio to use in the model.

Biokinetic Slope Factor

The original Bowers model, on which the USEPA ALM was based, was developed using a biokinetic slope factor of 0.375 μg/dL per μg/day (Bowers and Cohen 1998). The default biokinetic slope factor in the ALM is 0.4 μg/dL per μg/day. Because the Bowers adult lead model has been demonstrated to predict blood lead levels accurately using the lower biokinetic slope factor, the lower biokinetic value of 0.375 μg/dL per μg/day was used.

Baseline Blood Level

The baseline blood lead concentration is intended to represent a reasonable central value of blood concentration in women of child-bearing age who are not exposed to lead-contaminated soil and dust in the study area. The ALM default background value is 1.5 μg/dL (for homogeneous populations); based on recent studies in the United States, the default may be reduced to 1.0 μg/dL.

It is difficult to reliably determine a baseline blood lead level for La Oroya that is truly independent of effects of a smelter that has operated since 1922. An initial approximation was made from two studies in lowland areas of Peru. In a 1999 cross-sectional study, a mean blood lead level of 3.5 μg/dL was reported for 874 post-partum women in Lima and Callao (Espinoza et al. 2003). In a much smaller study, a mean blood lead level of 2.5 μg/dL was reported for 36 pregnant women in Trujillo (Naeher 2004). The degree to which baseline blood lead levels in La Oroya match these Peruvian values depends on several factors. Nationwide, the banning of leaded gasoline in 2004 is expected to lower blood lead levels in all urban populations. However, most of the population in La Oroya lives very close to roadways, with high exposure to vehicular exhaust and resuspended dust, factors that could raise the local baseline. An additional factor contributing to higher predicted baseline values in La Oroya is the increase in hematocrit, and therefore lead-carrying capacity of the blood, with altitude. Considering these factors, baseline blood lead levels for La Oroya are expected to be in the range of 2 to 3 μg/dL or higher.

The estimated baseline blood lead level for La Oroya was further modified in the model to account for lead exposures from site-related impacts to soil and diet. Exposures to lead in soil and diet were assessed indirectly on a community-wide basis via the baseline blood input value. Only outdoor dust lead concentrations were entered directly into the model for eacy community. Based on the 2008 diet study, the estimated mean dietary intake of lead for mothers in La Oroya ranges from 32 to 77 μg/day. At a biokinetic slope factor of 0.375 μg/dL per μg/day and an absorption factor of 8 percent (see discussion below), the estimated mean contribution of dietary lead intake to baseline blood lead level was calculated at 1 to 2 μg/dL. The contribution via soil ingestion was also calculated, using average soil lead concentrations from the 2008 samples. Assuming a biokinetic slope factor of 0.375 μg/dL per μg/day, an absorption factor for soil of 4.8 percent, and an ingestion rate of 0.02 g/day, the estimated mean contribution from soil ingestion to blood lead level in La Oroya Antigua is 0.5 to 0.75 μg/dL.

The mean increment in the baseline blood level due to dietary intake and soil ingestion combined was predicted to be 1.5 to 2.75 μg/dL. Added to the initial baseline blood lead level of 2 to 3 μg/dL, the adjusted baseline for use in the ALM model for current conditions was 4.5 μg/dL. Future baseline blood lead levels were assumed to be reduced slightly as lead emissions from the Complex are reduced; these were determined by professional judgment. A single baseline blood lead concentration was selected for current conditions and another for future conditions. Each baseline value was applied across all four communities.

Soil and Dust Ingestion Rate

For ALM modeling, the default dust ingestion rate of 0.05 g/day (USEPA 2003) was used to represent combined ingestion of outdoor dust and indoor dust. This is the same value used in the 2005 risk assessment.

Absorption Fraction for Dust

Based on the ALM guidance (USEPA 2003), USEPA assumes that the absorption fraction for soluble lead in water or diet is 0.2, and that absorption fraction for lead from soil is 0.12. However, a validated lead pharmacokinetic model developed by O'Flaherty (1993) used an adult lead absorption value of 0.08 (8 percent) for water and diet; this value was judged tomore accurately predicts adult lead exposures than the default value selected by USEPA. Bioavailability of lead in soil is generally less than that of soluble lead, with estimates of relative bioavailability ranging from 0.09 to 0.8 (USEPA 2003). Because lead in fine particulates released by the smelter is anticipated to be highly bioavailable, a relative bioavailability value of 0.7 was selected for lead in soil. This factor yields an absorption fraction of 0.056 (i.e., 0.08 times 0.7 = 0.056), the value used in the 2008 model.

Exposure Frequency

The default ALM exposure frequency is 250 days/year for indoor workers. Because the population of concern is full-time adult residents of La Oroya, exposure frequency was assumed to be 365 days per year. While some residents may spend a week or more away from home during the year, it was assumed that most residents do not.

Geometric Standard Deviation

The default value for geometric standard deviation (GSD) in the ALM model is now 1.8 (in 2005, it was 2.1). USEPA has also acknowledged that low GSD (1.6–1.8) is consistent with an analysis of blood concentration measured in populations in mining communities in the United States and Canada (USEPA 1992). The lowest values of GSD are expected among homogeneous populations.

This same pattern of higher GSDs in heterogeneous urban populations and lower GSDs in more homogeneous populations is also observed in Peru. Data from the 1999 blood lead study in Lima yield GSD values of 1.93 for women ages 20–24 years old and 2.01 for women ages 25–29

years old (DIGESA 1999), and 1.81 for all women of child-bearing age in Lima. In contrast, data from the 2007 blood lead study of pregnant women in La Oroya yield a GSD value of 1.62. (Table 4-16). Because the focus of the ALM modeling is to predict the blood lead concentration in women of child-bearing age, this value was selected for the risk assessment.

4.2.2.2 Comparison of Modeled Blood Lead Concentrations with Sampling Data

The input parameter values described above were used in the ALM to predict the distribution of blood lead concentrations for adults in La Oroya. The results were compared with mean and 90th percentile blood lead concentrations reported from the 2007 blood lead samples of 105 pregnant women. Because data for communities outside of La Oroya Antigua were limited, predictions were made for La Oroya Antigua, for the surrounding communities excluding Antigua, and for all communities combined. These results are summarized in Table 4-17.

The ALM results match well with the sampling data for the geometric mean in all scenarios. The geometric mean for all communities was measured to be 5.9 and the model predicted 6.2. The 90th percentile values were slightly overestimated; for all communities combined, the values were 10.4 for the sample and 11.4 for the model. For La Oroya Antigua, the difference was even greater. Nevertheless, the consistency between the geometric means of the modeled results and the blood sampling data supports the use of the model to predict future mean blood levels. However, predictions of upper percentile blood lead concentrations should be interpreted cautiously.

4.2.2.3 Assessing Future Scenarios

Based on available air modeling data, a future scenario was predicted for the time after planned emissions controls are fully implemented in late 2009. Changes in input values for the future scenario include lead concentration in dust and baseline blood lead level. These values are summarized in Table 4-15 and discussed below.

Percent reductions in air lead concentration and deposition rates were predicted from air modeling. The predicted decrease in annual average lead concentrations in air was used to generate values for lead concentrations in outdoor dust after 2009. As for the ISE model, it was assumed that lead concentrations in outdoor dust would not decline much below the soil concentrations. Because the predicted decrease in lead deposition after 2009 is greater than 90 percent for all the communities, direct application of the percent reduction value would have led to predictions that outdoor dust concentrations were lower than soil concentrations.[13] Consequently, it was assumed that after 2009, the outdoor dust concentrations would be slightly lower than the predicted soil concentrations.

[13] As described in Section 4.2.2.1, soil concentrations are assumed to be reduced by 10 percent of the predicted reduction in lead deposition.

The baseline blood lead value for women is not expected to decline substantially in the coming years. A baseline blood lead value of 4.0 μg/dL was selected for future scenarios. This drop of 0.5 μg/dL for the future scenario reflects predicted decreases in input from the diet and soil ingestion.

4.3 ASSESSING EXPOSURES TO METALS OTHER THAN LEAD

Metals other than lead were evaluated by calculating a daily average dose or intake in mg/kg body weight according to the general equation shown in the introduction of this section. The specific values selected for use calculating intakes are based on statistics, professional judgment, and risk assessment guidance to produce estimates of average exposures, termed the "central tendency exposure" (CTE) and the "reasonable maximum exposure" (RME). The CTE represents typical exposures for a given population. The RME is an estimate of the highest exposure that is reasonably expected. The RME is considered protective of sensitive subpopulations within the community. Typically, RME calculations are based on higher values for contact rate and exposure duration and average body weights, to protect the majority of people within a population. These values avoid an overestimation of risk based on the unreasonable assumption that the greatest intake will occur for the smallest individual.

Equations and input parameters used to calculate intake of ingested soil and dust, intakes inhaled from the air, and intake ingested from water are described below. These parameters are summarized in Table 4-18.

4.3.1 Exposure Assumptions for All Pathways

Four parameters have the same values for all of the exposure pathways: exposure frequency, exposure duration, averaging time, and body weight. In the 2005 risk assessment, the selection of the values for these input parameters was based on risk assessment guidance and literature sources. The same values were used in the complementary risk assessment.

4.3.1.1 Exposure Frequency

The exposure frequency parameter represents the number of days per year that someone contacts the air, water, dust, or soil containing the chemicals being evaluated. This value varies for each person, depending on the amount of time spent within the exposure area. Peruvian law requires that employers provide 1 month of paid vacation per year; however, many residents of La Oroya do not have full-time jobs and many residents may not leave the area even when not working. Therefore, the CTE exposure frequency value was selected to represent people who leave La Oroya for a portion of their non-working days each year, and the RME value was selected to represent people who stay in La Oroya every day. The exposure

frequency for the CTE adult and child scenarios is 335 days per year. The exposure frequency for the RME adult and child scenarios is 365 days per year.

4.3.1.2 Exposure Duration

The exposure duration parameter represents the total number of years that someone is in contact with the exposure media in La Oroya. Separate values for children and adults were selected for exposure duration. In accordance with USEPA human health risk assessment guidance (USEPA 1989), exposures to children are evaluated for the first 6 years of life, after which time exposures are evaluated under the adult scenario. The first 6 years are important because young children are expected to have the greatest exposures because their activities involve direct contact with soil and dust, and because their intakes of air, water, and food per kg of body weight are higher than those for adults. Therefore, the exposure duration for children is 6 years.

In 2001, Doe Run Peru, the Ministry of Health, and INEI compiled socioeconomic information for La Oroya. Doe Run Peru (DRP 2001b) reported that 40 percent of the residents have lived in La Oroya for less than 20 years, 21 percent have lived in La Oroya for 20 to 30 years, 22 percent have lived in La Oroya for 30 to 40 years, and 17 percent have lived in La Oroya for more than 40 years. Local public health representatives support these statistics, stating that many people move to or leave La Oroya seeking new employment opportunities.

Exposure duration selected for the CTE adult scenario is 30 years, representing approximately 60 percent of the population. The exposure duration selected for the RME adult scenario is 70 years, representing the life expectancy at birth for Peruvians (PAHO 2001). When the childhood exposure duration of 6 years is subtracted, the CTE and RME adult exposure durations are modified to 24 years and 64 years, respectively.

4.3.1.3 Averaging Time

The averaging time is the time period over which an exposure is averaged. Different averaging times are used for cancer risk and noncancer health effects. Chemical intakes are averaged over the full 70-year lifetime (25,550 days) when evaluating cancer risk (USEPA 1989). When evaluating noncancer health effects, however, chemical intakes are averaged over the exposure duration expressed in number of days an individual is expected to be exposed (USEPA 1989). For example, the averaging time for evaluating noncancer health effects in children is 2,190 days (6 years). The averaging time for evaluating noncancer health effects in adults is 8,760 days for the CTE scenario and 23,360 days for the RME scenario.

4.3.1.4 Body Weight

Body weight data for La Oroya residents are generally not available. However, body weight information was available for 788 children under the age of 6 years who participated in the November 2004 blood sampling event conducted by the Ministry of Health. The mean body weight for these children—13.4 kg—was used to represent the body weight for all children in the complementary risk assessment. This value is slightly lower than the 15-kg mean child body weight reported for the U.S. (USEPA 1989).

In 2005, adult body weight data not having been available for La Oroya adults, body weight had been calculated from the mean adult body weight reported for the United States of 70 kg (USEPA 1989). The U.S. adult weight was multiplied by 0.893, the ratio of La Oroya child body weight (13.4 kg) to U.S. child body weight (15 kg), yielding an adult mean for La Oroya of 63 kg. The 63-kg adult body weight represents both female and male residents.

The calculated body weight of 63 kg for La Oroya is similar to the mean adult body weight of 60.0 kg (range of 41.8 to 74 kg) reported by Tarazona-Santos et al. (2000) for 77 indigenous men in Huancavelica, Peru. In addition, mean body weight was 52.2 kg (range of 37.4 to 69.1 kg) for 11 females ages 21 to 46 years in the 2005 La Oroya dietary study (IIN 2005).

4.3.2 Soil and Dust Ingestion Intakes

The equation used to estimate intakes for assessing effects other than cancer for ingestion of metals in soil and dust is shown below. The following equation accounts for lifetime exposure, combining both the adult and child exposures into one intake calculation:

$$Intake = \left(\frac{C \times EF \times RAF}{AT \times CF} \right) \times \left(\frac{ED_{child} \times IR_{child}}{BW_{child}} + \frac{\left(ED_{adult} - ED_{child} \right) \times IR_{adult}}{BW_{adult}} \right)$$

Where:

Intake	=	Intake from incidental ingestion of soil and/or dust (mg/kg-day)
C	=	Concentration of metal in soil or dust (mg/kg)
IR	=	Ingestion rate (mg/day)
EF	=	Exposure frequency (day/year)
ED	=	Exposure duration (year)
AT	=	Averaging time (day)
BW	=	Body weight (kg)
CF	=	Unit conversion factor (1×10^6 mg/kg)

RAF = Relative absorption factor (unitless).

Exposure parameter values selected to estimate intake of metals in soil and dust for adult and child residents in La Oroya in the complementary risk assessment are presented in Table 4-18 and discussed below. Any differences from the assumptions for the 2005 risk assessment are also noted.

4.3.2.1 Soil/Dust Exposure Point Concentrations

Exposure point concentrations were calculated for arsenic, cadmium, antimony, and copper in soil. The derivation of EPCs is described in Section 3.3.2. Briefly, surface soil data from 2008 were used to estimate EPCs for current exposures to adult and child residents in the communities of La Oroya Antigua, La Oroya Nueva, Santa Rosa de Sacco, Huaynacancha, Paccha, and Huari. Data for La Oroya Antigua were sufficient to derive an upper confidence limit of the mean as the EPC. For the other communities, the maximum concentration was used.

For outdoor dust, EPCs were calculated for the same four metals evaluated in soil using outdoor dust data collected by Doe Run Peru in June 2008. The derivation of the EPCs is described in Section 3.3.3. As for soil, data for La Oroya Antigua were sufficient to derive an upper confidence limit of the mean as the EPC. For the other communities, the maximum concentration was used.

For indoor dust, combined data from samples collected by the Convenio in May 2007 and March 2008 were used to derive EPCs for arsenic, cadmium, antimony, and copper (see Section 3.3.4). Sufficient data were available for La Oroya Antigua to calculate upper confidence limits of the mean as the EPC. Due to very limited data for other neighborhoods, data for all other communities outside of La Oroya Antigua were combined to derive one upper confidence limit of the mean for the "other communities." This same EPC was applied for each of the individual neighborhoods.

Future concentrations of metals in soil and dust after 2009 were predicted on the basis planned reductions in emissions of arsenic and cadmium, and changes in deposition predicted from the air modeling study. Future deposition could not be predicted for Paccha or Huari because of limitations in the air model. In the 2005 risk assessment, it had been assumed that the reduction in emissions deposition would result in a direct reduction in metals concentrations in outdoor dust. That assumption could not be applied in the complementary risk assessment because future outdoor dust concentrations would have fallen below soil concentrations; it has already been assumed, however, that outdoor dust concentrations will not be less than soil concentrations.

For indoor dust it was assumed that arsenic and cadmium concentrations will decline as a function of the decline in outdoor dust concentrations. In other words, the ratio between outdoor dust and indoor dust concentrations is predicted to remain the same in the future.

Surface soil concentrations are predicted to decline by 10 percent of the reduction in metals deposition. For example a 90 percent decline in deposition is assumed to result in a 9 percent reduction in soil metal concentrations.

4.3.2.2 Soil and Dust Ingestion Rates

Incidental soil ingestion rates for direct exposures to soil and dust vary based on several factors including the following:

- Frequency of an individual's hand-to-mouth behaviors
- Seasonal climate conditions that affect availability of soil and dust (e.g., rainfall)
- Type of groundcover at the exposure location (e.g., grass or pavement vs. bare ground)
- Amount and type of outdoor activity
- Individual personal hygiene practices (e.g., frequency of hand washing, house cleaning).

Of these, the frequency of an individual's hand-to-mouth behaviors is considered a primary determinant of soil intake. Frequent mouthing behaviors typical of early childhood, particularly under the age of 6 years, increase the potential for exposure to contaminants in soil and dust. Although fewer studies of adult soil ingestion have been published, hand-to-mouth activities in adults are considered much less frequent than in children. For this reason, risk assessment guidance typically recommends higher soil ingestion rates for children than for adults.

The exposure factor values selected to represent the residential child soil/dust ingestion rates were derived from the ISE model during the evaluation of exposures to lead. For children, the CTE ingestion rate for combined soil and dust was 110 mg/day and the corresponding RME ingestion rate was 206 mg/day. Of the 110 mg/day ingested by the CTE child, 20 mg/day is assumed to be surface soil, 36 mg/day is assumed to be indoor dust, and 54 mg/day is assumed to be outdoor dust. For the RME ingestion rate of 206 mg/day, the comparable assumptions are 31 mg/day surface soil, 70 mg/ indoor dust, and 105 mg/day outdoor dust. These values are the same as those used in the 2005 risk assessment.

For mean soil ingestion by children under 6 years of age, USEPA (2002) recommends 100 mg/day of soil and dust as the best estimate, and 400 mg/day of soil and dust as an upper percentile estimate. The USEPA values are based on short-term population surveys conducted over 3 to 7 days, and USEPA (1997) notes that they do not represent usual intakes over longer time periods. One of these surveys included a pica child, who ate dirt intentionally. Including soil ingestion rates for a pica child causes overestimation of soil intakes for typical child behaviors (USEPA 1997). It is known that some children in La Oroya exhibit pica behavior (Vargas-Machuca Arajo 2008), which may significantly affect blood lead levels. In a blood lead study in Callao, for example, 12 percent of child participants who were reported by their

parents to eat soil also exhibited an excess 3.7 μg/dL of lead in their blood compared to other children in Callao (EHP 1999). Pica behavior in children was reported by approximately 40 percent of the mothers who participated in the 2008 diet study in La Oroya (Vargas-Machuca Arajo 2008).

Adult ingestion rates for soil and dust were developed through calibration of the adult lead model and professional judgment. The adult CTE ingestion rate for combined soil and dust was 70 mg/day, distributed as a soil ingestion rate of 20 mg/day, outdoor dust ingestion rate of 20 mg/day, and indoor dust ingestion rate of 30 mg/day. The adult RME ingestion rate for combined soil and dust was 110 mg/day, distributed as a soil ingestion rate of 32 mg/day, outdoor dust ingestion rate of 35 mg/day, and indoor dust ingestion rate of 43 mg/day. These values are the same as those used in the 2005 risk assessment.

Very few quantitative studies have assessed adult soil ingestion rates, and the available data are of limited reliability (USEPA 1997). In the past, USEPA has recommended RME adult soil ingestion rates of 50 mg/day for industrial settings and 100 mg/day for residential and agricultural scenarios (USEPA 1997). The Canadian Council of Ministers of the Environment, in accordance with Canadian government protocol (CCME 2000), recommends an adult soil ingestion rate of 20 mg/day. Mid-range estimates of adult soil ingestion include 10 mg/day, 65 mg/day (Calabrese et al. 1990), and 6 mg/day (Stanek et al. 1997). High-end estimates of adult soil ingestion include 100 mg/day (Calabrese et al. 1990) and 331 mg/day (Stanek et al. 1997), which are based on a short-term survey not representative of chronic ingestion rates.

4.3.2.3 Relative Absorption Factors

Relative absorption factors are applied to account for the difference in absorption of a chemical between the environmental medium of interest and the exposure medium in the study from which the toxicity value was derived. RAFs are important when evaluating soil and dust ingestion, because there are typically differences in bioavailability between soil/dust and the dosing formulations used in the toxicity studies (usually water, food, or oil). The absorption of a metal from soil or dust depends on many factors, including species of the metal, soil mineralogy, nutritional status of the population, weathering, and more (Kelley et al. 2002).

Relative absorption varies among metals. In the case of arsenic, oral toxicity values for inorganic arsenic are based on studies of human populations exposed to dissolved arsenic naturally present in drinking water. Arsenic dissolved in water is almost completely absorbed (ATSDR 2000). Arsenic in soil is typically one-tenth to one-half as bioavailable as arsenic dissolved in water (that is, the RAF would range from 0.1 to 0.5) (Kelley et al. 2002; Roberts et al. 2007). At a former smelter site in Anaconda, Montana, US, arsenic in soil was reported to have an RAF of 0.20, while indoor dust had an RAF of 0.28 (Freeman et al. 1995).

Absorption of cadmium from water or food is very low, in the range of 1–7 percent (ATSDR 1999). The relative bioavailability of cadmium in soil from a former zinc smelter site was 33 percent, an RAF of 0.33 (Schoof and Freeman 1995). Additional bioavailability studies for cadmium in soil yielded RAFs ranging from 0.2 to 0.9 (Schoof et al. in prep.; Schroder et al. 2003).

Based on this review of available bioavailability studies, RAFs of 0.50 and 0.80 were selected for arsenic in soil and dust, respectively. RAFs of 1.0 were used for other metals. These values were also be used in the 2005 risk assessment.

4.3.3 Inhalation Intakes

The equation used to estimate exposure intakes for inhalation of particulate metals by residents of La Oroya is shown below. This equation accounts for lifetime exposure, combining both the adult and child exposures into one intake calculation:

$$Intake = \left(\frac{C \times EF \times RAF}{AT \times CF} \right) \times \left(\frac{ED_{child} \times InhR_{child}}{BW_{child}} + \frac{\left(ED_{adult} - ED_{child}\right) \times InhR_{adult}}{BW_{adult}} \right)$$

Where:

Intake	=	Intake of chemicals from inhalation of vapors and particulates (mg/kg-day)
C	=	Concentration of chemical in air (mg/m^3)
InhR	=	Inhalation rate (m^3/day)
EF	=	Exposure frequency (day/year)
ED	=	Exposure duration (year)
AT	=	Averaging time (day)
BW	=	Body weight (kg)
CF	=	Unit conversion factor (1 x 10^3 mg/μg)
RAF	=	Relative absorption factor (unitless)

Exposure parameter values selected to estimate intake of metals in air for adult and child residents in La Oroya are presented in Table 4-18 and are discussed below.

4.3.3.1 Inhalation Exposure Point Concentrations

EPCs for inhalation exposure pathways for the current adult and child residents were derived from ambient air monitoring data collected during 2007. ProUCL was used to calculate the

upper 95th percentile confidence limit of the mean based on the appropriate statistical distribution for the monitoring data. The lower of either the maximum detected concentration or the UCLM for each metal was selected as the EPC.

Concentrations of metals in air after 2009 were estimated from the results of the air modeling study.

4.3.3.2 Inhalation Rate

Exposure to metals or other chemicals in ambient air is a function of the concentration of a particular chemical in ambient air and the amount of air inhaled by an individual (USEPA 1989). The internal dose of chemical that an individual receives from inhaled air also is a function of absorption across the lungs. Once the intake of a chemical is estimated, it is compared to health-protective values, which are based on estimates of a population inhalation rate and absorption.

Increased breathing rate is a common adaptation displayed by long-term residents at high altitude (Beall et al. 1997). In order to cope with a hypoxic environment, highlanders may have higher inhalation rates than those assumed for individuals living at low elevations. USEPA has compiled several studies of inhalation rates for various U.S. sample populations. Mean resting daily inhalation rates obtained from these studies range from 0.45 to 0.7 m^3/hour for adult males in the United States (USEPA 1997). In contrast, one study of Aymara highlanders of Bolivia found a mean resting ventilation rate of 0.78 m^3/hour (Beall et al. 1997). Nevertheless, because all air concentration data were reported in normal temperature and pressure, thereby reflecting conditions representative of lowland environments, inhalation rates recommended by USEPA were selected to evaluate exposures via inhalation. USEPA (1997) recommends daily inhalation rates of 11.3 m^3/day for women and 15.2 m^3/day for men. The average of these rates is 13.2 m^3/day. USEPA (1997) does not provide a high-end recommendation. In guidance for evaluating exposures to combustor emissions, USEPA (1998) recommends a rate of 19.9 m^3/day. Considering the range of values in USEPA guidance, 13 and 20 m^3/day were used as the CTE and RME inhalation rates, respectively, for adult residents in La Oroya.

USEPA (1997) recommends daily inhalation rates of 4.5, 6.8, and 8.3 m^3/day for children less than 1, 1–2, and 3–5 years old, respectively. The weighted average of these values is 7.2 m^3/day. In the combustor emissions guidance, USEPA (1998) recommends a rate of 10.1 m^3/day, based on metabolic rates. Considering the range of values in USEPA guidance, 7 and 10 m^3/day were used as the CTE and RME inhalation rates for children.

5 TOXICOLOGICAL ASSESSMENT

The purpose of a toxicity evaluation is to summarize adverse health effects associated with exposure to the chemicals of concern and to identify doses associated with those effects. The dose-response assessment then forms the basis for the identification of toxicity values that are used to predict the risk of adverse health effects from chemical exposures. Chemicals being evaluated in this risk assessment include sulfur dioxide and particulates, lead, arsenic, cadmium, antimony, and copper.

5.1 OVERVIEW OF TOXICOLOGICAL EVALUATION PROCESS

A toxicological evaluation begins by reviewing toxicity information for each chemical from governmental health authorities and in peer-reviewed publications. Toxicity values for cancerous (carcinogenic) and noncancerous (noncarcinogenic) health effects have been developed for many chemicals by government agencies, including the U.S. Environmental Protection Agency, the U.S. Agency for Toxic Substances and Disease Registry (ATSDR), and the World Health Organization (WHO). Numerical expressions of chemical dose and response, these toxicity values are affected by route of exposure (e.g., oral or inhalation), duration of exposure, and other factors.

A single chemical may have one toxicity value for long-term exposure (e.g., years), another for short-term exposure (e.g., hours or days), and a third for exposure of intermediate duration. In risk assessment terminology, long exposures are known as chronic, short exposures as acute, and intermediate as subacute. For many chemicals, the longer the exposure, the lower the dose that induces toxic effects.

5.1.1 Evaluation of Carcinogenic Effects

Cancer slope factors (CSFs) are estimates of the carcinogenic potency of chemicals. Established separately for oral and inhalation exposure routes, cancer slope factors are used to estimate the incremental risk of developing cancer over a lifetime of exposure. In standard risk assessment procedures, estimates of carcinogenic potency reflect the conservative assumption that no threshold exists for carcinogenic effects; in other words, every exposure to a carcinogenic chemical contributes to an individual's overall risk of developing cancer. The slope factor values recommended by USEPA are conservative upper-bound estimates of potential risk. As a result, the "true" cancer risk is unlikely to exceed the estimated risk calculated using the cancer slope factors.

Data obtained from both human and animal studies may be considered to evaluate a chemical's carcinogenicity. USEPA uses weight-of-evidence (WOE) classifications to characterize the extent to which the available data support the hypothesis that an agent causes cancer in humans.

When human data are available and sufficient to show clear carcinogencity, a chemical is categorized as a "known human carcinogen." Chemicals with lower levels of supporting data may be classified as "probable human carcinogens" or "possible human carcinogens." If a conclusion about carcinogenicity cannot be made, the chemical is considered "not classifiable as to human carcinogenicity." The category "evidence of non-carcinogenicity in humans" is assigned when studies provide information that the chemical does not cause cancer (USEPA 2005a).[14]

5.1.2 Evaluation of Noncarcinogenic Effects

Long exposures (i.e., chronic exposures) are defined as exposures exceeding 10 percent of a typical lifetime, usually assumed to be exposure for 7 years or longer. The potential for health effects other than cancer after at least 7 years of exposure is evaluated by comparing the estimated daily intake with a chronic oral or inhalation reference dose (RfD). These toxicity values represent average daily exposure levels at which no adverse health effects are expected to occur with chronic exposures. Subchronic RfDs are applied when exposures are less than 7 years, as is the case with children (i.e., 0 to 6 years). RfDs reflect the underlying assumption that systemic toxicity does not occur until a particular threshold has been reached.

The RfDs for many noncarcinogenic effects are generally derived from laboratory animal studies or human epidemiological studies. In such studies, the RfD is typically calculated by first identifying the highest concentration or dose that does not cause observable adverse effects (the no-observed-adverse-effect level or NOAEL) in the study subject. If an NOAEL cannot be identified from the study, a lowest-observed-adverse-effect level (LOAEL) may be used. This dose or concentration is then divided by uncertainty factors to calculate a reference dose.

The uncertainty factors account for limitations of the underlying data. They are intended to ensure that the calculated toxicity value is unlikely to result in adverse health effects in exposed human populations. For example, an uncertainty factor of 10 is applied to account for interspecies differences (if animal studies were used as the basis for the calculation), and another factor of 10 is applied to address the potentially greater sensitivity of subpopulations such as children or the elderly.

For each chemical addressed in this risk assessment, the toxicological evaluation followed standard procedures outlined by the USEPA (1989, 2003b). The primary source of toxicity values was USEPA's Integrated Risk Information System (IRIS). When subchronic reference values were not available from IRIS, the Agency for Toxic Substances and Disease Registry

[14] The weight of evidence (WOE) categories described in the final *Guidelines for Carcinogen Risk Assessment* (USEPA 2005a) as "standard hazard descriptors" differ from and may eventually supersede those used in USEPA's toxicity database, the Integrated Risk Information System or IRIS (USEPA 2005b). These descriptors include "carcinogenic to humans," "likely to be carcinogenic to humans," "suggestive evidence of carcinogenic potential," "inadequate information to assess carcinogenic potential," and "not likely to be carcinogenic to humans."

Minimal Risk Levels were consulted (ATSDR 2005). Similar to a reference dose, a Minimal Risk Level is an estimate, based on scientific data, of the daily human exposure to a hazardous substance that is likely to be without appreciable risk of adverse noncancer health effects over a specified period of time. The toxicity values selected from these sources for each chemical are summarized in Tables 5-1 and 5-2. The uncertainties and limitations associated with the toxicity values are discussed in the risk characterization section of this report. Key health effects of sulfur dioxide and particulates, lead, arsenic, cadmium, antimony, thallium, and copper are summarized below.

5.2 SULFUR DIOXIDE AND PARTICULATES

Currently the Complex releases large quantities of sulfur dioxide and particulate matter to the air. At sufficient concentrations, each of these pollutants contributes to adverse health effects, particularly in sensitive individuals. However, the specific toxicity of inhaled sulfur dioxide and particulates varies with the composition of the mixture as well as the exposure intensity and time. The content of the particulate material can include metal compounds, sulfuric acid droplets, and very small metal oxide particles coated with sulfuric acid. The air in La Oroya is also affected by vehicle exhaust, other combustion sources, and soil and dust whether windblown or resuspended by vehicle traffic. Sulfur dioxide released to the air by the smelter can also be converted to sulfate particles over time.

Historically, health effects of these compounds have been evaluated from epidemiological studies of people exposed to a mixture of pollutants, with little basis for distinguishing the contribution of each individual pollutant. With increasingly sophisticated statistical techniques and controlled human exposure studies, the singular effects of these pollutants are slowly being elucidated. However, it is clear that there is an interaction between sulfur dioxide and particulates. Both the singular effects and the interactions are discussed below.

The high elevation of La Oroya affects how people breathe and subsequently how they may be impacted by airborne contaminants like sulfur dioxide and particulates. It has been well documented that native and long-term resident populations living at high altitudes (3,000 meters and above) exhibit physiological adaptations to their low-oxygen environment. These adaptations include smaller stature, increased breathing rate, larger lung volume, and more efficient oxygen absorption (de Meer et al. 1995). Increased ventilation and larger lung volume may result in a higher internal dose than one would experience at sea level with the same air concentrations.

5.2.1 Sulfur Dioxide and Sulfuric Acid Health Effects

Sulfur dioxide is a colorless gas with a strong pungent odor. Oxidation of sulfur dioxide, especially at the surface of particles in the presence of a metallic catalyst, leads to the formation

of sulfurous and sulfuric acids. Sulfur dioxide and sulfuric acid are lung irritants. Sulfur dioxide is highly soluble in water and is absorbed in the mucous membranes of the nose and the upper respiratory tract. Sulfuric acid exists as a liquid aerosol or adheres to the surface of particles. When the particles are very small, the sulfuric acid is able to penetrate more deeply into the respiratory tract than sulfur dioxide. At the same concentration, sulfuric acid causes greater irritation than sulfur dioxide; its irritation effect is related to pH and not the sulfate. Ammonia in the body can neutralize the sulfuric acid and lessen or even prevent the irritation.

Sulfur dioxide can constrict the airways, causing difficulty in breathing, wheezing, and tightness in the chest. The sensitivity to sulfur dioxide is highly variable, however, with some individuals unaffected by concentrations that induce severe bronchoconstriction in others (WHO 2000). Studies with human volunteers indicate that most people experience an irritation effect at sulfur dioxide concentrations of 13,000 $\mu g/m^3$ (Klaassen 1996). These effects are reversible and generally disappear within hours after the exposure ends. Data from studies on human asthmatic volunteers suggest that sulfur dioxide-induced bronchoconstriction occurs within 10 minutes and increases minimally or is reduced after 10 minutes of exposure (NRC 2004).

Children and adults with asthma are especially sensitive to sulfur dioxide. The USEPA (1994) estimates that people with asthma may be 10 times as sensitive to sulfur dioxide as non-asthmatic individuals. Susceptibility to sulfur dioxide is determined primarily by respiratory health status and not age (ATSDR 1998).

The concentration of sulfur dioxide needed to induce a response as well as the magnitude of impact are affected by several variables, including mouth breathing, exercise, air temperature, and humidity. Because mouth breathing draws air more deeply into the lungs and allows it to pass over deeper regions of the lung with a thinner mucous blanket, mouth breathing of sulfur dioxide-laden air causes greater constriction than nose breathing. In causing increased respiration through the mouth, exercise can also intensify the reaction to sulfur dioxide. In non-asthmatic individuals, mouth breathing and exercise can lower the concentration required for a response from 13,000 $\mu g/m^3$ to a range of 2,620 $\mu g/m^3$ to 7,860 $\mu g/m^3$ (Klaassen 1996). Exercising asthmatics are even more sensitive than the general population but the responses to sulfur dioxide vary among individuals in this group. Approximately 10 to 20 percent of mild to moderate asthmatics exposed to sulfur dioxide at levels of 500 to 1,300 $\mu g/m^3$ during exercise would experience substantial respiratory effects (USEPA 1994). The most sensitive individuals could experience an incapacitating effect. Exposure to sulfur dioxide in cold or dry air can intensify the respiratory reaction, presumably due to a reduction in airway surface fluids, resulting in decreased absorption of the sulfur dioxide and a longer residence time in the lung (Graham et al. 1999). These conditions are expected to occur with greater frequency at altitude than in lower elevations.

Inhaled sulfuric acid also causes irritation effects leading to bronchoconstriction, but at lower concentrations than required for a similar response from sulfur dioxide. The sulfuric acid enters the respiratory system as a liquid aerosol or on the surface of particles. The liquid aerosols can grow by absorbing water from the humid respiratory tract. If the particles have already penetrated deep into the lung, this growth can lead to longer retention in the respiratory tract as the particles grow too large to exit from the small passages in the deeper regions of the respiratory tract. With less mucus protection and a higher density of sensitive areas than the upper airway, these deeper regions become relatively more irritated upon exposure. Deeper penetration into the respiratory tract also increases the time required for recovery after exposure to sulfuric acid aerosols.

Sulfur dioxide adsorbed onto the small metal oxide particles released from the Complex can oxidize to sulfuric acid. Studies have shown that as the diameter of particles decreases from 7 μm to less than 1 μm, less sulfuric acid is needed to induce irritation in the airway. With large particles, a concentration of 30,000 $\mu g/m^3$ did not cause airway constriction in guinea pigs. In contrast, a concentration of less than 1,000 $\mu g/m^3$ was sufficient to cause airway constriction when adsorbed onto particles with a diameter of 0.3 μm. The sensitivity of guinea pigs to sulfur dioxide and sulfates is similar to that of asthmatics (Klaassen 1996).

An extensive review of the scientific literature was conducted as part of this risk assessment; no studies were found on the responses to sulfur dioxide of populations living at high altitudes. Increased ventilation and pulmonary tidal volume in Andean populations could increase the penetration of sulfur dioxide and sulfuric acid into the lung. As discussed above, the deeper penetration could exacerbate the effect seen in the upper regions of the respiratory tract.

5.2.2 Sulfur Dioxide Health-Based Criteria

Health-based standards for ambient air concentrations of sulfur dioxide have been established by governmental and nongovernmental organizations. The criteria established by the Peruvian government, the WHO, and agencies in the U.S. were considered relevant for this risk assessment. Standards for acute exposures of less than 24 hours and long-term exposures are presented and discussed below.

5.2.2.1 Acute Inhalation Exposure Criteria for Sulfur Dioxide

In 2001, the government of Peru (CONAM 2001) established a health-based ambient 24-hour air quality standard for sulfur dioxide of 365 $\mu g/m^3$. This value matches the USEPA standard that, despite periodic review, has not changed since 1972. In 2005, the World Health Organization reduced its 24-hour air quality guideline (AQG) from 125 $\mu g/m^3$ to 20 $\mu g/m^3$. WHO and EPA appear to have used similar evidence as the basis for their standards, but have interpreted the data differently.

In 2008, the Peruvian government initiated a gradual reduction of standards to match the WHO guidelines: from the existing 365 μg/m^3, to 80 μg/m^3 in 2009, to 20 μg/m^3 in 2014.

The previous WHO 24-hour sulfur dioxide standard of 125 μg/m^3 had been calculated from the lowest-observed-effect level (LOEL) with an uncertainty factor of 2 applied (WHO 2005). More recent evidence demonstrates potential health effects at lower levels of exposure. The WHO acknowledges that the causal link between sulfur dioxide and adverse health effects remains uncertain, as epidemiological studies of sulfur dioxide exposure are almost always confounded by an array of other potentially damaging air pollutants. However, based on the assumption that reducing sulfur dioxide concentrations is an effective means to reduce exposure to a mixture of pollutants, the WHO revised the guideline to a conservative level of 20 μg/m^3.

USEPA's 24-hour standard for sulfur dioxide is based on epidemiological studies of mortality and bronchitis in London. From the mortality data, the USEPA concluded that a significant risk of increased mortality exists for sulfur dioxide exposures above 500 μg/m^3. The bronchitis study had also suggested a minimum sulfur dioxide air concentration leading to a significant response of 500 μg/m^3 (USEPA 1982). Both the mortality and bronchitis studies represented population groups among the most sensitive to pollutant effects (USEPA 1982). In 1982, the 24-hour standard was set at 365 μg/m^3 to provide an adequate margin of safety for inhalation effects. After a review of the 24-hour standard in 1996, the USEPA concluded a revision was not required.

The USEPA is again in the process of reviewing the primary National Ambient Air Quality Standards (NAAQS) for sulfur oxides. As part of that process, USEPA issued a second draft of its integrated science assessment (ISA) for sulfur oxides in May 2008 (USEPA 2008d). This draft is open for continued comment and review. USEPA's preliminary conclusion is that there is a causal relationship between short-term exposure to sulfur dioxide and respiratory morbidity. The relationship is less clear for cardiovascular effects: the agency has concluded that evidence is suggestive of but not sufficient to infer a causal relationship between sulfur dioxide and cardiovascular effects, morbidity, and mortality. Thus, the standard is likely to remain at 365 μg/m^3.

Another set of acute exposure criteria for sulfur dioxide is available from the National Research Council in the United States (NRC 2004). The National Research Council establishes acute exposure guideline levels (AEGLs) that represent limits for the general public for chemical exposures at five intervals ranging from 10 minutes to 8 hours. The AEGLs are three-tiered to reflect severity of response. The level one AEGL is the airborne concentration at which even sensitive individuals would experience only mild and reversible health effects. The level two AEGL is the concentration at which sensitive individuals would experience temporary health effects considered moderate to severe. The level three AEGL is the air concentration above which the general public, including sensitive individuals, could experience life-threatening health effects or death.

The AEGLs for sulfur dioxide provide a means to assess the severity of possible health effects when the ambient air concentrations in communities around the Complex exceed the Peruvian and USEPA air quality criteria. Like the ambient air quality standards, the sulfur dioxide AEGLs were developed to protect sensitive individuals from adverse health effects. The current set of AEGLs for sulfur dioxide are "interim values," established only after rigorous scientific review and public comment, but subject to a final review by the National Research Council Subcommittee.

The level one and level two AEGLs for sulfur dioxide are based on human studies of exercising adults. The level one AEGL value of 524 $\mu g/m^3$ is expected to result in temporary and reversible respiratory effects for asthmatics and to have no effect on healthy individuals. The level two AEGL value of 1,965 $\mu g/m^3$ is the threshold for moderate to severe, but reversible, respiratory response in exercising asthmatics. The level one and two AEGL values apply for all averaging times from 10 minutes to 8 hours, given the finding that the effects of sulfur dioxide generally occur in the first 10 minutes of the exposure and increase minimally or even decrease with continued exposure.

The level three AEGL values, for life-threatening or lethal exposures, were lowered in December 2006 (NAC 2006). The U.S. national advisory committee working on these revisions established a guideline of 78,600 $\mu g/m^3$ for averaging times of 10 to 60 minutes, 49,780 $\mu g/m^3$ for an averaging time of 4 hours, and 25,152 $\mu g/m^3$ for an averaging time of 8 hours. These compare to prior values of 110,000 $\mu g/m^3$ for 10 minutes, 84,000 $\mu g/m^3$ for 30 minutes, 71,000 $\mu g/m^3$ for 60 minutes, 50,000 $\mu g/m^3$ for 4 hours, and 42,000 $\mu g/m^3$ for 8 hours. Additionally, the National Institute of Occupational Safety and Health in the United States has set a threshold sulfur dioxide air concentration of 262,000 $\mu g/m^3$ as immediately dangerous to life and health (NIOSH 2005). This value is more appropriate for healthy workers rather than the general public.

For this complementary risk assessment, the Peruvian sulfur dioxide 24-hour ambient air quality standard of 365 $\mu g/m^3$ was used for inhalation exposures lasting 24 hours or less. The basis for the standard is the protection of human health for sensitive populations in the general public, and is therefore relevant for the populations evaluated in this risk assessment. The WHO 24-hour air quality guideline value is discussed in the risk characterization as a means to address uncertainty in defining the appropriate risk threshold. The AEGL values are used to evaluate the potential magnitude of health effects on an hourly basis, particularly when the 24-hour criteria are exceeded. The acute inhalation toxicity criteria selected for use in the risk characterization are summarized in Table 5-3.

5.2.2.2 Chronic Inhalation Exposure Criteria for Sulfur Dioxide

The Peruvian government (CONAM 2001) established an annual average sulfur dioxide ambient air standard of 80 $\mu g/m^3$, which represents an arithmetic mean value for a 12-month

period. In 2008, the Peruvian government proposed that the annual standard be reduced to 50 μg/m3 in 2012. By contrast, WHO determined in 2005 that an annual standard, previously set at 46 $\mu g/m^3$, was no longer necessary, as compliance with its new 20 $\mu g/m^3$ 24-hour standard would ensure low annual levels.

The USEPA's annual ambient air quality standard for sulfur dioxide is 80 $\mu g/m^3$ (40 CFR § 50, 1996). Noting in its most recent review the paucity of quantitative data with which to develop long-term concentration-response relationships for sulfur dioxide, the USEPA gave no indication that this standard will be modified.

For the risk characterization of chronic exposures in this complementary risk assessment, the current annual average standard of 80 $\mu g/m^3$ established by the Peruvian and U.S. governments is used as the health criterion.

5.2.3 Particulate Matter Health Effects and Health-based Criteria

Particulate matter is a complex mixture of components with diverse chemical and physical characteristics. This heterogeneity complicates the interpretation of findings on exposure and risk; different characteristics of particulates may be relevant to different health effects. For regulatory purposes, particles are described by their aerodynamic diameter, as size dictates the effects of dispersion and removal from the atmosphere as well as behavior in the respiratory system.

Coarse particles are usually defined as having a diameter less than 10 μm and are known as PM_{10}. They are generated from mechanical processes such as grinding and crushing, or from suspension of dusts and biological material such as pollen or mold. Coarse particles are subject to gravitational effects and typically travel only short distances over a period of hours. When inhaled, the coarse particles tend to stay in the thoracic region, or the upper reaches of the respiratory tract, and are closely associated with aggravation of existing respiratory conditions such as asthma.

Fine particles, with aerodynamic diameters less than 2.5 μm, are known as $PM_{2.5}$. Fine particles are generated primarily from high-temperature combustion or smelting processes, vapor condensation, or secondary reactions like the formation of sulfates from sulfur dioxide. They can result from the coagulation of even smaller particles and from the condensation of gas or vapor molecules on the surface of such smaller particles. These fine particles remain suspended in the atmosphere for much longer periods and travel much farther from their point of origin than do coarse particles. Once inhaled, fine particles are very likely to be deposited in the smaller conducting airways and alveoli. Inhalation exposures to fine particles are associated with morbidity effects such as aggravation of existing respiratory and cardiovascular disease, changes in lung function, and premature mortality in sensitive individuals.

Ultrafine particles of less than 0.1 μm in diameter are produced by the condensation of metals or organic compounds that are vaporized during high-temperature combustion, and by the condensation of gases that have been converted in atmospheric reactions to low vapor-pressure substances. One of the main precursor gases in these processes is sulfur dioxide. Thus, changes in concentrations of sulfur dioxide may affect ambient $PM_{2.5}$ concentrations.

5.2.3.1 Acute Inhalation Exposure Criteria for Particulates

In 2001 the Peruvian government established a 24-hour average air quality standard for PM_{10} of 150 $\mu g/m^3$. As shown in Table 5-4, the 24-hour PM_{10} standard is the same as that of the USEPA (1997b), though the EPA standard is not to be exceeded more than an average of one time in 3 years at a given location whereas the Peruvian standard may be exceeded up to three times per year.

An air quality standard for PM_{10} (150 $\mu g/m^3$) was first established in the US in 1987. By 1994, there were studies showing that mortality and morbidity persisted in sensitive populations in areas or at times that met the existing PM_{10} standard (USEPA 1997b). Comparison of health effects between fine ($PM_{2.5}$) and coarse (PM_{10}) particle fractions indicated that the fine fraction was a better indicator of mortality and morbidity. Accordingly, the standards were expanded in 1997 to include $PM_{2.5}$ in addition to PM_{10}.

The initial 24-hour $PM_{2.5}$ standard in the United States was 65 $\mu g/m^3$. After extensive review of epidemiological, clinical, and biomechanistic studies of exposure to ambient particulate matter and adverse health effects, USEPA reduced the 24-hour $PM_{2.5}$ standard from 65 to 35 $\mu g/m^3$. Among the health effects found were aggravated asthma, chronic bronchitis, reduced lung function, irregular heartbeat, heart attack, and premature death in people with heart or lung disease (USEPA 2006b). A location is considered in compliance with the standard if the 98th percentile of 24-hour $PM_{2.5}$ concentrations in a year, averaged over 3 years, does not exceed 35 $\mu g/m^3$.

The World Health Organization first established guidelines for particulate matter in ambient air in 2005 (WHO 2005). Based on a review of the scientific literature, the WHO concluded that the day-to-day variations in particulate matter correlate well with variations in health effects, and that these effects are seen at low levels of exposure commonly encountered in developed countries. Though the WHO asserts that air quality guidelines cannot be set low enough to provide complete protection, the guidelines are set to achieve the lowest concentrations possible. The 24-hour $PM_{2.5}$ standard is 25 $\mu g/m^3$, which is not to be exceeded more than three times per year. The corresponding PM_{10} standard is twice the $PM_{2.5}$ standard, or 50 $\mu g/m^3$. This ratio of $PM_{2.5}$ to PM_{10} is typical of urban areas in developing countries and represents the lower limit of the range found in urban areas of developed countries.

The Peruvian 24-hour standard for $PM_{2.5}$ of 65 μg/m^3 is higher than both the current USEPA standard and the WHO guideline. Consequently, the Peruvian government has proposed a gradual implementation of the WHO guideline, with a 24-hour standard of 40 μg/m^3 to be effective in 2010 and a further reduction to 25 μg/m^3 in 2012 (CONAM 2008a).

5.2.3.2 Chronic Inhalation Exposure Criteria for Particulates

The Peruvian government (CONAM 2001) has established an annual standard for PM_{10} of 50 μg/m^3. Peru does not currently have an annual standard for $PM_{2.5}$. It was proposed in 2008 that a standard be established to match the WHO guideline of 10μg/m^3. The standard would take effect in 2012 (CONAM 2008a). There has been no discussion of changes to the Peruvian annual standard for PM_{10}.

The USEPA previously held the same annual standard for PM_{10} of 50 μg/m^3 (40 CFR § 50, 1987). In 2006, however, concluding that the evidence linking long-term PM_{10} exposure and health problems was insufficient, USEPA (2006a) revoked the annual standard. The agency retained the $PM_{2.5}$ annual standard of 15 μg/m^3, which is considered to have been met if the average of the prior 3 years of measurements

In accordance with the increasing evidence of the health effects of fine particulates, the newly developed WHO (2005) guidelines for particulate matter are based on epidemiological studies using $PM_{2.5}$. The $PM_{2.5}$ annual guideline of 10 μg/m^3 was chosen on the basis of an American Cancer Society study finding this concentration to be the lower limit of the range over which significant effects on survival occur (Pope 2002). This value is supported by a long-term exposure study of six US cities, in which increased risk was observed at 11 μg/m^3 to 15 μg/m^3 (Dockery 1993).

5.3 LEAD

Lead occurs naturally in the environment as a bluish-gray metal. In its natural form, lead is present in small amounts within the earth's crust. Lead may combine with other chemicals to form lead salts and organic lead compounds. These forms of lead are also present in the environment, largely as a result of human activities. Lead released to the environment may be present in air, soil, water, dust, plants, and animals.

Different forms of lead have different properties that influence its behavior within the environment. For example, metallic lead does not dissolve in water, whereas lead salts may dissolve in water. The size of lead particles, the ease with which lead compounds evaporate, and meteorological conditions all affect the extent to which lead released to air will move away from the source and be deposited onto the ground or a body of water. Once deposited onto soil, the movement of lead is generally limited but varies with the type of lead salt or compound as well as different soil characteristics. Lead in soil and dust may result not only from air

deposition, but also from erosion of mineral deposits and weathering of lead-containing materials (e.g., lead-based paints) used on buildings or in other materials. Resuspension of lead in windblown soil may also contribute to lead in dust.

Health risks associated with lead exposures are assessed by determining the potential to exceed an absorbed dose of lead, measured as a blood lead concentration, that is associated with increased potential for adverse health effects (CDC 1997, 2002; USEPA 1998).

5.3.1 Lead Toxicokinetics

The absorption of lead into the body is influenced by the exposure route, chemical form, and exposure medium (e.g., paint, soil, dust). As discussed in further detail below, the age and physiological state of the exposed individual (e.g., fasting, nutritional calcium and iron status) also influences lead absorption. Lead absorption occurs primarily within the gastrointestinal and respiratory tracts. Following absorption, it is widely distributed to blood plasma and soft tissues. Lead is then redistributed in the body by exchanges between blood plasma and bone surfaces, as well as in the kidney and intestines. The exchange of lead between blood and bone results in the accumulation of lead in bone. In addition, lead freely crosses the placenta, a pathway that results in exposure to the fetus throughout pregnancy.

Lead that is not retained in the body is excreted primarily in the feces and urine. Studies of suckling mice and rats suggest that as much as one-third of the maternal dose of lead in mother's milk may be transferred during lactation. Thus, for nursing mothers, lead may also be excreted in breast milk.

Bone represents a significant potential reservoir of lead within the body. Lead deposited in bone during bone growth and remodeling may be released from bone stores and contribute to blood lead concentrations during bone resorption. Life stages such as pregnancy, menopause, and advanced age, as well as disease states, such as osteoporosis or prolonged periods of immobilization, may result in greater release of lead from bone, increasing lead concentrations in blood.

The exchange of lead between blood plasma and bone surfaces is also influenced by how well lead is absorbed by the gastrointestinal system and how well it is excreted from the body (ATSDR 2007b). In infants and young children, gastrointestinal absorption and excretion efficiencies are higher than in adults (Klaassen 1996). The combination of these factors and increased bone turnover rates in children results in greater transfers of bone lead to blood in children. Conversely, reduced bone turnover rates in adults results in increased retention of absorbed lead in bone. This accounts for the lower percentage of bone lead to total body burden in children (73 percent) compared with adults (94 percent) (ATSDR 2007b).

Dietary insufficiencies may also contribute to increased absorption of lead. An inverse relationship has been observed between dietary intake of calcium and blood lead concentrations in children and adults (ATSDR 2007b). A similar relationship has been reported for nutritional status related to iron. Comparisons of blood lead concentrations in iron-deficient children with those in iron-replete children suggest that the deficiency may result in higher lead absorption or alter lead biokinetics in a manner that contributes to elevated blood lead levels (ATSDR 2007b; Kwong et al. 2004; Solon et al. 2008). Mechanisms contributing to lead-calcium and lead-iron interactions in humans have also been suggested for lead interactions with copper, cadmium, magnesium, and zinc (ATSDR 2007b).

In addition to factors including developmental life-stage, disease state, and nutritional status, the altitude of the residing population may affect the absorption and distribution of lead in the body. This factor is important for considering blood lead levels and health effects associated with lead exposure in high-altitude populations, such as that of La Oroya.

Populations residing at high elevations are expected to have altered blood lead levels in response to lead exposures compared with populations residing at low elevations. Lead in blood is contained primarily in red blood cells. As shown by higher hematocrit and hemoglobin values, high-altitude populations have more red blood cells (Ramirez-Cardich et al. 2004; Beall et al. 1998). Several models exist for correcting hemoglobin levels for altitude; the most recent research suggests an exponential curve is more appropriate than a linear correction, indicating that the effects of altitude on hemoglobin levels are more extreme at higher elevations (Dirren et al. 1994). Based on the model of Dirren et al. (1994), the population of La Oroya residing at 3745 meters could be expected to have hemoglobin levels 20-25 percent higher than those of residents of Lima. When lead enters the red blood cell, it binds mainly to hemoglobin; an individual who resides at a higher elevation will likely have more red blood cells and more available binding sites (UCDEH 1997). The increased number of binding sites will result in a higher blood lead level than an identically exposed individual living at sea level. Thus, high-altitude populations may have a lower body burden and less health risk than low-altitude populations with similar blood lead levels. Conversely, people with anemia and subsequent low hematocrit levels may have higher body burdens and greater risk than nonanemic people with comparable blood lead levels (CDC 2002).

References to the occurrence of toxic effects at various blood lead levels in the following sections are for low-altitude populations. High-altitude populations, such as residents of La Oroya, may experience the same effects at blood lead levels 20-25 percent greater than those listed if there is a direct correlation between hemoglobin levels and blood lead levels. The role of these factors in La Oroya is discussed in the Risk Characterization, Section 6.

5.3.2 Lead Health Effects

Proposed mechanisms of lead toxicity are believed to involve fundamental biochemical processes, such as changes in cell membrane cation transport systems and interference with heme biosynthesis. These processes can affect almost every organ and system in the body. The kinds of effects caused by lead are the same at comparable doses whether lead is inhaled or ingested.

5.3.2.1 Interpretation of Health Effects Data

Numerous studies of occupationally exposed groups and the general population provide dose-effect data for lead. The specific biomarker of exposure and time at which the biomarker is measured are important considerations for interpreting epidemiological data. Specifically, blood lead levels more closely reflect recent exposure to lead, while measures of lead in bone or elevated zinc protoporphyrin (ZPP) levels have been reported as reliable indicators of chronic exposures. Releases of lead from bone that occur after an exposure has stopped may make it difficult to interpret lead health effects that are observed in different populations with similar blood lead concentrations. Measured blood lead levels may not account for the level and duration of past exposures to lead, and may therefore not reflect an accurate cumulative exposure history from which to evaluate observed effects. For instance, ATSDR (2007b) reports that some occupational exposure studies have detected a number of neurobehavioral endpoints associated with current blood lead levels between 40 and 80 μg/dL in workers, but that measures of cumulative exposure may better predict impaired performance in workers with current blood lead levels less than 40 μg/dL.

Similarly, lead accumulated in the mother's bone may be transferred to the fetus during pregnancy and to the newborn via breast milk, even in the absence of recent maternal exposures to lead. Thus, exposure to lead during fetal and newborn development will reflect both past and current lead exposures of the mother.

The time at which exposure occurs may also influence lead's toxicity. For instance, the developing nervous system is affected at lower exposures than the mature system; thus children are more sensitive to lead exposure than are adults. In addition, several recent studies suggest that prenatal exposure to lead may play a larger role than post-natal exposure in causing neurodevelopmental deficits associated with elevated blood lead in children (Schnass et al. 2006; Ronchetti et al. 2006).

Because blood lead concentrations may reflect past and recent exposures and because certain windows of exposure may differentially influence its toxicity, interpretation of blood lead data must be considered in the context of the individual's past history of exposure.

5.3.2.2 Summary of Health Effects

Lead has been shown to exert a broad range of adverse health effects on multiple organ systems. Health effects have been observed on heme[15] biosynthesis and related functions, neurological development and function, reproduction and physical development, kidney function, and cardiovascular function. The developing neurological system is particularly sensitive to the effects of lead; effects to this system provide the basis for lead screening guidelines. An overview of health effects associated with lead, organized generally by blood lead concentration, is provided below.

Many of lead's health effects may occur without overt signs of toxicity. For instance, effects on heme metabolism such as inhibition of the activity of δ-aminolevulinic acid dehydratase (ALAD), an enzyme involved in heme biosynthesis, can be detected at blood lead levels below 10 μg/dL in all ages. With prolonged exposure to much higher levels, clinically significant effects on heme synthesis may occur. These effects include decreased hemoglobin production and destruction of red blood cells. In occupationally exposed adults, USEPA estimated the threshold blood lead level for a decrease in hemoglobin to be 50 μg/dL. In children, a blood lead threshold of about 40 μg/dL has been suggested for decreased hemoglobin levels (ATSDR 2007b).

Lead also impairs the activity of zinc-requiring enzymes in the heme biosynthesis pathway. Thus, insufficient levels of zinc in the diet could exacerbate the effects of lead exposure. Conversely, nutritionally adequate dietary intakes of zinc may help to reduce the risks of lead toxicity because of the protection offered by zinc against lead-induced inhibition of zinc-dependent enzymes (ATSDR 2007b).

Effects on neurobehavioral function such as decreased performance on IQ tests and other measures have been reported at blood lead levels below 10 μg/dL in children (ATSDR 2007b; Lanphear et al. 2005; Canfield et al. 2003; Min et al. 2006; Tellez Rojo et al. 2008). No threshold for the effects of lead on IQ has been identified. Several recent studies have reported that the rate of decline in performance is greater at lower levels of blood lead, suggesting a supra-linear shape in the dose-effect relationship (Canfield et al. 2003; Hu et al. 2006; Schnass et al. 2008, Lanphear et al. 2005; Tellez Rojo et al. 2008). There is, however, no scientific consensus on the dose-effect relationship between lead and neurobehavioral performance in children.

Inconsistent findings of effects on fetuses of low-level lead exposures have been reported; however, shortened gestational length and lower birth weights have been reported at maternal blood lead levels lower than 15 μg/dL in some epidemiological studies (ATSDR 2007b). It is noteworthy that these low-level effects of lead are apparent only in studies comparing

[15] Heme is the iron-containing component of hemoglobin in red blood cells. Hemoglobin is responsible for carrying oxygen from the lungs to other tissues in the body.

populations of children with different blood lead levels. These effects would not be detectable in an individual child.

Prenatal and early childhood exposure to lead may also slow mental development and cause cognitive deficits later in childhood. There is some evidence that these effects may persist beyond childhood. Cecil et al. 2008 reported that childhood blood lead in the range of 4.7-37 μg/dL was associated with decreased volumes of gray matter in the adult brain in regions responsible for executive functions, mood regulation, and decision making. In addition, the study found a positive correlation between fine-motor skills and the volume of gray matter in these areas.

More pronounced effects of exposure to lead may occur in the blood lead range of 15-30 μg/dL. These effects are particularly apparent in children. Cardiovascular effects such as degenerative changes in myocardium and electrocardiogram abnormalities have been reported in studies of children with blood lead levels ranging from 6 to 20 μg/dL. Anemia (defined as a hematocrit less than 35 percent in populations living at sea level) has also been reported in young children at 25 μg/dL blood lead (ATSDR 2007b).

At blood lead levels exceeding 30 μg/dL in infants and children, kidney changes and growth retardation have been reported in association with exposure to lead (ATSDR 2007b). In the blood lead range of 33-120 μg/dL, impairment of vitamin D metabolism may also occur, particularly in cases of chronically high lead exposures of children who are nutritionally deficient in calcium, phosphorus, and vitamin D. At blood lead levels greater than 30 μg/dL, more overt neurological impairment may also become apparent (ATSDR 2007b).

Reduced sperm count and other effects on the male reproductive system have been observed in adult occupational studies at blood lead levels of 40-50 μg/dL. In adult occupational exposure studies (primarily via inhalation), blood lead levels in the range of 40-60 μg/dL have been associated with neurological symptoms including weakness of extensor muscles and upper limbs, loss of appetite, lower limb numbness and tingling, cognitive impairment, visual-motor coordination effects, and impaired verbal reasoning ability. Exposures in this range have also been associated with altered levels of thyroid, and testicular hormones (ATSDR 2007b). Some adult worker studies also report colic at blood leads in this range; however, such gastrointestinal effects more typically occur at much higher levels (i.e., 100-200 μg/dL).

In children, ingestion of large amounts of lead may result in colic (60-100 μg/dL); irritability, lethargy, and behavioral problems (60-450 μg/dL); and encephalopathy (>80-800 μg/dL) (ATSDR 2007b).

The effects associated with a range of blood lead levels in adults and children are depicted in Figure 5-1.

5.3.2.3 CDC Level of Concern

In the U.S. the Centers for Disease Control (CDC 1991, 2002) has identified a level of concern of 10 μg/dL as the concentration above which further evaluation may be warranted for an individual child. The 10 μg/dL blood lead level was selected based on studies indicating that exposures resulting in blood lead levels at or above this concentration may present an increased health risk to children (CDC 1991, 1997, 2002; USEPA 1998). The screening guideline is a risk management tool and does not represent a threshold for lead toxicity.

As shown in Figure 5-2 the 10-μg/dL blood lead level of concern is considerably lower than earlier levels selected by the CDC in the 1960s. The trend toward lower blood lead levels of concern over time reflects the continued identification of new information concerning lower doses at which adverse effects related to lead could occur.

Since the 10-μg/dL level was selected, additional studies have been published examining the effects of low levels of lead on children's health. These studies are described above. The CDC (2004) reviewed these studies and decided to retain the 10-μg/dL blood lead level of concern for the following reasons:

- No effective clinical interventions are known to lower blood lead levels for children with levels less than 10 μg/dL or to reduce the risks for adverse developmental effects.
- Children cannot be accurately classified as having blood lead levels above or below 10 μg/dL because of the inaccuracy inherent in laboratory testing.
- There is no evidence of a threshold below which adverse effects are not experienced. Thus, any decision to establish a new level of concern would be arbitrary and provide uncertain benefits.

Because children are more susceptible to lead exposures and effects than adults, the CDC's blood lead level of concern in children is considered health-protective of adults. Specifically, early childhood (ages 0 to 6 years) represents a period of rapid neurological development that is particularly sensitive to critical effects caused by lead exposure (ATSDR 2007b). Children also engage in hand-to-mouth activities more frequently than adults. Such behavior increases their potential for ingestion of lead. In addition, young children also tend to spend more time on ground surfaces where lead deposits are likely to be present. Nursing infants may also be exposed via breast milk from mothers with prior or ongoing lead exposures.

5.3.3 Lead Carcinogenicity

The USEPA (2008a) has determined that lead is a probable human carcinogen based on sufficient evidence of carcinogenicity in animals. Specifically, bioassays in rats and mice reported statistically significant increases in renal tumors after dietary and subcutaneous exposure to several soluble lead salts. The animal assays provided reproducible results in

several laboratories, in multiple rat strains, and with some evidence of multiple tumor sites. Short-term studies indicated that lead affects gene expression. Evidence of lead carcinogenicity in human studies was found to be inadequate. Despite the finding that lead is a probable human carcinogen, USEPA has determined that noncancer effects of lead provide a more sensitive toxicity endpoint than cancer effects, and no toxicity values have been derived for cancer endpoints.

5.4 ARSENIC

Arsenic is a natural element that is widely distributed in much of the earth's crust. Volcanic eruptions have contributed to its ubiquitous distribution in the environment. Human activities, including mining of ores associated with arsenic (e.g., copper and lead), burning of arsenic-containing coal and other waste products in coal-fired power plants or for incineration, and use of arsenical pesticides, also contribute to arsenic present in the environment. Arsenic in soil and minerals may enter the air, water, and land from windblown dust. Arsenic may also enter water via leaching or runoff.

Arsenic is found in several forms within environmental and biological systems. It exists in multiple oxidation states and in a number of inorganic and organic forms. The inorganic forms are the most toxic. Inorganic forms of arsenic include trivalent arsenic (As[III]), also called arsenite (the form found in arsenic trioxide), and pentavelant arsenic (As[V]), also called arsenate. Organic forms of arsenic include trivalent monomethyarsinous acid (MMA[III]), pentavalent monomethylarsinic acid (MMA[V]), dimethylarsinous acid (DMA[III]), and dimethylarsinic acid (DMA[V]). Arsenocholine, arsenobetaine, and arseno-sugars are organic forms commonly found in seafood.

The predominant forms of inorganic arsenic compounds in soils are trivalent and pentavalent. The solubility of inorganic arsenic compounds in water varies widely. Sodium arsenate and arsenic trioxide are highly water-soluble; less soluble forms include sulfide minerals; complex oxides; and arsenic present in iron, manganese, and phosphate mineral species. Ionic forms of inorganic arsenic may adsorb to soil constituents. The presence of less soluble mineral phases and ionic forms that are strongly adsorbed to soil particles or coprecipitated with other elements in soil is thought to contribute to the reduced bioavailability of arsenic in soil.

Because arsenic occurs naturally in the environment, all humans are exposed to low doses. For most populations, the primary source of exposure to inorganic arsenic is the diet. Globally, drinking water is the main source of excessive arsenic exposure and poisoning, with some Asian and South American populations exposed to concentrations in excess of 100 μg/L in drinking water. Consumption of fish and seafood also represents a significant source of dietary arsenic intake for many people. However, arsenic in seafood is largely in nontoxic organic forms, such as arsenobetaine.

In addition to typical sources of arsenic exposure in the diet and drinking water, individuals may have habits that cause additional exposure. For example, arsenic in wine and beer (Pedersen et al. 1994) could contribute to greater than normal arsenic intake. Arsenic is present in tobacco smoke (inhaled directly or indirectly) and some studies have detected increased exposures to arsenic in smokers and their families (de Peyster and Silvers 1995; Chiba and Maseroni 1992). In contrast, other studies found no difference in arsenic levels between smokers and nonsmokers (Gebel et al. 1998; Kraus et al. 2000). The amount of arsenic in cigarettes may vary with growing conditions for tobacco crops, and this variability may contribute to the variation in findings. Arsenic has also been detected in homeopathic medicines (Kerr and Saryan 1986), Chinese proprietary medicines manufactured in Asia (Chan 1994), and leaf samples from medicinal plants (Reddy and Reddy 1997). Rare cases of acute arsenic poisoning have been reported in children and adults using Chinese proprietary medicines (Chan 1994).

5.4.1 Arsenic Toxicokinetics

When present in a water-soluble form, ingested inorganic arsenic is well absorbed; studies in humans demonstrate that greater than 95 percent of arsenic in this form may be absorbed (ATSDR 2007a; Klaassen 2001). Oral bioavailability of inorganic arsenic is reduced when ingested as soil or dust. Less soluble forms of arsenic are reported to be one-half to one-tenth as bioavailable as the more soluble forms of arsenic (Roberts et al. 2007; USEPA 2005e).

When inhaled, the water-soluble forms of arsenic are most rapidly and efficiently absorbed, whereas the absorption of particulate-bound arsenic is greatly dependent on the dynamics of deposition and clearance of particles by the respiratory system (ATSDR 2007a). The deposition and clearance of particles are influenced by the properties of the particles and exposure conditions. Dermal absorption of arsenic is low compared with other routes of exposure (ATSDR 2007a), and dermal absorption from soil is negligible (Lowney et al. 2007).

Following absorption, arsenic is widely distributed throughout the body; it does not show preferential accumulation in any internal organs. Inorganic arsenic does not appear to cross the blood-brain barrier; however, its ability to transfer across the placenta has been reported in both humans and rats (ATSDR 2007a).

Inorganic arsenic is metabolized through a series of reduction and oxidative methylation reactions. In the first step of metabolism, inorganic arsenate (As[V]) is reduced to arsenite (As[III]). Following the initial reduction step, arsenite is methylated to MMA(V), which is reduced to MMA(III), and then methylated to the principle metabolite, DMA. While arsenic metabolism occurs in many tissues, the main site of methylation activity is the liver. Although the process of methylation is saturable, under normal conditions the availability of methyl donors (methionine, choline, cysteine) is not limited, and the process does not reach capacity.

However, conditions including dietary deficiencies (e.g., restriction of methyl donor intake) can result in decreased methylating capacity (ATSDR 2007a).

While earlier studies reported that stable pentavalent methyl derivatives of arsenic appeared to be less toxic than inorganic forms, recent studies evaluating multiple toxicity endpoints have suggested that the less stable trivalent methyl forms may have greater toxicity than inorganic arsenic forms. One study measuring toxicity in hepatocytes found that MMA(III) was more toxic than both arsenite (As[III]) and MMA(V). MMA(III) and DMA(III) have also been found to be more effective than As(III) in inducing DNA damage (Health Canada 2006). Further work is needed to confirm these findings and establish the role of various metabolites of inorganic arsenic in its toxicity (ATSDR 2007a).

The primary pathway of elimination of arsenic is via urine. Approximately 75 percent of the absorbed dose of arsenic is eliminated by this pathway. Inorganic arsenic is rapidly excreted in urine, mostly within the first day following ingestion, whereas the methylated forms are mostly excreted within 2 to 3 days after exposure (Health Canada 2006). A small fraction of arsenic is excreted through feces, bile, sweat, and breast milk (ATSDR 2007a; Health Canada 2006).

5.4.2 Arsenic Health Effects

The vast majority of available studies evaluating arsenic toxicity are through the oral route of exposure. A large number of studies in human populations exposed to high levels of arsenic in drinking water provide extensive data on toxicity via this route. The data available to quantify the dose response of effects following inhalation is more limited. The majority of evaluations of inhalation toxicity are studies of occupational exposure often limited by incomplete control of potential confounders. Studies for inhalation also frequently involve short-term exposures to high doses of arsenic.

Summaries of noncarcinogenic health effects and cancer effects are presented below.

5.4.2.1 Noncancer Effects

Arsenic is a well-known poison when administered in high doses. Long-term exposures at lower doses are associated with a wide variety of health effects. Effects of short-term, high-dose (acute) exposures are described first, followed by descriptions of effects of longer-term (chronic and subchronic) exposures.

Acute Exposures

Acute exposures to moderate doses of arsenic may cause gastrointestinal symptoms in humans including nausea, vomiting, and diarrhea. These effects tend to disappear following cessation of exposure (ATSDR 2007a). At higher doses (8 mg/kg-day), hematemesis, hemoperitoneum, gastrointestinal hemorrhage, and necrosis have been reported (ATSDR 2007a). Evidence of

liver toxicity in acute poisoning cases has been reported at doses of 2 mg/kg-day. However, a higher dose (19 mg/kg-day) exposure of an infant did not produce any hepatic effects (ATSDR 2007a). Neurological effects including headache, lethargy, mental confusion, hallucination, seizures, and coma have been reported for acute, high-dose oral exposures to arsenic (2 mg/kg-day or above).

Chronic and Subchronic Exposures

This section first reviews systemic effects of arsenic, followed by reviews of neurological effects, and reproductive and developmental effects. The basis for chronic and subchronic toxicity values is also described.

Systemic Effects. The available data from humans identify skin as the most sensitive noncancer endpoint of long-term oral arsenic exposure. Hyperkeratinization of the skin, formation of multiple hyperkeratinized corns or warts, and hyperpigmentation of the skin with interspersed spots of hypopigmentation are the most common types of lesion associated with oral arsenic exposure. The majority of studies demonstrate that these effects manifest at arsenic levels of approximately 0.002-0.2 mg/kg-day (ATSDR 2007a).

Dermal effects are also seen following inhalation of arsenic; however, the associated doses are not well established. Altered dermal pigmentation and hyperkeratosis have been reported in humans exposed to inorganic arsenic via inhalation. Occupational studies of exposures to arsenic in dusts provide evidence that direct contact with skin may cause mild irritation and dermatitis symptoms. These symptoms usually heal without treatment upon cessation of exposure (ASTDR 2007a).

Studies in humans have also reported cardiovascular effects following oral exposures to arsenic. A few studies also report cardiovascular effects following inhalation, but these effects are less consistently reported. Cardiac effects are numerous and include altered myocardial depolarization, cardiac arrhythmias, and ischemic heart disease. Chronic exposure to arsenic has also been shown to affect the vascular system. Blackfoot disease, characterized by loss of circulation to the hands and feet, necrosis, and gangrene, has been found in Taiwanese populations, corresponding to arsenic doses of approximately 0.014-0.065 mg/kg-day. Other vascular effects that have been associated with arsenic include increased incidence of Raynaud's disease, cyanosis, hypertension, and vascular occlusion of the blood vessels (ATSDR 2007a).

While some studies have reported minor respiratory symptoms in individuals following chronic oral exposure to arsenic at 0.03–0.05 mg/kg-day, more serious respiratory effects generally have not been associated with long-term repeated oral ingestion to low doses of arsenic. Studies of occupationally exposed individuals have reported increased mortality due to respiratory illness, as well as respiratory symptoms, including nose, throat, and lung irritation due to chronic inhalation of inorganic arsenic. Most of these studies contain limitations including small sample sizes and incomplete treatment of potential confounders,

and dose-response data for the symptoms are sparse. Whether respiratory effects following inhalation are due to arsenic, a secondary effect caused by damage to the pulmonary vasculature, or a general effect of foreign material in the lungs is not known (ATSDR 2007a).

Gastrointestinal effects including nausea, vomiting, and diarrhea are associated with chronic long-term oral exposures to arsenic of approximately 0.01 mg/kg-day. The effects usually diminish with cessation of the exposure (ATSDR 2007a)

Oral exposure to arsenic at doses of 0.05 mg/kg-day has been associated with anemia and leukemia, although hematological effects are not reported following all cases of exposure at these levels. No studies have reported hematological effects following inhalation to arsenic.

Hepatic effects including swelling of the liver, portal tract fibrosis, and cirrhosis have been reported in individuals chronically exposed to arsenic. Swelling, one of the more sensitive hepatic effects, has been associated with exposure in the range of 0.01-0.1 mg/kg-day. There is no evidence that inhalation of arsenic causes effects to the liver; however, few studies evaluating this endpoint are available.

Although little is known regarding the effects of arsenic on the endocrine system, several studies have reported an association between exposure to relatively high levels of arsenic in drinking water and diabetes mellitus (ATSDR 2007a). More recently, Navas-Acien et al. (2008) reported that following adjustment for disease risk factors and seafood intake, increasing levels of total urine arsenic were positively associated with diabetes mellitus prevalence in a U.S. population with low to moderate arsenic exposure (total urine arsenic 3.6-13.9 μg/L). Other recent studies indicate that arsenic acts as an endocrine disruptor in altering gene regulation by steroid and estrogen receptors; the precise mechanism by which hormone-stimulated gene regulation is altered remains undetermined (Davey et al. 2007). Non-specific mechanisms including oxidative stress, inflammation, and apoptosis have also been suggested as playing a role in arsenic-related diabetes (Navas-Acien et al. 2008).

Neurological Effects. Chronic exposure to inorganic arsenic at levels of 0.03-0.1 mg/kg-day through oral and inhalation routes have been associated with peripheral neuropathy. Peripheral neuropathy is characterized initially by numbness in the hands and feet, and with increased exposure, symptoms may progress to a painful sensation of “pins and needles" followed by weakness, loss of reflexes, and wrist-drop or ankle-drop in more advanced cases. Neuropathy may partially diminish with cessation of exposure (ATSDR 2007a). At lower chronic exposures to arsenic, effects including headache, depression, and dizziness have been reported, although these effects are less consistently reported. More recent studies have reported decreased intelligence scores in children chronically exposed to arsenic (ATSDR 2007a; von Ehrenstein et al. 2007; Wasserman et al. 2007).

Reproductive and Developmental Effects. Developmental effects following oral and inhalation exposure to arsenic are uncertain. Chronic exposure of women via drinking water in Bangladesh, India, and Taiwan have shown excess incidence of miscarriages, stillbirths, preterm births, and low birth weights; however, dose-response data are not currently available for these effects. Occupationally exposed individuals and populations residing in close proximity to smelters and arsenic pesticide facilities have shown increased incidence of spontaneous abortion and stillbirth. However, these studies were small and suffered from incomplete treatment of confounders. While studies in laboratory animals by oral and inhalation exposure have also found developmental effects, these studies were conducted at relatively high doses that also produced maternal toxicity (ATSDR 2007a).

Toxicity Values for Noncancer Effects

EPA established an oral RfD of 0.0003 mg/kg-day based on the critical effect of characteristic changes in the skin and possible vascular complications. The principal study used in deriving the RfD, a study of a Taiwanese population exposed to high levels of arsenic (several hundred micrograms per day) reported a NOAEL of 0.009 mg/L. Assumptions applied in establishing the RfD include a water consumption rate of 4.5 L/day, body weight of 55 kg, and an uncertainty factor of 3. The uncertainty factor accounts for both the lack of data to preclude reproductive toxicity as a critical effect and some uncertainty in whether the NOAEL of the critical study accounts for all sensitive individuals. EPA ranked confidence in the oral RfD as medium. Limitations of the study included poor exposure characterization and potential confounding with other contaminants present (USEPA 2008a).

EPA does not provide an RfD for subchronic exposure. Tsuji et al. (2004) developed a reference level of 0.005 mg/kg-day for subchronic exposures (e.g., 14 days to 16 years). The reference level was established by reviewing health effects in children exposed to arsenic for subchronic durations. A study of children aged 0-9 who showed skin effects when exposed to arsenic via drinking water provided the basis for the reference level. Similar to the EPA's RfD, the subchronic reference level is based on the most sensitive endpoint established for arsenic—changes to the skin. Based on the greater than 10-fold difference between EPA's chronic RfD and the subchronic reference level established by Tsuji et al. (2004), the use of EPA's chronic RfD to evaluate subchronic exposure to arsenic is likely to considerably overestimate risk of adverse health effects following arsenic exposure.

No inhalation toxicity value is available from EPA.

5.4.2.2 Carcinogenic Effects

Human epidemiological studies provide clear evidence that long-term exposure to arsenic at high doses is associated with increased cancer risk. USEPA (2008a) has classified arsenic as a known human carcinogen.

The majority of data on the carcinogenic effects of arsenic come from populations chronically exposed to high levels of arsenic in drinking water. Following chronic exposure to arsenic, squamous cell carcinomas of the skin and bladder as well as respiratory tumors have been reported. While human studies provide clear evidence of an association between oral arsenic exposure at high doses and increased cancer risk, there is considerable uncertainty in extrapolating the observed dose-response relationship to much lower doses.

Studies have reported increased risk of lung cancer in smelter workers (Enterline and Marsh 1982; Lee-Feldstein 1983; Axelson et al. 1978; Tokudome and Kuratsune 1976; Rencher et al. 1977) and pesticide manufacturing workers (Ott et al. 1974; Mabuchi et al. 1979) exposed to arsenic via inhalation. A study of residents living near a pesticide manufacturing plant (Matanoski et al. 1981) provides further support for excess lung cancer risk associated with arsenic inhalation. Other studies of residents living within close proximity to smelters or arsenical plants have not consistently indicated increased risk for cancer. Populations with chronic inhalation exposure of 0.07 mg/m^3 arsenic or greater have shown increased risk of lung cancer, while the effects below those levels are less clear (ATSDR 2007a).

Toxicity Values for Carcinogenic Effects

Oral. USEPA has established an oral cancer slope factor of 1.5 per mg/kg-day and a corresponding drinking water unit risk of 5×10^{-5} L/µg. The risk is based on an assessment of increased incidence of skin cancer in a Taiwanese population exposed to high levels of arsenic (several hundred micrograms per day) in drinking water (Tseng et al. 1968; Tseng 1977). The risk estimate is based on an assumption of linear dose-response.

Since its completion, EPA's oral assessment has been highly controversial and the subject of many reviews. Numerous weaknesses have been identified regarding the studies underlying the USEPA cancer slope factor. Uncertainties associated with the exposure assessment, as well as inadequate consideration of differences in genetic, nutritional, cultural, social, economic, and lifestyle factors between the study population and populations outside that region have been identified. The use of linear extrapolation to estimate risks at lower arsenic exposures also contributes to unreliable estimates of dose-response for carcinogenicity.

A number of aspects of the drinking water exposure analyses contribute to these uncertainties. Data on concentrations of arsenic in drinking wells in the Taiwanese villages are not comprehensive; not all wells present in each of the villages were sampled. For those villages in which more than one well was tested, considerable variability in arsenic concentrations existed (NRC 1999). In addition, wells experience temporal variability in arsenic concentrations; therefore, the limited sampling conducted may not accurately reflect concentrations in the wells over time. The problem in using these data for dose-response assessments is that each village was assigned a single arsenic value, and it was assumed that all persons were exposed to that single selected concentration. Several analyses have demonstrated that lack of precise exposure data has led to overestimation of the responses associated with a given exposure to arsenic

(Brown and Chen 1995; Brown 2007). Although these analyses addressed risk for internal cancers, similar consequences are expected for risk estimates of skin cancers.

In addition to uncertainties associated with drinking water sources, factors such as health and nutritional status may affect the human response to arsenic. For example, results from several studies reviewed by NRC (2001) suggest that diets low in certain nutrients may exacerbate arsenic toxicity. Uncertainties in the overall impact of nutritional status on toxicity, therefore, add to uncertainties in extrapolating risks across populations.

More recent epidemiology studies in Chile and Argentina are cited in support of findings of the Taiwan studies (Hopenhayn-Rich et al. 1996, 1998; Smith et al. 1998). However, the ecological study design used in these studies has been criticized as providing inadequate information for estimating the magnitude of risk at specific arsenic concentrations (Brown and Beck 1996). Conversely, increased incidence of skin cancer is not indicated based on studies of U.S. populations consuming relatively high arsenic concentrations (~0.1-0.2 mg/L) in drinking water (Goldsmith and Deane 1972; Harrington et al. 1978; Morton et al. 1976; Southwick et al. 1981). While the U.S. studies lend support to the possibility that risk estimated based on the Taiwanese population may be overestimated, these studies are limited by small sample sizes.

Linear extrapolation of incremental cancer risk from effects observed at high doses to those expected at lower doses may result in overestimated risk at the lower dose. There is now substantial mode-of-action evidence that the dose-response for induction of cancer by arsenic is nonlinear (e.g., Germolec et al. 1996; Zhao et al. 1997; Shimizu et al. 1998; Barchowsky et al. 1999; Kaltreider et al. 1999; Kirkpatrick et al. 2000; Menzel et al. 2000; Trouba et al. 2000; Andrew et al. 2003; Kitchin and Ahmad 2003). Studies show that a given incremental dose of arsenic yields a relative response that is smaller when total exposures are low than the same incremental dose at higher exposure levels. While the precise mode of action of arsenic-induced carcinogenesis is not well established, it is generally agreed that arsenic carcinogenesis involves indirect, rather than direct interactions with DNA, and that its toxicity is elicited not through a single mechanism, but rather through a number of interrelated pathways (NRC 2001; Schoen et al. 2004; Rossman 2003). The majority of plausible mechanisms (e.g., oxidative damage, disruption of DNA methylation, inhibition of DNA repair systems, chromosomal damage, modulation of signal transduction pathways, and alteration of gene transcription) are consistent with a sublinear dose-response relationship for arsenic carcinogenicity (Schoen et al. 2004, Rudel et al. 1996) [16]. In other words, low doses of arsenic are likely to be relatively less effective in causing cancer than higher doses, and may, in fact, be associated with zero risk.

In addition, there is biochemical and cellular evidence that subtoxic levels of arsenic are protective or induce cellular protective mechanisms (Moore et al. 1993; Lee et al. 1985, 1986; Liu

[16] Sister chromatid exchange is reported by Rudel et al. (1996) as the "one effect consistently induced by arsenic with a linear or superlinear dose response". Given the fact that this toxic mode of action is hypothesized to be acting with others, the overall dose-response relationship for arsenic toxicity is not expected to be linear.

et al. 1994; Wang et al. 1994; Germolec et al. 1996; Barchowsky et al. 1999; Snow et al. 1999; Pott et al. 2000; Romach et al. 2000; Trouba et al. 2000; Snow et al. 2005). Evidence that arsenic can induce cellular protective responses at low doses provides further support that the effects of low doses of arsenic cannot be accurately predicted by linear extrapolation from high doses.

Extrapolations of response at lower arsenic exposures from known toxicity at higher doses, as was used in USEPA's derivation of an oral slope factor, therefore, overpredict true risk of adverse health effects at lower doses.

Inhalation. USEPA derived a unit risk estimate for arsenic exposure in air of 0.0043 per μg/m3 (USEPA 2008a). The unit cancer risk represents the excess lifetime risk of lung cancer due to a continuous, constant lifetime exposure to one unit of carcinogenic arsenic concentration in air. This unit air risk for arsenic corresponds to an inhalation cancer slope factor of 15 per mg/kg-day and is based on a linear extrapolation model. The cancer risk was derived from studies (i.e., Brown and Chu 1983a,b,c; Lee-Feldstein 1983; Higgins et al. 1982; Enterline and Marsh 1982) indicating increased lung cancer mortality in exposed worker populations at two copper smelters.

There are limitations in using occupational studies to determine risks associated with arsenic inhalation in residential settings. Exposure estimates are often hard to obtain, especially from earlier time periods. The predominant form of airborne arsenic in copper smelters is arsenic trioxide dust (ATSDR 2007a), whereas residential exposures via inhalation are more likely to be resuspended soil particulates containing a variety of arsenic forms. In occupational settings, exposures via oral and dermal pathways are also likely to occur; therefore, the risk associated solely with inhalation exposure is difficult to decipher. Co-exposures to other metals and chemicals may also confound associations in occupational studies.

5.5 CADMIUM

In pure form, cadmium is a soft silver-white metal. In the environment, cadmium typically occurs as a mineral combined with other elements. Complexes with oxides, sulfides, and carbonates in zinc, lead, and copper ores are most common; complexes with chlorides and sulfates occur to a lesser extent (ATSDR 1999a; NTP 2005).

Cadmium enters the environment through natural and human activities. Weathering of cadmium minerals contained in rocks is a significant source of release to river water and the ocean. Natural releases to air occur through forest fires and volcanoes. Human activities including mining, smelting, burning of fossil fuels and of household wastes, crop fertilization, and industrial processes also contribute to cadmium levels in the environment (ATSDR 1999a).

The mobility, bioavailability, and residence times of cadmium in different environmental media are affected by physical and chemical processes. In air, cadmium compounds are typically

found in or attached to small particles. The principal chemical form in air is cadmium oxide, although other cadmium compounds are known (e.g., cadmium chloride and cadmium sulfate) (ATSDR 1999a). The type of compound influences cadmium's solubility in water. In general, cadmium chlorides and sulfates are more water soluble than other forms. In soil, cadmium solubility also varies with form, ranging from slightly soluble (sulfides) to moderately soluble (sulfates) to highly soluble (carbonates) (Kelley et al. 2002). While the form of cadmium present in the environment may change under different conditions, the cadmium metal itself does not disappear from the environment.

For the general population, exposures may occur through ingestion of cadmium in food, drinking water, soil, or dust, and through inhalation of cadmium-containing particles in ambient air or cigarette smoke. The relative contribution of these sources varies with the smoking status of the exposed individual. For instance, in the U.S., food is the primary source of cadmium exposure to nonsmokers, mainly through grain cereal products, potatoes, and other vegetables. Within the general U.S. population of nonsmoking adults, these food sources are thought to constitute the largest contribution of cadmium to total daily intake, which is estimated at approximately 30 μg/day (NTP 2005). Tobacco smokers are exposed to an estimated 1.7 μg of cadmium per cigarette (NTP 2005).

Occupational exposures to cadmium occur primarily by the inhalation of dusts and fumes. Other exposure routes include incidental ingestion of cadmium-containing dusts on hands, cigarettes, or food.

5.5.1 Cadmium Toxicokinetics

Cadmium may enter the body via ingestion or inhalation. Most ingested cadmium passes through the gastrointestinal tract without being absorbed; approximately 2.5 percent of total ingested cadmium in food and 5 percent of total ingested cadmium in water is absorbed (USEPA 2008a). Factors affecting cadmium absorption included metal-metal and metal-protein interactions in the body, food, and water (ATSDR 1999a). Cadmium absorption is known to increase with iron or calcium deficiency and with increased dietary fat (ATSDR 1999a).

In contrast with its limited absorption when ingested, approximately one-quarter of total inhaled cadmium is absorbed. Absorption and distribution within the body appear to be affected by the chemical form, particle size of inhaled material, and solubility in biological fluids (ATSDR 1999a). Cadmium metal and cadmium salts have low volatility, existing in air as fine suspended particulate matter. When inhaled, some portion of the particulate matter is deposited in the airways or lungs. The absorption of cadmium compounds from the lung does not always correlate with water solubility (ATSDR 1999a).

Long-term exposures to cadmium, whether ingested or inhaled, may cause it to accumulate in the body at concentrations that cause adverse effects. Nearly half of the cadmium in the body is

stored in the kidney and liver (ATSDR 2008), where the metal is eliminated only slowly. Between 6 and 38 years are required to eliminate half the cadmium in the kidney; the comparable time for the liver is 4 to 19 years (ATSDR 1999a). Because of this accumulation and long-term storage, urinary cadmium concentration is the best measure of total body burden. Blood concentration reflects only recent exposure.

5.5.2 Cadmium Health Effects

For both general and occupationally exposed populations, the kidney is the primary target organ for toxic effects of cadmium. An early sign of kidney impairment is the presence of excessive amounts of protein in the urine (proteinuria). In the early stages of cadmium-induced kidney damage, effects on the renal tubules result in decreased reabsorption of filtered low molecular weight proteins. Increased accumulation of cadmium, due to higher exposure levels or longer exposure durations, causes more pronounced excretion of higher molecular weight proteins. This type of proteinuria indicates more severe damage to the kidney. Damage to the kidney's glomerulae and tubules also may also lower the reabsorption of calcium, glucose, amino acids, enzymes, phosphorus, and copper, as well as disrupt the metabolism of vitamin D (ATSDR 1999a). As described in the following paragraphs, cadmium also creates adverse effects on other organs.

5.5.2.1 Inhalation Exposure

Lung function is affected by exposure to respirable cadmium. In human and animal studies involving acute exposure, destruction of lung epithelial cells with subsequent pulmonary edema, tracheobronchitis, and pneumonitis has been reported at cadmium concentrations above 5 mg/m^3 (ATSDR 1999a). Decreased lung function, emphysema, and damage to olfactory function have been associated with longer-term exposure to lower concentrations. Human and animal studies also suggest that it may be possible to develop tolerance to cadmium-induced lung irritation and to recover respiratory function when exposure ends (ATSDR 1999a).

Proteinuria does not necessarily disappear after exposure is over (ATSDR 1999a), as shown by workers who experienced continued kidney damage following an inhalation exposure to cadmium. Roels et al. (1997, as cited in ATSDR 1999a) examined the reversibility of kidney damage in a worker population with various body burdens of cadmium. For workers with mild proteinuria, kidney damage (e.g., tubule dysfunction) showed signs of reversibility. However, workers with greater body burdens and more severe cases of proteinuria showed continued tubule dysfunction after exposure ended.

Neither the WHO nor the USEPA issues ambient air quality standards for cadmium, although the USEPA does specify emission limits for specific industries. The Peruvian government has proposed an annual ambient air standard for cadmium 0.05 $\mu g/ m^3$ to take effect in 2010 (CONAM 2008b).

5.5.2.2 Ingestion Exposure

Oral exposure to high levels of cadmium has been shown to irritate the gastrointestinal epithelium in both humans and animals. Nausea, vomiting, salivation, diarrhea, cramps, and abdominal pain are reported in children exposed via ingestion of cadmium in beverages and food at doses of about 70 μg/kg (ATSDR 1999a).

Cadmium-induced interference with metabolism of vitamin D in the kidney is thought to result in imbalances in calcium absorption and excretion. Increased calcium excretion secondary to cadmium-induced renal damage is suggested as a risk factor for osteoporosis, particularly in post-menopausal women. Some subchronic- and chronic-duration animal exposure studies are supportive of skeletal effects related to cadmium exposure. Specifically, studies of rats report decreased bone calcium content and increased urinary calcium excretion with exposure in the range of 2-8 mg/kg-day cadmium (ATSDR 1999a). These findings support the association of cadmium exposure with painful bone disorders and spontaneous bone fractures that have been reported for populations in cadmium-contaminated areas of Japan (ATSDR 1999a). Such associations must, however, be considered in light of contributory risk factors for bone changes, such as nutritional calcium deficiencies, age at exposure (bone turnover rates), and multiple rounds of gestation and lactation.

Little information is available regarding the reproductive, developmental, and genototoxic effects of ingested cadmium in humans. From studies in animals, however, neurobehavioral effects appear to be the most sensitive indicator of developmental toxicity. For example, decreased locomotor activity was reported in the offspring of female rats orally exposed to cadmium at a dose of 0.04 mg/kg-day before and during gestation (ATSDR 1999a).

The toxicity of cadmium is influenced by the nutritional status of the exposed individual. Low levels of dietary iron, zinc, calcium, vitamin D, and protein result in increased absorption of cadmium. Increased cadmium absorption may then contribute to decreased absorption or metabolism of calcium and vitamin D, amplifying the effects of cadmium exposures on the skeletal system (ATSDR 1999b). The effects of this cycle are magnified by other environmental exposures contributing to osteoporosis, such as alcohol and lead.

Numerous studies have demonstrated an antagonistic relationship between the intake of cadmium and zinc. Intake of sufficient quantities of zinc moderates health effects, such as proteinuria, caused by exposure to cadmium. A potential mechanism for this effect is zinc's ability to induce the production of metallothionein, a protein that binds cadmium and reduces its toxic effects. The interactions between cadmium and zinc are particularly important to consider for smelter sites because zinc is typically emitted at high concentrations from lead and zinc smelters that also emit cadmium. Magnesium also is reported to induce metallothionein synthesis, which may contribute to decreased cadmium toxicity (ATSDR 1999a).

USEPA derived an oral RfD for cadmium based on its concentration in the human renal cortex that is not associated with significant proteinuria (200 μg cadmium/gram wet human renal cortex) (USEPA 2005a). USEPA applied toxicokinetic modeling to determine the daily cadmium intake in food or water over a 50-year time period that would result in this concentration. A NOAEL of 0.005 mg/kg-day was calculated for food and a NOAEL of 0.01 mg/kg-day was calculated for water. The assumed absorption of cadmium from food and water was 2.5 and 5 percent, respectively. Applying an uncertainty factor to account for inter-individual variability, USEPA established an oral RfD for cadmium in food of 0.0005 mg/kg-day and in water of 0.001 mg/kg-day.

5.5.3 Cadmium Carcinogenicity

Human and animal studies do not indicate that oral exposure to cadmium is associated with increased cancer rates (ATSDR 1999a; USEPA 2005b). However, inhalation exposures to cadmium have been associated with an increased risk of certain cancers. Increased incidence of lung cancers have been reported in populations with occupational inhalation exposures. These studies include workers from various manufacturing or processing facilities in England, Sweden, and the U.S. However, the findings are confounded by various factors such as the presence of other metals in the exposure media and cigarette smoking behavior within the study population.

In a closely controlled cohort study of workers exposed to cadmium dusts in the U.S., the USEPA (2005b) concluded that investigators adequately accounted for confounding factors. Based on the findings of this study, as well as limited findings of cadmium carcinogenicity in humans reported in similar studies, the USEPA classified cadmium as a probable human carcinogen via inhalation exposure. Information from the U.S. cohort studied provides the basis for USEPA's inhalation unit risk of 1.8×10^{-3} $m^3/\mu g$ for lifetime exposure cadmium (USEPA 2005b). This unit air risk for cadmium corresponds to an inhalation CSF of 6.3 per mg/kg-day.

USEPA's assessment of cadmium carcinogenicity is supported by laboratory studies involving chronic inhalation exposures of rats to cadmium dusts and fumes. Increased lung nodules and tumors were observed with increased dose in rats exposed for 18 months in two separate studies. However, tumor incidence was not observed in controlled studies involving mice and hamsters (ATSDR 1999a). More recently, cadmium exposure in rats has been shown to cause tumors in the pituitary gland (DHHS 2005).

In their *Report on Carcinogens,* the U.S. National Toxicology Program (DHHS 2005) has also concluded that inhaled cadmium and cadmium compounds are carcinogenic, citing follow-up epidemiological studies that show a positive relationship between exposure to cadmium and lung cancer. In addition, the NIOSH (2000) has classified cadmium as a human carcinogen via the inhalation exposure route on the basis of increased risk of lung and prostate cancer.

5.6 ANTIMONY

Antimony is a metal naturally found in the earth's crust in small amounts. It occurs as uncombined metal; oxides; or in combination with sulfur, lead, copper, and silver (Elinder and Friberg 1986). Antimony enters the environment during mining and processing of its ores, as well as in the production of antimony metal, alloys, antimony oxide, and combinations of antimony with other substances. Antimony in the ambient environment can be present in air, soil, water, dust, plants, and animals.

Most antimony in the environment collects in the soil or sediment, where it attaches strongly to particles that contain iron, manganese, or aluminum (ATSDR 1992a). It does not exist in significant amounts as an airborne particulate. If it becomes airborne, antimony is quickly transformed into antimony oxides (Newton et al. 1994). In water, dissolved antimony is found mostly as hydroxides in the trivalent and pentavalent states (Mok and Wai 1990).

Neither the WHO nor the USEPA issues ambient air quality standards for antimony, although the USEPA does specify emission limits for specific industries. However, the Peruvian government has proposed an annual ambient air standard for antimony of 0.2 μg/ m^3, to take effect in 2010 (CONAM 2008b).

5.6.1 Antimony Toxicokinetics

Background exposures to antimony occur through intake of food, drinking water, and air. The absorption of antimony into the body depends on exposure route, chemical species, exposure medium (e.g., soil, dust, air), particle size, solubility, and age and diet of the exposed individual. The limited quantitative information available suggests that less than 10 percent of ingested antimony is absorbed, a process that takes place primarily through the gastrointestinal and respiratory tracts. Absorbed antimony is distributed mostly to the liver, lungs, intestines, and spleen. Antimony is mostly excreted in the urine and feces (ATSDR 1992a).

A study of antimony distribution in pregnant mice after oral exposure shows that while pregnancy results in a higher antimony body burden, transport across the placenta appears limited. Exposure of mice to antimony during lactation results in high antimony levels in newborns, suggesting that antimony may also be excreted in breast milk (ATSDR 1992a).

5.6.2 Antimony Health Effects

As with other metals, the toxic effects of antimony are related to its chemical form. For example, the acute toxicity of pentavalent antimony compounds is much less than that of the trivalent compounds. The mechanism of toxicity of antimony compounds is not well understood. It is thought to be related to the high affinity of the metal for sulfhydryl groups, which could affect the structure and function of proteins (de Wolff 1995).

The chemical and toxicity characteristics of antimony resemble those of arsenic. Both elements are often found together as environmental contaminants, resulting in simultaneous exposure. Trivalent antimony altered the genotoxicity of trivalent arsenic in an *in vitro* study (DeBoeck et al. 2003), which suggests that antimony could affect arsenic genotoxicity and carcinogenicity in humans. Other studies show that inhaled antimony compounds cause lung tumors in both rodents and smelter workers. However, both in experimental systems and in workers, simultaneous exposure to other carcinogenic compounds, such as arsenic, cannot be ruled out.

5.6.2.1 Ingestion Exposure

There are few data regarding the effects of antimony ingestion on human health. In an oral toxicity study, rats exposed to a lifetime of low levels of antimony experienced decreased lifespan, decreased blood glucose, and altered serum cholesterol levels. These effects were observed by Schroeder et al. (1970), who exposed rats to 5 ppm (i.e., 5 mg/L) potassium antimony tartrate, a trivalent antimony compound, in water, equivalent to 0.35 mg/kg-day. In 1991, USEPA selected this dose as the basis for their oral reference dose, applying an uncertainty factor of 1,000 to account for interspecies differences, exposure of sensitive subpopulations, and conversion of the LOAEL to a NOAEL. Confidence in the resulting chronic RfD of 0.0004 mg/kg-day is rated as low because of limitations in the supporting study and toxicity database (USEPA 2005a). In addition, potassium antimony tartrate is soluble in water, which makes the antimony relatively more bioavailable and more toxic than the undissolved antimony compounds in environmental exposure media such as soil and dust.

In a subchronic (13-week dose length) toxicity study in rats given 0.5-500 ppm potassium antimony tartrate in drinking water (equivalent to approximately 0.06-46 mg/kg-day), Poon et al. (1998) observed decreased blood glucose in female rats, hematologic effects, increased liver enzyme activity, and mild adaptive histological changes in several tissues. In a 1999 provisional assessment, USEPA's National Center for Environmental Assessment selected this dose as the basis for their oral reference dose, and released a revised subchronic RfD of 0.0002 mg/kg-day (USEPA 2002).

5.6.2.2 Inhalation Exposure

Studies of workers exposed to antimony trioxide via inhalation report a variety of respiratory ailments, largely due to the lung's physiological response to the accumulation of dust, inflammation, and irritation. Respiratory effects of exposure include bronchospasm, airway obstruction, chronic bronchitis, chronic emphysema, and pleural adhesion (ATSDR 1992a). Workers with pneumoconiosis (inflammation and irritation of the lung) exhibited symptoms such as wheezing and coughing (ATSDR 1992a). Additionally, one study found that exposure to 2.15 mg/m^3 antimony trisulfide for periods less than 2 years resulted in both increased blood pressure and altered EKG readings (ATSDR 1992a). An early study of female factory workers showed an increased incidence of spontaneous abortion and altered menstrual cycles following

inhalation exposure to antimony trioxide, antimony pentasulfide, and metallic antimony (ATSDR 1992a). However, uncertainties associated with the study diminish confidence in the significance of these effects.

Respiratory effects similar to those reported for workers exposed to airborne antimony trioxide also have been observed in animal studies. As with humans, macrophage proliferation is a typical inflammation response to accumulation of dust in the lungs of laboratory animals. With continued exposure, macrophage proliferation is thought to contribute to development of fibrosis of the lung. In some cases, the inflammatory response continues after exposure has ceased (ATSDR 1992a). For example, rats exposed to 70 $\mu g/m^3$ antimony trioxide for 1 year showed continued macrophage production 1 year after exposures were halted (ATSDR 1992a). Interstitial fibrosis and lipoid pneumonia were reported in rats following 1 year of exposure to 1.6 to 83.6 mg/m^3 antimony trisulfide or antimony trioxide (ATSDR 1992a).

The primary effects seen in a subchronic antimony trioxide inhalation study in rats (length 13 weeks, dose 0-23.46 mg/m^3) were corneal irregularities, cataracts, and microscopic changes in the lungs consistent with interstitial inflammation, granulomatous inflammation/granulomas, and fibrosis (Newton et al. 1994). On the basis of this study, the National Center for Environmental Assessment developed a provisional subchronic inhalation reference concentration (RfC) for antimony of 0.0004 mg/m^3 in 1999 (USEPA 2002).

5.6.3 Antimony Carcinogenicity

Antimony trioxide, which has been reported as an animal carcinogen (Watt 1983; Groth et al. 1986), was classified as carcinogenic in laboratory animals (International Agency for Research on Cancer [IARC] 1989). However, a recent inhalation study of rats exposed to antimony trioxide at doses ranging from 0.06 to 4.5 mg/m^3 did not find an increase in tumor incidence (NTP 2005). There is limited evidence for carcinogenicity of antimony trisulfide in laboratory animals (IARC 1989).

USEPA concluded that antimony compounds are not classifiable for cancer effects in humans (ATSDR 1992a). IARC classifies antimony trioxide as possibly carcinogenic to humans and antimony trisulfide as not classifiable with respect to carcinogenicity in humans. The existing human carcinogenicity studies of antimony compounds, such as epidemiological studies of art glass industry workers exposed to powdered antimony and a mortality study of workers in an antimony smelter plant, are difficult to evaluate given the frequency of co-exposure to arsenic and the existence of other co-exposures and confounders (DeBoeck et al. 2003).

5.7 COPPER

Copper in pure form is a malleable reddish metal. It exists in four oxidation states: metallic copper, and +1, +2, and +3 valence states, of which the +2 valence state is most commonly found

in the environment. Found in a wide variety of mineral salts and organic compounds, copper can also occur naturally in its metallic or elemental form.

Copper is released into the environment naturally and as a result of human activities. Natural sources of copper to the air include windblown dust from the earth's crust, forest fires, volcanoes, biogenic processes, and sea spray. Anthropogenic sources include nonferrous metal production, wood production, iron and steel production, waste incineration, industrial applications, coal combustion, nonferrous metal mining, oil and gasoline combustion, and phosphate fertilizer manufacture (ATSDR 2004a; IPCS 1998). Much of the copper that enters environmental waters is associated with particulate matter. Copper in soil becomes available for transport via runoff into streams and waterways from both natural weathering and anthropogenic disturbances (e.g., sewage treatment waste, industrial effluent, stormwater, agricultural runoff, leachate from municipal landfills) (ATSDR 2004a). Copper that enters water eventually collects in the sediments of rivers, lakes, and estuaries. The largest release of copper, however, is to land. Major anthropogenic sources of copper released to land are mining, agriculture, solid waste, and sewage sludge (IPCS 1998).

The +2 oxidation state of copper (Cu[II]) is the most important environmentally. Unless it is stabilized in a complex, Cu(I) in water is quickly oxidized to Cu(II). Unlike copper present in other oxidation states, Cu(II) compounds and complexes are frequently soluble in water. Cu(II) readily binds to dissolved organics in water, soils, and sediment (ATSDR 2004; IPCS 1998). It also readily absorbs to a variety of inorganics and metal oxides including iron, aluminum, and manganese (IPCS 1998). Cu(III) is strongly oxidizing and occurs in few compounds. At present, none of these compounds is industrially important or environmentally significant (ATSDR 2004a; IPCS 1998).

In addition to species, numerous factors affect the fate of copper in environmental media. In air, copper is typically attached to small particles. The transport in and removal of these airborne particles is dependent on particle size and wind velocity. The fate and transport of copper discharged to water in the particulate form is dependent on factors including water hardness and alkalinity, pH, ionic strength, suspended particulate matter content, and carbon content. In terrestrial environments, the factors include the nature of the soil, pH, presence of oxides, redox potential, and organic matter content (IPCS 1998).

For the general population, the highest exposures to copper, an essential nutrient, are from drinking water and food, with copper intake estimated as approximately 0.15 mg/day from drinking water and 2 mg/day from food (ATSDR 2004a). In households where corrosive water has stood in copper pipes, the drinking water may contain elevated concentrations of copper, with a corresponding increase in exposure (IPCS 1998). Certain foods, including shellfish, organ meats, legumes, and nuts, contain higher levels of copper (IOM 2001). Regular consumption of shellfish may increase dietary intake of copper by 2-150 mg/day (ATSDR 2004a). Exposure can also occur through inhalation of the compound in soil or dust, with intake estimated as

0.1-4.0 μg/day for adults in the general population (ATSDR 2004a). The use of copper-containing fungicides and algaecides provides an additional exposure pathway.

Occupational exposure is also possible. Workers in agriculture may be exposed to copper, as can those in copper production, metal plating, and other industries utilizing copper-containing products or intermediaries.

5.7.1 Copper Toxicokinetics

Copper is absorbed into the body primarily through ingestion, although small amounts of copper may enter via inhalation and skin contact. Twenty to 60 percent of dietary copper is absorbed through the gastrointestinal tract, with the rest excreted primarily through the feces (IPCS 1998; ATSDR 2004a). Copper can also cross the placental barrier to be taken up by the fetus (USEPA 1987). Interactions with other metals can affect absorption. Several studies have reported decreased absorption of copper in the presence of excess zinc. Dietary exposure to cadmium, ferrous iron, and stannous tin has also been shown to decrease absorption of copper (ATSDR 2004a).

Following ingestion of copper, blood concentrations rise rapidly. Bound to albumin and other plasma carrier proteins, copper is delivered to the liver and kidney. The liver is the major organ responsible for copper distribution. From the liver, copper is partitioned for excretion through the bile or transported for incorporation into peripheral tissues by carrier-mediated processes involving ceruloplasmin or other plasma proteins.

Bile is the major pathway for excretion of copper. Approximately 70 percent (ATSDR 2004a) to 80 percent (IPCS 1998) of the copper leaving the liver is excreted via the bile. Between 0.5 and 3 percent of daily copper intake is eliminated through urine (ATSDR 2004a).

5.7.2 Copper Health Effects

As an essential nutrient, copper facilitates the function of metalloenzymes required for cellular respiration, elastin and collagen synthesis, free radical defense, neurotransmitter function, and cellular iron metabolism (Klaassen 2001; IPCS 1998). Copper also plays a role in the activation and repression of gene transcription (IPCS 1998). The requirement for copper in various organs is regulated by homoeostatic control mechanisms that maintain copper's availability while limiting its toxicity. Toxicity is likely to occur only when homoeostatic control is overwhelmed. In such circumstances, copper's toxicity can be elicited through structural and functional alteration of biomolecules (e.g., DNA), membranes, and proteins, or through oxidative stress.

Acute toxicity due to ingestion of copper occurs infrequently in humans. Symptoms associated with high levels of copper (0.4-100 g Cu) include vomiting, lethargy, acute hemolytic anemia,

renal and liver damage, neurotoxicity, increased blood pressure, and increased respiratory rates (IPCS 1998).

Consumption of drinking water contaminated with copper has been associated with gastrointestinal effects. Nausea, abdominal pain, and vomiting have been reported following weeks- to months-long exposure to drinking water containing copper at approximately 0.07-0.9 mg /kg-day. Effects usually occur shortly after ingestion and do not persist after exposure ceases (ATSDR 2004a). Incomplete treatment of confounding factors such as the microbiological activity of the drinking water and poorly quantified doses of copper ingested introduce uncertainty into the dose-response characterization of these studies (IPCS 1998).

Liver damage associated with copper is rarely observed. Individuals exposed for 2 months to copper at 0.17 mg/kg-day as copper sulfate in drinking water showed no alteration in biomarkers of liver damage (Araya et al. 2003). Infants exposed for 9 months to 0.315 mg/kg-day copper as copper sulfate in drinking water similarly experienced no adverse effects on the hepatic system; however, design limitations were noted in this study (Olivares et al. 1998).

Individuals with one of three rare syndromes are susceptible to hepatic effects due to copper (ATSDR 2004a); the toxicity is associated with genetic defects that impair homeostatic regulation. The genetic disorder known as Wilson's disease, or hepatolenticular degeneration, affects 1 in 30,000 individuals. In this disease, a defect in the gene encoding a P-type ATPase that delivers copper to ceruloplasmin results in impaired biliary excretion of copper. The resulting accumulation of copper causes hepatic injury characterized by jaundice, hypoalbuminemia, ascites, coagulation defects, hyperammonemia, hepatic encephalopathy, and liver failure. Neurological symptoms including tremors and speech abnormalities, and psychiatric and behavioral symptoms may also result. Indian childhood cirrhosis (ICC) and idiopathic copper toxicosis are also associated with high levels of copper in the liver. Infants and young children with these syndromes experience liver cirrhosis. Although the cause of these conditions has not been firmly established, both a genetic component and a high copper intake are believed to contribute.

Limited human data are available on other health effects (cardiovascular, hematological, renal, immunological, neurological, reproductive, and developmental) following oral exposure to copper. Several studies of renal toxicity in mice and rats have reported necrosis and degeneration of proximal tubule cells. A subset of the studies reported regeneration of proximal tubule cells following removal of exposure (ATSDR 2004a). Immunotoxicity assessments in mice reported impaired cellular and humoral immunity following 8 weeks of exposure to copper at 13 mg /kg-day (Pocino et al. 1991). A single rat study reported delayed growth and development in offspring exposed to 130 mg/kg-day copper as copper sulfate in the diet for 7 weeks prior to mating and through gestation (Haddad et al. 1991). While findings in animal studies may be suggestive of human effects in these systems, the toxicity of copper is highly species-dependent.

Studies of workers exposed to copper dust have reported respiratory irritation including coughing, sneezing, pulmonary fibrosis, and increased vascularity of the nasal mucosa (ATSDR 2004a). In susceptible individuals, copper or its salts may induce allergic contact dermatitis, characterized by itching, redness, and swelling (IPCS 1998).

There has been some suggestion that a deficiency in the enzyme glucose-6-phosphate dehydrogenase (G6PD) may lead to increased sensitivity to the toxic effects of copper. In cases of acute copper sulfate poisoning and in human cells incubated with copper, the G6PD enzyme has been shown to be essential in producing reduced glutathione (GSH), a major thiol that protects against free radicals and oxidizing agents. Some have suggested that individuals with a G6PD deficiency are more susceptible to the hematological effects of copper because the deficiency could reduce the amount of GSH in red blood cells (Calabrese et al. 1979; Calabrese and Moore 1979). Goldstein et al. (1985), however, concluded that a significant decrease in GSH and functional deficits are unlikely.

Currently no RfDs or RfCs are available for copper in the USEPA toxicity database (IRIS); however, USEPA is in the process of updating its copper toxicity assessment, with release of a public comment draft scheduled for October 2008 (USEPA 2008c).

USEPA (2003c) has established a maximum allowable level of 1.3 mg/L for copper in drinking water. The standard is derived from a 1-day health advisory based on data for acute effects to the gastrointestinal tract (USEPA 1988). According to USEPA (1988), reliance on the 1-day health advisory rather than a chronic toxicity value is an appropriate basis for derivation of the limit given the absence of data indicating that copper will accumulate in the body or cause chronic effects at these levels.

ATSDR (2003) has derived an intermediate-duration oral minimal risk level (MRL[17]) of 0.01 mg/kg-day for copper. The MRL is based on gastrointestinal disturbances in adults ingesting copper at 0.091 mg/kg-day in drinking water for 2 months; no adverse effects were observed at a drinking water dose of 0.042 mg/kg-day (Araya et al. 2003).

The Food and Nutrition Board of the Institute of Medicine in the U.S. has established a recommended dietary allowance (RDA[18]) of 0.9 mg/day and a tolerable upper intake level (UL[19]) of 10 mg/day for adults (IOM 2001).

[17] An estimate of daily human exposure to a hazardous substance that is likely to be without an appreciable risk of adverse noncancer health effects over a specified route and duration of exposure. Intermediate MRLs are derived for 15-365 days of exposure.
[18] RDA is the average daily dietary intake level that is sufficient to meet the nutrient requirement of nearly all (97-98 percent) healthy individuals in a particular life stage or gender group.
[19] UL is the highest level of daily nutrient intake that is likely to pose no risk of adverse health effects for almost all individuals.

5.7.3 Copper Carcinogenicity

Human and animal studies do not provide adequate evidence with which to assess copper's ability to cause increased cancer risk in humans. Although an increased risk of cancer has been found among copper miners and smelter employees, conclusions about copper's carcinogenicity are confounded by the workers' high occurrence of smoking, co-exposure to other metals, and co-exposure to radioactivity. Animal studies have not found increased cancer risks in orally exposed mice (USEPA 2008a). *In vivo* mutagenicity assays for copper have yielded equivocal results (USEPA 1987, 2008a).

USEPA has classified copper in Group D, not classifiable as to human carcinogenicity; however, as noted above, USEPA (2008c) is in the process of updating its copper toxicity assessment.

5.8 THALLIUM

Pure thallium (Tl) is a soft, bluish-white metal that is widely distributed in trace amounts in the earth's crust (ATSDR 1992b). Thallium exists in two states—monovalent and trivalent. The monovalent state is more stable and more prevalent in the environment. Thallium is naturally present in air, water, and soil (ATSDR 1992b). Monovalent salts of thallium are generally soluble in water (ATSDR 1992b), but thallium (III) oxide is insoluble (USEPA 2008b). Thallium is also naturally present in food. Although little data exist on the amount of thallium in specific foods (ATSDR 1992b), available data indicate that concentrations are generally less than 1 mg/kg dry weight (IPCS 1996). Cigarettes appear to be a source of human exposure: people who smoke cigarettes have been shown to excrete about twice as much thallium in their urine as nonsmokers (ATSDR 1992b). Industrial sources of thallium release to the environment include combustion of fossil fuels, petroleum refining, ferrous and nonferrous metals smelting, and other processes such as cement production and brick works (USEPA 2008b).

Human biomonitoring studies provide direct evidence of widespread, low-level thallium exposure in the general population. Since 1999, urinary thallium has been measured in the U.S. National Health and Nutrition Examination Survey (NCEH 2005), which is designed to provide data for a representative cross section of the U.S. population. Urinary thallium for U.S. adults age 20 and older averaged 0.17 μg/L (geometric mean) during 1999 to 2000 and 0.16 μg/L during 2001 to 2002, with 95th percentile values of 0.45 and 0.44 μg/L during these two periods, respectively. According to NCEH (2005), previous studies had suggested that normal background urinary thallium concentrations were less than 1 μg/L (Schaller et al. 1980; Brockhaus et al. 1981; Minoia et al. 1990, all as cited in NCEH 2005). NCEH (2005) also cites other population surveys that demonstrated urinary levels in adults of roughly similar magnitude (White and Sabbioni 1998; Minoia et al. 1990; Paschal et al. 1998, all as cited in NCEH 2005).

5.8.1 Thallium Toxicokinetics

In humans and animals, absorption of soluble salts of thallium is nearly complete. Once ingested, thallium rapidly distributes to various parts of the body, concentrating in the kidneys and liver. It is cleared from the body slowly, mostly in urine and a smaller amount in feces (ATSDR 1992b). There is little or no available information to assess the bioavailability of forms of thallium found in soil.

In a mouse study, thallium injected as thallous sulfate was shown to cross the placenta and reach the fetus. The concentration of thallium in the fetus was substantially lower than that in maternal tissues (ATSDR 1992b).

5.8.2 Thallium Health Effects

Health effects of thallium are described separately for oral and inhalation exposure. Alopecia or hair loss is a classic sign of thallium poisoning. For low-dose exposures, interpretation of toxicity studies hinges on determining the significance of limited, reversible hair loss.

5.8.2.1 Ingestion Exposure

Toxic effects of oral exposure to thallium compounds in humans have been seen in two main populations: workers in industries producing or using thallium-containing materials and workers at metal smelters (ATSDR 1992b). Acute oral exposure to high doses of thallium in humans (54 to 110 mg/kg) was reported to elicit adverse effects in the respiratory, gastrointestinal, and cardiovascular systems as well as the kidney and liver, although information regarding these effects is very limited (ATSDR 1992b). High-dose oral exposures to thallium are also reported to elicit neurological effects, including cranial and peripheral neuropathy (ATSDR 1992b). Examination of the peripheral nerves in fatal human poisoning cases revealed axonal degeneration. Gastrointestinal illness was also reported in cases of thallium poisoning in a Chinese population that consumed thallium-contaminated cabbage (ATSDR 1992b). Health effects in the exposed population included gastroenteritis, diarrhea or constipation, vomiting, and abdominal pain.

Hair loss has been reported in humans following thallium ingestion (ATSDR 1992b). Hair was lost from the body, scalp, and beard, but the loss was temporary. Exposure of rats to 1.8 mg/kg-day thallium resulted in hair loss due to atrophy of hair follicles and decrease in size of sebaceous glands (ATSDR 1992b).

Data on developmental and reproductive effects of thallium exposure to humans are limited. Rats exposed prenatally to thallium showed signs of impaired learning; however, no dose-response relationship was observed and no structural alterations were reported. Male rats

exposed to thallium sulfate for 60 days displayed an increased number of immature sperm cells and reduced motility in sperm cells (ATSDR 1992b).

As the basis for its oral RfD, USEPA (1986b) used a 90-day subchronic study in which rats were exposed to various concentrations of thallium sulfate. While the study found apparent dose-related increases in hair loss, as well as moderate dose-related changes in several blood chemistry parameters, these effects were not considered adverse. Therefore, the highest dose from the study, 0.25 mg/kg-day, was considered a NOAEL. An uncertainty factor of 3,000 was applied to the NOAEL to account for the subchronic study duration, interspecies differences, sensitive subpopulations, and a lack of chronic and reproductive data, resulting in an oral RfD of 8×10^{-5} mg/kg-day for thallium sulfate, thallium chloride, and thallium carbonate, and an oral RfD of 9×10^{-5} mg/kg-day for thallium acetate and thallium nitrate[20]. USEPA's confidence in the RfD is rated as low because of its low confidence in the toxicity database and supporting toxicity study (USEPA 2008a).

USEPA (2008a) recently released a draft revised assessment of the toxicity of ingested thallium. The newly proposed oral reference dose for soluble (monovalent) thallium salts is 1×10^{-5} mg thallium/kg body weight. No RfD is proposed for insoluble (trivalent) thallium oxide or thallium selenite. This RfD is lower than the prior RfDs by a factor of 4-4.5 (if the prior RfDs were converted and stated as mg thallium, instead of presented in terms of molecular weights of specific salts). The current draft RfD and prior RfDs were derived from the same study (a 90-day study of rats exposed orally to thallium sulfate). The difference is that the highest dose is now judged to be a lowest-observed-adverse-effects level (LOAEL) (due to alopecia) and the next highest dose, which is now considered the no-observed-adverse-effects level (NOAEL), is used as the point of departure for the RfD derivation. This is a controversial decision that was questioned by some of the external reviewers. The total uncertainty factor was 3,000, which is the same factor applied previously but based on a different set of assumptions. It is anticipated that USEPA may issue revised RfDs for thallium salts later in 2008.

5.8.2.2 Inhalation Exposure

Workers in cement production who were exposed to airborne thallium for up to 44 years exhibited neurological damage, including paresthesia, numbness of the digits, and muscle cramps (ATSDR 1992b). Limitations of the study, such as pre-existing illness and lack of a control study population, contribute to uncertainty regarding the significance of these findings. No other reports of health effects following inhalation exposures were encountered.

USEPA (2008a,b) has not developed RfCs for use in evaluating exposure to inhaled thallium. Neither the WHO nor the USEPA has issued ambient air quality standards for thallium, although the USEPA establishes emission limits for specific industries. The Peruvian

[20] The differences in oral RfD values for the various thallium compounds reflect the conversion from a NOAEL of 0.25 mg/kg-day thallium sulfate to a comparable molecular weight of the thallium compound of interest.

government has proposed an annual ambient air standard for thallium to take effect in 2010. It is not clear if this criterion has a health basis. The standard would be met if the annual average at a location does not exceed 0.1 $\mu g/m^3$ (CONAM 2008b).

5.8.3 Thallium Carcinogenicity

Limited occupational studies of exposed workers have not indicated that thallium is a carcinogen. No animal studies that have specifically evaluated carcinogenicity were found.

USEPA (2008a) has determined that thallium is not classifiable as to human carcinogenicity (WOE Class D) because human and animal carcinogenicity data are lacking.

5.9 HEALTH EFFECTS OF MIXTURES

The toxicity assessment generally presents the toxic effects of exposure to individual chemicals. However, residents at most contaminated sites are exposed to mixtures of chemicals. This is certainly true in La Oroya, where people are exposed to mixtures of metals. The nature of interactions that may occur from exposures to mixtures may result in increases or decreases in the health risks. The possibility of interactions among chemicals is greatest when chemicals in the mixture have the same kind of health effects. For example, both lead and cadmium may affect bone density. Lead, cadmium, and arsenic may all cause anemia, and both lead and arsenic may contribute to increased risk of hypertension.

Sometimes the effects of multiple chemicals are simply additive, which is to say that the total health risk may be estimated by simply summing the predicted risk for the two chemicals. In other cases, the actual health risks may be greater than the sum of expected effects. Sometimes, health risks are reduced if one chemical interferes with the effects of another chemical. A review by Borgert et al. (2004) provides a good description of the mechanisms by which such interactions may occur and notes that the occurrence of interactions depends on the level of exposures. Borgert et al. (2004) also describe critical issues in assessing health effects of mixtures and summarize U.S. guidance on risk assessment for mixtures (ATSDR 2001a,b; USEPA 1988, 1989, 1999, 2000a, 2001).

6 RISK CHARACTERIZATION

In this risk assessment, the approach to risk characterization varied from chemical to chemical. Sulfur dioxide and particulates were evaluated by comparing measured air concentrations with health-based air quality standards and guidelines. For lead, predicted concentrations in blood of children and adults were compared with acceptable blood lead levels established by health and regulatory agencies. For metals other than lead, quantitative estimates of exposure and toxicity were combined to yield numerical estimates of potential health risk. After presentation of the approaches and results for sulfur dioxide and particulates, lead, and other metals, potential risks from mixtures of these chemicals is discussed. The final section of the risk characterization presents a qualitative evaluation of uncertainties associated with the risk assessment.

6.1 SULFUR DIOXIDE AND PARTICULATE MATTER HEALTH RISKS

For sulfur dioxide, risks were evaluated for inhalation exposures at existing concentrations and at those predicted after implementing additional emissions control projects. For particulates, inhalation risks were specified quantitatively for existing conditions but only qualitatively for future conditions; future reductions in air concentrations of particulates could not be calculated precisely, precluding a quantitative assessment. The basis for existing exposures was the ambient air monitoring data collected for the year 2007 from six monitoring locations in La Oroya at various distances from the Complex. Conditions at selected monitoring locations and relevant exposure considerations are discussed in Section 3.

6.1.1 Sulfur Dioxide Risk Characterization

The potential risks from inhalation of sulfur dioxide were evaluated by comparing current and predicted ambient air concentrations with the annual average and 24-hour air quality standards established by the Peruvian government. The Peruvian annual average standard is 80 $\mu g/m^3$ and the 24-hour standard is 365 $\mu g/m^3$.[21] These standards are equivalent to ambient air quality standards established by USEPA for sulfur dioxide.

The potential effects of exposure to short-term peak concentrations of sulfur dioxide in ambient air were also evaluated by comparison with acute exposure guideline levels (AEGLs) developed by the National Academy of Sciences (NAS) in the U.S. These values represent threshold exposure limits to protect the general public in the United States from emergency exposures of 10 minutes to 8 hours.

[21] The 24-hour standard is not to be exceeded more than once per year. A new 24-hour standard of 80$\mu g/m^3$ will take effect in January 2009. In 2014, the 24-hour standard will be reduced to 20µg/m3.

The following discussion presents details of the risk characterization first for annual average and 24-hour exposure periods and then for shorter acute exposures.

6.1.1.1 Annual Average Sulfur Dioxide Concentrations

Annual average sulfur dioxide concentrations were calculated from 2007 monitoring data collected at six local air monitoring stations. These values were compared with the Peruvian health-based standard to evaluate long-term health risks from inhalation exposure to sulfur dioxide under current conditions. The annual average concentrations at all six of the monitors exceeded the annual average ambient air quality standard of 80 μg/m^3 established by the government of Peru for sulfur dioxide. These annual averages are summarized in Table 4-1. The highest annual average sulfur dioxide concentration—706 μg/m^3, found at the Sindicato monitor—is nearly 9 times as high as the Peruvian standard. The Hotel Inca monitor had the next highest sulfur dioxide annual average concentration—435 μg/m^3. Even the lowest value—110μg/m^3, measured at the Casaracra monitor—is higher than the standard. These concentrations are higher than those recorded in 2004. At that time the annual standard had been exceeded at three out of four community monitoring stations, listed here in descending order: Sindicato at 492 μg/m^3, Hotel Inca at 394 μg/m^3, and Cushurupampa at 386 μg/m^3. Casaracra was the only station where the average (29 μg/m^3) had remained below the Peruvian standard.

As discussed in Section 5, there is little quantitative evidence with which to assess the long-term concentration-response relationship for sulfur dioxide. For this reason, it is difficult to identify the health consequences of chronic exposure to the elevated sulfur dioxide concentrations found in La Oroya.

All but one of the annual average monitoring values for 2007 was below 500 μg/m^3, a value USEPA (1982) identifies as a 24-hour-exposure threshold for increased mortality and bronchitis. The consequences of exceeding this value on a regular basis are of significant concern, as discussed below. Elevated sulfur dioxide concentrations combined with the particulate emissions from the Complex are likely to have an adverse impact on lung function for residents in the neighboring communities. This impact will likely be greater for people with existing respiratory conditions such as asthma.

6.1.1.2 24-Hour Sulfur Dioxide Concentrations

The 24-hour average sulfur dioxide concentrations were compiled for each monitoring station for the year 2007. Each daily value was compared with the 24-hour health-based standard established by the government of Peru (365 μg/m^3). Significant exceedance of the Peruvian standard was measured at four of the six monitors: Sindicato, Hotel Inca, Marcavalle, and Huari. Figure 6-1 shows the number of days each month the average concentration at each of

the four monitors exceeded the Peruvian 24-hour standard of 365 μg/m^3. As shown in the figure, the standard was exceeded at each monitor during some portion of every month in 2007.

At the Sindicato station, the standard was exceeded on 243 days (67 percent) of the year. Comparable numbers for the other stations are 183 (52 percent) days of the year at Hotel Inca and 142 (43 percent) of the days when data were recorded at Marcavalle. At the Huari station, which began monitoring operations in March 2007, the standard was exceeded on 129 monitoring days (43 percent). Exceedance was infrequent at the other stations: 1 day in April at Casaracra and 3 days in June and July at Huaynacancha. These latter stations are not included in the figure.

The 24-hour standard was exceeded least often in May through August at Sindicato, Hotel Inca, and Marcavalle (Figure 6-1). This finding is consistent with 2004 data presented in the 2005 risk assessment, and may be due to a control strategy that curtails operations during early morning. This strategy is used on days when meteorological conditions are expected to limit dispersion. The 24-hour standard was exceeded most frequently in October through December at most stations. At the Huari station, however, the pattern in 2007 was reversed: peak exceedances occurred in May and June, and a modest decline is observed during October through December.

In 2007, the Peruvian 24-hour standard was exceeded most frequently and by the greatest degree at the Sindicato monitor. Its second highest 24-hour sulfur dioxide concentration (2,840 μg/m^3) was nearly 8 times the Peruvian standard (365 μg/m^3). On 24 days in 2007, the Sindicato average exceeded 1,500 μg/m^3. At no time in 2007 did the average reach this level at the Hotel Inca. These findings contrast with those of 2004, when the 24-hour average sulfur dioxide standard was exceeded most often at the Hotel Inca, including 8 days above 1,500 μg/m^3; at no time in 2004 did the Sindicato average reach this concentration. The conditions in 2007 are considered to be more representative of the relative concentrations between these two stations in most years, i.e., sulfur dioxide concentrations are typically higher at the Sindicato station.

The frequency and magnitude of exceedance at four monitors in 2007 (i.e., Sindicato, Hotel Inca, Marcavalle, and Huari) indicates that sulfur dioxide could cause increased respiratory problems in La Oroya Antigua, La Oroya Nueva, Marcavalle, Chucchis, and Huari. Daily average sulfur dioxide concentrations were above 500 μg/m^3, the threshold for increased mortality and morbidity effects identified by USEPA (1982). However, the exact nature of the adverse health impacts is difficult to determine. Evaluation is further complicated because the air that contains the sulfur dioxide usually contains particulates and other chemicals that can cause adverse health effects.

Inhalation studies of sulfur dioxide exposure have identified association between exposure and morbidity (other than pulmonary irritation) and mortality effects, but not causal links. As an irritant, inhaled sulfur dioxide can be expected to cause respiratory constriction, especially in

asthmatics and other sensitive individuals. The atmospheric conversion of sulfur dioxide to sulfates, especially sulfuric acid, exacerbates the effects. Respiratory irritation associated with sulfur dioxide and sulfuric acid exposure is temporary, ceasing when air concentrations fall below the effects threshold. Because of the lack of causal links and dose-response data, the potential for excess mortality associated with the current sulfur dioxide exposures at La Oroya cannot be quantified from the observed 24-hour concentrations.

6.1.1.3 Hourly Sulfur Dioxide Concentrations

Hourly concentrations at the monitors were also examined. Absent Peruvian ambient air quality standards for sulfur dioxide at averaging times less than 24 hours, the acute exposure guideline levels developed by the National Academy of Sciences in the U.S. were used for the analysis. As discussed in Section 5, the AEGLs represent threshold exposure limits for three levels of health effects.

The AEGL-1 and AEGL-2 values are the same for all exposure times evaluated (10 minutes to 8 hours). The AEGL-1 value of 524 $\mu g/m^3$ is based on the threshold at which exercising asthmatics develop mild temporary respiratory effects. The AEGL-2 value of 1,965 $\mu g/m^3$ is the threshold at which exercising asthmatics experience moderate to severe temporary respiratory effects. Neither level is expected to have an effect on healthy individuals, who react much less severely than exercising asthmatics to sulfur dioxide and sulfuric acid exposure. The AEGL-3 values vary with exposure time (10 minutes to 8 hours), and are for life-threatening effects.

AEGL-1 Comparison

Hourly sulfur dioxide values greater than the AEGL-1 of 524 $\mu g/m^3$ were recorded at all monitoring stations, as shown in Figures 6-2 through 6-5. Because there were very few hours during which the AEGL-1 value was exceeded at Huaynacancha and Casaracra, data for these two monitoring stations are not shown in the figures. In rank order, the stations with the highest number of hours exceeding AEGL-1 were Sindicato (1,764 hours), Marcavalle (1,311 hours), Hotel Inca (1,275 hours), Huari (1,128 hours), Huaynacancha (214 hours), and Casaracra (100 hours). The total number of monitoring hours varied by station, ranging from 5,237 at Huaynacancha to 8,709 at Sindicato. Table 6-1 also summarizes the percentage of hours when sulfur dioxide exceeded AEGL-1 and the number of days during the year in which a station monitored more than 12 hours of sulfur dioxide above the AEGL-1.

The AEGL-1 value was exceeded during all seasons of the year at all monitoring sites. In general, the number of days in 2007 with exceedance was lower in winter months, except at Huari, which showed a slight increase. This trend is consistent with that seen when comparing daily average concentrations with the Peruvian 24-hour standard.

As discussed in Section 4, sulfur dioxide ambient air concentrations tend to build during the morning, peak in mid to late morning, and then decrease substantially during afternoon and

evening. This pattern is evident in Figure 6-6 (Sindicato), Figure 6-7 (Hotel Inca), Figure 6-8 (Marcavalle), and Figure 6-9 (Huari), which show the time of day when hourly concentrations exceeded the AEGL-1 value during 2007. Exceedances occurred at all times of the day, most commonly between 9 am and 1 pm. The pattern at the Huari station is shifted slightly earlier, with exceedances primarily between 8 am and 11 am and very few in the afternoon.

AEGL-2 Comparison

The comparison between the AEGL-2 value (1,965 $\mu g/m^3$) and hourly sulfur dioxide concentrations for 2007 is similar to that for AEGL-1; the worst conditions consistently occur at the Sindicato monitoring station whether expressed as number of hours per day or per year when the hourly concentrations were above the AEGL-2 (Table 6-2, Figures 6-10 through 6-13). The Sindicato monitor was the only station where the AEGL-2 value was exceeded for more than 12 hours on any given day in 2007 (twice). On 27 days, the exceedance occurred during at least 6 hours at Sindicato but on only 4 days at Huari, 1 day at Marcavalle, and never at the other stations (i.e., Hotel Inca, Huaynacancha, and Casaracra). In total there were 912 hours above the AEGL-2 at the Sindicato monitor, 474 at Hotel Inca, 316 in Huari, 295 in Marcavalle, and 5 in Huaynacancha, all during in the peak late morning and early afternoon hours. The seasonal pattern of lower frequency of exceedance in the winter held true when data were compared to AEGL-2 values.

Comparison with the AEGL-1 and AEGL-2 values indicate significant potential for short-term respiratory health effects for the most sensitive individuals. The frequency and magnitude of exceedance indicate that most individuals are likely to experience some temporary respiratory irritation.

The short-term (i.e., 6-hour) peaks during which the AEGL-2 value of 1,965 $\mu g/m^3$ was exceeded at the Sindicato station occurred primarily in the summer months between December and April. These short-term peaks indicate a potential for moderate to severe respiratory problems in sensitive individuals. Other individuals could also experience mild to moderate respiratory irritation, given the 13,000 $\mu g/m^3$ threshold for the general population discussed in Section 5. People who exercised or undertook other strenuous activities would be more likely to experience respiratory irritation. In all cases, however, the health effects would be expected to end soon after sulfur dioxide levels subsided.

AEGL-3 Comparisons

As described in Section 5, AEGL-3 defines a concentration of sulfur dioxide above which the general public, including sensitive individuals, could experience life-threatening health effects. The AEGL-3 is the same for averaging times of 10, 30, and 60 minutes: 78,600 $\mu g/m^3$. The 4-hour and 8-hour AEGL-3 are 49,780 $\mu g/m^3$ and 25,152 $\mu g/m^3$, respectively. The maximum hourly concentrations at each station are found in Table 6-3. The highest maximum (19,100 $\mu g/m^3$)

occurred at the Sindicato monitor in September. This concentration is about 25 percent of the 60 minute AEGL-3 value.

Comparison to AEGL-3 values shows that lethal or life-threatening effects are not likely from the acute exposures to sulfur dioxide released by the Complex, even under the worst conditions at the Sindicato monitor.

In summary, 2007 ambient air concentrations of sulfur dioxide at air monitors regularly exceeded Peruvian health-based standards throughout the year, although exceedance at Huaynacancha and Casaracra was nominal. As discussed in Section 5, the long-term implications to human health of sustained exposure to elevated sulfur dioxide concentrations are unclear. Short-term exposures to concentrations in excess of the acute exposure guideline values are predicted to result in temporary respiratory effects such as wheezing, tightness of the chest, and coughing. These results suggest that concentrations are sufficient to induce respiratory effects, but are well below lethal or life-threatening levels.

6.1.1.4 Future Sulfur Dioxide Health Risks

Risk characterization for future exposures was based on emissions predicted for periods after 2009. As described in Section 3.2, the CALPUFF air dispersion model was used to predict the percent reductions in sulfur dioxide air concentrations in the communities due to decreases in emissions at the Complex. The main stack at the Complex is the primary source of sulfur dioxide. The remaining sulfur dioxide is released as fugitive emissions from vents, open buildings, and other uncontrolled sources.

Minor decreases in sulfur dioxide stack and fugitive emissions are predicted to occur at the end of 2008. However, substantial reductions are expected with the installation of the third and final sulfuric acid plant in November 2009. After the third sulfuric acid plant begins operations, the sulfur dioxide stack emissions are projected to decrease by 77 percent compared with 2007, and the fugitive emission rates by 93 percent. Estimated annual stack and fugitive emissions are shown in Table 6-4.

Using the estimated sulfur dioxide emission reductions after 2009, the CALPUFF air dispersion model predicted reductions in air concentrations in La Oroya Antigua, La Oroya Nueva, and Marcavalle. Results from the air modeling of outlying communities were not reliable for the other monitoring sites, so these communities were not included in the analysis. Two different emissions scenarios were considered for post-2009. The first scenario assumes that the smelter main stack will remain in its current location. The second scenario assumes that the stack has been moved to the top of Cerro Somi, effectively elevating the top of the stack 100 meters higher. Table 6-5 provides a summary of the 2007 sulfur dioxide data as well as the highest predicted 24-hour and annual averages for both scenarios after 2009. The table also includes the percent reduction in emissions expected after all of the major technology changes are made at

the smelter. Peruvian sulfur dioxide standards are provided for reference. The 24-hour standard will drop from 365 μg/m^3 at present (2008) to 80 μg/m^3 in 2009 and then to 20 μg/m^3 in 2014. It is assumed that these changes will render the annual standard irrelevant. In the three communities modeled, with the main stack remaining in its current location, the sulfur dioxide impacts are predicted to decrease dramatically after 2009, with 78 to 82percent declines in annual average concentrations and 60 to 66 percent declines in the 24-hour average concentrations. La Oroya Antigua is projected to have a 24-hour high of 1,000 μg/m^3, La Oroya Nueva 587 μg/m^3, and Marcavalle 502 μg/m^3. Nonetheless, air concentrations will remain above both the present Peruvian standard of 365 μg/m^3 and the new standard of 80 μg/m^3.

In an effort to achieve compliance with sulfur dioxide standards, Doe Run Peru has proposed a more aggressive mitigation strategy. Moving the main stack up to the top of Cerro Somi will allow for more dispersion of sulfur dioxide as it leaves the chimney. On average, a new Cerro Somi stack is predicted to reduce 24-hour concentrations at the monitoring site by 40 to 50 percent more than would occur if the stack remains in its current location. La Oroya Nueva is predicted to have a 24-hour high of 282 μg/m^3, and Marcavalle/Chucchis is predicted to have a high of 321 μg/m^3, both of which would be in compliance with the current 24-hour standard (365 μg/m^3). La Oroya Antigua would still fail to meet the standard on approximately 9 days of the year. However, none of the communities will be in compliance with the proposed 80 μg/m^3 standard to effect in January 2009.

Moving the stack higher actually causes an increase in the predicted annual average concentration of sulfur dioxide in Marcavalle/Chucchis. The concentration was predicted to be 80 μg/m^3 without moving the chimney and 95 μg/m^3 if the stack is at the top of the hill. The gain is nominal and the 1- and 24-hour highs are expected to decline. It makes sense that more dispersion would lead to higher annual averages in the outlying communities; however, the benefits for La Oroya Antigua and La Oroya Nueva, as well as the improvements in short-term highs for Marcavalle/Chucchis, outweigh this drawback.

In both scenarios, the predicted reductions in sulfur dioxide concentrations post-2009 are significant for all of the areas surrounding the Complex. The number of hours in excess of the AEGLs is likely to decrease in both frequency and magnitude at all locations. However, since the Peruvian 24-hour standard will decrease by nearly 80 percent (to 80 μg/m^3), the number of days out of compliance with the standard is likely to remain quite high, regardless of the main stack location. Health impacts are still expected after 2009 from the short-term elevations in sulfur dioxide air concentrations that typically occur in mid-morning and early afternoon; however, these effects should be substantially reduced in frequency and intensity. The most obvious will be temporary respiratory effects, with a greater potential in sensitive individuals such as asthmatics and children and in people engaged in exercise or strenuous labor. Moving the stack to the top of Cerro Somi will reduce these risks significantly and will minimize the number of hours in which AEGLs are not achieved.

6.1.2 Particulate Matter Risk Characterization

Emissions from the Complex include other air toxics together with particulate matter that have been associated with adverse health effects. The toxicity of the particulate matter varies with the nature and particle sizes of the mixture. As discussed in Section 4, potential risks from inhalation of particulate matter were evaluated by comparing current and predicted ambient air concentrations with Peruvian and USEPA standards. Peru has two PM_{10} standards: a 24-hour standard of 150 $\mu g/m^3$, not to be exceeded more than three times per year, and an annual average of 50 $\mu g/m^3$. The USEPA maintains the same 24-hour standard as Peru[22], but has recently revoked its annual standard (see Section 5).

As expected, the highest annual average PM_{10} concentrations in 2007 were detected at the Sindicato monitor and the lowest concentrations were at the Casaracra monitor. The annual average concentration at Sindicato was 64 $\mu g/m^3$. This is 28 percent higher than the Peruvian standard of 50 $\mu g/m^3$. The Peruvian standard was also exceeded at Marcavalle (52 $\mu g/m^3$) and Huaynacancha (64 $\mu g/m^3$), but not at Hotel Inca (equivalent to the standard). Values at both Huari (46 $\mu g/m^3$) and Casaracra (26 $\mu g/m^3$) fell below the standard.

The highest 24-hour average was also found at Sindicato (164 $\mu g/m^3$). This one measurement occurred on the only day when the Peruvian 24-hour standard was exceeded at any monitoring station. Because this standard allows three exceedances per year, all areas were in compliance; the USEPA standard, which permits one exceedance per year, would also have been met at all monitoring stations. The 24-hour PM_{10} values for all stations are summarized in Table 4-2.

The PM_{10} concentrations observed for 2007 indicate low potential for adverse health effects in La Oroya due to inhalation of coarse particulate matter. However, there are epidemiological studies indicating increased mortality and morbidity at ambient concentrations below the PM_{10} standard USEPA (1997b). This observation was the motivation behind the USEPA's establishment of a $PM_{2.5}$ standard, as it is believed to be a better indicator for potential health effects.

Doe Run Peru began collecting $PM_{2.5}$ data in June 2006. With only one sample collected at each station every month (on different days), it is difficult to discern meaningful patterns or trends. The data are summarized in Table 4-3. In 2007, annual average concentrations ranged between 20 $\mu g/m^3$ at Casaracra and 37 $\mu g/m^3$ at Sindicato. Currently, Peru does not have an annual standard. The USEPA annual standard is 15 $\mu g/m^3$, based on a 3-year average of a weighted mean concentration. Doe Run Peru does not have 3 years of data to evaluate, although the existing 1-year average at all stations is greater than the USEPA standard[23].

[22] The U.S. 24-hour standard of 150$\mu g/m^3$ is not to be exceeded more than once per year on average over 3 years.
[23] Due to infrequent sampling of $PM_{2.5}$, the annual average is not a reliable estimate of mean concentrations.

Maximum 24-hour values of $PM_{2.5}$ in 2007 ranged from 33 μg/m^3 at Casaracra to 59 μg/m^3 at Sindicato. All measured concentrations fall below the current Peruvian standard of 65 μg/m^3. However, in 2008, it has been proposed that the $PM_{2.5}$ standard be reduced to 50 μg/m^3 starting in 2010 and to 25 μg/m^3 in 2014. Maximum values at Sindicato, Hotel Inca, and Marcavalle exceed the proposed Peruvian standard, with 24-hour maximums of 59 μg/m^3, 51 μg/m^3, and 56 μg/m^3, respectively. The USEPA 24-standard for $PM_{2.5}$ is 35 μg/m^3, based on a 3-year average of the 98th percentile of 24-hour concentrations. The available data are insufficient to calculate such a value; however, maximum values at all stations except Casaracra are above the USEPA standard.

The air modeling effort conducted for this risk assessment did not address future changes in particulate concentrations. Although the controls on Complex emissions of metals and sulfur dioxide will reduce ambient air particulate concentrations, it was not possible to quantify such reduction. The Complex has reduced particulate emissions since 2005, and further substantial reductions will occur after 2009. Nevertheless, smelting operations and sulfur dioxide emissions are especially associated with the $PM_{2.5}$ and finer fractions, and the Complex will continue to be a source of some particulate emissions. The proposed emissions reductions will likely reduce concentrations of fine particulates and the associated health effects.

It is important to note, however, that there are diverse sources of both coarse and fine particulates in La Oroya. As the Complex continues to reduce both stack and fugitive emissions, nonpoint sources of particulates such as vehicle exhaust and wood combustion will become more prominent; these sources may still cause the $PM_{2.5}$ standard to be exceeded. A recent study in Peru reported annual $PM_{2.5}$ concentrations of 51 μg/m^3 for Lima-Callao, 22 μg/m^3 for Trujillo, and 25 μg/m^3 for other cities on average (Larsen and Strukova 2006). These values represent a baseline for non-smelter communities and indicate the presence of nonpoint sources of fine particulates. These values are only slightly lower than the annual concentrations found near the Complex, indicating that there is likely to be a threshold after which reductions in Complex emissions will have little effect on ambient concentrations.

6.2 LEAD HEALTH RISKS

As described in Section 3.1.5, blood lead studies have demonstrated that children and adults in La Oroya have elevated lead exposures, putting them at risk for a variety of adverse effects. The complementary risk assessment was designed to evaluate current and future human health risks from the Complex and to characterize the extent to which people are exposed to chemicals released from the Complex. Risks due to lead exposure have been calculated based on data from 2007 and 2008 and are presented in the sections below. These risks are discussed relative to past and future predicted risk. Significant operational changes have occurred since the 2005 risk assessment; these changes are reflected in both measured blood lead levels and results of risk calculations using environmental data. As operational changes are made at the Complex,

the relative contribution of different exposure pathways will continue to shift. The health effects of lead are described in Section 5.3. As is the case for all chemicals, the occurrence and severity of health effects are dependent on dose or levels of exposures. Typically, the risk of adverse health effects from lead is stated in terms of blood lead levels. Blood lead level is primarily an indicator of recent exposure, but is also influenced by previous exposure if lead stored in bone is released to the blood (as is often the case during pregnancy or old age).

6.2.1 Influence of Altitude, Anemia, and Lead Toxicity on Blood Lead Levels

Because lead in the blood is found primarily in red blood cells, blood lead concentrations can be influenced by factors that affect hematocrit or hemoglobin levels. Interpretation of blood lead levels in La Oroya is complicated by two such factors. As described in Section 5.3, hematocrit and hemoglobin levels increase exponentially with altitude, with levels in high-altitude populations such as those in La Oroya potentially 20 to 25 percent higher than those of people living close to sea level (Dirren et al. 1994). On the other hand, many people in La Oroya have low iron intakes, possibly resulting in iron-deficiency anemia and lower-than-expected levels of hemoglobin. Furthermore, elevated lead exposures can compromise heme synthesis and subsequent hemoglobin production.

These factors make it difficult to rely solely on blood lead levels for the purpose of predicting adverse health effects in La Oroya. Toxicokinetic modeling has confirmed that lead body burdens do not increase as blood lead increases with altitude (UCDEH 1997). Thus, people in La Oroya who are not anemic may not experience adverse health effects until their blood lead levels are about 20 percent higher than those that affect sea level residents. People in La Oroya who are anemic may experience adverse health effects at blood lead levels similar to those that cause adverse effects in healthy low-altitude residents.

The 2008 diet study showed that the median intake of iron as a percentage of the recommended daily intake was only 50 percent for children and 20 percent for pregnant women (Vargas-Machuca 2008), which suggests that a significant percentage of the population could be iron-deficient. It is also possible that treatment of anemia may actually cause increases in blood lead levels as hematocrit levels rise. However, this phenomenon would be difficult to discern on a population-wide basis. Blood lead data can be more reliably interpreted with simultaneous measurements of hematocrit, hemoglobin, and iron status.

6.2.2 Lead Health Risks in Children

As described in Section 4.2, the ISE model was used to predict childhood lead exposure based on current and future environmental conditions. Using the model to predict current risk is valuable in two ways. First, predictions based on current environmental data can be compared to measured blood lead levels in the population to ascertain the validity and precision of the

model. Second, the model can be used to clarify the relative contributions of different exposure pathways (e.g., indoor dust, outdoor dust, soil), which can then be used to focus corrective actions. Future predictions help quantify the extent to which lead exposure risk will change over time. As was predicted in the 2005 risk assessment (Integral 2005a), mean blood lead levels have decreased in the past 3 years. However, the children in La Oroya remain at risk.

6.2.2.1 Current Risks for Children

The predicted blood lead levels for children are summarized in Table 6-6 by community. The table also presents the predicted health risk, expressed as the probability that a child's blood lead value will exceed 10 μg/dL ("P10" in the table). The incremental risk target for children whose exposure is similar is 5 percent; in other words, the probability that a child in the group will have a blood lead concentration of 10 μg/dL should be no greater than 5 percent (USEPA 1994). As can be seen from the table, nearly all of the children in La Oroya Antigua are predicted to exceed the 10 μg/dL level, the concentration at which CDC recommends further evaluation in the form of additional blood lead monitoring and education on ways to reduce lead exposures. In other communities, there is a lower probability that children will exceed this level.

Percentile values of predicted blood lead concentrations show that the children in La Oroya Antigua remain at the greatest risk for health effects due to lead exposure. Fifty percent of the children are predicted by the model to have blood lead levels above 20 μg/dL, a level at which the CDC recommends an environmental hazard evaluation and more active medical monitoring. Paccha is the community with the lowest risk. Seventy-five percent of the children in Paccha are expected to have blood lead concentrations below the CDC level of concern.

Comparison of Modeled Blood Lead Concentrations with Sampling Data

As described in Section 4.2, the ISE model was calibrated using the environmental data for La Oroya Antigua; this is the community with the most comprehensive data set. In the calibration process, model results were compared with sampling results, and input parameters of the model were adjusted in order to more closely match the sampling data. Table 6-7 shows the comparison between the sampled data and the modeled blood lead concentrations. For La Oroya Antigua, the model closely matched the mean, median, and the 25th and 75th percentile values. However, the model predicted lower blood lead levels than were found in the samples for the 90th and 95th percentiles. In the other communities, the model and sample data were well matched at the 25th percentile, however, the model underpredicted blood lead levels in all other percentiles, with the discrepancy being greatest at the 95th percentile.

The tendency of the model to underpredict blood lead levels at the upper end may be attributable to the presence of a few children in each community who have unusually high exposure to lead. These high intakes could be due to a variety of factors such as pica for soil (reported by 40 percent of the mothers surveyed in the diet study), poor hygiene practices, or

frequent exposures to areas immediately adjacent to the Complex. The underprediction is most notable in the outlying communities like Huari and Paccha, where the 95th percentile predictions were 14 μg/m^3 and 13 μg/m^3, respectively while the observed 95th percentile values in these communities were 38 μg/m^3 and 25 μg/m^3. In both of these communities, the sample size of each group was quite small, and one or two children with elevated blood lead levels had a significant influence on the upper percentile values. It is possible that in each of these communities, there are a few children who may be exposed via poor hygiene practices or time spent in communities closer to the smelter. In these communities, the median value gives a better sense of overall risk; however, the fact that there are some outliers in each group highlights the importance of continued community education and hygiene efforts.

The poor correlation between the model and the blood lead results in Huari and Paccha are also due to limited environmental data specific to those communities. Inputs for soil and outdoor dust concentrations were based on only a small number of samples and indoor dust estimates were reflective of all of the outlying communities and not specific to Huari or Paccha. Collection of more environmental data in these areas would likely result in more accurate model predictions.

Predicted Health Effects in La Oroya

As described in Section 5.3, the number of health effects from lead exposure increases with dose, as does the severity of effects. Most of the children in La Oroya are at risk for neurobehavioral effects and effects on heme biosynthesis. The latter effects may cause or worsen anemia. Children with the highest blood lead levels may also be at risk for effects on the heart, kidneys, bone, and vitamin D metabolism. Many of these effects are subtle and cannot be easily attributed to lead exposure when examining an individual child.

The effects of lead exposures are difficult to discern when examining individual children because lead's effects, such as iron-deficiency-induced anemia or neurobehavioral effects, are similar to those caused by other factors. Studies of specific health endpoints yield more meaningful results when they include control populations that are properly matched for altitude, socioeconomic status, and urbanization. If suitable control populations cannot be identified, investigations designed to compare specific health endpoints in children who live at different distances from a lead source would preclude at least some of the interpretive difficulties that arise when confounding factors are not fully considered in study design.

6.2.2.2 Future Reductions in Children's Lead Exposures

As described in section 4.2.1.9, reductions in air emissions and subsequent lead deposition are expected to have only a small effect on lead concentrations in soil. For post-2009, soil concentrations are assumed to be reduced by a factor of 0.2 relative to lead deposition for La Oroya Antigua and La Oroya Nueva. A factor of 0.1 was used for the soil in Marcavalle/Chucchis. These factors were selected based on observations of data in 2005 and

2008. Future dust concentrations are expected to be limited by soil concentrations due to the contribution of windblown soil. Thus, community dust concentrations were reduced by a factor of 0.2 below soil concentrations in La Oroya Antigua and La Oroya Nueva and a factor of 0.1 in Marcavalle/Chucchis. Indoor dust concentrations were calculated as a percent of outdoor dust concentrations, based on the observed ratio of indoor to outdoor dust concentrations sampled in 2007 (a factor of 0.6). The summary input values for the future predictions are listed in Tables 4-12 through 4-14.

Post-2009 blood lead levels predicted for children in La Oroya Antigua, La Oroya Nueva, and Marcavalle and Chucchis are shown in Table 6-6. The predicted mean value for La Oroya Antigua is 15 μg/dL. This is an impressive reduction from the observed value in 2007 of 21 μg/dL. The observed 2007 values are listed in Table 6-7. The mean predicted values for La Oroya Nueva and Marcavalle/Chucchis post-2009 are 10 μg/dL and 7 μg/dL, respectively. These compare favorably with the 2007 observed mean value of 15 μg/dL.[24] The 95th percentile values for La Oroya Antigua, La Oroya Nueva, and Marcavalle/Chucchis are predicted to be 20 μg/dL, 13 μg/dL, and 11 μg/dL, respectively. Given the observed tendency of the ISE model to underpredict concentrations at the upper end of the distribution, future predictions for above the 75th percentile may be lower than actually occur for the most highly exposed children.

Although declines in blood lead concentrations are expected to continue in the coming years, nearly all of the children (98 percent) residing in La Oroya Antigua are expected to continue having blood lead levels above10 μg/dL, as are half of the children of La Oroya Nueva. Only a small percentage (7 percent) of the children in Marcavalle and Chucchis are expected to exceed the risk target. None of the communities evaluated is predicted to meet the risk target (i.e., no more than a 5 percent probability that blood lead will exceed 10 μg/dL). Because of limitations in the air model, predictions for Paccha and Huari could not be generated, though it is expected that these communities will also demonstrate significant decreases in blood lead levels.

Confidence in predictions of future lead exposures is dependent on the accuracy of the air model deposition estimates for lead emitted from the Complex as well as professional judgment regarding the relative declines in concentrations in soil and dust. Estimates of future reductions were based on observed reductions in La Oroya between 2004 and 2007 as well as trends observed at another smelter facility. Uncertainty regarding the sensitivity of the model to different exposure inputs is addressed in the sensitivity analysis presented in Section 6.5.3.

6.2.2.3 Exposure Pathway Contributions to Lead Exposures in Children

To better understand the relative contributions to blood lead levels from outdoor dust, indoor dust, soil, diet, air, and drinking water, the mean absorbed doses from each of these pathways were compared. The results for 2007 are summarized in Table 6-8. The dominant exposure

[24] The same mean value was seen in both La Oroya Nueva and Marcavalle/Chucchis.

pathway for all communities is ingestion of outdoor dust, accounting for at least half of the child mean absorbed dose in La Oroya Antigua (56 percent of the total), followed by Santa Rosa de Sacco (52 percent), Huari and La Oroya Nueva (50 percent), and Paccha (38 percent).

Indoor dust was the second greatest contributor, accounting for 20 to 30 percent of the total absorbed dose. Soil contributions ranged from 8 to 16 percent, which is higher than the 5 to 6 percent calculated for the year 2007 by the ISE model in 2005. The contributions of diet and water were relatively low in all communities, but are likely to have been overestimated. Lead was not detected in any water or food sample collected in 2007; a default value of one-half the detection limit was used in the analysis, which may overestimate actual exposure. As was the case in 2005, inhalation of lead in air was a relatively minor exposure pathway, contributing only 1 to 5 percent of total exposure.

Relative contributions of the various exposure sources were also evaluated for the time after 2009 (see Table 6-9). As smelter emissions are reduced, the percent contribution from air becomes insignificant (0.2 to 0.4 percent). The contribution from soil increases (15 to 17 percent). Indoor dust and outdoor dust contributions remain about the same (20 to 21 percent for indoor dust and 48 to 56 percent for outdoor dust). Dusts remain significant sources in the model because it was assumed that outdoor dust lead concentrations (and the related indoor values) will be limited by soil concentrations, regardless of emissions reductions at the Complex. These predictions suggest that additional actions may eventually be needed to reduce lead exposures from soil. Limitations and uncertainties of the future predictions are discussed in Section 6.5.

6.2.3 Lead Health Risks for Adults

As described in Section 5.3, maternal blood lead levels lower than 15 μg/dL have been associated with lower birth weight and shortened gestational time in some epidemiological studies. Because other adverse health effects in adults are generally less sensitive to blood lead levels, the adult lead model is designed to predict risks of adverse effects to the fetus. Fetal blood lead levels are lower than those in the pregnant woman, and both values are predicted by the model. The health protection goal is to have no more than a 5 percent probability that fetal blood lead levels will exceed 10 μg/dL (USEPA 1994).

6.2.3.1 Current Risks for Adults

As shown in Table 4-10, blood lead levels in women of child-bearing age in La Oroya are much lower than blood lead levels in children. The predicted adult and fetal blood lead levels are summarized in Table 6-10. The results are expressed as geometric mean of blood lead concentrations for adult women, as well as geometric mean and 95th percentile of calculated blood lead concentrations among fetuses. In 2007, in La Oroya Antigua, there is an 18 percent chance that fetal blood lead levels will exceed 10 μg/dL. This demonstrates substantial

improvement since 2004, when the predicted risk was 86 percent. In communities outside of La Oroya Antigua, the probability is 7 percent.

6.2.3.2 Future Reductions in Adult Lead Exposures

Predicted future blood lead levels after 2009 for adults are shown in Table 6-10. With predicted reductions in lead emissions, adult and fetal blood lead levels are anticipated to meet the target risk levels by the end of 2009 in all of the communities. In La Oroya Antigua it is predicted that approximately 5 percent of fetuses will have blood lead levels above 10 μg/dL, and in communities outside of La Oroya Antigua, the prediction is 3 percent. Because of design limitations in the adult lead model, predicted future blood lead levels for adults are associated with a greater degree of uncertainty than are those for children.

6.3 RISKS FOR METALS OTHER THAN LEAD

Metals other than lead evaluated in this risk assessment are arsenic, cadmium, antimony, copper, and thallium. As described in their respective toxicological evaluations (Section 5), a range of health effects has been reported in association with elevated exposure to these metals. Depending on the specific metal and route of exposure the principal health effects of concern may be cancer or other health effects. As discussed in Section 5.1, potential cancer risks are characterized differently than are those for effects other than cancer.

Specifically, cancer risk estimates represent the incremental probability that an individual will develop cancer during his or her lifetime because of exposure to site-related chemicals. "Incremental probability" refers to the additional or excess chance of developing cancer that is above a background or baseline probability expected in the absence of the site-related exposures. An excess upper-bound lifetime risk range of 1 in 10,000 (i.e., 1×10^{-4}) to 1 in 1 million (i.e., 1×10^{-6}) is considered by USEPA to represent an acceptable range of cancer risks.

This incremental risk should be considered in light of high background cancer rates, which range from 1 in 3 to 1 in 4 in many populations. A 1 in 4 cancer risk is represented as a probability of 0.25 (of getting cancer in a lifetime). An incremental risk of 1 in 10,000 means that the background cancer risk would increase from 0.2500 to 0.2501.

For health effects other than cancer, site-related exposure is expressed as a dose estimate and compared with a toxicity value representing the dose of a chemical that will not cause adverse health effects in any members of a population. This dose is called the "reference dose."

In both cases, risk characterization involves combining quantitative estimates of exposure and toxicity (Tables 5-1 and 5-2) to yield numerical estimates of potential health risk. The methods used to characterize risks due to exposures to site-related metals other than lead are described

below. Quantitative estimates of cancer risks and risks for health effects other than cancer are also presented.

6.3.1 Characterization of Cancer Risks

Cancer risks for non-lead metals included in this risk assessment were estimated for ingestion of arsenic in soil, dust, and drinking water, and for inhalation of arsenic and cadmium in the air in La Oroya. Ingestion of cadmium, antimony, copper, and thallium does not present a cancer risk. Risks were calculated for both current exposures and predicted exposures after 2009, following implementation of planned emissions reduction strategies.

6.3.1.1 Calculation of Cancer Risks

Excess (incremental) lifetime cancer risks for the oral and inhalation exposure pathways are calculated using pathway-specific intake estimates and corresponding cancer slope factors according to one of two equations, depending upon the relative magnitude of risk predicted (USEPA 1989). The first equation is valid only when the intake is relatively low (i.e., corresponding to a risk level lower than 0.01 or 1×10^{-2}). It is based on the linear portion of the multistage model dose-response curve (USEPA 1989):

$$Cancer\ Risk = Intake\left(\frac{mg}{kg \cdot day}\right) \times CancerSlopeFactor\left(\frac{mg}{kg \cdot day}\right)^{-1}$$

The second equation, called the "one-hit equation," is used when the intake is high, corresponding to a risk level greater than 0.01 or 1×10^{-2} (USEPA 1989):

$$CancerRisk = 1 - EXP\left[Intake\left(\frac{mg}{kg \cdot day}\right) \times CancerSlopeFactor\left(\frac{mg}{kg \cdot day}\right)^{-1}\right]$$

When intake multiplied by cancer slope factor is small, the two equations are equivalent mathematically. In this risk assessment, only the first equation was used. In the 2005 risk assessment, the second equation was used to estimate cancer risks for inhalation exposure to arsenic, as air concentrations of arsenic were high. This equation was not needed in the complementary risk assessment because air arsenic concentrations during 2007 were much lower.

In risk assessment, cancer risks are generally assumed to be additive (USEPA 1989). Cancer risk estimates for arsenic and cadmium in air were summed for each community to produce a total risk estimate via the inhalation pathway under typical and high-end exposure conditions. Similarly, total cancer risks for ingested arsenic under typical and upper-end exposures at each community were calculated as the sum of contributions from arsenic ingested in indoor dust,

outdoor dust, and surface soil. Cancer risks for ingestion of drinking water were kept separate because the Complex does not seem to be contributing to the reported concentrations.

Cancer risk estimates were developed using exposure under current conditions and under predicted conditions after 2009 when Doe Run Peru's emission reduction plan will have been implemented. A discussion of these risk estimates is provided below.

6.3.1.2 Cancer Risk Estimates for Current Exposures

The methods and assumptions used to estimate current exposure intakes for ingestion of arsenic in dust, soil, and drinking water, and for inhalation of arsenic and cadmium in air are described in Section 4. Cancer risk estimates for ingestion of arsenic in indoor dust, outdoor dust, and surface soil by residents of each community under current conditions are discussed below. For drinking water, arsenic was detected in 4 of 19 samples, all 4 from La Oroya Antigua, with a maximum arsenic concentration of 0.025 mg/L in Reservorio Iquitos. This value is 2.5 times the SUNASS limit. The incremental cancer risk calculated for the maximum arsenic concentration of 0.025 mg/L is 6 in 10,000 (6×10^{-4}) for the CTE and 1 in 1,000 (1×10^{-3}) for the upper end exposure estimate. The origin of arsenic in these samples is not known. Cancer risk estimates for inhalation of arsenic and cadmium in air under current conditions are also discussed below. In general, risks were greatest in La Oroya Antigua for both typical and reasonable maximum exposures.

Summary of Current Cancer Risks Due to Ingestion of Arsenic

Combined cancer risks for incidental ingestion of arsenic in indoor dust, outdoor dust, and soil are summarized in Table 6-11. For typical or central tendency exposures, the highest risk estimate, 2 in 1,000 (2×10^{-3}), was for the community of La Oroya Antigua. In the other communities, risk estimates for typical exposures were lower, ranging from 2 in 10,000 (2×10^{-4}) to 6 in 10,000 (6×10^{-4}). For upper end exposures, the highest risk estimate, 5 in 1,000 (5×10^{-3}), was for the community of La Oroya Antigua. Risk estimates for the other communities were slightly lower, ranging from 7 in 10,000 (7×10^{-4}) to 2 in 1,000 (2×10^{-3}).

Many of these risk estimates have fallen slightly compared with those of the 2005 risk assessment; however, they are still above the excess upper-bound lifetime risk range of 1 in 10,000 (1×10^{-4}) to 1 in 1 million (1×10^{-6}) that USEPA considers to represent an acceptable range of cancer risks. In all communities, the highest contribution to total cancer risk for oral exposure came from incidental ingestion of arsenic contained in outdoor dust. The contribution from indoor dust was lower than or in some cases equal to that from outdoor dust. The contribution from incidental ingestion of arsenic in surface soil was generally lower than that from outdoor dust, although its relative contribution was greater than in 2005, when the soil to outdoor dust risk ratio had been 1:10. The risk ratio in 2007 was 1:5 for all neighborhoods.

Summary of Current Cancer Risks Due to Inhalation of Arsenic and Cadmium

Combined cancer risks for inhalation of arsenic and cadmium in air are summarized in Table 6-12. For typical exposures the highest risk estimate, 2 in 1,000 (2×10^{-3}), was for the communities of La Oroya Antigua and La Oroya Nueva. In the other communities, risk estimates for typical exposures ranged from 4 in 10,000 (4×10^{-4}) to 1 in 1,000 (1×10^{-3}). For upper end exposures, the highest risk estimate, 4 in 1,000 (4×10^{-3}), was for the community of La Oroya Antigua. Risk estimates for the other communities ranged from 7 in 10,000 (7×10^{-4}) to 3 in 1,000 (3×10^{-3}).

All of these risk estimates have fallen compared with those from the 2005 risk assessment; in 2005 La Oroya Antigua had the highest risk estimate for both typical and upper end exposures at 5 in 1,000 (5×10^{-3}) and 2 in 100 (2×10^{-2}), respectively. The 2007 risk estimates of combined inhalation of cadmium and arsenic in air, for both typical and upper end exposures, continue to exceed USEPA's acceptable risk range in all communities. Risks contributed by inhalation of arsenic are generally about 100 times as great as those of cadmium (Table 6-12). In fact, for typical exposures in all of the communities evaluated, risks due to inhalation of cadmium alone are within the USEPA acceptable risk range.

6.3.1.3 Cancer Risk Estimates for Future Exposures

Cancer risk estimates for predicted future exposures were developed using results of air dispersion modeling; the model assumed that Doe Run Peru's emission reduction plan was fully implemented and predicted conditions after 2009 accordingly. Due to limitations in the air dispersion model, estimates of future concentrations are available only for La Oroya Antigua, La Oroya Nueva, and Marcavalle/Chucchis.

Summary of Future Cancer Risks Due to Ingestion of Arsenic

Combined cancer risks for incidental ingestion of arsenic in indoor dust, outdoor dust, and soil are summarized in Table 6-13. For typical CTE exposures the highest risk estimate, 3 in 10,000 (3×10^{-4}), was for the community of La Oroya Antigua. In La Oroya Nueva and in Marcavalle/Chucchis, typical exposure risk estimates were 1 in 10,000 (1×10^{-4}) and 9 in 100,000 (9×10^{-5}). For upper end (RME) exposures, the highest risk estimate, 1 in 1,000 (1×10^{-3}), was also for the community of La Oroya Antigua, followed by La Oroya Nueva (4 in 10,000 [4×10^{-4}]) and Marcavalle/Chucchis (3 in 10,000 [3×10^{-4}]). Except for the CTE exposures in La Oroya Nueva and Marcavalle/Chucchis, these risk estimates remain above USEPA's range of acceptable cancer risks. These results indicate that after 2009, cancer risk estimates for intake of arsenic via incidental ingestion of dust and soil are expected to decrease approximately 30 to 50 percent compared with current conditions.

For both typical and upper end exposures, the predicted contribution of outdoor and indoor dust to total risk after 2009 remains higher than that for soil. However, the results in Table 6-13

indicate that the magnitude of difference between these exposure media (i.e., dust vs. soil) is not as great as under current conditions (Table 6-11). This finding is consistent with the anticipated effect of Doe Run Peru's implementation of emission control strategies, which are expected to significantly reduce emissions of arsenic to air. Reductions in air emissions are expected to have a more significant and immediate effect on concentrations of metals in dusts relative to those in soils, which reflect historical deposition of metals from the Complex.

Summary of Future Cancer Risks Due to Inhalation of Arsenic and Cadmium

Combined future cancer risks for inhalation of arsenic and cadmium in air are summarized in Table 6-14. These risks are dramatically reduced from current conditions, and all of them fall within the upper end of USEPA's acceptable cancer risk range. The highest risk estimate, 8 in 100,000 (8×10^{-5}), was for RME exposures in La Oroya Antigua, which falls within the acceptable risk range. CTE and RME exposure risks for La Oroya Nueva and Marcavalle/Chucchis all fall between 2 in 100,000 and 6 in 100,000. As under current conditions, arsenic remains the primary contributor to total cancer risk via inhalation after 2009.

6.3.2 Characterization of Noncancer Risks

Noncancer health risk estimates for all communities were calculated for both current exposures and predicted exposures after 2009 (i.e., following implementation of planned emissions reduction strategies). Ingestion exposures were assessed for arsenic, cadmium, antimony, and copper in indoor dust, outdoor dust, and surface soil. Drinking water ingestion exposures were assessed for arsenic and antimony. Inhalation exposures were assessed for arsenic, antimony, and cadmium.

6.3.2.1 Calculation of Noncancer Risks

Noncancer health risks are characterized as the increased likelihood that an individual will suffer adverse health effects as a result of exposure to a chemical. An individual exposed to a chemical at a level less than or equal to an acceptable reference level (reference dose) is not expected to experience adverse health effects related to that exposure. Exposures above the reference dose do not mean that adverse human health effects will occur, but rather that further evaluation is required (USEPA 1989).

To evaluate noncancer risks, the ratio of the average daily intake to the reference dose is calculated. This ratio is referred to as the hazard quotient. If the calculated value of hazard quotient is less than 1.0, no adverse health effects are expected. If the calculated value of the hazard quotient is greater than 1.0, then further risk evaluation is needed.

For the ingestion and inhalation pathways, the hazard quotient was calculated using the following equation:

$$HQ = \frac{Intake}{RfD}$$

Where:

HQ = Hazard quotient associated with exposure to the chemical via the specified route of exposure (dimensionless)

Intake = Estimated average daily intake of the chemical via the specified exposure route (mg/kg-day)

RfD = Reference dose or appropriate substitute toxicity value identified for the chemical of concern (mg/kg-day).

To evaluate the effect of exposure to multiple chemicals that act on the body in a similar manner, the hazard quotients for each exposure pathway for individual chemicals are typically summed to determine a noncancer hazard index using the following formula:

$$HazardIndex = \frac{I_1}{RfD_1} + \frac{I_2}{RfD_2} + \ldots + \frac{I_i}{RfD_i}$$

Where:

I_i = Intake for chemical *i* (mg/kg-day)

RfD_i = Reference dose or concentration for the i^{th} chemical (mg/kg-day).

Hazard indices for multiple chemicals are generally not summed unless the reference doses are based on effects in the same target organ; noncancer health risks associated with chemicals that affect different target organs are unlikely to be additive. As summarized in Table 5-1 and 5-2, the reference doses for antimony, arsenic, cadmium, and copper are based on effects on different organs or systems within the body (e.g., cadmium is based on kidney effects and arsenic is based on skin effects). Because of these differences, hazard quotients for different chemicals were not summed in this complementary risk assessment. However, given the levels of exposure to these metals in La Oroya, it is possible that interactions between the chemicals could result in increased effects on certain organs or systems in the body. The kinds of interactions that are expected to be most significant in La Oroya are discussed in Section 6.4.

6.3.2.2 Noncancer Risk Estimates for Current Exposures

The methods and assumptions used to estimate current exposure intakes for the pathways and metals discussed here are described in Section 4.5. Noncancer risk estimates for ingestion of metals in indoor dust, outdoor dust, and surface soil by a person residing in each community under current conditions are presented in Table 6-15 and discussed below. For drinking water, as described above, arsenic was detected in four samples from La Oroya Antigua, with a

maximum arsenic concentration of 0.025 mg/L, 2.5 times the SUNASS limit. There is no SUNASS limit for antimony, which was detected in only two samples at the detection limit of 0.01 mg/L. Hazard indices for arsenic in drinking water were 3 and 7 for the central tendency and upper end exposures, respectively. For antimony the CTE hazard index was 0.9, and the RME index was 2. These hazard indices were not added to those for dust and soil because the origin of the drinking water supplies and potential impacts from the Complex on the supplies are not clear. Noncancer risk estimates for inhalation of metals in air under current conditions are presented in Table 6-16.

Summary of Current Noncancer Risks Due to Ingestion of Arsenic, Cadmium, Antimony, and Copper

Current noncancer risk estimates for ingestion of dust and soil combined were highest for arsenic, with hazard quotients exceeding 1 in all communities. Hazard quotients in La Oroya Antigua for typical exposures were 9, while in the other communities they ranged from 1 to 3. Hazard quotients for upper end exposures in La Oroya Antigua were 20, and ranged from 4 to 10 in the other communities. Noncancer risk estimates were below levels of concern for all other metals in all communities, with the exception of upper end exposures to antimony in La Oroya Antigua (hazard quotient of 3).

Given the magnitude of risks associated with chronic exposure to arsenic within these communities, risks associated with shorter-term (i.e., subchronic) exposures may also be elevated. The potential for elevated risks due to shorter exposure periods is particularly relevant for children who may be more sensitive than adults to exposure during their early years (birth to age 6). To estimate the magnitude of potential risk for this sensitive subpopulation, exposures to children 0 to 6 years old from incidental ingestion of outdoor dust, indoor dust, and surface soil were compared with an arsenic subchronic reference dose of 5×10^{-3} mg/kg-day. The resulting upper end exposure of a child resident in La Oroya Antigua is expected to be approximately 4 times as high as the subchronic reference dose for arsenic (hazard quotient [HQ] = 4). Childhood exposures to arsenic in Marcavalle/Chucchis are expected to be approximately twice the subchronic reference dose (HQ = 2), indicating a possible concern in that community as well. In La Oroya Nueva, Santa Rose de Saco/Huaynacancha, Paccha and Huari, such exposures are not expected to exceed the subchronic reference dose (HQ = 1), indicating that subchronic noncancer risks due to arsenic in these communities are not of concern.

Summary of Current Noncancer Risks Due to Inhalation of Arsenic, Cadmium, and Antimony

Noncancer risk estimates for inhalation of arsenic, cadmium, and antimony in air are summarized in Table 6-16. Arsenic yielded the highest risk estimates. In Huari, Paccha, and Santa Rosa de Sacco/Huaynacancha, hazard quotients ranged from 8 to 10 for typical exposure conditions and from 10 to 20 for upper end exposures. In Marcavalle/Chucchis, the hazard

quotients were 20 for the CTE and 30 for the RME. In La Oroya Nueva and La Oroya Antigua the hazard quotients were 40 for the CTE and 60 for the RME.

Hazard quotients for cadmium were 2 or less for CTE and RME exposures in all communities, indicating very limited risks. Cadmium risks have declined significantly since 2005; La Oroya Antigua had an RME hazard of 20 and a CTE of 6. Antimony RME hazard quotients ranged from 4 to 6 in La Oroya Nueva, La Oroya Antigua, and Marcavalle/Chucchis, while CTE hazard quotients ranged from 2 to 4. In Huari, Paccha, and Santa Rosa de Sacco/Huaynacancha, antimony hazard quotients were all 3 or less.

In the 2005 risk assessment, noncancer risk estimates were calculated for cadmium only because verified RfCs were not available for arsenic and antimony. The RfC values for arsenic and antimony used in the complementary risk assessment are still not verified by the U.S. EPA, making these risk estimates highly uncertain.

6.3.2.3 Noncancer Risk Estimates for Future Exposures

Due to limitations in the air dispersion model, estimates of future concentrations are available only for arsenic and cadmium in La Oroya Antigua, La Oroya Nueva, and Marcavalle/Chucchis. Noncancer risk estimates are provided in Table 6-17 for incidental ingestion of outdoor dust, indoor dust, and surface soil. Table 6-18 summarizes noncancer risk estimates for inhalation after 2009.

Summary of Future Noncancer Risks Due to Ingestion of Arsenic and Cadmium

Future noncancer ingestion risks are predicted to drop dramatically after 2009. The predicted RME hazard quotient for arsenic in La Oroya Antigua is 5 (compared with 20 for current conditions). After 2009, soil (hazard quotient of 3) is predicted to make the greatest contribution to arsenic exposures. A hazard quotients for arsenic of 2 were calculated for CTE exposures in La Oroya Antigua and for RME exposures in La Oroya Nueva. The RME hazard quotient for Marcavalle/Chucchis is 1. The CTE hazard quotients in La Oroya Nueva and Marcavalle/Chucchis are less than 1. For cadmium, all predicted hazard quotients are much less than 1.

Summary of Future Noncancer Risks Due to Inhalation of Arsenic and Cadmium

Future noncancer inhalation risks are predicted to drop dramatically after 2009. Predicted arsenic hazard quotients range from 0.4 to 1 and cadmium hazard quotients from 0.2 to 0.6.

6.4 EVALUATION OF RISKS FROM MULTIPLE CHEMICAL EXPOSURES

As described in Section 5.8, chemicals in mixtures can interact to either increase or decrease overall health effects. For mixtures of carcinogenic chemicals, standard risk assessment practice is to assume that risks are additive (USEPA 1989). Assessment of mixtures is a developing area of toxicology that is not fully understood, and the USEPA guidance for risk assessment of mixtures does not yet provide consistent methods for quantitative analysis of effects other than cancer (Borgert et al. 2004).

The potential for significant interactions among chemicals in La Oroya is great because of the high levels of exposure and the similarity of potential effects. While possible interactions in La Oroya cannot be quantified, it is very important to understand the multiple factors that may contribute to the primary health effects and to account for them in any future health studies. To that end, the sections below review the principal expected health effects and their contributing factors, organized by affected organ.

6.4.1 Effects on the Lung

The air in La Oroya contains a mixture of particulate matter and sulfur dioxide. The nature of this mixture influences the nature and magnitude of the resulting pulmonary effects. The air contains particulate matter and sulfur dioxide at concentrations above health-based standards; each chemical alone would indicate the potential for adverse effects on the lung. As discussed earlier, the metal oxides in ultrafine particulates released from the Complex help convert sulfur dioxide to the more potent sulfuric acid. Inhalation of sulfuric acid can alter the body's ability to clear particles from the lungs, thereby compromising a significant defense mechanism (Klaassen 1996). Long-term exposures to elevated concentrations of sulfuric acid can lead to chronic bronchitis, which can lead, in turn, to increased deposition of particles in the respiratory system. The chronic bronchitis results in a thickened mucus layer and increased potential for yet further impaction of particles.

The mixture of gases and particles found in the air at La Oroya may magnify effects on the lung. The degree of this synergy cannot be quantified in this risk assessment; however, because the air quality standards were derived from studies of mixtures that may have included the chemicals present in the air in La Oroya, the standards may already take such synergy into account.

6.4.2 Neurological Effects

Lead, arsenic, and cadmium have been associated with neurological effects. In addition to effects on neurobehavioral function reported at lower blood lead levels in children, higher blood lead levels have been associated with neurological symptoms such as muscle weakness

and numbness and tingling in the extremities (ATSDR 2007b). Similar neurological effects have also been reported with chronic exposure to arsenic (ATSDR 2000). In addition, neurobehavioral effects have been identified as the most sensitive indicator of developmental toxicity associated with cadmium exposure based on some studies in animals (ATSDR 1999a).

Potential mechanisms of interaction between lead and arsenic, as well as between lead and cadmium have been suggested. When administered together in some animal studies, arsenic and lead have been shown to affect each other's concentrations in the brain, but cadmium and lead have not (ATSDR 2004b). Lead, arsenic, and cadmium individually have been reported to affect neurotransmitter levels in the brain. However, the precise mechanisms by which the chemicals interact to affect neurological systems are not clear, partly because the effect mechanisms for each individual chemical are so complex (ATSDR 2004b).

6.4.3 Anemia

Interactive effects on the hematological system during simultaneous exposure to lead with arsenic and to lead with cadmium are possible (ATSDR 2004). As noted in Section 5, exposure to each individual chemical has been associated with anemia. For lead, the anemia results from the decreased hemoglobin production and destruction of red blood cells due to alteration of heme synthesis. With arsenic, decreased production of red blood cells can result from chronic ingestion of high concentrations. In individuals with low iron intake, cadmium decreases absorption of iron from the gastrointestinal tract, indirectly inhibiting heme synthesis, which may further contribute to anemia.

Dietary deficiencies of iron may also contribute to increased absorption of lead. As noted previously, comparisons of blood lead concentrations in iron-deficient and iron-replete children suggest that iron deficiency results in higher lead absorption, or conversely, that iron sufficiency alters lead biokinetics in a way that helps prevent higher blood lead levels (ATSDR 2007b). In contrast, certain animal studies indicate that cadmium's effects on the gastrointestinal tract may result in lower absorption of lead and in lower blood lead levels in individuals exposed to lead with cadmium (ATSDR 2004).

6.4.4 Effects on Bone

Skeletal system effects, such as osteoporosis, may be due to the combination of poor nutritional status and exposure-induced interferences on key biochemical pathways in the body. For example, nutritional deficiencies in iron, zinc, calcium, vitamin D, and protein may result in increased absorption of cadmium, whose presence, in turn, may further decrease absorption or metabolism of calcium and vitamin D (ATSDR 2007b). Impairment of vitamin D metabolism may also occur at high blood lead levels (33-120 μg/dL). This effect on vitamin D metabolism is particularly evident in cases of chronically high lead exposures of children who are

nutritionally deficient in calcium, phosphorus, and vitamin D (ATSDR 2007b). Other external factors, such as alcohol use, may exacerbate effects on the skeletal system.

6.5 UNCERTAINTY EVALUATION

As described above, risk assessments predict the likelihood of health effects in a population, but do not directly measure the occurrence of health effects. The predicted risks are based on many assumptions about the ways that people come into contact with chemicals in the environment. Although many of these assumptions are based on general scientific studies or site-specific data, uncertainty remains regarding how well the available data reflect the ways residents are actually exposed to chemicals. The degree of confidence in the results of a risk assessment depends on how closely the data and assumptions used match actual conditions.

6.5.1 Risk Assessment Scope

It is important that uncertainty be evaluated in the context of the intended scope of the risk assessment. The goals of this risk assessment were to evaluate current human health risks in the community due to air emissions from the Complex and to predict changes in future health risks as smelter emissions are reduced. Because of these goals, the risk assessment did not consider risks associated with releases to water or land (e.g., from wastes deposited on land). Neither risks to workers at the Complex nor ecological risks were evaluated.

Evaluation of current health risks focused on characterizing the ways people are exposed to Complex air emissions and the relative contribution of various exposure pathways to total exposure. No effort was made to determine the land area affected by historical Complex emissions because this was outside the scope of this risk assessment.

Limited data were available for the communities evaluated in the risk assessment. Greater emphasis was placed on La Oroya Antigua, because it is the community where the greatest impacts from Complex emissions were expected. Communities located farther from the Complex receive less deposition and have lower air concentrations, resulting in lower expected health risks. Results of this risk assessment are useful in understanding possible exposure pathways at more distant communities.

6.5.2 Confidence in the Risk Assessment

This risk assessment can be categorized into three primary parts: inhalation exposures, ingestion exposure to lead, and ingestion exposure to metals other than lead. The confidence in the current and future risk estimates for these three parts of the risk assessment are described below.

Uncertainties in current inhalation risks have been minimized by the availability of air monitoring data from a variety of locations within residential areas of La Oroya for sulfur dioxide, particulates, lead, and other metals. The exposure assessment for inhalation of these chemicals is expected to be more accurate than is the case in most risk assessments. Inhalation rates are well documented and fewer assumptions were required to estimate current inhalation exposures than for other exposure pathways. The air modeling conducted by MMA predicted future annual average air concentrations of sulfur dioxide that are considered to be reliable and adequate for risk assessment purposes. Predicted peak 24-hour average concentrations are less reliable, but the predicted frequency of exceedances of the 24-hour standard are deemed to be a reliable indicator of the potential magnitude of health risks. It was not possible to predict future concentrations of particulates. Predicted annual average metal concentrations are likely to be sufficiently reliable to support a determination of the magnitude of potential health risks.

Uncertainties for estimating current lead exposure have been greatly reduced by the availability of high quality blood lead data for the population. There is uncertainty in the relative contribution of some of the sources (i.e., outdoor dust, indoor dust, and soil), but the sum of these exposures is judged to be accurate. Confidence in predictions of future lead exposures is dependent mainly on the accuracy of the air model deposition estimates for lead emitted from the Complex. The air model supported highly reliable predictions for the neighborhoods adjacent to the Complex. Annual average and highest 24-hour average concentrations of lead were generated by the model and deemed to be reliable. The resulting deposition estimates are judged to be adequate to support the risk estimates.

For ingestion exposures to metals other than lead, predicted risks are relatively less certain because more assumptions were needed. Nevertheless, confidence in the assessment of these metals was enhanced by relying on some of the assumptions developed for lead. Oral exposure estimates for metals other than lead are expected to be more reliable than those of typical U.S. risk assessments.

In general, where uncertainties existed, conservative parameters, assumptions, and methodologies were used to enhance the likelihood that potential exposures and risks would not be underestimated. Specific sources of uncertainty in various steps of the risk assessment are described in Table 6-19. The Table details the source and nature of these uncertainties and provides an estimate of the magnitude of impact they may have on the risk estimates.

6.5.3 Children's Blood Lead Model Sensitivity Analysis

As a result of the changes in Complex operations described in section 2.1, it is expected that there will be dramatic reductions in air concentrations and subsequent deposition of lead. Based on air modeling results provided by McVehil-Monnett, the lead deposition is predicted to decrease by approximately 95 percent in the communities closest to the Complex (i.e. La Oroya Antigua, La Oroya Nueva, and Marcavalle/Chucchis). Continued community sanitation and

education efforts to reduce exposures are also anticipated to influence future blood lead levels. However, with these dramatic decreases in deposition, uncertainty exists regarding the extent of lead concentration declines in soil, outdoor dust, and indoor dust. Several scenarios were constructed to evaluate the sensitivity of the ISE model to assumptions other than the primary scenario described in section 4.2.1.9 and used to make the future predictions outlined in section 6.2.2.2. The sensitivity analysis was applied only to La Oroya Antigua, the community for which the most extensive data are available.

In the 2005 risk assessment, predicted reductions in lead concentrations in dust and soil were based on information gathered from another smelter site in Trail, Canada. Observed reductions in La Oroya between 2005 and 2007 differed somewhat from the Trail-based predictions. The observed reductions in La Oroya provide important information for what may happen in the future as air emissions continue to decline. These observations were considered in the selection of the primary scenario used to predict risk as well as the construction of the alternative scenarios used in the sensitivity analysis.

As described in sections 4.2.1.9 and 6.2.2.2, the primary scenario used to evaluate future risk in La Oroya Antigua assumed that soil concentrations would be reduced by a factor of 0.2 relative to the decline in lead deposition.. Community dust concentrations were reduced by a factor of 0.2 below the soil concentration. Indoor dust concentrations were calculated as a percent of outdoor dust concentrations, based on the observed ratio of indoor to outdoor dust concentrations sampled in 2007 (60 percent).

The sensitivity analysis examined five alternative scenarios. The input parameters and results of these scenarios, along with the original scenario, are summarized in Table 6-20.The first through third alternate scenarios assume a 10 percent reduction in soil concentrations relative to reductions in lead deposition, resulting in a soil lead concentration input value of 2667 mg/kg. The first scenario assumes that lead in outdoor dust will be reduced to levels 10 percent below the soil concentrations. The second assumes a 20 percent relative reduction in outdoor dust and the third scenario assumes a 30 percent relative reduction. In all scenarios, indoor dust levels are maintained in the same ratio to outdoor dust as was measured in the 2007-2008 samples (i.e. indoor dust concentration is 60 percent of outdoor dust concentration).

Scenarios 4 and 5 assume a 20 percent decline in soil concentration relative to declines in air concentrations, resulting in a soil lead concentration input of 2388 mg/kg. The fourth scenario assumes the outdoor dust concentration will be 10 percent below the soil concentration. Scenario 5 assumes an outdoor dust concentration 30 percent below soil concentrations. Indoor dust concentrations are maintained at the 60 percent ratio of outdoor dust concentrations described above.

Additional inputs to the model include dietary lead intake, water, and maternal blood lead levels. These were not changed in the sensitivity analysis, as the relative contributions from

these factors are minimal. The inputs for these parameters are described in section 4.2.1.9 and are listed in Table 6-20.

As described above, the primary uncertainties in predicting future blood lead levels are the degree to which lead concentrations in soil and dust will change based on reductions in emissions. The assumptions made in the sensitivity analysis reflect modest reductions in both soil and dust concentrations. Given these assumptions, the range of potential outcomes is relatively narrow. The difference between a 10 percent reduction in soil concentration and a 20 percent reduction results in a one point difference in mean blood lead levels, at each assumed level of dust reduction. Similarly, increasing the relative reduction in outdoor dust by 10 percent results in a one-point drop in mean blood lead level, at both levels of reduction in soil lead concentrations.

The most conservative scenario (scenario 1) assumes a 10 percent decline in soil concentrations relative to lead deposition and a 10 percent reduction in outdoor dust concentrations relative to soil. This results in a predicted mean of 17 μg/dL. The most optimistic scenario (scenario 5) assumes a 20 percent reduction in soil concentrations relative to deposition and a 30 percent decline in outdoor dust relative to soil concentrations. This results in a predicted mean of 14 μg/dL. Overall, the mean blood lead level is not expected to differ substantially. This demonstrates that the mean estimates from the model are not particularly sensitive to differences in soil concentrations.

As is shown in Table 6-9, exposure to soil is responsible for 15-19 percent of the total contribution from different media. If the assumption holds that dust lead levels are, in fact, significantly limited by soil lead concentrations, it is anticipated that our primary scenario will be relatively accurate with a margin of error demonstrated by the sensitivity analysis. If, however, the dust lead concentrations fall well-below concentrations in the soil, it can be expected that blood lead levels are likely to drop more significantly. The primary exposure pathway in La Oroya is ingestion of outdoor dust, accounting for approximately 50 percent of relative contribution. Thus, more dramatic reductions in outdoor dust concentrations will have a significant impact on blood lead concentrations.

7 CONCLUSIONS AND RECOMMENDATIONS

In this section, the primary findings of the 2005 and complementary risk assessments are summarized. Recommendations from the 2005 risk assessment are then reviewed and updated. New recommendations reflecting the findings of the complementary risk assessment are also offered.

The 2005 risk assessment concluded that exposure to lead in emissions from the Doe Run Peru Complex created the primary health risk factor for the population of La Oroya, with particular concern for neurobehavioral effects in children. The effects of sulfur dioxide releases and resulting sulfuric acid concentrations in air were also found to burden the majority of the population with transient pulmonary irritation and risk of nonspecific increases in morbidity and mortality. Elevated risks of adverse health effects were also found for arsenic and cadmium. This complementary risk assessment confirms the continued existence of the same health risks, with the difference that the magnitude of exposures to lead and other metals during 2007 has been substantially reduced compared with 2005; those for sulfur dioxide have not.

Additional improvements in operations and emissions controls at the Complex are planned for 2008 and 2009; these changes are predicted to result in marked decreases in pollutant concentrations. Annual average sulfur dioxide concentrations are predicted to fall by 80 percent from 2007 levels, while air concentrations and deposition of lead and arsenic will fall by more than 90 percent. Cadmium concentrations and deposition are predicted to fall by more than 70 percent. These declines will reduce exposures of the population. As the concentrations decline in air and dustfall, however, exposure to residual metals in soil and dust from historical operations will become proportionately greater. In other words, the benefits of reducing metal emissions from the smelter will be somewhat limited until other sources of exposure are also addressed.

In its report on La Oroya, the U.S. Centers for Disease Control and Prevention (CDC 2005) recommended that all stakeholders collaborate in a coordinated program to oversee efforts to reduce exposures, including efforts to reduce emissions and remediate historical contamination. Integral's 2005 report strongly supported the CDC's recommendation and further recommended formation of a stakeholder advisory group constituting representatives of local government, community organizations (including local religious groups), the Convenio, Peruvian Ministry of Energy and Mines (MEM), Ministry of Health's Environmental Health Directorate (DIGESA), and Doe Run Peru. To our knowledge, a stakeholder group inclusive of all affected parties has not yet been formed. We continue to recommend that such a group be formed and that this group meet regularly to share information about the Complex operations and about community activities undertaken to reduce health impacts to the local population.

Integral's 2005 report also recommended specific actions related to facility operation, exposure assessment, environmental monitoring, community interventions, and dietary studies and interventions. The status of these actions and recommended updates are described in the following sections.

7.1 FACILITY OPERATIONS

Air emissions of sulfur dioxide and metal particulates from the Complex have been the principal focus of the 2005 and complementary risk assessments. These emissions—both stack emissions from the main stack and the sinter plant scrubber stack, and fugitive emissions from buildings and ducts–are affected by the specific metals produced, by production volumes, and by operating conditions and emissions controls. Numerous technological and operational changes have already been implemented to reduce emissions:

- Completion of a sulfuric acid plant for the zinc circuit
- Installation of baghouses for the lead furnaces and other facilities to reduce the volume of dust going to the main stack
- Closing off of lead furnaces, the foaming plant, and anodic residues plants, and replacement of humid-gas cleaning technology systems with baghouses in the lead agglomeration plant
- Implementation of complementary environmental projects such as paving of industrial areas and use of street sweepers and tire washers
- Installation of three domestic and one industrial water treatment plants to control total liquid effluents from the La Oroya metallurgical complex.

Future changes include construction of sulfuric acid plants for the lead and copper circuits, planned for completion in September 2008 and October of 2009, respectively. Additionally, a new Isamelt furnace will be installed and additional Tuyere Control systems will be added to the lead furnaces. With the completion of these changes, our recommendations from 2005 will have been fully implemented. In an effort to achieve compliance with Peruvian sulfur dioxide air quality standards, Doe Run Peru has proposed moving the main stack to the top of an adjacent hill, Cerro Somi. As noted in section 6, this would improve dispersion of sulfur dioxide and significantly reduce air concentrations, particularly in the communities adjacent to the smelter.

7.2 EXPOSURE ASSESSMENT AND ENVIRONMENTAL MONITORING

The 2005 report recommended continuing collection of data on chemical concentrations in air, dust, and soil, with results evaluated to show how exposures might be changing over time and whether actions to reduce emissions from the Complex are effectively lowering concentrations

in the environmental media to which people are exposed. The following sections provide monitoring recommendations for air, dustfall, outdoor dust, and soil.

7.2.1 Air Monitoring

In 2005 Integral recommended that the air monitoring network currently operated by Doe Run Peru be continued and that additional air monitoring stations be added. We also recommended relocating the Cushurupampa monitoring station to a lower elevation within the residential area. With the addition of air monitoring stations in Paccha, Huaynacancha, and Huari, and the relocation of the Cushurupampa station to a lower elevation in Marcavalle, we consider that this recommendation has been fulfilled.

Integral recommended continued monitoring of sulfur dioxide, particulates as PM_{10}, lead, arsenic, and cadmium. We also recommended examining the sulfur dioxide monitoring equipment to see if its upper concentration limit could be increased to allow more accurate tracking of short-term peak sulfur dioxide concentrations. This recommendation was implemented, with the limit increased from 6,000 $\mu g/m^3$ to 26,200 $\mu g/m^3$ at the Sindicato and Hotel Inca monitors. The concentration limit at other monitoring stations is 5,240 $\mu g/m^3$.

In addition to fulfilling the recommendation for continued monitoring of the listed chemicals, Doe Run Peru initiated monitoring for $PM_{2.5}$, and also analysis for additional metals. In this way, Doe Run Peru has exceeded our recommendation. The addition of monitoring for the fine particulates ($PM_{2.5}$) is important because increasing emphasis is being placed on this particulate fraction by the governments of Peru and the U.S. as studies around the world demonstrate its health effects. With this increased emphasis on fine particulates, it may be necessary for Doe Run Peru to increase the frequency of $PM_{2.5}$ sampling, currently once per month. It is recommended that Doe Run Peru consult with MEM to determine if PM_{10} sampling can be discontinued and replaced with $PM_{2.5}$ sampling.

The 2005 report recommended regular calibration of the monitoring equipment and improved quality assurance/quality control (QA/QC) procedures. Implementation of a data quality oversight program by the proposed stakeholder group had also been recommended. An additional recommendation was that the monitoring program be expanded to include collection and analysis of split samples by a third party to provide transparency in the environmental monitoring program. Doe Run Peru has improved the calibration and QA/QC procedures consistent with our recommendation. The high-flow PM_{10} monitors are now calibrated monthly by Doe Run Peru and every 6 months by an external lab. The sulfur dioxide monitors are now calibrated monthly by Doe Run Peru and annually by an external lab. The continuous PM monitors were calibrated for the first time in July 2008. Collection of split samples by a third party has not been initiated. We continue to recommend this action.

The 2005 report also recommended routine calibration of surface meteorological stations and continued efforts to obtain high-quality upper air data. As discussed in the air monitoring report (MMA 2008), surface meteorological data quality was improved as recommended, but efforts to obtain reliable upper air data failed. Doe Run Peru invested considerable time, money, and effort in these attempts, and no feasible technological solutions were identified. Consequently, the air model was adjusted to attempt to correct for the lack of upper air data. We have no further recommendations related to characterizing upper air conditions.

7.2.2 Air Modeling

The 2005 risk assessment report summarized recommendations for updating and improving the air dispersion model developed by McVehil-Monnett. The implementation of these recommendations and the resulting revised air dispersion model are described in the final air modeling report (MMA 2008b). We have no further recommendations on this topic.

7.2.3 Monitoring of Metals in Dustfall and Outdoor Dust

The air model predicts deposition rates for lead, arsenic, and cadmium. Deposition is a measure of the rate at which particulates emitted from the Complex fall to the ground and settle on paved surfaces and soil. Deposition of airborne dust can be measured directly by setting out open-top containers on surfaces in various locations. The amount of dust or of specific metals in a container with a known surface area provides a measure of dustfall (usually reported in mg/m^2). The 2005 report had recommended a dustfall monitoring program to determine if deposition rates of particulates from the Complex are being reduced as emissions are reduced. Trends in dustfall rates also can be compared to trends in outdoor dust metal concentrations to see if reduced deposition is associated with reduced concentrations in the outdoor dust. This program has been implemented by Doe Run Peru, and the recommendation has been fulfilled.

7.3 COMMUNITY INTERVENTIONS

Ongoing activities conducted by both Doe Run Peru and the Convenio de Cooperación between the Ministry of Health and Doe Run Peru have addressed hygiene education at the community and individual level. These activities range from regular street cleaning and waste disposal to provision of shower facilities and public dining rooms. Residents have also been provided with information regarding home cleaning practices, personal hygiene, food preparation practices, and nutrition.

As in 2005, continuation of community education programs in La Oroya Antigua is recommended to further instruct residents on methods of reducing exposure within the home. In 2005 it had been recommended that educational outreach programs be expanded from La Oroya Antigua to the communities of La Oroya Nueva, Marcavalle, and Chucchis. These

programs are underway in all of the affected communities. Substantial progress has been made in Huari with paving of the plaza, installation of public sanitation facilities, and improvements to the school; however, the high levels of exposure evident in this community indicate these efforts should continue. Support for the following specific programs had been recommended; current status is also provided:

- **Schools** – Given the importance of personal hygiene (e.g., hand washing) in reducing exposures, particularly for children, it had been recommended that the personal hygiene training program in schools be continued. We assume this activity continues, and recommend that it also be continued in the future. We had also recommended frequent cleaning to remove dust in classrooms and playgrounds. Indoor dust samples collected by the Convenio in 2008 showed that some schools have extremely high dust lead concentrations. On the basis of this finding, we continue to recommend implementation of a program to regularly remove all interior dust on floors and surfaces accessible to children within the schools. Currently, schools in La Oroya Antigua are cleaned twice a month. Increasing the frequency of cleaning is recommended, which may require hiring additional staff. Furthermore, it is advisable that no schools be constructed in La Oroya Antigua. It would be preferable to bus all residents of La Oroya Antigua to schools in other communities.
- **Public sanitation facilities** – It had been recommended that the program to make structural improvements to public sanitation facilities be continued. The facilities constructed in Huari are an example of the implementation of this recommendation. The adequacy of available facilities should be reviewed to determine if further structural improvements are needed. Currently, a technical study is underway in La Oroya Antigua to assess the feasibility and requirements of installing sanitary infrastructure in the community.
- **Cleaning of streets and sidewalks** – Continued cleaning of streets and sidewalks had been recommended, as had additional cleaning of paved play areas, including school courtyards, plazas, and playfields (soccer and basketball). As recommended, frequency of street and sidewalk cleaning has increased and all of the neighborhoods surrounding the Complex are now included in the program. Neighborhood common areas are being cleaned with either water or industrial vacuums; however, the vacuum cleaners do not reach the upper areas of La Oroya, where many children play. In 2008, the program underwent a period of restructuring in an effort to reduce the amount of water being used, and more attention was focused on the use of vacuum trucks. However, the total area covered in 2008 was significantly less than 2007. We recommend that these activities continue at levels similar to 2007 and that they continue to be conducted on a regularly throughout the year. It is also important that children are encouraged to play in areas that are regularly cleaned.

- **Educational outreach** – A program sponsored by the Convenio called, "Healthy Families and Homes" was established in 2006. The program has created a network of health surveillance in the communities surrounding the Complex by training health promoters. These agents visit individual families to educate adults and children on effective hygiene, health, and nutrition practices.
- **Blood lead studies** – The annual blood lead studies conducted by DIGESA/Convenio de Cooperación have continued as had been recommended, with expansion to more communities. We recommend that this annual program continue, as it will reveal the efficacy of reductions in Complex emissions, intervention programs, and future remediation of contamination. Children with the highest blood lead levels should continue to be identified and targeted for educational (e.g., hygiene, nutrition) and clinical (nutritional supplements, medical testing) interventions tailored to the child's home environment and economic means. We also recommend that blood lead studies continue to include measurement of hematocrit and hemoglobin levels and that assessment of iron status be added.
- **Paving of dirt roads, walkways, and play areas** – The program to pave dirt roads and walkways has continued as had been recommended. In 2007 and 2008, 19 projects were completed and four more projects are to be completed before the end of 2008. This program is expected to reduce the generation of windblown dust that enters homes. The extent of remaining unpaved areas should be assessed to identify additional areas that might benefit from paving.
- **Door mats** – It had been recommended that door mats composed of a material that traps dirt be provided to reduce the amount of contaminated dirt and dust tracked into homes. Since 2006, door mats have been gradually introduced into the community to families that have children under 6 with a high risk of dust and soil exposure. To date, 90 families in La Oroya have received door mats. Other residents are advised to place a wet towel at the entrance to their home. We recommend that the effectiveness of this program be assessed to determine if it should be continued and if continued, how frequently the mats should be replaced.
- **Planting of grass and trees on exposed soil** –The program to grow grass on exposed soils and to plant trees to reduce windblown dust has continued, as had been recommended. This program should be reviewed after 2009 when major reductions in sulfur dioxide emissions are achieved, to determine how best to facilitate re-greening of exposed soils. If a program to remediate contaminated soil is implemented by Activos Mineros, it should include a planting program.

- **Soil amendments** –A study to evaluate changes in lead bioavailability due to the addition of phosphates to La Oroya soils had been recommended. Doe Run Peru supported Integral in conducting a preliminary experiment with soil shipped from La Oroya to our U.S. laboratory in Colorado. This experiment was unsuccessful. We recommend that further evaluation of soil amendments be deferred until after completion of the major improvements in emission reductions in November 2009.
- **House construction improvements** – Many houses in La Oroya are constructed of adobe; some have dirt floors, corrugated sheet metal roofs, or adobe roofs. The walls and ceilings of many adobe homes are covered with plaster, which prevents the sloughing off of dirt into homes. In 2005, we had recommended developing a program to improve adobe homes with exposed dirt or roofs of corrugated metal sheets to reduce generation of indoor dust containing elevated metal concentrations. This program has been implemented by Doe Run Peru. It is directed at families with children who have the highest blood lead levels and whose homes are currently being selected for improvements. The program has also been extended to the communities outside of La Oroya Antigua. We recommend that the program be continued in its expanded capacity.
- **Leaded gasoline** – In 2005, we had recommended that the community and DIGESA take action to ensure that leaded gasoline was not being sold in the La Oroya region. It is our understanding that leaded gasoline is no longer available for sale in La Oroya.

7.4 DIETARY STUDIES AND INTERVENTIONS

A pilot dietary study conducted in 2005 in La Oroya Antigua by the Instituto de Investigacion Nutricional (IIN) examined intake of several nutrients that can affect lead exposure and health effects. In addition to identifying the diet as an important contributor to lead exposure, this study found intakes of calcium and iron to be insufficient. On the basis of these findings, a series of actions had been recommended to identify ways to reduce lead intakes and to improve nutritional status.

The IIN recommended a larger study to obtain more widely representative results. This recommendation was implemented in 2008; study methods and results are summarized in Section 3. The primary goal of the 2008 study was to measure nutrient and lead intakes. Another goal—identify specific actions residents could take to reduce their exposure to lead and other metals—was addressed by investigating food handling and storage practices. From interviews and direct observation, researchers found inadequacies in food, water, and utensil storage as well as in food-, utensil-, and hand-washing practices, all of which may increase exposure to lead-contaminated dust. It is recommended that these findings be used to develop and improve community programs. The following specific recommendations are offered:

- Because proper storage techniques are so important in reducing exposure to and ingestion of contaminated dust, the community should determine the best way to ensure that all households have the necessary resources to store food, water, and utensils in closed containers. This practice should be taught in community education programs.
- Because washing of food, hands, and cooking surfaces before preparing and eating meals is known to reduce exposure to contaminated dust, proper washing techniques should continue to be taught in community education programs.

Further study should also be undertaken to investigate means outside the home (e.g., at outdoor markets) by which lead and other metals are transferred to food. Findings from such research should be used to develop programs to reduce this exposure.

Based on the findings of the IIN pilot study, in 2005 it had been recommended that additional studies and interventions be performed to ensure that residents have adequate iron and calcium intakes. Adequate iron intakes are particularly important because both low iron intake and high lead intake cause neurobehavioral disorders and anemia. The 2008 study measured iron and calcium intakes in a larger sample size and confirmed the pilot study's findings that iron and calcium intakes are inadequate in both women and children in this community. It is recommended that this information be used to develop programs to ensure adequate intakes of these nutrients.

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FIGURES

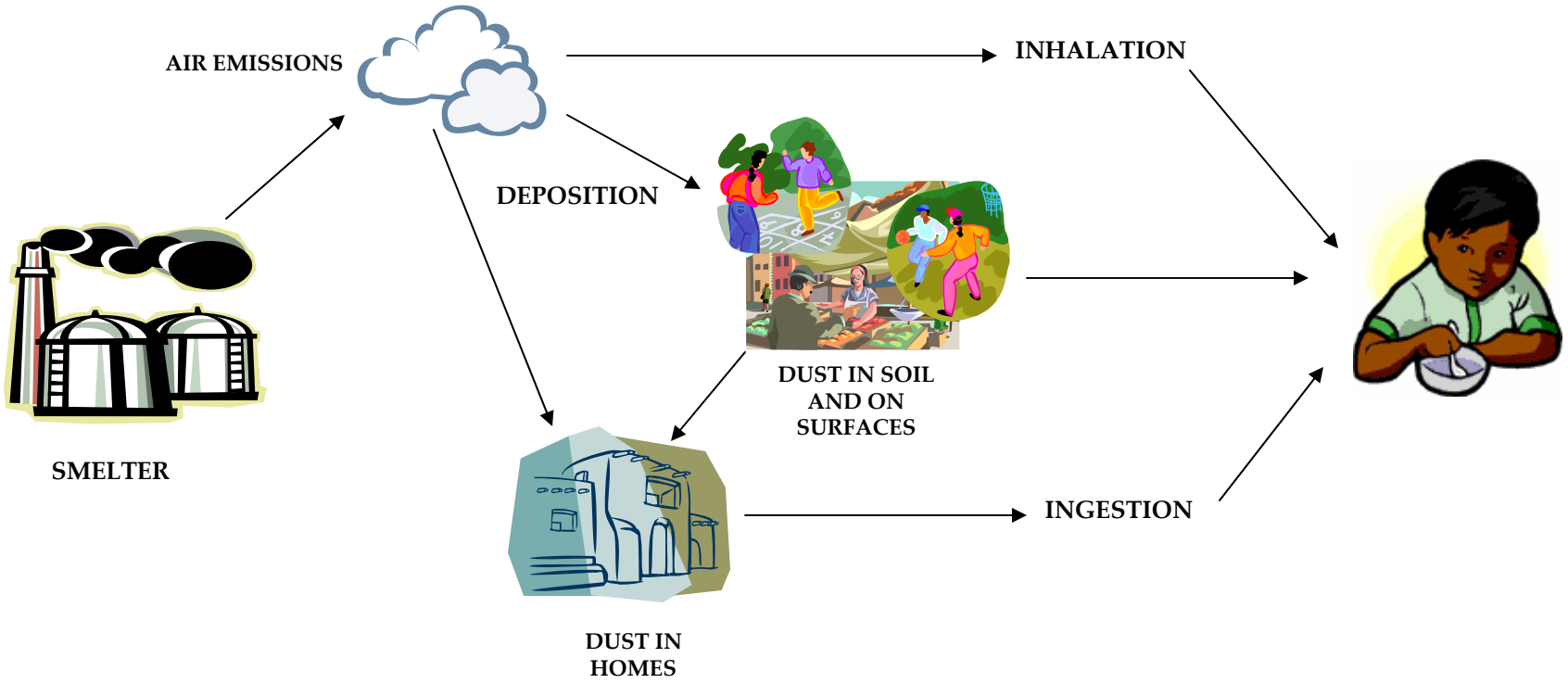


Figure 2-1. Exposure Pathways for Emissions from the Complex

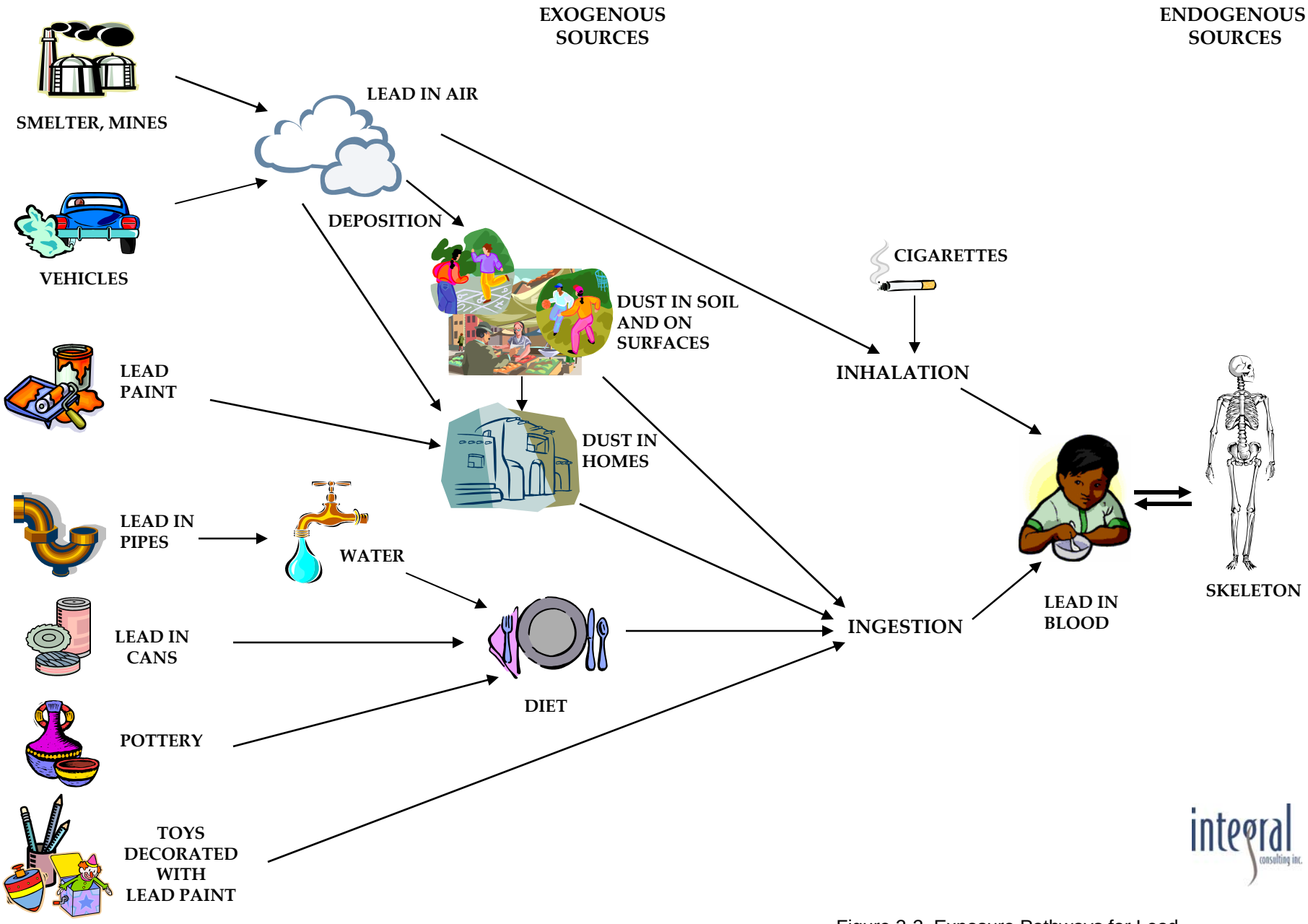
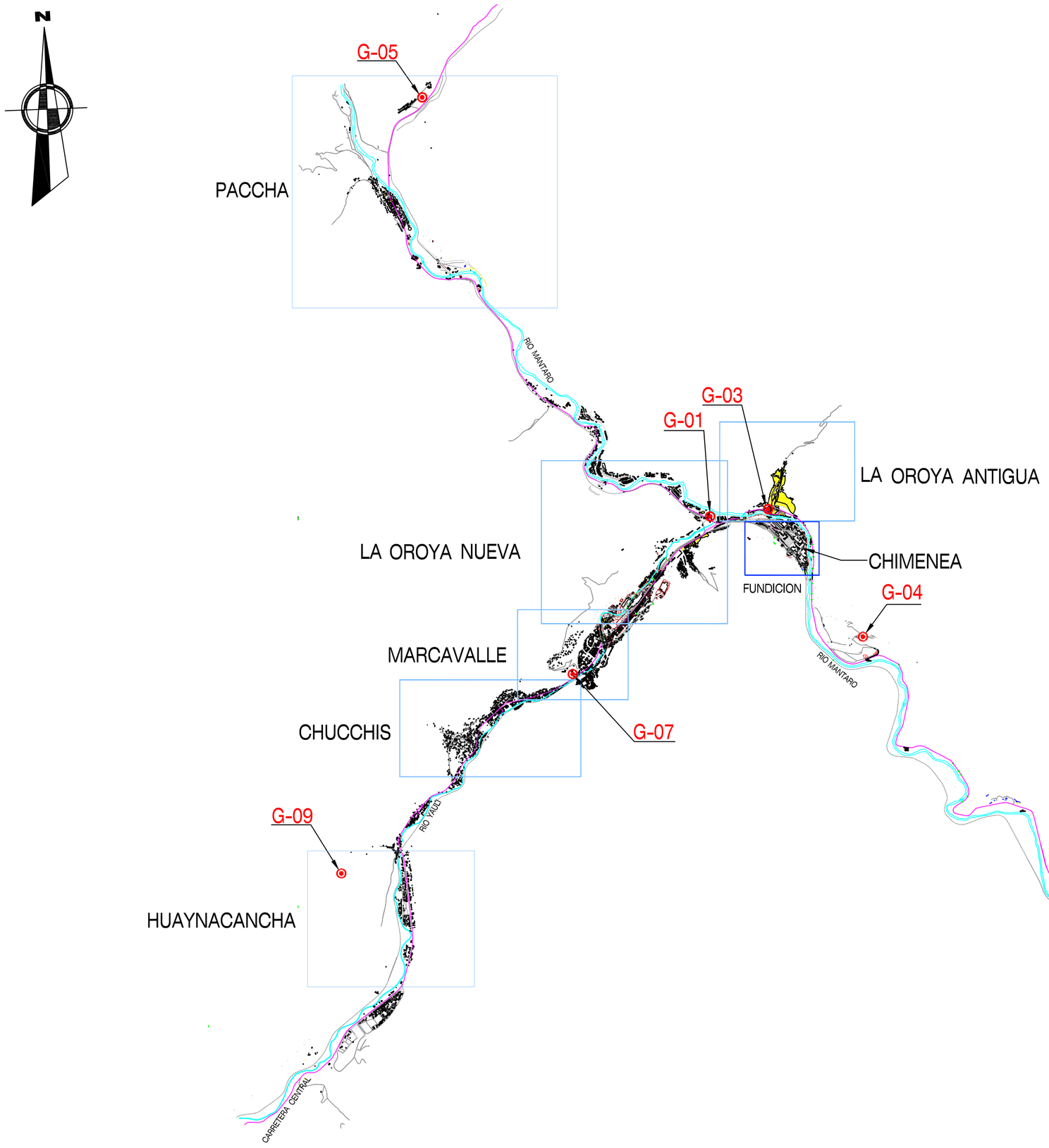


Figure 2-2. Exposure Pathways for Lead



LEYENDA

ESTACIONES DE CALIDAD DE AIRE

		COORDENADAS UTM	
		NORTE	ESTE
ESTACION HOTEL INCA	G-01	8726557.98	400905.78
ESTACION SINDICATO DE OBREROS	G-03	8726680.50	401876.80
ESTACION HUANCHAN (AREA INDUSTRIAL)	G-04	8724541.64	403465.58
ESTACION CASARACRA	G-05	8733582.42	39608067
ESTACION MARCAVALLE	G-07	8723915.83	398602.97
ESTACION HUARI	G-08	8712666.19	408883.12
ESTACION HUAYNACANCHA	G-09	8720573.78	394726.50

: RIO YAULI
: RIO MANTARO
: COMUNIDADES
: FUNDICION
: CARRETERA CENTRAL
: EDIFICIOS

REV.	DATE	REVISED DESCRIPTION	REVISED BY	APPROVED BY	REFERENCE DWG. N°	DESCRIPTION

DESIGNED BY: DATE:

DRAWN BY: GEOMASTER SAC E. VERA DATE: 22-09-08

CHECKED BY: M. AVALOS DATE: 23-09-08

APPROVED BY: J. MIRANDA DATE:

DOE RUN PERU
La Oroya Division

ASUNTOS AMBIENTALES

OROYA – ASUNTOS AMBIENTALES

ESTACIONES DE MONITOREO DE CALIDAD DE AIRE Y DISTRIBUCION DE COMUNIDADES
ARREGLO GENERAL

SCALE: 1/50000

DRAWING NUMBER: PRE 1-380-01-2-018

REV.

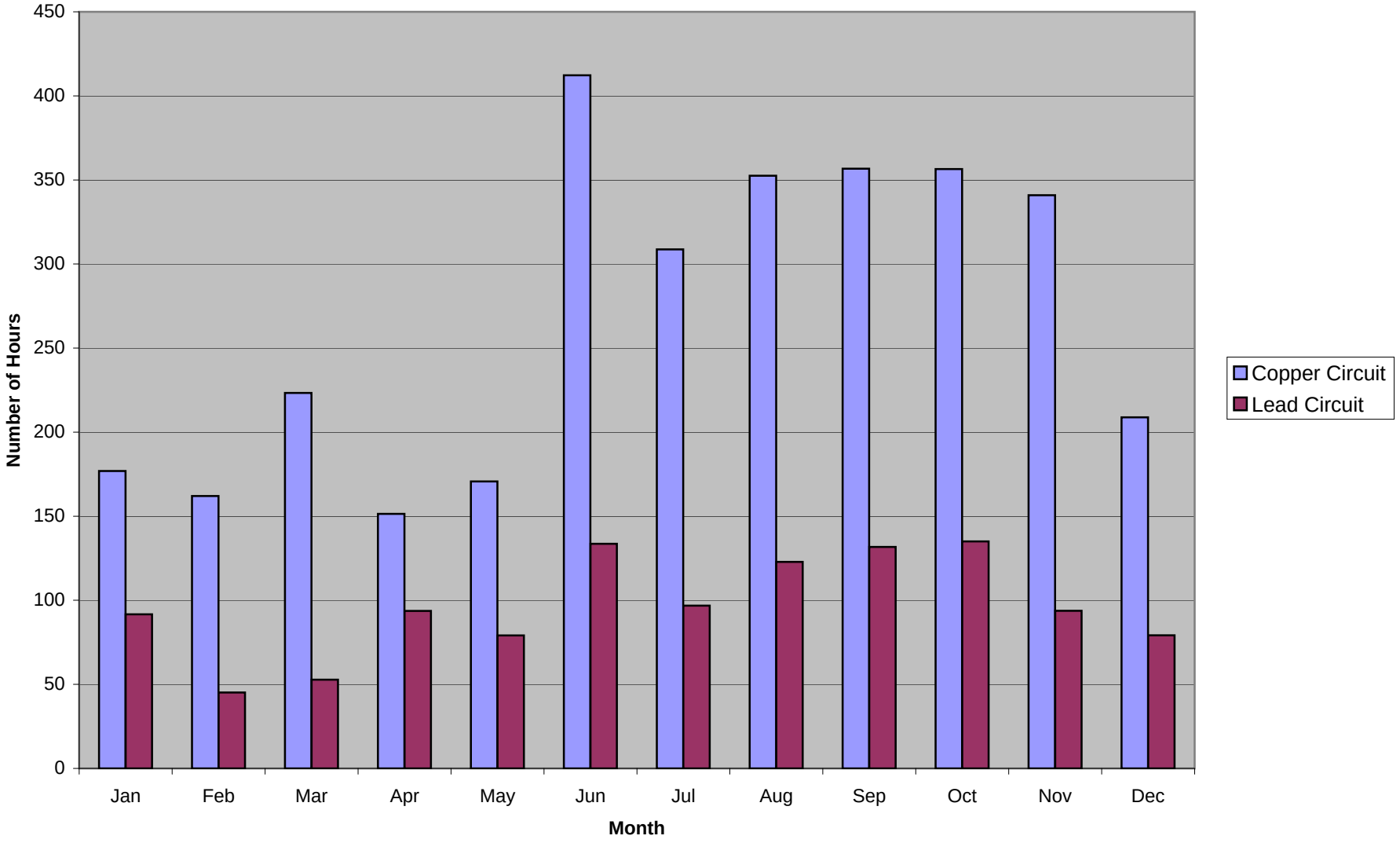


Figure 3-2. Suspension in plant operations in 2007

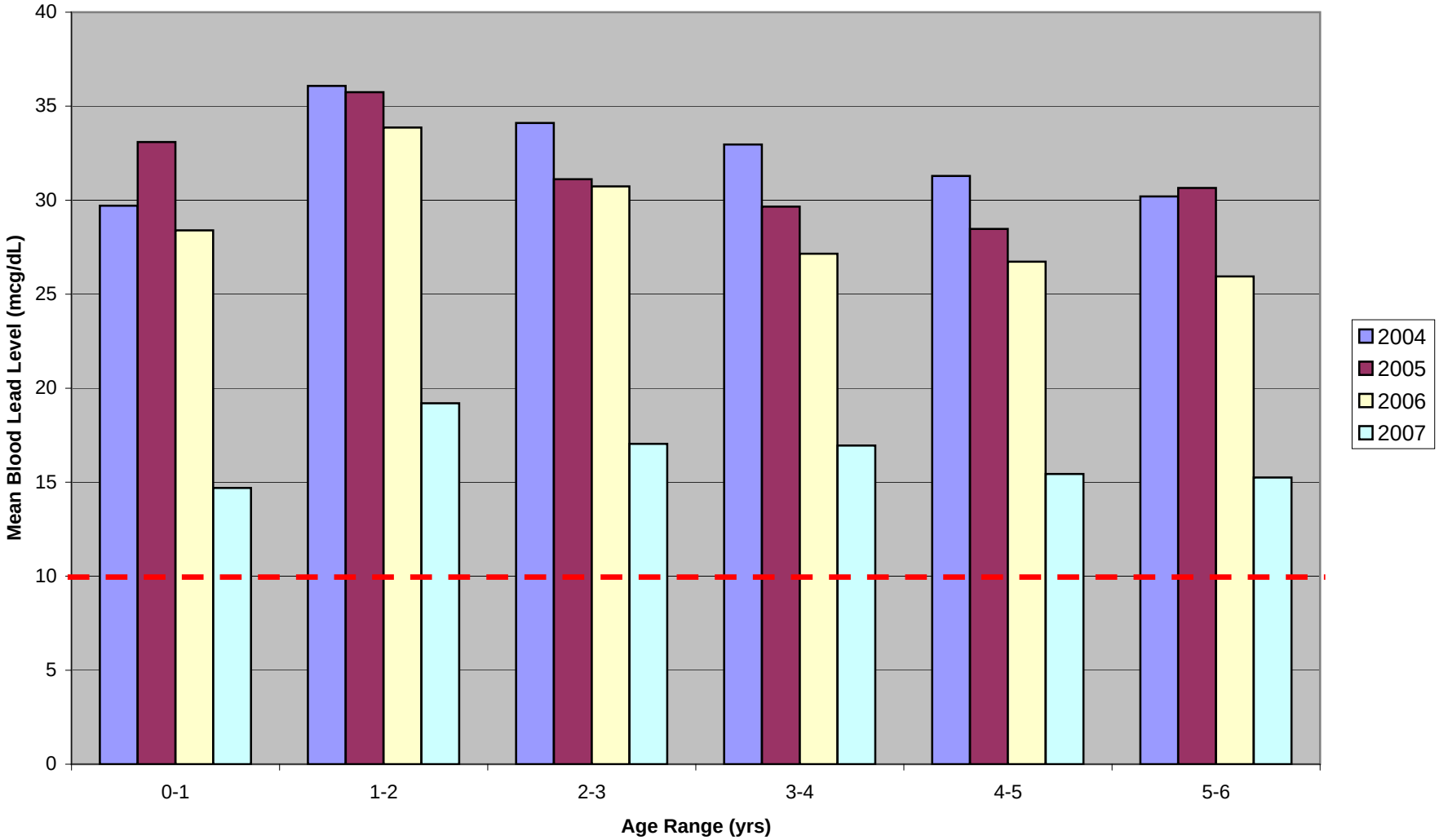


Figure 3-3. Mean blood lead levels in children 2004 - 2007
Note: --- 10 mcg/dL CDC Risk Management Level for Children

Figure 3-4. Iron Intake as a Percentage of the Recommended Daily Intake

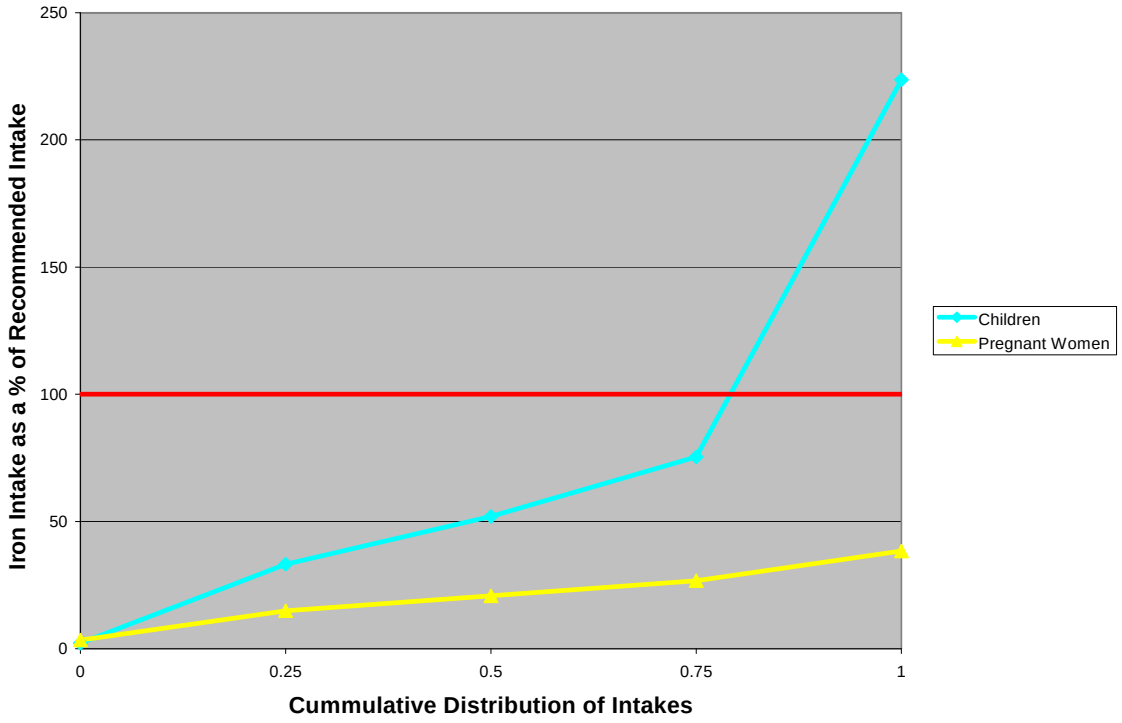


Figure 3-5. Mean Daily Iron Intake for Women and Children

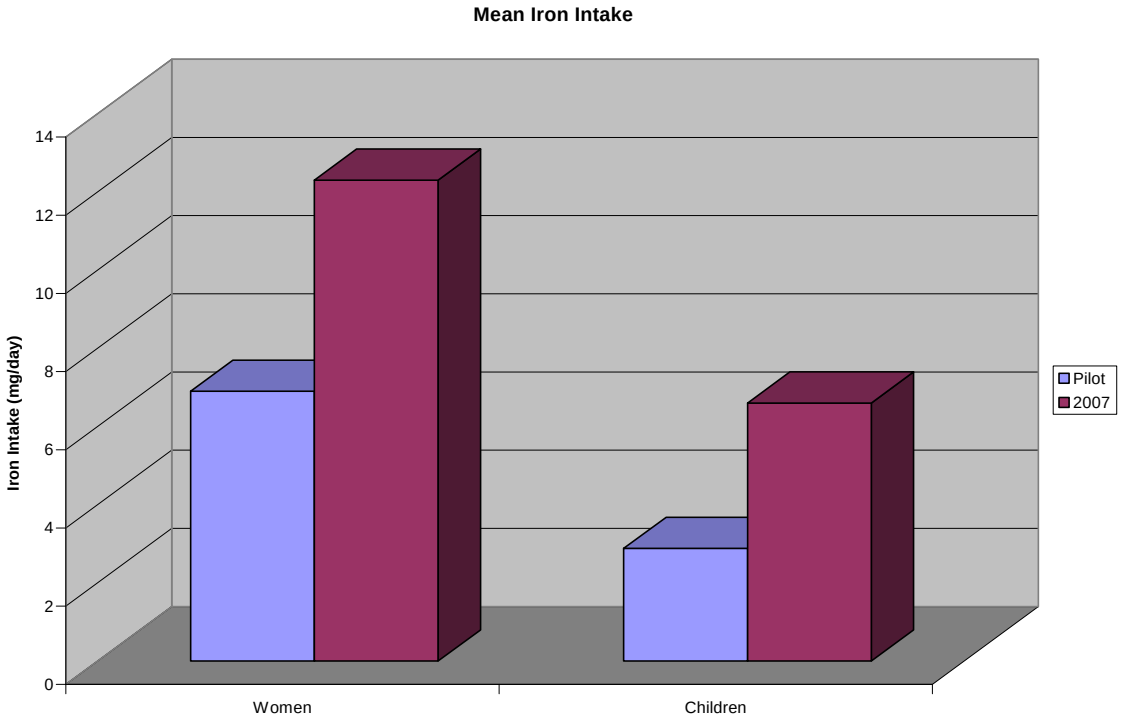


Figure 3-6. Mean Daily Zinc Intake for Women and Children

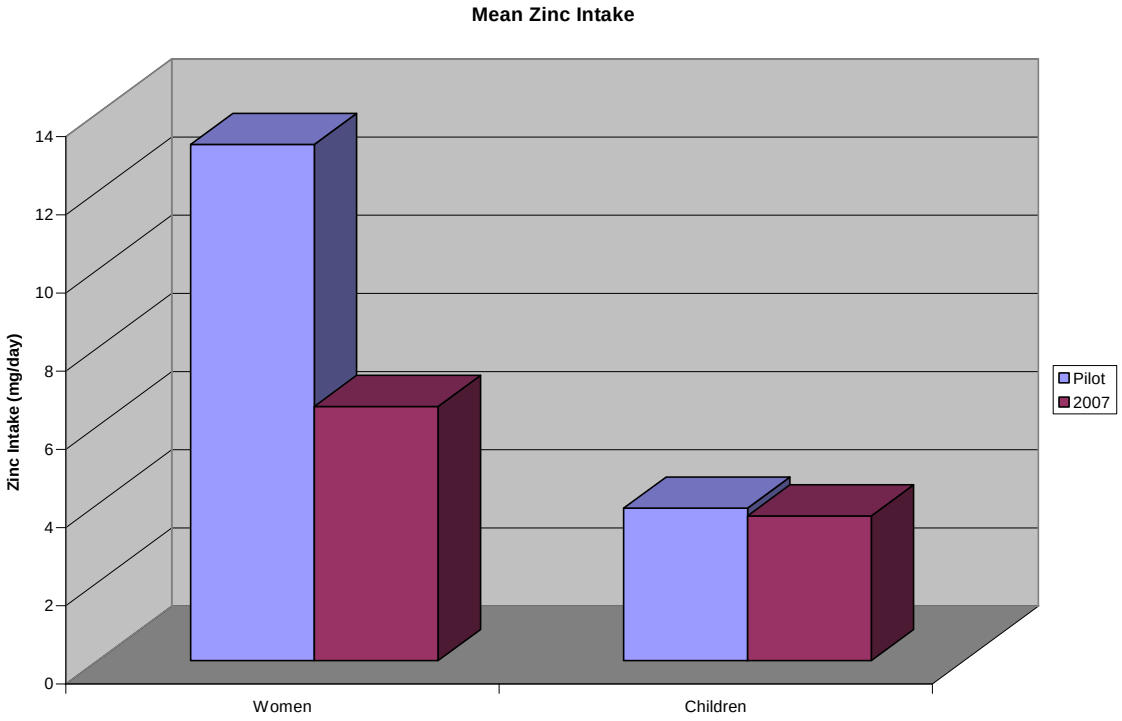


Figure 3-7. Zinc Intake as a Percentage of the Recommended Daily Intake

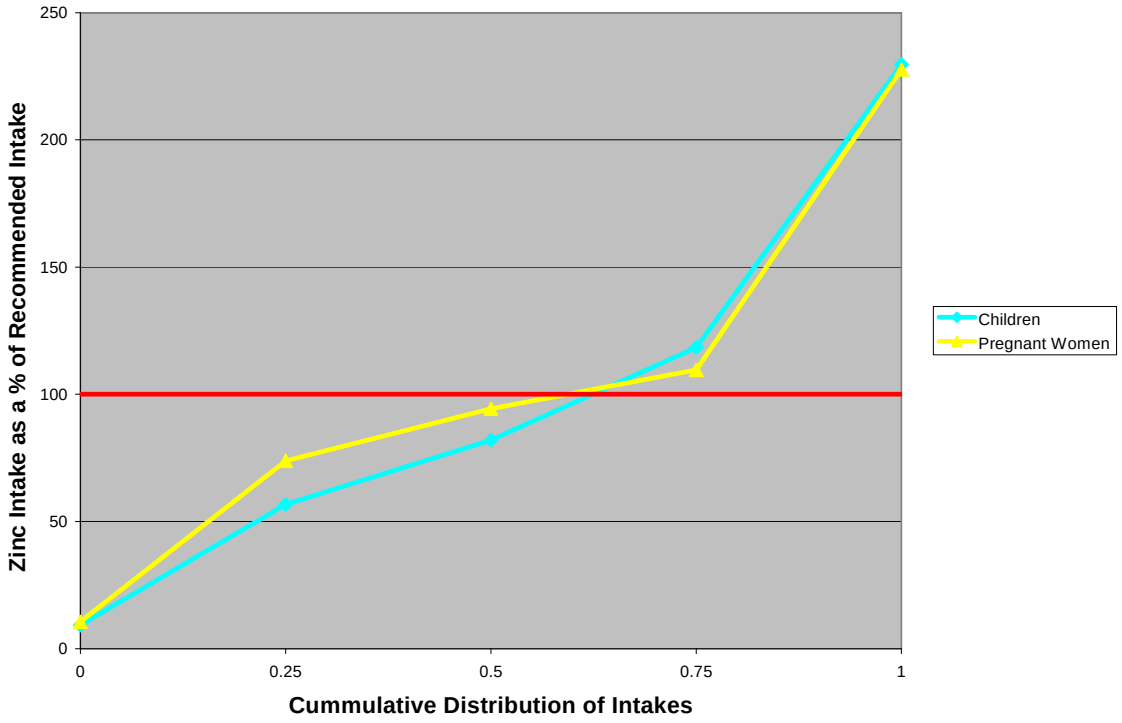


Figure 3-8. Calcium Intake as a Percentage of the Recommended Daily Intake

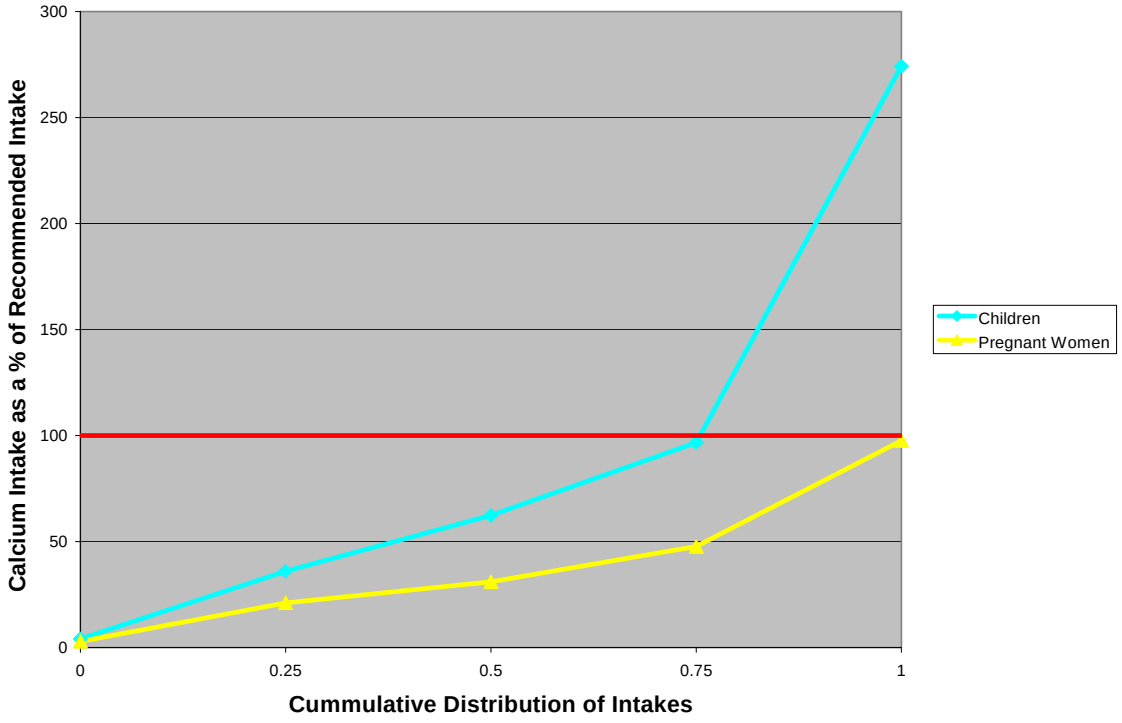


Figure 3-9. Mean Daily Calcium Intake for Women and Children

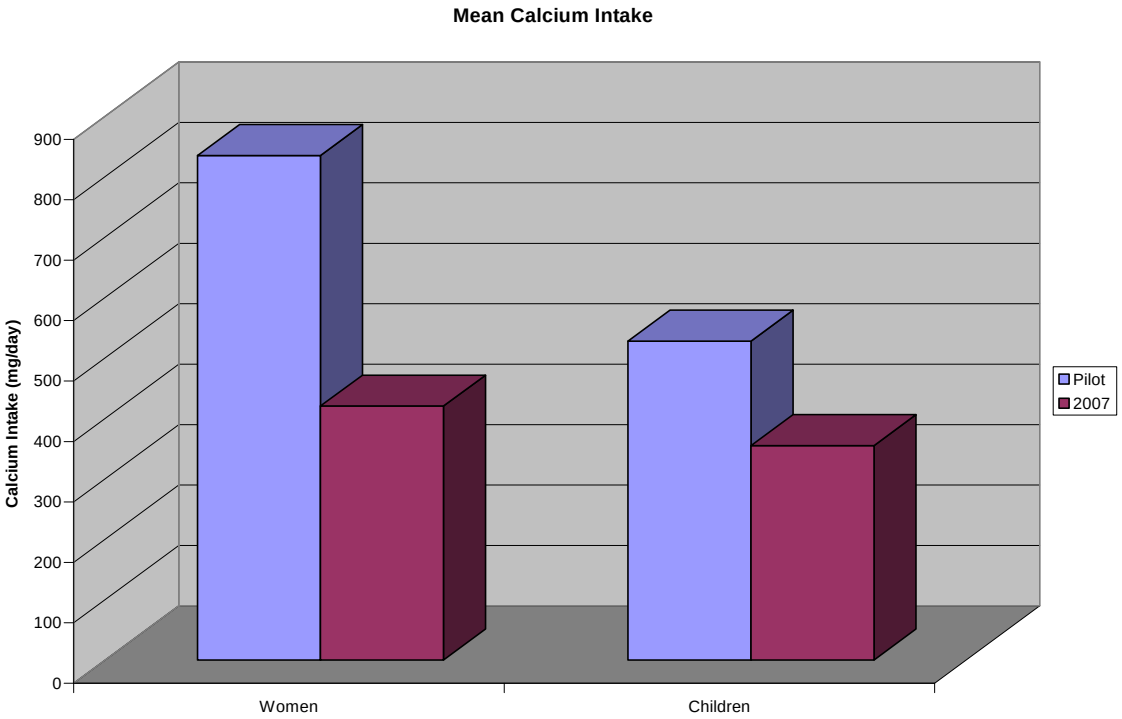


Figure 3-10. Protein Intake as a Percentage of the Recommended Daily Intake

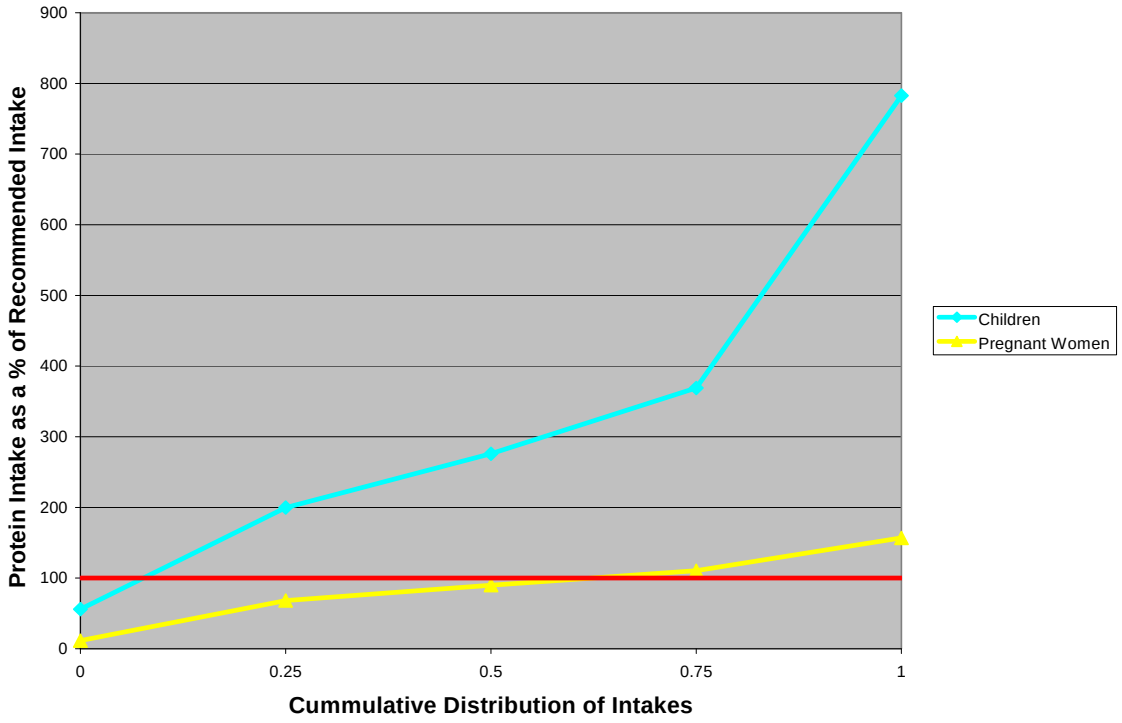
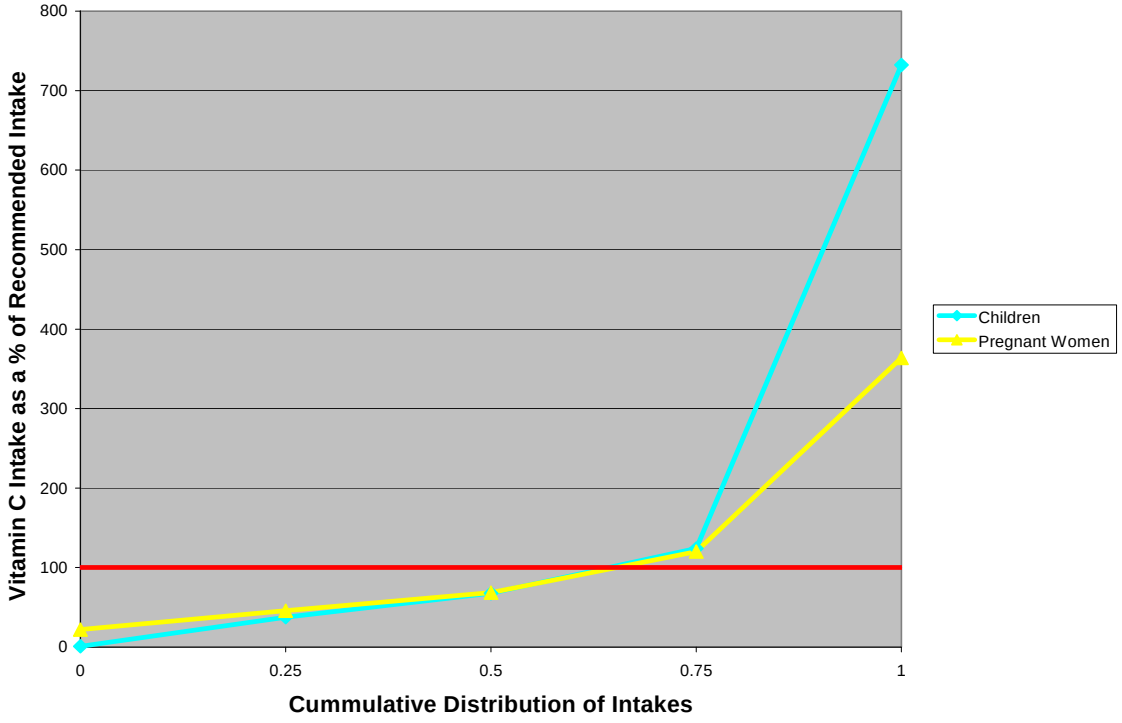


Figure 3-10. Vitamin C Intake as a Percentage of the Recommended Daily Intake



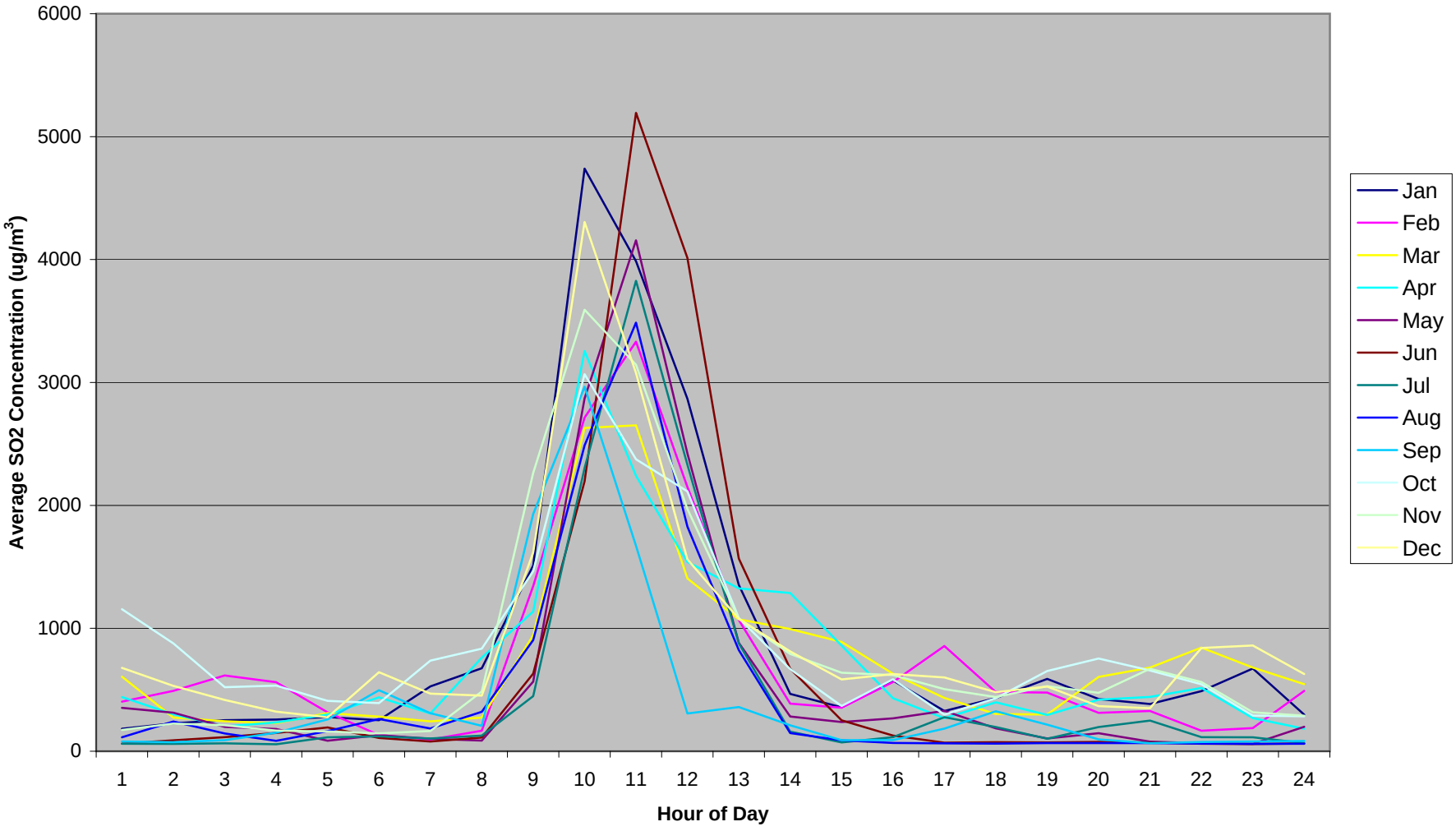


Figure 4-1. Average Hourly Sulfur Dioxide Concentration, Sindicato, 2007

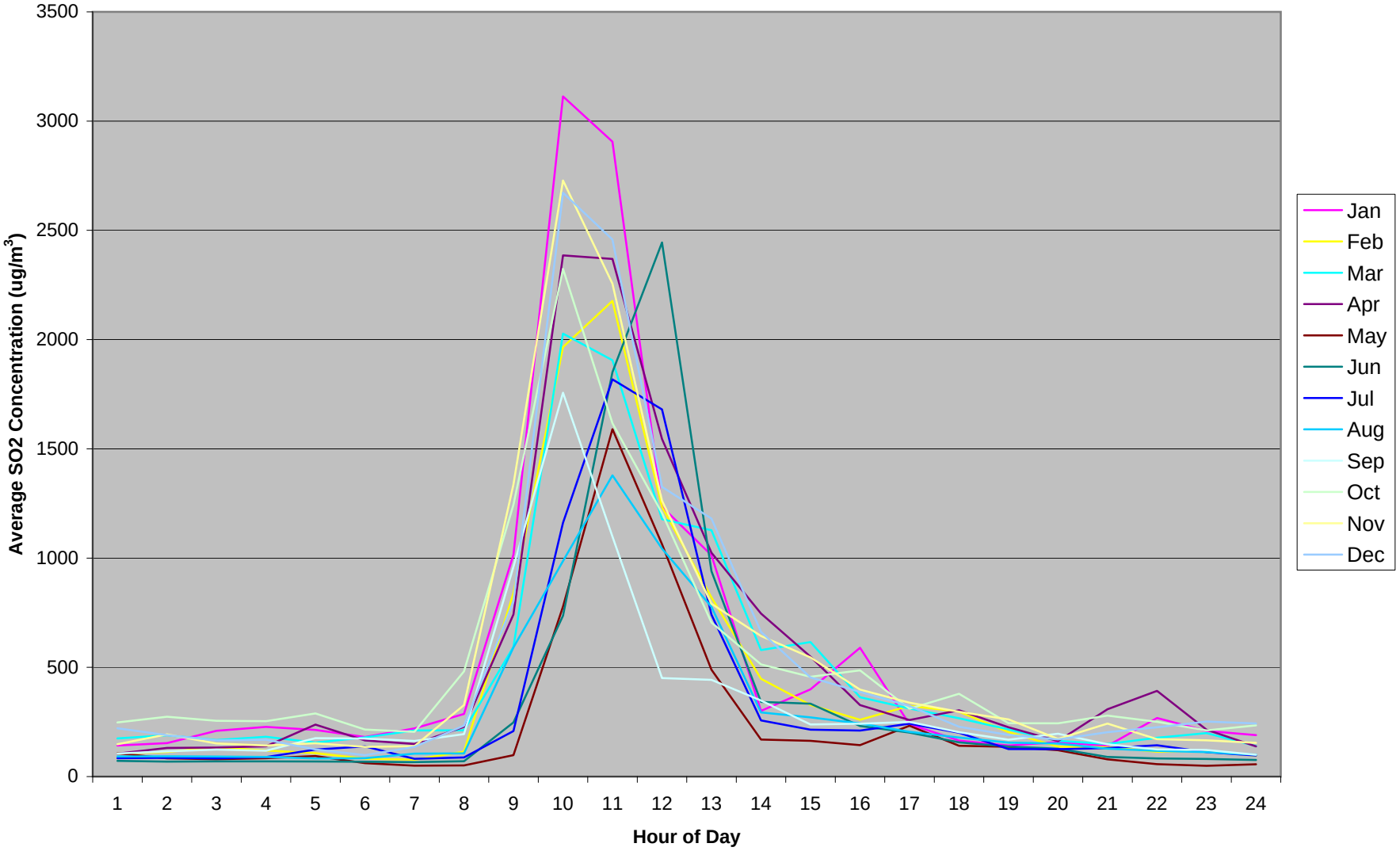


Figure 4-2. Average Hourly Sulfur Dioxide Concentration, Hotel Inca, 2007

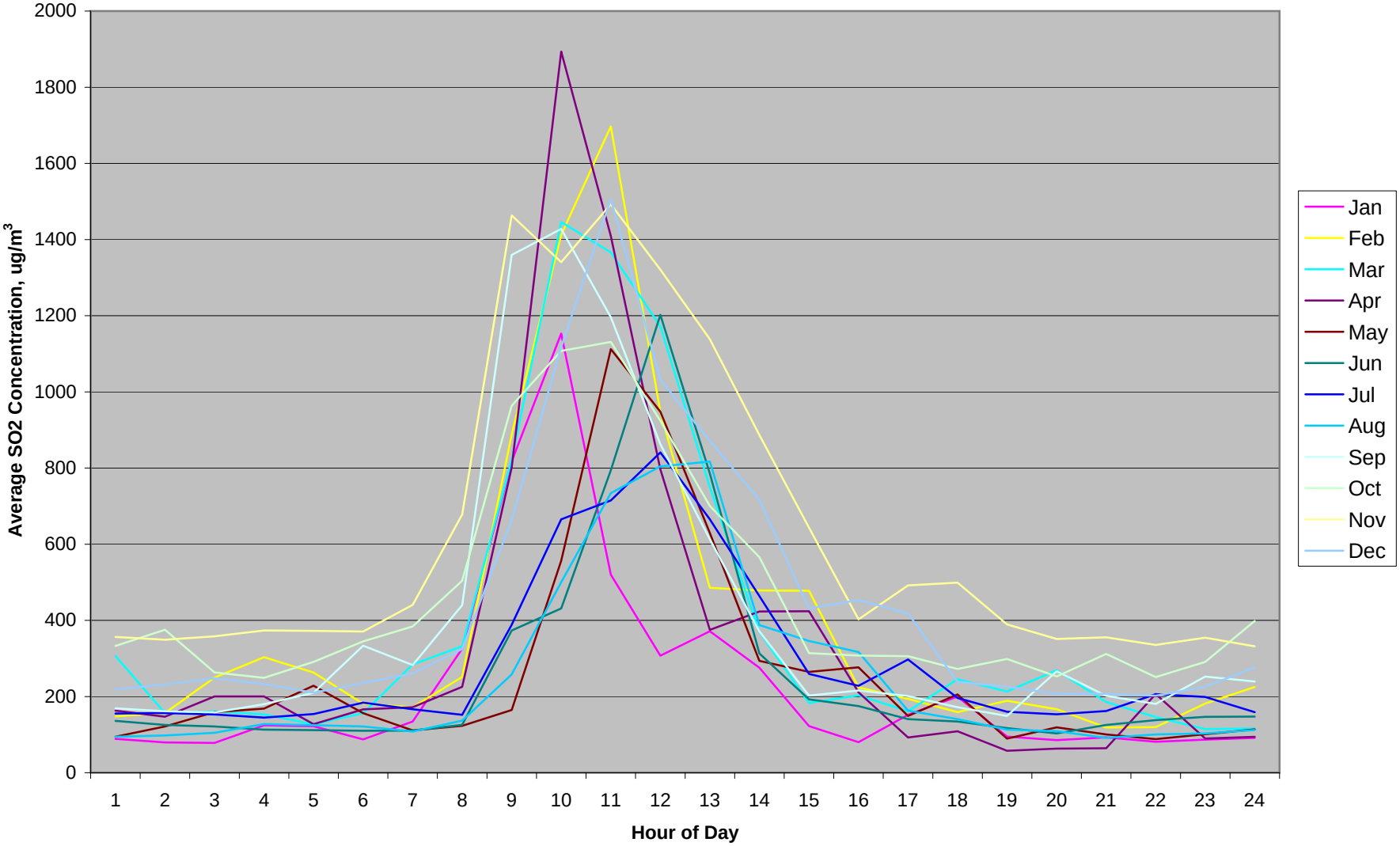


Figure 4-3. Average Hourly Sulfur Dioxide Concentration, Marcavalle, 2007

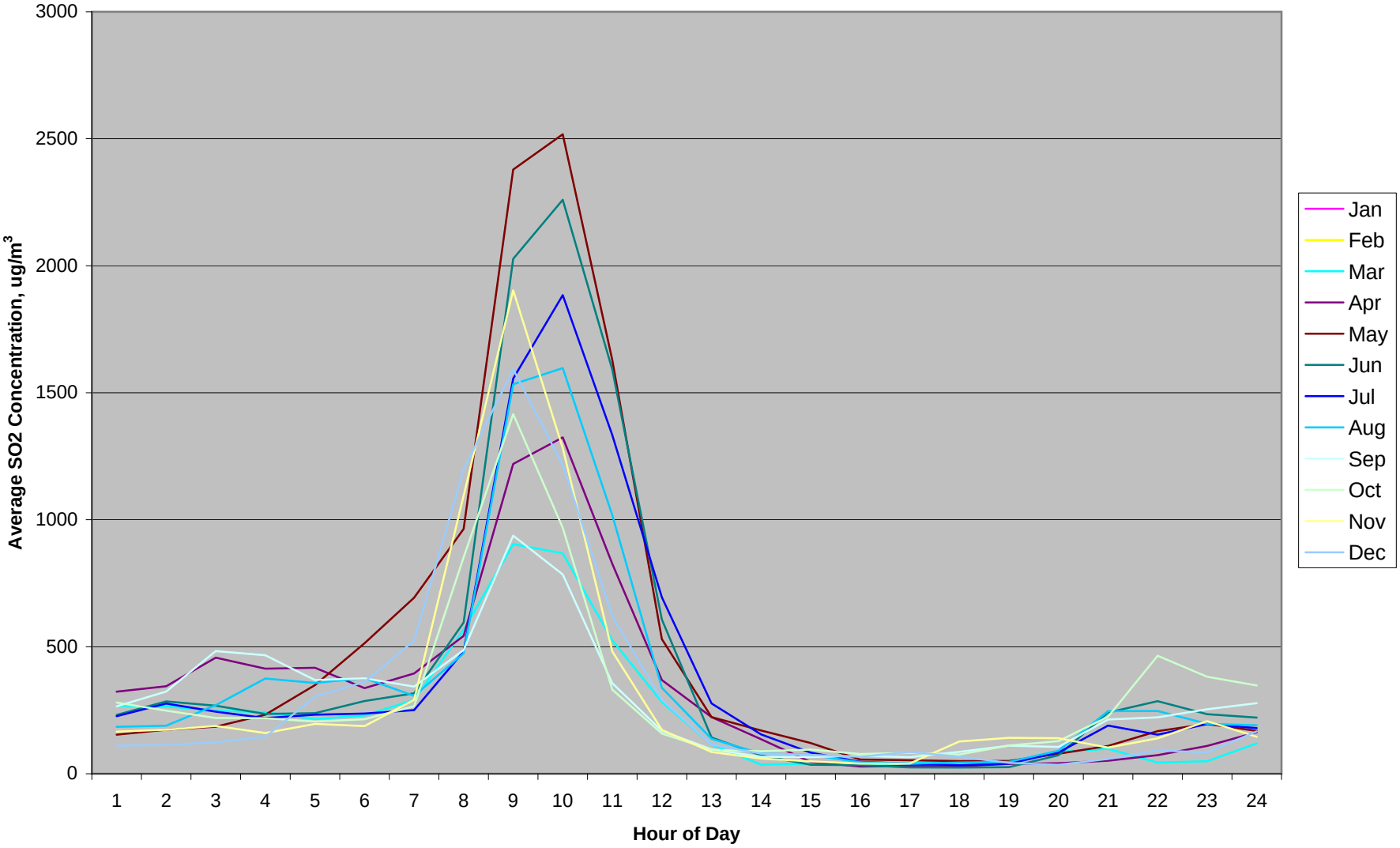


Figure 4-4. Average Hourly Sulfur Dioxide Concentration, Huari, 2007

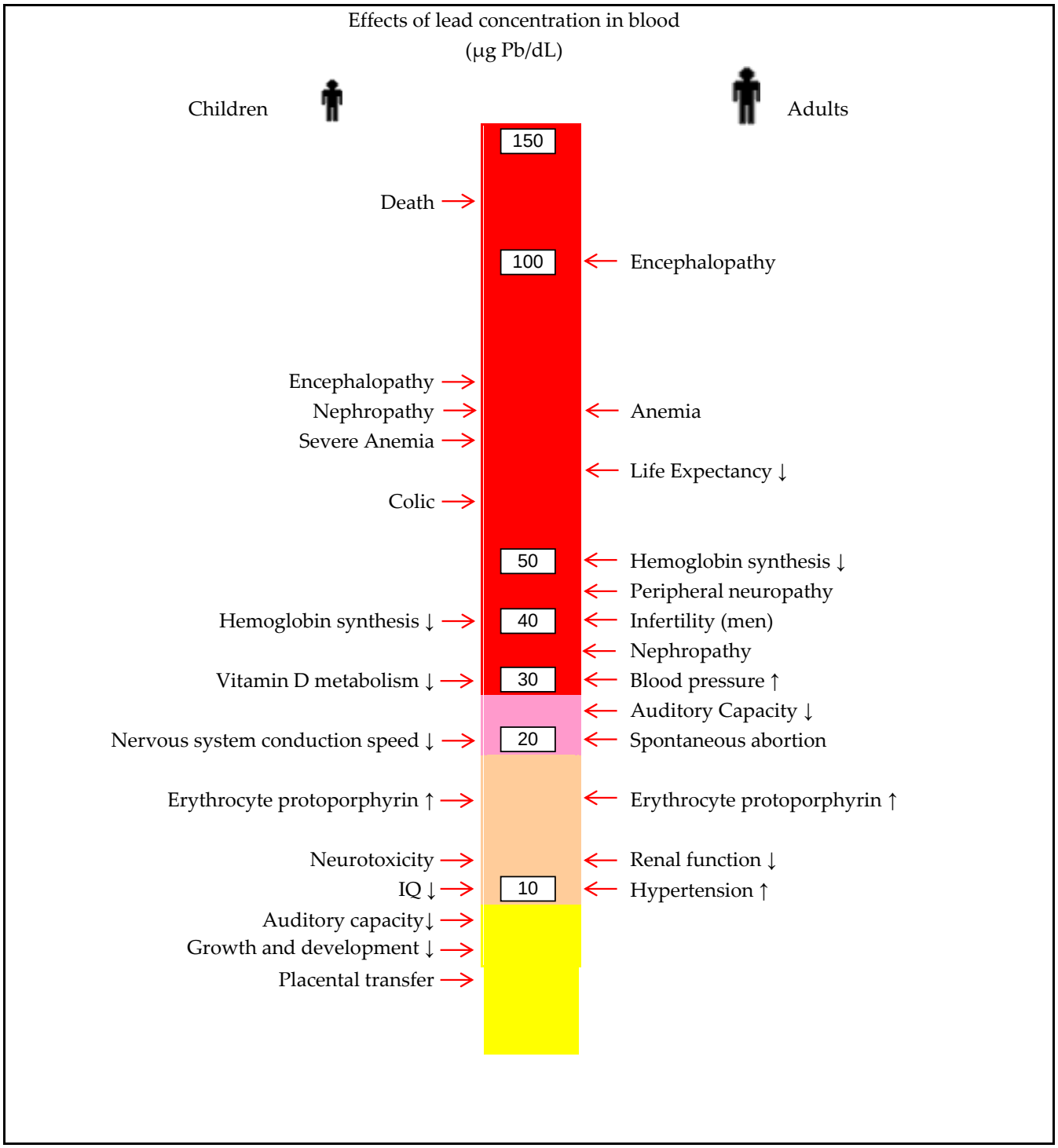


Figure 5-1. Lead concentration in blood

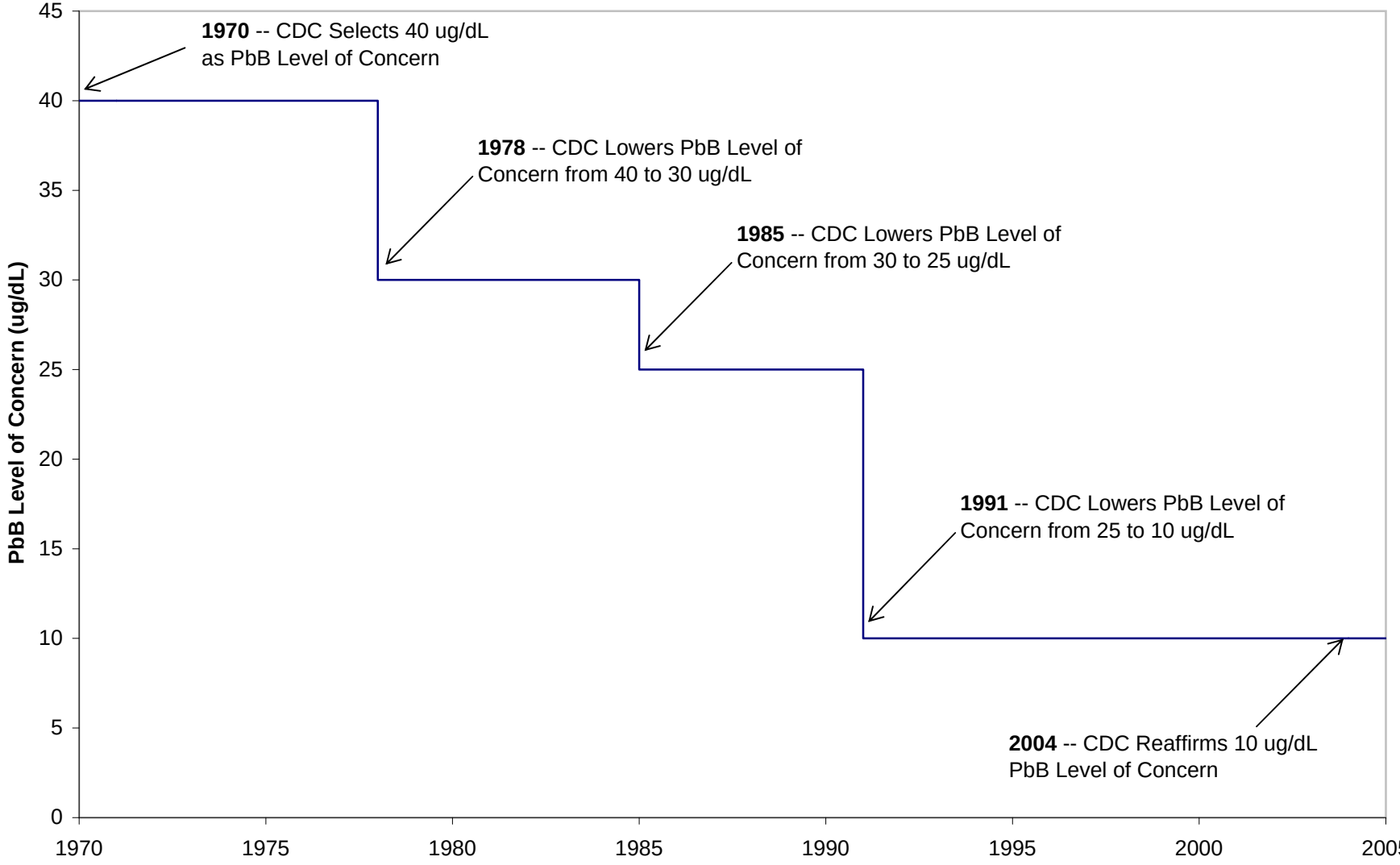


Figure 5-2. Historical Blood Lead Levels of Concern Selected by the CDC

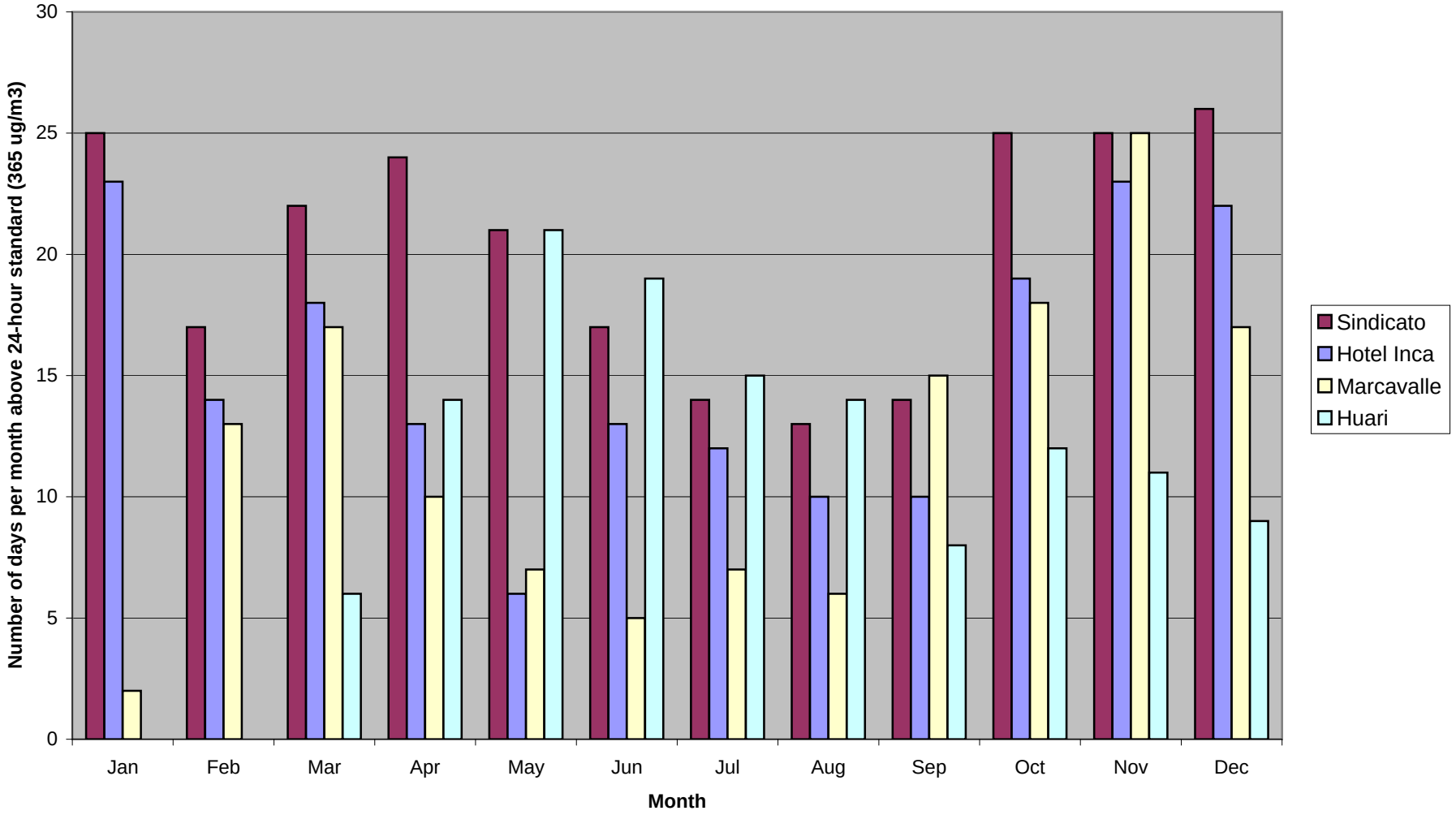


Figure 6-1. Exceedance of Peruvian Air Quality Standards for SO_2 in 2007
Notes: Marcavalle data begins on January 16, 2007
Huari data begins on March 1, 2007

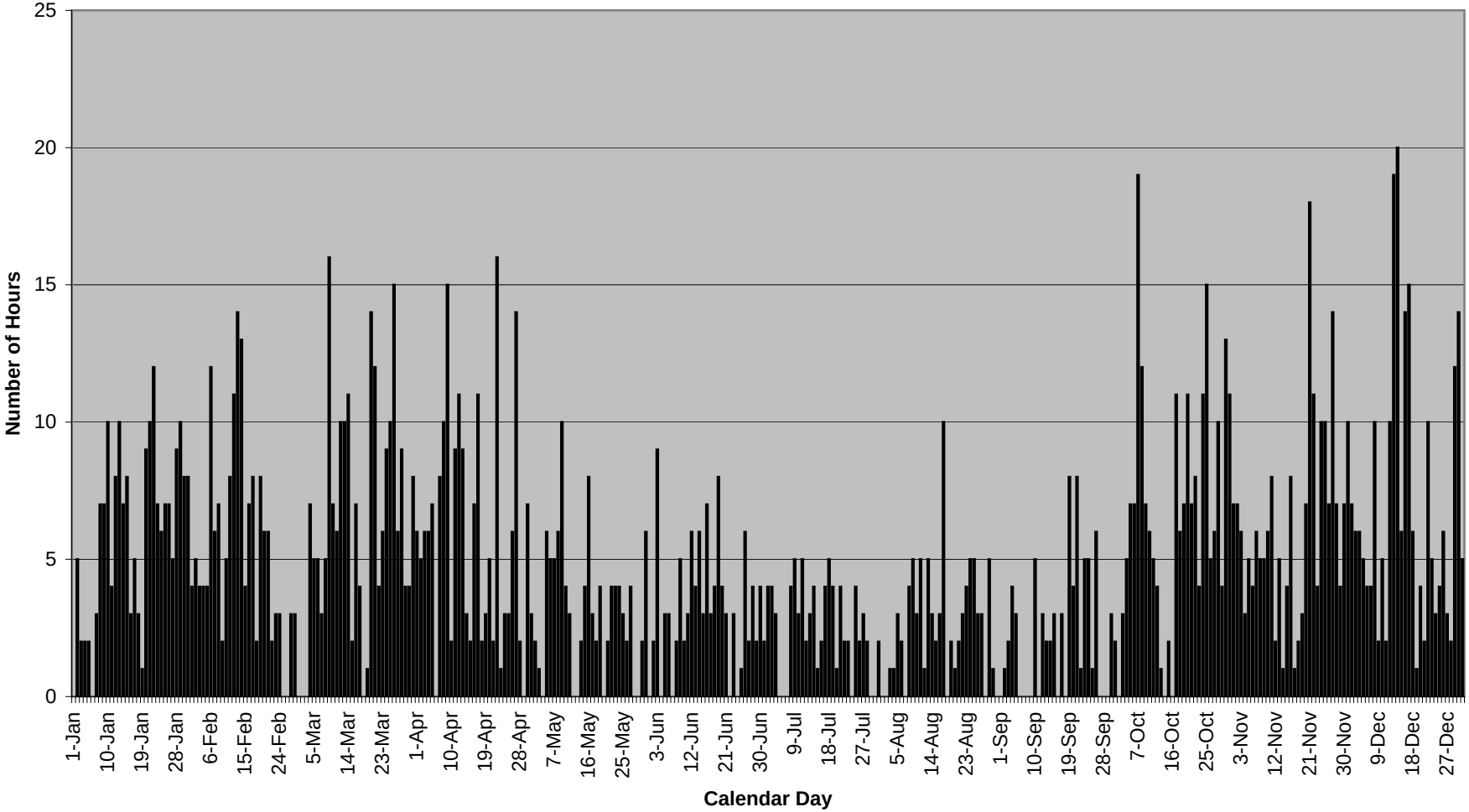


Figure 6-2. Number of hours per day in 2007 that sulfur dioxide levels exceed the AEGL-1(524 $\mu g/m^3$) at Sindicato

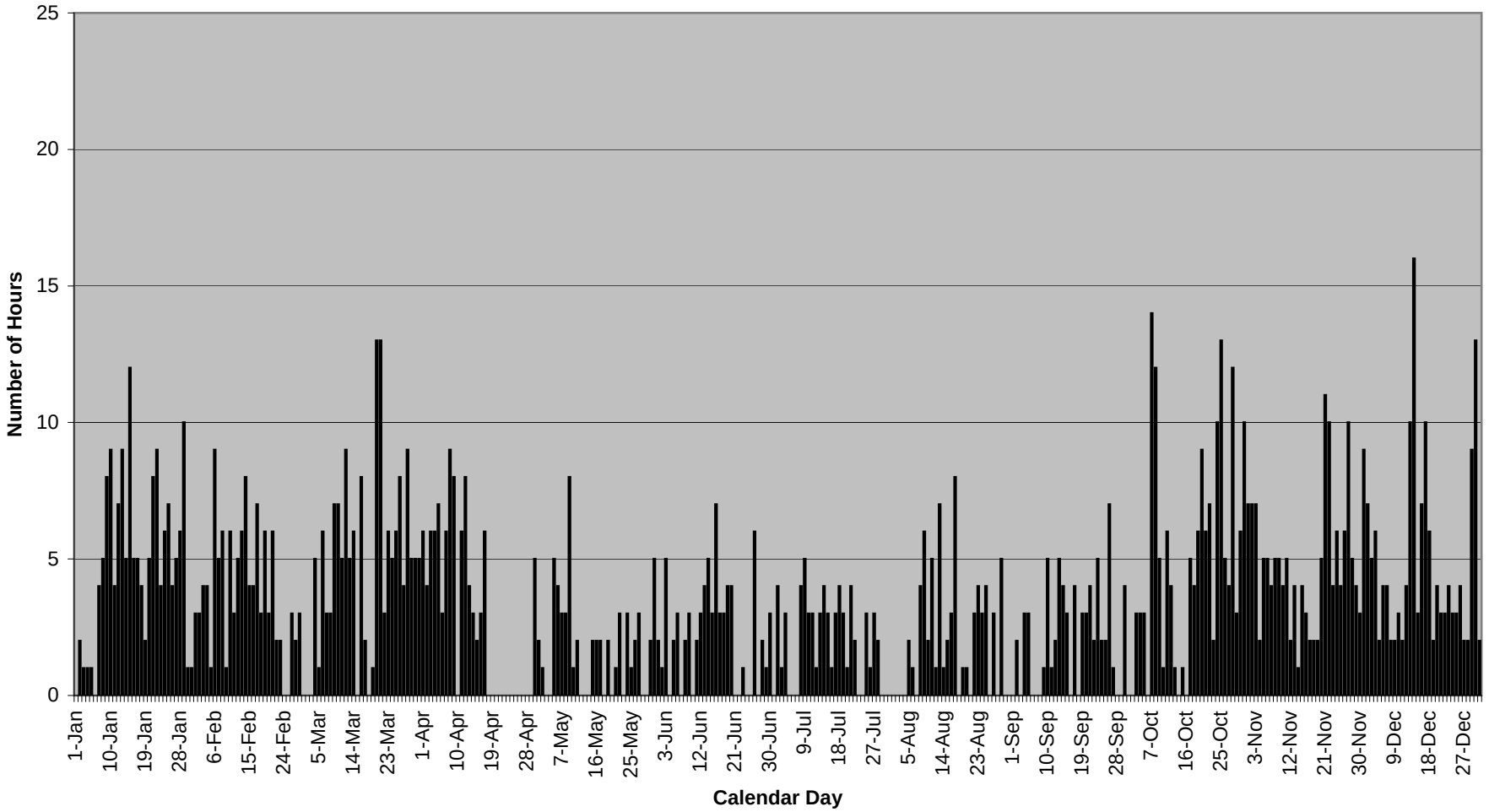


Figure 6-3. Number of hours per day in 2007 that sulfur dioxide levels exceed the AEGL-I (524 μg/m3) at Hotel Inca

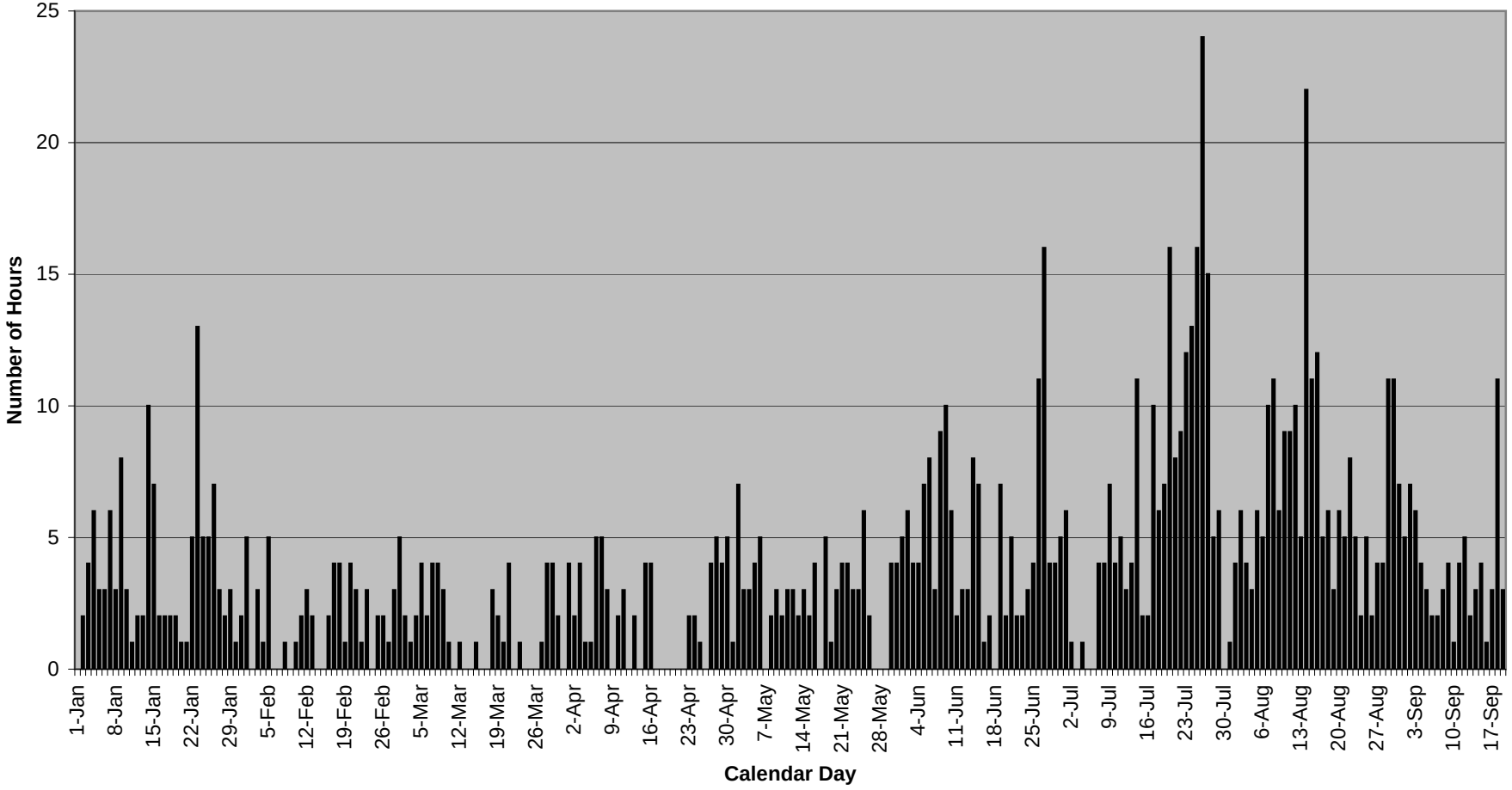


Figure 6-4. Number of hours per day that sulfur dioxide levels exceed the AEGL-1 (524 μg/m^3) at Marcavalle

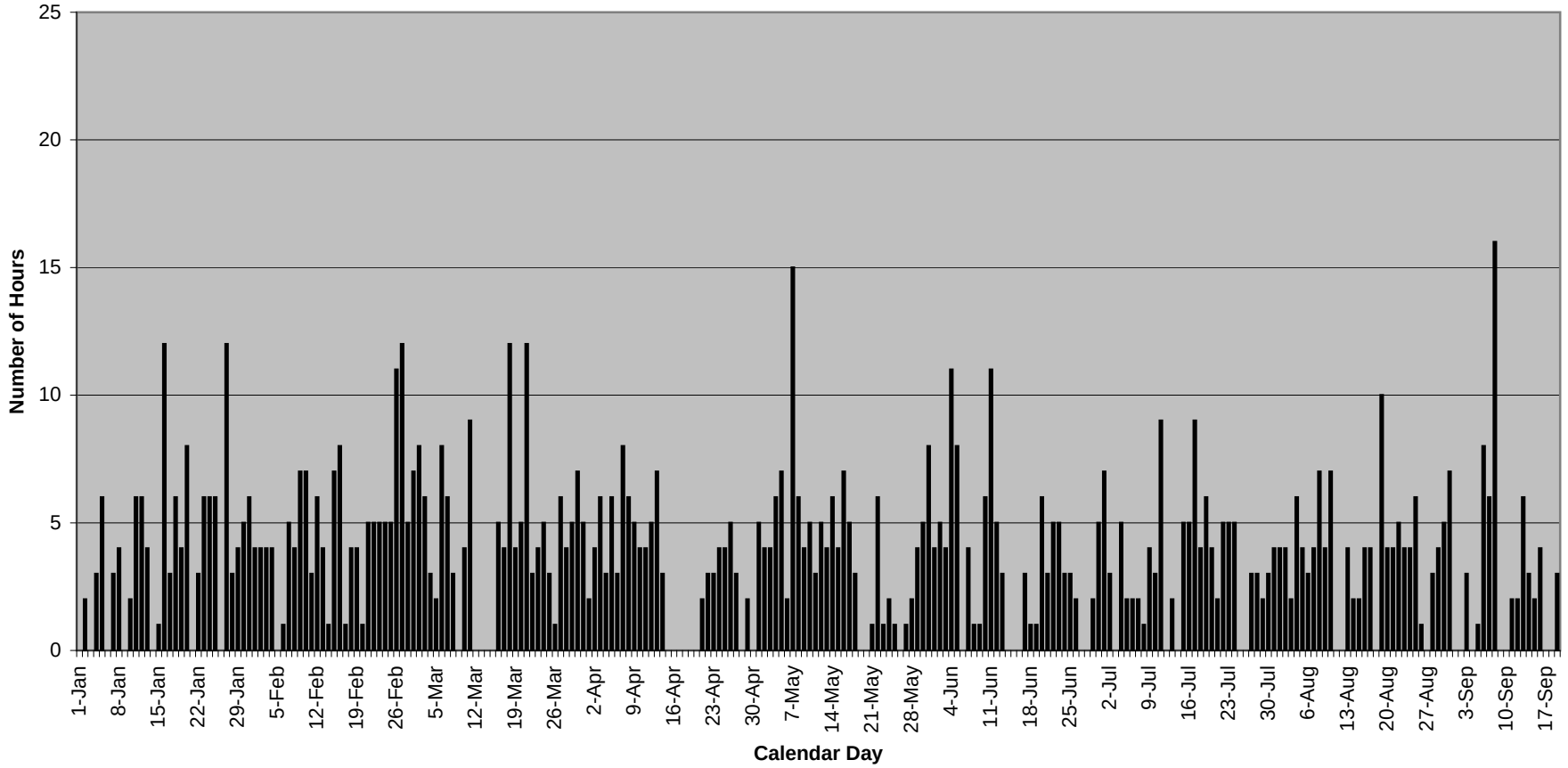


Figure 6-5. Number of hours per day that sulfur dioxide levels exceed the AEGL-1 (524 $\mu g/m^3$) at Marcavalle

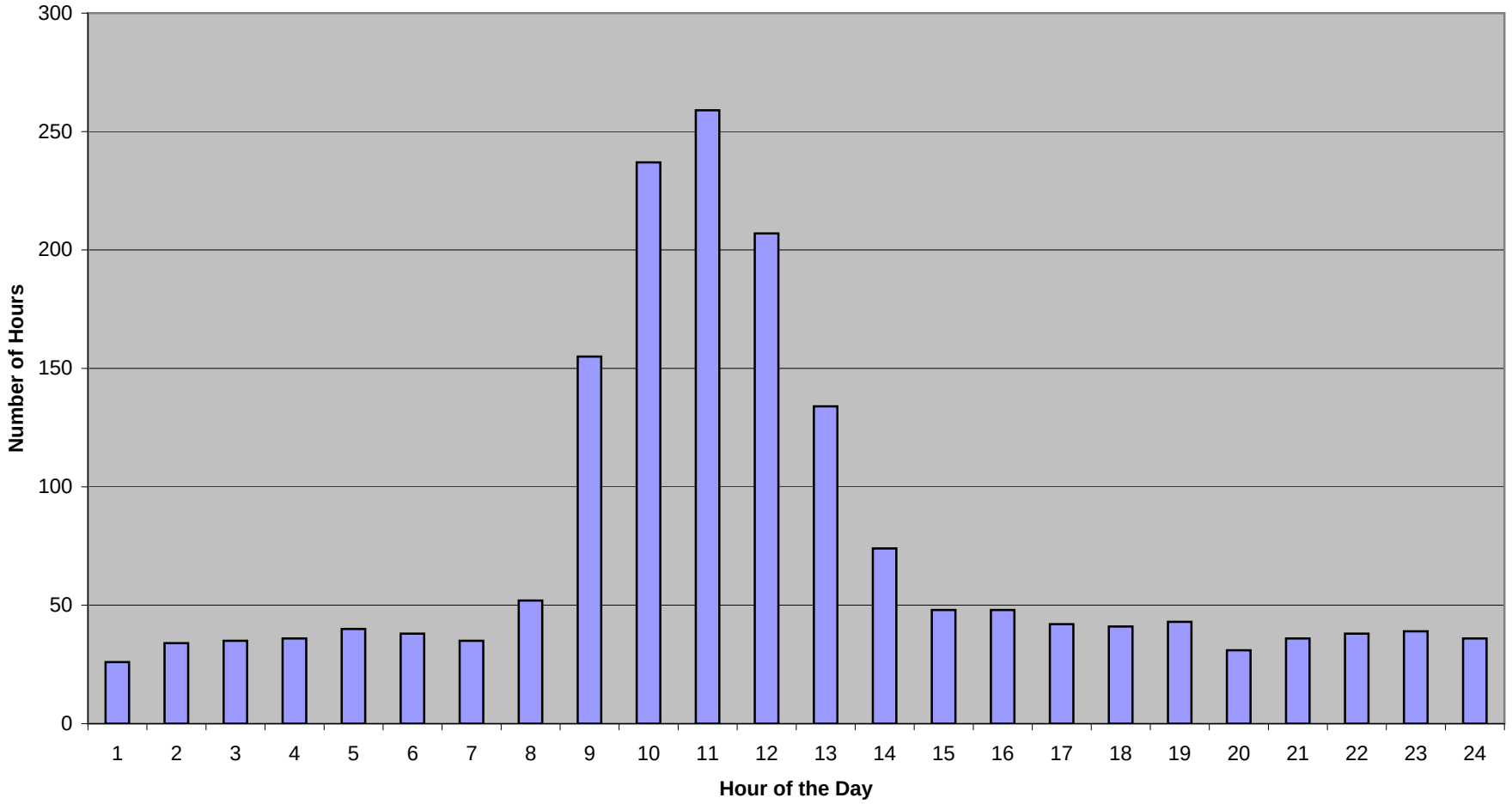


Figure 6-6. Total number of hours in 2007 sulfur dioxide concentrations exceed the AEGL-1 (524 $\mu g/m^3$) at Sindicato

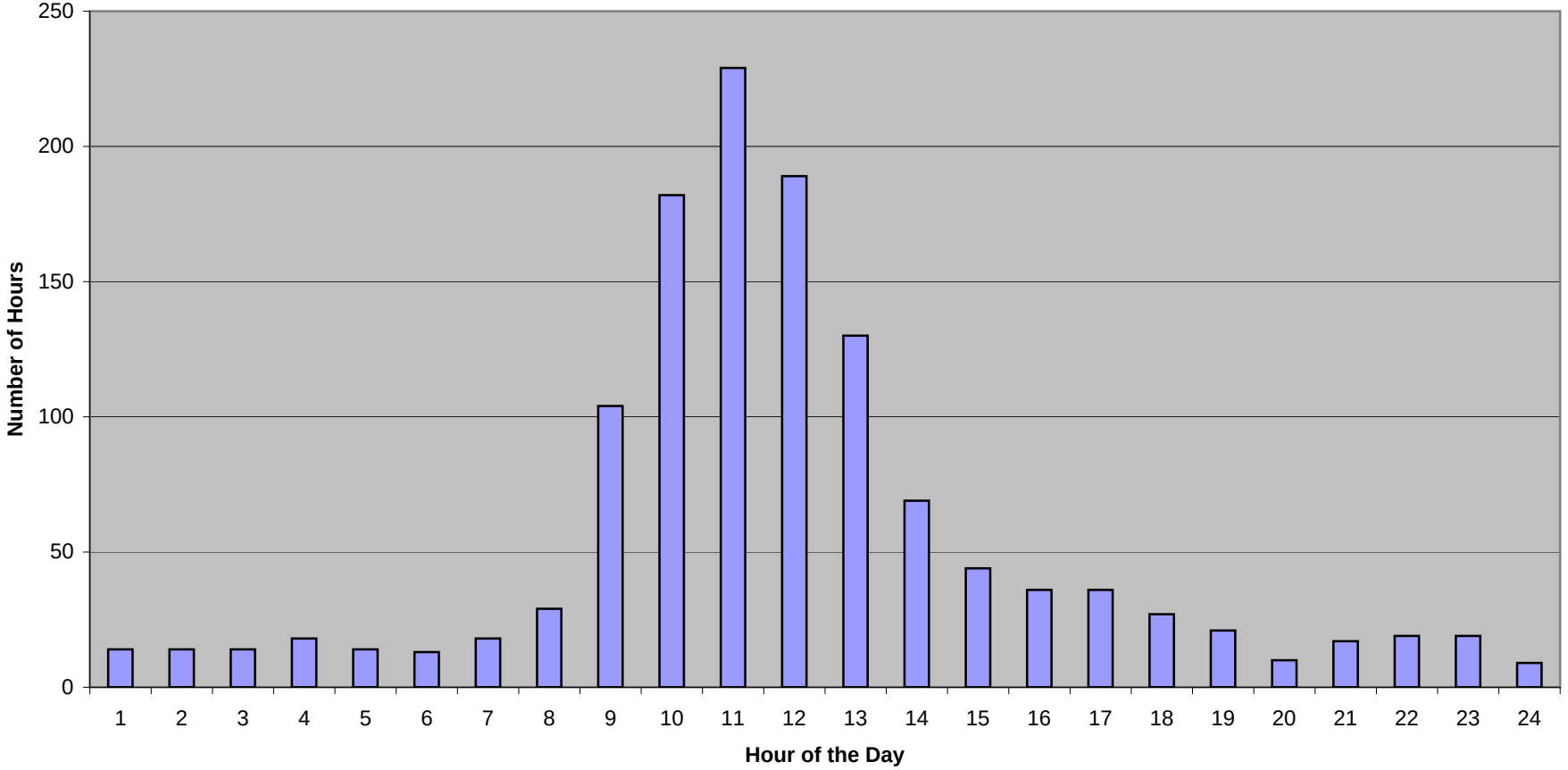


Figure 6-7. Total number of hours in 2007 sulfur dioxide concentrations exceed the AEGL-1 (524 $\mu g/m^3$) at Hotel Inca

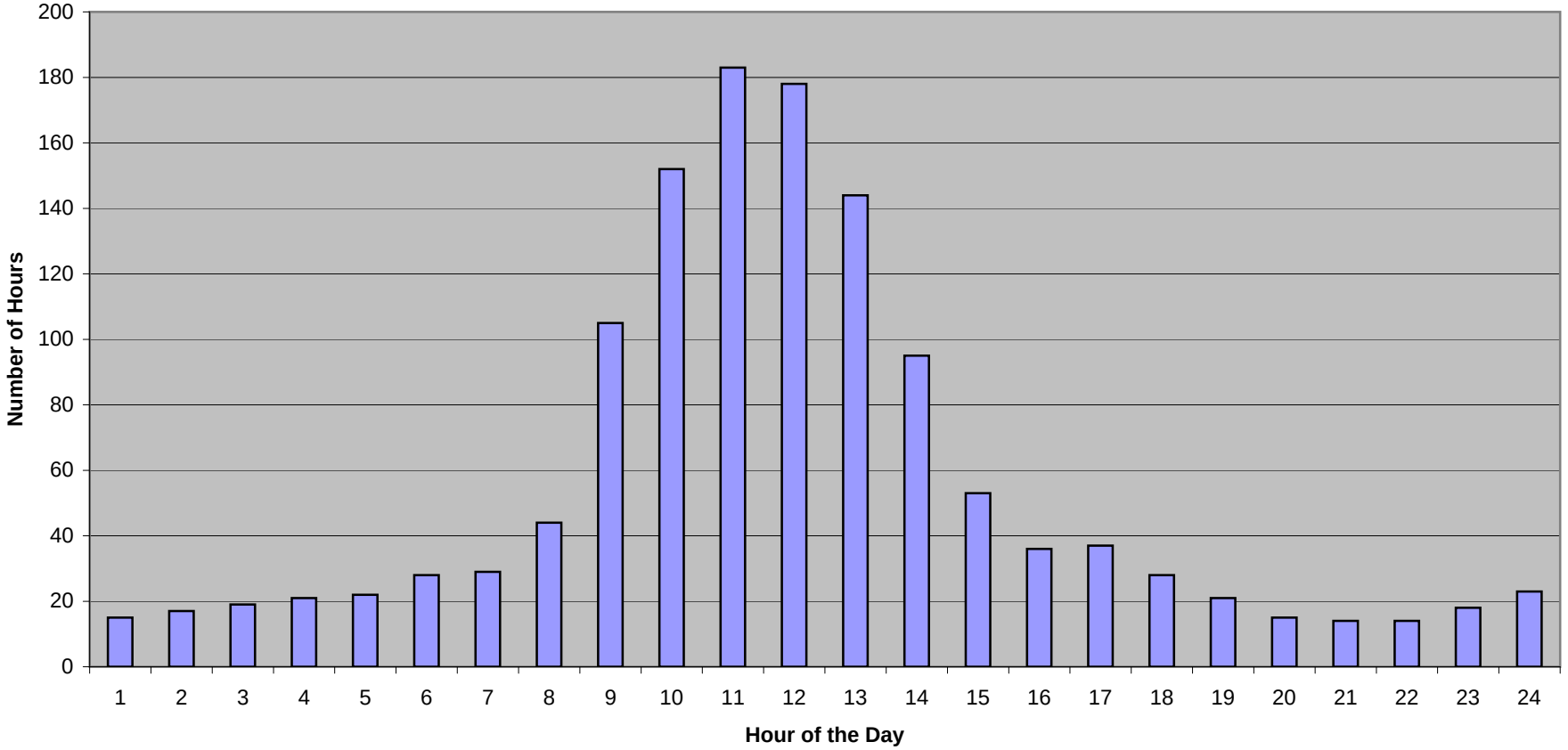


Figure 6-8. Total number of hours in 2007 sulfur dioxide concentrations exceed the AEGL-1 (524 μg/m3) at Marcavalle

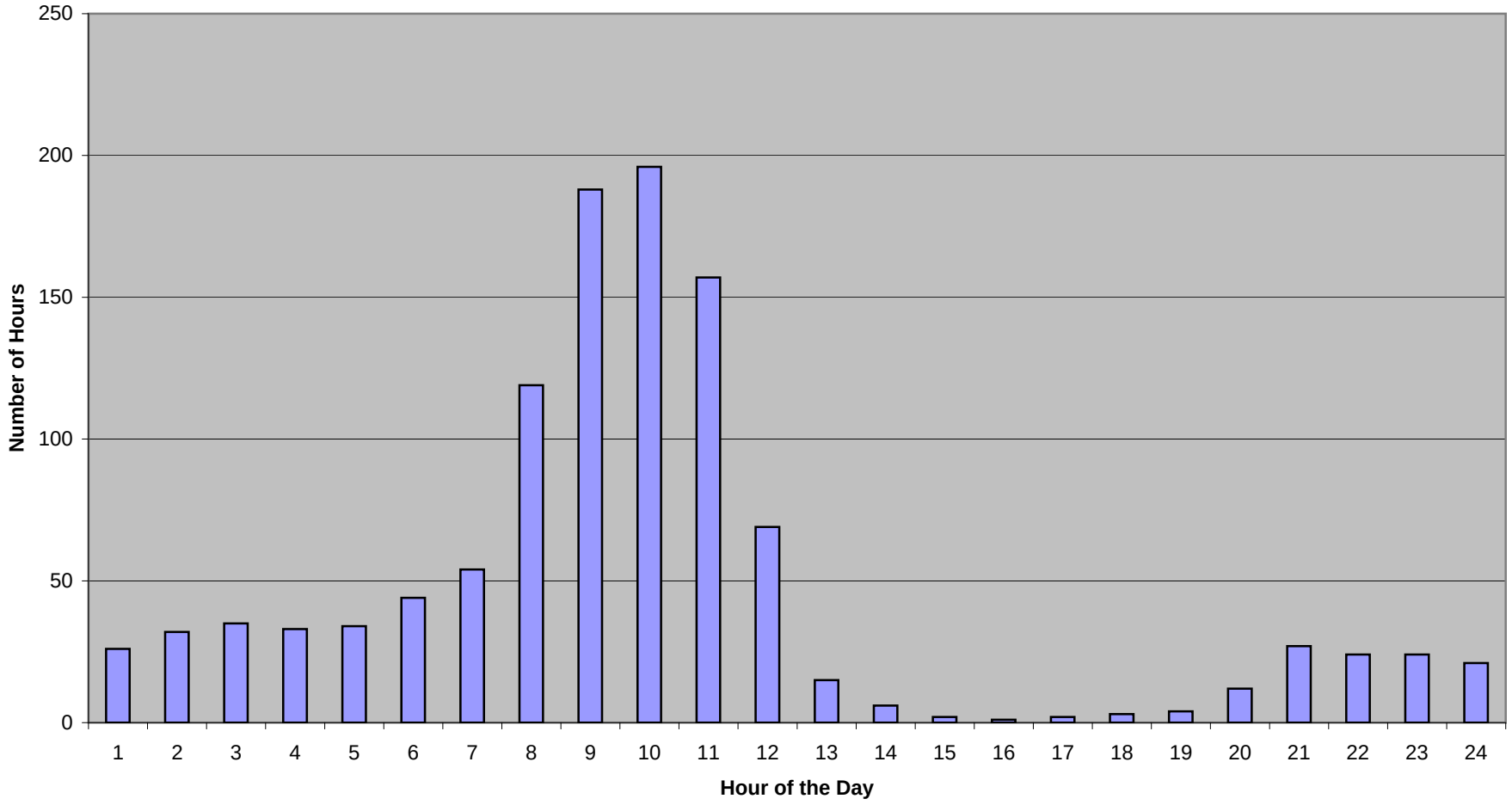


Figure 6-9. Total number of hours in 2007 sulfur dioxide concentrations exceed the AEGL-1 (524 μg/m^3) at Huari

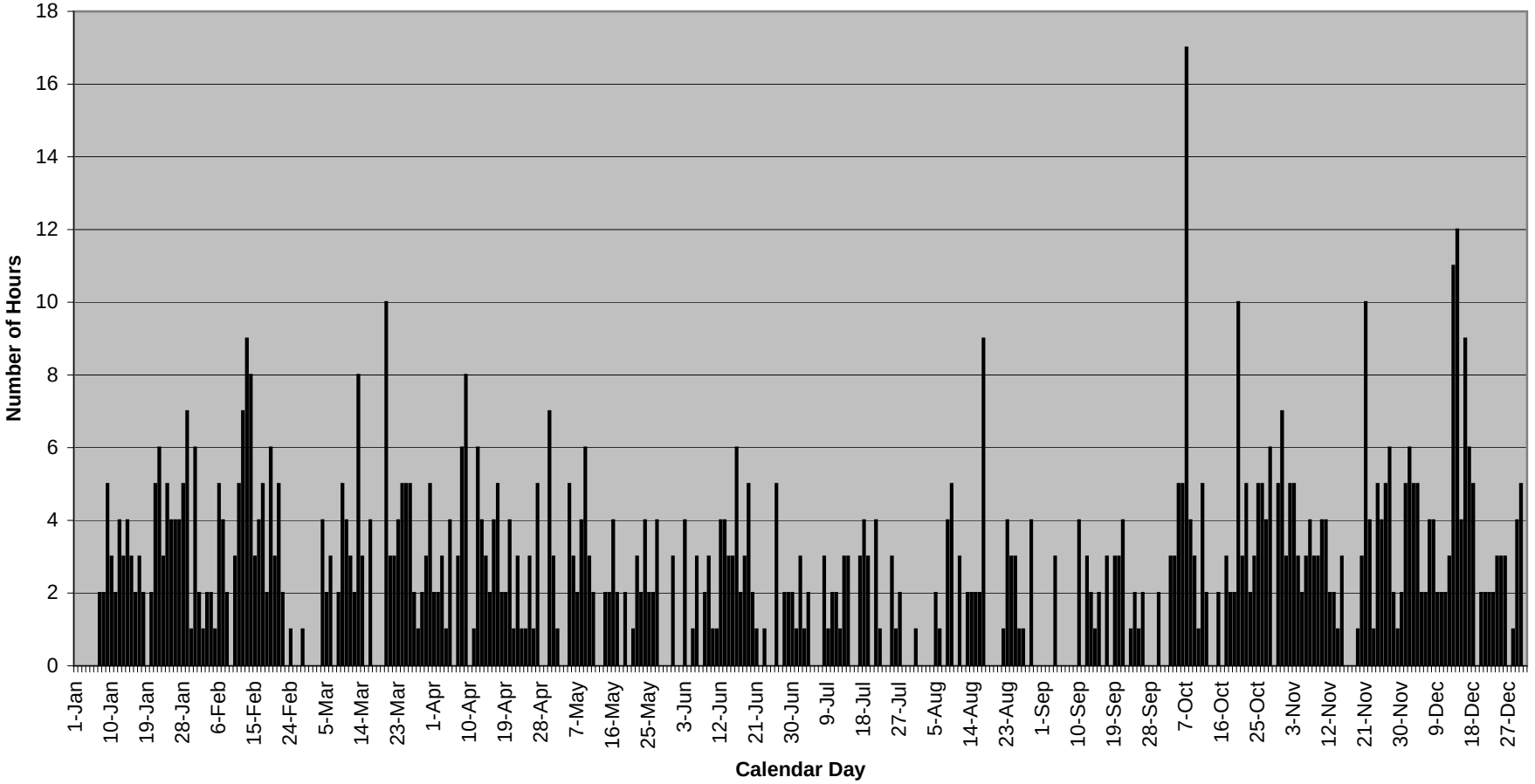


Figure 6-10. Number of hours per day in 2007 when sulfur dioxide concentrations exceed the AEGL-2 (1,965 $\mu g/m^3$) at Sindicato

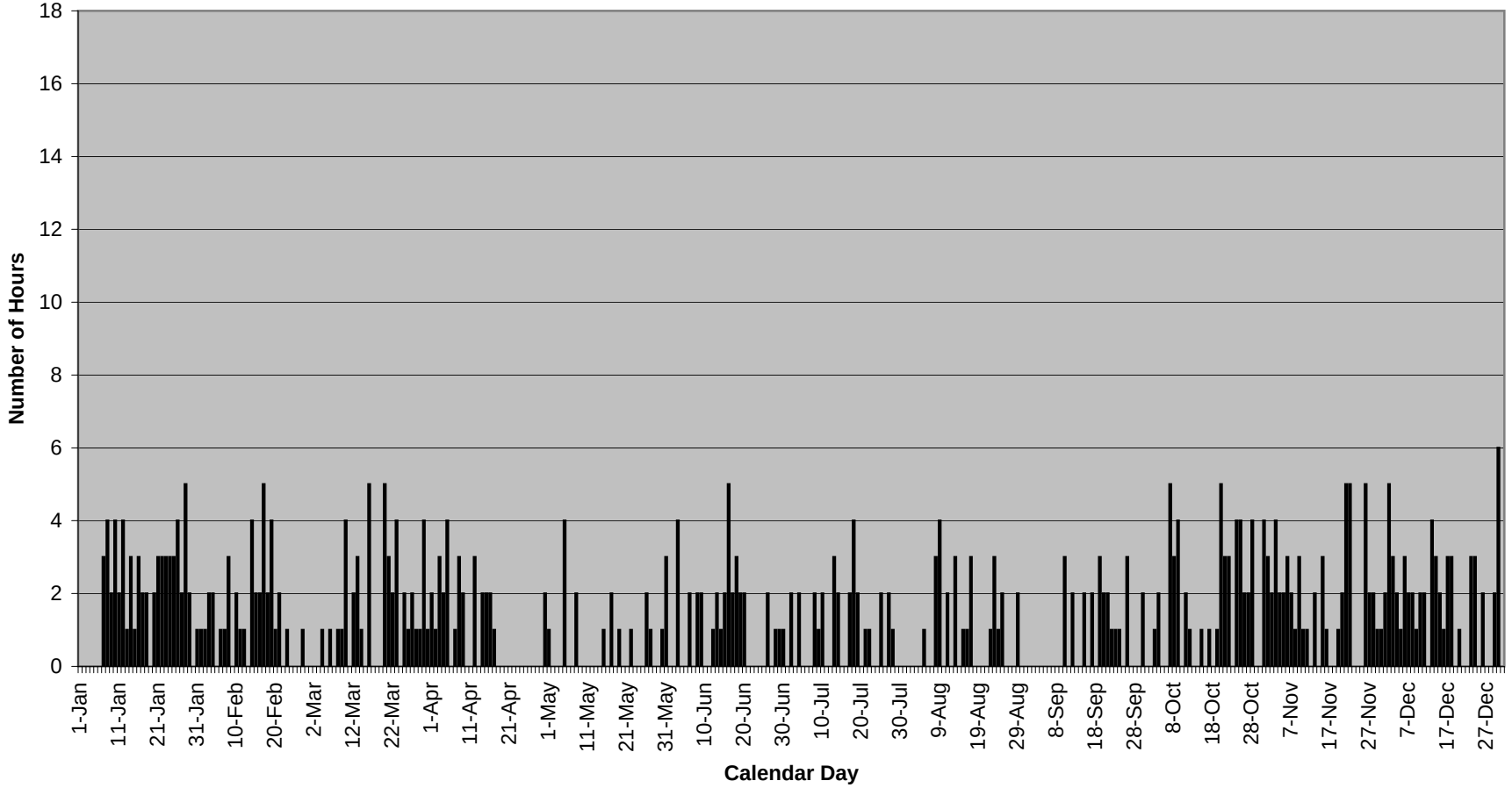


Figure 6-11. Number of hours per day in 2007 when sulfur dioxide concentrations exceed the AEGL-2 (1,965 $\mu g/m^3$) at Hotel Inca

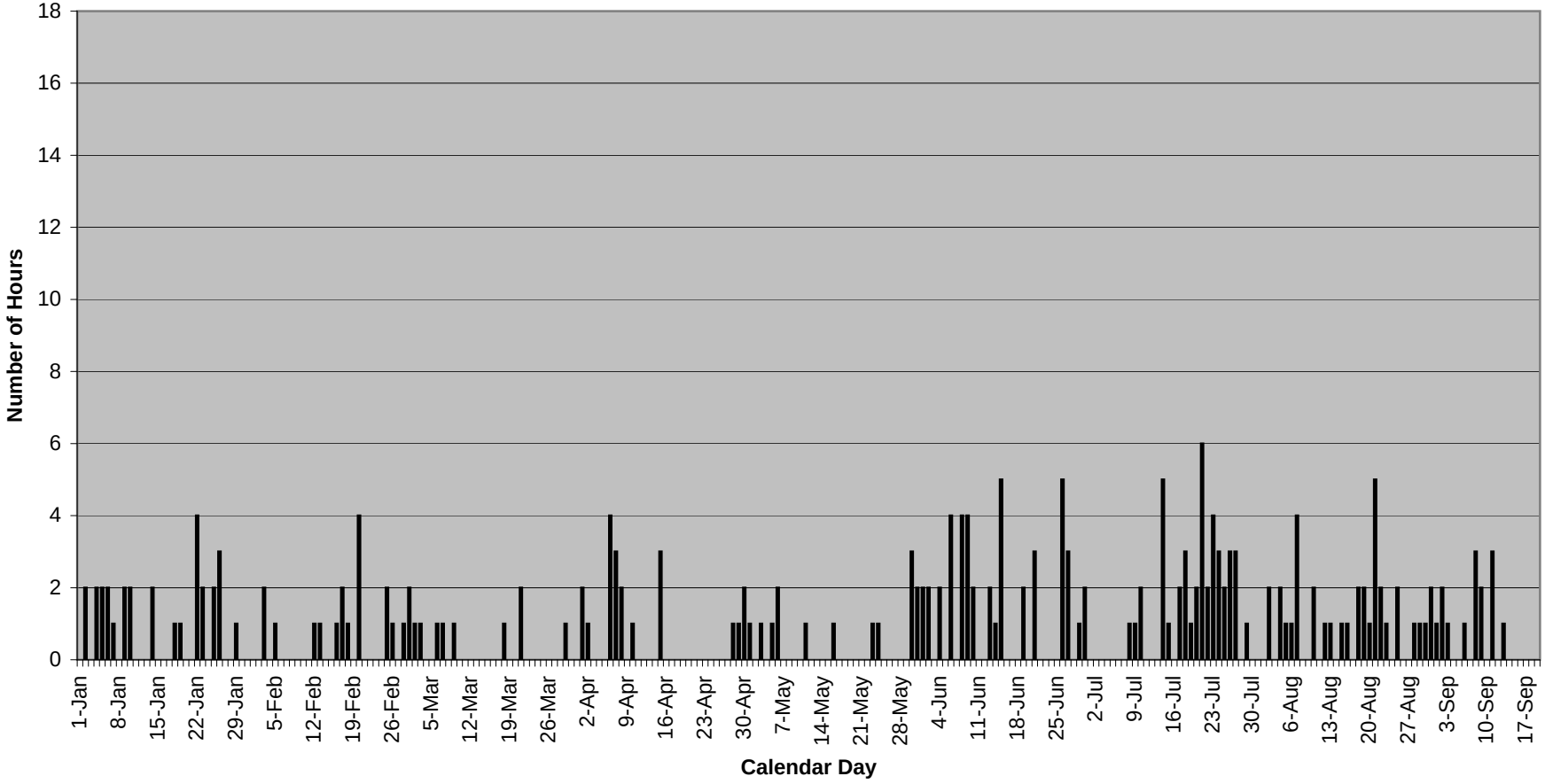


Figure 6-12. Number of hours per day in 2007 when sulfur dioxide concentrations exceed the AEGL-2 (1,965 $\mu g/m^3$) at Marcavalle

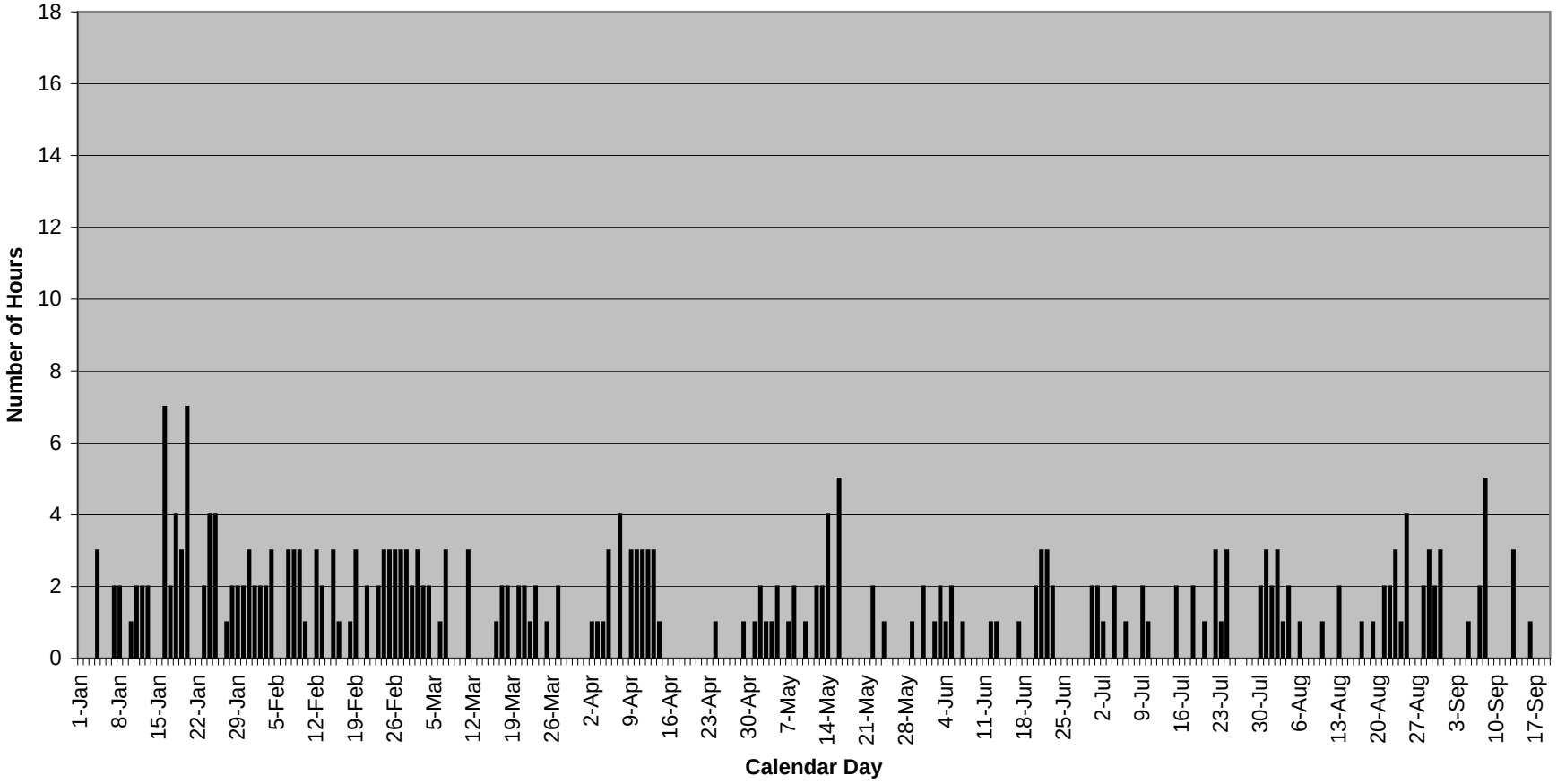


Figure 6-13. Number of hours per day in 2007 when sulfur dioxide concentrations exceed the AEGL-2 (1,965 $\mu g/m^3$) at Hotel Inca

TABLES

Table 3-1. Percent of Hours during Monitoring Period with Usable Sulfur Dioxide Data (2007)

Monitoring Station	N	Percent Completeness
Sindicato	8,709	99.4
Inca	8,452	96.5
Marcavalle [a]	7,893	94.1
Huaynacancha [b]	5,237	93.6
Huari [c]	7,117	97.0
Casaracra	8,393	95.8

Notes:
[a] Marcavalle station began monitoring on January 16, 2007
[b] Huaynacancha began monitoring on May 12, 2007
[c] Huari began monitoring on March 2, 2007

Table 3-2. Percent of Hours during Monitoring Period with Usable Particulate Data (2007)

Monitoring Station	N	Percent Completeness
Sindicato	8,678	99.1
Inca	8,412	96.0
Marcavalle [a]	7,841	93.8
Huaynacancha [b]	5,226	93.4
Huari [c]	7,022	96.1
Casaracra	8,383	95.7

Notes:
[a] Marcavalle station began monitoring on January 16, 2007
[b] Huaynacancha began monitoring on May 12, 2007
[c] Huari began monitoring on March 1, 2007

Table 3-3. Percent of Hours during Monitoring Period with Usable Metals in PM_{10} Data (2007)

	Lead		Arsenic		Cadmium		Antimony		Bismuth		Thallium	
Monitoring Station	N	Percent Complete	N	Percent Complete	N	Percent Complete	N	Percent Complete	N	Percent Complete	N	Percent Complete
Sindicato	121	99%	121	99%	121	99%	121	99%	121	99%	121	99%
Hotel Inca	122	100%	122	100%	122	100%	122	100%	122	100%	122	100%
Marcavalle [a]	118	100%	118	100%	118	100%	118	100%	118	100%	118	100%
Huaynacancha [b]	92	100%	92	100%	91	99%	92	100%	92	100%	92	100%
Huari [c]	107	100%	107	100%	105	98%	107	100%	107	100%	107	100%
Casaracra	122	100%	122	100%	120	98%	122	100%	122	100%	122	100%

Notes:

[a] Marcavalle station began monitoring on January 14, 2007

[b] Huaynacancha began monitoring on April 1, 2007

[c] Huari began monitoring on February 16, 2007

Table 3-4. 2007 Soil Sampling (3-10cm) - Mean Values from Three Samples (Mar., Oct., Dec. 2007)

	Antimonio mg/kg (ppm)	Arsenico mg/kg (ppm)	Bismuto mg/kg (ppm)	Cadmio mg/kg (ppm)	Plomo mg/kg (ppm)
La Oroya Antigua					
Escuela Antonio Encinas	46.7	471.3	73.7	32.8	1632.0
Escuela Manuel Scorza, techo de la Dirección	25.0	272.7	48.3	21.9	1012.7
Parte Alta del sector de Santa Gregoria	75.3	1129.3	110.0	63.9	2367.0
Sector de Cruz de Mayo	14.0	202.0	26.0	10.2	604.0
Parte Alta de la Prolongación San Martín	83.0	1520.7	169.7	64.5	3739.7
Casa de la Familia Izquierdo, Iquitos N° 245	162.3	1779.0	203.3	87.3	5044.7
Unidad de Gestión Educativa UGEL	26.0	519.0	53.0	19.1	1429.0
La Oroya Nueva					
Estación Meteorologica del Hotel El Inca	46.3	834.0	107.0	64.2	2809.3
Lado derecho del puente	43.7	1291.0	91.3	18.3	2041.0
Campo recreacional ex Golf.	19.7	319.3	34.0	16.7	957.0
Estación de monitoreo de Mayupampa	18.0	305.0	34.3	18.3	920.0
Loza deportiva de Norman King.	12.0	202.3	16.5	7.5	280.7
Costado de puente nuevo	14.7	187.7	17.5	6.8	334.0
Marcavalle					
Centro Educativo Domingo Savio.	22.7	273.0	28.3	17.8	936.7
Las lozas deportivas de BBSS y Huampani	26.7	298.0	35.3	20.2	1106.7
Plaza Principal de Tupac Amaru	13.3	210.0	27.0	8.6	545.0
Chucchis					
Jardín Indoamericano.	19.0	286.7	31.3	22.9	876.7
Santa Rosa de Sacco					
Centro Educativo (Escuela)	19.7	245.3	32.3	19.1	1473.3
Huaynacancha					
Escuela Heroes de Cenepa N° 31362	40.0	881.7	40.0	13.0	1306.0
Curipata					
Casa del Sr. Fidencio Quiquia Mz 29	10.7	174.7	14.5	7.7	308.0
Huari					
Plaza principal Huari	4.7	56.0	<10	2.2	100.3
Control Quiulla	6.0	97.0	20.0	5.9	248.0
Paccha					
Jardín Virgen del Carmen.	8.0	90.3	11.0	7.1	267.0
Estación de Monitoreo Casaracra	6.7	38.0	<10	2.7	142.3

Table 3-5. Summary of Surface Soil (0-2 cm) Samples Collected in 2008

Metal	Frequency of Detection	Min (mg/kg)	Max (mg/kg)	Mean (mg/kg)
La Oroya Antigua				
Ag	10/10	4.8	73.8	29.9
As	10/10	219.0	1,989.0	1,008.5
Bi	10/10	19.0	295.0	133.5
Cd	10/10	13.1	193.9	90.9
Cu	10/10	334.1	3,559.0	1,419.5
Hg	9/10	0.7	4.8	1.8
Pb	10/10	636.0	6,487.0	2,946.2
Sb	10/10	15.0	183.0	66.5
Se	5/10	23.0	40.0	30.2
Tl	0/10	--	--	--
Zn	10/10	724.0	5,706.0	2,825.3
Paccha				
Ag	1/1	1.6	1.6	1.6
As	1/1	278.0	278.0	278.0
Bi	1/1	21.0	21.0	21.0
Cd	1/1	10.0	10.0	10.0
Cu	1/1	191.6	191.6	191.6
Hg	0/1	--	--	--
Pb	1/1	583.0	583.0	583.0
Sb	1/1	10.0	10.0	10.0
Se	0/1	--	--	--
Tl	0/1	--	--	--
Zn	1/1	568.0	568.0	568.0
La Oroya Nueva				
Ag	3/3	2.7	12.1	8.1
As	3/3	119.0	757.0	380.7
Bi	3/3	15.0	129.0	55.3
Cd	3/3	9.4	67.0	32.6
Cu	3/3	234.3	818.5	511.7
Hg	1/3	0.9	0.9	0.9
Pb	3/3	475.0	2,726.0	1,419.0
Sb	3/3	9.0	40.0	22.0
Se	0/3	--	--	--
Tl	0/3	--	--	--
Zn	3/3	586.0	2,070.0	1,429.3

Table 3-5. Summary of Surface Soil (0-2 cm) Samples Collected in 2008

Metal	Frequency of Detection	Min (mg/kg)	Max (mg/kg)	Mean (mg/kg)
Huaynacancha				
Ag	1/1	3.0	3.0	3.0
As	1/1	247.0	247.0	247.0
Bi	1/1	17.0	17.0	17.0
Cd	1/1	7.4	7.4	7.4
Cu	1/1	524.6	524.6	524.6
Hg	0/1	--	--	--
Pb	1/1	521.0	521.0	521.0
Sb	1/1	13.0	13.0	13.0
Se	0/1	--	--	--
Tl	0/1	--	--	--
Zn	1/1	435.0	435.0	435.0
Marcavalle				
Ag	5/5	1.6	7.8	4.6
As	5/5	99.0	375.0	233.2
Bi	4/5	14.0	57.0	26.5
Cd	5/5	7.7	37.1	16.7
Cu	5/5	110.9	507.8	297.3
Hg	0/5	--	--	--
Pb	5/5	322.0	1,387.0	830.6
Sb	5/5	8.0	21.0	14.8
Se	0/5	--	--	--
Tl	0/5	--	--	--
Zn	5/5	314.0	7,687.0	2,218.4
Huari				
Ag	3/3	0.8	14.0	6.3
As	3/3	83.0	380.0	269.0
Bi	2/3	28.0	39.0	33.5
Cd	3/3	5.9	41.1	21.9
Cu	3/3	70.0	1,236.4	555.4
Hg	1/3	0.6	0.6	0.6
Pb	3/3	333.0	2,065.0	1,096.3
Sb	3/3	7.0	51.0	25.0
Se	0/3	--	--	--
Tl	0/3	--	--	--
Zn	3/3	437.0	4,674.0	2,051.3

Table 3-6. Summary of Subsurface Soil (2-10 cm) Samples Collected in 2008

Metal	Frequency of Detection	Min (mg/kg)	Max (mg/kg)	Mean (mg/kg)
La Oroya Antigua				
Ag	10/10	2.0	63.5	21.6
As	10/10	94.0	1,937.0	809.6
Bi	9/10	41.0	296.0	113.8
Cd	10/10	8.4	170.2	68.7
Cu	10/10	198.0	3,238.3	1,053.9
Hg	8/10	0.6	3.5	1.4
Pb	10/10	346.0	6,107.0	2,271.3
Sb	10/10	10.0	165.0	48.1
Se	3/10	22.0	37.0	29.3
Tl	0/10	--	--	--
Zn	10/10	711.0	5,439.0	2,211.6
Paccha				
Ag	1/1	1.7	1.7	1.7
As	1/1	230.0	230.0	230.0
Bi	1/1	17.0	17.0	17.0
Cd	1/1	12.2	12.2	12.2
Cu	1/1	129.0	129.0	129.0
Hg	0/1	--	--	--
Pb	1/1	536.0	536.0	536.0
Sb	1/1	7.0	7.0	7.0
Se	0/1	--	--	--
Tl	0/1	--	--	--
Zn	1/1	531.0	531.0	531.0
La Oroya Nueva				
Ag	3/3	1.2	14.5	7.7
As	3/3	68.0	593.0	340.3
Bi	2/3	38.0	66.0	52.0
Cd	3/3	4.3	63.5	35.5
Cu	3/3	92.5	827.1	549.8
Hg	0/3	--	--	--
Pb	3/3	263.0	1,812.0	1,237.7
Sb	3/3	5.0	32.0	20.7
Se	0/3	--	--	--
Tl	0/3	--	--	--
Zn	3/3	287.0	2,799.0	1,539.3

Table 3-6. Summary of Subsurface Soil (2-10 cm) Samples Collected in 2008

Metal	Frequency of Detection	Min (mg/kg)	Max (mg/kg)	Mean (mg/kg)
Huaynacancha				
Ag	1/1	1.4	1.4	1.4
As	1/1	197.0	197.0	197.0
Bi	1/1	12.0	12.0	12.0
Cd	1/1	8.5	8.5	8.5
Cu	1/1	319.4	319.4	319.4
Hg	0/1	--	--	--
Pb	1/1	383.0	383.0	383.0
Sb	1/1	8.0	8.0	8.0
Se	0/1	--	--	--
Tl	0/1	--	--	--
Zn	1/1	207.0	207.0	207.0
Marcavalle				
Ag	5/5	1.6	10.5	5.3
As	5/5	99.0	329.0	234.8
Bi	5/5	10.0	28.0	17.4
Cd	5/5	6.5	39.8	16.3
Cu	5/5	102.1	378.1	260.2
Hg	0/5	--	--	--
Pb	5/5	322.0	1,495.0	760.8
Sb	5/5	8.0	22.0	13.0
Se	0/5	--	--	--
Tl	0/5	--	--	--
Zn	5/5	327.0	7,828.0	2,154.0
Huari				
Ag	3/3	0.7	19.9	7.8
As	3/3	139.0	459.0	300.0
Bi	2/3	23.0	44.0	33.5
Cd	3/3	6.3	47.9	22.8
Cu	3/3	72.5	1,634.8	650.0
Hg	1/3	0.8	0.8	0.8
Pb	3/3	349.0	2,517.0	1,172.3
Sb	3/3	6.0	39.0	20.7
Se	0/3	--	--	--
Tl	0/3	--	--	--
Zn	3/3	409.0	5,845.0	2,294.0

Table 3-7a. Predicted Concentrations of Sulfur Dioxide after 2009 ($\mu g/m^3$)

	Hotel Inca	Sindicato	Marcavalle
Highest One-Hour Concentration	2,552	4,537	2,743
Highest 24-Hour Concentration	587	1,000	502
Second Highest 24-Hour Concentration	456	829	390
Annual Average Concentration	91	130	83

Table 3-7b. Predicted Concentrations of Sulfur Dioxide after 2009 ($\mu g/m^3$) - stack on hill

	Hotel Inca	Sindicato	Marcavalle
Highest One-Hour Concentration	2,169	2,268	1,673
Highest 24-Hour Concentration	282	590	321
Second Highest 24-Hour Concentration	219	489	250
Annual Average Concentration	32	75	95

Table 3-8. Summary of Outdoor Dust Samples Collected in 2008

Metal	Frequency of Detection	Min (mg/kg)	Max (mg/kg)	Mean (mg/kg)
La Oroya Antigua				
Ag	10/10	7.40	122.70	32.35
As	10/10	427.00	3812.00	1203.10
Bi	10/10	35.00	624.00	137.20
Cd	10/10	35.30	471.70	113.10
Cu	10/10	687.10	6565.40	2288.41
Hg	8/10	0.80	16.10	3.36
Pb	10/10	1334.00	12513.00	3653.50
Sb	10/10	39.00	418.00	107.40
Se	10/10	14.00	74.00	27.80
Tl	0/10	ND	ND	ND
Zn	10/10	1837.00	8692.00	3741.50
Paccha				
Ag	1/1	6.80	6.80	6.80
As	1/1	182.00	182.00	182.00
Bi	1/1	19.00	19.00	19.00
Cd	1/1	18.90	18.90	18.90
Cu	1/1	310.70	310.70	310.70
Hg	0/1	ND	ND	ND
Pb	1/1	722.00	722.00	722.00
Sb	1/1	20.00	20.00	20.00
Se	1/1	11.00	11.00	11.00
Tl	0/1	ND	ND	ND
Zn	1/1	2470.00	2470.00	2470.00
La Oroya Nueva				
Ag	3/3	5.20	12.40	8.10
As	3/3	140.00	386.00	248.33
Bi	3/3	19.00	32.00	25.67
Cd	3/3	13.70	23.60	17.10
Cu	3/3	164.40	417.10	300.30
Hg	0/3	ND	ND	ND
Pb	3/3	644.00	2073.00	1144.67
Sb	3/3	14.00	18.00	15.67
Se	3/3	11.00	12.00	11.33
Tl	0/3	ND	ND	ND
Zn	3/3	726.00	1354.00	965.67

Table 3-8. Summary of Outdoor Dust Samples Collected in 2008

Metal	Frequency of Detection	Min (mg/kg)	Max (mg/kg)	Mean (mg/kg)
Huaynacancha				
Ag	1/1	8.60	8.60	8.60
As	1/1	240.00	240.00	240.00
Bi	1/1	23.00	23.00	23.00
Cd	1/1	20.40	20.40	20.40
Cu	1/1	405.30	405.30	405.30
Hg	0/1	ND	ND	ND
Pb	1/1	1332.00	1332.00	1332.00
Sb	1/1	27.00	27.00	27.00
Se	1/1	11.00	11.00	11.00
Tl	0/1	ND	ND	ND
Zn	1/1	1805.00	1805.00	1805.00
Marcavalle/Chucchis				
Ag	5/5	4.10	15.50	8.86
As	5/5	146.00	935.00	417.20
Bi	5/5	16.00	81.00	41.80
Cd	5/5	11.40	52.30	26.96
Cu	5/5	206.00	1106.60	516.84
Hg	1/5	1.80	1.80	1.80
Pb	5/5	610.00	2340.00	1388.20
Sb	5/5	12.00	75.00	41.60
Se	5/5	10.00	26.00	15.80
Tl	0/5	ND	ND	ND
Zn	5/5	998.00	11815.00	5083.20
Huari				
Ag	3/3	1.80	4.90	3.87
As	3/3	197.00	267.00	222.33
Bi	1/3	25.00	25.00	25.00
Cd	3/3	7.80	20.00	15.10
Cu	3/3	277.10	364.90	312.73
Hg	0/3	ND	ND	ND
Pb	3/3	645.00	1404.00	951.67
Sb	3/3	15.00	79.00	55.33
Se	3/3	9.00	10.00	9.33
Tl	0/3	ND	ND	ND
Zn	3/3	1088.00	6855.00	3953.67

Table 3-9. Metals in Drinking Water - 2007

Station	Arsenic (Total) mg/L	Antimony (Total) mg/L	Cadmium (Total) mg/L	Copper (Total) mg/L	Lead (Total) mg/L	Thallium (Total) mg/L	Zinc (Total) mg/L
La Oroya Antigua							
Manantial Chumachay 1	0.013	<0.01	<0.001	<0.003	<0.010	<0.02	0.015
Manantial Chumachay 2	<0.010	<0.01	<0.001	0.003	<0.010	<0.02	0.017
Manantial Pichjapuquio[a]	0.014	<0.01	<0.001	0.024	<0.010	<0.02	0.059
Reservorio Iquitos	0.025	0.01	<0.001	0.012	<0.010	<0.02	0.018
C.E. Jorge Basadre	0.02	0.01	<0.001	0.003	<0.010	<0.02	0.166
C.E. Manuel Escorza	<0.010	<0.01	<0.001	0.003	<0.010	<0.02	0.095
La Oroya Nueva							
Tayapuquio	<0.010	<0.01	<0.001	<0.003	<0.010	<0.02	0.0181
Chulec vivienda 98	<0.010	<0.01	<0.001	<0.003	<0.010	<0.02	0.036
Juan Pablo mz I Lote 9	<0.010	<0.01	<0.001	0.006	<0.010	<0.02	0.028
Marcavalle							
La Rivera mz. B Lote 3	<0.010	<0.01	<0.001	0.005	<0.010	<0.02	0.036
C.E. Amalia Espinoza	<0.010	<0.01	<0.001	0.004	<0.010	<0.02	0.079
Santa Rosa de Sacco							
Red Sacco	<0.010	<0.01	<0.001	<0.003	<0.010	<0.02	0.026
Huari							
Fuente captacion localidad de Huari	<0.010	<0.01	<0.001	<0.003	<0.010	<0.02	0.018
Reservorio Huari	<0.010	<0.01	<0.001	<0.003	<0.010	<0.02	0.024
Red Huari	<0.010	<0.01	<0.001	0.003	<0.010	<0.02	0.025
Paccha							
Cuna Jardin Casaracra	<0.010	<0.01	<0.001	<0.003	<0.010	<0.02	0.664
Captacion manantial al cristal Puquio-Paccha	<0.010	<0.01	<0.001	<0.003	<0.010	<0.02	0.015
Reservorio Paccha	<0.010	<0.01	<0.001	<0.003	<0.010	<0.02	0.016
Red Paccha	<0.010	<0.01	<0.001	0.003	<0.010	<0.02	0.027
SUNASS Max limit	0.01	0.05	0.003	3.0	0.1	NA	NA

[a] Due to data concerns, this site was sampled again in August 2008. The values listed here are from the 2008 sample.

Table 3-10. Children's Blood Lead Levels (2004-2007)[a]

Year	Count	Mean	Max	Percentiles					Distribution
				25	50	75	90	95	
All Neighborhoods									
2004	793	32	76	26	32	37	45	50	Non-parametric
2005	1096	32	91	23	30	39	48	53	Non-parametric
2006	1114	29	87	20	28	37	43	49	Non-parametric
2007	1806	18	55	11	15	21	27	31	Gamma

[a]All blood lead values expressed in μg/dL

Table 3-11. November 2007 Blood Lead Levels in La Oroya Children

Age Range	0-1	1-2	2-3	3-4	4-5	5-6
Count	173	352	383	316	326	269
Minimum	2.1	1.1	2.4	2.4	2.5	3.1
Maximim	34.6	55.4	51.4	47.6	42.4	35.3
Mean	14.7	19.2	17.0	17.0	15.4	15.3
Median	14.5	17.5	15.6	15.9	13.9	14.3
Distribution	Normal	Gamma	Gamma	Gamma	Normal	Gamma
>10 μg/dL	127	305	321	256	254	205
% > 10 μg/dL	73%	87%	84%	81%	78%	76%

Table 3-12. Concentration of Metals in Food Samples (mg/kg)

Sample	Pb	Cd	As
Chicken Soup	<.04	<.01	<.01
Trout	<.04	<.01	<.01
Sheep Meat	0.76	<.01	<.01
Lettuce	0.65	<.01	<.01
Ceviche	<.04	<.01	<.01
Mixed Salad	<.04	<.01	<.01
Olluco soup	0.43	<.01	<.01
Flavored meat	0.7	<.01	<.01
Pork	0.98	<.01	<.01
Patazca Soup	0.5	<.01	<.01
Celery	1.17	<.01	<.01
Macroni dish	<.04	<.01	<.01
Dection Limits	0.04	0.01	0.01

Table 3-13. Predicted Concentrations of Lead in PM_{10} after 2009 ($\mu g/m^3$)

	Hotel Inca	Sindicato	Marcavalle
Highest 24-Hour	0.169	0.254	0.137
Highest Monthly	0.060	0.090	0.050
Annual Average	0.043	0.066	0.030

Table 3-14. Summary Statistics and Selection of COPCs for Air

Air Monitoring Stations (µg/m^3)	Percent Complete	Min	Max	Mean	Screening Level[a]	Selected for analysis?	Rationale	Distribution	95% UCLM	EPC
All Communities										
Antimony			1.620		0.2	Yes	ASL			
Arsenic			10.083		0.0002	Yes	ASL			
Cadmium			0.253		0.0006	Yes	ASL			
Lead			6.663		NA	Yes	--			
Bismuth			1.017		3.8	No	BSL			
Thallium			0.135		0.1	Yes	ASL			
Sindicato - La Oroya Antigua										
Antimony	99%	0.004	1.448	0.361				Nonparametric	0.591	0.591
Arsenic	99%	0.004	10.083	1.082				Gamma	1.333	1.333
Cadmium	99%	0.000	0.253	0.029				Gamma	0.0348	0.0348
Lead	99%	0.071	6.663	1.239				Gamma	1.438	1.438
Thallium	99%	0.006	0.135	0.023				Nonparametric	0.0359	0.0359
Hotel Inca - La Oroya Nueva										
Antimony	100%	0.004	1.290	0.284				Nonparametric	0.458	0.458
Arsenic	100%	0.004	3.907	0.829				Nonparametric	1.259	1.259
Cadmium	100%	0.000	0.096	0.023				Gamma	0.0262	0.0262
Lead	100%	0.046	3.324	0.925				Gamma	1.048	1.048
Thallium	100%	0.006	0.088	0.020				Nonparametric	0.0314	0.0314
Marcavalle - Marcavalle / Chucchis										
Antimony	100%	0.004	1.620	0.200				Nonparametric	0.392	0.392
Arsenic	100%	0.004	2.485	0.410				Nonparametric	0.646	0.646
Cadmium	100%	0.000	0.068	0.013				Gamma	0.0155	0.0155
Lead	100%	0.038	2.495	0.588				Gamma	0.654	0.654
Thallium	100%	0.008	0.117	0.020				Nonparametric	0.0323	0.0323
Huaynacancha - Santa Rosa de Sacco / Huaynacancha										
Antimony	100%	0.004	0.157	0.045				Gamma	0.0525	0.0525
Arsenic	100%	0.004	0.703	0.182				Nonparametric	0.274	0.274
Cadmium	100%	0.000	0.028	0.007				Nonparametric	0.00991	0.00991
Lead	100%	0.011	0.941	0.335				Gamma	0.375	0.375
Thallium	100%	0.008	0.010	0.008				Normal	0.00855	0.00855
Casaracra - Paccha										
Antimony	100%	0.004	1.005	0.164				Nonparametric	0.35	0.35
Arsenic	100%	0.004	2.297	0.208				Nonparametric	0.421	0.421
Cadmium	100%	0.000	0.074	0.007				Nonparametric	0.0115	0.0115
Lead	100%	0.004	3.675	0.225				Nonparametric	0.484	0.484
Thallium	100%	0.007	0.100	0.022				Nonparametric	0.0336	0.0336
Huari - Huari										
Antimony	100%	0.003	0.924	0.126				Gamma	0.153	0.153
Arsenic	100%	0.004	1.667	0.386				Gamma	0.474	0.474
Cadmium	100%	0.000	0.061	0.016				Nonparametric	0.0216	0.0216
Lead	100%	0.006	2.635	0.613				Nonparametric	0.909	0.909
Thallium	100%	0.008	0.092	0.012				Normal	0.0141	0.0141

Notes:
NA = Not available
ASL = concentration is above the screening level
BSL = concentration is below the screening level
UCLM = 95th upper confidence limit of the mean
µg/m^3 = micrograms per cubic meter

[a] Screening levels for antimonio, arsenico, and cadmio are from USEPA's IRIS database. Screening levels represent the unit risk air concentration corresponding to a 1E-06 risk level. For antimony, value is for antimony trioxide. Bismuto and talio screening levels correspond to proposed ambient air quality standards by the Peruvian government. Lead will be evaluated separately.

Table 3-15. Summary Statistics and Selection of COPCs for Outdoor Dust

Outdoor Dust (mg/kg, ww)	Frequency of Detection	Min	Max	Mean	Screening Level[a]	Selected for analysis?	Rationale	Distribution	95% UCLM	EPC
All Communities										
Antimony	23 / 23	12	418	67	31	Yes	ASL	Lognormal	101.7	101.7
Arsenic	23 / 23	140	3812	693.5	0.39	Yes	ASL	Gamma	985.2	985.2
Cadmium	23 / 23	7.8	471.7	60.9	70	Yes	ASL	Lognormal	92.84	92.84
Copper	23 / 23	164.4	6565.4	1218.4	3100	Yes	ASL	Lognormal	2316	2316
Lead	23 / 23	610	12513	2253	400	Yes	ASL	Gamma	3075	3075
Bismuth	21 / 23	5	624	75.4	--	No	NSL			
Selenium	23 / 23	9	74	19.2	390	No	BSL			
Thallium	0 / 23	2	2.0	2	5.1	No	LFOD			
Zinc	23 / 23	726	11815	3559.3	23000	No	BSL			
Silver	23 / 23	1.8	122.7	18.2	390	No	BSL			
Mercury	9 / 23	0.3	16.1	1.4	23	No	BSL			
La Oroya Antigua										
Antimony	10 / 10	39.0	418	107.4	31			Lognormal	186.2	186.2
Arsenic	10 / 10	427	3812	1203	0.39			Gamma	1923	1923
Cadmium	10 / 10	35.3	471.7	113.1	70			Gamma	202.2	202.2
Copper	10 / 10	687.1	6565.4	2288	3100			Gamma	3712	3712
Lead	10 / 10	1334	12513	3654	400			Gamma	5903	5903
La Oroya Nueva										
Antimony	3 / 3	14.0	18	15.7	31			--	--	18
Arsenic	3 / 3	140	386	248	0.39			--	--	386
Cadmium	3 / 3	13.7	23.6	17.1	70			--	--	23.6
Copper	3 / 3	164.4	417.1	300	3100			--	--	417.1
Lead	3 / 3	644	2073	1145	400			--	--	2073
Marcavalle / Chucchis										
Antimony	5 / 5	12.0	75	41.6	31			--	--	75
Arsenic	5 / 5	146	935	417	0.39			--	--	935
Cadmium	5 / 5	11.4	52.3	27.0	70			--	--	52.3
Copper	5 / 5	206	1106.6	517	3100			--	--	1106.6
Lead	5 / 5	610	2340	1388	400			--	--	2340
Santa Rosa de Sacco / Huaynacancha										
Antimony	1 / 1	27.0	27	27.0	31			--	--	27
Arsenic	1 / 1	240	240	240	0.39			--	--	240
Cadmium	1 / 1	20.4	20.4	20.4	70			--	--	20.4
Copper	1 / 1	405.3	405.3	405	3100			--	--	405.3
Lead	1 / 1	1332	1332	1332	400			--	--	1332
Paccha										
Antimony	1 / 1	20.0	20	20.0	31			--	--	20
Arsenic	1 / 1	182	182	182	0.39			--	--	182
Cadmium	1 / 1	18.9	18.9	18.9	70			--	--	18.9
Copper	1 / 1	310.7	310.7	311	3100			--	--	310.7
Lead	1 / 1	722	722	722	400			--	--	722
Huari										
Antimony	3 / 3	15.0	79	55.3	31			--	--	79
Arsenic	3 / 3	197	267	222	0.39			--	--	267
Cadmium	3 / 3	7.8	20.0	15.1	70			--	--	20
Copper	3 / 3	277.1	364.9	313	3100			--	--	364.9
Lead	3 / 3	645	1404	952	400			--	--	1404

Notes:
mg/kg, ww = milligram per kilogram, wet weight
NA = Not available
-- = statistical analysis not possible due to small sample size
ASL = concentration is above the screening level
BSL = concentration is below the screening level
LFOD = low frequency of detection (1 or fewer detects and less than 10% detections)
NSL = no screening level
UCLM = 95th upper confidence limit of the mean

[a] Screening levels obtained from USEPA Regional Screening Level Table; residential soil values.

Table 3-16. Summary Statistics and Selection of COPCs for Indoor Dust

Indoor Dust (mg/kg, ww)	Frequency of Detection	Min	Max	Mean	Screening Level[a]	Selected for analysis?	Rationale	Distribution	95% UCLM	EPC
All Communities[b]										
Antimony	34 / 34	3	325	81	31	Yes	ASL	Lognormal	139.4	139.4
Arsenic	34 / 34	44	3016	535	0.39	Yes	ASL	Gamma	716.2	716.2
Cadmium	34 / 34	3	136.6	32.7	70	Yes	ASL	Lognormal	49.32	49.32
Copper	34 / 34	37.5	6326	950	3100	Yes	ASL	Gamma	1310	1310
Lead	34 / 34	69	8891	1751	400	Yes	ASL	Gamma	2333	2333
Bismuth	18 / 20	10	278	65	NA	No	NSL	NA	NA	NA
Selenium	34 / 34	3	56	12	390	No	BSL	NA	NA	NA
Thallium	0 / 34	2	2	2	5.1	No	LFOD/BSL	NA	NA	NA
Zinc	34 / 34	193	12776	3030	23000	No	BSL	NA	NA	NA
Silver	33 / 34	1	52	13	390	No	BSL	NA	NA	NA
Mercury	25 / 34	0.6	7.7	1.8	23	No	BSL	NA	NA	NA
La Oroya Antigua										
Antimony	22 / 22	16.0	325	110.4				Gamma	154.7	154.7
Arsenic	22 / 22	102	3016	727				Gamma	1013	1013
Cadmium	22 / 22	7.0	136.6	41.5				Gamma	58.23	58.23
Copper	22 / 22	161.3	6326	1266				Gamma	1811	1811
Lead	22 / 22	333	8891	2224				Gamma	3086	3086
Other Communities										
Antimony	12 / 12	3.0	65	26.2				Normal	35.86	35.86
Arsenic	12 / 12	44	428	184				Normal	241.6	241.6
Cadmium	12 / 12	3.0	80.0	16.3				Lognormal	31.22	31.22
Copper	12 / 12	37.5	1193	372				Gamma	652.3	652.3
Lead	12 / 12	69	3005	884				Gamma	1500	1500

Notes:
ASL = concentration is above the screening level
BSL = concentration is below the screening level
LFOD = low frequency of detection (1 or fewer detects and less than 10% detections)
UCLM = 95th upper confidence limit of the mean
mg/kg, ww = milligram per kilogram, wet weight
NA = Not available
NSL = no screening level

[a] Screening levels obtained from USEPA Regional Screening Level Table; residential soil values.
[b] The 2008 household indoor dust sample collected from Escuela Antonio Encinas was eliminated from the dataset. It represents an outlier.

Table 3-17. Summary Statistics and Selection of COPCs for Surface Soil

Surface Soil (0-2 cm bgs) (mg/kg, ww)	Frequency of Detection	Min	Max	Mean	Screening Level[a]	Selected for analysis?	Rationale	Distribution	95% UCLM	EPC
All Communities										
Antimony	23 / 23	7	183	39.3	31	Yes	ASL	Gamma	55.74	55.74
Arsenic	23 / 23	83	1989	596.7	0.39	Yes	ASL	Gamma	826.6	826.6
Cadmium	23 / 23	5.9	193.9	51	70	Yes	ASL	Gamma	75.75	75.75
Copper	23 / 23	70	3559	852.1	3100	Yes	ASL	Gamma	1212	1212
Lead	23 / 23	322	6487	1837.6	400	Yes	ASL	Gamma	2532	2532
Bismuth	21 / 23	5	295	74.9	NA	No	NSL			
Selenium	5 / 23	1	40	7.3	390	No	BSL			
Thallium	0 / 23	2	2	2	6.3	No	LFOD			
Zinc	23 / 23	314	7687	2208.3	23000	No	BSL			
Silver	23 / 23	0.8	73.8	16.1	390	No	BSL			
Mercury	11 / 23	0.3	4.8	0.9	23	No	BSL			
La Oroya Antigua										
Antimony	10 / 10	15.0	183	66.5	31			Gamma	109.8	109.8
Arsenic	10 / 10	219	1989	1009	0.39			Normal	1348	1348
Cadmium	10 / 10	13.1	193.9	90.9	70			Normal	126.7	126.7
Copper	10 / 10	334.1	3559	1419	3100			Normal	2007	2007
Lead	10 / 10	636	6487	2946	400			Normal	4058	4058
La Oroya Nueva										
Antimony	3 / 3	9.0	40	22.0	31			--	--	40
Arsenic	3 / 3	119	757	381	0.39			--	--	757
Cadmium	3 / 3	9.4	67.0	32.6	70			--	--	67
Copper	3 / 3	234.3	818.5	512	3100			--	--	818.5
Lead	3 / 3	475	2726	1419	400			--	--	2726
Marcavalle / Chucchis										
Antimony	5 / 5	8.0	21	14.8	31			--	--	21
Arsenic	5 / 5	99	375	233	0.39			--	--	375
Cadmium	5 / 5	7.7	37.1	16.7	70			--	--	37.1
Copper	5 / 5	110.9	507.8	297	3100			--	--	507.8
Lead	5 / 5	322	1387	831	400			--	--	1387
Santa Rosa de Sacco / Huaynacancha										
Antimony	1 / 1	13.0	13	13.0	31			--	--	13
Arsenic	1 / 1	247	247	247	0.39			--	--	247
Cadmium	1 / 1	7.4	7.4	7.4	70			--	--	7.4
Copper	1 / 1	524.6	524.6	525	3100			--	--	524.6
Lead	1 / 1	521	521	521	400			--	--	521
Paccha										
Antimony	1 / 1	10.0	10	10.0	31			--	--	10
Arsenic	1 / 1	278	278	278	0.39			--	--	278
Cadmium	1 / 1	10.0	10.0	10.0	70			--	--	10
Copper	1 / 1	191.6	191.6	192	3100			--	--	191.6
Lead	1 / 1	583	583	583	400			--	--	583
Huari										
Antimony	3 / 3	7.0	51	25.0	31			--	--	51
Arsenic	3 / 3	83	380	269	0.39			--	--	380
Cadmium	3 / 3	5.9	41.1	21.9	70			--	--	41.1
Copper	3 / 3	70	1236.4	555	3100			--	--	1236.4
Lead	3 / 3	333	2065	1096	400			--	--	2065

Notes:
mg/kg, ww = milligram per kilogram, wet weight
NA = Not available
-- = statistical analysis not possible due to small sample size
ASL = concentration is above the screening level
BSL = concentration is below the screening level
LFOD = low frequency of detection (1 or fewer detects and less than 10% detections)
NSL = no screening level
UCLM = 95th upper confidence limit of the mean

[a] Screening levels obtained from USEPA Regional Screening Level table; residential soil values.

Table 3-18. Summary Statistics and Selection of COPCs for Drinking Water

Water (μg/L)	Frequency of Detection	Min	Max	Mean	Screening Level[a]	Selected for analysis?	Rationale	Distribution	95% UCLM	EPC
All Communities										
Antimony	2 / 19	0.0050	0.0100	0.0060	0.006	Yes	ASL	NA	NA	0.01
Arsenic	4 / 19	0.0050	0.0250	0.0080	0.01	Yes	ASL	NA	NA	0.025
Cadmium	0 / 19	0.0010	0.0010	0.0010	0.003	No	BSL/LFOD	NA	NA	NA
Copper	10 / 19	0.0020	0.0240	0.0040	3	No	BSL	NA	NA	NA
Lead	1 / 19	0.0050	0.0970	0.0100	0.1	No	BSL/LFOD	NA	NA	NA
Thallium	0 / 19	0.0100	0.0100	0.0100	0.002	No	LFOD	NA	NA	NA
Zinc	19 / 19	0.0150	0.6640	0.0730	11	No	BSL	NA	NA	NA
La Oroya Antigua										
Antimony	2 / 19	0.0050	0.0100	0.0060	0.006			--	--	0.01
Arsenic	4 / 19	0.0050	0.0250	0.0080	0.01			--	--	0.025

Notes:
ASL = concentration is above the screening level
BSL = concentration is below the screening level
LFOD = low frequency of detection (1 or fewer detects and less than 10% detections)
μg/L = microgram per liter
UCLM = 95th upper confidence limit of the mean

[a] Screening level for antimony and thallium is USEPA MCL. USEPA Regional Screening Table value for tapwater used for zinc. SUNASS Limits used for all other metals.

Table 3-19. Chemical Screening Criteria

Chemicals of Potential Concern	Ingestion of Soil/Dust (mg/kg)	Source	Ingestion of Drinking Water (mg/L)	Source	Inhalation of Ambient Air (ug/m^3)	Source
Antimony	31	USEPA 2008	0.006	USEPA 2005b	0.2	USEPA 2005a
Arsenic	0.39[a,b]	USEPA 2008	0.01	USEPA 2005b	0.0002	USEPA 2005a
Bismuth	--	--	--	--	3.8000	CONAM 2008
Cadmium	70[a,c]	USEPA 2008	0.003	SUNASS	0.0006	USEPA 2005a
Copper	3100	USEPA 2008	1.3	SUNASS	--	--
Lead	400	USEPA 2008	0.015	SUNASS	--	--
Mercury	23[d]	USEPA 2008	--	--	--	--
Selenium	390	USEPA 2008	--	--	--	--
Silver	390	USEPA 2008	--	--	--	--
Thallium	5.1	USEPA 2008	0.002	USEPA 2005b	0.1	CONAM 2008
Zinc	23,000	USEPA 2008	11	USEPA 2008	--	--

Source:
CONAM 2008. Standard of Environmental Quality for Cadmium, Arsenic, Bismuth, Antimony, and Thallium
SUNASS 2000 Oficio Circular No. 677-2000/SUNASS-INF
USEPA 2005a. IRIS (http://www.epa.gov/iris/).
USEPA 2005b. List of Drinking Water Contaminants & MCLs (http://www.epa.gov/safewater/mcl.html).
USEPA 2008. Regional Screening Levels for Chemical Contaminants at Superfund Sites(http://epa-prgs.ornl.gov/chemicals/index.shtml)

Notes:
[a]Calculated based on combined exposure via ingestion and dermal contact.
[b]Calculated values correspond to a cancer risk of 1 in 1,000,000.
[c]Based on dietary RfD for cadmium.
[d]Based on RfD for mercuric chloride.

Table 3-20. Comparison of Available Soil Data for Use in the Update

					t-test (2-tailed, p < 0.05)	
	Frequency of Detection	Max	Screening Level	Exeeds Screening Level?	Comparison to 2008 Soil Data (0-2 cm bgs)	Comparison to 2008 Soil Data (2-10 cm bgs)
2007 DRP Soil Data (3-10 cm bgs)						
Antimony	68 / 68	373	31	Yes	0.56	0.80
Arsenic	68 / 68	3635	0.39	Yes	0.47	0.94
Cadmium	68 / 68	196.4	70	Yes	**0.00**	**0.03**
Lead	68 / 68	10854	400	Yes	0.16	0.55
Bismuth	55 / 68	428	NA	No	0.16	0.68
Thallium	0 / 68	<4	5.1	No		
2008 DRP Soil Data (0-2 cm bgs)						
Antimony	23 / 23	183	31	Yes		0.42
Arsenic	23 / 23	1989	0.39	Yes		0.53
Cadmium	23 / 23	193.9	70	Yes		0.53
Copper	23 / 23	3559	3100	Yes		0.49
Lead	23 / 23	6487	400	Yes		0.46
Bismuth	21 / 23	295	NA	No		0.44
Selenium	5 / 23	40	390	No		0.44
Thallium	0 / 23	<4	5.1	No		NA
Zinc	23 / 23	7687	23000	No		0.68
Silver	23 / 23	73.8	390	No		0.52
Mercury	11 / 23	4.8	23	No		0.43
2008 Soil Data (2-10 cm bgs)						
Antimony	23 / 23	165	31	Yes		
Arsenic	23 / 23	1937	0.39	Yes		
Cadmium	23 / 23	170.2	70	Yes		
Copper	23 / 23	3238.3	3100	Yes		
Lead	23 / 23	6107	400	Yes		
Bismuth	20 / 23	296	NA	No		
Selenium	3 / 23	37	390	No		
Thallium	0 / 23	<4	5.1	No		
Zinc	23 / 23	7828	23000	No		
Silver	23 / 23	63.5	390	No		
Mercury	9 / 23	3.5	23	No		

Notes:
mg/kg, ww = milligram per kilogram, wet weight
bgs = below ground surface

Table 3-21. Comparison of 2007 and 2008 Convenio Household Dust Data

	Antimony		Arsenic		Cadmium		Copper		Lead	
	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008
La Oroya Antigua										
# of Samples	11	6	11	6	11	6	11	6	11	6
Average Indoor Dust	95	124	462	1021	37	43	740	2065	1446	3209
Average Outdoor Dust	132	54	1096	664	93	27	5167	1175	3959	1680
Minimum Ratio	0.17	0.58	0.09	0.24	0.08	0.32	0.03	0.27	0.07	0.28
Average Ratio	0.97	2.61	0.58	1.79	0.57	1.69	0.37	1.78	0.56	2.09
Maximum Ratio	2.51	6.32	1.33	4.20	1.56	3.83	1.22	3.83	1.47	4.12
Other Communities										
# of Samples	3	8	3	8	3	8	3	8	3	8
Average Indoor Dust	17	25	109	182	10	18	186	386	350	933
Average Outdoor Dust	23	19	296	196	19	11	465	290	958	797
Minimum Ratio	0.29	0.21	0.25	0.20	0.33	0.25	0.17	0.12	0.21	0.09
Average Ratio	1.12	1.81	0.47	0.98	0.60	1.65	0.51	2.24	0.47	1.53
Maximum Ratio	2.64	6.00	0.88	1.49	0.80	4.32	1.13	8.95	0.94	3.40

	Maximum COC Concentration Above Screening Levels				
2007 Indoor Dust	Antimony	Arsenic	Cadmium	--	Lead
2007 Outdoor Dust	Antimony	Arsenic	Cadmium	Copper	Lead
2008 Indoor Dust	Antimony	Arsenic	Cadmium	Copper	Lead
2008 Outdoor Dust	Antimony	Arsenic	Cadmium	Copper	Lead

Table 4-1. Annual Average and Second Highest Daily Average Concentrations of Sulfur Dioxide (µg/m^3)

Averaging Time	Peruvian AQS	Monitor	2005	2006	2007	2008[a]
Annual	80	Sindicato	492	571	706	---
		Hotel Inca	394	400	435	---
		Cushurupampa[b]	386	400	---	---
		Marcavalle[c]	---	---	374	---
		Casaracra	29	59	110	---
		Huaynacancha[d]	---	---	142	---
		Huari[e]	---	---	346	---
24-hour (2nd highest value)	365[f]	Sindicato	1581	2745	2840	2913
		Hotel Inca	1235	3125	1451	1505
		Cushurupampa[b]	1375	1516	---	---
		Marcavalle[c]	---	---	1208	1017
		Casaracra	155	338	312	919
		Huaynacancha[d]	---	---	370	862
		Huari[e]	---	---	1239	599

Notes:

[a] First quarter monitoring results only.

[b]Cushurupampa data collection ended on January 12, 2007

[c]Marcavalle data collection began on January 16, 2007

[d]Huaynacancha data collection began on May 12, 2007

[e]Huari data collection began on March 1, 2007

[f] Current 24-hour standard is not to be exceeded more than once per year. A new 24-hour standard of 80ug/m3 will take effect in January 2009.

Table 4-2. Annual Average and Second Highest Daily Average Concentrations (µg/m^3) of Coarse Particulate Matter (PM_{10})

Averaging Time	Peruvian AQS	Monitor	2005	2006	2007	2008[a]
Annual	150	Sindicato	77	72	64	---
		Hotel Inca	64	56	50	---
		Cushurupampa[b]	56	46	---	---
		Marcavalle[c]	---	---	52	---
		Casaracra	28	29	26	---
		Huaynacancha[d]	---	---	64	---
		Huari[e]	---	---	46	---
24-hour (2nd highest value)	50	Sindicato	133	142	120	99
		Hotel Inca	122	117	91	73
		Cushurupampa[b]	118	85	---	---
		Marcavalle[c]	---	---	102	70
		Casaracra	59	67	96	48
		Huaynacancha[d]	---	---	130	71
		Huari[e]	---	---	110	47

Notes:

[a] First quarter monitoring results only.

[b]Cushurupampa data collection ended on January 12, 2007

[c]Marcavalle data collection began on January 16, 2007

[d]Huaynacancha data collection began on May 12, 2007

[e]Huari data collection began on March 1, 2007

Table 4-3. $PM_{2.5}$ Concentrations by Station - 2007

	Sindicato	Hotel Inca	Marcavalle	Huaynacancha[a]	Casaracra	Huari[b]
	$PM_{2.5}$ ($\mu g/m^3$)	$PM_{2.5}$ ($\mu g/m^3$)	$PM_{2.5}$ ($\mu g/m^3$)	$PM_{2.5}$ ($\mu g/m^3$)	$PM_{2.5}$ ($\mu g/m^3$)	$PM_{2.5}$ ($\mu g/m^3$)
Annual Average	37	30	29	31	20	27
24-hour Maximum	59	51	56	45	33	46

Notes:
One measurement is taken per month at each monitoring station for a total of twelve samples per year.

[a]Huaynacancha began monitoring on May 12, 2007; nine samples total.
[b]Huari began monitoring on March 2, 2007; eleven samples total.

Table 4-4. ISE Input Parameters Used for All Simulations

Parameter	Units	Distribution	Point Value / Mean / Min[a]	Standard Deviation / Likliest[a]	Maximum	Rationale / Source
Exposure Frequency	days/yr	Point	365			USEPA default assumption
Averaging Time	days/yr	Point	365			USEPA default assumption
Dust Ingestion Rate	mg/day	Lognormal	90	75		Best professional judgement, best model fit
Dust/Soil Ingestion Rate Scale Factor - Ages						
0-1		Point	0.6296			USEPA default assumption
1-2		Point	1			USEPA default assumption
2-3		Point	1			USEPA default assumption
3-4		Point	1			USEPA default assumption
4-5		Point	0.7407			USEPA default assumption
5-6		Point	0.6666			USEPA default assumption
6-7		Point	0.6296			USEPA default assumption
F (Fraction of intake that is outdoor dust)		Point	0.6			Observation & interviews with area residents
Water Ingestion Rate Scale Factor - Ages						
0-1	L/day	Point	0.2			USEPA default assumption
1-2	L/day	Point	0.5			USEPA default assumption
2-3	L/day	Point	0.52			USEPA default assumption
3-4	L/day	Point	0.53			USEPA default assumption
4-5	L/day	Point	0.55			USEPA default assumption
5-6	L/day	Point	0.58			USEPA default assumption
6-7	L/day	Point	0.59			USEPA default assumption
Absorption						
Outdoor Dust	%	Triangular	15	35	65	Best professional judgement, best model fit
Residential Dust	%	Triangular	15	35	65	Best professional judgement, best model fit
Water	%	Triangular	30	50	70	Best professional judgement, best model fit
Diet	%	Triangular	30	50	70	Best professional judgement, best model fit
Soil	%	Triangular	10	30	50	Best professional judgement, best model fit
Passive Fraction	%	Point	0.2			USEPA default assumption
Half Saturation Level	µg/day	Point	100			USEPA default assumption
Ventiliation Rate - Ages						
0-1	m^3/day	Point	2			USEPA default assumption
1-2	m^3/day	Point	3			USEPA default assumption
2-3	m^3/day	Point	5			USEPA default assumption
3-4	m^3/day	Point	5			USEPA default assumption
4-5	m^3/day	Point	5			USEPA default assumption
5-6	m^3/day	Point	7			USEPA default assumption
6-7	m^3/day	Point	7			USEPA default assumption
Indoor Concentration (% of Outdoor)	%	Point	30			USEPA default assumption
Time Spent Outdoors - Ages						
0-1	hr/day	Point	4			Observation & interviews with residents
1-2	hr/day	Point	8			Observation & interviews with residents
2-3	hr/day	Point	8			Observation & interviews with residents
3-4	hr/day	Point	8			Observation & interviews with residents
4-5	hr/day	Point	8			Observation & interviews with residents
5-6	hr/day	Point	6			Observation & interviews with residents
6-7	hr/day	Point	6			Observation & interviews with residents
Lung Absorption - Ages						
0-1	%	Point	32			USEPA default assumption
1-2	%	Point	32			USEPA default assumption
2-3	%	Point	32			USEPA default assumption
3-4	%	Point	32			USEPA default assumption
4-5	%	Point	32			USEPA default assumption
5-6	%	Point	32			USEPA default assumption
6-7	%	Point	32			USEPA default assumption

Note:
[a] The ISE model calls for input of arithmetic mean and arithmetic standard deviation for both log normal and normal distributions.

Table 4-5. ISE Input Parameters that Vary with Time and/or Community - La Oroya Antigua

Parameter	Units	Distribution	Point Value/ Mean/Min[a]	Standard Deviation / Likliest[a]	Rationale/Source
La Oroya Antigua - 2007					
Soil Lead Intake - Ages (listed as "Other" in model)					
0-1	µg/day	Lognormal	37.1	15.5	Best professional judgement, best model fit
1-2	µg/day	Lognormal	58.9	24.5	Best professional judgement, best model fit
2-3	µg/day	Lognormal	58.9	24.5	Best professional judgement, best model fit
3-4	µg/day	Lognormal	58.9	24.5	Best professional judgement, best model fit
4-5	µg/day	Lognormal	43.6	18.2	Best professional judgement, best model fit
5-6	µg/day	Lognormal	39.3	16.4	Best professional judgement, best model fit
6-7	µg/day	Lognormal	37.1	15.5	Best professional judgement, best model fit
Air Concentration	$\mu g/m^3$	Lognormal	1.2	1.2	Based on site-specific sampling data
Community Dust Concentration (listed as "Soil" in model)	µg/g	Lognormal	3,654	3,345	Based on site-specific sampling data
Residential Dust Concentration (listed as "Dust" in model)	µg/g	Lognormal	2,224	1,538	Based on site-specific sampling data
Drinking Water Concentration	µg/L	Point	5	--	Based on site-specific sampling data
Maternal Blood Lead Concentration	µg/dL	Point	8	--	Based on site-specific sampling data
Diet Intake - Ages					
0-1	µg/day	Normal	18	8	Based on air model results, judgement
1-2	µg/day	Normal	18	8	Based on air model results, judgement
2-3	µg/day	Normal	18	8	Based on air model results, judgement
3-4	µg/day	Normal	18	8	Based on air model results, judgement
4-5	µg/day	Normal	18	8	Based on air model results, judgement
5-6	µg/day	Normal	18	8	Based on air model results, judgement
6-7	µg/day	Normal	18	8	Based on air model results, judgement
La Oroya Antigua - Post 2009					
Soil Lead Intake - Ages (listed as "Other" in model)					
0-1	µg/day	Lognormal	30.1	12.5	Best professional judgement, best model fit
1-2	µg/day	Lognormal	47.8	19.9	Best professional judgement, best model fit
2-3	µg/day	Lognormal	47.8	19.9	Best professional judgement, best model fit
3-4	µg/day	Lognormal	47.8	19.9	Best professional judgement, best model fit
4-5	µg/day	Lognormal	35.4	14.7	Best professional judgement, best model fit
5-6	µg/day	Lognormal	31.9	13.3	Best professional judgement, best model fit
6-7	µg/day	Lognormal	30.1	12.5	Best professional judgement, best model fit
Air Concentration	$\mu g/m^3$	Lognormal	0.06	0.06	Based on air model results
Community Dust Concentration (listed as "Soil" in model)	µg/g	Lognormal	1,910	1,757	Based on air model results
Residential Dust Concentration (listed as "Dust" in model)	µg/g	Lognormal	1,163	814	Based on air model results
Drinking Water Concentration - La Oroya Antigua	µg/L	Normal	5	--	Based on site-specific sampling data
Maternal Blood Lead Concentration	µg/dL	Point	6	--	Based on adult lead model results
Diet Intake - Ages					
0-1	µg/day	Normal	8	4	Based on air model results, judgement
1-2	µg/day	Normal	8	4	Based on air model results, judgement
2-3	µg/day	Normal	8	4	Based on air model results, judgement
3-4	µg/day	Normal	8	4	Based on air model results, judgement
4-5	µg/day	Normal	8	4	Based on air model results, judgement
5-6	µg/day	Normal	8	4	Based on air model results, judgement
6-7	µg/day	Normal	8	4	Based on air model results, judgement

Note:
[a] The ISE model calls for input of arithmetic mean and arithmetic standard deviation for both log normal and normal distributions.

Table 4-6. ISE Input Parameters That Vary with Time and Community - La Oroya Nueva

Parameter	Units	Distribution	Point Value/ Mean/Min[a]	Standard Deviation/ Likliest[a]	Rationale/Source
La Oroya Nueva - 2007					
Soil Lead Intake - Ages (listed as "Other" in model)					
0-1	µg/day	Lognormal	17.9	7.5	Best professional judgement, best model fit
1-2	µg/day	Lognormal	28.4	11.8	Best professional judgement, best model fit
2-3	µg/day	Lognormal	28.4	11.8	Best professional judgement, best model fit
3-4	µg/day	Lognormal	28.4	11.8	Best professional judgement, best model fit
4-5	µg/day	Lognormal	21.0	8.8	Best professional judgement, best model fit
5-6	µg/day	Lognormal	18.9	7.9	Best professional judgement, best model fit
6-7	µg/day	Lognormal	17.9	7.5	Best professional judgement, best model fit
Air Concentration	$\mu g/m^3$	Lognormal	0.9	0.7	Based on site-specific sampling data
Community Dust Concentration (listed as "Soil" in model)	µg/g	Lognormal	1444	888	Based on site-specific sampling data
Residential Dust Concentration (listed as "Dust" in model)	µg/g	Lognormal	884	853	Based on site-specific sampling data
Drinking Water Concentration	µg/L	Point	5	--	Based on site-specific sampling data
Maternal Blood Lead Concentration	µg/dL	Point	6	--	Based on site-specific sampling data
Diet Intake - Ages					
0-1	µg/day	Normal	15	5	Based on site-specific sampling data
1-2	µg/day	Normal	15	5	Based on site-specific sampling data
2-3	µg/day	Normal	15	5	Based on site-specific sampling data
3-4	µg/day	Normal	15	5	Based on site-specific sampling data
4-5	µg/day	Normal	15	5	Based on site-specific sampling data
5-6	µg/day	Normal	15	5	Based on site-specific sampling data
6-7	µg/day	Normal	15	5	Based on site-specific sampling data
La Oroya Nueva - Post 2009					
Soil Lead Intake - Ages (listed as "Other" in model)					
0-1	µg/day	Lognormal	16.2	6.7	Best professional judgement, best model fit
1-2	µg/day	Lognormal	25.7	10.7	Best professional judgement, best model fit
2-3	µg/day	Lognormal	25.7	10.7	Best professional judgement, best model fit
3-4	µg/day	Lognormal	25.7	10.7	Best professional judgement, best model fit
4-5	µg/day	Lognormal	19.0	7.9	Best professional judgement, best model fit
5-6	µg/day	Lognormal	17.1	7.1	Best professional judgement, best model fit
6-7	µg/day	Lognormal	16.2	6.7	Best professional judgement, best model fit
Air Concentration	$\mu g/m^3$	Lognormal	0.06	0.05	Based on air model results
Community Dust Concentration (listed as "Soil" in model)	µg/g	Normal	1287	785	Based on air model results
Residential Dust Concentration (listed as "Dust" in model)	µg/g	Normal	788.0	756	Based on air model results
Drinking Water Concentration - La Oroya Nueva	µg/L	Point	5	--	Based on site-specific sampling data
Maternal Blood Lead Concentration	µg/dL	Point	4.5	--	Based on adult lead model results
Diet Intake - Ages					
0-1	µg/day	Normal	7	2	Based on air model results, judgement
1-2	µg/day	Normal	7	2	Based on air model results, judgement
2-3	µg/day	Normal	7	2	Based on air model results, judgement
3-4	µg/day	Normal	7	2	Based on air model results, judgement
4-5	µg/day	Normal	7	2	Based on air model results, judgement
5-6	µg/day	Normal	7	2	Based on air model results, judgement
6-7	µg/day	Normal	7	2	Based on air model results, judgement

Note:
[a] The ISE model calls for input of arithmetic mean and arithmetic standard deviation for both log normal and normal distributions.

Table 4-7. ISE Input Parameters That Vary with Time and Community - Marcavalle/Chucchis

Parameter	Units	Distribution	Point Value/ Mean/ Min[a]	Standard Deviation/ Likliest[a]	Rationale/Source
Marcavalle/Chucchis - 2007					
Soil Lead Intake - Ages (listed as "Other" in model)					
0-1	µg/day	Lognormal	10.5	4.4	Best professional judgement, best model fit
1-2	µg/day	Lognormal	16.6	6.9	Best professional judgement, best model fit
2-3	µg/day	Lognormal	16.6	6.9	Best professional judgement, best model fit
3-4	µg/day	Lognormal	16.6	6.9	Best professional judgement, best model fit
4-5	µg/day	Lognormal	12.3	5.1	Best professional judgement, best model fit
5-6	µg/day	Lognormal	11.1	4.6	Best professional judgement, best model fit
6-7	µg/day	Lognormal	10.5	4.4	Best professional judgement, best model fit
Air Concentration	µg/m^3	Lognormal	0.6	0.4	Based on site-specific sampling data
Community Dust Concentration (listed as "Soil" in model)	µg/g	Lognormal	1,388	1,273	Based on site-specific sampling data
Residential Dust Concentration (listed as "Dust" in model)	µg/g	Lognormal	884	853	Based on site-specific sampling data
Drinking Water Concentration	µg/L	Point	5	--	Based on site-specific sampling data
Maternal Blood Lead Concentration	µg/dL	Point	6	--	Based on site-specific sampling data
Diet Intake - Ages					
0-1	µg/day	Normal	15	5	Based on site-specific sampling data
1-2	µg/day	Normal	15	5	Based on site-specific sampling data
2-3	µg/day	Normal	15	5	Based on site-specific sampling data
3-4	µg/day	Normal	15	5	Based on site-specific sampling data
4-5	µg/day	Normal	15	5	Based on site-specific sampling data
5-6	µg/day	Normal	15	5	Based on site-specific sampling data
6-7	µg/day	Normal	15	5	Based on site-specific sampling data
Marcavalle/Chucchis - Post 2009					
Soil Lead Intake - Ages (listed as "Other" in model)					
0-1	µg/day	Lognormal	9.4	3.9	Best professional judgement, best model fit
1-2	µg/day	Lognormal	15.0	6.3	Best professional judgement, best model fit
2-3	µg/day	Lognormal	15.0	6.3	Best professional judgement, best model fit
3-4	µg/day	Lognormal	15.0	6.3	Best professional judgement, best model fit
4-5	µg/day	Lognormal	11.1	4.6	Best professional judgement, best model fit
5-6	µg/day	Lognormal	10.0	4.2	Best professional judgement, best model fit
6-7	µg/day	Lognormal	9.4	3.9	Best professional judgement, best model fit
Air Concentration	µg/m^3	Lognormal	0.03	0.02	Based on air model results
Community Dust Concentration (listed as "Soil" in model)	µg/g	Normal	677	621	Based on air model results
Residential Dust Concentration (listed as "Dust" in model)	µg/g	Normal	431	416	Based on air model results
Drinking Water Concentration - Marcavalle	µg/L	Normal	5	--	Based on site-specific sampling data
Maternal Blood Lead Concentration	µg/dL	Point	4.5	--	Based on adult lead model results
Diet Intake - Ages					
0-1	µg/day	Normal	7	2	Based on air model results, judgement
1-2	µg/day	Normal	7	2	Based on air model results, judgement
2-3	µg/day	Normal	7	2	Based on air model results, judgement
3-4	µg/day	Normal	7	2	Based on air model results, judgement
4-5	µg/day	Normal	7	2	Based on air model results, judgement
5-6	µg/day	Normal	7	2	Based on air model results, judgement
6-7	µg/day	Normal	7	2	Based on air model results, judgement

Note:
[a] The ISE model calls for input of arithmetic mean and arithmetic standard deviation for both log normal and normal distributions.

Table 4-8. ISE Input Parameters that Vary with Time and Community - Huari

Parameter	Units	Distribution	Point Value/ Mean/Min[a]	Standard Deviation/ Likliest[a]	Rationale/Source
Huari - 2007					
Soil Lead Intake - Ages (listed as "Other" in model)					
0-1	µg/day	Lognormal	13.8	5.7	Best professional judgement, best model fit
1-2	µg/day	Lognormal	21.9	9.1	Best professional judgement, best model fit
2-3	µg/day	Lognormal	21.9	9.1	Best professional judgement, best model fit
3-4	µg/day	Lognormal	21.9	9.1	Best professional judgement, best model fit
4-5	µg/day	Lognormal	16.2	6.8	Best professional judgement, best model fit
5-6	µg/day	Lognormal	14.6	6.1	Best professional judgement, best model fit
6-7	µg/day	Lognormal	13.8	5.7	Best professional judgement, best model fit
Air Concentration	$\mu g/m^3$	Lognormal	0.6	0.5	Based on site-specific sampling data
Community Dust Concentration (listed as "Soil" in model)	µg/g	Lognormal	952	327	Based on site-specific sampling data
Residential Dust Concentration (listed as "Dust" in model)	µg/g	Lognormal	884	853	Based on site-specific sampling data
Drinking Water Concentration	µg/L	Point	5	--	Based on site-specific sampling data
Maternal Blood Lead Concentration	µg/dL	Point	6	--	Based on site-specific sampling data
Diet Intake - Ages					
0-1	µg/day	Normal	15	5	Based on site-specific sampling data
1-2	µg/day	Normal	15	5	Based on site-specific sampling data
2-3	µg/day	Normal	15	5	Based on site-specific sampling data
3-4	µg/day	Normal	15	5	Based on site-specific sampling data
4-5	µg/day	Normal	15	5	Based on site-specific sampling data
5-6	µg/day	Normal	15	5	Based on site-specific sampling data
6-7	µg/day	Normal	15	5	Based on site-specific sampling data

Note:
[a] The ISE model calls for input of arithmetic mean and arithmetic standard deviation for both log normal and normal distributions.

Table 4-9. ISE Input Parameters That Vary with Time and Community - Paccha

Parameter	Units	Distribution	Point Value/ Mean/Min[a]	Standard Deviation/ Likliest[a]	Rationale/Source
Paccha - 2007					
Soil Lead Intake - Ages (listed as "Other" in model)					
0-1	µg/day	Lognormal	7.4	3.1	Best professional judgement, best model fit
1-2	µg/day	Lognormal	11.7	4.9	Best professional judgement, best model fit
2-3	µg/day	Lognormal	11.7	4.9	Best professional judgement, best model fit
3-4	µg/day	Lognormal	11.7	4.9	Best professional judgement, best model fit
4-5	µg/day	Lognormal	8.7	3.6	Best professional judgement, best model fit
5-6	µg/day	Lognormal	7.8	3.2	Best professional judgement, best model fit
6-7	µg/day	Lognormal	7.4	3.1	Best professional judgement, best model fit
Air Concentration	µg/m^3	Lognormal	0.2	0.5	Based on site-specific sampling data
Community Dust Concentration (listed as "Soil" in model)	µg/g	Point	722	--	Based on site-specific sampling data
Residential Dust Concentration (listed as "Dust" in model)	µg/g	Lognormal	884	853	Based on site-specific sampling data
Drinking Water Concentration	µg/L	Lognormal	5	--	Based on site-specific sampling data
Maternal Blood Lead Concentration	µg/dL	Point	6	--	Based on site-specific sampling data
Diet Intake - Ages					
0-1	µg/day	Normal	15	5	Based on site-specific sampling data
1-2	µg/day	Normal	15	5	Based on site-specific sampling data
2-3	µg/day	Normal	15	5	Based on site-specific sampling data
3-4	µg/day	Normal	15	5	Based on site-specific sampling data
4-5	µg/day	Normal	15	5	Based on site-specific sampling data
5-6	µg/day	Normal	15	5	Based on site-specific sampling data
6-7	µg/day	Normal	15	5	Based on site-specific sampling data

Note:
[a] The ISE model calls for input of arithmetic mean and arithmetic standard deviation for both log normal and normal distributions

Table 4-10. 2007 Blood Lead Sample of Pregnant Women in La Oroya

Distribution	Geometric Mean	Mean	10th	25th	50th	75th	90th
La Oroya Antigua							
Lognormal	7.4	7.9	3.8	6.4	8.2	9.8	11.7
Other Communities							
Lognormal	5.5	6.1	3.4	4.2	5.2	7.3	9.4
All Communities							
Lognormal	5.9	6.6	3.6	4.4	5.7	8.3	10.4

Table 4-11. Statistical Comparison of 2004 and 2007 Children Blood Lead Data

Age Group	Number of PbB Samples	Statistical Distribution of PbB Samples	Mean (µg/dL)	10th Percentile (µg/dL)	25th Percentile (µg/dL)	50th Percentile (µg/dL)	75th Percentile (µg/dL)	90th Percentile (µg/dL)
2007 Sampling Data								
All	1819	Gamma	17	8	11	15	21	27
0-1	173	Normal	15	6	10	14	19	23
1-2	352	Gamma	19	9	13	17	24	31
2-3	383	Gamma	17	8	12	16	22	27
3-4	316	Gamma	17	8	11	16	22	25
4-5	326	Normal	15	8	11	14	20	25
5-6	269	Gamma	15	8	10	14	20	24
2004 Sampling Data								
All	758	Non-parametric	32	20	26	33	37	45
0-1	78	Normal	31	17	23	30	37	44
1-2	119	Normal	36	20	30	36	43	49
2-3	128	Gamma	34	20	26	33	40	49
3-4	115	Gamma	33	20	27	31	37	44
4-5	137	Normal	32	21	27	32	37	41
5-6	181	Non-parametric	30	20	23	30	36	41

Table 4-12 . Summary of Input Values for Future ISE Modeling for La Oroya Antigua

			Post 2009	
Varible	Unit	2007/2008	Projected % Change[c]	Input Value
Pb Concentration in Air[a]	µg/m^3	1.20	-94.7%	0.06
Mean Pb Conc. in Soil	mg/kg	2,946	-18.9%	2,388
Mean Pb Conc. in Community Dust	mg/kg	3,654	20% below soil	1,910
Mean Pb Conc. in Residential Dust[b]	mg/kg	2,225	Ratio	1,163
Mean Pb Diet Intake	µg/day	18	-56.8%	8
Mean Pb Conc. in Water	µg/L	5	0.0%	5

Notes:

[a]Pb air concentration for 2007 was determined based on monitoring results at the Sindicato station.

[b]The future residential dust concentration is calculated based on the ratio of community to residential dust found in 2007.

[c]The projected percent changes for air concentration and deposition were based on the MMA modeling report.
Declines in lead deposition are assumed to be equivalent to declines in air emissions.

Table 4-13. Summary of Input Values for Future ISE Modeling for La Oroya Nueva

			Post 2009	
Varible	Unit	2007/2008	Projected % Change[c]	Input Value
Pb Concentration in Air[a]	µg/m^3	0.90	-95.4%	0.04
Mean Pb Conc. in Soil	mg/kg	1,419	-19.1%	1,148
Mean Pb Conc. in Community Dust	mg/kg	1,444	10% below soil	1,033
Mean Pb Conc. in Residential Dust[b]	mg/kg	884	Ratio	633
Mean Pb Diet Intake	µg/day	15	-57.2%	6
Mean Pb Conc. in Water	µg/L	5	0.0%	5

Notes:

[a]Pb air concentration for 2007 was determined based on monitoring results at the Hotel Inca station.

[b]The future residential dust concentration is calculated based on the ratio of community to residential dust found in 2007.

[c]The projected percent changes for air concentration and deposition were based on the MMA modeling report.
Declines in lead deposition are assumed to be equivalent to declines in air emissions.

Table 4-14. Summary of Input Values for Future ISE Modeling for Marcavalle/Chucchis

			Post 2009	
Varible	Unit	2007/2008	Projected % change[c]	Input Value
Pb Concentration in Air[a]	µg/m^3	0.63	-95.2%	0.03
Mean Pb Conc. in Soil	mg/kg	831	-9.5%	752
Mean Pb Conc. in Community Dust	mg/kg	1388	10% below soil	677
Mean Pb Conc. in Residential Dust[b]	mg/kg	884	Ratio	431
Mean Pb Diet Intake	µg/day	15	-57.1%	6
Mean Pb Conc. in Water	µg/L	5	0.0%	5

Notes:

[a]Pb air concentration for 2007 was determined based on monitoring results at the Marcavalle station.

[b]The future residential dust concentration is calculated based on the ratio of community to residential dust found in 2007.

[c]The projected percent changes for air concentration and deposition were based on the MMA modeling report.
Declines in lead deposition are assumed to be equivalent to declines in air emissions.

Table 4-15. Input Parameters for the ALM Model

Variable	Unit	Definition	Input Value
$R_{fetal/maternal}$	unitless	Fetal/maternal PbB ratio	0.9
BKSF	µg/dL per µg/day	Biokinetic Slope Factor	0.375
GSD_i	unitless	Geometric standard deviation PbB	1.62
IR_{S+D}	g/day	Total ingestion rate (including soil-derived indoor dust)	0.05
$AF_{S,D}$	unitless	Absorption fraction	0.056
$EF_{S,D}$	days/yr	Exposure frequency (same for soil and dust)	365
$AT_{S,D}$	days/yr	Averaging time (same for soil and dust)	365
K_{SD}	unitless	Mass fraction of outdoor dust in indoor dust	0.5
W_s	unitless	Weighting factor (fraction of IR ingested as outdoor dust)	0.4
PbB_0	µg/dL	Baseline blood Pb concentration - 2007	4.5
PbB_0	µg/dL	Baseline blood Pb concentration - after 2009	4.0
PBS	mg/kg	Community Dust Concentration - La Oroya Antigua 2007	3,654
PBS	mg/kg	Community Dust Concentration - La Oroya Antigua after 2009	1,910
PBS	mg/kg	Community Dust Concentration - Surrounding Communities 2007	1,176
PBS	mg/kg	Community Dust Concentration - Surrounding Communities after 2009	677
PBS	mg/kg	Community Dust Concentration - All Communities 2007	2,253
PBS	mg/kg	Community Dust Concentration - All communities after 2009	1,217

Table 4-16. Calculation of Site-Specific GSD for La Oroya Using Blood Lead Sampling Data for Year 2007

Method:	$GSD = e[(Ln(CV^2 + 1)^{0.5}]$		
	CV = SD / AM		
	SD = Arithmetic standard deviation		
	AM = Arithmetic mean		
	CV = Coefficient of variation		
2007 PbB Sampling Results from La Oroya			
	For pregnant women:		
	N =	105	
	Mean =	6.6	µg/dL
	Std Dev =	3.4	µg/dL
	GSD =	**1.62**	
1999 Sampling Results from Lima, Peru			
	For post-partum women		
	N =	383	
	Mean =	6.5	µg/dL
	Std Dev =	4.2	µg/dL
	GSD =	**1.81**	

Table 4-17. Comparison of 2007 Adult Blood Lead Data and ALM Model Results

Location	Number of Samples	Statistical Distribution of Samples	Geometric Mean (µg/dL)	90th Percentile (µg/dL)
Antigua				
Data	25	Lognormal	7.4	11.7
Model		Lognormal	7.2	13.3
All Communities				
Data	105	Lognormal	5.9	10.4
Model		Lognormal	6.2	11.4
All except Antigua				
Data	80	Lognormal	5.5	9.4
Model		Lognormal	5.4	9.9

Table 4-18. Exposure Parameters for Adult and Child Residents

Parameter	Units	Child		Reference	Adult		Reference
		CTE	RME		CTE	RME	
EPC	mg/kg m^3/day mg/L	Chemical specific, see Tables 5-3 and 5-4			Chemical specific, see Tables 5-3 and 5-4		
InhR-chronic	m^3/day	7	10	USEPA 1997, USEPA 1998	13	20	USEPA 1997, USEPA 1998
IR - water	L/day	1	1	USEPA 1997	2	2	USEPA 1997
EF	day/year	335	365	CTE assumes family leaves town for 30 days vacation per year	335	365	CTE assumes family leaves town for 30 days vacation per year
ED	years	6	6	USEPA 1989, Child ages 0 - 6 yrs.	24	64	CTE assumes total residence time of 30 years; RME assumes total residence time of 70 years
IR-soil	mg/day	20	31	Estimated from ISE modeling	20	32	Estimated from ALM, Professional judgement
IR-residential dust	mg/day	36	70	Estimated from ISE modeling	30	43	Estimated from ALM, Professional judgement
IR-comm. dust	mg/day	54	105	Estimated from ISE modeling	20	35	Estimated from ALM, Professional judgement
RAF-dust	unitless	0.8	0.8	Best professional judgement	0.8	0.8	Best professional judgement
RAF-soil	unitless	0.5	0.5	Best professional judgement	0.5	0.5	Best professional judgement
BW	kg	13	13	Mean for children in La Oroya who participated in blood lead sampling program	63	63	Adult body weight proportional to La Oroya child body weight
ATnc	days	2190	2190	AT = ED x 365 day/year	8760	23360	AT = ED x 365 day/year
ATc	days	25550	25550	AT = 70 years x 365 day/year	25550	25550	AT = 70 years x 365 day/year
CF	mg/µg	1.00E-03	1.00E-03	--	1.00E-03	1.00E-03	--
CF	mg/kg	1.00E+06	1.00E+06	--	1.00E+06	1.00E+06	--

Note:
RAF for arsenic only

Table 5-1. Ingestion Toxicity Criteria

Chemicals of Potential Concern	Oral Route									
	CSF_o (kg-d/mg)	Water Unit Risk Factor (L/µg)	Source	WOE	Source	Chronic RfD_o (mg/kg-d)	Critical Organ / Effect	Source	RfD_o (mg/kg-d)	Source
Metals										
Antimony	NA	NA	--	NA[a]	USEPA 2008a	4.0E-04	Longevity, blood glucose, cholesterol	USEPA 2008a	NA	--
Arsenic	1.5E+00	5.0E-05	USEPA 2008	A	USEPA 2008a	3.0E-04	Hyperpigmentation, keratosis, possible vascular complications	USEPA 2008a	5.0E-03	Tsuji et al. 2004
Cadmium (food)	NA	NA	--	B1	USEPA 2008a	1.0E-03	Significant proteinuria	USEPA 2008a	NA	--
Cadmium (water)	NA	NA	--	B1	USEPA 2008a	5.0E-04	Significant proteinuria	USEPA 2008a	NA	--
Copper	NA	NA	--	D	USEPA 2008a	4.0E-02	Liver or kidney damage	USEPA 2008b[b]	1.0E-02	ATSDR 2008
Lead	NA	NA	--	B2	USEPA 2008a	NA		USEPA 2008a	NA	--
Mercury	NA	NA	--	C	USEPA 2008a	3.0E-04	Autoimmune effects	USEPA 2008a	2.0E-03	ATSDR 2008
Selenium	NA	NA	--	D	USEPA 2008a	5.0E-03	Clinical selenosis	USEPA 2008a	NA	--
Silver	NA	NA	--	D	USEPA 2008a	5.0E-03	Argyria	USEPA 2008a	NA	--
Thallium	NA	NA	--	D	USEPA 2008a	6.5E-05	No adverse effects	USEPA 2008a[c]	6.5E-04	USEPA 2008a[d]
Zinc	NA	NA	--	D	USEPA 2008a	3.0E-01	volunteers	USEPA 2008a	3.0E-01	ATSDR 2008

Source:
USEPA 2008a. IRIS (http://www.epa.gov/iris/).
ATSDR 2005. MRLs (http://www.atsdr.cdc.gov/mrls.html).
USEPA 2008b. http://www.epa.gov/safewater/contaminants/dw_contamfs/copper.html

Notes:
CSF = cancer slope factor
NA = not available
RfD = reference dose
WOE = weight of evidence (see text for description)
ESOD = erythrocyte Cu, Zn-superoxide dismutase

[a] This substance/agent has not undergone a complete evaluation and determination under US EPA's IRIS program for evidence of human carcinogenic potential.
[b] Based on conversion of current U.S. National Primary Drinking Water Regulations' maximum contaminant level goal for copper, 1.3 mg/L, to an RfD for chronic and subchronic oral exposure.
[c] Based on adjustment of chronic oral RfD for Thallium (I) Sulfate to account for contribution of thallium metal to molecular weight of this compound.
[d] Based on chronic oral RfD for Thallium without adjustment for extrapolation of subchronic to chronic data.

Table 5-2. Inhalation Toxicity Criteria

Chemicals of Potential Concern	Inhalation Route																	
	Unit Risk ($m^3/\mu g$)	Source	WOE	Source	Chronic RfC (mg/m^3)	Critical Organ / Effect	Source	Subchronic RfC (mg/m^3)	Source	Acute RfC (mg/m^3)	Source	Inhalation CSF (kg-d/mg)	Source	Chronic RfD (mg/kg-d)	Source	Subhronic RfD (mg/kg-d)	Source	Acute RfD (mg/kg-d)	Source
Metals																			
Antimony	NA	--	NA[a]	USEPA 2008	1.4E-04	Pulmonary toxicity, chronic interstitial inflammation	USEPA 2008[b]	NA	--	NA	--	NA	--	4.1E-05	--	NA	--	NA	--
Arsenic	4.3E-03	USEPA 2008	A	USEPA 2008	3E-05	Development; cardiovascular system; nervous system	OEHHA 2008	NA	--	1.90E-04	OEHHA 2008	1.5E+01	USEPA 1995	8.6E-06	OEHHA 2008	NA	--	5.4E-05	OEHHA 2008
Cadmium	1.8E-03	USEPA 2008	B1	USEPA 2008	2E-05	Kidney; respiratory system	OEHHA 2008	NA	--	NA	--	6.3E+00	USEPA 1995	5.7E-06	OEHHA 2008	NA	--	NA	--
Lead	NA	--	B2	USEPA 2008	NA	--	--	NA	--	NA	--	NA	--	NA	--	NA	--	NA	--
Thallium	NA	--	D	USEPA 2008	NA	--	--	NA	--	NA	--	NA	--	NA	--	NA	--	NA	--

Source:
USEPA 2008. IRIS (http://www.epa.gov/iris/).
ATSDR 2005. MRLs (http://www.atsdr.cdc.gov/mrls.html).
USEPA 1995. The Inhalation Slope Factor was calculated from inhalation unit risk as described in Supplemental Guidance from RAGS: Region 4 Bulletins, Human Health Risk Assessment (Interim Guidance) (November 1995).
OEHHA 2008. http://www.oehha.ca.gov/air/chronic_rels/AllChrels.html & http://www.oehha.ca.gov/air/acute_rels/allAcRELs.html

Notes:
NA = not available
RfC = reference concentration
WOE = weight of evidence (see text for description)

[a] This substance/agent has not undergone a complete evaluation and determination under US EPA's IRIS program for evidence of human carcinogenic potential.
[b] Based on adjustment of chronic RfC for Antimony Trioxide to account for contribution of antimony metal to molecular weight of this compound.

Table 5-3. Summary of Sulfur Dioxide Standards

	24-Hour ($\mu g/m^3$)	Annual ($\mu g/m^3$)
Sulfur Dioxide		
Peru[a]	365	80
USEPA	365	80
WHO	20	--

	10 min ($\mu g/m^3$)	30 min ($\mu g/m^3$)	60 min ($\mu g/m^3$)	4 hr ($\mu g/m^3$)	8 hr ($\mu g/m^3$)
AEGL-1	524	524	524	524	524
AEGL-2	1,965	1,965	1,965	1,965	1,965
AEGl-3	78,600	78,600	78,600	49,780	25,152

Note:
[a]The 24-hour standard is not to be exceeded more than once per year. A new 24-hour standard of 80µg/m ^{3} will take effect in January 2009; in 2014, the 24-hour standard will be reduced to 20µg/m ^{3}.

Table 5-4. Summary of Ambient Air Quality Standards for Particulate Matter

	24-Hour (µg/m3)	Annual (µg/m3)
PM_{10}		
Peru	150[a]	50
USEPA	150[b]	Revoked[c]
WHO	50	20
$PM_{2.5}$		
Peru[d]	65	---
USEPA	35[e]	15[f]
WHO	25	10

Notes:

[a]Not to be exceeded more than three times per year

[b]Not to be exceeded more than once per year on average over three years.

[c]Due to a lack of evidence linking health problems to long-term exposure to coarse particulate pollution, the agency revoked the annual PM_{10} standard in 2006 (effective December 17, 2006).

[d]A new 24-hour standard of 50µg/m^3 is proposed to take effect in 2010; in 2014, it is proposed that the 24-hour standard will be reduced to 25µg/m^3 and an annual standard of 10µg/m^3 will be adopted.

[e]The 3-year average of the 98th percentile of 24-hour concentrations at each population-oriented monitor within an area must not exceed 35µg/m^3

[f]The 3-year average of the weighted annual mean $PM_{2.5}$ concentrations from single or multiple community-oriented monitors must not exceed 15µg/m^3.

Table 6-1. Hourly Exceedance of Sulfur Dioxide AEGL-1 (524µg/m^3)

Monitoring Station	N	Exceedances	% hours in exceedance	≥ 12 hours in one day
Sindicato	8,709	1,764	20%	23
Hotel Inca	8,452	1,275	15%	9
Marcavalle	7,893	1,311	17%	10
Huaynacancha	5,237	214	4%	0
Huari	7,117	1,128	16%	8
Casaracra	8,393	100	1%	0

Table 6-2. Hourly exceedance of sulfur dioxide AEGL-2 (1,965µg/m^3)

Monitoring Station	N	Exceedances	% hours in exceedance	≥ 12 hours in one day
Sindicato	8,709	912	10.5%	2
Hotel Inca	8,452	474	5.6%	0
Marcavalle	7,893	295	3.7%	0
Huaynacancha	5,237	5	0.1%	0
Huari	7,117	316	4.4%	0
Casaracra	8,393	1	0.0%	0

Notes:
N = number of total hours sampled in 2007

Table 6-3. Maxmium Hourly Sulfur Dioxide Values ($\mu g/m^3$) by Month 2007

	Sindicato	Hotel Inca	Marcavalle	Huaynacancha	Casaraca	Huari
Jan	18,000	13,188	2,107	---	1,480	---
Feb	13,321	9,966	5,244	---	801	---
Mar	15,071	12,488	6,028	---	1,929	5,108
Apr	14,724	12,688	5,479	---	2,103	3,898
May	13,661	9,528	4,942	3,346	830	6,015
Jun	17,904	10,784	4,418	1,444	754	5,873
Jul	17,640	9,623	5,047	2,950	219	5,542
Aug	18,118	7,883	5,010	944	638	6,009
Sep	19,100	10,059	5,719	2,108	660	3,449
Oct	13,326	9,872	4,861	1,234	1,768	4,155
Nov	10,638	11,506	5,591	1,242	1,304	6,013
Dec	18,969	15,406	6,000	2,086	1,686	5,984

Notes:
Shaded cells indicate maxiumum value for the year

Table 6-4a. Estimated Annual Stack and Fugitive Sulfur Dioxide Emissions (ton/day)

	Stack	Fugitive
2007	770	70
2008 (Oct)	573	52
2009 (Nov)	175	5
Percent Decrease (2007-2009)	77%	93%

Table 6-4b. Estimated Annual Stack and Fugitive Lead Emissions (ton/day)

	Stack	Fugitive
2007	0.87	0.7
2008 (Oct)	0.70	0.56
2009 (Nov)	0.08	0.01
Percent Decrease (2007-2009)	91%	99%

Table 6-5. Predicted Sulfur Dioxide Concentration in Ambient Air (µg/m^3)

Averaging Time	Peruvian Air Quality Standard	Location	2007	After 2009		Stack on Hill >2009	
			Monitored Ambient Air Concentration	Estimated Air Concentation	Predicted Percent Reduction	Estimated Air Concentation	Predicted Percent Reduction
Annual	80	La Oroya Antigua[b]	706	130	82%	75	89%
		La Oroya Nueva[c]	435	91	79%	32	93%
		Marcavalle[d]	374	83	78%	95	75%
Highest 24-hour	365[a]	La Oroya Antigua	2,966	1,000	66%	590	80%
		La Oroya Nueva	1,452	587	60%	282	81%
		Marcavalle	1,443	502	65%	321	78%

Notes:

[a] A new 24-hour standard of 80 µg/m3 will be instituted in January 2009 and lowered to 20 µg/m3 in January 2014.

[b]Sindicato monitoring data used for this location.

[c]Hotel Inca monitoring data used for this location.

[d]Marcavalle monitoring data used for this location.

Table 6-6. ISE Model Results for 2007 and 2009

	La Oroya Antigua		La Oroya Nueva		Marcavalle/Chucchis		Paccha	Huari
	2007	2009	2007	2009	2007	2009	2007	2007
P10 (%)	100	98	93	39	78	7	36	68
Mean (μg/dL)	21	15	13	10	12	7	10	11
25th Percentile	17	13	11	8	10	6	8	10
50th Percentile	21	14	13	10	12	7	9	11
75th Percentile	24	16	14	11	13	8	11	12
90th Percentile	27	18	16	12	15	10	12	13
95th Percentile	29	20	17	13	17	11	13	14

Notes:
P10 percent is the percentage of the population that is predicted to have a blood lead level exceeding 10μg/dL
Future predictions for Paccha and Huari were not possible due to limitations in the air model.

Table 6-7. Comparison of 2007 Sampling Data and Modeled Blood Lead Concentrations

	La Oroya Antigua		La Oroya Nueva		Marcavalle/Chucchis		Paccha		Huari	
	Data	Model	Data	Model	Data	Model	Data	Model	Data	Model
Mean (μg/dL)	21	21	15	13	15	12	13	10	19	11
25th Percentile	15	17	11	11	10	10	8	8	11	10
50th Percentile	20	21	14	13	13	12	12	9	17	11
75th Percentile	25	24	19	14	18	13	17	11	23	12
90th Percentile	30	27	25	16	24	16	22	12	29	13
95th Percentile	32	29	29	17	28	17	25	13	38	14

Table 6-8. Relative Contributions from Different Media to 2007 Modeled Child Blood Lead Concentrations

	Air (µg/day)	Soil (µg/day)	Indoor Dust (µg/day)	Outdoor Dust (µg/day)	Diet (µg/day)	Water (µg/day)	Total (µg/day)
La Oroya Antigua							
Intake Amount	3.20	58.9	80.06	197.32	18.0	2.65	360.13
% Contribution	0.9	16.4	22.2	54.8	5.0	0.7	100.0
Absorption Factor	1	0.3	0.4	0.4	0.5	0.5	
Absorbed Amount	3.20	17.67	32.03	78.93	9.00	1.33	142.15
Corrected % Contribution	**2.3**	**12.4**	**22.5**	**55.5**	**6.3**	**0.9**	100.0
La Oroya Nueva							
Intake Amount	2.40	28.4	31.82	77.98	15.0	2.65	158.25
% Contribution	1.5	17.9	20.1	49.3	9.5	1.7	100.0
Absorption Factor	1	0.3	0.4	0.4	0.5	0.5	
Absorbed Amount	2.40	8.52	12.73	31.19	7.50	1.33	63.67
Corrected % Contribution	**3.8**	**13.4**	**20.0**	**49.0**	**11.8**	**2.1**	100.0
Marcavalle/Chucchis							
Intake Amount	1.60	16.6	31.82	74.95	15.0	2.65	142.63
% Contribution	1.1	11.6	22.3	52.6	10.5	1.9	100.0
Absorption Factor	1	0.3	0.4	0.4	0.5	0.5	
Absorbed Amount	1.60	4.98	12.73	29.98	7.50	1.33	58.12
Corrected % Contribution	**2.8**	**8.6**	**21.9**	**51.6**	**12.9**	**2.3**	100.0
Paccha							
Intake Amount	0.53	11.7	31.82	38.99	15.0	2.65	100.70
% Contribution	0.5	11.6	31.6	38.7	14.9	2.6	100.0
Absorption Factor	1	0.3	0.4	0.4	0.5	0.5	
Absorbed Amount	0.53	3.51	12.73	15.60	7.50	1.33	41.19
Corrected % Contribution	**1.3**	**8.5**	**30.9**	**37.9**	**18.2**	**3.2**	100.0
Huari							
Intake Amount	1.6	21.9	31.8	51.4	15.0	2.7	124.4
% Contribution	1.6	21.7	31.6	51.1	14.9	2.6	123.5
Absorption Factor	1.0	0.3	0.4	0.4	0.5	0.5	
Absorbed Amount	1.6	6.6	12.7	20.6	7.5	1.3	50.3
Corrected % Contribution	**3.9**	**15.9**	**30.9**	**49.9**	**18.2**	**3.2**	122.1

Note:
Calculations are based on 2007 and 2008 data, central intake values, and mean absorption factors.
Values in bold highlight the corrected contribution

Table 6-9. Relative Contributions from Different Media to 2009 Modeled Child Blood Lead Concentrations

	Air (µg/day)	Soil (µg/day)	Indoor Dust (µg/day)	Outdoor Dust (µg/day)	Diet (µg/day)	Water (µg/day)	Total (µg/day)
La Oroya Antigua							
Intake Amount	0.16	47.8	41.87	114.65	8.0	2.65	215.13
% Contribution	0.1	22.2	19.5	53.3	3.7	1.2	100.0
Absorption Factor	1	0.3	0.4	0.4	0.5	0.5	
Absorbed Amount	0.16	14.34	16.75	45.86	4.00	1.33	82.43
Corrected % Contribution	**0.2**	**17.4**	**20.3**	**55.6**	**4.9**	**1.6**	100.0
La Oroya Nueva							
Intake Amount	0.19	22.9	22.79	55.78	7.0	2.65	111.31
% Contribution	0.2	20.6	20.5	50.1	6.3	2.4	100.0
Absorption Factor	1	0.3	0.4	0.4	0.5	0.5	
Absorbed Amount	0.19	6.87	9.12	22.31	3.50	1.33	43.31
Corrected % Contribution	**0.4**	**15.9**	**21.0**	**51.5**	**8.1**	**3.1**	100.0
Marcavalle/Chucchis							
Intake Amount	0.08	15.0	15.52	36.56	7.0	2.65	76.80
% Contribution	0.1	19.5	20.2	47.6	9.1	3.5	100.0
Absorption Factor	1	0.3	0.4	0.4	0.5	0.5	
Absorbed Amount	0.08	4.50	6.21	14.62	3.50	1.33	30.23
Corrected % Contribution	**0.3**	**14.9**	**20.5**	**48.4**	**11.6**	**4.4**	100.0

Note:

Calculations are based on air modeling predictions, central intake values, and mean absorption factors.

Values in bold highlight the corrected contribution

Table 6-10. Predicted Adult and Fetal Blood Lead Concentrations (Geometric mean values in µg/dL)

La Oroya Antigua	2004[a]	2007	>2009	Other than Antigua	2007	>2009	All Communities	2007	>2009
PbB_{adult}	16.8	7.2	5.4	PbB_{adult}	5.4	4.5	PbB_{adult}	6.2	4.9
PbB_{fetus}	15.1	6.5	4.9	PbB_{fetus}	4.8	4.0	PbB_{fetus}	5.5	4.4
$PbB_{fetal, 0.95}$	27.2	14.3	10.8	$PbB_{fetal, 0.95}$	10.7	9.0	$PbB_{fetal, 0.95}$	12.3	9.7
P(PbBfetal > PbBt)	86%	18%	5%	P(PbBfetal > PbBt)	7%	3%	P(PbBfetal > PbBt)	11%	5%

Notes:

PbB_{adult} = Blood lead of female adults, geometric mean

PbB_{fetus} = Blood lead of fetus, geometric mean

$PbB_{fetal, 0.95}$ = 95th percentile blood lead among fetuses of adults

P(PbBfetal > PbBt) = Probability of fetal blood lead levels exceeding blood lead threshold of 10 µg/dL

[a]Data from 2004 were summarized by individual community, therefore community-wide comparisons cannot be made.

Table 6-11. Summary of Current Cancer Risks - Ingestion Exposures.

	Cancer Risk - CTE	Cancer Risk - RME
	Arsenic	Arsenic
All Neighborhoods		
Indoor Dust Ingestion	3E-04	9E-04
Outdoor Dust Ingestion	5E-04	1E-03
Surface Soil Ingestion	1E-04	4E-04
Total Cancer Risk	1E-03	3E-03
La Oroya Antigua		
Indoor Dust Ingestion	4E-04	1E-03
Outdoor Dust Ingestion	1E-03	3E-03
Surface Soil Ingestion	2E-04	7E-04
Total Cancer Risk	2E-03	5E-03
La Oroya Nueva		
Indoor Dust Ingestion	1E-04	3E-04
Outdoor Dust Ingestion	2E-04	6E-04
Surface Soil Ingestion	1E-04	4E-04
Total Cancer Risk	4E-04	1E-03
Marcavalle / Chucchis		
Indoor Dust Ingestion	1E-04	3E-04
Outdoor Dust Ingestion	5E-04	1E-03
Surface Soil Ingestion	6E-05	2E-04
Total Cancer Risk	6E-04	2E-03
Santa Rosa de Sacco / Huaynacancha		
Indoor Dust Ingestion	1E-04	3E-04
Outdoor Dust Ingestion	1E-04	3E-04
Surface Soil Ingestion	4E-05	1E-04
Total Cancer Risk	3E-04	8E-04
Paccha		
Indoor Dust Ingestion	1E-04	3E-04
Outdoor Dust Ingestion	9E-05	3E-04
Surface Soil Ingestion	5E-05	1E-04
Total Cancer Risk	2E-04	7E-04
Huari		
Indoor Dust Ingestion	1E-04	3E-04
Outdoor Dust Ingestion	1E-04	4E-04
Surface Soil Ingestion	6E-05	2E-04
Total Cancer Risk	3E-04	9E-04

Table 6-12. Summary of Current Cancer Risks - Inhalation Exposures

	Cancer Evaluation	
	CTE Risk	RME Risk
La Oroya Antigua		
Arsenic	2E-03	4.E-03
Cadmium	2E-05	4.E-05
Total Cancer Risk	2E-03	4.E-03
La Oroya Nueva		
Arsenic	2E-03	3.E-03
Cadmium	2E-05	3.E-05
Total Cancer Risk	2E-03	3.E-03
Marcavalle / Chucchis		
Arsenic	1E-03	2.E-03
Cadmium	1E-05	2.E-05
Total Cancer Risk	1E-03	2.E-03
Santa Rosa de Sacco / Huaynacancha		
Arsenic	4E-04	7.E-04
Cadmium	7E-06	1.E-05
Total Cancer Risk	4E-04	7.E-04
Paccha		
Arsenic	7E-04	1.E-03
Cadmium	8E-06	1.E-05
Total Cancer Risk	7E-04	1.E-03
Huari		
Arsenic	8E-04	1.E-03
Cadmium	1E-05	2.E-05
Total Cancer Risk	8E-04	1.E-03

Table 6-13. Summary of Cancer Risks for Post 2009 - Ingestion Exposures

	Cancer Risk - CTE Arsenic	Cancer Risk - RME Arsenic
La Oroya Antigua		
Indoor Dust Ingestion	1.E-04	3.E-04
Outdoor Dust Ingestion	2E-05	6E-05
Surface Soil Ingestion	2E-04	6E-04
Total Cancer Risk	3E-04	1E-03
La Oroya Nueva		
Indoor Dust Ingestion	2E-05	7E-05
Outdoor Dust Ingestion	3E-06	9E-06
Surface Soil Ingestion	1E-04	3E-04
Total Cancer Risk	1E-04	4E-04
Marcavalle / Chucchis		
Indoor Dust Ingestion	2E-05	7E-05
Outdoor Dust Ingestion	1E-05	3E-05
Surface Soil Ingestion	6E-05	2E-04
Total Cancer Risk	9E-05	3E-04

Table 6-14. Summary of Cancer Risks for Post 2009 - Inhalation Exposures

	Cancer Evaluation	
	CTE Risk	RME Risk
La Oroya Antigua		
Arsenic	4E-05	7E-05
Cadmium	3E-06	5E-06
Total Cancer Risk	5E-05	8E-05
La Oroya Nueva		
Arsenic	3E-05	5E-05
Cadmium	2E-06	4E-06
Total Cancer Risk	3E-05	6E-05
Marcavalle / Chucchis		
Arsenic	2E-05	4E-05
Cadmium	1E-06	2E-06
Total Cancer Risk	2E-05	4E-05

Table 6-15. Summary of Current Noncancer Risks - Ingestion Exposures

	Noncancer Evaluation - CTE Resident				Noncancer Evaluation - RME Resident			
	Antimony	Arsenic	Cadmium	Copper	Antimony	Arsenic	Cadmium	Copper
All Neighborhoods								
Indoor Dust Ingestion	3E-01	2E+00	4E-02	3E-02	9E-01	5E+00	1E-01	8E-02
Outdoor Dust Ingestion	3E-01	3E+00	9E-02	6E-02	7E-01	7E+00	3E-01	2E-01
Surface Soil Ingestion	7E-02	7E-01	4E-02	2E-02	2E-01	2E+00	1E-01	5E-02
Hazard Quotient (by analyte)	6E-01	5E+00	2E-01	1E-01	2E+00	1E+01	5E-01	3E-01
La Oroya Antigua								
Indoor Dust Ingestion	3E-01	2E+00	5E-02	4E-02	1E+00	7E+00	1E-01	1E-01
Outdoor Dust Ingestion	5E-01	5E+00	2E-01	9E-02	1E+00	1E+01	6E-01	3E-01
Surface Soil Ingestion	1E-01	1E+00	7E-02	3E-02	4E-01	4E+00	2E-01	8E-02
Hazard Quotient (by analyte)	9E-01	9E+00	3E-01	2E-01	3E+00	2E+01	9E-01	5E-01
La Oroya Nueva								
Indoor Dust Ingestion	8E-02	6E-01	3E-02	1E-02	2E-01	2E+00	8E-02	4E-02
Outdoor Dust Ingestion	4E-02	1E+00	2E-02	1E-02	1E-01	3E+00	7E-02	3E-02
Surface Soil Ingestion	5E-02	7E-01	3E-02	1E-02	2E-01	2E+00	1E-01	3E-02
Hazard Quotient (by analyte)	2E-01	2E+00	8E-02	3E-02	5E-01	6E+00	2E-01	1E-01
Marcavalle / Chucchis								
Indoor Dust Ingestion	8E-02	6E-01	3E-02	1E-02	2E-01	2E+00	8E-02	4E-02
Outdoor Dust Ingestion	2E-01	2E+00	5E-02	3E-02	5E-01	7E+00	1E-01	8E-02
Surface Soil Ingestion	3E-02	3E-01	2E-02	7E-03	8E-02	1E+00	6E-02	2E-02
Hazard Quotient (by analyte)	3E-01	3E+00	1E-01	5E-02	8E-01	1E+01	3E-01	1E-01
Santa Rosa de Sacco / Huaynacancha								
Indoor Dust Ingestion	8E-02	6E-01	3E-02	1E-02	2E-01	2E+00	8E-02	4E-02
Outdoor Dust Ingestion	7E-02	6E-01	2E-02	1E-02	2E-01	2E+00	6E-02	3E-02
Surface Soil Ingestion	2E-02	2E-01	4E-03	7E-03	5E-02	6E-01	1E-02	2E-02
Hazard Quotient (by analyte)	2E-01	1E+00	5E-02	3E-02	5E-01	4E+00	1E-01	9E-02
Paccha								
Indoor Dust Ingestion	8E-02	6E-01	3E-02	1E-02	2E-01	2E+00	8E-02	4E-02
Outdoor Dust Ingestion	5E-02	5E-01	2E-02	8E-03	1E-01	1E+00	5E-02	2E-02
Surface Soil Ingestion	1E-02	2E-01	5E-03	2E-03	4E-02	7E-01	2E-02	7E-03
Hazard Quotient (by analyte)	1E-01	1E+00	5E-02	2E-02	4E-01	4E+00	1E-01	7E-02
Huari								
Indoor Dust Ingestion	8E-02	6E-01	3E-02	1E-02	2E-01	2E+00	8E-02	4E-02
Outdoor Dust Ingestion	2E-01	7E-01	2E-02	9E-03	6E-01	2E+00	6E-02	3E-02
Surface Soil Ingestion	7E-02	3E-01	2E-02	2E-02	2E-01	1E+00	6E-02	5E-02
Hazard Quotient (by analyte)	3E-01	2E+00	7E-02	4E-02	1E+00	5E+00	2E-01	1E-01

Table 6-16. Summary of Current Noncancer Risks - Inhalation Exposures

	NonCancer Evaluation	
	CTE Hazard	RME Hazard
La Oroya Antigua		
Antimony	4E+00	6E+00
Arsenic	4E+01	6E+01
Cadmium	2E+00	2E+00
La Oroya Nueva		
Antimony	3E+00	5E+00
Arsenic	4E+01	6E+01
Cadmium	1E+00	2E+00
Marcavalle / Chucchis		
Antimony	2E+00	4E+00
Arsenic	2E+01	3E+01
Cadmium	7E-01	1E+00
Santa Rosa de Sacco / Huaynacancha		
Antimony	3E-01	5E-01
Arsenic	8E+00	1E+01
Cadmium	4E-01	7E-01
Paccha		
Antimony	2E+00	3E+00
Arsenic	1E+01	2E+01
Cadmium	5E-01	8E-01
Huari		
Antimony	9E-01	2E+00
Arsenic	1E+01	2E+01
Cadmium	9E-01	2E+00

Table 6-17. Summary of Noncancer Risks for Post 2009 - Ingestion Exposures

	Noncancer Evaluation - CTE Resident		Noncancer Evaluation - RME Resident	
	Arsénico	Cádmio	Arsénico	Cádmio
La Oroya Antigua				
Indoor Dust Ingestion	5E-01	2E-02	1E+00	5E-02
Outdoor Dust Ingestion	1E-01	3E-02	3E-01	8E-02
Surface Soil Ingestion	1E+00	6E-02	3E+00	2E-01
Hazard Quotient (by analyte)	2E+00	1E-01	5E+00	3E-01
La Oroya Nueva				
Indoor Dust Ingestion	1E-01	8E-03	3E-01	2E-02
Outdoor Dust Ingestion	2E-02	3E-03	5E-02	9E-03
Surface Soil Ingestion	6E-01	3E-02	2E+00	1E-01
Hazard Quotient (by analyte)	7E-01	4E-02	2E+00	1E-01
Marcavalle / Chucchis				
Indoor Dust Ingestion	1E-01	8E-03	4E-01	2E-02
Outdoor Dust Ingestion	5E-02	7E-03	2E-01	2E-02
Surface Soil Ingestion	3E-01	2E-02	9E-01	5E-02
Hazard Quotient (by analyte)	5E-01	3E-02	1E+00	1E-01

Table 6-18. Summary of Noncancer Risks for Post Year 2009 - Inhalation Exposures

	NonCancer Evaluation	
	CTE Hazard	RME Hazard
La Oroya Antigua		
Arsenic	8E-01	1E+00
Cadmium	2E-01	3E-01
La Oroya Nueva		
Arsenic	6E-01	1E+00
Cadmium	1E-01	2E-01
Marcavalle / Chucchis		
Arsenic	4E-01	7E-01
Cadmium	1E-01	2E-01

Table 6-19. Key Uncertainties for the Human Health Risk Assessment.

Source of Uncertainty	Effect on Risk Estimates	Potential Magnitude of Effect	Explanation and Rationale for Assumptions
Air Quality Data			
Air monitoring stations are not representative of all residences.	Over- or underestimate	Low	The data obtained from air monitoring stations are not likely to provide exact estimates of breathing-zone chemical concentrations for residents in all communities. This uncertainty has been reduced since 2005 with relocation and addition of air monitoring stations.
Low frequency of collection of $PM_{2.5}$ samples	Over- or underestimate	Low	$PM_{2.5}$ samples were not collected frequently enough to establish annual average concentrations; however, PM_{10} data provided adequate data for assessment of particulate health risk.
Air Modeling			
Site-specific upper air meteorological data were not available.	Over- or underestimate	Medium	Due to the absence of these data, it was necessary to adjust the air dispersion model based on empirical observations. With these adjustments, the model predicts air concentrations with adequate accuracy to support the risk assessment for communities close to the Complex. The accuracy is more limited for communities at greater distances and future concentrations could not be predicted for Paccha and Huari.
The air model did not account for wet deposition.	Over- or underestimate	Medium	The air model only included dry deposition. Wet deposition occurs when rain washes gases and particulates from the air. This factor could reduce concentrations of sulfur dioxide and metals at increasing distances from the smelter during the rainy season. Inclusion of wet deposition in the air model would likely increase the accuracy of predictions for both sulfur dioxide and metal concentrations at varying distances from the smelter.
The smelter was assumed to operate continuously regardless of weather conditions	Overestimate	Medium	The intermittent control strategy implemented to reduce emissions when inversions are forecast was not taken into account in the model, which results in an overestimate of the maximum 24 hour sulfur dioxide concentrations.

Table 6-19. Key Uncertainties for the Human Health Risk Assessment.

Source of Uncertainty	Effect on Risk Estimates	Potential Magnitude of Effect	Explanation and Rationale for Assumptions
Dust and Soil Data			
The number of samples collected was relatively small	Over- or underestimate	Medium	Stack emissions from the Complex are widely dispersed throughout La Oroya. For that reason, it was judged that a small number of samples could be used to assess the magnitude of contamination. However, concentrations of metals were found to vary substantially both within communities and also between communities. The use of a maximum or an upper bound estimate of the true mean concentrations for metals other than lead in a community may have resulted in overestimates of typical metal concentrations throughout the community. Conversely, the small number of samples could mean some areas with higher concentrations were not sampled.
The exact method by which indoor dust samples were collected was not clear	Over- or underestimate	Medium	Indoor dust metal concentrations were used in the risk assessment, but only the wipe method of dust collection and calculation of dust loads was described. It was assumed that the dust metals concentrations were reported as mg metal per kg dust.
Indoor dust concentrations were assumed to be the same in all communities	Overestimate	Medium	Exposure to metals in indoor dust are likely overestimated for communities farther from the Complex because most samples were from La Oroya Antigua or other nearby communities
Chemical Selection			
USEPA default screening values were used to determine which chemicals should be included in the risk assessment.	Underestimate	Low	Risk-based screening levels may or may not be representative of exposures in La Oroya. The most toxic metals were included in the risk assessment, so exclusion of metals that were screened out is not likely to have had an impact on overall risk estimates.
Thallium was screened in as a chemical of concern for air based on exceedances of the Peruvian air quality criterion.	Underestimate	Low	No health effect basis for the Peruvian standard was identified. USEPA does not have an inhalation toxicity criterion for thallium, so inhalation risks for thallium were not quantified.
Dietary Data			
Lead was not detected in food samples.	Overestimate	Medium	Dietary lead intakes were calculated using half the detection limit. Because lead was not detected in any of the samples, this assumption has likely lead to an overestimate of lead intake from the diet. The overestimation is likely to be greatest in communities farthest from the Complex

Table 6-19. Key Uncertainties for the Human Health Risk Assessment.

Source of Uncertainty	Effect on Risk Estimates	Potential Magnitude of Effect	Explanation and Rationale for Assumptions
The diet study only included pregnant women and children less than 3 years old.	Neutral	Low	Pregnant women and young children (0-6 years old) are the primary populations of concern for lead. Dietary intakes by pregnant women may be higher than for other adults. Similarly, intakes by children younger than 3 may be higher than those of children 3-6 years old.
Dietary intakes of cadmium and arsenic were not calculated in the risk assessment.	Underestimate	Medium	Intake of cadmium and arsenic from smelter emissions via food ingestion is likely to be low relative to other intake pathways (ingestion of dust, soil). Much of the arsenic measured in food samples may be from natural sources unrelated to the smelter and include nontoxic organic arsenicals.
Lead Exposure Models			
The relative contribution of outdoor dust, indoor dust and soil to lead exposures was not known, but outdoor dust was assumed to be the primary source of exposure.	Over- or underestimate	Low	Studies in other smelter communities have demonstrated that outdoor dust is a primary factor controlling lead exposures. Risk estimates for current exposures will not be affected if this assumption is incorrect because the exposure models were fit to the data from site-specific blood lead studies for both children and adults. However, if outdoor dust is not as important as assumed in the models, the impact of future emissions reductions may be overestimated.
The distributions of intake rates of outdoor dust, indoor dust and soil by children were not known.	Over- or underestimate	Medium	The distributions used in the ISE lead exposure model were selected to produce overall lead exposures that best matched the observed blood lead distributions from the 2004 study in La Oroya Antigua. The match achieved was best in the range of 25^{th} to 75^{th} percentiles of the population. Despite the selection of lognormal distributions for dust and soil intake rates, the model underpredicted the upper percentile blood lead levels, suggesting that some children with extremely high exposures are not being accurately represented by the present model. These high intakes could be due to a variety of factors such as pica for soil (reported for children by 40 percent of the mothers in the diet study), poor hygiene practices, or unusual exposures.
The relative bioavailability of lead in dust and soil was not measured, and the distribution of bioavailability is not known.	Overestimate	Medium	Because this is an active smelter site, the relative bioavailability of lead in dust and soil was assumed to be higher than typical default values. Triangular distributions were selected because of the likely existence of upper and lower bounds to lead absorption.

Table 6-19. Key Uncertainties for the Human Health Risk Assessment.

Source of Uncertainty	Effect on Risk Estimates	Potential Magnitude of Effect	Explanation and Rationale for Assumptions
One half the detection limit was used as the exposure concentration for lead in drinking water	Overestimate	Low	Lead was not detected in most drinking water samples. Use of half the detection limit as the exposure concentration may slightly overestimate exposure via water
Dietary lead intake data were only available for children between the ages of 12 and 36 months old. The overall average and distribution of lead intakes for these children were applied to younger and older children in the ISE model.	Over- or underestimate	Low	Dietary lead intakes may be overestimated for children less than 12 months old and underestimated for children greater than 36 months old. The overall predicted distribution of blood lead levels is not expected to be much affected by this factor.
The impact of future lead emissions reductions on lead in outdoor dust, indoor dust, soil, and diet was estimated.	Over- or underestimate	Medium	Estimates were based, in part, on reductions measured in dust and soil in another smelter community after similar emissions reductions.
Blood lead data used to fit the exposure model did not include the time lived in the current residence.	Over- or underestimate	Low	If children and adults recently moved to La Oroya their blood lead levels may not yet accurately reflect current exposures. On the other hand, if they have moved from a community close to the smelter to one farther away, their blood lead levels may be higher than would be expected at their current location. These inconsistencies could affect the assumptions used for the lead exposure models.
For children, little to no blood sampling data from 2004 were available for communities outside of La Oroya Antigua.	Over- or underestimate	Low	This limitation affected the ability to assure the lead exposure model for children was accurately calibrated for communities other than La Oroya Antigua; however, the assumption that exposure patterns would be similar in all the communities was judged to be reasonable. This assumption was supported by comparison of model predictions with blood lead data from 2000 for the other communities.
The adult lead exposure model did not allow entry of separate inputs for all of the exposure pathways considered to be important in La Oroya. Consequently, all pathways other than outdoor dust were considered to contribute to the baseline blood lead level.	Over- or underestimate	Low	This model limitation did not affect the overall risk estimates because the model was fitted to site-specific blood lead data; however, the relative contribution of exposure pathways other than outdoor dust cannot be observed with the current model.

Table 6-19. Key Uncertainties for the Human Health Risk Assessment.

Source of Uncertainty	Effect on Risk Estimates	Potential Magnitude of Effect	Explanation and Rationale for Assumptions
Exposure Assessment for Arsenic, Cadmium, Antimony and Copper			
Exposure input parameters for other metals were estimated based on the outcome of the lead exposure models.	Over- or underestimate	Medium	Exposure pathways for these metals are expected to the same as those for lead, so reliance on the inputs developed for lead is a reasonable way to derive site-specific assumptions.
Dermal contact with chemicals was not included as an exposure pathway.	Underestimate	Low	Dermal absorption of metals is low and is not likely to have had an impact on overall risk estimates.
The relative bioavailability of metals in dust and soil was not measured.	Overestimate	Medium	Because this is an active smelter site, the relative bioavailability of metals in dust and soil was assumed to be higher than typical default values.
The impact of future metal emissions reductions on metals in outdoor dust, indoor dust, soil, and diet was estimated.	Over- or underestimate	Medium	Estimates were based on both professional judgment and on reductions measured in dust and soil in another smelter community after similar emissions reductions. The actual reductions may be greater or smaller than those predicted.
Toxicity Assessment for SO_2 and Particulates			
Epidemiological studies suggesting a link between elevated sulfur dioxide concentrations and increased morbidity and mortality are confounded by exposure to mixtures containing particulate matter.	Over- or underestimate	Medium	Due to this confounding, USEPA has not established air quality standards for sulfur dioxide that are based on the endpoints of general morbidity and mortality.
Morbidity and mortality associated with particulates is more closely correlated with the smallest particles, i.e., particles 2.5 microns or less in diameter or $PM_{2.5}$.	Underestimate	Medium	Particulate exposures were assessed using data for air particles ten microns or less in diameter (i.e., PM_{10}). USEPA recently updated their air quality standards for both $PM_{2.5}$ and withdrew the standard for PM_{10}. For now, comparison with the Peruvian PM_{10} standard provides a reasonable assessment of health risk, but after completion of operational changes at the Complex it will be useful to consider the $PM_{2.5}$ data and standard.
Toxicity Assessment for Lead			
Populations living at high altitudes have increased hematocrits, making blood lead levels increase relative to body burden.	Overestimate	Medium	Blood lead levels associated with toxicity in epidemiology studies of sea level populations may overstate the toxicity of similar blood lead levels in high altitude populations such as that of La Oroya.

Table 6-19. Key Uncertainties for the Human Health Risk Assessment.

Source of Uncertainty	Effect on Risk Estimates	Potential Magnitude of Effect	Explanation and Rationale for Assumptions
Anemia may lead to decreased blood lead levels relative to body burden.	Underestimate	Medium	Blood lead levels associated with toxicity in epidemiology studies of non-anemic populations may understate the toxicity of similar blood lead levels in a population with a high prevalence of anemia such as that of La Oroya.
Cancer slope factors for arsenic and cadmium assume lack of a threshold for cancer induction.	Overestimate	High	This assumption may lead to high risk estimates when risks may actually be as low as zero. There is considerable evidence that the dose-response for ingested arsenic is nonlinear, with a possible threshold below which cancer risks are not increased.
The reference doses used to assess health effects other than cancer are designed to be health protective, i.e., to minimize that chance that risks will be underestimated.	Overestimate	High	Standard procedures use multiple uncertainty factors to extrapolate toxicity estimates from animal studies to humans, to account for inter-individual variability, and to account for deficiencies in available toxicity data. The uncertainty factors are based on the upper bounds of observed differences in these factors for other chemicals and are likely to overestimate toxicity.
The toxicity database for antimony is limited.	Overestimate	Medium	Chemical and toxicity characteristics of antimony resemble those of arsenic, thus when exposure to both metals occurs simultaneously, the effects due to arsenic versus antimony may be difficult to delineate.
The reference dose used to assess toxicity of copper ingested in soil and dust was based on gastrointestinal upsets after ingestion of water with high copper concentrations.	Overestimate	Medium	The health endpoint for the reference dose likely is not a health endpoint of concern for ingestion of copper in soil and dust.
The toxicity database for thallium is limited.	Over- or underestimate	High	The mechanism by which thallium exerts its toxicity is unclear and there are many uncertainties in the toxicity database, such that USEPA has assigned a low confidence rating to the reference dose for thallium.
Risk Characterization for SO_2 and Particulates			
The air model and available data did not permit prediction of future short-term sulfur dioxide concentrations for time periods much less than 24 hours.	Underestimate	Medium	Transient pulmonary irritation may occur due to short times with elevated sulfur dioxide concentrations. These short times with elevated concentrations may be missed when 24 hour averages are evaluated.

Table 6-19. Key Uncertainties for the Human Health Risk Assessment.

Source of Uncertainty	Effect on Risk Estimates	Potential Magnitude of Effect	Explanation and Rationale for Assumptions
The composition and particle size distribution is not known for particulates, and neither is the contribution from sources other than the Complex. Predictions of future particle emission rates were also not available.	Over- or underestimate	Low	Predicted health risks from particulates were much lower than risks for sulfur dioxide. Consequently, the uncertainty associated with characterization of particulates is not likely to have a significant impact on the reliability of risk estimates. Prediction of future risks is also not a high priority.
Risk Characterization for Lead			
The blood lead exposure model may underestimate blood lead levels of children with the highest exposures.	Underestimate	Medium	A greater percentage of children than predicted by the model may exceed target blood lead levels.
Health risks based on sea level populations may overestimate health risks for the high altitude of La Oroya.	Overestimate	Medium	Blood lead levels associated with health risks may be approximately 20 percent higher in La Oroya than at sea level.
Health risks based on non-anemic populations may underestimate health risks for people with anemia.	Underestimate	Medium	A high prevalence of anemia is expected in La Oroya based both on the dietary study conducted in La Oroya Antigua and also on other studies of Peruvian Andean populations.
Risk Characterization for Arsenic, Cadmium, Antimony and Thallium			
Risks for multiple chemicals were not addressed quantitatively.	Over- or underestimate	Medium	Simultaneous exposure to multiple chemicals is typically assumed to result in additive risks; however, actual health risks may reflect synergistic or antagonistic interactions among chemicals. The potential for such interactions is thought to be dose dependent, and to vary for different exposure conditions. Although the potential impacts of interactions on health risks in La Oroya could not be quantified, a qualitative discussion of health effects that could be subject to such interactions is provided as a guide for any future health studies that might be conducted.

Table 6-19. Key Uncertainties for the Human Health Risk Assessment.

Source of Uncertainty	Effect on Risk Estimates	Potential Magnitude of Effect	Explanation and Rationale for Assumptions
Risks for all chemicals are given equal weight regardless of confidence in the toxicity factor or severity of the health endpoint of concern	Over- or underestimate	Low	This approach is standard risk assessment practice, but does not account for the fact that some risk estimates are based on toxicity studies in humans, while others are extrapolated from animals. Similarly, risk estimates for some chemicals are based on severe health effects, while others are based on much less severe health effects. The impact of this factor is limited because of the small number of chemicals contributing to risk estimates in La Oroya, and the extensive amount of toxicity data available for the principal chemicals contributing to risks, i.e., arsenic and cadmium.

Table 6-20. Sensitivity Analysis for Children Blood Lead Level

Primary Scenario: Soil reduced by 20%, outdoor dust reductions 10% below soil concentration

				Post 2009		**Results**	
Variable	Unit	2005	2007	Projected % changed	Input Value	P10 (%)	99
Pb Concentration in Air	µg/m3	2.87	1.2	-94.70%	0.06	Mean (mg/dL)	16
Mean Pb Conc. in Soil	mg/kg	2407	2946	-18.90%	2388	25th Percentile	13
Mean Pb Conc. in Community Dust[b]	mg/kg	7684	3654	Soil limited (10%)	2149	50th Percentile	15
Mean Pb Conc. in Residential Dust[c]	mg/kg	2795	2225	Ratio	1309	75th Percentile	17
Mean Pb Diet Intake	µg/day	55	18	-5.70%	17	90th Percentile	20
Mean Pb Conc. in Water	µg/L	7	5	0.00%	5	95th Percentile	22

Scenario 1: Soil reduced by 10%, outdoor dust reductions 10% below soil concentration

				Post 2009			
Variable	Unit	2005	2007	Projected % change[d]	Input Value	P10 (%)	100
Pb Concentration in Air	µg/m^3	2.87	1.20	-94.7%	0.06	Mean (µg/dL)	17
Mean Pb Conc. in Soil	mg/kg	2407	2946	-9.5%	2667	25th Percentile	15
Mean Pb Conc. in Community Dust[b]	mg/kg	7684	3654	Soil limited (10%)	2400	50th Percentile	17
Mean Pb Conc. in Residential Dust[c]	mg/kg	2795	2225	Ratio	1462	75th Percentile	19
Mean Pb Diet Intake	µg/day	55	18	-5.7%	17	90th Percentile	21
Mean Pb Conc. in Water	µg/L	7	5	0.0%	5	95th Percentile	23

Scenario 2: Soil reduced by 10%, outdoor dust reductions 20% below soil concentration

				Post 2009			
Variable	Unit	2005	2007	Projected % changed	Input Value	P10 (%)	99
Pb Concentration in Air	µg/m3	2.87	1.20	-94.7%	0.06	Mean (µg/dL)	16
Mean Pb Conc. in Soil	mg/kg	2407	2946	-9.5%	2667	25th Percentile	13
Mean Pb Conc. in Community Dustb	mg/kg	7684	3654	Soil limited (20%)	2134	50th Percentile	15
Mean Pb Conc. in Residential Dustc	mg/kg	2795	2225	Ratio	1299	75th Percentile	18
Mean Pb Diet Intake	µg/day	55	18	-5.7%	17	90th Percentile	20
Mean Pb Conc. in Water	µg/L	7	5	0.0%	5	95th Percentile	21

Table 6-20. Sensitivity Analysis for Children Blood Lead Level

Scenario 3: Soil reduced by 10%, outdoor dust reductions 30% below soil concentration

				Post 2009			
Variable	Unit	2005	2007	Projected % changed	Input Value	P10 (%)	98
Pb Concentration in Air	µg/m3	2.87	1.20	-94.7%	0.06	Mean (µg/dL)	15
Mean Pb Conc. in Soil	mg/kg	2407	2946	-9.5%	2667	25th Percentile	13
Mean Pb Conc. in Community Dustb	mg/kg	7684	3654	Soil limited (30%)	1867	50th Percentile	15
Mean Pb Conc. in Residential Dustc	mg/kg	2795	2225	Ratio	1137	75th Percentile	17
Mean Pb Diet Intake	µg/day	55	18	-5.7%	17	90th Percentile	19
Mean Pb Conc. in Water	µg/L	7	5	0.0%	5	95th Percentile	20

Scenario 4: Soil reduced by 20%, outdoor dust reductions 10% below soil concentration

				Post 2009			
Variable	Unit	2005	2007	Projected % changed	Input Value	P10 (%)	99
Pb Concentration in Air	µg/m3	2.87	1.20	-94.7%	0.06	Mean (µg/dL)	16
Mean Pb Conc. in Soil	mg/kg	2407	2946	-18.9%	2388	25th Percentile	13
Mean Pb Conc. in Community Dustb	mg/kg	7684	3654	Soil limited (10%)	2149	50th Percentile	15
Mean Pb Conc. in Residential Dustc	mg/kg	2795	2225	Ratio	1309	75th Percentile	17
Mean Pb Diet Intake	µg/day	55	18	-5.7%	17	90th Percentile	20
Mean Pb Conc. in Water	µg/L	7	5	0.0%	5	95th Percentile	22

Scenario 5: Soil reduced by 20%, outdoor dust reductions 30% below soil concentration

				Post 2009			
Variable	Unit	2005	2007	Projected % changed	Input Value	P10 (%)	94
Pb Concentration in Air	µg/m3	2.87	1.2	-94.7%	0.06	Mean (µg/dL)	14
Mean Pb Conc. in Soil	mg/kg	2407	2946	-18.9%	2388	25th Percentile	12
Mean Pb Conc. in Community Dustb	mg/kg	7684	3654	Soil limited 30%)	1672	50th Percentile	13
Mean Pb Conc. in Residential Dustc	mg/kg	2795	2225	Ratio	1018	75th Percentile	15
Mean Pb Diet Intake	µg/day	55	18	-5.7%	17	90th Percentile	17
Mean Pb Conc. in Water	µg/L	7	5	0.0%	5	95th Percentile	18

APPENDIX A

DISCUSSION OF LA OROYA BLOOD LEAD DATA QUALITY ISSUES

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MEMORANDUM

To:	Jose Mogrovejo, Doe Run Peru
From:	Craig Hutchings, Erica Lorenzen, Rosalind Schoof
Date:	May 7, 2008
Subject:	Discussion of La Oroya Blood Lead Data Quality Issues
Project No.:	C422-105

In November of 2007, Doe Run Peru contracted Blufstein Clinical Laboratory S.A. (Blufstein) to conduct blood lead testing in the communities surrounding the La Oroya Metallurgical Complex. In this study, blood was drawn from 1874 children between the ages of six months and nine years. One hundred and five pregnant women were also evaluated for blood lead at this time. After the blood was collected in La Oroya, it was immediately sent to Lima for analysis at Blufstein Laboratories.

The Centro Nacional de Salud Ocupacional y Protección del Ambiente para la Salud (CENSOPAS) of Peru raised a number of concerns about the results of the analysis performed by Blufstein. The report from CENSOPAS (2008) and responses from Blufstein (2008) were reviewed to determine the usability of the analytical results. While insufficient information is provided to reach a conclusion, the nature of the comments suggests that further review of the data may be of value to determine if the data is of sufficient quality for use in risk assessment.

CONCERNS RAISED BY CENSOPAS

Many of the findings of CENSOPAS were minor documentation deficiencies. These findings include out of date training records and organizational charting, inconsistent denominations of laboratory procedures, the laboratory Quality Manual and procedures referencing out of date laboratory procedures, laboratory procedures not providing enough specific detail on sample handling and instrument operation, lack of refrigerator temperature records, and incomplete sample receipt forms and instrument maintenance

logs. While these findings are unfortunate, they do not necessarily indicate data of poor quality. Deficiencies such as these could be found at nearly any laboratory as many laboratories are so focused on providing data of good quality that they do not manage to keep their records as up to date and complete as they should. Blufstein Clinical Laboratories should strive to correct these shortfalls, but they are insufficient reason to reject the use of the data.

Several of the findings by CENSOPAS are more troubling and do have direct bearing on the quality of the data. Questions concerning sample receipt and storage conditions, the use of a non-standard analytical method, expired calibration standards, and a lack of documentation concerning the analytical sequences must be fully answered in order accurately determine the quality of the data. These findings are discussed in greater detail below.

Sample Receipt and Storage Conditions

The laboratory Quality Manual and procedures specify inconsistent temperature ranges for sample storage, ranges of ≤ 4°C, approximately 4°C, 2 to 10°C, and 4 to 8°C are all given. Additionally, no information on sample preservation is provided. These deficiencies indicate poor attention to detail, however all indications are that the samples were kept refrigerated at <10°C. The concentration of lead in blood preserved with heparin is stable for up to 10 weeks, even when stored at room temperature (22°C) (Wang, 1985).

Documentation should be obtained to indicate that the samples were preserved with heparin, as is indicated in the laboratory procedure "Operational Instruction for the Taking and Transport of the Sample for Lead Analysis, HGA-900" (Blufstein, 2008). *If the samples were preserved with heparin, concerns regarding the impact of storage conditions on data quality would be greatly reduced.*

Non-Standard Method

The analytical method used by the laboratory is considered to be non-standard by CENSOPAS; however, the specific reason for this is not specified in the documents reviewed. Documentation of method validation was not available to CENSOPAS during the laboratory audit. The laboratory claims to employ a method provided by the instrument manufacturer, PerkinElmer, and that the instrument supplier, Cientifica Andina SAC, has documentation providing method validation. In addition, Blufstein indicates that method validation was performed in 2004.

The laboratory states they participated in an inter-laboratory study in September 2007, with acceptable results. Blufstein indicates documentation of the method validation and

the inter-laboratory study were provided to CENSOPAS; however, these documents unavailable for this review.

Documentation of the method validation studies, both from Perkin-Elmer and Blufstein, and the results of the inter-laboratory study should be obtained to provide evidence that the analytical method provides results of sufficient quality. *If this documentation can be provided, the comments of CENOPAS may be adequately addressed.*

Expired Calibration Standards

CENSOPAS noted that an expired lead standard was used in the analysis of 572 samples. These samples were re-analyzed by the laboratory with a current lead standard and Blufstein indicates there was good agreement between the results of the two analyses. CENSOPAS notes that the laboratory employed an "adequate reference material" for the initial analyses.

Documentation of the lead standard used for the re-analyses and results from the initial analyses should be compared to the re-analyses to determine the effect on data quality. As noted above lead concentrations in properly preserved blood have been shown to be stable for extended periods of time. *If the samples were preserved correctly and the re-analyses have acceptable calibration standards the data should be usable.*

Analytical Documentation

CENSOPAS noted that no documentation of the instrument performance before or during the analyses was available. This documentation is critical in evaluating the data quality as the performance of the calibration curve, calibration verification standards, and reference materials are necessary to evaluate the performance of the method. This documentation would also be useful in determining the validity of the analytical method and any effect the expired calibration standards may have had on the data. Additionally, no information on quality control analyses was provided with the data. The performance of laboratory blanks, blank and matrix spikes, and any other QC analyses performed are also necessary to evaluate the performance of the method.

Documentation of instrument performance and quality control samples should be obtained in order to evaluate instrumental operating conditions and method performance. This documentation should include, but is not limited to:

- Sample preparation worksheets
- Verification of the lead lamp energy and alignment
- Documentation of instrument and method detection limit studies

- Instrument run log
- Calibration curve and calibration verification performance
- Preparation and instrument blank data
- Reference material performance
- Laboratory duplicate performance
- Blank spike or laboratory control sample performance
- Matrix spike performance
- Method of standard additions data (if performed)

CONCLUSION

Many of the findings of CENSOPAS were minor documentation deficiencies, but four of the findings may have direct bearing on determining if the data are of adequate quality for use in risk assessment. It is possible that additional documentation could resolve the comments of CENOPAS. Documentation of sample preservation and storage, method validation, sample re-analyses, instrument performance, and quality control analyses should be obtained in order to more adequately evaluate the quality of the data.

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APPENDIX B

EVALUATION OF LA OROYA BLOOD LEAD DATA RELIABILITY FOR USE IN RISK ASSESSMENT

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MEMORANDUM

To:	Jose Mogrovejo, Doe Run Peru
From:	Craig Hutchings, Erica Lorenzen, Rosalind Schoof
Date:	July 17, 2008
Subject:	Evaluation of La Oroya Blood Lead Data Reliability for Use in Risk Assessment
Project No.:	C422-105

In November of 2007, Doe Run Peru contracted Blufstein Clinical Laboratory S.A. (Blufstein) to conduct blood lead testing in the communities surrounding the La Oroya Metallurgical Complex. As discussed in a previous memo (Integral, 2008), the Centro Nacional de Salud Ocupacional y Protección del Ambiente para lad Salud (CENSOPAS) expressed concerns over the quality of the data generated by Blufstein.

Briefly, the major concerns included: sample receipt and storage conditions, the use of a non-standard method, expired calibration standards, and a lack of analytical documentation. Since the writing of the last memo, Blufstein has submitted several documents to address these issues. These documents support the determination that the data is of sufficient quality for use in the risk assessment.

DISCUSSION OF BLUFSTEIN SUBMITTALS

In response to the request for more information regarding the methods, standards, and documentation used with the 2007 blood lead sampling in La Oroya, Blufstein submitted the following documents:

- Letter specifying the specifications of sample preservation
- Laboratory instructions regarding the taking and transport of blood lead samples in adherence with CDC lab procedure, 2004
- Letter detailing the use of the atomic absorption method and graphite furnace analysis

- Article on Graphite Furnace Analysis of Pb in Blood using continuous source background correction (Bosnak, 1993)
- Letters from Cientifica Andina certifying the analytical method of the atomic absorption technique and the alignment of the lamps used in the atomic absorption technique
- Memo regarding the validation method of the atomic absorption technique
- Comparison of 10 results from Blufstein with results from Specialty Labs (Table 1)
- A comparison of first and second samples taken in response to the discovery of an expired calibration standard (Table 2)
- Results of two quality control assessments by the College of American Pathologies
- Precision controls document
- Registration of instrument maintenance
- Calibration curves
- Certificate of verification of performance of Analyst 400, HGA900/AS800.

These documents were reviewed by Integral scientists, as described below.

Receipt and Storage Conditions

It had been noted by CENSOPAS that samples received in November and December of 2007 arrived at the laboratory at temperatures from 2°C to 10°C, indicating that samples may not have been preserved properly. Blufstein has submitted a letter from Q.F. Luz Rosana Medina Carrion indicating that all samples were taken in Vacutainer® tubes preserved with lithium heparin and stored at -20°C. Pages from a U.S. Centers for Disease Control and Prevention (CDC) laboratory procedure manual were also submitted indicating that whole blood samples for lead analysis are stable for several months at -20°C. As was noted in our previous memo, lead in heparin-preserved blood has been shown to be stable for up to 20 weeks at room temperature. Therefore, even if all samples arrived at the laboratory at 10°C there is no reason to doubt the veracity of the results.

The delivery of samples at >4°C is a deviation from the CDC procedure and Blufstein's SOPs, however this deviation has no affect on the analytical results.

Non-Standard Method

CENSOPAS stated that Blufstein employed an unvalidated non-standard method for the analysis, noting that under the stipulations outlined in "Guide to Carry Out Validation of Essay Methods" (Resolution Commission of Technical and Commercial Methods, 2003) methods from recognized publications or equipment manufacturers are considered to be unvalidated methods. In order for the method to be validated the veracity, precision, selectivity, linear range, detection and quantification limits, uncertainty, sensibility, and

robustness of the method must be evaluated. Furthermore, CENSOPAS noted that Blufstein had not demonstrated the technical competence to correctly apply the method and obtain technically valid, exact, and reliable results.

Blufstein has submitted an article from Atomic Spectroscopy that describes the method (Bosnak, 1993). Additionally, they have submitted a letter from the manager of operations and quality of Cientifica Andina S.A.C., the provider of the instrumentation, verifying that the method was validated in-house at the company headquarters. While this does not satisfy the referenced criteria for method validation, it does show that the method has been evaluated for veracity, precision, selectivity, linear range, detection and quantification limits, uncertainty, sensibility, and robustness of the method. Blufstein further addresses the following elements of method validation with the indicated submittals:

- **Veracity** – The results from two College of American Pathologists (CAP) interlaboratory studies from 2007 indicating satisfactory performance and a comparison of 10 samples analyzed by Blufstein and Specialty Laboratories of Valencia, California, USA is provided, showing good comparability between the two laboratories. The results of the analyses from Blufstein and Specialty Laboratories are summarized in Table 1, and are discussed below. Additionally, Blufstein submitted results from the analyses of reference materials, further demonstrating analytical accuracy.
- **Precision** – The results from a series of analyses over a period of one month are provided, indicating that the method provides acceptable precision using BIORAD reference materials at two levels (9.2 μg/dL and 26 μg/dL), with coefficients of variation for both levels being less than 10%.
- **Selectivity** – The above submittals for veracity and precision also demonstrate the selectivity of the method, confirming that the method is capable of discerning lead in a blood matrix.
- **Linear Range** – A demonstration of linearity is submitted indicating acceptable linearity to 100 μg/dL.
- **Uncertainty** – The above submittal for precision demonstrates that the employed method has an uncertainty less than 10%. Additionally, the submittals for Veracity demonstrate the uncertainty of the employed method is comparable to other methodologies.

- **Robustness** –The submitted interlaboratory studies and BIORAD reference materials indicate the method is robust as it delivers results comparable to other methods in blood samples from three different sources of blood: BIORAD reference material, the CAP interlaboratory study samples, and samples from the study in question.
- **Sensibility** – All of the above points demonstrate the ability of the employed method to adequately quantify levels of lead in blood, and thus it is sensible to use this method.

Blufstein did not submit any data to demonstrate the detection and quantification limits of the method, leaving potential uncertainty regarding the accuracy at low concentrations. However, two of the samples from the CAP interlaboratory studies and three of the samples analyzed by Specialty Laboratories have blood lead levels less than 5 μg/dL, well below typical levels found in LaOroya, and the method reference indicates a detection limit of 0.48 μg/dL.

The above indicates that Blufstein has demonstrated the technical competence to correctly apply the analytical method in question, obtaining technically valid, exact, and reliable results. Blufstein is working to further validate the analytical method and expects to have the process complete later this summer.

Expired Calibration Standard

CENSOPAS noted that an expired lead standard was used in the analysis of some of the samples. These samples were re-analyzed by the laboratory with a current lead standard and these data were reported. A comparison of the data from the first and second analyses is presented in Table 2. The results from both analyses agree well, further demonstrating the precision of the analytical method and the stability of the samples. As noted above, when properly preserved and stored at the laboratory sample stability is not an issue. As the samples were re-analyzed with acceptable standards there is no affect on data quality.

Analytical Documentation

CENSOPAS noted that there was no documentation of the instrument lamp alignment, lamp energy, calibration verification standards, or BIORAD reference materials. Blufstein has submitted reports from Cientifico Andina showing that routine instrument maintenance occurred in May 2008 and that all instruments were performing satisfactorily and no repairs were required. An instrument maintenance record was submitted, however, it only indicates that the operating conditions were acceptable. The lamp alignment and energy readings, calibration verification standards, and BIORAD reference

materials results are not recorded. Acceptance criteria for these parameters have not been provided, which was a criticism of CENSOPAS.

It is unfortunate that Blufstein does not record details of the instrument operating conditions on a daily basis. Revising the instrument maintenance log to record this information and indicate the acceptance criteria for the above parameters would prevent this issue from re-occurring. Blufstein has submitted control charts for the results of the BIORAD reference materials, Graficia de Control De Precision, indicating a good faith effort on their part to begin documenting the instrument operating conditions.

However, the absence of recorded operating conditions does not indicate that they are unacceptable. The results of the CAP interlaboratory studies, the comparison of Blufstein's data to that of Specialty Analytical, and the results of the BIORAD reference materials all demonstrate Blufstein's technical competence and the veracity of their results.

COMPARSIONS OF RESULTS

A comparison of results between Specialty Laboratories and Blufstein for 10 samples from November and December 2007 sampling are presented in Table 1. The CDC blood lead proficiency testing program considers results acceptable if they are within 6 μg/dL of the mean value for values less than 40 μg/dL, and within 15% of the mean for values greater than 40 μg/dL (OSHA, 2008). The mean results and differences from the mean are shown in the comparison, and all results are well within the acceptance limits. Additionally, Specialty Laboratories analyzed the samples in March 2008, providing further evidence of sample stability over several months.

The results of 180 samples that were re-analyzed by Blufstein following the discovery of the expired calibration standard are presented in Table 2. The data are compared using relative percent differences (RPD). Generally, a control limit of 20% is used in evaluating RPDs for metals data, however this control limit may be expanded to 35% depending on the matrix (USEPA 2004). Five (2.8%) of the 180 results have an RPD of greater than 20%, and only two (1.1%) results have an RPD of greater than 35%. These results demonstrate that the method has excellent precision between analytical batches and across a wide range of concentrations.

CONCLUSION

Blufstein has repeatedly demonstrated their ability to produce data comparable to that of other laboratories and has shown good faith efforts to address the issues raised by

CENSOPAS. While not all of the criticisms from CENSOPAS were answered by the most recent submissions by Blufstein, there is no reason to doubt the veracity of the data.

While Blufstein labs should strive to correct their documentation deficiencies and better document daily instrument performance, the data appear to be acceptable for its intended purpose.

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Table 1. Comparison of Results from Blufstein Laboratories and Specialty Laboratories

Code	Specialty Laboratories result ug/dL	Blufstein result ug/dL	Mean result ug/dL	Specialty Difference	Blufstein Difference
OAJ24568	22.3	21.59	21.9	0.4	0.4
MQO245676	2.6	2.46	2.5	0.1	0.1
FPA249807	9.8	9.66	9.7	0.1	0.1
CBC249808	39.2	33.41	36.3	2.9	2.9
CFW249809	44.4	38.9	41.7	2.8	2.8
CMA250661	4.2	2.84	3.5	0.7	0.7
RHJ250623	39.7	32.7	36.2	3.5	3.5
BSA250681	44.3	35.53	39.9	4.4	4.4
SCA250692	34.9	33.58	34.2	0.7	0.7
HIB250631	3.0	3.29	3.1	0.1	0.1

Table 2. Comparison of First and Second Assay Results

	Lead (µg/dL)		
Code	1st assay	2nd assay	RPD
CMD1921	6.732	6.919	2.7%
CMD3002	6.663	7.483	11.6%
CMD3003	16.283	17.070	4.7%
CMD3004	10.810	10.650	1.5%
CMD868	8.415	8.299	1.4%
CMD860	7.251	6.945	4.3%
CMD1862	6.713	6.856	2.1%
CMD3005	13.650	13.520	1.0%
CMD871	11.770	11.520	2.1%
CMD3007	6.812	6.117	10.8%
CMD858	4.615	4.497	2.6%
CMD3013	3.730	3.897	4.4%
CMD3009	5.142	5.583	8.2%
CMD3008	5.234	4.880	7.0%
CMD3017	6.337	6.348	0.2%
CMD3016	1.615	1.130	35.3%
CMDG435	2.690	2.072	26.0%
CMDG437	3.698	3.761	1.7%
CMD851	8.779	7.610	14.3%
CMDG434	1.196	1.055	12.5%
CMD3006	3.720	4.200	12.1%
CMD1858	6.642	6.917	4.1%
CMDG438	5.163	4.792	7.5%
CMD3019	7.183	6.603	8.4%
CMD3014	11.470	11.900	3.7%
CMD877	10.530	10.770	2.3%
CMD3018	17.090	17.040	0.3%
CMD852	10.340	9.166	12.0%
CMD1860	25.680	25.490	0.7%
CMD3022	7.283	6.065	18.2%
CMD1901	10.430	11.470	9.5%
CMDG436	3.345	4.473	28.9%
CMD3015	9.990	10.790	7.7%
CMD3024	20.390	19.800	2.9%
CMD3025	17.620	17.720	0.6%
CMD1875	12.310	12.370	0.5%
CMD3020	3.238	4.097	23.4%
CMD3023	18.170	20.020	9.7%
CMD1942	13.240	14.620	9.9%
CMDG439	5.368	6.073	12.3%
CONTROL	12.690	12.520	1.3%

Table 2. Comparison of First and Second Assay Results

	Lead (µg/dL)		
Code	1st assay	2nd assay	RPD
CMD3021	11.670	11.570	0.9%
CMD2137	22.250	23.160	4.0%
CMD2129	14.800	15.690	5.8%
CMD1846	9.680	8.801	9.5%
CMD875	8.648	8.440	2.4%
CMD876	23.230	22.670	2.4%
CMD1307	24.780	25.420	2.5%
CMD1020	19.670	19.540	0.7%
CMD1018	15.830	16.540	4.4%
CMD3010	33.610	33.420	0.6%
CMD3026	11.410	11.840	3.7%
CMD1927	16.250	16.540	1.8%
CMD1903	30.340	30.670	1.1%
CMD961	13.350	14.410	7.6%
CMD1905	18.740	19.630	4.6%
CMD1906	15.570	15.430	0.9%
CMD1844	25.840	25.290	2.2%
CMD1932	14.520	14.710	1.3%
CMD3027	8.340	8.487	1.7%
CMD3028	9.536	9.073	5.0%
CMDG440	10.100	10.830	7.0%
CMD3029	13.170	12.490	5.3%
CMD3030	20.450	21.350	4.3%
CMD1843	35.560	36.120	1.6%
CMD1229	50.590	51.370	1.5%
CDM864	18.470	17.530	5.2%
CMD850	22.280	23.070	3.5%
CMD1926	11.660	11.470	1.6%
CMD1873	9.804	10.370	5.6%
CMD3031	13.540	14.530	7.1%
CMD1841	46.500	44.400	4.6%
CMD1842	27.420	26.560	3.2%
CMD3034	22.760	23.330	2.5%
CMD3032	13.510	14.510	7.1%
CMD3033	20.720	21.440	3.4%
CMD3035	11.550	11.560	0.1%
CMD3011	11.320	11.990	5.7%
CMD3037	14.110	14.640	3.7%
CMD3036	9.274	9.132	1.5%
CMD818	21.460	21.620	0.7%
CMD3039	6.751	6.203	8.5%
CMD3038	8.549	8.324	2.7%
CMD1817	12.720	12.860	1.1%

Table 2. Comparison of First and Second Assay Results

	Lead (µg/dL)		
Code	1st assay	2nd assay	RPD
CMD3042	12.270	12.470	1.6%
CMD3041	6.157	6.477	5.1%
CMD3043	13.190	14.290	8.0%
CMD3040	17.360	16.510	5.0%
CMDG441	9.646	9.119	5.6%
CMD1493	24.720	24.750	0.1%
CMD3045	9.674	9.428	2.6%
CMD3044	11.540	11.730	1.6%
CMD827	10.690	10.050	6.2%
CMD3046	10.220	10.250	0.3%
CMD3047	15.290	15.450	1.0%
CMDG442	11.100	11.850	6.5%
CMD1487	17.120	17.310	1.1%
CMD1959	22.680	22.850	0.7%
CMD3049	39.770	39.580	0.5%
CMD1836	24.240	23.600	2.7%
CMD1835	21.540	21.780	1.1%
CMD831	14.370	15.190	5.5%
CMD3050	5.182	6.763	26.5%
CMD1822	37.380	36.550	2.2%
CMD3048	55.640	55.410	0.4%
CMD3051	16.470	14.490	12.8%
CMD3052	21.810	21.370	2.0%
CMD825	16.350	17.390	6.2%
CMD3053	29.510	28.620	3.1%
CMD1489	21.870	21.170	3.3%
CMD3055	19.560	20.590	5.1%
CMD2901	9.342	8.434	10.2%
CMD3054	13.230	12.710	4.0%
CMD1296	7.047	6.235	12.2%
CMDG443	7.408	8.538	14.2%
CMD2644	15.420	14.850	3.8%
CMD2257	12.950	13.370	3.2%
CMD2676	12.080	12.520	3.6%
CMD2522	19.080	19.280	1.0%
CMD2935	32.260	32.420	0.5%
CMD3056	2.463	2.416	1.9%
CMD2613	14.360	14.570	1.5%
CMD2562	20.600	21.570	4.6%
CMD3059	21.170	22.580	6.4%
CMD2692	15.970	16.820	5.2%
CMD3058	17.460	17.690	1.3%
CMD3057	5.197	5.775	10.5%

Table 2. Comparison of First and Second Assay Results

	Lead (µg/dL)		
Code	1st assay	2nd assay	RPD
CMD796	24.310	24.700	1.6%
CMD2539	26.270	26.240	0.1%
CMD3060	8.226	8.503	3.3%
CMD989	11.630	11.110	4.6%
CMD3061	20.620	12.500	49.0%
CMD2052	30.530	30.300	0.8%
CMD2709	10.470	10.090	3.7%
CMD2677	24.780	24.550	0.9%
CMD2672	28.370	28.440	0.2%
CMD1288	32.440	32.120	1.0%
CMD884	15.730	16.810	6.6%
CMD881	20.280	20.120	0.8%
CMDG444	5.919	5.224	12.5%
CMD171	32.630	32.760	0.4%
CMD2799	11.860	12.540	5.6%
CMD3064	13.330	12.660	5.2%
CMD2609	20.210	20.610	2.0%
CMDG446	5.323	4.853	9.2%
CMD2569	21.320	20.770	2.6%
CMDG445	10.130	9.461	6.8%
CMD2639	12.330	12.440	0.9%
CMD3063	18.760	19.200	2.3%
CMD2666	24.910	25.180	1.1%
PARTICULAR	3.312	2.385	32.5%
CMD2185	25.560	24.930	2.5%
CMD2667	21.370	21.840	2.2%
CMD3062	16.160	15.380	4.9%
CMD2927	23.800	23.050	3.2%
CMD3066	12.590	12.630	0.3%
CND3067	21.710	22.300	2.7%
CMDG447	6.760	6.603	2.3%
CMD3065	13.220	12.060	9.2%
CMD3068	21.580	21.520	0.3%
CMD2682	7.347	8.461	14.1%
CMD3069	7.422	8.284	11.0%
CMD2650	10.090	10.760	6.4%
CMD1436	19.700	19.590	0.6%
CMD2669	9.404	8.720	7.5%
CMD3070	27.780	27.700	0.3%
CMD3072	18.810	17.520	7.1%
CMD3071	9.803	9.520	2.9%
CMD3074	20.440	19.600	4.2%
CMD3075	17.450	18.540	6.1%

Table 2. Comparison of First and Second Assay Results

	Lead (µg/dL)		
Code	1st assay	2nd assay	RPD
CMD3073	8.993	8.751	2.7%
CMD2575	12.840	12.380	3.6%
CMD3076	13.750	13.690	0.4%
CMD3077	17.750	18.090	1.9%
CMD2576	18.820	18.790	0.2%
CMD3078	11.690	11.670	0.2%
CMD2605	25.540	25.280	1.0%
CMD3079	29.370	30.410	3.5%
CMD2574	42.720	41.550	2.8%
CMD2573	16.740	17.470	4.3%

Notes:
Relative percent difference = | (Result 1 – Result 2) / ((Result 1 + Result 2) / 2) | X 100

APPENDIX C

MORBIDITY AND MORTALITY OF WORKERS AT DOE RUN METALLURGICAL COMPLEX

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DRAFT MEMORANDUM

To:	Jose Mogrovejo and Jorge Miranda Doe Run Peru, Lima, Peru
From:	Rosalind Schoof and Erica Lorenzen
Date:	October 24, 2008
Subject:	Morbidity and mortality of workers at Doe Run Peru Metallurgical Complex in La Oroya, Peru
Project No.:	C422-0103

The Ministry of Energy and Mines has requested, as a supplement to the Complementary Risk Assessment (Integral 2008), a review and analysis of worker morbidity and mortality at the Doe Run Peru (DRP) Metallurgical Complex in La Oroya, Peru. Specifically, the Terms of Reference (TOR) of the 2008 complementary risk assessment in La Oroya stated that DRP must assess Complex workers' health, mortality, morbidity conditions, and causes of death. To this end, DRP provided Integral Consulting (Integral) with several sources of health information. These data are described below and relevant trends in morbidity are assessed. Although not specified in the TOR, Integral has focused on whether the available data provide information that could be used to assess the effects of worker exposures to smelter-related chemicals on health. In addition, available biomonitoring data on arsenic, cadmium, and lead levels in workers are described. Injuries such as back pain and musculoskeletal strains are noted and may be the result of occupational hazard, but they are not the focus of this review.

HEALTH DATA REVIEW

There are two main sources of health data for workers employed by DRP in La Oroya: clinical data collected by local healthcare facilities and annual exam data collected by DRP. Essalud, the government health service, provides medical services to DRP workers who have health concerns resulting in time away from work. The most common pathologies seen in the Essalud clinic have been provided to Integral. Similarly, data

from a clinic located in Chulec, a facility where managerial staff and their families go for routine medical care, have been provided. Due to confidentiality concerns (Law no. 28841), these data are tabulated by visit rather than by patient and are categorized in very unspecific terms. Consequently, these data give only a general sense of common complaints among workers at the Complex, and do not provide a context for how many workers become ill or how illnesses are distributed among job categories.

DRP conducts mandatory annual physical examinations for all workers as well as biannual metals monitoring for exposed workers. The data from annual examinations are described below and trends in morbidity among workers are highlighted. The metals monitoring data are also reviewed for insights to possible causes of disease.

Mortality of workers, including cause of death and area of work, is recorded by social services (Servicio Social). The data from 2005 to 2007 were provided to Integral and are discussed below.

In many cases, the categories of morbidity used by the clinics were not sufficiently detailed to allow Integral to make determinations regarding the cause of illnesses. For example, the category of respiratory illness is likely to primarily reflect infectious diseases such as colds and influenza, rather than respiratory disease related to working at the smelter. While it is possible that occupational exposures (both chemical and physical) have contributed to worker morbidity, other unrelated factors such as genetics, lifestyle habits, and underlying infections may all be significant contributors to ill health. In the absence of more comprehensive information from patient records regarding diagnoses as well as comparative data from an unexposed population, accurate causal determinations are not possible.

CLINIC VISITS

As noted above, Essalud provides general statistics regarding visits to the clinic for ailments that result in sick leave. In the fiscal year 2007, Essalud recorded 1,104 such visits. The reason for the visit is recorded by one of 12 general diagnostic categories; the full list of conditions diagnosed by Essalud is shown in Table 1. Of the 1,104 visits, 22 percent were recorded as back pain or injury. Lesions to extremities were the second most common cause, accounting for 18 percent of all visits. All other recorded illnesses and pathologies accounted for less than 10 percent each of the total. Data from 2002 to 2007 show a consistent pattern of back injury and injuries to the extremities accounting for approximately 40 percent of all visits. However, it is worth noting that many of these could be repeat visits by the same individual seeking treatment for a chronic condition; the data do not reflect incidence or prevalence of any particular condition.

At the Chulec clinic, which provides services to management staff at the Complex, the reason for the visit is also recorded as one of 12 categories (Table 2), but the categories are not the same as those used by Essalud. The dominant reason for a visit was upper respiratory illness. In 2007, 158 visits were reported, 41 percent of which were for respiratory concerns. The second most common visit was related to cholesterol disorders, accounting for 14 percent of all consultations. These visits were not necessarily related to missing time from work. It is important to note that there is no consistency in reporting between the Essalud clinic and the Chulec clinic; it is not known whether the same complaint would be similarly diagnosed and recorded at each clinic.

ANNUAL EXAM RESULTS

In 2007, 2,759 workers were evaluated in a complete physical examination: 2,100 were on the regular payroll at DRP, 615 were contract employees, and 44 were involved in a DRP training program. Of all individuals evaluated, 678 (25 percent) were diagnosed with some form of illness or injury. The number and percentage of employees with each diagnosis are listed in one of 15 categories, only some of which are the same as the categories used by Essalud (Table 3). The most common diagnosed illness was respiratory illness, with 182 workers identified. For respiratory illnesses, additional detail is provided regarding the nature of the observed pathology. Of those 182 cases, 79 were diagnosed as a common cold; an additional 46 workers of this group were diagnosed with a sore throat. All but seven of the cases in this category were acute conditions. Chronic conditions included laryngitis, sinusitis, pharyngitis, pleural effusion, and sequelae to tuberculosis. The second most common ailment was digestive disturbance, with diagnoses for 78 workers, followed by infections and parasites found in 71 workers. Two workers were found to have cancer in the year 2007. Both were diagnosed with prostate cancer; one was age 64 and worked in logistics, the other was age 61 and worked on the railroad.

METALS MONITORING

Since 1997, DRP has monitored blood lead levels and urinary cadmium and arsenic levels of selected groups of employees. Blood lead levels were tested in many employees, whereas much smaller groups of employees were considered to be potentially exposed to arsenic and cadmium, and therefore tested. Monitoring occurs twice yearly in April and October and results are tabulated with regard to exposure and area of work.

Lead

There is a clear reduction in blood lead levels since 1997; the average level of exposed workers in 1997 was 51 μg/dL and the average in 2007 was 32 μg/dL. In the second half of 2007, blood lead levels were taken for 1,139 workers. Among exposed workers, the highest blood lead levels occurred in mechanical maintenance workers. The average level among these 100 workers during the second half of 2007 was 41 μg/dL, with two workers having levels that exceeded 59 μg/dL. The 149 workers in the lead smelter had an average blood lead level of 34 μg/dL, also with two workers exceeding 59 μg/dL. The lowest blood lead levels among exposed workers were found in the security staff. Among the four security guards, the average level for the second half of 2007 was 17 μg/dL. Women employed by DRP work in positions that are considered "non-exposed." The average blood lead level of the 80 women who were tested was 10 μg/dL; five women had blood lead levels between 20 and 29 μg/dL, and 31 had levels between 10 and 19 μg/dL. The remaining 44 women all had levels below 10 μg/dL.

Arsenic

There are five work areas from which workers are selected to be tested for arsenic: the central cottrell, maintenance of buildings and grounds, mechanical maintenance, short rotary furnace, and the copper and arsenic toasters. In 2007, 178 workers were tested in the first semester and 175 in the second; the average urinary arsenic values were 83 μg/L and 97 μg/L, respectively. Table 4 lists the number of workers in each work area that were tested during each semester and a mean concentration for each category of worker. In both samples, the maintenance mechanics for the arsenic plants had the highest average concentrations. For these 21 men, the average was 94 μg/L in the first semester and 122 μg/L in the second. In both the first and second tests of 2007, six men had levels between 250 μg/L and 350 μg/L. There were no samples that exceeded 350 μg/L. DRP references a maximum permissible value of 400 μg/L (DS 03-94-EM). The United States Centers for Disease Control and Prevention (CDC) has used a reference level for total arsenic in urine of 50 μg/L, noting that a level between 50 μg/L and 200 μg/L should be monitored by a physician but does not necessarily present a health risk (CDC 2006).

It is important to note that because inorganic arsenic occurs naturally in the environment; all humans are exposed at low doses. Exposure can occur through the diet (particularly seafood), drinking water, tobacco smoke, and herbal medicines. Arsenic also occurs in seafood in a number of organic forms that are generally nontoxic. The organic arsenic concentrations in fish are high and can lead to very high urine arsenic measurements for a few days after consuming a fish meal. It is important to identify the contribution of inorganic arsenic to the arsenic measured in urine before drawing conclusions about the source and risks of exposure.

Cadmium

Urinary cadmium reflects integrated exposure over time and total body burden. Urinary cadmium levels do not rise significantly after acute exposure and are not useful for testing in the acute setting. Since 2002, levels of urinary cadmium in DRP exposed workers have declined and stabilized at an average level of 5 μg/L. There are five work areas from which workers are selected to be tested for urinary cadmium: the central Cottrell, leaching ZRP, maintenance of the cadmium mechanical plants, cadmium plant, and short rotary furnace. In 2007, 91 workers were tested in the first semester and 73 in the second. The overall averages were 4.3 μg/L and 4.8 μg/L, respectively. The highest levels occur for workers in the leaching area and in the cadmium plant. In the latter half of 2007, three workers in the cadmium plant had urinary cadmium levels above 20 μg/L, which is considered the maximum permissible limit in Peru (DS 03-94-EM). Table 5 lists the number of workers in each area that were tested during each semester and the mean concentration for each category of worker.

It is standard practice in occupational medicine to normalize cadmium levels to creatinine excretion. Since there can be large variations of urine volume output rate both between individuals and in a given individual during a day, normalizing results to creatinine levels yields more reliable estimates of exposure. The United States Department of Labor Occupational Safety and Health Administration has an acceptable upper limit for cadmium in urine of 3 μg/g creatinine (29 CFR 1910.1027). The World Health Organization (WHO) standard for urinary cadmium is 5 μg/g creatinine (WHO 1999).

While creatinine-normalized concentrations are generally similar to directly measured concentrations, there is some variability. For example, if the creatinine concentration is measured at 1 g/L, the corrected value would be the same as the μg/L values reported above. However, WHO defines a range of normal urinary creatinine levels between 0.3 g/L to 3 g/L (Barr et al. 2006). Thus, use of creatinine corrected values would be expected to improve the accuracy of estimating exposure in the worker populations.

MORTALITY OF WORKERS

Between 2005 and 2007, only nine deaths were recorded for workers at the Complex. Given the small data set, there are no apparent trends in cause of death. All workers were stationed in different areas of the Complex, and in all cases, the cause of death was not immediately related to the work at hand. The year, area of work, and cause of death are shown in Table 6.

CONCLUSIONS AND RECOMMENDATIONS

Integral was provided with limited data describing morbidity and mortality of workers at DRP Metallurgical Complex in La Oroya. There does not appear to be a clear pattern of work-related morbidity or mortality. However, without more comprehensive data, it is impossible to know if workers are experiencing illnesses or injuries that they would not otherwise experience or getting sick more frequently than would otherwise be expected. Deaths and cancer cases appear to be unrelated to occupational hazard. It is worth noting that cancer incidence is tied closely to lifespan; as longevity increases in the community of La Oroya, cancer rates will likely increase as well, regardless of changes in exposure. This trend is already evident in Peru as a whole and is a natural consequence of demographic transition.

The metals monitoring program provides important information with regard to exposure and should be continued. It is important that all individuals who are highly exposed to a particular metal be tested. To ensure this occurs, it may be prudent for DRP to screen periodically a broader range of individuals. We also have the following specific recommendations:

- In order to conform to international standards for evaluating exposure, we recommend that DRP measure urine creatinine concentrations and report creatinine corrected urine cadmium levels. This would ensure a more reliable estimate of exposure and enable comparisons to other occupational data.
- DRP should also consider the influence of fish and shellfish consumption on total arsenic concentration in the urine. At the time the sample is taken, each worker should be asked if he or she has consumed any fish or shellfish (including canned foods or soups) during the prior 3 days. As noted above, the CDC level of concern of 50 μg/L for total urine arsenic, but they indicate that levels between 50 μg/L and 200 μg/L may not present a health risk. Considering that most of the workers tested exceeded the 50 μg/L level of concern, we recommend that DRP focus on workers with levels above 200 μg/L. We also recommend that any workers exceeding 200 μg/L be retested at a time when they have not consumed any seafood for the prior 3 days to see if the elevated concentration persists.
- Retesting and medical follow-up are advised for those individuals that have blood lead or urinary arsenic and cadmium concentrations above the respective levels of concern.

If a more comprehensive surveillance and medical monitoring program is desired, DRP should work with an industrial hygienist to develop a program that is specifically focused on identifying and tracking occupational illness and injury. This would require more

detailed reporting of health concerns as well as categorical monitoring of anticipated occupational exposures and associated outcomes.

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TABLES[1]

Table 1. Visits to Essalud for illness requiring time away from work (2007)

Pathology	No.	%
Back pain	244	22
Injuries to extremities	196	18
Digestive illness	104	9
Surgery	103	9
Strains and sprains	90	8
Injuries to other body parts	87	8
Respiratory illness	83	7
Follow-up in Lima or Huancayo	27	2
Headache	27	2
Dental issues	24	2
Eye-related	11	1
Other	108	10

Table 2. Visits to Chulec clinic (2007)

Pathology	No.	%
Upper respiratory illness	65	41
Cholesterol metabolism	22	14
Intestinal infection	11	7
Diabetes	11	7
Urticaria	6	4
Obesity	6	4
Urinary tract infection	5	3
Hypertension	5	3
Vertigo	3	2
Osteoarthritis	3	2
Menopause	3	2
Other	17	10

[1] All data in tables was provided to Integral by Doe Run Peru. May 12, 2008.

Table 3. Worker pathologies detected in DRP annual exam (2007)

Pathology	No.	%
Respiratory	182	27
Digestive	78	12
Infections and parasites	71	11
Musculoskeletal injury	65	10
Altitude	44	6
Eye-related	31	5
Hypertension	30	4
Skin-related	28	4
Headache	26	4
Varicose veins	20	3
Cuts and contusions	17	2
Obesity	16	2
Dental	12	2
Fever	12	2
Other	45	7

Table 4. Arsenic concentration in urine of exposed workers based on bi-annual monitoring (2007)

	Semester 1		Semester 2	
Area of work	No. of workers	Mean concentration (μg/L)	No. of workers	Mean concentration (μg/L)
Central cottrell	12	73.8	11	50.1
Maintenance of buildings and grounds	14	64.9	14	92.1
Mechanical maintenance	21	93.9	21	121.7
Short rotary furnace	17	77.2	15	81.3
Copper and arsenic toasters	114	85	114	100
Total	178	82.9	175	97.3

Table 5. Cadmium concentration in urine of exposed workers based on bi-annual monitoring (2007)

	Semester 1		Semester 2	
Area of work	No. of workers	Mean concentration (μg/L)	No. of workers	Mean concentration (μg/L)
Central cottrell	11	1.48	11	1.87
Leaching ZRP	10	7.61	10	6.16
Maintenance of cadmium plants	9	1.93	9	2.07
Cadmium plant	28	3.89	28	7.66
Short rotary furnace	15	1.72	15	2.54
Total	73	3.35	73	4.84

Table 6. Worker cause of death (2005–2007)

Year	Area of work	Cause of death
2007	Logistics	Liver cirrhosis
2007	Zinc circuit	Stroke
2007	Lead circuit	Murdered in the street
2007	Laundry	Stroke
2006	Administration	Sudden death
2006	Maintenance	Cardiomyopathy
2005	Railroad	Pneumonia
2005	Projects	Sepsis
2005	Maintenance	Cancer

Exhibit D

Expert Comments on the Exceptional Fulfillment Extension Request for the Sulfuric Acid Plant Project of La Oroya Metallurgical Complex PAMA. Report to J. Bonelli Arenas, Dirección General de Asuntos Ambientales Mineros. Prepared by Scott Clark, Eric Partelpoeg, and James Young. May 10, 2006.

May 12, 2006

Dirección General de Asuntos Ambientales Mineros
Julio Bonelli Arenas
Av. Las Artes 260
San Borja
Lima 41- Peru

Dear Mr. Bonelli:

Enclosed are two signed copies of our report that provides our opinions and recommendations regarding the PAMA extension request of DRP for their La Oroya metallurgical complex.

We believe that this independent assessment of the La Oroya issues will help MEM and DRP to work out a solution that is fair to all parties and lead to a safe environment to the residents of La Oroya. We have enjoyed working with you and your professional staff and look forward to future opportunities where we can be of assistance.

Best regards,

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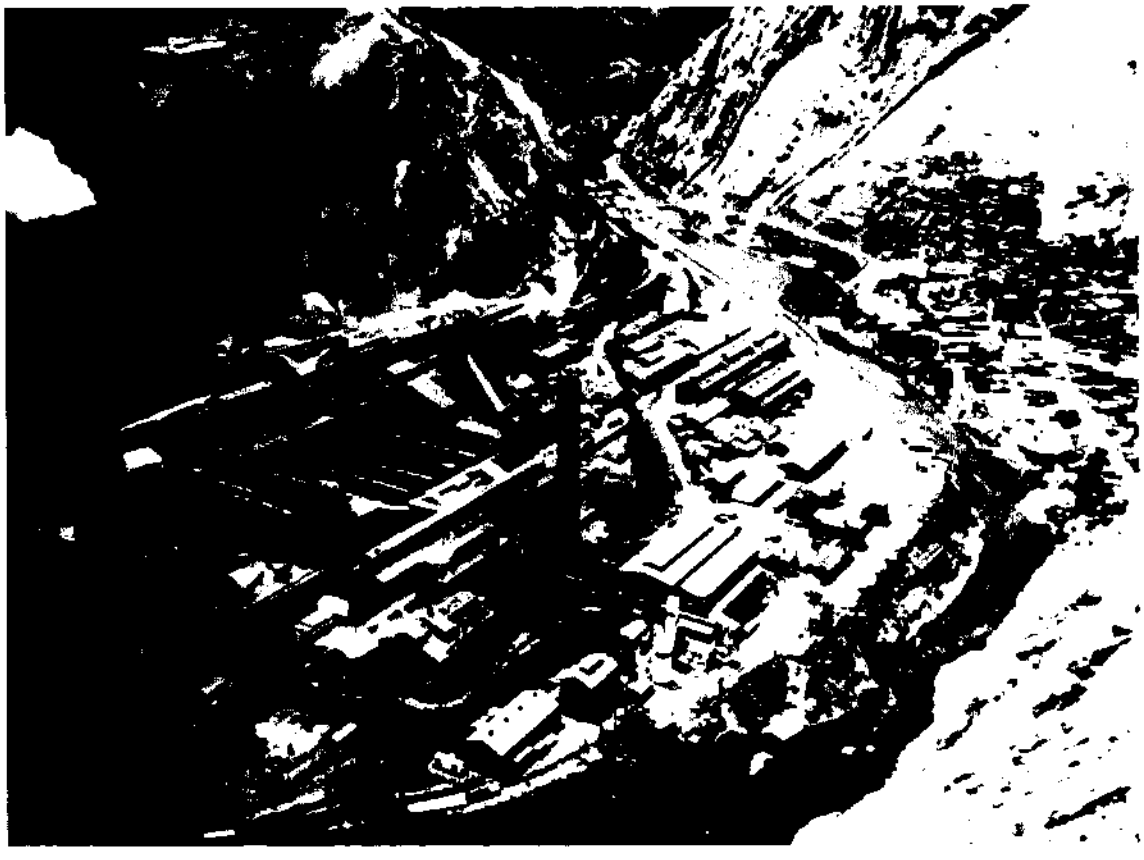
Expert Comments on Exceptional Fulfillment Extension Request for the Sulfuric Acid Plant Project of La Oroya Metallurgical Complex

May 10, 2006



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DISCLAIMER

This report is based on the best information available to the Panel of Experts within the time constraints, budget and terms of reference of the review. The material in it reflects the Panel of Expert's best judgement in light of the information available to it at the time of preparation. Specifically, it is based on information supplied by site representatives, a review of reports, examination of data records and a visual inspection of the facility and the surrounding area. The Panel of Experts has prepared this report using information understood to be factual and correct and shall not be responsible for conditions arising from information or facts which were not fully disclosed to the Panel of Experts by site representatives, or for conditions which can only be confirmed through sampling or monitoring.

This report was prepared by the Panel of Experts for the Ministry of Energy and Mines, Peru to aid in their decision-making with respect to an Exceptional Extension Request for the Sulfuric Acid Plants project of La Oroya Metallurgical Complex PAMA. Any use of, or reliance or decision based on this report by any third party is the sole and exclusive responsibility of such third party. The Panel of Experts accepts no responsibility for damages, if any, suffered by any third party as a result of the use of, or reliance or decision based on, this report.

Dr. Scott Clark | Dr. Eric Partelpoeg | Dr. James W.S. Young

1.0 INTRODUCTION

Doe Run Peru (DRP) has requested an Exceptional Fulfillment Extension Request for the Sulfuric Acid Plants project of La Oroya Metallurgical Complex PAMA. In order to help The Government of Peru (in particular the Ministry of Energy and Mines,--MEM) assembled the following panel of experts to assist the Ministry of Mines with their evaluation:

1. Dr. Scott Clark is Professor of Environmental Health at the University of Cincinnati, where he is Director of the Division of Occupational and Environmental Hygiene in the Department of Environmental Health. He received his PhD from the Johns Hopkins University. He has over thirty years experience as part of a team conducting environmental health studies of children exposed to lead. These studies have resulted in an increase in the understanding of the direct and indirect pathways though which children are exposed. The primary sources of exposure in these studies have been: (a) lead-based paint related, (b) mining related and (c) combinations of the two. His research has also involved in the evaluation of interventions aimed at reducing exposure to lead-contaminated soil and dust (exterior and interior) and to lead-based paint. He has also performed research in the use of field-based portable X-Ray Fluorescence Analyzers for determining lead levels in air, dust, soil and paint. His studies have been conducted in a number of countries in addition to the U.S., including Poland, India and Malaysia. He has also provided advice to the Community Task Force in Trail, British Columbia as they were developing their strategies for reducing exposures to past and present emissions from a lead/zinc smelter and to the Herculaneum Focus Meeting in Herculaneum, Missouri to assist them in evaluating data developed as part of efforts to reduce exposure to releases associated with the Doe Run smelter located there.
2. Dr. Eric Partelpoeg received his Ph.D from the University of Arizona. His smelter experience includes direct operations involvement in smelters in Finland, Canada, and the United States. He has participated in smelter

projects in Australia, Asia (China, India, and Thailand), Africa, Europe, and South America (Brazil, Chile, and Peru). His pollution control experience includes project design, management, and construction of baghouses, electrostatic precipitators, scrubbers, and sulfuric acid plants.

3. Dr. James. W.S. Young has more than 34 years of experience in the direction and management of atmospheric research and its application in the areas of acid rain, toxic chemicals, climate change, emergency response, weather forecasting and the development of policy. He has an international reputation in air quality and has developed and directed strategic planning exercises for Environment Canada. He has represented Canada on international scientific panels, lectured at the University level, and given expert testimony before hearing boards and government committees. He is the author of over 100 scientific and applied papers and articles. A graduate of Queens University, he received his Ph.D. in Mechanical Engineering from the University of Waterloo. He is a member of the Association of Professional Engineers of Ontario and past President and member of CMOS (the Canadian Meteorological and Oceanographic Society). Dr. Young has extensive experience in liaising with government departments at all levels, other nations, international organizations as well as with industry, universities and the private sector. With respect to air quality modeling and meteorology, he directed all of the SENES air quality modeling projects from 1990 to 2003 and he teaches an Air Pollution Meteorology and Modeling Course to government and industry practitioners nationally and internationally (he has specifically trained 140 people in Peru over two years). He directed an acid rain modeling study and a mixing height climatology study that produced a new climatology for North America as well as analyzed the methodology and updated it to be more physically correct. Finally he is part of the team that developed the FReSH-4 Weather Forecasting System and FReSH Air (FReSH-4 linked with CALMET/CALPUFF) that is being used for process control by one major mining company in Canada (Inco).

This report is based on an April 10-12, 2006 site visit to the La Oroya Metallurgical Complex and the nearby area and a review of relevant data and documents that were provided during and subsequent to the site visit. A few documents were provided one week in advance of the site visit. This tight schedule (the final report was issued April xx, 2006) precludes the possibility of comprehensive, in-depth analysis of every issue associated with the task and all documents relating to it. This caveat notwithstanding, the authors believe that the opinions and recommendations would be sustained even if more time was allowed for the evaluation. The authors have made a good faith effort to request the appropriate documents from DPR from which to develop the opinions and recommendations in this report. DPR was forthcoming with most requests. The accuracy of opinions and recommendations of this report assume that there are no significant documents that were either not requested or not provided.

Dr. James W. S. Young was asked to evaluate the validity of the air quality dispersion model produced input concentrations to the human health risk assessment study. The dispersion model used was the CALPUFF model, run by McVehil-Monnett Associates Inc. in support of the DRP submission.

Dr. Young was asked to address the following specific items:

1. Evaluate the grade of exposure and air contaminants acceptable level in the city of La Oroya and its surroundings, taking into account the estimated emissions though the air quality dispersion model presented in the request file;
2. To give his opinion related to the air quality and emissions monitoring program, that includes the correct location of the air quality and emissions monitoring stations, procedures on the calibration of the equipments, etc.;
3. Analyze the impact of the environmental mitigation measures that DRP suggests, in order to reduce the particulate matter emissions from the stacks and the fugitive emissions;

4. Analyze the influence of the concentrations of historical lead on La Oroya's air quality and its surroundings;
5. Analyze how meteorological characteristics and climatic effects influence the dispersion of contaminants;
6. Formulate recommendations to avoid greater contaminant concentrations in La Oroya's atmosphere during thermal inversion periods;
7. Recommend the measures and environmental studies that should be required by DRP, that might improve air quality in La Oroya and provide input to the assessment of progress in the people's health risk reduction; and
8. Make any other recommendation that he believes are relevant to the scope.

Dr. Scott Clark was asked to review specific studies, such as the one of human health risk assessment prepared by Integral Consulting Inc. using inputs from the dispersion model.

Dr. Clark was asked to address the following specific items:

1. Human Health Risk Assessment Study. Evaluate and give his opinion about the human health risk assessment study prepared by Integral Consulting and presented by Doe Run Peru. (DRP).
2. Exposure Evaluation. Evaluate the exposures to heavy metals (lead, arsenic, cadmium and others) and to sulfur dioxide (SO_2) in the City of La Oroya and surroundings after the year 2006, taking into account the estimated emissions from the air quality dispersion model presented by DRP in the file for the present application for the extension.
3. Prevention and Mitigation Measures. Propose the prevention and mitigation measures and recommendations in order to not affect human health by the effect of the concentrations of air contaminants arising from the estimated emissions of the operation of the Metallurgical Complex of La Oroya during the period of extension of the "Sulfuric Acid Plants " project.

4. Standards for Metal Concentrations in Soil. Evaluate the acceptable levels of metal concentrations in soil, according to international standards, proposing recommendations in order to reduce human health risks coming from this contamination source.
5. Additional Environmental Studies Needed. Recommend the measures and environmental studies that should be required to DRP, so as to reduce human health risks for exposure to air contaminants that will allow improving the air quality in La Oroya and assess the reached progress in the people's health risk reduction.
6. Make any other recommendation that he believes are relevant to the scope.

Dr. Partelpoeg was asked to address the following specific items:

1. Review the technology used in the copper, lead and zinc circuits, with particular attention to the impact of the technology on emissions and the level of ease / difficulty associated with controlling these emissions.
2. Analyze the copper and lead pyrometallurgical production circuits, in order to evaluate the existing measures and propose additional measures for the management/elimination of recirculating flows (particularly fine dusts) in those production circuits.
3. Analyze the copper and lead pyrometallurgical production circuits, in order to evaluate the existing measures and propose additional measures for the reduction of fugitive emissions and emissions from the stack in the copper, lead and zinc production circuits, which include, among other aspects: design and efficiency of the baghouses, electrostatic precipitator units, and the collection of the gases collected into theses systems.
4. Review and comment on the DRP execution plans to reduce fugitive emissions, including a review of the investment and task execution schedules.
5. Review and comment on the copper pyrometallurgical upgrade project, with particular focus on minimization of project schedule while maximizing SO_2 collection efficiency.

6. Review and comment on the sulfuric acid production processes of the lead and copper circuits.
7. Evaluate the project schedule for the implementation of the proposed lead circuit's sulfuric acid plant. Offer suggestions to improve the schedule, if possible.
8. Evaluate the execution deadline for each of the activities proposed for the modernization and implementation of the copper circuit's sulfuric acid plant, which include the monthly investment schedules and tasks execution schedules. Offer suggestions to improve the schedule, if possible.
9. Analyze and propose reorganizations in the Environmental Management Program and Contingency Program for the operation and maintenance of the different systems and equipments to be implemented.
10. Make any other recommendations that are relevant to the project.

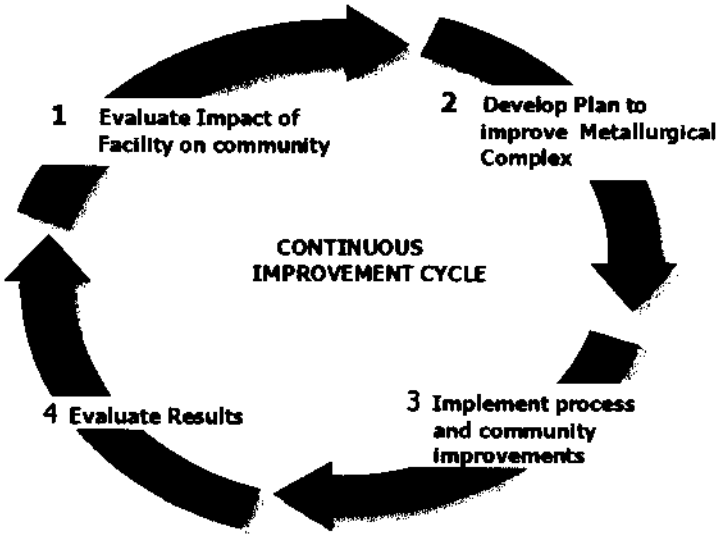
2.0 DESCRIPTION OF VISIT AND INFORMATION RECEIVED

Details of the actual activities undertaken by each expert are presented in their individual appendices. In general terms the following types of activities were undertaken:

- review of documents;
- discussion with Doe Run staff and their consultants;
- review of plans and data (emissions, air concentrations, meteorology, blood lead levels, etc.);
- visit the communities;
- visit the monitoring locations;
- independent calculations and spot checks;
- discussions with other members of the expert review team;
- discussions with MEM staff;
- detailed discussions with specific Doe Run Staff and followup with them regarding outstanding information requests;
- visits to various parts of the Doe Run Peru Facility in La Oroya to become familiar with the processes and the complex nature of the area;
- meeting with staff from other agencies active in the La Oroya area; and
- attending a press conference chaired by MEM.

3.0 PERSPECTIVE OF SMELTER MODERNIZATION PROJECTS

In Section 5.1 of this report the goal of continuous improvement at La Oroya is discussed. Historically the decrease in emissions at other smelters has been a consequence of continuous improvement as depicted below and should involve all stakeholders.



Based on community needs (Step 1), smelters respond by developing a plan to mitigate environmental issues (Step 2). The plan is implemented (Step 3) and the results are evaluated (Step 4). With continuous improvement, the cycle is repeated until emissions and health effects reach standards that are acceptable to the community. The timeline for these cycles varies. For some health related items, such as improved cleaning procedures, cycle times can be measured in weeks or a few months. The time the smelter begins a program to develop an improvement plan to the time that a single cycle is complete is measured in years. For metallurgical process plant improvements, following are typical time frames for steps 2-3 (since the health effects of high emissions have already been determined for the case of La Oroya).

1. Develop plan for improvement which include the following steps:

    a. Scoping level studies to quantify smelter operating parameters, 1-2 years. These studies will determine base operating parameters in the smelter as well as developing a "short-list" of acceptable technologies for the process changes.

b. Prefeasibility and feasibility studies. These are required to obtain +/- 15% cost estimates to secure funding as well as to develop the design criteria essential for detail engineering. The time required for pre-feasibility and feasibility studies is in the range of 1 year.

2. Project Implementation

a. Detail engineering. This phase of the project (typically one year) clearly defines the process design conditions. During this phase of the project all engineering drawings are developed and equipment specifications are written to enable the purchase of equipments.

b. Procurement (purchasing). This phase of the project includes:

i. Issuing requests for quotations to suppliers of equipment (much of this effort can be done concurrently with detail engineering).

ii. Waiting for suppliers to respond to the requests. For complex turn-key systems (for example sulfuric acid plants), vendors required 2-3 months to develop competitive bids.

iii. Bid analysis (two weeks is required for complex systems).

iv. Final contract negotiations (often one month is required to agree to all terms and conditions).

v. Delivery of equipment (1-1.5 years for complex equipment, the upper end of this range is appropriate to use during periods of economic expansion (such as 2005-2006) as fabrication shops are busy.

c. Construction. This phase of the project can require up to 1-1.5 years and includes:

i. Site work (civil and concrete)

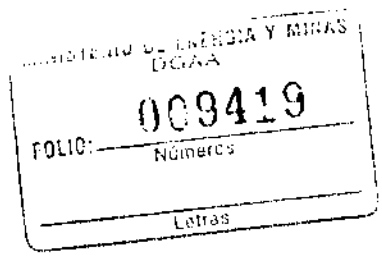
ii. Structural steel and setting equipment in place

iii. Installing piping, instrumentation and electrical power to the equipment

iv. Installing support utilities for the process as required (for example cooling water systems, pressurized air)

d. Commissioning and start-up. For complex operations, equipment commissioning and start-up typically requires a period of several months.

The total of all activities shown above is in the range of five years. Fast-track projects can be accomplished more quickly as some, but not all activities can be ongoing concurrently.



4.0 RESPONSES TO KEY QUESTIONS

In addition to the specific questions posed to the panel (Section 1.0) MEM requested that the authors comment on the following specific items:

1. The panel's general impression of DRP from experiences during our visit.
2. Whether the PAMA extension will solve the problems in La Oroya.
3. What is the minimum time required to execute the PAMA extension projects?
4. What complementary programs should DRP consider to minimize the ambient impact?
5. What community programs are recommended to mitigate the effects of lead and other contaminants, from current and previous smelter operations, in the shortest possible time?

These items are discussed below.

4.1 THE PANEL'S GENERAL IMPRESSION OF DRP

For the most part, the panel's efforts resulted in dispersal of the team to different areas of the DRP and the community. Partelpoeg focused on operating areas and the DRP project team, Young focused the DRP team responsible for monitoring stack emissions, doing modeling, monitoring the air quality and the meteorology, and Clark dedicated most of his time either in the La Oroya community or with DRP personnel in the health and environment departments.

Partelpoeg and Young had all of their questions answered and were provided detailed analysis on request. This cooperation continued after the site visit. All requested information was supplied if it was available. Clark had most of his questions addressed, both during and after the visit, but a key person involved in the DRP-MINSA agreement projects was not available during his visit.

Most of the resources of the MINSA-DRP agreement activities were devoted to the support of staff involved in the program and little to other resources needed for

actual mitigation of hazards, particularly in the environments of children with dangerously elevated blood lead in the highest categories: above 69 µg/dL and those 45-69 µg/dL. Many streets and sidewalks appeared to be either missed by the mechanical or manual wet cleaning methods or were not cleaned often enough by them. No soil remediation activities were observed in the community and no efforts to make permanent improvements in housing were evident. A number of the DRP community efforts appeared to be focused on overall regional improvement such as the improvement of pastures, animal husbandry and the development of new dairy products.

4.2 PAMA EXTENSION / LA OROYA PROBLEM RESOLUTION

It is the opinion of the panel that granting the PAMA extension and implementing the DRP process improvement programs will not, by themselves be sufficient to resolve the La Oroya region community health problems. That being said, the ongoing program to decrease fugitive emissions from the smelter is an important step towards long term resolution of the lead issues and the installation of the lead and copper circuit acid plants will be a significant move towards reducing SO_2 levels in the community. Some immediate efforts need to be made to protect the health of children already having dangerously elevated blood lead levels, such as through the provision of temporary lead-safe housing, and to minimize the likelihood of other children who reach such levels in the future.

As in most major undertakings of this type, there is a need for continuous improvement and review. This is especially true in La Oroya as a result of the over 80 years of uncontrolled emissions creating heavy metal reservoirs throughout the study area.

4.3 MINIMUM TIME REQUIRED TO EXECUTE THE PAMA EXTENSION PROJECTS.

All parties associated with and impacted by the emissions at the La Oroya metallurgical complex desire a fast-track time frame for the execution of the PAMA extension projects. Figure 4-1 shows the project schedules for the three major projects. To a large extent the basis for these projects is the BHA gas flow and gas handling equipment survey that was conducted for DRP in 2001. This study led to further studies and the current list of projects. It is the opinion of Partelpoeg that DRP's schedules for these projects are in fact, very aggressive and require an extraordinary effort to ensure their timely completion.

Issues that particularly challenge the on-time completion of these projects include:

1. As shown on Figure 4-1, engineering activities on all projects are required in 2006. It is impossible to assign completely independent teams to each project and resources must be shared. Situations may arise when a 2006 crisis pulls resources from the lead or copper acid plant projects which will only further challenge these projects in 2007-2008.
2. The international business climate for projects such as La Oroya is creating a shortage of qualified shops to manufacture specialized equipment.
3. La Oroya projects must be engineered to accommodate the size restrictions associated with the transport of equipment from Lima to La Oroya. Transportation constraints put heavy demands on local La Oroya businesses to provide fabrication support for the projects.

Figure 4-1 PAMA Extension Project Schedules

ID	Fugitive Emission Projects	Start	Finish
1	Scoping, Feasibility Study	1/5/2001	1/4/2005
2	Engineering	1/6/2005	7/28/2006
3	Purchasing	6/10/2005	10/31/2006
4	Construction	1/3/2005	10/27/2006
5	Start-up	10/2/2006	12/20/2006

ID	Lead Acid Plant Project	Start	Finish
1	Scoping, Feasibility Study	1/5/2004	1/5/2005
2	Engineering	1/3/2005	12/26/2006
3	Purchasing	10/2/2006	12/31/2007
4	Construction	7/2/2007	9/30/2008
5	Start-up	10/1/2008	12/15/2008

ID	Copper Circuit Project	Start	Finish
1	Scoping, Feasibility Study	10/1/2004	2/28/2006
2	Engineering	3/1/2006	3/30/2007
3	Purchasing	12/15/2006	3/31/2009
4	Construction	7/3/2006	9/1/2009
5	Start-up	7/7/2009	12/29/2009

4.4 COMPLEMENTARY PROGRAMS TO REDUCE AMBIENT IMPACT

The community is impacted directly and indirectly. Direct impacts are caused by on-going process emissions and fugitives. A plan is in place to address these emissions and reduce them. Indirect impacts are being caused by the accumulation of dusts over the short and long term in different soil areas (reservoirs) in the community. Short term impacts are being caused by the re-suspension of emissions that deposit to soils and other flat surfaces in the community. Long term impacts are being caused by the re-suspension of previously deposited dusts. Neither the short nor the long term indirect impacts are being addressed effectively. DRP has undertaken some paving of work areas and separation of roadways plus the purchase of two sweepers to decrease the dust loadings with the facility and on the streets of La Oroya but the sweeper models purchased may be partly responsible for the increase in lead concentrations noted at the town monitoring stations even though the lead emissions have already been reduced. A more formal and detailed dust control plan is needed both for the

facility as well as the community. Smaller-sized vacuum units need to be acquired for cleaning sidewalks and narrow streets. It is essential that the effectiveness of the cleaning and the adequacy of the cleaning frequency be documented through appropriate street dust loading monitoring. Some community streets seemed to be missed by both the wet mopping and mechanical cleaning operations.

4.5 COMMUNITY PROGRAMS TO REDUCE IMPACT OF CURRENT AND PREVIOUS EMISSIONS

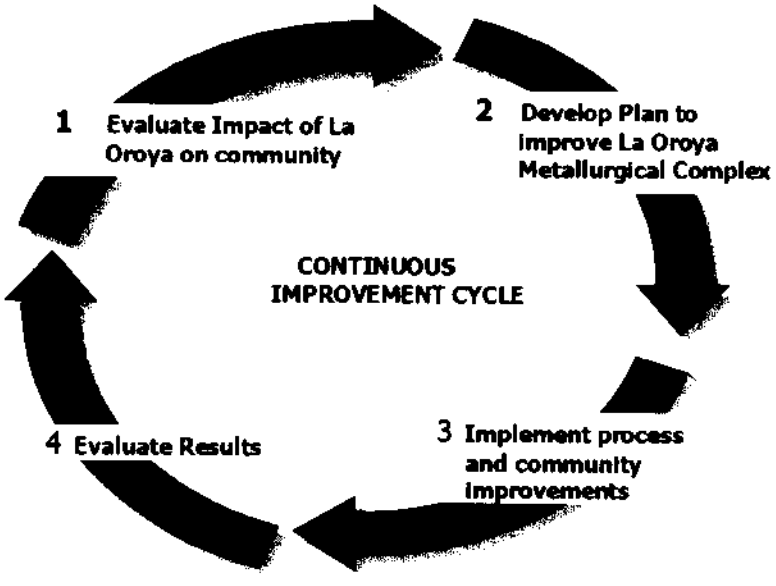
In addition to changes in street cleaning methods and frequency previously mentioned programs to: evaluate the reservoirs of lead-contaminated dust in housing, determine community-wide soil lead patterns and determine pathways of lead exposure for children in the La Oroya area need. In most mining communities, airborne lead, soil lead and house dust lead, or some combination thereof, are major determinants of blood lead. Extremely high dust lead loadings have been found in La Oroya housing but it is not known if the current cleaning practices are sufficient to reduce these levels; it is possible that reservoirs of lead-contaminated dust exist in the housing such as beneath or within cracks of houses with wooden floors. An area-wide soil lead survey also urgently needed to determine hot spots of contamination and develop and implement appropriate control measures. Currently available X-Ray Fluorescence Analyzers are capable of rapidly determining on a semi-quantitative basis soil lead levels *in situ.* An alternative method to determine pathways of exposure in La Oroya, rather than the one used in the Human Health Risk Assessment performed for DRP, needs to be used to help tailor intervention efforts effectively.

5.0 RECOMMENDATIONS

5.1 BASIS OF RECOMMENDATIONS

Our limited discussions with DRP suggest that they are committed to a continuous improvement cycle as shown in Figure 5-1 (translated from a DRP presentation). The recommendations of this report are subject to the commitment of DRP to continuous improvement. The granting of the extension of the PAMA, subject to implementation of the majority of the recommendations contained in this report including the appendices, and the successful execution of the programs indicated in the PAMA documents should not be construed as the final operating mode of the complex. Rather, the improvements indicated in the plan are recognized as what they are: a significant and substantial step towards improving the La Oroya community air shed and the health of its residents. Once these steps are implemented (Step 3 of Figure 5-1), the continuous improvement cycle should continue.

Figure 5-1 Continuous Improvement Cycle



Some examples of continuous improvement include:

- Progressive reduction in the areas of lead accumulation (reservoirs), such as in soil areas and in housing, (especially the ones within the community

close to where people live and eat) that can become re-suspended due to the action of the wind or where exposure is by direct contact or through tracking into homes. Soil surfaces, for example, need to be treated by creation of an effective barrier between the contamination and the surface. Simple revegetation is only a temporary remedy since it is not permanent and needs extensive maintenance, especially in high use areas.

- Long-term plans to further reduce emissions beyond those indicated in the PAMA extension request.

5.2 OVERALL RECOMMENDATION

The authors recommend that DRP's request for the PAMA extension be granted contingent upon acceptance of the majority of detailed recommendations shown below.

While it is clear that DRP is financially responsible for the process recommendations (Section 5.3), it is possible that DRP and government agencies may share in the cost of the air modeling recommendations (Section 5.4). The cost responsibility of the health related recommendations (Section 5.5) is a more complex issue and it is beyond the scope of this report to address this issue. It is our understanding that this cost will likely be shared between government agencies, Centromin, and DRP.

With the limited site visits associated with this report it is possible that the authors have not identified the optimal method of achieving the goals of the recommendations discussed below. MEM and DRP may be able to develop alternative methodologies to achieve the goals outlined in the recommendations.

5.3 PROCESS / PROJECT RECOMMENDATIONS

The following process / project recommendations are presented in order of importance:

1. All of the DRP projects (2006 completion of fugitive gas reduction, 2008 completion of the lead circuit acid plant, and 2009 completion of the copper circuit upgrade and acid plant) are on tight timelines. DRP provided detailed project schedules and indicated that they have expediting support from former DRP US experts. It is recommended that DRP develop a concise (absolutely limited to one page) project update report that is issued weekly. This report should provide an executive level summary that either affirms the project schedule or reports on schedule variances along with the action plan to recover from the variance. Vendors and outside shops should be required to provide input to this report with either a confirmation that all phases are on schedule or what action is being taken to recover time.

2. Once DRP makes the decision on whether COPRIM or Indec (see Partelpoeg's Appendix) is selected for the copper modernization project, they should be asked to review the construction schedule of the fugitive emission program to confirm that the schedule is achievable as published or if modifications are required.

3. DRP should consider a program similar to the one described in Young's and Partelpoeg's report appendices that describe how the SCS program can be improved.

4. The decision not to install a copper converter fugitive gas collection system (separate from the concept of using these gases as dilution air to the acid plant) should be reviewed with care. The copper circuit modernization plan should include a provision to send gases through the main stack when there is a sudden failure of the acid plant.

5. The lead sinter area scrubbers should not be shut down until the replacement baghouse is ready for start-up.

6. A review of the vehicle wash station efficiency should be carried out to determine its effectiveness in removing dust from tire treads and the underbody of vehicles.

7. The reliability of ducts and heat exchangers of the zinc acid plant should be reviewed to determine if an upgrade program is required to reduce the frequency and severity of gas leaks from the zinc acid plant.

5.4 AIR MODELING RECOMMENDATIONS

The following recommendations are presented in order of importance; the most important one being presented first:

1. Input detailed 3-dimensional meteorology into the CALMET/CALPUFF Model from a state-of-the-science weather forecast model in order to properly simulate the complex flow patterns in and over the La Oroya area. At the very least one year (2005) of hourly meteorological data should be used in order to properly represent the future air quality impacts in an updated risk assessment as well as to meet the requirement to determine the final destiny for each pollutant emission stream;
2. Add the missing process (stack and process fugitives of copper lead refinery in La Oroya Nuevo) and non-process fugitive emission sources (on-site wind-blown, offsite wind-blown, offsite roads, plume impact area south of Cerro Zinc), re-run the model on an hour-by-hour basis for 2005, compare the results against the individual day-by-day monitoring data (all stations and all air quality and meteorological parameters) and calculate the standard EPA statistics for model performance, as well as the source attribution analysis at each monitor location;
3. The re-modeling should focus on SO_2 and heavy metals but should also be run in the future for PM_{10} impacts. Particle size distributions are simple to measure (amount passing a 200 mesh screen and then analyzed for metal content) and should be made locally as part of the new model input:
4. Create and implement a dust management plan for the whole facility in order to control, to the extent possible, on-site non-process fugitives;

5. The SCS and the new government requirements for an Alerting System should be combined by using a real-time weather forecast model tailored to the La Oroya Area so that the air quality model becomes an operational tool rather than just a study tool. The advantages of this approach are: (1) SCS will be more precise leading to less downtime than the current SCS system requires, (2) an hour-by-hour forecast at least one day in advance will be available to use for process operations planning as well as informing the community of potential higher than normal pollution levels, and (3) the existing 6 monitoring stations can be used to asses, in real time, the performance of the air quality model providing better information to the public. If this type of system is adopted, real-time samplers (CEMs) should be used on the main stack to provide real-time inputs to the model;

6. The 2005 re-run of the air quality model can be used to give house-by-house inputs to an updated risk assessment for both the current and future conditions; and

7. A detailed independent audit of the air quality / meteorology monitoring system should be undertaken. For air quality, this audit should include testing the whole pathway from presentation of a blind concentration at the monitor input, through the correct value being recorded at the central station, to a check of all calculations performed on this data to its storage in the data archive. For meteorology, the similar pathway should be tested beginning with equipment set-up and calibration, through a blind direction being input at each monitor and being correctly captured at the central station, to long term averaging particularly of wind directions.

5.5 HEALTH RELATED RECOMMENDATIONS

1. Children with very high blood lead levels (beginning with the children 70 µg/dL and higher and then those in the 45 µg/dL to 69 µg/dL) can not be allowed to remain in the same home until hazard control measures have been implemented. In most cases it may take some time to identify these sources and to reduce access to them. During the interim period the family should be provided on a temporary basis with lead-safe housing in the La

Oroya area at no additional cost to them. The hazard control measures may include such activities as those designed to prevent exposures from lead-contaminated soil areas, more extensive exterior dust control, sealing of floors and walls in housing to permit more effective cleaning. The criteria for establishing and operating the lead-safe housing should be flexible to accommodate specific needs of the family. The lead-safe housing should have modern indoor plumbing for bathroom and kitchen facilities. The family should be allowed to stay in the relocation housing until the blood lead reaches an acceptable level, as determined by the pediatrician, for two successive months.

2. The dangerously high floor dust lead loadings that have been reported in La Oroya (Cornejo and Gottesfeld 2004) are evidence of the urgency for clean-up of interior dust lead. In order to be effectively cleaned, interior surfaces (floors, walls, etc) must be cleanable. Wood floors with large cracks between boards, common in some La Oroya homes, can not be cleaned effectively to remove the dust reservoirs in these cracks and similar spaces. Similarly, porous walls such as those found in adobe houses in La Oroya can not be cleaned. A number of houses have had a plaster or cement coating applied to the adobe walls. Such treatment, if properly maintained, can result in a wall surface that can be effectively cleaned. Other permanent wall coverings, exterior as well as interior, need to be urgently evaluated and implemented, particularly for children with high blood lead(ties in with (1) above.

3. A sufficient number of water-spray equipped vacuum street cleaning units, , that have been independently shown to be capable of removing lead-contaminated dusts, should be purchased. Some of these units should be smaller sized ones able to maneuver in narrow streets and on sidewalks. It is strongly recommended that the additional equipment be purchased as soon as possible so that all streets and paved areas can be cleaned at least twice per week unless street dust lead monitoring indicates that another frequency is appropriate.

4. The effectiveness of the wet cleaning of paved areas should be determined through dust lead monitoring at intervals between cleanings and that the need for the detergents, disinfectants and deodorizers now used be examined.

5 A comprehensive area-wide soil lead assessment be performed in the near future to identify "hot spots" of exposure to children and that would serve as a useful guide in developing a remediation plan for the entire area. Field portable X-Ray Fluorescence technology has greatly advanced in the past decade and instruments is now available that would permit such a survey to be performed in an expeditious manner.

6. Expanded efforts need to be made immediately to prevent exposure from lead-contaminated soil. This source is thought to be a critical one for some of the children with very high blood lead. In most cases it may not be technically feasible to remove the soil. Two approaches involving installation of permanent barriers over the contaminated areas are presented in Appendix C for consideration- others can probably readily be developed. Pilot testing of these methods can begin relatively soon for the high soil lead areas thought to be sources of lead for children whose families are being relocated (see recommendation 1).

7. Results of the census of housing that has been performed should be reviewed to determine what gaps exist in knowledge of housing- such as availability of a public water supply and bathroom facilities in the home and structural integrity. Using results from recommendation 2, an assessment of possible reservoirs of contaminated dust in the housing- such as below floors and in other inaccessible areas- and the type of walls and floors could be included. It is important that structural integrity, particularly for those on steep grades, be carefully evaluated because some of the houses should be demolished and replaced by sound housing in suitable areas.

8. Possible impact of the Huanchan slag storage area on the environment needs further investigation. Bioavailability tests should be performed on dustfall samples from this area and from other areas such as La Oroya

Antigua to attempt to verify the common assumption that the vitreous nature of the slag makes the contents relatively unavailable. Samples of slag produced at various times in the past can be examined to determine the stability of the slag materials.

9. A health study focusing on the impact of sulfur dioxide on the respiratory and other systems of the local population should be conducted with input from those experts in lung function at high altitudes.

10. It is recommended that the DRP policy of temporarily shutting down the smelter when an inversion is predicted be refined to include other meteorological and facility operating conditions in order to maximize its health benefit to the community. Procedures for doing this are outlined in Young's and Partelpoeg's Appendices.

6.0 COMMENTS

6.1 PROCESS / PROJECT RELATED COMMENTS

If MEM decides to grant the PAMA extension with conditions such as those recommended in this report, both MEM and DRP will be scrutinized by parties opposing the decision and open communications between MEM and DRP must be maintained. If DRP adopts the first process / project recommendation (Section 5.3), the weekly project schedule update could be shared with MEM. The suppliers to DRP already recognize the importance of this project to DRP and Peru, but if schedules slip, it is important that MEM be appraised of this.

Often, the commissioning and start-up of a new process can be difficult. DRP has recognized this and it appears that some of their decisions on suppliers has been based on start-up assistance. GE / BHA have the ability and corporate commitment to help with baghouse projects. DRP's favorable opinion of ISASmelt technology for the copper circuit is in part due to ISASmelt's reputation of start-up assistance and the fact that there are numerous ISASmelt copper operations where training can be provided. By the time the DRP ISASmelt is commissioned, Southern Copper (at Ilo, Peru) will have three years of operational experience with their ISASmelt (scheduled for start-up in mid to late 2006).

6.2 AIR MODELING RELATED COMMENTS

The following comments are offered as additional input into a long-standing continuous impact on the environment:

1. Since pollution concentration is directly proportional to emission rate and release height, if technically possible, the plume rise from the main stack should be improved through either increasing the plume temperature or the exit velocity (through coning);
2. The Doppler Acoustic Sounder is not considered to be a reliable operational tool. It is recommended that it be moved to the background Casaraca Station

and the data collected over time used to do a retrospective comparison against the forecast meteorology for those parameters that can be usefully and reliably monitored;

3. It is recommended that all emissions and ambient monitoring data be reported in local conditions rather than being converted to standard conditions. This makes air quality modeling simpler (no corrections required on either inputs or outputs) with less chance for error and allows the data to be fed directly into the risk assessment;

4. Establish one residence in La Oroya Antigua as a research centre to determine the source receptor pathways to humans from the different metals reservoirs such as lead in air, lead in old disturbed soil, wind blown lead, current lead deposition on flat surfaces, etc.; and

5. If more street sweepers are to be bought the Tymco Regenerative Air Sweeper or the Tennants Centurion is preferred in order to maximize PM_{10} collection and minimize re-distribution and emissions. However, if enough water is available, DRP should consider wet flushing in lieu of dry sweeping in order to minimize the impacts on the human receptor, especially in La Oroya Antigua.

6.3 HEALTH RELATED COMMENTS

1. Since DRP is already temporarily shutting down certain operations during times of inversion, timing these shutdowns with real-time process performance problems and air modeling predictions of high impact conditions, the health benefit to the community could be enhanced. Such real time decision making to alleviate impact on human health could have applications to other industrial operations in industrial areas.

2. The blood lead levels in La Oroya area and the house dust lead loadings reported in 2004 are among the highest in the world. The May 2005 CDC report on the "Development of an Integrated Intervention Plan to Reduce Exposure to Lead and Other Contaminants in the Mining Center of La Oroya,

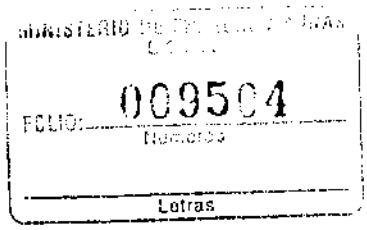
Peru" contained a number of recommendations in a section called "Problems/Issues/Concerns Clearly Stated" that need to be addressed. Some of these are mentioned in this report.

3. Many of the houses in this area, and in La Oroya Antiqua in particular, may be in such poor structural shape or located on such large deposits of lead-contaminated soil/dust that a comprehensive plan for their removal and replacement is the best alternative for the health of the present and future occupants. Former operators of the La Oroya smelter complex have a history of creating and managing special housing for their employees. This may be an appropriate time for such a policy to be continued for high risk residents of La Oroya, regardless of their employment.

4. Participation in programs of the MINSA-DRP Agreement have apparently been focused on children in the highest two blood lead categories, namely those with 45 µg/dL and higher. Those groups need to have priority but those in the 20 to 44 µg/dL, also deserve attention. Ideally, all children above the target level of 10 µg/dL need to have nutritional and health support services available. These services should not be abruptly terminated at the time of the first blood lead moving them into a category "not eligible for services". Such lower levels on two successive monthly samples would be a more appropriate plan.

5. With the health-related recommendations outlined in this report, the programs of the MINSA-DRP Agreement, if that is the group charged with carrying them out, will have to be greatly expanded and with a much larger share of their resources going to actual exposure reduction efforts.

Appendix C- Health Related Issues



DISCLAIMER

This report is based on the best information available to the Scott Clark within the time constraints of the review. The material in it reflects his best judgement in light of the information available to him at the time of preparation. Specifically, it is based on information supplied by site representatives, a review of reports, discussions with individuals, a brief walk through of part of the facility and the surrounding area. He has prepared this report using information understood to be factual and correct and shall not be responsible for conditions arising from information or facts which were not fully disclosed to him, or for conditions which can only be confirmed through sampling or monitoring.

This report was prepared by the Dr. Scott Clark for the Ministry of Energy and Mines, Peru to aid in their decision-making with respect to an Exceptional Extension Request for the Sulphuric Acid Plants project of La Oroya Metallurgical Complex PAMA. Any use of, or reliance or decision based on this report by any third party is the sole and exclusive responsibility of such third party. Dr. Clark accepts no responsibility for damages, if any, suffered by any third party as a result of the use of, or reliance or decision based on, this report.

1.0 SCOPE OF REVIEW

Dr. Clark was asked to address the following specific items:

1. Human Health Risk Assessment Study. Evaluate and give his opinion about the human health risk assessment study prepared by Integral Consulting and presented by Doe Run Peru. (DRP).

2. Exposure Evaluation. Evaluate the exposures to heavy metals (lead, arsenic, cadmium and others) and to sulfur dioxide (SO_2) in the City of La Oroya and surroundings after the year 2006, taking into account the estimated emissions from the air quality dispersion model presented by DRP in the file for the present application for the extension.

3. Prevention and Mitigation Measures. Propose the prevention and mitigation measures and recommendations in order to not affect human health by the effect of the concentrations of air contaminants arising from the estimated emissions of the operation of the Metallurgical Complex of La Oroya during the period of extension of the "Sulfuric Acid Plants "project.

4. Standards for Metal Concentrations in Soil. Evaluate the acceptable levels of metal concentrations in soil, according to international standards, proposing recommendations in order to reduce human health risks coming from this contamination source.

5. Additional Environmental Studies Needed. Recommend the measures and environmental studies that should be required to DRP, so as to reduce human health risks for exposure to air contaminants that will allow improving the air quality in La Oroya and assess the reached progress in the people's health risk reduction.

6. Other Recommendations. Any other recommendations that may arise during the course of this review.

7. Additional Questions Presented April 13, 2006. Subsequent to the meeting of the expert panel with MEM staff in the afternoon of April 13, 2006, a list of thirteen health risk-related questions were sent by e-mail. Responses to some of these

questions are included in the response to items (1) to (5) above. The others are addressed in this separate section.

8. SUMMARY OF CREDENTIALS

Dr. Scott Clark is Professor of Environmental Health at the University of Cincinnati and Director of the Division of Occupational and Environmental Hygiene in the Department of Environmental Health. He received his PhD degree from the Johns Hopkins University. He has over thirty years experience as part of a team conducting environmental health studies of children exposed to lead. These studies have resulted in an increase in the understanding of the direct and indirect pathways though which children are exposed. The primary sources of exposure in these studies have been: (a) lead-based paint related, (b) mining related and (c) combinations of the two. His research has also involved in the evaluation of interventions aimed at reducing exposure to lead-contaminated soil and dust (exterior and interior) and to lead-based paint. He has also performed research in the use of field-based portable X-Ray Fluorescence (XRF) Analyzers for determining lead levels in soil, dust, air and paint. His studies have been conducted in a number of countries in addition to the U.S., including Poland, India and Malaysia. He has also provided advice to the Community Task Force in Trail, British Columbia as they were developing their strategies for reducing exposures to past and present emissions from a lead/zinc smelter and to the Focus Meetings of the Task Force in Herculaneum, Missouri to assist them in evaluating data developed as part of efforts to reduce exposure to releases associated with the Doe Run smelter located there.

2.0 SUMMARY OF ACTIVITIES AT LA OROYA AND DOCUMENTS REVIEWED

Scott Clark's two and one-half days on-site in La Oroya (Monday afternoon April 10, 2006 through Wednesday April 12, 2006 at approximately 7:30 pm) were divided approximately equally between time spent at the smelter complex site and in the community. He was accompanied during this time by at least one representative each from MEM and DRP.

On-Smelter Complex Site Activities: Overview presentation by DRP followed by visit to parts of the complex (attended by all three member of expert panel). Start of second day MEM, DRP and panel meeting to plan schedule for day. End of second day brief meeting. Third day: activity planning meeting, brief overview visits to concentrate unloading (truck and railcar) and storage areas and to slag storage area. (Met with other panel members and MEM staff). Presentation by DRP industrial hygienist (also in attendance- Mr. Vorberg of Doe Run and DRP physician and associate). Meeting with Dr. Schoof of Integral Consulting.

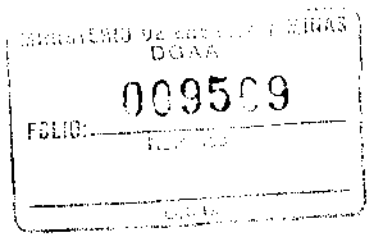
Community Activities. Second day morning: power point presentation by Coordinator of MINSA-DRP Agreement, visit to area where wet washing of street by Agreement staff and volunteers was actively underway, brief visit to one home, Visit to school area which had been improved by addition of modern bathroom and shower facilities and paving of formerly dirt play areas; tour of Agreement facility (joined by Mr. Vorberg of DRP and Dr. R. Schoof of Integral Consulting for rest of morning) to see classrooms and evaluation facilities. Visit to day care center at Casaracra (not operating currently since it was recently re-painted), computer facility added at Agreement-supported school, dairy products development area, pasture improvement and cattle treatment and handling facility. Afternoon: walking tour of La Oroya Antigua including visits to several houses- some of which were home to children with elevated blood lead. Wednesday morning: meeting at Agreement center to discuss dust collection practice (joined by Dr. Schoof), purchase of samples of new residential paint (to follow-up on

statement earlier in week that some locally-available paint was thought to contain high levels of lead), brief visits with representatives of two community groups (one in La Oroya Antigua and one in La Oroya Nuevo). Attended meeting of governmental agencies followed by a press conference.

Information Received and Reviewed: Human Health Risk Assessment prepared by Integral Consulting Inc for Doe Run Peru, December 2, 2005, including appendices; "Development of an Integrated Intervention Plan to Reduce Exposures to Lead and Other Contaminants in the Mining Center of La Oroya Peru" prepared for United States Agency for International Development, Peru Mission by U.S. Centers for Disease Control and Prevention, May 2005; "Interior Dust Levels in La Oroya Peru" prepared by Asociacion Civil Labor and Occupational Knowledge International October 2004. Copy in English of the Ninety (90) comments to the materials that DRP submitted in support of its request for an Extension to the PAMA. An English version of DRP responses was not available at the time of the preparation of this report. Through conversations with others since the visit to La Oroya and up to the moment of completion of this report, the availability of additional relevant material became apparent but time was not available for review.

Activities April 14, 2006 in Lima Peru. Telephone conversation with Alejandro Farrell of the Presbyterian Church USA and the Movement for Health of La Oroya. I had received his name from a person in the US who heard that I was going to La Oroya. He was concerned that we may not have access to comments on the PAMA extension request and Human Health Risk Assessment such as that prepared by Dr. Anna Cederstav, a co-author of "La Oroya Can't Wait". Ms. Maria Chappuis, identifying herself as formerly with "the Ministry" called about 4:00 pm April 14 and requested that she be able to talk with me briefly. We met at about 6:30 pm April 14. She expressed her view that DRP had not acted on the PAMA in a timely manner since its inception. I indicated that I was focusing on present conditions and those anticipated in the future and was not attempting to evaluate past performance, which would require much different activities.

April 21, 2006 Dr. Anna Cederstav called me on Friday April 21, 2006 and during the conversation expressed her support of independent review of the La Oroya situation but that the brief time available for my review was very inadequate. She expressed the need for continuity of efforts and her disappointment that the recommendations in the report prepared by the US Centers for Disease Control and Prevention (mentioned above), for example, were largely unaddressed.



3.0 BACKGROUND INFORMATION ON OTHER EXPOSED POPULATIONS

Many other communities around the world have experienced health problems with emissions from lead and other smelters and from other sources. Information from two such communities with which I have some personal experience will be briefly presented in the interest in putting into perspective the situation in La Oroya. One community is Trail, British Columbia (Canada) which has been the site of a major lead and zinc smelting facility since 1916 and the other is Herculaneum, Missouri (US) where a lead smelter has been in operation since the late 19th century, about 115 years ago. The average blood lead in the Trail BC community was 22 µg/dl in 1975; 11.5 µg/dl in 1996, the year before the new lead smelter was installed; and decreased to 5.9 µg/dl in 1999.

In a January 2001 report, 24 % of the children in Herculaneum were reported to have a blood lead level of 10 µg/dl or higher with an average of 8.9 µg/dl. As a result of the findings in Herculaneum in 2001 (24 % of children with levels of 10 or above, about 100 households were temporarily relocated while Doe Run cleaned up contaminated yards and homes. From recently assembled data (Sterling 2006) blood lead samples collected during the 1992-1999 period had an average value of 13.4 µg/dL with 73 % exceeding 10 µg/dL. During the late 1990s a number of improvements were made at the smelter including emission controls at the stack and containments over areas producing fugitive emissions.

To assist the Trail Community Lead Task Force in the identification of remedial options, exposure pathways investigations were undertaken. Data were collected on potential exposure risk factors through questionnaires administered to parents and from environmental samples (yard soil, interior floor dust lead, interior windowsill dust lead, exterior yard dust and street dust; peeling paint films and garden vegetables were collected where available. The resulting lead exposure pathway as determined by structural equations modeling at the University of Cincinnati is shown in **Figure C.1** below which was taken from "Exposure Pathways Investigations, Final Report, Trail Community Lead Task Force September 1995 (Hilts et al 1995). Time spent outdoors

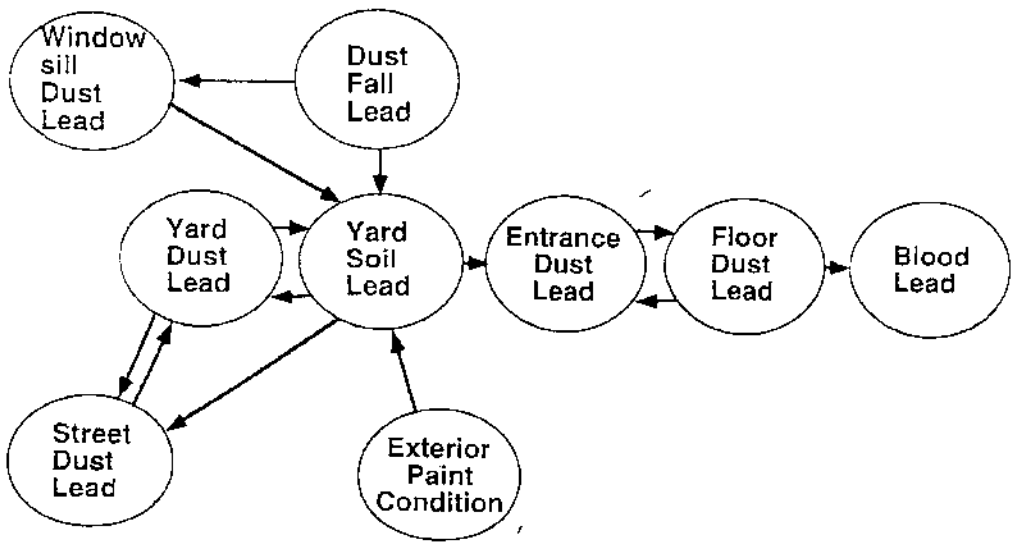
was also a predictor of blood lead and likely is a surrogate for direct exposure to exterior sources such as soil and exterior dust.

Figure C.1 Trail Lead Program Environmental Lead Exposure Pathway (from Hilts et al 1995)

FIGURE 2.1

TRAIL LEAD PROGRAM
ENVIRONMENTAL LEAD EXPOSURE PATHWAY

N = 176, R^2 = 69.15%



Air lead at the time of the pathways analysis was about 0.5 µg/m^3, about one-tenth that currently measured at some times in La Oroya. Air lead levels in Trail BC during the 1969 to 1999 period are presented in **Figure C.2** (Hilts et al 2001). Concentrations have decreased considerably since the early part of this period when they were in the 2.5 to 3.5 µg/m^3 range and dropped further from 0.6 µg/m^3 to about 0.3µg/m^3 when the new lead smelter was placed into operation in early 1997. Thus, most of the decrease occurred before the new smelter was placed into operation in 1997. Patterns of lead in dustfall (mg/m^2/day (**Figure 3**) and street dust lead (ppm) (**Figure 4**) in several communities in the Trail area, some of which lie along the

Columbia River (Hilts et al 2001). The patterns are similar. [note: The limited data available indicates much higher street dust levels in La Oroya – Section 6.3.]

Figure C.2 Air Lead Levels in Trail, B.C. 1969-1999

(from Hilts et al 2001)

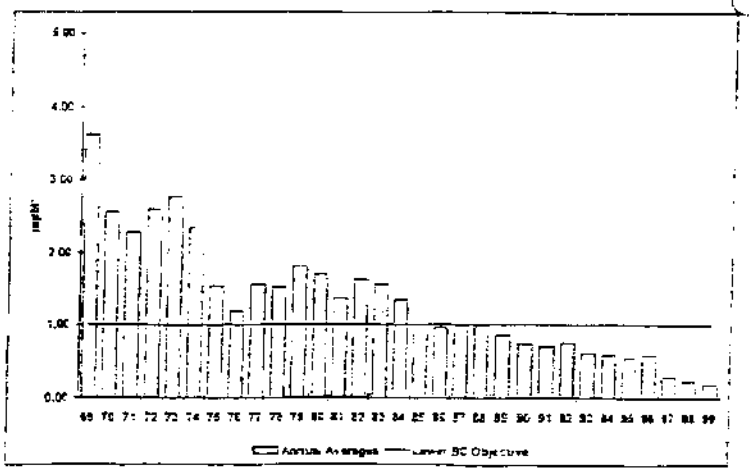


Figure C.3 1992 Dustfall Lead (mg/m^2/day) In Several Communities in the Trail, BC Area

(from Hilts et al 2001)

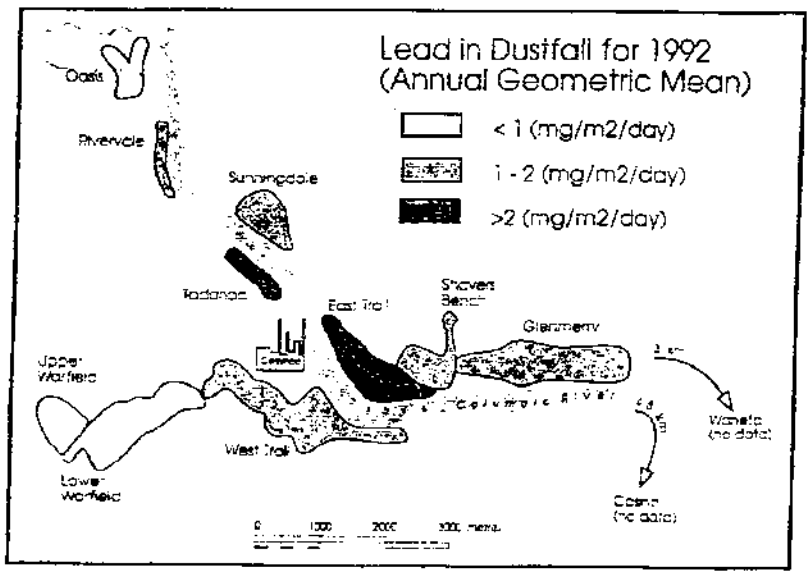


Figure 10: Lead in dustfall in the neighbourhoods of Trail.

Figure C.4 1992 Street Dust Lead Levels (ppm) in Several Communities in the Trail, BC Area (from Hilts et al 2001)

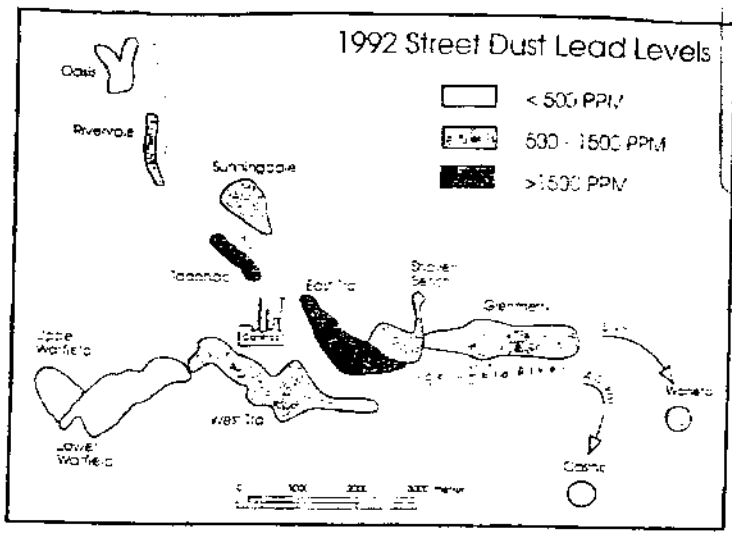


Figure 7: Streetdust lead levels in the neighbourhoods of Trail.

As part of their planning process the Trail Community Lead Task Force also compiled data on thirteen (13) lead exposure pathways studies, with brief description of measurements made, blood lead levels, the strongest determinant of blood lead and the second strongest determinant (Hilts et al 1995). Eleven of the thirteen studies were of mining communities (**Table C.1**, from Hilts et al 1995). The community most similar to La Oroya with respect to blood lead is Silver Creek, Idaho (US) which had active smelter.mines at the time of the study. Average blood lead level was 38 µg/dl, similar to that in La Oroya Antigua. Air lead concentration was the strongest predictor of blood lead with soil lead the second strongest. [note: These findings contrast strikingly with the HHRA estimate that outdoor dust is the predominant source of exposure with indoor dust a distant second and inhalation of air lead is a very small source].

Table C.1 Examples of Lead Exposure Pathways Studies Conducted at Other Sites (from Hilts et al 1995)

Table 3.3-1a Examples of Lead Exposure Pathways Studies Conducted at Other Sites

Study Description	Strongest Determinant of Blood Lead	2nd Strongest Determinant of Blood Lead
Silver Valley, Idaho, 1974 (Yankel et. al., 1977) Average blood lead: 39 µg/dL Measured lead in: soil, floor dust (conc. only), exterior dust, paint, grass, garden vegetables, ambient air,	Air lead	Soil lead
Boston, Massachusetts, 1979-81 (Rabinowitz et. al., 1985) Average blood lead:6.8 µg/dL Measured lead in: soil, floor dust (loading only), paint, indoor air	Floor dust lead	Soil lead
Silver Valley, Idaho, 1983 (Panhandle Dist. Hlth. Dept. et. al, 1986) Average blood lead: 14 µg/dL Measured lead in: soil, floor dust (conc. only), paint, garden vegetables, ambient air	Floor dust lead	Soil lead
East Helena, Montana, 1983 (Lewis & Clark County Hlth. Dept. et. al., 1986) Average blood lead: 13.0 µg/dL Measured lead in: soil, floor dust (conc. only), paint, garden vegetables, drinking water, ambient air,	Floor dust lead	Air lead
Cincinnati, Ohio, 1985 (Bornschein et.al., 1986) Average blood lead: 16.9 µg/dL Measured lead in: floor dust (loading and concentration), exterior surface dust, paint	Floor dust lead	Paint lead
Telluride, Colorado, 1986 (Bornschein et. al., 1988) Average blood lead: 6.1 µg/dL Measured lead in: soil, floor dust (loading and conc.), windowsill dust, paint, drinking water	Floor dust lead	Soil lead

In Herculaneum, exposure reduction efforts included a buy-out of houses with high lead soil and a community-wide program of housecleaning and replacement of high lead soil. Extensive monitoring efforts were undertaken including street dust lead loading determination. Cleaning of community streets with a modern vacuum-equipped cleaning vehicle was performed continuously throughout the day. Street dust lead levels were thought to be increased by trucks using residential streets in hauling concentrate to the smelter. Concentrate had previously been hauled by railroad. A series of Herculaneum Focus Meetings were held with members of their Task Force and others to develop a Home Interior Dust Lead Cleanup Strategy. The environmental monitoring program included dustfall sample collection, street dust sampling with a vacuum method developed by the US EPA contractor, soil sampling and interior dust sampling with a vacuum method and with the standard dust wipe. .method. Eight (8)

air monitoring stations were used to collect samples for the determination of airborne lead. For the station with the highest three month average during July-September 2002, 1.01 µg/m^3, daily values ranged from 0.06 to 4.73 µg/m^3.

Table 3.3-1b Examples of Lead Exposure Pathways Studies Conducted at Other Sites, Cont'd

Study Description	Strongest Determinant of Blood Lead	2nd Strongest Determinant of Blood Lead
Leadville, Colorado, 1987 (Cook et. al., 1993) Average blood lead: 8.7 µg/dL Measured lead in: soil, floor and windowsill dust (conc. only), paint, drinking water	Soil lead	
Trail, British Columbia, 1989 (Hertzman et. al., 1989) Average blood lead: 13.1 µg/dL Measured lead in: soil, floor and windowsill dust (conc. only), paint, garden vegetables	Soil lead	Windowsill dust lead
Midvale, Utah, 1989 (University of Cincinnati, 1990) Average blood lead: 5.2 µg/dL Measured lead in: soil, floor dust (loading and conc.), exterior surface dust, paint, drinking water	Soil lead	Paint lead
Butte, Montana, 1990 (Butte-Silver Bow Hlth. Dept. & Univ. of Cinc., 1992) Average blood lead: 3.5 µg/dL Measured lead in: soil, floor dust (loading and conc.), exterior surface dust, paint, drinking water	Floor dust lead	Soil lead
Broken Hill, New South Wales, Australia, 1991 (NSW Hlth. Dept., 1994) Average blood lead: 16.0 µg/dL Measured lead in: soil, floor dust (conc. only), peeling paint, drinking water	Soil lead	
Granite City, Illinois, 1991 (ATSDR, 1994) Average blood lead: 5.6 µg/dL Measured lead in: soil, floor dust (loading and conc.), paint, drinking water	Floor dust lead	
Trail, British Columbia, 1992 (This report) Average blood lead: 10.8 µg/dL Measured lead in: soil, floor dust (loading and conc.), windowsill dust, exterior surface dust, peeling paint, garden vegetables	Floor dust lead	Soil lead

4.0 COMMENTS ON HUMAN HEALTH RISK ASSESSMENT STUDY

The Human Health Risk Assessment (HHRA) Study prepared by Integral Consulting Inc. contains the recommended US EPA cancer risk assessment methodology and it appears to be an appropriate assessment. For upper end exposures, the highest combined risk estimate for the inhalation of arsenic and cadmium is two in one hundred. (much higher than the USEPA range of acceptability of one in ten thousand to one in a million). Since the exposures result from DRP operations, occupational exposures would be much higher than residential exposures. A health survey of present and former DRP employees may yield important information on the extent of cancer risks due to DRP (see first paragraph of **Section 9.0** for more details).

The HHRA risk characterization that the elevated sulfur dioxide concentrations combined with the particulate emissions are likely to have an adverse impact on lung function for residents in neighboring communities appears to be well-supported. Current DRP efforts to curtail production at times designed to mitigate these exposures should be encourage and expanded. Levels are projected to exceed the Peru standard by several fold and to be lower than but near the threshold for increased mortality and bronchitis. The impact of this exposure will be aggravated, particularly for asthmatics, by the presence of particulates.

The model for predicting blood lead levels developed in the above study (the Integrated Exposure Uptake Biokinetic (IEUBK) model, supplemented by the Integrated Stochastic Model (ISE) is not appropriate for Peru. The IEUBK was developed for US populations and has an underlying premise, as stated in the HHRA, that exposures are dominated by soil ingestion. It requires numerous parameter estimates that are not well validated for US populations and are even more difficult to estimate for a population such as in the La Oroya area. The model does not result in a determination of the direct and indirect pathways through which children are exposed to lead... These

pathways are needed in order to effectively design mitigation efforts in the La Oroya communities and to design monitoring systems to help evaluate the effectiveness of DRP complex improvements on lead levels in the La Oroya area. The interior dust lead collection method used in the Integral study does not produce results that are comparable to health-based standards for lead in dust which are expressed in terms of loading (quantity of lead per unit area). There is a standardized wipe procedure that produces results in units of mass of lead per unit surface area. This method is the one used in the October 2004 report on Interior Dust Lead Levels in La Oroya, Peru.

The IEUBK model was developed by the USEPA for use on Superfund sites to determine risk from various exposure pathways. This model involves numerous input variables, which must be estimated. . The estimates are often derived from literature variables. The model predictions for blood lead were compared with actual blood lead data and variables adjusted until the model agrees with the actual blood lead levels. The ISE model that was used allowed for a range of values for the variables to be used through use of monte carlo procedures. The input variables can be adjusted so that the results match the actual values as closely as possible. The resulting model was then used to predict the impact on blood lead of changes of future DRP emissions predicted from the air dispersion model. The predictive model does not contain the actual pathways of exposure of the children in La Oroya but are more appropriately 'artifacts' of the model.

An example of an alternative approach, one not involving the large number of assumptions needed for the IEUBK model, has been used for a number of years to estimate the direct and indirect pathways contributing to blood lead levels. (See Section 4.0, Background Information on Other Lead Smelter Exposure Sites). This model, known as the structural equations model, involves the simultaneous linear regression equations to predict major variables such as exterior dust, interior dust and blood lead independent variables such as, for example, air lead, distance from smelter, direction from smelter, paved/unpaved road, house accessed from hillside steps, number of children in home, number of adults in home. The resulting model would show the direct and indirect pathways leading to blood lead. The air dispersion model discussed elsewhere in the report (**Appendix B**) could be used to develop air

concentration data as average levels for particular time periods, specific to the location of each child's house, and other location where a major portion of time is spent. By adjusting the values of some of the input variables such as might occur from emissions reductions efforts, such as air lead and settled dust loading, a prediction can be made of the resulting blood lead. If the changes in emission reduction efforts and community dust and soil level reductions are not adequate to reach the desired goals of no more than five (5) percent of the blood lead levels exceeding than 10 ug/dl, the model can be used to determine what other exposure factors need to be changed.

An alternative approach needs to be undertaken that includes such exposure indices as house floor dust wipe lead loading (µg lead per unit area), neighborhood soil and exterior dust lead levels and air lead at the location of the child's home, and other major location where time is spent- this can be estimated using the revised air model presented elsewhere in this report.

5.0 EXPOSURE EVALUATION

Comments on the exposure evaluation for carcinogens, sulfur dioxide, lead and other metals were included in the comments on the Human Health Risk Assessment in Section 5.0.

The very high blood lead levels of children in the La Oroya area and the very high air and dust lead levels that have been reported are evidence that a severe health problem exists. This problem has been evident for several years and was undoubtedly in existence for many years in the past. The behavioral and cognitive results of exposures at the levels in the La Oroya area have been documented in a number of carefully designed and executed studies. One of these studies, the Cincinnati longitudinal study included in the table of exposure pathways (Table C.1 b), has been the first to find actual changes in the brain associated with the behavioral and cognitive findings. Through analysis of Magnetic Resonance Imaging on these individuals, now ages 20 – 23 years, reductions were found in total brain volume with regional gray and white deficits that correlate with childhood blood lead levels (average by child of 4.7 to 37 µg/dL (Cecil et al 2006)..

6.0 PREVENTION AND MITIGATION MEASURES

6.1 IMMEDIATE NEED FOR LEAD-SAFE RELOCATION HOUSING

Children with elevated blood lead levels can not be allowed to remain in the same home until hazard control measures have been implemented. Priority needs to be given to children whose levels are 45 µg/dL and higher but must be extended to those at 20 µg/dL and above unless community-wide efforts at exposure reduction are unable to reduce the levels to less than 20 µg/dL . This recommendation is also supported by the CDC report reviewed (CDC 2005). In Appendix I of the CDC report, which discusses the use and limitations of chelation where it is stated, "On the other hand, chelation is definitely life saving when used in the highest risk patients, primarily those with blood lead levels greater than 70 µg/dL. These children are at risk of lead related encephalopathy and death". The CDC recommendation for children in the 20 to 44 µg/dL category is to "identify and eliminate sources of lead exposure". In most cases it will take some time to identify these sources and to reduce access to them. During the interim period the family should be provided on a temporary basis with lead-safe housing in the La Oroya area. The hazard control measures may include such activities as those designed to prevent exposures from lead-contaminated soil areas, more extensive exterior dust control, sealing of floors and walls in housing to permit more effective cleaning. The criteria for establishing and operating the lead-safe housing should be flexible to accommodate specific needs of the family and should not require that the family have additional expenditures for housing costs. The lead-safe housing should have modern indoor plumbing for bathroom and kitchen facilities. Kitchens should be equipped. The family should be allowed to stay in the relocation housing until the blood lead reaches an acceptable level, as determined by the pediatrician, for two successive months. Measures to reduce exposure to lead will also serve to reduce exposure to other metals. [Note: In the process of obtaining lead-safe relocation housing, care must be taken not to use new lead-based paints. In a brief survey of five cans of new paint from each of two readily-available brands purchased in La Oroya, the green and yellow samples from each brand contained very high levels of lead- 34,200 ppm and 25,500 ppm for one brand and 20,100 ppm and 20,700 ppm for the other.

Only one paint from each brand contained a lead level that would meet the international standard of 400 ppm. No single color met the 400 ppm limit for both brands.]

6.2 REFINEMENT OF CURRENT PERIODIC SHUTDOWN OF OPERATIONS FOR HEALTH REASONS

It is recommended that the current DRP policy of temporarily shutting down the smelter when an inversion is predicted be refined to include other meteorological and facility operating conditions. In Appendix B (Section B.6 pg 13) the implementation of a Supplemental Control System real-time meteorological data to minimize the impact of DRP operations on the local community" is recommended. Supplemental Control Systems (SCS) are outlined (Section 7.9 of Appendix A) to tie these process changes into actual plant performance. Thus it is proposed that the benefits of DRPs current practice of temporarily cutting back smelter complex operations be enhanced by utilizing the improvements recommended to the air quality monitoring system so that the curtailment of operations can occur during periods of time when there are operational problems and/or when meteorological conditions are such that DRP operations would have particularly heavy impact on the nearby areas. This temporary and selective curtailment of DRP operations would have a beneficial impact on exposures, including those with high lead levels. [Note: In a future effort it would be useful to estimate what portion of the current exposure results from those situations when plant operations experience difficulties and/or when unfavorable meteorological conditions prevail.]

6.3 EXTERIOR CLEAN-UP OF DUST BY WET AND VACUUM METHODS

Exterior dust is very likely to be a very important source of lead exposure either through direct contact or through tracking into homes, which have very high dust lead loadings

(see Section 6.5). Thus exterior dust cleaning is vital, particularly during the period until emissions from the smelter complex are under control The Street Cleaning carried out manually by volunteers and DRP-MINSA staff was observed. (**Figures C.5** and **C.6**) On a long-term basis this method can be greatly enhanced if a public water supply was installed throughout La Oroya Antigua so that large tank trucks would not have to be brought to often narrow and usually very busy streets.

Figure C.5 Photograph of Manual Wet Washing of Street using Detergents et al

Figure C.6 Photograph of Truck Which Supplied Water for Manual Washing of Street

Although visible dirt was removed during the cleaning observed, it was not able to be determined if any monitoring was routinely performed to determine how effective the cleaning was and how frequently it should be performed. Five detergents, disinfectants, and deodorizers are used in the wet cleaning of streets. It is recommended that the effectiveness of the wet cleaning of paved areas be determined through dust lead monitoring at intervals between cleanings and that the need for the detergents, disinfectants and deodorizers utilized be examined to determine if they need to be used. Cleaning agents recommended for lead removeal such as high phosphate detergents (trisodium phosphate), lead dissolve, or the equivalent should be adequate. If disinfection agents are needed for a purpose other than lead removal, then they should be evaluated for that objective. Published methods are available on procedures to collect exterior dust sample to determine dust lead loadings. An evaluation of street cleaning effectiveness is urgently needed. If the wash water could be collected, then consideration should be given to expanding the areas receiving wet cleaning.

From information provided by DRP, it appears that one street cleaning machine equipped with a vacuum and brush system is apparently devoted to certain La Oroya Antigua streets for one day each week. This machine is used to clean the streets on two days of the week with some areas being cleaned twice and others once during the day of the cleaning. 3857 meters of roadway are cleaned each week, with a total area of 25, 120 sq m of area, according to DRP data. The area cleaned needs to be expanded to other communities and to include sidewalks. Street dust loading monitoring is needed to determine the extent of the area and the frequency of cleaning needed.

Another pavement cleaning machine is devoted to cleaning paved areas on the smelter complex. From observations made during walking tours of La Oroya Antigua, it is evident that the cleaning is inadequate in many areas.

Limited data were available on the chemical analysis and quantity of material removed by the street cleaning equipment operating on the smelter complex and in La Oroya Antigua. For only one day, Feb 19, 2006, was data available on the chemical analyses of the material removed for both streets of La Oroya and areas of the smelter complex. The metal content of the materials collected on this day (Table C.2) was very similar to the two areas. This suggests that the street dust collected from La Oroya was primarily DRP complex material with little dilution from other sources of street dust. On two other days the concentration of lead in the dust collected in La Oroya by the cleaning machines was determined: levels were 24,000 ppm on one of the days and 22,000 ppm on the other. One location of exterior dust sample collection in the HHRE was identified as "near road" and the lead concentration at that location was about 8,000 to 9,000 ppm (Figure ES-2). The geometric mean street dust concentration in US high risk housing areas was 431 ppm (Clark et al 2004).

Table C.2 Metal Concentrations of Material Collected by Street Cleaning Machines Operating in La Oroya and in Smelter Complex (ppm)

Metal	La Oroya	Smelter Complex
Lead	42,000	37,000
Antimony	7,200	7,400
Arsenic	17,000	11,000
Bismuth	1,700	1,200
Cadmium	400	600
Thallium	45.0	30.0

Data provided by DRP for materials collected 19-Feb-06

Vacuum equipment for cleaning streets and sidewalks has been evaluated for use in interventions in Cincinnati Ohio in the late 1980s and recently (Menrath 2005). These interventions were directed towards reducing exposure to lead-containing dusts originating primarily from lead-based paints. The earlier testing indicated that the

machines were capable of removing up to 95 % of the applied leaded dusts. The smaller sized sidewalk-sized equipment selected for the more recent project (TENNANT 3640), a walk behind unit with an optional vacuum wand for cleaning hard to reach areas), removed 80 % of the applied leaded dust. At least weekly cleaning was thought to be necessary.

It is recommended that additional water-spray equipped vacuum street cleaning equipment, be purchased as well as smaller sized units able to maneuver in narrow streets and on sidewalks. We strongly recommend that, once appropriate cleaning units are identified, additional equipment be purchased as soon as possible so that all streets and paved areas can be cleaned at least twice per week. A minimum of two units of each type need to be available to allow for equipment breakdown and maintenance. Availability of parts and maintenance services should be considered in making the decisions on units to purchase. Street dust lead monitoring needs to be conducted to determine if the frequency is adequate. From the schedule for cleaning paved areas on the DRP property, it appears that the areas cleaned are done so daily with some being cleaned two or three times. Time was not available to determine if all paved areas were included in the cleaning program; from visual observations it is evident that the cleaning frequency is not adequate in some areas. DRP provided data indicating that 3857 meters of roadway in La Oroya, with a total area of 25,120 m^2 , were in the machine cleaning program. Areas outside La Oroya need to be included in the street and sidewalk cleaning program. Additional monitoring is needed to made decisions on the areas needing cleaning. Areas along the concentrate transport route are among those that need to be considered.

6.4 SOIL LEAD EXPOSURE MITIGATION EFFORTS

Few efforts were observed that are directed towards controlling exposures of children to contaminated soil. Greatly expanded efforts need to be made immediately to prevent exposure from lead-contaminated soil, particularly to

children with elevated blood lead.. This source is thought to be a critical one for some of the children with very high blood lead. In most cases it may not be technically feasible to remove the soil. Two approaches involving installation of permanent barriers over the contaminated areas after appropriate grading and surface preparation are suggested for consideration- others can probably readily be developed.

The two approaches that are suggested are: constructing terraces that can be filled with low lead soil and converted to relatively flat play or garden areas- Peru has a long history of constructing stable terraces which might be called "Inca Terraces". One such has existed for a number of years on the river bank adjacent to the smelter complex and contains the name of the smelter complex on a grass cover. An example of the type of area where a terrace may be feasible is in the photo below. (**Figure C.7**) Another approach, capping the soil area, after appropriate grading, and applying fabric designed to hold soil in place. This method is being used currently by DRP to cover slag pile areas adjacent to the highway near the slag pile (**Figure C.8**) In some cases, paving may be an appropriate solution such as was done on a heavily used school playground.

Figure C.7 Photograph of Soil Area Where a Terrace May Be Able to be Constructed as a Barrier Over Contaminated Soil

Figure C.8 Photograph of Slag Area That Has Been Covered with a Liner, Soil and Vegetation – a Process Which May Be Able to be Used as a Soil Lead Hazard Control Measure

6.5 INTERIOR DUST LEAD CLEAN-UP IN HOUSING

Most studies of childhood lead exposure find that a large share of the actual exposure occurs inside the housing unit. The dangerously high floor dust lead loadings that have been reported in La Oroya (Cornejo and Gottesfeld 2004) are evidence of the urgency for clean up of interior dust lead. Average floor dust lead loading levels were found to be 335 $\mu g/ft^2$ in La Oroya Antigua and 138 $\mu g/ft^2$ in La Oroya Nueva. Floor dust lead loading levels associated with a goal of less than five (5) percent of blood levels less than 10 µg/dL has been estimated to be about 7 $\mu g/ft^2$, substantially lower than the current US EPA level of 40 $\mu g/ft^2$ (Lanphear et al 1998). At a geometric mean floor dust lead loading of For the children in Herculaneum, a level of 20 $\mu g/ft^2$ has been estimated to be appropriate for the goal of no more than five percent of the children with blood lead levels at or above 10 µg/dL (Sterling and Clark 2004).

In order to be effectively cleaned, interior surfaces (floors, walls, etc) must be cleanable. Wood floors with large cracks between boards, common in some La Oroya homes, cannot be cleaned effectively to remove the dust reservoirs in these cracks and similar spaces. Similarly, porous walls such as those found in adobe houses in La Oroya cannot be cleaned in their natural form. A number of houses have had a plaster

or cement coating applied to the adobe walls. Such treatment, if properly maintained, can result in a wall surface that can be effectively cleaned.

Permanent wall coverings, applied to exterior as well as interior adobe surfaces, need to be urgently evaluated and implemented, particularly for children with high blood lead. [This recommendation is similar to Item No. 67 regarding the PAMA Extension Request materials]. Similarly, a program to make floor surfaces cleanable needs to be developed evaluated and applied to housing of children with elevated blood lead levels. The effectiveness of the current house cleaning efforts used in La Oroya Antigua needs to be evaluated by floor dust lead loading monitoring before and after the cleaning.

7.0 STANDARDS FOR METAL CONCENTRATIONS IN SOIL

Soil standards have been established by the US EPA for lead in residential areas. For bare areas the standard is 400 ppm; for other areas of the yard it is an average of 1200 ppm (USEPA 2001). The State of New Jersey Department of Environmental Protection (May 4, 2006) has proposed soil standards for residential and non-residential areas for a number of chemicals expressed as mg/kg (ppm). The values, for residential and non-residential areas respectively, are: antimony 31 and 450, arsenic 0.4 and 2.0, cadmium 34 and 560, lead 400 and 800, and thallium 5 and 70.

The US EPA (USEPA Soil Screening Guidance 2006) has established a system for establishing Soil Screening Levels that can be used as clean-up goals for sites to protect populations exposed to hazardous constituents in soil. Procedures are available to adapt these levels to specific areas if appropriate data are available. Otherwise, Generic soil screening levels that have been developed can be used. These generic soil screening levels are compared to those of the State of New Jersey in Table C.3.

Table C.3 Standards for Metal Content in Residential Soil (mg/kg)

Metal	US EPA Generic Soil Screening Levels[a]	New Jersey Proposed Soil Standards[b]
Lead (Pb)	400	400
Arsenic (As)	0.4	0.4
Cadmium (Cd)	78	34
Antimony (Sb)	31	31
Thallium (Tl)	Not available	5

[a] U.S. EPA Soil Screening Guidance (2006) and U.S. EPA (2001).

[b] State of New Jersey Proposed Soil Screening Standards (2006).

It is recommended that the US EPA generic soil screening levels be utilized for the La Oroya area and those for New Jersey be used for thallium since a US EPA values has not been established.

8.0 ADDITIONAL ENVIRONMENTAL STUDIES NEEDED.

8.1 AREA-WIDE SOIL LEAD ASSESSMENT

Little is known about the soil lead levels throughout La Oroya and the surrounding communities; the Human Health Risk Assessment, for example, only analyzed soil from nine locations, each at two times. It is very important that a comprehensive area-wide soil lead assessment be performed in the near future. [This recommendation is similar to Comment No. 43 on PAMA Extension Material]. This would help identify "hot spots" of exposure to children and would serve as a useful guide in developing a remediation plan for the entire area. Field portable X-Ray Fluorescence technology has greatly advanced in the past decade and instruments is now available that would permit such a survey to be performed in an expeditious manner.

Based on my experience and that of others, a combination of *in situ* XRF determinations and selected sample collection for later XRF analyses after sample sieving and for quality control purposes would be an appropriate procedure. A portion of the samples for laboratory analyses could also be analyzed by another method such as atomic absorption. Initial efforts should begin in areas where the children with high blood lead reside.

Housing conditions vary widely in La Oroya Antigua and likely in other communities as well.

8.2 HOUSING CENSUS

Results of the census of housing that has been performed should be reviewed to determine what gaps exist in knowledge of housing- such as availability of a public water supply and bathroom facilities in the home and structural integrity. An assessment of possible reservoirs of contaminated dust in the housing-

such as below floors and in other inaccessible areas could be included in the survey.

It was observed that a number of the houses on the hillsides appear to have structural defects related to the topography which may preclude or limit remediation efforts in the house.

8.3 PROVISIONS FOR WATER SUPPLY AND WASTEWATER DISPOSAL SYSTEMS

Adequate replacement housing needs to be located or created for occupants of structurally unsound dwellings, taking into residents preferences for neighborhood characteristics (availability of shops etc.). A survey is needed to assess the number of houses that may need to be replaced. Provisions for public water supply and wastewater collection and treatment facilities are needed for a number of reasons including for implementing on-going interior and exterior dust remediation efforts.

8.4 POSSIBLE IMPACT OF HUANCHAN SLAG STORAGE

Possible impact of the Huanchan slag storage area on the environment needs further investigation. Bioavailability tests should be performed on dustfall samples from this area and from other areas such as La Oroya Antigua to attempt to verify the common assumption that the vitreous nature of the slag makes the contents relatively unavailable. Samples of slag produced at various times in the past can be examined to determine the stability of the slag materials. [This recommendation is similar to Item No. 11 in the comments assembled by MEM regarding the PAMA Extension Materials].

9.0 OTHER RECOMMENDATIONS

The excess cancer risks from the exposures over a lifetime are estimated in the HHRA to be as high as two in one hundred, much higher than the *US EPA* acceptable range of one in ten thousand to one in one million. Since the exposures result from the smelter complex operations, occupational exposures would be expected to be much higher than residential exposures.

9.1 HEALTH STUDY OF PRESENT AND FORMER SMELTER COMPLEX EMPLOYEES

A health study of present and former smelter complex employees is needed since it may yield important information on the extent of cancer risks due to DRP, and effects of other emissions such as sulfur dioxide, and it is strongly recommended that one be undertaken. Such a study should include an assessment of current health condition of employees and a mortality study of the causes of death of former employees. A feasibility study should be conducted initially to determine the type and quality of information recorded on death certificates and whether it can be supplemented by other sources.

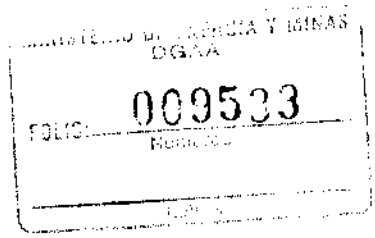
The relative stability of the population should be helpful in the conduct of the study. [This recommendation is similar to comment No.66 on PAMA Extension Material, which states that DRP should do a complementary human health risk study].

9.2 STUDY OF EFFECTS OF SULFUR DIOXIDE AND PARTICULATES ON POPULATION OF THE COMMUNITIES

The impact of exposures to sulfur dioxide and particulates on populations living at high altitudes does not appear to be well known and hinders a more accurate assessment of the health impact of DRP on residents. According to CDC (2005) the La Oroya health clinic data indicates a high morbidity rate of respiratory illness among

local residents. There are reports of difficulties in climbing steps in the community during periods of time when sulfur emissions from the smelter complex are noticeable.

A well planned health study of the impact of sulfur dioxide on the respiratory and other systems of the local population should be conducted. Experts in lung function at high altitudes should be involved.



10.0 ADDITIONAL QUESTIONS PRESENTED APRIL 13, 2006.

Actual questions are paraphrased.

1. Acceptable levels of cancer risk:

The range of "acceptable risks" according to the US EPA is cited in the HHRA and is one in ten thousand to one in a million. Risks estimated by the HHRA are in many cases much higher than this range and should be progressively reduced.

2. What are the blood lead changes resulting from planned DRP improvements?

The modeling in the HHRA is not adequate to make such predictions with confidence because of limitations discussed in Section 5.0.

3. Give your opinion on the need for a new study, time frame, type and new elements.

These are described in Section 5 with background information included in Section 4. A study focused on the broader community, beginning with past and present smelter complex employees is discussed briefly in Section 10. The new evaluation of the effects of lead exposure on children would include such new inputs as child-specific air lead data (can be developed from the air dispersion model as modified by recommendations in this report), interior floor dust wipe data (it is possible that such data may be available from two recent studies in La Oroya), exterior dust lead loading and neighborhood/house soil lead level. The entire study should be able to be accomplished within one year.

4. Is it appropriate to focus on children 6 mos. to 6 years and pregnant women?

Children in that age range are vulnerable for several reasons: brain development is much higher (particularly up to two years of age), behaviors are most likely to favor

lead intake, and lead absorption is higher in this age range. This age range is not precise and does not fit every child's developmental and behavioral patterns. Pregnant mothers pass their lead on to their babies during gestation; birth weight tends to decline with increasing blood lead of the mother. Most lead is stored in the bones so that even after blood lead declines, the major portion of the lead remains in the body.

5. Agreement between Health Ministry and DRP only applies to La Oroya Antigua. Is this agreement important and is the area restriction important?

Yes to both. Although the agreement seems to be focused more on treatment of children with elevated blood lead and not on environmental remediation efforts, it does involve two important stakeholders and is performing useful functions. Since children in other areas are now being reported to have elevated blood lead, efforts should be made to expand the geographic scope of the agreement. Other emissions from the plant extend far beyond La Oroya Antigua as the air monitoring indicates and the health effects on populations in this expanded area need to be understood and appropriate remediation efforts undertaken.

6. What should the outcomes of the epidemiologic studies being done by DRP and the Health Ministry?

Some ideas were discussed in Section 5.0 and Section 10.0.

7. Sulfur dioxide effects.

Same response as above.

8. How to verify risk reduction from exposure to heavy metals and sulfur dioxide? Effects of sulfur dioxide exposure?

Actual monitoring data is important for the first part of the question and the HHRA documents the latter from the literature.

9. Need for evaluating heavy metals in adults?

A study of present and former smelter complex workers would be useful for this purpose.

10, Dietary recommendations to reduce exposure to sulfur dioxide.

Briefly, protecting food from contamination from the market to the preparation to consumption. Lack of potable water in some homes will limit the ability to do this.

11. Life expectancy due to sulfur dioxide?

See HHRA. Specific information re La Oroya is not available.

12. What is your opinion regarding how soil, exterior and interior dust are being monitored.

Only limited soil samples appear to have been collected. In some cases a surface scraping was the collection method. It is preferable to also collect a top 2.5 cm core sample. Hammer attachments for soil corers make sampling in compacted soils practical. We have sampled throughout cold winters using such attachments which are available from Art's Manufacturing Co. and probably elsewhere. For interior dust, the standard USEPA/HUD dust wipe method which provides a result in lead loading per unit area is appropriate to use as the standard interior dust collection method. Interior dust lead loading should be determined prior to and subsequent to house cleaning to determine if the cleaning is effective and how persistently the impact is maintained. I was not able to determine if such monitoring is currently performed. The street dust collection procedure should be one that can produce results in terms of lead loading, μg of lead per unit area. The external dust standard currently in use in the US is 400 μg lead per sq ft and is usually applied to areas just outside the entrance to the house. The official US HUD method uses a wipe to collect the sample. The wipe method has

been compared to two vacuum methods. One was developed at the University of Cincinnati and has been used to determine exterior dust lead loadings in a number of communities across the U.S. Another vacuum method was developed by a US EPA contractor for use in determining street dust lead loadings in Herculaneum, Missouri, location of a Doe Run lead smelter. Published methods are available to collect exterior dust sample to determine dust lead loading (US HUD (1995), Clark et al 2004). It is critical that street dust lead monitoring be performed to determine if the cleaning is effective and if the cleaning frequency is adequate. [This comment is similar to Comment No. 42 on the PAMA Extension Request Materials].

13. Give opinion re use of phosphates to reduce soil lead bioavailability.

This method still appears to be experimental and its long term effectiveness is unknown. Pursuing this method should not be a major part of the soil exposure mitigation effort. Preferable methods involve either removal of contaminated soil or placing a barrier over the contaminated soil. The former method has the drawback of increasing exposure during implementation and can be practically limited on steep slopes such as in the La Oroya area. Two suggestions for permanent coverings are presented in **Section 7.0**.

14. Attention needed for various age groups concerning lead exposure.

See response to 4.

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Submitted by Scott Clark

C. Scott Clark

May 10, 2006

Exhibit E

Excerpts from Remediation of the Areas Affected by Emissions from the CMLO, Todd Hamilton, GWI, Lima, May 13, 2009

Remediation of the Areas Affected by Emissions from the CMLO (La Oroya Metallurgical Complex)

Lima, May 13, 2009

Presenter: Todd Hamilton, GWI

Evaluation of Risk to Human Health

Lead	Arsenic	Antimony and Cadmium
Direct contact with the soil surface and pica behavior represent the main health concerns. There is a significant probability (24 to 96%) that a child in any of the communities of interest evaluated will have levels of blood lead above 10 µg/dl based solely on exposure to contaminated soils. The nutritional status of children is an important factor that can regulate the effects of lead absorption and toxicity.	Estimates of incremental lifetime cancer risks range from 2.5 cancers in 10,000 people and 2.2 cases of cancer per 1,000 people as a result of exposure to inorganic arsenic in the soil. This inorganic arsenic in soil may be readily bioavailable (for example, 68% of inorganic arsenic is available in drinking water). Accidental ingestion of soil by children ranges between 31 and 91 mg/day.	Exposure to antimony and cadmium by contact is not considered a significant risk to human health, in comparison to lead and arsenic. Noncancer risks to health are below the HQ (Hazard Quotient) value of 1.0 for children in all scenarios. Incremental lifetime cancer risks resulting from exposure to cadmium by inhaling fugitive dust particles were less than 1 case of cancer per 100,000 people.

To sum up: Risks to human health because of contaminated soil in CDI are unacceptable.

Remediación de las Áreas Afectadas por Emisiones del CMLO

Lima, 13 de mayo de 2009

Presentador: Todd Hamilton, GWI

Evaluación de Riesgo para la Salud Humana - Resultados

Plomo	Arsénico	Antimonio y Cadmio
• El contacto directo con la superficie del suelo y comportamiento pica representas la preocupaciónes principal para la salud. • Existe una probabilidad significativa (entre 24 y 96%) de que un niño presente niveles de plomo en la sangre por encima de 10 µg/dL en todos los comunidades de interes evaluadas, solo en base de la exposcion a los suelos contaminados • El estado nutricional de los niños es un factor importante que puede regular los efectos de la absorción de plomo y la toxicidad.	• Los riesgos incrementales de cáncer en el periodo de vida estimados fluctúan entre 2.5 casos de cáncer en 10,000 personas y 2.2 casos de cáncer por 1,000 personas como resultado de la exposición a arsénico orgánico en el suelo. • El arsénico inorgánico presente en suelos puede ser fácilmente bioaccesible (por ejemplo, el 68% de arsénico inorgánico disponible en agua potable). • Ingesta accidental de suelo en niños fluctúa entre 31 y 91 mg/día.	• Las exposiciones a antimonio y cadmio debido al contacto, no son considerados un riesgo significativo para la salud humana en comparación con el plomo y el arsénico. • Los riesgos no cancerígenos para la salud se encuentran por debajo del valor HQ de 1.0 en niños bajo todos los escenarios. • Los riesgos incrementales de cáncer en el periodo de vida resultantes de las exposiciones al cadmio a través de la inhalación de partículas de polvo fugitivas fueron menores a 1 caso de cáncer por 100,000 personas.

En resumen: Riesgos a la salud humana debido de suelos contaminados en CDI son <u>inaceptables</u>