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TECHNICAL MEMORANDUM

DATE: May 23, 2016

TO: Lauri Gorton, METG

FROM: Bob Anderson, Hydrometrics, Inc.
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SUBJECT: Existing Information and Data Compilation for the Former East Helena
                 Smelter Slag Pile Area

1.0 INTRODUCTION

This technical memorandum provides a compilation and summary of available environmental data and other relevant information related to the Former East Helena Smelter slag pile (Figure 1). The purpose of this memorandum is to update the project team with the available information and current understanding of the slag pile in terms of potential contaminant loading from the slag, or from other material(s) potentially located within or beneath the slag pile, to groundwater. Following review by the project team, the information presented in this memo will be used to further evaluate potential corrective measures to mitigate the contaminant loading, if warranted.

1.1 BACKGROUND

Slag is a byproduct of the metal smelting process and was produced at the Former East Helena Smelter (former smelter) from 1888 when the smelter began operation until 2001 when the smelter shutdown. Following crushing and roasting, the ore was mixed with a fuel source (i.e., coke, coal) and various fluxes (calcium and iron sources) in the blast furnace, where the ore was melted and the slag byproduct produced. Nonferrous slag generated through base metal smelting operations, such as the former smelter, is composed primarily of iron, silica, aluminum and calcium, although slag typically contains various trace metals and other constituents present in the feed ore (Piatak et al., 2015).

Two types of slag were produced at the former smelter, fumed and unfumed slag. Fumed slag was generated through operation of the zinc plant from the early 1940s until 1982. The zinc plant recovered zinc oxide from the slag through injection of air into the molten slag. Prior to and after the zinc plant operational period (1888 to early 1940s and 1982 to 2001),

unfumed slag was produced directly from the blast furnace. Due to the distinct time periods that the two slag types were produced, the fumed and unfumed slag are generally segregated in the slag pile. The slag was placed onto the slag pile either as solidified, granular material (gravel to cobble size), in large blocks dumped from pots or crucibles, or as molten slag.

2.0 SLAG PILE CHARACTERISTICS

2.1 SLAG PILE DIMENSIONS AND FEATURES

Expansion of the slag pile over time and the slag pile dimensions were evaluated through review of current and historic aerial photos and maps of the former smelter. Relevant information compiled through the aerial photo and map review includes the location of the slag pile footprint over time, particularly relevant to the periods when fumed and unfumed slag were produced, and pre-existing features now buried beneath the slag that could affect groundwater flow, such as former creek channels and ditches. The aerial photos and maps with relevant features shown are included as Attachment A, with the information summarized in Figure 2.

The current slag pile covers about 45 acres, is 120 feet tall at its highest point, and contains approximately 3,560,000 cubic yards (cy) of slag. The pile topography includes steep side slopes (1.5H:1V or steeper) with the top of the pile generally flat (Figure 3). The flat topography minimizes storm water runoff and increases infiltration into the pile. Although infiltration rates are high, the percolation rate, or amount of deep infiltration reaching the base of the slag, has been estimated to be low considering the lack of surface runoff. Previous analyses using the HELP model yielded percolation rates of 2.36 inches/year (20% of annual precipitation) through a slag thickness of 100 feet, with the majority of precipitation lost to evaporation.

Two large pits are located on the slag pile with both pits located in fumed slag (Figure 3). One pit is located in the northwest corner of the slag pile and is the result of the excavation and use of fumed slag as backfill on the plant site during the plant site demolition program. The pit is about 2 acres in area with the bulk of material (30,500 cy) excavated in 2006 and an additional 12,500 cy excavated in 2015. The current pit volume is about 43,000 cy (Figure 4). The second pit is in the northeast portion of the slag pile and is the result of excavation and use of fumed slag by the Ash Grove Cement Company in the cement production process. The Ash Grove pit is also about 2 acres in size and is actively being mined on an intermittent basis. The two pits may increase infiltration and possible deep percolation of precipitation by concentrating storm water. Deep percolation through the slag pile is of interest due to its role as a possible contaminant transport mechanism from slag to groundwater.

Based on review of historical maps and photos, the unfumed slag is located in two general areas. Unfumed slag generated prior to the early 1940s is located in the south portion of the pile as approximated by the 1941 pile footprint (Figure 5 and Figures A-3 and A-14, Attachment A). The post-1982 unfumed slag is confined to an upper lift on top of the slag

pile (Figures 3 and 5). The upper lift is about 8 acres in size, 40 to 50 feet high, and contains approximately 585,000 cy of unfumed slag. Differentiation of the fumed and unfumed slag is of interest since the unfumed slag contains higher metals concentrations than the fumed slag.

Relevant pre-existing features now buried beneath the slag pile are shown in Attachment A and summarized on Figure 2. The main features of interest are former channels of Prickly Pear Creek, the former Wilson Ditch overflow channel, and former irrigation channels beneath the northwest corner of the pile (Figure 2). Also of interest is a former pond identified in the 1955 aerial photo (Figure A-6, Attachment A) now buried beneath the northwest corner of the pile. All of these features have the potential to influence groundwater flow rates and patterns beneath the slag pile and/or promote groundwater contact with the base of the slag. A groundwater seep has been observed in the past during exceptionally wet periods where an old creek channel daylights along the north side of the pile (DH-10A Area Seep, Figure 2). When sampled in 2010, the seep water had an arsenic concentration of 0.65 mg/L and a selenium concentration of 0.08 mg/L. The elevated concentrations in this sample may be due to contact of the shallow subsurface water with the base of the slag.

2.2 EXISTING DATA REVIEW

Following is a summary of environmental data from the slag pile and surrounding area obtained through various site characterization programs dating back to the 1980s. The data compilation is used in developing a current understanding of the slag pile area conditions, as well as identifying potential data gaps.

2.2.1 Slag Geochemistry

Geochemical characterization of slag has consisted of (1) determination of total element concentrations; (2) determination of leachable concentrations using a variety of batch-type single solution extraction procedures; and (3) determination of geochemical phases of slag using sequential extraction procedures.

2.2.1.1 Slag Total Element Concentrations

Total element concentrations with depth for all slag pile borings are in Attachment B. These data summaries also indicate the type of material sampled (fumed or unfumed slag vs. other material) and the approximate depth of saturated material. Borings with significant numbers of slag samples analyzed include DH-55, DH-56, DH-65, DH-68, DH-69, DH-74, DH-75, and DH-76 (Figure 1). In addition, an investigation conducted in 1997 on a portion of the post-1982 upper lift of unfumed slag in order to assay slag for possible metals recovery included analysis of composite samples from 48 borings within the relatively small area shown on Figure 1.

The geochemistry of the East Helena slag pile is heterogeneous both laterally and vertically, likely due to variations in the feedstock (ore) composition, length of slag placement and weathering, and plant process changes over time. Exhibit 1 presents total arsenic, selenium, and zinc concentrations with depth in slag samples (and underlying sediments) for borings

DH-55, DH-56, DH-65, DH-68, DH-69, DH-74, DH-75, and DH-76, along with a schematic cross-section showing locations of fumed and unfumed slag. Average concentrations of arsenic, selenium, and zinc are also shown on Exhibit 1 for unfumed slag (both the pre-early 1940s deeper layer and the post-1982 upper lift), fumed slag, and underlying sediments at each boring. Summary statistics (minimum, maximum, and average concentrations) for total arsenic, copper, lead, selenium, and zinc are presented in Table 1 for older (pre-1940s) unfumed slag, younger (post-1982) unfumed slag, and fumed slag. Note that, as shown on Exhibit 1, boring DH-55 is located above the approximate older unfumed /fumed slag contact at depth. Based on the observed total metals concentrations in slag at DH-55 and their similarity to other fumed slag samples, the deeper slag at this boring appears to be fumed slag. This information was used to estimate the contact location.

The data summarized on Exhibit 1 and in Table 1 indicate that total concentrations in slag vary over orders of magnitude among different boring locations (laterally), within a single boring (vertically), and among the various types of slag. Average concentrations of arsenic, copper, selenium, and zinc are highest in the upper unfumed slag lift, lower in the older (deeper) unfumed slag layer, and lowest in fumed slag (Table 1). For example, the average arsenic concentration of 755 mg/kg in the upper unfumed slag lift compares with 622 mg/kg in the deeper unfumed slag and 90 mg/kg in fumed slag; similarly, average selenium concentrations are 132 mg/kg in the upper unfumed slag lift, 70 mg/kg in the deeper unfumed slag and 10 mg/kg in fumed slag. Average total lead concentrations are higher in the older unfumed slag (14,334 mg/kg) than in the upper lift (8,453 mg/kg); however, these averages are both an order of magnitude higher than the average lead concentration for fumed slag of 136 mg/kg (Table 1). Average metals concentrations of samples from the 1997 slag investigation (Hydrometrics, 1997) were not combined with other samples for statistical calculations in Table 1 due to differences in sample collection (1997 results are for full boring composites) and analytical methods (1997 samples were analyzed at the on-site Asarco assay facility); however, average concentrations reported for the 1997 samples are consistent with the upper unfumed slag results in Table 1. Average concentrations of copper (9,902 mg/kg), lead (10,232 mg/kg) and zinc (112,220 mg/kg) from the 1997 investigation (Attachment B) are similar to the upper lift unfumed slag averages in Table 1.

The clearest example of vertical variability in total concentrations and the contrast in unfumed and fumed slag is observable in borings DH-74 and DH-75, which were completed through post-1982 unfumed slag to a depth of 40 to 55 feet, then through deeper fumed slag (Exhibit 1). Significant changes in total concentrations occur below the unfumed/fumed slag interface. Average arsenic concentrations in the unfumed slag at DH-74 and DH-75 ranged from 736 to 1,399 mg/kg, compared with 79 to 98 mg/kg in fumed slag; similarly, average selenium (76 to 154 mg/kg) and zinc (103,960 to 124,622 mg/kg) concentrations in unfumed slag are higher than average selenium (10 to 11 mg/kg) and zinc (12,319 to 14,196 mg/kg) concentrations in fumed slag (Exhibit 1).

Total element concentrations are generally lower in sediments underlying the slag pile, compared with the slag pile itself. As shown on Exhibit 1, average arsenic concentrations in unconsolidated sediments beneath the slag pile range from 9 to 97 mg/kg, and average selenium concentrations range from <5 to 32 mg/kg. In the overlying fumed and unfumed

slag, average arsenic concentrations range from 40 to 1,399 mg/kg, and selenium concentrations range from 10 to 168 mg/kg. Some borings in the slag pile do show variable concentration trends with depth. At well DH-56, for example, total concentrations in the deepest slag sample collected (65-67' depth) are substantially higher for a number of elements compared with concentrations in shallower slag. Arsenic (377 mg/kg), cadmium (36 mg/kg), and lead (4425 mg/kg) concentrations in the deeper slag contrast with the ranges of 38 to 150 mg/kg arsenic, <10 mg/kg cadmium, and <10 to 337 mg/kg lead in shallower slag.

2.2.1.2 Slag Leaching Results

Slag leach test results for samples from the former East Helena smelter are in Attachment C, and are summarized in Table 1. The limited number of leach tests conducted to date on slag have typically generated low to moderate concentrations of contaminants, relative to concentrations observed in groundwater beneath the former smelter site. Table 1 presents the results of Synthetic Precipitation Leaching Procedure (SPLP) tests conducted on slag samples, intended to directly approximate leaching through exposure to precipitation, as well as the results from RI/FS slag infiltration test basins. Two slag infiltration catchment basins were constructed; one in a typical location in the fumed slag, and one in a typical location in unfumed (post-1982 upper lift) slag (Figure 1). Construction of the test basins included removal of a 2 to 3 meter layer of slag, placement of an impervious liner in the excavation, installation of a collection sump, and replacement of the slag. Water elevations in the collection sumps were measured periodically, and after rainfall or snowmelt events to determine water accumulation in the test basins. In addition, water samples were collected from the sumps for water quality analysis to evaluate the leaching potential of the slag. Although additional slag leach tests using acidic extraction solutions (TCLP and EP Toxicity tests summarized in Attachment C) were occasionally conducted by Asarco for internal use, these tests are not generally considered representative of ambient environmental leaching conditions, and are not presented in Table 1; as shown in Attachment C, these weak-acid leach tests generated leachate concentrations from slag of up to 1.2 mg/L arsenic, 30 mg/L lead, and 6 mg/L zinc. Most of the TCLP and EP Toxicity slag leach test samples are not identified as fumed or unfumed slag.

Slag infiltration basin water quality results show significant differences between unfumed and fumed slag (Table 1). Average concentrations of potassium (2,173 mg/L), sodium (3,198 mg/L), and sulfate (7,225 mg/L) are particularly elevated in unfumed slag infiltration basin water, compared with water from the fumed slag basin (65 mg/L potassium, 70 mg/L sodium, and 1,179 mg/L sulfate). Infiltration basin samples from unfumed slag also had elevated pH (9.48 to 9.97) and higher arsenic concentrations (0.35 to 0.62 mg/L) than fumed slag samples (6.16 to 7.77 pH, 0.028 to 0.054 mg/L arsenic). Fumed slag did generate higher leachate concentrations than unfumed slag for some constituents, including zinc (average of 2.65 mg/L for fumed slag and 0.05 mg/L for unfumed slag; Table 1). Overall, infiltration test basin water quality results indicate a sodium-potassium-sulfate type water with high TDS and arsenic leachate concentrations averaging 0.529 mg/L for unfumed slag, and a calcium-sulfate type water with order-of-magnitude lower TDS and arsenic leachate concentrations but higher zinc concentrations for fumed slag. The sodium-potassium-sulfate signature for

the unfumed slag leachate correlates well with the groundwater chemistry observed within the east lobe of the selenium plume beneath the slag pile (Section 2.2.3).

The SPLP results in Table 1 indicate higher arsenic leachate concentrations from unfumed slag (average of 0.099 mg/L for pre-early 1940s unfumed slag and 0.072 mg/L for post-1982 upper lift unfumed slag) compared with fumed slag (0.028 mg/L). In addition, the unfumed slag samples also generated selenium leachate concentrations ranging from 0.036 mg/L to as high as 0.4 mg/L (obtained on a sample from the upper unfumed slag lift). Note that the available slag SPLP data is limited to one sample of pre-early 1940s unfumed slag, three samples of post-1982 upper lift slag, and one sample of fumed slag (Table 1), and that the fumed slag leachate was not analyzed for selenium. The slag SPLP leachate concentrations are similar to or lower than groundwater concentrations currently observed beneath portions of the slag pile, but demonstrate that slag can generate concentrations an order of magnitude greater than applicable groundwater standards for arsenic and selenium. The SPLP solid:liquid testing ratio of 1:20 also likely dilutes leachate concentrations below what might be expected under ambient infiltration and leaching conditions.

2.2.1.3 Slag Area Sequential Extraction Results

Sequential extraction test results of slag well boring samples are in Attachment D and are summarized in Table 2 for arsenic, cadmium, and selenium. Data from tests conducted on sediments below the slag pile indicate that contaminants in underlying sediments may be associated with a variety of operationally-defined geochemical phases, from more available (water-soluble) to less available (crystalline iron oxide or residual phases). Samples from well DH-55 indicated significant percentages of arsenic and cadmium present in relatively leachable phases, with 23 to 40% of the total arsenic and 51 to 62% of the total cadmium present in the soluble/exchangeable/carbonate phase (Table 2). The low total arsenic and cadmium concentrations reported for these samples, however (23 to 32 mg/kg arsenic and <10 mg/kg cadmium), suggest limited potential for significant loading to groundwater from these sediments.

The sequential extraction data obtained on two unfumed slag samples from the Phase II RFI indicated selenium was present in more refractory phases (presumed to be more resistant to leaching), with one sample showing 50% of selenium present in a sulfide/selenide phase and 45% in a residual phase, and the other sample showing 86% present in the residual phase (Table 2). Arsenic was distributed throughout a wider variety of geochemical phases in the Phase II RFI samples, with about 20% reported in a carbonate phase, 17% in amorphous iron and/or crystalline manganese oxide phases, 25% in crystalline iron oxide, and 30% in sulfide/selenide phases. Note that the slag sequential extraction data was obtained from two samples of unfumed slag from a single boring (DH-76); given the observed heterogeneity in total element concentrations, it is likely that phase associations and mineralogy also vary throughout the fumed and unfumed portions of the slag pile.

2.2.2 Groundwater Occurrence

The slag pile is located on the former Prickly Pear Creek floodplain and shallow alluvial aquifer. The detailed stratigraphy in the area includes, from top to bottom, up to 110 feet of slag overlying a thin layer of fine grained sediments (organic rich clay to silty sand), which in turn overlies alluvial sands and gravels. A well by well summary of the slag pile area stratigraphy is included in Table 3. Generalized geologic cross-sections through the slag pile area, along with water levels measured in October 2010 and November 2015 are shown on Exhibit 2.

The slag thickness ranges from 31 feet at well DH-69 at the south end of the pile, to 110 feet at DH-74 and 75 near the pile center (Figure 1; Exhibit 2). The slag is identified as granular (sand to cobble size) in all well logs, including DH-76 which provided a continuous sonic core of the slag profile. A fine-grained (lower permeability) layer is identified beneath the slag in all drill logs although the nature of the fine grained layer varies from site to site. In the south half of the pile (wells DH-55, 76, 68, and 69), the underlying layer is a dark gray to black organic-rich clay, while in the north half the fine grained layer is described as a brown-orange silty sand to sandy silt. Underlying the fine-grained layer is typical alluvium consisting of sand, gravel and cobbles.

According to the well logs, the slag was dry throughout the entire profile at most sites. The lower one foot of slag was saturated at well DH-55 due to a thin zone of perched water on top of the underlying organic-rich clay. The presence of this perched zone suggests some precipitation does infiltrate to the base of the slag at this location. At all other locations, first water was encountered below the slag/fine-grained layer contact.

The underlying alluvium was saturated at all locations to the total depth of drilling. The alluvium is penetrated deepest at well DH-75 which terminates in gravelly sand at a depth of 147 feet (32 feet below the top of alluvium), or elevation 3852 feet.

Although the base of the slag pile is above groundwater (with the exception of the perched zone at DH-55), groundwater beneath the slag pile is under pressure (artesian) due to the low permeability silt/clay layer beneath the pile. Therefore, although the alluvial groundwater did not appear to be in contact with the slag where drilled, the potentiometric surface is higher than the base of the slag in the south half of the pile. This suggests that the alluvial groundwater could be in contact with the slag if the intervening low permeability fine grained layer is absent or is more permeable in places. This relationship is shown on cross-section A-A', Exhibit 2.

A groundwater potentiometric map of the slag pile area is shown on Exhibit 3 and on Figure 6. Groundwater flow is northward beneath the south half of the pile, and veers sharply to the northwest beneath the north half. This change in flow direction is believed to be due to the influence of Prickly Pear Creek and possibly the former creek channels beneath the slag pile (Figure 2). Leakage from the creek likely flows subsurface across the sharp bend in the creek, possibly facilitated by the coarser, higher permeability sediments associated with the former creek channels.

Exhibit 3 includes water level hydrographs from monitoring wells located on and around the slag pile. Apparent from the hydrographs is that wells in the eastern part of the slag pile (DH-68, DH-76, DH-55, DH-65) have exhibited little or no decline in water levels since initiation of the South Plant Hydraulic Control Interim Measure (SPHC IM), whereas wells on the west side show a definite decline (3 feet at DH-56 and 2 feet at DH-74 and -75). This is due to the greater influence of Prickly Pear Creek on groundwater flow beneath the eastern portion of the pile as compared to further west, which is more influenced by the plant site groundwater system, and thus the SPHC IM. This greater decline in water levels beneath the west side of the slag pile has increased the northwestward flow direction beneath the northern portion of the slag pile.

Complementary wells DH-74 and DH-75 were drilled in 2010 to provide additional information on lateral and vertical variability in groundwater conditions beneath the slag pile. Well DH-74 is screened at a depth of 118 to 128 feet (8 to 18 feet below the bottom of the slag), and DH-75 is screened from 136 to 146 feet or 26 to 36 feet beneath the slag. Corresponding water levels collected monthly between September 2010 and November 2015 show a consistent downward vertical hydraulic gradient at this location, with an average downward gradient of 0.021 ft/ft (minimum 0.015, maximum 0.026). This downward gradient coupled with the significantly higher contaminant concentrations in the shallower well (DH-74) may indicate recharge and contaminant loading from a source above the groundwater table (i.e., the slag pile).

2.2.3 Groundwater Chemistry

Complete groundwater quality results and a statistical summary for slag pile and slag pile perimeter monitoring wells are in Attachment E. Groundwater quality trend plots for selected parameters during the post-plant shutdown period (2002-2015) are also in Attachment E. Figure 7 shows the location of the slag pile relative to the arsenic and selenium groundwater plumes emanating from the former smelter; the plumes are also shown with the October 2015 potentiometric contours and slag area monitoring wells on Figure 6.

2.2.3.1 Arsenic and Selenium Plumes

As shown on Figures 6 and 7, the east lobe of the selenium plume originates beneath the slag pile between wells DH-55 and DH-56, migrating northwest through East Helena into Lamping Field, where it merges with the west lobe of the selenium plume that originates in the West Selenium Area. Selenium concentrations exceeding the 0.05 mg/L groundwater standard are currently confined to wells within the north portion of the slag pile (at and north of DH-55). For arsenic, concentrations exceeding 1 mg/L persist at well DH-6, located on American Chemet property north of the northwest portion of the slag pile; however, all slag pile and slag pile perimeter wells (with the exception of wells to the east across Prickly Pear Creek) exceed the 0.01 mg/L arsenic groundwater standard, and the 0.01 mg/L arsenic plume extends downgradient (north) from the slag pile and through East Helena approximately 2000 feet (Figure 7). Concentrations of most other trace constituents in slag area wells are near or below reporting limits (Attachment E).

Based on 2014 calibrations, the numerical groundwater fate and transport model developed for the Facility estimates that arsenic and selenium mass fluxes from Slag Pile area sources comprise about 12% of the total arsenic flux and 49% of the total selenium flux migrating off the site. The model is well-calibrated to observed concentrations in the Slag Pile and downgradient of the Slag Pile, to the northwest. However, the model is less well-calibrated to observed concentrations north of the Slag Pile, which could lead to greater uncertainty in mass fluxes calculated at the Facility boundary located directly north the Slag Pile. The period-of-record average arsenic (1.01 mg/L based on 874 samples) and selenium (0.174 mg/L based on 393 samples) concentrations in slag pile area groundwater, while elevated relative to groundwater standards, are one or more orders of magnitude lower than concentrations observed in other former smelter source areas such as the West Selenium, North Plant Arsenic, and Acid Plant areas. As noted above, however, due to the higher groundwater flux rates, groundwater model results indicate the slag pile area contributes roughly half of the total selenium groundwater load leaving the plant site, with the other half attributable to the West Selenium Source Area.

2.2.3.2 Slag Area Groundwater Quality

For the purposes of discussion, wells within and surrounding the slag pile have been categorized as West Perimeter wells (DH-6, DH-73, DH-51), East Perimeter wells (DH-7, DH-11), North Perimeter wells (DH-6, DH-15, DH-10A, DH-52, and DH-53), South Slag wells (DH-5, DH-5A, DH-4, DH-14, DH-68, DH-69, and DH-76), and North Slag wells (DH-55, DH-56, DH-65, DH-74, and DH-75). These well sets are shown on Figure 8, along with period-of-record average concentrations of arsenic, selenium, potassium, and sulfate in each slag area monitoring well. Reviews of historic groundwater data for all former smelter site wells have suggested that potassium concentrations are uniquely elevated in some slag area wells, and sulfate is a good general indicator of former smelter groundwater impacts, along with arsenic and selenium concentrations. A summary of slag area groundwater quality is presented in Table 4. Figures 9 and 10 show trend plots of arsenic and selenium concentrations at individual wells.

Groundwater pH in slag pile area wells is near neutral. Average pH values range from 6.6 to 7.3 in East and West Perimeter wells, 7.1 to 7.6 in South Slag wells, 7.0 to 7.9 in North Slag wells, and 6.8 to 7.3 in North Perimeter wells (Table 4). Slightly higher pH values are observed in wells completed through the slag compared with other well sets; as discussed above, unfumed slag test basin leachate exhibited elevated pH (average pH of 9,66), indicating that higher pH values may be associated with slag leaching impacts.

East Perimeter wells DH-7 and DH-11, located east of Prickly Pear Creek, show little evidence of any smelter- or slag-related impacts, with low arsenic, selenium, and potassium concentrations as well as relatively low sulfate concentrations (Figure 8). Along the West Perimeter, well DH-9 (now dry) shows the highest historic contaminant concentrations, with an average arsenic concentration of 2.99 mg/L and a slightly elevated average potassium concentration of 55 mg/L (Figure 8). Prior to going dry, selenium, zinc, and potassium concentrations were increasing at well DH-9, although arsenic concentrations were decreasing. Deeper well DH-73, adjacent to DH-9, has low arsenic (<0.002 to 0.006 mg/L) and selenium (<0.001 to 0.008 mg/L) concentrations.

South Slag well groundwater quality is characterized by slightly reducing conditions (average iron concentrations as high as 18.1 mg/L and manganese concentrations as high as 6.1 mg/L at DH-4), with relatively low sulfate (7 to 202 mg/L) and chloride (7 to 44 mg/L) concentrations (Table 4). The South Slag wells have moderate arsenic concentrations and very low or below detect selenium concentrations, typically <0.001 mg/L. As shown on Figure 8, average arsenic concentrations in the South Slag wells range from 0.006 mg/L at well DH-14 to 2.66 mg/L at well DH-4, and arsenic concentration trends at South Slag wells are currently relatively stable (Figure 9). Potassium concentrations in South Slag wells are low, with averages ranging from 3.3 to 8.2 mg/L (Table 4). Paired wells DH-4 and DH-14 show contrasting water quality, with higher average concentrations of smelter-related constituents such as arsenic and sulfate at shallower well DH-4 (2.66 mg/L arsenic and 202 mg/L sulfate) compared with DH-14 (0.006 mg/L arsenic and 59 mg/L sulfate). The groundwater level and water quality at well DH-5 was apparently impacted historically by a leaking water line adjacent to the well; when this well was abandoned in 2013 the water level at DH-5 dropped 2 to 3 feet, and major ion and zinc concentrations showed immediate increases. Sulfate concentrations at DH-5 increased from 28 mg/L in June 2013 to 320 mg/L in September 2013, and zinc concentrations increased from 0.78 mg/L to 4.02 mg/L over the same period. Sulfate concentrations have also recently increased at well DH-69, north (downgradient) of DH-5, with sulfate increasing from an average of about 7 mg/L prior to 2015, to over 300 mg/L in 2015.

The North Slag wells generally have distinctly different groundwater chemistry from the South Slag wells, with higher dissolved solids concentrations (see specific conductance values in Table 4), a different major ion signature, and higher overall concentrations of arsenic and selenium (Figure 8). Well DH-56 typically shows the highest selenium concentrations of any slag area well, with a maximum of 2.02 mg/L selenium observed in June 2011 (Figure 10). Despite the persistence of higher arsenic and selenium concentrations in North Slag wells, decreasing trends since the implementation of the SPHC IM are apparent for arsenic at wells DH-55, DH-56, and DH-74 (Figure 9), and for selenium at well DH-55 (Figure 10).

North Slag area groundwater chemistry has elevated potassium, sodium, and sulfate concentrations compared with the upgradient South Slag wells (Table 4). The potassium concentrations in North Slag wells (averaging 27 to 395 mg/L) are unique to this portion of the former smelter, and average sulfate concentrations range from 547 to 1,377 mg/L. The sodium-potassium-sulfate chemistry of North Slag wells contrasts with the calcium-sodium-bicarbonate signature of upgradient South Slag wells, and also corresponds with the higher selenium concentrations that appear in well DH-55 and northward. As noted previously, unfumed slag test basin leachate also exhibited a sodium-potassium-sulfate signature, indicating possible groundwater impacts from leaching of unfumed slag to North Slag area wells.

Well DH-75 shows significantly lower average potassium (27 mg/L), arsenic (0.003 mg/L) and selenium (0.024 mg/L) concentrations compared with other North Slag area wells (Figure 8), where average arsenic concentrations range from 0.516 to 1.3 mg/L and average

selenium concentrations range from 0.067 to 0.777 mg/L. The water chemistry differences between shallower well DH-74 (higher arsenic, selenium, and potassium) compared with deeper well DH-75 shown on Figure 8 could indicate a loading source from above, such as slag leaching, rather than a lateral source such as historic loading from Lower Lake seepage.

Elevated arsenic and selenium concentrations persist in North Perimeter wells on the downgradient end of the slag pile, with average concentrations ranging from 0.005 to 2.7 mg/L for arsenic, and 0.005 to 0.497 mg/L for selenium (Table 4 and Figure 8). Well pair DH-6 and DH-15 show similar selenium and sulfate concentrations, but contrasting average arsenic concentrations (2.7 mg/L in shallow well DH-6 and 0.005 mg/L deep well DH-15) and average potassium concentrations (179 mg/L at DH-6 and 7.7 mg/L at DH-15). The other North Perimeter wells (DH-10A, DH-52, and DH-53) also have elevated average potassium concentrations ranging from 61 to 179 mg/L, which increase from east to west, along with selenium and sulfate concentrations (Figure 8). Overall, arsenic and selenium concentrations are currently decreasing at North Perimeter wells DH-6, DH-10A, and DH-52 during the post-SPHC period (Figures 9 and 10)

Selenium data prior to 2007 for slag area wells is limited (as with other Facility monitoring wells); however, available data from four sampling events in 1985 from wells DH-4, DH-5, DH-6, DH-7, DH-9, and DH-11 show uniformly low concentrations ranging from <0.002 to 0.013 mg/L. In 2001, South Slag well DH-4 had 0.008 mg/L selenium, and North Perimeter well DH-52 had 0.18 mg/L selenium. In 2007, when routine analysis for selenium was added to the groundwater monitoring analytical schedule for the former smelter, concentrations in the North Slag and North Perimeter wells were as high as 0.109 mg/L at DH-52, 0.346 mg/L at DH-55, 0.608 mg/L at DH-6, and 1.38 mg/L at DH-56; the observed selenium concentration increase at DH-6 from 1985 to 2007 was several orders of magnitude (0.0045 to 0.608 mg/L), and potassium concentrations at DH-6 also increased sharply between 1993 and 1998 when unfumed slag was being placed on the upper lift (see Figure 5), possibly indicating the upper unfumed slag lift as a selenium and potassium source to groundwater. In contrast, arsenic concentrations in 1985 at well DH-6 were in the 7 to 13 mg/L range, and had decreased by 2007 to 1.5 mg/L. This suggests that selenium loading to groundwater in the slag area wells may have initially occurred sometime between 1985 and 2001, when the upper lift of unfumed slag was being placed, and that arsenic loading was occurring prior to 1985.

As shown in the graph below, the wells showing the highest historic selenium concentrations in the slag pile area (DH-56 and DH-6) show reasonably strong correlations between selenium and potassium concentrations, possibly indicating a common source; since unfumed slag leaches high potassium concentrations, it may be the source of both selenium and potassium in groundwater. Selenium migrates a significant distance downgradient from the slag pile area; however, potassium concentrations decrease rapidly with downgradient distance.   In addition, deeper well DH-15 has selenium concentrations similar to DH-6, but much lower potassium (Figure 8). This could indicate separate sources for selenium and potassium in groundwater, or loss of potassium from solution through adsorption or other attenuation processes. Dance and Reardon (1983), for example, conducted a major cation tracer test and found an order of attenuation from strongest to weakest of K>Mg>Na, with

both transport model and field results showing "pronounced K^+ attenuation during flow of the injection solution." Potassium also has a well-established tendency for preferential retention by certain clay minerals (Bohn et al., 1985).
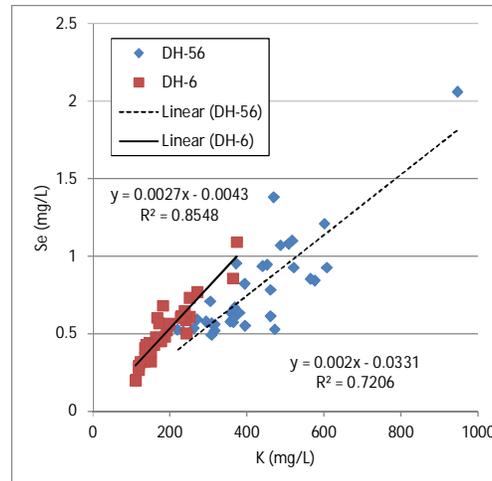
In addition to the wells within and surrounding the slag pile, a seep emanating from the north toe of the slag pile has been identified and sampled several times during water resources monitoring events at the former smelter. Originally designated "Seep 1" during initial monitoring in 1985 and 1987, the seep was sampled again in 2010 and identified as "DH-10A Area Seep" (Figures 1 and 2). Water quality results for the Seep 1/DH-10A Area Seep sampling are summarized in Table 5. The results in Table 5 show similar concentrations between the 1985/1987 and 2010 sampling events for many constituents; arsenic concentrations, however, averaged 5.9 mg/L in 1985/1987, decreasing to 0.649 mg/L in 2010. Potassium (53 mg/L in 1985/1987, 88 mg/L in 2010) and sulfate (271 mg/L in 1985/1987, 390 mg/L in 2010) have increased in concentration over time. Selenium was not analyzed in 1985/1987, but was reported at 0.078 mg/L in 2010. The 2010 arsenic, selenium, and potassium concentrations at this seep are similar to local shallow groundwater quality observed at wells DH-52, DH-10A, and DH-6.

2.2.4 Surface Water

Prickly Pear Creek currently flows along the east and north sides of the slag pile (Figure 1), and in certain locations the slag pile is in direct contact with the creek. Water quality and flow data for Prickly Pear Creek monitoring stations upstream of, adjacent to, and downstream of the slag pile (Figure 1) are in Attachment F.

Previous investigations, including the RI/FS (Hydrometrics, 1990) and the CC/RA (1999) have assessed the potential for impacts from the slag pile to Prickly Pear Creek surface water. These investigations noted that the most significant potential impact from the slag pile to Prickly Pear Creek is erosion of slag where the slag pile functions as the streambank. Table 6 summarizes total recoverable arsenic, copper, lead, selenium, and zinc concentrations for the last five years (2011 through 2015), along with instantaneous flow measurements

collected during synoptic monitoring at sites along Prickly Pear Creek upstream (site PPC-3A), adjacent to (PPC-5), and immediately downstream (PPC-7) of the slag pile (Figure 1). Calculated instream loads of arsenic, copper, lead, and zinc at these three Prickly Pear Creek sites are also presented in Table 6, based on the observed concentration and the measured flow. Average load increases from PPC-3A to PPC-5, and from PPC-5 to PPC-7 are also in Table 6.

The data in Table 6 indicate small calculated downstream increases in arsenic, copper, and lead loads in Prickly Pear Creek from sites PPC-3A to PPC-5, and again from site PPC-5 to PPC-7, from 0.04 to 0.18 lb/day. Zinc loads show a net decrease on average from PPC-3A to PPC-5, but an increase of 3.1 lb/day from PPC-5 to PPC-7. These average load increases shown in Table 6 are about 10% of the overall average measured instream loads of 1.7 lb/day arsenic, 1.4 lb/day copper, 1.8 lb/day lead, and 20.7 lb/day zinc; thus, while the observed load increases appear relatively consistent, they are based on calculated loads that are likely within or nearly within the combined error of field flow measurements and laboratory analytical measurements. Overall, the 2011-2015 Prickly Pear Creek water quality and flow data suggest small instream load increases possibly attributable to creek interaction with the slag pile.

Both a Baseline Ecological Risk Assessment (BERA) and a related Ecological Site Investigation of the East Helena Facility were conducted by Gradient in 2010, including evaluation of Prickly Pear Creek and associated riparian areas upstream of, adjacent to, and downstream of the Facility (Gradient, 2010). Targeted sample matrices included surface water, sediment, soil, benthic and other aquatic invertebrate tissues, fish and amphibian tissues, and soil invertebrate tissues. Regarding Prickly Pear Creek, the BERA report (Gradient, 2010) concluded that:

> Prickly Pear Creek provides a range of habitats for aquatic and terrestrial receptors and is relatively undisturbed, except near the Facility. Current COPC [chemical of potential concern] concentrations in Prickly Pear Creek and associated riparian areas appear to pose minimal risks to the aquatic and terrestrial community. Further, onsite COPC concentrations are generally within the range of concentrations found in reference areas.

Prickly Pear Creek surface water quality data and ecological risk assessment results indicate a low level of direct slag impacts to Prickly Pear Creek water and sediment chemistry. Furthermore, the Prickly Pear Creek Realignment component of the SPHC IM (currently under construction) will relocate the creek channel away from direct contact with the slag pile, mitigating potential impacts from erosion that might occur under high runoff conditions.

3.0 SUMMARY AND DISCUSSION

The former East Helena smelter slag pile is approximately 45 acres in size and contains about 3,560,000 cy of slag. The pre-1940s unfumed slag is located at the south end of the pile and is overlain in part by younger fumed slag. Post-1982 unfumed slag is restricted to an upper

lift on top of the pile about 585,000 cy in volume. Based on review of historic maps and aerial photos, the slag pile is underlain by a number of former creek channels and ditches which could act as preferential flow pathways, especially during periods of high surface water and groundwater levels.

Based on the slag pile history, features, composition, and characterization activities presented in this memorandum, the primary findings regarding the slag pile as a potential contaminant loading source to groundwater are summarized in Figure 11. The numbered bullet points below correspond to the numbered discussion points on Figure 11.

1. A perched groundwater zone identified on top of the fine-grained organic-rich clay below the slag but above the coarse-grained alluvium during drilling of well DH-55 suggests that some precipitation recharge percolates to the base of the slag at this location where the slag is about 78 feet thick.
2. Thinner slag layers such as the south end of the slag pile (about 31 feet thick) and beneath the two borrow pits (about 40 feet thick) represent areas of greater potential recharge to groundwater through infiltration, due to the shorter distance required for infiltrating water to travel.
3. Paired wells DH-74/DH-75 show both a downward vertical gradient, and higher arsenic, selenium, and potassium concentrations in the shallower well (DH-74) compared with the deeper well (DH-75), suggesting a possible loading source from above (i.e., slag leaching).
4. The slag infiltration test basin in unfumed slag generated high leachate concentrations of sodium, potassium, sulfate, and arsenic compared with the fumed slag test basin (selenium was not analyzed). Groundwater beneath the north portion of the slag pile shows a similar sodium-potassium-sulfate major ion signature, along with elevated selenium and arsenic concentrations, suggesting that unfumed slag leaching could be impacting groundwater in this area.
5. Groundwater quality evolves along the flowpath from south to north underneath the slag pile, with relatively low concentrations of selenium, potassium, and sulfate in south slag area wells progressively increasing to the north. Increasing concentrations are first apparent in the vicinity of well DH-55, and are highest about 800 feet downgradient at well DH-56.
6. Well DH-6 along the north perimeter of the slag pile showed a significant increase in selenium concentration sometime between 1985 and 2007, and a significant increase in potassium concentration between 1993 and 1998. These trends may be indicative of contaminant loading from the post-1982 unfumed slag upper lift.
7. Total metals concentrations (including both arsenic and selenium) are generally highest in post-1982 unfumed slag, which constitutes the upper lift of the slag pile. Older unfumed slag concentrations are lower on average, and fumed slag total concentrations are lowest. SPLP leach tests of unfumed slag have generated up to 0.13 mg/L arsenic and 0.4 mg/L selenium. No fumed slag SPLP results are available for selenium, and relatively few unfumed slag SPLP leaching results are available for arsenic and selenium (one to three samples of the older and younger unfumed slag).
8. While the information reviewed above currently provides evidence that slag may be impacting groundwater quality beneath and downgradient of the slag pile, concentration trends for arsenic and selenium at most slag area wells are currently

stable or decreasing, including those on the north end and along the north downgradient perimeter of the slag pile.

The information presented above suggests that portions of the slag pile may act as a current source of contaminant loading to groundwater. This information is intended to support further discussions on appropriate action(s), if any, at the slag pile.

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