RESULTS OF JUNE 2015 PILOT STUDY

Huancavelica Mercury Remediation Project
Huancavelica, Peru

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Introduction

The Environmental Health Council (EHC) conducted a pilot study from June 28 to July 6, 2015 to address elevated mercury (Hg) vapor and Hg in dust/debris within earthen homes identified in the Remedial Investigation (RI), dated July 30, 2015. Forty five homes were identified in the RI as having either dust and/or vapor from walls and floors above risk-based, site specific screening values.

The EHC conducted a pilot study to test one remedial action alternative consisting of encapsulation of contaminated material and to develop cost estimates for other alternatives. Encapsulation by plastering the walls and putting down a layer of concrete on the floor is a culturally relevant and relatively inexpensive remediation method. The intent of encapsulation is to:

1. Reduce ingestion of contaminated dusts /debris generated from exposed walls and floors.
2. Reduce inhalation exposure to inhabitants by eliminating or significantly reducing vapor migration from walls and floors into the indoor air space,
3. Reduce exposure to other heavy metals such as arsenic (As) and lead (Pb) in adobe walls and floors.

Six of the most-contaminated homes were identified for the study which included Hg vapor analysis pre and post treatment. Six others were assessed for future remedial action. The following report presents the primary activities and results of the pilot study and recommendations for further remedial action. The results of this study will subsequently be incorporated into the Feasibility Study (FS). To our knowledge, this is the first study which has tested, and demonstrated the efficacy of, this remediation technique on earthen homes contaminated by mercury. Such a method could also be used in other regions where similar conditions exist.

Background

The EHC completed a Remedial Investigation in July 2015 which summarized several assessments conducted between 2009 and 2013 addressing mercury contamination in homes, indoor air, and local food, soil, and sediment. The RI also incorporated a risk assessment which defined the risk to occupants of homes contaminated with mercury. The risk assessment did not address other contaminants commonly associated with mines and mineralized zones, such as arsenic and lead. This report provides a preliminary assessment of those heavy metals.

The results of the RI warranted assessment of treatment options for the homes as well as additional assessment of homes for mercury and other heavy metals. Thus, the EHC conducted a pilot study to assess encapsulation of contaminated walls and floors and this report provides the primary results of that study, which was conducted in June and July of 2015.

Site Description

The city of Huancavelica is located in the Department of Huancavelica, Peru in the central Andes at an elevation of approximately 12000 ft (3,676 meters) above mean sea level (amsl). Situated in the Ichu River valley, approximately 48,000 people, live in the city, and about 52% of them live in adobe or rammed earth homes (2007 Censos Nationales). The Site refers to the city of Huancavelica and includes five neighborhoods (Ascención, Yananaco, Santa Ana, San Cristóbal and Santa Bárbara), all from which various samples were collected during several phases of the RI. Hg contamination throughout the city has affected different areas in varying magnitudes. Figure 1 presents a Site Location Map and Figure 2 presents a Site Map with approximate extents of the Site, neighborhood boundaries, and other significant features. Future assessment work may include nearby communities such as Sacsamarca, where preliminary vapor analysis conducted during the Pilot Study indicated elevated Hg vapor near tailings exposed along the margin of the town plaza.

Additional background, site information, and details of the remedial investigation and associated risk assessment can be found in the RI (July 30, 2015).

Home Selection

Homes were selected using a ranking system which prioritized the most contaminated homes. The four media (walls, floors, dust, and indoor air vapor) assessed in the RI were used to create a simplified ranking of the homes. Other elements such as the presence of children in the home or if a wall or floor was covered was also included in the calculation. The following are the elements of the ranking calculation:

- Percent exceedance of a screening value was calculated per home per media result.
  - Walls – percent over the screening value
  - Floors – percent over the screening value
  - Dust – percent over the screening value
  - Vapor – percent over the screening value
- 100 points was given to each child in a home
- 10 points were given to a house with uncovered (by stucco) walls
- 10 points were given to a house with uncovered (by concrete) floors

A ranking table of the homes assessed in the RI is presented in Appendix A. It should be noted that the value given to the presence of children was simply based on a rough estimation of percentage exceedances of each media. The intent was to equally weight the presence of children to the general exceedance of the screening values, thereby allowing both an exceedance of a screening value and the presence of a child to have a similar weight in the ranking. Since most homes in the study had exposed walls and floors, there was little significance of including whether or not a wall or floor was covered.

It should be kept in mind that just because a wall or floor was covered prior to treatment does not mean that the home was treated to the standards expected to be protective of human health. Many homes have partially covered or stuccoed walls, some have temporary floor coverings such as rugs, or wall coverings such as plastic sheeting, none of which meet the standards required for current and future protection of human health.

Each media percentage exceedance was summed which provided a range of 28% to 3030% exceedance of screening values. Then the children values were added, along with the wall and floor covering values. All 60 homes were then ranked from high to low of the final summed values.

It should be noted that the term "home" is used in this document to represent a household which may have one or more rooms. The home identification numbers such as YA-3 represent the whole household. Although each room was assessed and compared to screening values individually, the original ranking was based on results of assessment of the whole household and not a specific room within that household.

Upon completion of the ranking, the top twelve homes in the ranking were chosen for additional evaluation. Within this group, ten of the homeowners opted to participate in the remediation phase and signed informed consent documents to that effect consistent with the Duke University Institutional Review Board protocol under which the project has been conducted. Of these, the six most contaminated were remediated during the June/July 2015 event, and the remaining four are pending funding. The generic identification for the homes is as follows:

YA-3, Yananaco
YA-11, Yananaco
YA-6, Yananaco
AS-4, Ascension
SC-2, San Cristobal
SC-3, San Cristobal

Additionally, six of the next ranked homes were assessed for indoor Hg vapor during the pilot study in support of future remedial action.

Coordination with Association Nuevavelica/local support

The EHC implemented the remediation work in concert with the EHC's local partner, the Asociación Nuevavelica (AN), a local environmental non-profit, which assisted in project organization, outreach and implementation.

Sampling and Analysis

The following section presents the sampling and analysis activities, including the type of equipment used, analysis parameters, quality assurance measures, background analysis, and the general activities of the field assessment program. The results of the study and discussion are presented in the Results of Investigation section below.

Field Assessment Program

Hg Vapor (Indoor and Background)

On June 29, 2015 the EHC/AN began analyzing the six priority homes for Hg vapor using a Lumex RA 915+ Hg vapor analyzer (Lumex). Specific rooms within the household were analyzed individually. The Lumex detection limit is 2 nanograms per meter cubed (ng/m^3). Analysis was conducted prior to treatment of the homes by spot checking walls, floors, and corners of homes by holding the analyzer intake a few cm above the floor, or a few cm away from the walls, with a final analysis for 4 minutes with the windows and doors closed. The 4 minute analysis was conducted with the analyzer placed about 40 cm above the floor in the center of the room.

In addition, the analyzer inlet was placed within several cm of areas on walls and floors that were scuffed or disturbed just prior to analysis. This was done as means of determining if the surface was either acting as an encapsulation layer or if the surface material had lower volatile Hg levels in comparison to "fresh" undisturbed wall and floor material. Analysis for disturbed floors and walls was done after the 4 minute run time analysis.

Other information at each house was collected, such as latitude/longitude, owner, use of rooms, presence of tailings at or nearby the home, or other factors that may have influenced the Hg vapor results.

The following presents the general layout and naming of the rooms per household:

- YA-3 consisted of 4 rooms, first floor south, first floor north, second floor south, and second floor north.
- YA-11 consisted of the east room and the west room
- YA-6 consisted of one room
- AS-4 consisted of the west room which was the only room in the study with wood walls, and the east room
- SC-2 consisted of one room
- SC-3 consisted of a partially walled room (referred to as an open air room in the field notes), and a fully-walled room like the others.

Each of the six homes that were planned for treatment (presented above) had initial pre-treatment analysis conducted at least once on June 29 and/or June 30, 2015. Once the homes planned for treatment were initially assessed, additional homes in the ranking were assessed for potential future remedial action. These included SC-4, SC-1, SC-18, SA-9, YA-32, and AS-14 which were assessed on July 2, 2015.

Each day during the field program, usually in the morning before assessment of homes, the Lumex was tested using the on board Hg test cell following the procedures outlined in the Lumex operations manual (Appendix B). Test cell results are tabulated in the QA Table in Appendix C. When the Lumex was not fully warmed up, the R (%), or the relative deviation from test cell concentration, was out of operable range (above 25%), the Lumex was allowed to continue warming up before use. Generally it took about 30 minutes in the morning to reach acceptable R (%) values below 25%. The tabulated QA results are for test cell analysis are presented in Appendix C. Occasionally the test cell analysis was conducted in the afternoon as another quality assurance check.

Several times throughout the day, background outdoor air was analyzed. This occurred at the Plaza de Armas in the mornings prior to beginning the daily house analysis routine. Background outdoor air was also analyzed outside of the homes in the pilot study immediately prior to or immediately following analysis. Background was generally analyzed on a 30 second run time several times at or near the home to be analyzed. Occasionally background was analyzed on a 4 minute run time, but no appreciable difference in results was noticed between run times of 30 seconds or 4 minutes. Background results are presented in the field notes and tabulated in Appendix C.

Upon completion of treatment, which is further explained below, the indoor air of the treated homes was analyzed again following the pre-treatment protocol, 4 minutes within the center of the closed room about 18 inches above the floor. An attempt was made to mimic the same conditions as the pre-treatment analysis. However, some furniture, cooking equipment, and personal belongings were in the homes during pre-treatment analysis. All of the homes analyzed post treatment were empty.

Rock/Soil Samples for Total Metals

Fifteen soil/rock/adobe samples were collected from various locations in and around Huancavelica for analysis of additional heavy metals using inductively-coupled mass spectroscopy. Samples were collected by chipping stone fragments from the rocky material or hand excavating from soil/adobe and placing the material in new clean plastic bags. Samples were analyzed for a number of metals, however the heavy metals of concern (As, Hg, Pb) are the only ones presented in this report.

Removal Work

Subsequent to relocation of residents, the removal of all property, the completion of analysis of indoor air and a Health and Safety Plan (HASP) meeting, EHC's contractor, civil engineer Edwin Cardenas, and his crew began treatment of the walls and floors of 6 homes (YA-3, YA-11, YA-6, AS-4, SC-2, and SC-3). Treatment of homes began on July 1st, 2015, and was complete on July 5, 2015.

A minimum of about 1 cm of gesso/plaster was placed on the walls from the edge of the ceiling/wall location to about 30 cm above the floor surface. Plaster was initially thinned with water and "splashed" on the walls to prepare the surface for the thicker final layer of plaster. Local municipal water was used for mixing with plaster. Plaster was placed as close as possible to the ceiling/wall connection, but in some cases, small amounts of earthen wall remained exposed in this area. The plaster used was a gypsum (CaSo4*2H2O)-based plaster.

Concrete was mixed on site with Portland cement and a sand and gravel mix which came from an alluvial quarry along the Ichu River upstream of the edge of town.   Earthen floors were leveled prior to placement of concrete. Completed floor thickness were a minimum of 8 cm (3 inches) and concrete was used to connect the floor to the wall plaster with a "stub" wall of sorts which consisted of a 6 to 10 cm thick concrete wall ranging in height from about 30 to 40 cm about the finished floor. The "stub" wall generally protruded from the completed plaster wall by about 5 cm.   In at least one home, the terraced nature of the earthen floor was handled by simply terracing the concrete over the approximate meter wide terrace and placing concrete on the face of the terrace.

Home SC-2 was treated differently than the rest of the homes, and received a concrete facing on the walls instead of plaster. Once SC-2 was completed with concrete floor and walls, the surface of the concrete was treated with a siloxane/water mixture. Siloxane is a water-based silica treatment used to seal porous masonry and porous rock materials. Siloxane sealant was purchased at a retail building supply store in Lima.

Results of Investigation

Background Results

Approximately 76 individual outdoor background Hg vapor readings (concentrations) were collected by the Lumex throughout Huancavelica during the project. The 76 readings ranged from 2 to 150 ng/m^3, with an average of the 26 ng/m^3. The four highest readings, all above 100 ng/m^3 were collected in locations that were presumed to have increased Hg vapor sources such as areas where recent roadwork was conducted, or in close proximity to known tailings. If those readings are considered anomalous and removed from the background dataset, the average is 22 ng/m^3. The geometric mean of the dataset is 21 ng/m^3, which is similar to removing the anomalous readings by means of weighting each value equally, thus the great number of readings in the 10 to 30 range provides a more appropriate average for the dataset.

Average global atmospheric Hg vapor concentrations in areas that are uninfluenced by Hg sources, range from 1.3 to 1.5 ng/m^3 in the northern hemisphere and 0.9 to 1.2 ng/m^3 in the southern hemisphere (Position Paper on Mercury, European Union). Regardless, based on the thorough background dataset, the geometric mean of 21 ng/m^3 will be considered the background Hg vapor concentration for the pilot project. This is approximately 20 times above the global average. It should be kept in mind that the background Hg vapor concentration is used merely for a reference level to identify potential Hg vapor sources.

A general review of the dataset suggests that vapor concentrations above 50 ng/m^3 may be related to a localized source of Hg. Certainly readings above 100 ng/m^3 are very likely representative of a localized source. At thirteen background sample locations, three or more consecutive readings of 30 seconds or more were collected in order to identify stabilization of readings. Most of the sets had less than 10% change between readings, suggesting that the analysis was stable, at least at the lower concentrations.

There were no diurnal trends in the background Hg vapor dataset, nor were there any trends that suggested any obvious influences from other parameters such as elevation, temperature, soil moisture, winds or stillness of the air, or other factors.

House Results

Pre and post Hg vapor readings (concentrations) are presented in Tables 1 through 6, per individual home. Generally pre-treatment Hg vapor readings were above The World Health Organization (WHO) screening value for chronic exposure of 200 ng/m^3. Home-specific pre-treatment Hg vapor readings including Jerome 431x and Lumex readings, are presented below:

YA-3 – ranged from 177 to 322 ng/m^3
YA-11 – ranged from 74 to 408 ng/m^3
YA-6 – 434 ng/m^3
AS-4 – 41 and 98 ng/m^3, during floor leveling Hg vapor was measured at 5000 ng/m^3
SC-2 – ranged from 96 to 1798 ng/m^3
SC-3 – 47 and 77 ng/m^3

Percent reduction in Hg vapor, post treatment of walls and floors, ranged from -64 to 380% for the homes. Hg vapor reduction for multiple rooms per household were summed for the household. Jerome 431x results were not included in the percent reduction calculations because of the lower resolution of the equipment in comparison to the Lumex. Also, only two of the homes had detections on the Jerome. The Lumex has a very high resolution and minor fluctuations, caused by changes in ambient air, minor sources, or other factors that affect the Lumex at the ng/m^3 level can appear to be magnified. With this in mind, emphasis should not be put on trends in results that are below about 100 ng/m^3 level.

Two of the homes had negative reductions, in other words Hg vapor was slightly higher after treatment than prior to treatment. Four of the homes had reductions in Hg vapor which ranged from 16 to 334%. House YA-3 had a reduction of 77%, YA-11 had an increase of 64%, YA-6 had a reduction of 334%, AS-4 had a reduction of 16%, SC-2 had a reduction of 380%, and SC-3 had an increase of 48%. Individual results for each room analyzed at the household are presented in the tables.

All of the rooms of each of the households had final Hg vapor concentrations below WHO screening value for chronic exposure of 200 ng/m^3. The WHO screening value was determined in the RI to be the site-specific screening value/action level.

During pre-treatment analysis in each of the homes, readings in all the homes were collected several cm above the floor immediately after scuffing or scratching the floor. Generally Hg vapor concentrations briefly increased. In addition, during floor leveling of the west room of AS-4, Hg vapor concentrations in the breathing zone were sustained at about 5000 ng/m^3. This suggests that the undisturbed surface had either decreased elemental Hg in the soil, or a less permeable layer at the surface of the soil. This is an important factor that may be responsible for temporal increases in Hg vapor during construction and may be responsible for the slight increase in Hg vapor concentrations post treatment. Post treatment analysis was conducted at most 2 to 3 days post treatment due to the constraints of the field event. Concrete and plaster were not fully cured, which could also be partially responsible for the slight increases in Hg vapor.

Additional Hg vapor analysis should be conducted on the homes in the future as a means of determining temporal/seasonal fluctuations as well as to evaluate if the Hg vapor reduces further once concrete and plaster have cured fully. It should be noted that ng/m3 (parts per trillion) levels are at the lower end of the detection range of the Lumex and minor fluctuations may not be representative of the true Hg vapor in the air being assessed.

Treatment of the walls and floors consisted of a layer of clean material (plaster and concrete) which essentially eliminates the exposure of the residents to particulate bound Hg in dust or other debris from the walls and floors. Dust was very noticeable within the homes before treatment, reflecting the age, limited cohesiveness of adobe/tapial materials, and general use of the home. Dust, wall material, and floor material were identified in the RI as having Hg above risk-based concentrations for incidental ingestion. Therefore, encapsulation (treatment of floors and walls) is an effective method to significantly reduce or eliminate concentrations of particle-bound Hg and in dust and debris originating within the home. In addition, other heavy metals that may be co-located with Hg in walls and floors, are also essentially eliminated from the incidental ingestion pathway. Further discussion on As and Pb results are presented below. The only area's with some exposed earthen wall in some of the homes is where the ceiling meets the wall, although this area is very limited.

Without analysis for total Hg in plaster and concrete, it is not likely total Hg in the plaster and concrete is above the site-specific screening value/action level of 75 milligrams per kilogram (mg/kg) (RI, 2015). General building materials such as gypsum and Portland cement are not likely to have heavy metals at levels above human health screening values.

Additional analysis of dust in the home after a year or two could reveal whether additional contaminated dust has either been released from the ceiling or wood beams, or if dust has come into the home from outside sources. Although external sources are difficult to control, with proper hygiene and cleaning, this exposure can be significantly reduced.

The additional six homes that were not treated had mercury vapor results for a 4 minute reading ranging from 50 to 656 ng/m^3 (Lumex results, only). Individual results are below:

- SC-4 – 656 ng/m^3 with a high of 900 ng/m^3 where floor was scuffed
- SC-1 – 54 ng/m^3 with a 2010 Jerome reading of 1080 ng/m^3
- SC-18 – 62 ng/m^3 with a 2010 Jerome reading of 1080 ng/m^3
- SA-9 – 50 ng/m^3 with a 2010 Jerome reading of 1080 ng/m^3
- YA-32 – 88 and 80 ng/m^3 (two rooms) with a high of 270 ng/$m^3$where the wall was scuffed
- AS-14 – 169 ng/m^3 with a 2010 Jerome reading of 480 ng/m^3

These results indicate that each of the six homes require treatment. In addition, exposed floors and walls of most of the homes in the original 60 homes in the RI, suggest that particulate-bound Hg is elevated above screening levels, further requiring the need for treatment.

Results of Rock/Soil/Abode Samples

Rock/Soil samples results for total metals are presented below per metal:

- Arsenic (As) results ranged from 12 to 1060 mg/kg, with the higher concentrations found in the travertine rock samples or the tailings (calcine) material. Concentrations in travertine samples ranged from 530 to 887 mg/kg and in calcine samples from 436 to 562 mg/kg. Background As was not determined yet is likely higher than background levels commonly found in the US (roughly 10 to 20 mg/kg). The US EPA Regional Screening Level for As in soil is 0.39 mg/kg for a 30 year residential exposure period. Generally most cleanup sites in the US and likely elsewhere in the world cannot meet this level simply due to background concentration being an order or two greater.

- Mercury (Hg) results ranged 0.7 to 206 mg/kg, with the higher concentrations found in calcine material. Concentrations ranged from 107 to 246 mg/kg in calcine material or floor material that appeared to be heavily impacted by calcine.

- Lead (Pb) results ranged from 7 to 179,300 mg/kg, with the higher concentrations found in calcine material. Concentrations ranged from 828 to 179,300 mg/kg in calcine material, or floor material that appeared to be heavily impacted by calcine.

Generally elevated heavy metals of concern (As, Hg, and Pb) were associated with calcine or calcine impacted material (walls and floor material with some reddish/pinkish rocks). Travertine, which is precipitated from mineral-induced groundwater, had elevated As, which is not surprising as As is often elevated in groundwater in mineralized zones in volcanic provinces. With this in mind, walls and floors that are constricted of tailings or travertine, may have As and Pb above screening levels for residential use.

Remedial Action Costs

The following section provides a preliminary evaluation of remedial action costs which can be further refined for a focused FS. The remedial action conducted during the pilot study, consisted of installing a concrete floor over an earthen floor and covering the earthen walls with plaster. This will be referred to in the cost evaluation as encapsulation. Both components are locally available and are common final construction attributes to earthen homes in this area. Often the home owner does not have the funds to complete a house to this standard, thus the walls and floors remain exposed. Locally derived and locally accepted treatment methods are important aspects in an FS.

The average cost to encapsulate the floors and walls (during the June/July 2015 pilot study), was about 1231 US dollars (USD) per home. This equates to about 6.5 USD per square foot of home. This alternative includes:

- Logistical preparations
- Temporary relocation of residents
- Material for concrete floor, including earthen floor leveling
- Material for plaster walls
- Installation of concrete floor and plaster walls

Preliminary cost evaluations of this and other remedial action alternatives were prepared for this report and are as follows in order of least cost to highest cost:

1. No action – no cost, or limited costs for the home owner, which may be due to attempts to cover walls with plastic sheeting, or paper.

2. Encapsulation (concrete floor and geotextile/plastic wall covering) – consists of covering the floor with concrete and the walls with geotextile (heavy plastic sheeting). Estimated cost is about 1002 USD per home.

3. Encapsulation (concrete floor and plaster walls) – consists of covering the floor with concrete and the walls with plaster which was tested in the pilot study. Estimated cost is about 1231 USD per home.

4. Remove and replace home – consists of completely removing the home and replacing with new uncontaminated material. Estimated cost is about 17,300 USD.

Detailed cost breakdowns for the different remedial action alternatives are presented in Table 8. Preliminarily, based on the effectiveness of the tested remedial action alternative (encapsulation with concrete and plaster) as identified in the pilot study, the encapsulation method of concrete and plaster appears to be an effective alternative that will be protective, long-term, reliable, implementable, culturally relevant and moderate to low cost. This information will be incorporated into the focused FS and will include a detailed evaluation of standard FS balancing factors.

Conclusions and Recommendations

The EHC and AN conducted a pilot study in June and July 2015 to assess the efficacy of encapsulation of contaminated walls and floors in six mercury-contaminated earthen homes in Huancavelica, Peru. The results of this study are presented in this report and support completion of a focused FS that will identify the most cost effective and protective remedial action for Hg-contaminated homes in Huancavelica. In addition, analysis of soil, adobe and rock for other heavy metals were further evaluated during the pilot study and have also been included in this report. The results of the pilot study are summarized below:

- Mercury vapor was analyzed in ambient outdoor air for determination of a background concentration (21 ng/m^3). This is twenty time above global background levels.

- Mercury vapor in six homes was analyzed before the home was treated using the encapsulation method of installing a concrete floor and plaster or cement walls. Mercury vapor reductions ranged from 16 to 280%, with two homes having a slight increase in Hg vapor. Final Hg vapor concentrations in each of the treated homes, was below the WHO screening value of 200 ng/m^3 for chronic exposure.

- Mercury vapor was analyzed with the Lumex in six other homes that were not treated during the pilot study, with readings ranging from 50 to 656 ng/m^3.

- Samples of tailings, travertine, soil and adobe (common building materials in Huancavelica) had elevated concentrations of As, Hg, and Pb, all of which were above screening levels for residential use. Arsenic and Pb were not included in the Risk Assessment, however additional analysis and evaluation is warranted, based on these findings.

Based on the results presented above and supported in more detail in this report, the following conclusions and recommendations are made:

- Treatment of floors and walls with encapsulation such as concrete and plaster is an effective treatment method to reduce or eliminate indoor sources of incidental ingestion exposure to particulate-bound Hg as well as other heavy metals that may be co-located with Hg. It is also, on the whole, effective in reducing inhalation exposure to indoor Hg vapor. Exposure to particle-bound Hg in floors and walls was found to be the higher risk driver in the Risk Assessment. The encapsulation method of installing a concrete floor and plastering walls should be compared to other remedial action alternatives in the FS. This alternative preliminarily appears to be the most cost effective and protective remedy.

- Due to the slight increase of Hg vapor after treatment in two of the homes, additional periodic monitoring of Hg vapor in treated homes should be conducted to determine if the increase is due to curing concrete or residual increases from floor leveling. In addition, activities that disturb earthen floors and walls (scuffing, sweeping, remodeling) can temporarily but significantly increase Hg vapor in the home.

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Disclaimer and Limitations

The lead author of this document works for the Oregon DEQ, yet this report is not endorsed by Oregon DEQ or Oregon Health Authority, nor were State of Oregon funds used in the preparation of this report or the assessment activities associated with this project. The lead author is a registered geologist in the State of Oregon (United States) and as such, this document was prepared following professional standards and ethics associated with the professional certification under the Oregon State Board of Geologist Examiners. There is no religious or political bias in the recommendations and conclusions of this report. The lead author's motivation for developing this report is solely for promoting human welfare.

The information presented in this report was collected, analyzed, and interpreted following the standards of care, skill, and diligence ordinarily provided by a professional in the performance of similar activities as of the time the activities were performed. This report and the conclusions and/or recommendations contained in it are based solely upon research and/or observations, and physical sampling and analytical activities that were conducted. The quality of information, conclusions, and estimates contained herein is based on: i) information available at the time of preparation, ii) data supplied by outside sources, and iii) the assumptions, conditions, and qualifications set forth in this report

Tables

Figures

Appendices