

DRAFT MEMORANDUM

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TO Nicole DeNovio and Lee Holder Golder Associates USA Inc.

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EVALUATION OF MANGANESE IN GROUNDWATER WITHIN THE VALLEY FILL AQUIFER

1.0 OVERVIEW

In response to Ohio Environmental Protection Agency (OEPA) comment #5 (OEPA 2021), an evaluation of manganese in groundwater within the Valley Fill Aquifer (VFA) was conducted. Water chemistry samples collected from the VFA were compared to samples collected from both surface water (Cross Creek and pools) and other groundwater bearing units (Interflow Zone, Colluvial Soil Water-Bearing Zone, Under Coal Zone, Upper Casselman, seeps, and bedrock) at the Site. Additionally, manganese concentrations of solid materials, both soil and industrial byproducts, were evaluated to determine likely sources of manganese to VFA groundwater.

Groundwater in eastern Ohio with manganese concentrations above the US EPA secondary Maximum Contaminant Level (MCL) of 50 μ g/L has been well established (Jagucki et al. 2015, McMahon et al. 2019, OEPA 2017, OEPA 2022). Of all regional aquifer types (sandstone, carbonate, or sand and gravel) in Ohio, sand and gravel aquifers (e.g., Valley Fill) were most likely to contain groundwater with elevated concentrations of manganese (>600 μ g/L; OEPA 2014). However, due to the industrial history of the Site (coal mining and ferrochrome production), additional sources of manganese in Valley Fill groundwater may be present. Possible sources of manganese to the VFA include:

- Coal Mine Drainage (CMD) from historic coal mining
- Natural soils elevated in manganese
- Ferrochrome byproducts (e.g., slag)

Groundwater flow within the VFA follows Cross Creek, migrating south then east across the Site. The VFA is confined and underlies a clay aquitard which separates overlying perched aquifers (the Interflow Zone and Colluvial Soil Water-Bearing Zone) from the VFA. Groundwater within the perched interflow aquifer could have migrated through ferrochrome byproducts, creating potential migration pathways for constituents originating from these byproducts to the VFA in locations where the aquitard is leaky.

North of the VFA is the former mine area, where wells of variable depths are screened in the Lower Pittsburgh formation and Under Coal Zone (siltstone and claystone) and the Upper Casselman formation (limestone and sandstone). Groundwater from the former mine area could migrate to the VFA through one of three pathways:

(1) horizontal flow of groundwater from the former mine area to the VFA, (2) flow from the former mine area into colluvial soil water which migrates downslope into the VFA, or (3) recharge from pooled surface water located at the toe slope of the former mine area (originally sourced from groundwater) to the VFA. Previously published research conducted by the United States Geological Survey (USGS), at the J11 watershed located approximately 10 miles southwest of the Site, examined groundwater quality before and after coal mining (Hren 1986). Postmining, groundwater at J11 contained substantially higher concentrations of sulfate (360 mg/L), manganese (595 μ g/L), and total dissolved solids (814 mg/L) compared to pre-mining baseline samples (84 mg/L, 30 μ g/L, and 335 mg/L, respectively). These results indicate that if a migration pathway between the former mine area and the VFA exists, the former mine area would be a likely source of manganese to the VFA.

While deeper groundwater is typically associated with reducing conditions that are favorable for manganese mobility in groundwater, recent studies have shown that groundwater sampled from shallow wells (<50 m) generally contains the highest concentrations of manganese (Fisher and Davidson 2007; Gillispie et al. 2016). High manganese concentrations in these shallow groundwater systems are attributed to 1) shallow soils rich in total organic carbon (anoxic conditions), 2) underlying weathering bedrock, and 3) water-rock chemical disequilibrium. The VFA overlies weathered bedrock, is screened in the shallow subsurface in moderately reducing to slightly oxic conditions, and is likely comprised of young groundwater. A natural release of manganese to the VFA may thus be the cause for the elevated manganese concentrations.

2.0 MANGANESE GEOCHEMISTRY

Iron oxide coatings naturally form on sands and gravels of Valley Fill. In oxic conditions, manganese adsorbs to these iron oxide coatings, but in reducing conditions, manganese dissolves into groundwater (Hem 1985; OEPA 2014). The pH also plays an important role in the speciation and adsorption of manganese. Manganese in groundwater is generally present as Mn(II), but when conditions are alkaline (pH >10.5) or when groundwater is oxidized, Mn(IV) (hydr)oxides become the predominant manganese species and generally precipitate out of solution. The pH also impacts the adsorption of manganese onto iron oxides; at circumneutral to slightly basic pH (6.5 to 9), manganese is strongly adsorbed. However, when groundwater is acidic (<5) or basic (>10) manganese sorption onto iron oxides is ineffective and manganese which was previously adsorbed may be released. Thus, pH, redox conditions, and the presence or absence of iron oxides are important controls for manganese mobility in groundwater.

3.0 MANGANESE IN SOLIDS

Manganese concentrations were measured in solids associated with ferrochrome production, surficial soils collected from the former mine area, and soils from water bearing units at the Site (Interflow Zone, clay aquitard, VFA, and bedrock; Table 1). The dataset for manganese collected from solids at the Site is relatively large, but irregularly distributed, with most samples concentrated in the Site's lowlands. As a result, the solids data for the former mine area is limited.

Several background soil samples were collected from upland and lowland locations that are considered representative of natural soil in the area. Coal was not sampled as part of the Remedial Investigation (RI). Instead, the USGS database COALQUAL was used to determine manganese concentrations in coal in Jefferson County, Ohio (Palmer et al. 2015).

Site Location	Material	Minimum Concentration (mg/kg)	Median Concentration (mg/kg)	Maximum Concentration (mg/kg)	Samples Collected
Former Mine Area	Coal	4	15	105	23
Former Mine Area	Surficial Soil	13	510	5,400	30
Former Mine Area/Ridgetop	Slag	83	299	7,530	22
Lowlands ²	Slag	94	616	3,640	11
Lowlands ²	Building Dust	550	3,500	65,000	13
Lowlands ²	Interflow Materials (sands and gravel with some fill)	690	18,000	56,000	5
Aquitard	Clay	360	780	6,000	28
Lowlands ³	Valley Fill	300	1,100	3,400	13
Lowlands ² /Ridgetop	Bedrock	310	850	1,200	3
Off-Site	Upland Background Soil	44	685	2,000	24
Off-Site	Lowland Background Soil	280	785	1,100	24

Table 1: Summary of Manganese Content of Various Site Materials

Notes:

¹Coal concentrations for Jefferson County, OH from the USGS COALQUAL database.

² Indicates materials collected from above the clay aquitard.

³ Indicates materials collected from below the clay aquitard.

Manganese concentrations at the Site were highest in building dust and Interflow Zone soils. Slag samples contained low concentrations of manganese (Figure 1). The clay aquitard underlying the Interflow Zone generally had a lower median concentration of manganese (780 mg/kg) compared to the overlying Interflow Zone (18,000 mg/kg) or underlying Valley Fill (1,100 mg/kg). The substantial difference in manganese concentrations between these layers likely indicates a limited connection (if any) between VFA solids and overlying Interflow Zone Solids.

While median manganese concentrations for VFA sands and gravels (1,100 mg/kg) were lower than the median manganese concentrations for building dust (3,500 mg/kg) or Interflow Zone materials (18,000 mg/kg), the concentration of manganese in VFA materials is still high relative to most soil. For comparison, the average

manganese concentration in eastern United States soils is 260 mg/kg (Smith and Huyck 1999). Manganese depth profiles discussed in Gillispie et al. (2016) showed that shallow soils with elevated manganese concentrations (>500 mg/kg) generally correlate with elevated manganese concentrations in shallow groundwater (>50 µg/L). These results indicate that VFA sands and gravels likely contain sufficient manganese alone to elevate manganese concentrations in groundwater.

Manganese concentrations of materials associated with the former mine area (coal and surficial soil) were generally lower than manganese concentrations of materials collected from other Site locations. Additionally, coal typically contains lower concentrations of manganese, while manganese in CMD is typically high (Larsen and Mann 2005). The potential impact of CMD to the VFA is discussed further in Section 4.0.

The median manganese concentrations of background soil samples collected from upland and lowland locations ranged from 685 to 785 mg/kg, respectively. A maximum manganese concentration of 2,000 mg/kg observed in upland background soils indicates that manganese concentrations are locally elevated in some background soils.

4.0 MANGANESE IN VFA GROUNDWATER

A Piper plot was generated for groundwater and surface water samples to facilitate the identification of water types and source contributions to the VFA (Figure 2a, 2b). Figure 2a shows samples collected from the VFA compared to groundwater samples collected from primary groundwater bearing units at the Site (former mine area groundwater, seeps sourced from the former mine area, and the bedrock aquifer) and perched water units (Interflow Zone and Colluvial Soil Water-Bearing Zone). VFA groundwater samples were generally water type Ca-HCO3, although several VFA samples were water type Na-Cl or Ca-Cl, similar to bedrock aquifer groundwater samples (Na-Cl or Na-HCO3). Groundwater samples collected from perched aquifers (Interflow Zone and Colluvial Soil Water-Bearing Zone) were also typically water type Ca-HCO3, potentially indicating flow from perched water to the underlying VFA. Groundwater samples collected from the former mine area were mostly water type Ca-SO4; the high relative abundance of sulfate in former mine area groundwater likely indicates impacts from historic coal mining (Hren 1986; Larsen and Mann 2005). Several seeps were water type Ca-HCO3 similar to VFA groundwater, however, these samples were clearly impacted by slag (pH>10). Seep sample SSW-071 (water type Ca-HCO3) may not be impacted by slag (average pH of 7.8) but may be sourced from a thin limestone unit in the Ridgetop area which is parallel to the seep.

Figure 2b, shows groundwater samples collected from the VFA compared to surface water samples (Cross Creek and ponds). Generally, surface water samples were water type Ca-SO4, similar to groundwater samples collected from the former mine area (Figure 2a). Several pond water samples were water type Ca-HCO3 like most VFA groundwater. Similar to seeps with Ca-HCO3 water type, these ponds also were high in pH (>10), indicating impacts from slag, and likely do not reflect mixing between ponds and VFA groundwater.

4.1 Saturation Index Modeling

To evaluate the potential for manganese reactions in Interflow Zone wells and VFA wells (which could affect the interpretation of manganese concentration data), precipitation of manganese-bearing minerals was evaluated with the help of the geochemical modeling code PHREEQC (Parkhurst and Appelo 2013), using a saturation index (SI) calculation:

SI = log (IAP/Ksp)

The saturation index is the ratio of the ion activity product (IAP) of a mineral to the solubility product (Ksp). An SI value greater than zero indicates that the solution is supersaturated with respect to a particular mineral phase and, therefore, precipitation of this mineral may occur. An evaluation of precipitation kinetics is then required to determine whether the supersaturated mineral will indeed form. An SI value less than zero indicates the solution is undersaturated with respect to a particular mineral phase. An SI value less than zero indicates equilibrium conditions exist between the mineral and the solution. SI values between -0.5 and 0.5 are generally considered to represent "equilibrium" herein to account for the uncertainties inherent in the analytical methods and geochemical modeling (Nordstrom and Alpers 1999). The widely accepted thermodynamic database Minteq.v4, 2017 edition (USEPA 1998, as amended) was used as a basis for the thermodynamic constants required for modeling, with additions and modifications from recent literature as required. Relevant manganese-bearing minerals that were evaluated included rhodochrosite, manganite, and others that would be kinetically feasible to form under low-temperature conditions, as listed in Table 6.14 in Nordstrom and Alpers (1999). Calculated mineral saturation indices are presented in Table 2.

Mineral saturation can play an important role in the attenuation of manganese directly by their removal through precipitation (e.g., manganese minerals) or by providing sorptive surfaces or opportunities for co-precipitation (e.g., manganese co-precipitation on calcite). The results of the saturation index modeling can be summarized as follows:

- Iron-bearing minerals: Ferrihydrite [Fe(OH)3(am)] was indicated to be oversaturated in VFA wells MW-03 and MW-10 and Interflow Zone wells MW-11 and MW-12, indicating potential for ongoing precipitation of solid-phase iron oxides in some groundwater. However, sequestration of manganese through sorption onto ferrihydrite is known to be minimal in high pH groundwater (e.g., impacted by slag) (see Section 2). Siderite (FeCO3) was found to be in equilibrium with groundwater in VFA wells MW-02 and KMW-01.
- Other minerals: All Interflow Zone and VFA groundwater samples were simulated to be in equilibrium or oversaturated with respect to calcite (CaCO3). Rhodochrosite (MnCO3) was oversaturated or in equilibrium in most groundwater samples. Manganese (hydr)oxides were undersaturated in Interflow Zone and VFA groundwater.

In summary, several mineral phases likely help govern groundwater composition at some or all Interflow Zone and VFA wells: calcite, ferrihydrite, siderite, and rhodochrosite. In the case of rhodochrosite, the dissolved concentrations of manganese may be reduced through its formation, and some manganese may also be attenuated through sorption onto ferrihydrite at circumneutral to slightly basic pH. Manganese co-precipitation with calcite is also likely based on the literature (e.g., Roadcap et al. 2005) and was confirmed through analysis of seep precipitates on-Site (manganese concentrations ranging from 230 to 290 mg/kg).

4.2 MW-01 and MW-02

VFA wells MW-01 and MW-02 had the highest manganese concentrations of all VFA wells (dissolved and total manganese concentrations ranging from 3,200 to 3,600 µg/L and 3,000 to 3,600 µg/L, respectively; see Figures 3 to 6). These wells are located at the toe-slope of the former mine area and its primary surface water drainage (see Remedial Investigation (RI) Figure 1.4-6), and downgradient of the Plant Area. The close proximity of MW-01 and MW-02 to both the former mine area and Plant Area requires an evaluation of both areas as possible sources.

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While some manganese may be released naturally from local soil/rocks in the VFA at MW-01 and MW-02, the manganese concentrations observed at these wells were approximately 13 standard deviations higher than the mean total manganese concentration for sand and gravel aquifers in Ohio (mean 195 μ g/L, standard deviation of 230 μ g/L; OEPA 2016). These results indicate that sands and gravels of the VFA are unlikely to be a significant source of manganese in MW-01 and MW-02.

The major relative ion abundance of MW-01 and MW-02 was compared to former mine area waters (groundwater, seeps, ponds, colluvial soil water) and Plant Area groundwater (Interflow Zone well MW-15) using a Piper diagram (Figure 7a). Samples collected from MW-01 and MW-02 were similar in water type (Ca-HCO₃) to colluvial soil water (MW-09) but plotted away from former mine area seeps (SSW-11), former mine area groundwater (MW105-S, MW106, MW114-S), former mine area ponds (SSW-10) and Plant Area groundwater (MW-15). These results indicate that colluvial soil water may be migrating to the underlying VFA in locations where the clay aquitard is leaky or not present.

Schoeller diagrams presenting major ions and manganese showed elevated concentrations of sulfate in former mine area waters (MW114-S, MW-105-S, MW106, SSW11, and SSW10) and MW-01 relative to other samples, suggesting an influence from CMD (Figure 7b). Manganese concentrations were also elevated (max concentrations >3,000 µg/L) in these samples, except for seep and pond samples SSW10 and SSW11, providing additional support for a release of manganese from the former mine area. Oxic conditions (average dissolved oxygen concentration of 3 mg/L) at SSW10 and SSW11 likely cause the removal of manganese through precipitation of manganese hydroxides (Section 2.0), resulting in lower concentrations of manganese in seeps and ponds than in groundwater. Carbonate alkalinity (HCO₃ plus CO₃) was low in some former mine area groundwater samples, likely due to the consumption of alkalinity by acidity generated through oxidation of sulfide minerals present in coal and coal waste products. The lower pH of former mine area groundwater samples MW105-S and MW106 (5.59 and 6.65, respectively) supports this hypothesis.

Contour maps of manganese (total and dissolved) and sulfate in groundwater also indicate that manganese is likely migrating from the former mine area to MW-01 and MW-02 (Figures 3 to 6, and 8). Sulfate is a common byproduct of CMD but was observed at low concentrations (<10 mg/L) in waters impacted by slag (SSW-05, SSW-043, and SSW-081). Sulfate concentrations in MW-01 and MW-02 were approximately two (MW-01) to four (MW-02) standard deviations higher than the average sulfate concentration in groundwater from Ohio sand and gravel aquifers (mean concentration of 74 mg/L, standard deviation of 44 mg/L; OEPA 2016). Additionally, MW-01 contained the highest concentration of sulfate in all the VFA wells (280 mg/L) and is located closest to the former mine area. Therefore, manganese in MW-01 and MW-02 likely originates from the former mine area.

4.3 MW-03

MW-03 is located in the Plant Area, between the North Mill Building and Cross Creek, within the surface water drainage of the former mine area (RI Figure 1.4-6). Total and dissolved manganese concentrations in MW-03 were variable, ranging from 120 to 770 μ g/L and 110 to 700 μ g/L, respectively. Sulfate concentrations in MW-03 (average concentration of 125 mg/L) were similar to VFA well MW-02 (average concentrations of 125 mg/L), potentially indicating a component of flow from the former mine area to MW-03 (Figure 8). However, the manganese concentrations observed in MW-03 were substantially lower than in MW-02 (maximum of 770 μ g/L compared to 3,600 μ g/L for total manganese, respectively). MW-03 is screened beneath a thick zone of the clay aquitard (12 feet) and within a surface water drainage where a smaller fraction of the total flow originates within the former mine area.

Piper diagrams comparing MW-03 to upgradient waters and downgradient waters are shown in Figures 9a and 9b. MW-03 contained a lower relative abundance of magnesium and bicarbonate compared to waters in the Plant Area (Figure 9a) but plotted closely with VFA wells MW-01, MW-02, MW-016, and colluvial soil water sample MW-09 (Figure 9b). Ternary diagrams of conservative ions chloride, sulfate, and sodium for upgradient and downgradient waters also showed MW-03 plotting closely with downgradient VFA/colluvial soil water samples and away from most upgradient water samples (Figures 10a and 10b). Additionally, the hydraulic gradient of groundwater within perched water zones of the former mine area (Under Coal/Upper Casselman) is south towards the VFA, implying that some former mine area groundwater is migrating to the VFA. While the water chemistry results are not definitive (e.g., VFA hydraulic gradient trends north/east away from the former mine area), CMD from the former mine area entering through the surface water drainage area is likely the predominant source of manganese to MW-03.

4.4 MW-05 and MW-06

MW-05 is located southeast of the South Mill Building just north of Cross Creek while MW-06 is located approximately 1,000 feet south of MW-05. Total manganese concentrations in groundwater samples collected from MW-05 and MW-06 ranged from 370 to 920 μ g/L and 100 to 180 μ g/L, respectively. Dissolved manganese concentrations of groundwater samples collected from MW-05 and MW-06 ranged from 290 to 910 μ g/L and 88 to 160 μ g/L, respectively. A Piper diagram (Figure 11) displaying samples collected from MW-05 and MW-06 and MW-06 compared to MW-11, MW-12, and other nearby wells, shows that MW-05 and MW-06 were similar in water type to MW-11 (water type Ca-HCO3), but differed from MW-12 (water type K-HCO3). This result may indicate that seepage from the Interflow Zone to the VFA near the South Mill Building is limited, despite positive detections for hexavalent chromium in both Interflow Zone well MW-12 (0.68 to 1.4 mg/L) and VFA well MW-05 (0.038 mg/L).

Perched groundwater sample RBH-03S, which is screened below slag on the Ridgetop, also displayed a similar water type as MW-05 and MW-06 and may indicate flow from the Ridgetop to the VFA. However, the relative abundance of major ions for MW-05 and MW-06 was most similar to VFA well RBA-04S (a downgradient well with no history of exceedances) and also comparable to Ohio sand and gravel aquifer averages (OEPA 2016), indicating that manganese in MW-05 and MW-06 may also be naturally occurring. East of the RBA-4 well cluster, an area which includes MW-05 and MW-06, groundwater in the VFA is generally reduced (Eh <-140 mV) and pH is circumneutral (Figure 12 and 13), creating conditions that promote the natural release of manganese to groundwater.

Sulfate concentrations observed in MW-05 and MW-06 (77 to 84 mg/L and 55 to 69 mg/L, respectively) were similar to the average sulfate concentration for sand and gravel aquifers in Ohio (74 mg/L; OEPA 2016), but substantially lower than sulfate concentrations of perched groundwater and seeps of the former mine area (>300 mg/L). Additionally, MW-05 and MW-06 are located far enough away from the surface drainage and groundwater pathways (0.35 and 0.5 miles, respectively) that flow from the former mine area to MW-05 and MW-06 is unlikely.

Average concentrations of manganese (total and dissolved) in MW-11 (99 μ g/L total and 1.6 μ g/L dissolved) and MW-12 (46 μ g/L total and non-detect for dissolved) were substantially lower compared to VFA wells (average of 880 μ g/L total and 820 μ g/L dissolved). Higher total manganese concentrations relative to dissolved manganese in Interflow Zone Wells MW-11 and MW-12 indicate that some manganese is present in solution, but likely as colloidal-sized particulate matter or as precipitating minerals (e.g., calcite; Roadcap et al. 2005; Table 2).

Manganese present as particulate matter in the Interflow Zone is unlikely to migrate through the clay aquitard to the underlying VFA.

MW-05 and MW-06 were similar in water type and major ion concentration to averages for Ohio sand and gravel aquifers, supporting the conclusion that manganese may be naturally occurring.

4.5 MW-10

MW-10 is located at the toe slope of the Ridgetop at the intersection between Cross Creek and McIntyre Creek upgradient of both the former mine area and the Plant Area. Manganese concentrations for MW-10 ranged from 830 to 1,300 µg/L for total manganese and 190 to 390 µg/L for dissolved manganese. A Piper diagram (Figure 14) displaying bedrock wells screened below the VFA (RBA-04D and RBA-05D), MW-10, and upgradient VFA well RBA-05I shows similarity in water type between MW-10 and bedrock wells (RBA-05D and RBA-04D: water type Na-Cl). Groundwater in MW-10 and bedrock well RBA-04D contained elevated concentrations of sodium and chloride relative to all other wells on site, with sodium concentrations greater than 1,200 mg/L and chloride concentrations greater than 1,900 mg/L. Molar ratios of nearly 1:1 between sodium and chloride and high total dissolved solids concentrations (>2,800 mg/L) at both MW-10 and RBA-04D indicate dissolution of evaporative minerals may be occurring (e.g., halite (NaCI)). While water type and concentrations of major ions were similar between MW-10 and RBA-04D, manganese concentrations at MW-10 (maximum total manganese concentration of 1.300 µg/L) were elevated relative to RBA-04D (maximum total manganese concentration of $64 \mu g/L$), indicating that while major ions at MW-10 appear to be sourced from bedrock, manganese may not be. Nonetheless, chemical indicators for other sources (e.g., sulfate for former mine area or chromium for slag) were found at low concentrations in MW-10 (<1 mg/L sulfate and <0.05 mg/L for total chromium), indicating that manganese at MW-10 may be naturally released from weathered bedrock near MW-10.

5.0 CONCLUSIONS

This review of manganese sources and potential pathways to VFA wells was conducted to evaluate manganese concentrations in groundwater greater than the MCL (50 μ g/L) found in Site wells MW-01, MW-02, MW-03, MW-05, MW-06, and MW-10. Based on the results of this assessment, the following is concluded for manganese in VFA groundwater:

- CMD from the former mine area is likely the predominant source of manganese in wells MW-01, MW-02, and MW-03
- Manganese in wells MW-05, MW-06, and MW-10 is likely due to natural release of manganese from soils in the VFA
- Manganese release from slag is likely very limited

Attachments:

TABLES

Table 1 Summary of Manganese Content of Various Site MaterialsTable 2 Relevant Mineral Phases – Saturation Indices

FIGURES

Figure 1 Manganese of Solids - Maximum

Figure 2 Trilinear (Piper) Diagrams of Groundwater (a) and Surface Water (b) at the Site

Figure 3 Dissolved Manganese in Groundwater - Minimum

Figure 4 Dissolved Manganese in Groundwater - Maximum

Figure 5 Total Manganese in Groundwater - Minimum

Figure 6 Total Manganese in Groundwater - Maximum

Figure 7 Trilinear (Piper) (a) and Schoeller (b) Diagrams of Groundwater Near VFA Wells MW-01 and MW-02

Figure 8 Sulfate in Groundwater - Maximum

Figure 9 Trilinear (Piper) Diagrams of Groundwater Upgradient (a) and Downgradient (b) of MW-03

Figure 10 Ternary Diagrams of Groundwater Upgradient (a) and Downgradient (b) of MW-03

Figure 11 Trilinear (Piper) Diagram of Groundwater Near MW-05 and MW-06

Figure 12 ORP of Valley Fill Aquifer Groundwater - Minimum

Figure 13 pH of Valley Fill Aquifer Groundwater - Minimum

Figure 14 Trilinear (Piper) Diagram of Groundwater Near MW-10

https://golderassociates.sharepoint.com/sites/100059g/deliverables/ri report/mn_comment_response/memorandum/draft to agency/12393309-04-m-rev. c-manganese comment reponse_071822_r1.docx



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Table

TABLE 2 GEOCHEMICAL MODELING RELEVANT MINERAL PHASES - Saturation Indices VALLEY FILL AQUIFER AND INTERFLOW ZONE, FORMER SATRALLOY SITE

MINE	RAL PHASES - Saturation Indices	MW01	MW02	MW03	MW05	MW06	MW10	MW16	RBA04S	RBA04I	KMW01	RBA05I	MW11	MW12	MW14	MW15
Ferrihydrite	Fe(OH) ₃	-2.34	-0.80	1.41	-1.69	-2.48	2.20	-5.22	-0.63	-1.01	-0.95	-2.41	0.23	1.62	-0.41	-2.73
Siderite	FeCO ₃	-1.03	-0.30	-1.02	-1.52	-0.93	-1.30	-2.08	-1.35	-0.64	0.05	-0.98	-8.42	-4.68	-0.75	-1.24
Manganite	MnO(OH)	-9.93	-7.91	-6.25	-9.23	-10.70	-6.04	-15.17	-9.55	-8.43	-10.71	-10.00	-2.36	-3.61	-8.51	-9.29
Pyrochroite	Mn(OH) ₂	-6.12	-3.30	-5.37	-6.64	-6.22	-6.86	-10.15	-7.59	-4.90	-6.20	-5.30	-0.63	-2.14	-6.55	-5.90
Pyrolusite	MnO ₂	-21.23	-19.92	-14.89	-19.66	-23.26	-13.44	-27.94	-19.02	-20.63	-22.85	-22.70	-11.38	-12.34	-19.09	-21.52
Rhodochrosite	MnCO ₃	0.39	1.63	0.26	-0.14	-0.30	-0.72	-3.09	-1.25	0.63	-0.74	0.30	-1.94	-0.83	-0.15	0.85
Calcite	CaCO ₃	0.19	1.19	0.65	0.01	0.50	-0.10	-0.48	0.17	0.74	0.33	0.33	2.56	1.41	-0.32	0.44

Notes:

Saturation indices >-0.5 identified by red bold type and grey shading







Figures



H: G:\GlS\Sites\Satralloy\1239330902_600_005_Manganese.mxd

	Sampling Location - Manganese EXISTING FACILITY			8,000 - 7,000 8,000 - 8,000
[EXISTING ON-SITE ACCESS ROAD			9,000 - 9,000
	COUNTY ROAD			10,000 - 10,000
	FENCE LINE			20,000 - 10,000
				20,000 - 20,000
				30,000 - 20,000
	AED TRANSMISSION LINE			
	EXISTING PROPERTY BOUNDARY			
	INHOLDING PROPERTY BOUNDARY			
	EXISTING RAILROAD			
<u> </u>	FORMER RAIL SPUR/LOW RAIL SPUR			
<u> </u>	EXISTING SLURRY PIPELINE			
— I	MAJOR DRAINAGE DITCH			
;	STORM PIPELINE			
	INTERMITTENT JURISDICTIONAL WATERS	OF THE U.S. (CORPS)		
		THE U.S. (CORPS)		
		N)		
(CONTOUR (50 FT INTERVAL)			
Mangane	256			
	20 - 400			
ļ	500 - 800			
	900 - 1,000			
	2,000 - 2,000			
	3,000 - 2,000			
	3,000 - 3,000			
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	4,000 - 4,000			
	5,000 - 4,000			
	6.000 - 5.000			
	6,000 - 6,000			
· · ·	7,000 - 7,000			
2. PROF	PERTY BOUNDARY BY BONAR SURVE ANDS DELINEATION PERFORMED IN RCES, INC.	YING, BERGHOLZ, OH 2015 AND 2016, PRO	IIO, DATE	D OCTOBER 17, WESTLAND
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TITITIE IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM:





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 ◆ ◆ ▲ 					
◆▲	COLLUVIAL SO	JIL		Mn Co	ncentration (µg/L)
	INTERFLOW				0
	LOWER PITTS	BURGH			∠∪U 400
•	PERCHED BE	DROCK			600
+	REGIONAL BE	DROCK			800
•	SITE SURFAC	E WATER			1000
	UNDER COAL	ZONE			1200
	UPPER CASS	ELMAN			1400
•	VALLEY FILL				1600
	EXISTING FAC	XILITY			1800
		-SITE ACCESS ROAD			2000
	COUNTY ROA	D			2200
		,			2400
		IARKER AND LABEL			2600
	CROSS CREE	K			3000
	AEP TRANSM	ISSION LINE			3200
	EXISTING PR	OPERTY BOUNDARY			3400
	INHOLDING P	ROPERTY BOUNDARY			3600
-++	EXISTING RAI	LROAD			3800
	FORMER RAIL	_ SPUR/LOW RAIL SPUR			
	EXISTING SLU	JRRY PIPELINE			
	MAJOR DRAIN	IAGE DITCH			
	STORM PIPEL	INE			
			י חב ט.ג. (CORPS) N)		
			••)		
	CONTOUR (50) FT INTERVAL)			
	CONTOUR (10) FT INTERVAL)			
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3. WET RESOL 4. THE WEBSI 5. SITE 6. SITE INTERI REFER 1. JEFF 2. BON 3. WES	JRCES, INC. RIVER MILE TE, JUNE 201 ADDRESS: 4 INFRASTRU IM ACTION RE ENCE(S) FERSON COU IAR SURVEYI	MARKERS SHOWN FOR C 12. 1243 COUNTY ROAD 74, MI CTURE IS DEPICTED AS E EPORT FOR MORE RECEN INTY (TOPOGRAPHY, 2003 NG (PROPERTY BOUNDAR DURCES, INC. (WET, AND S	ROSS CREEK ARE FR NGO JUNCTION, OH 4 XISTING AT THE TIME IT MODIFICATIONS TO) RY, 2006)	ROM OHIC 43938 5 OF THE 0 SITE INF	O STATE DNR RI/FS. SEE THE FRASTRUCTURE.
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3. WET RESOL 4. THE WEBSI 5. SITE 6. SITE INTERI 7. JEFF 2. BON 3. WES 4. COC CLIENT CYPI PROJE SATE	JRCES, INC. RIVER MILE ITE, JUNE 20' ADDRESS: 4 INFRASTRU IM ACTION RE RENCE(S) FERSON COL IAR SURVEYI STLAND RESO ORDINATE SY	MARKERS SHOWN FOR C 12. 1243 COUNTY ROAD 74, MI CTURE IS DEPICTED AS E EPORT FOR MORE RECEN JNTY (TOPOGRAPHY, 2003 NG (PROPERTY BOUNDAF DURCES, INC. (WETLANDS STEM: NAD 1983, STATE P X MINERALS CON REMEDIAL INVEST	ROSS CREEK ARE FR NGO JUNCTION, OH 4 XISTING AT THE TIME IT MODIFICATIONS TO () (Y, 2006) 5, 2013) LANE OHIO NORTH (F MPANY	ROM OHIC 43938 E OF THE D SITE INF	9 STATE DNR RI/FS. SEE THE FRASTRUCTURE.
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3. WET RESOL 4. THE WEBSI 5. SITE 6. SITE INTERI 7. JEFF 2. BON 3. WES 4. COC CLIENT CYPI PROJE SATF TITLE DISS	JRCES, INC. RIVER MILE ITE, JUNE 20' ADDRESS: 4 INFRASTRU IM ACTION RI ENCE(S) FERSON COLLIAR SURVEYI STLAND RESO DRDINATE SY RUS AMA	MARKERS SHOWN FOR C 12. 1243 COUNTY ROAD 74, MI CTURE IS DEPICTED AS E EPORT FOR MORE RECEN JNTY (TOPOGRAPHY, 2003 NG (PROPERTY BOUNDAF DURCES, INC. (WETLANDS STEM: NAD 1983, STATE P AX MINERALS CON REMEDIAL INVEST JANGANESE IN G	ROSS CREEK ARE FR NGO JUNCTION, OH 4 XISTING AT THE TIME IT MODIFICATIONS TO () (Y, 2006) (S, 2013) LANE OHIO NORTH (F APANY TIGATION ROUNDWATER	ROM OHIC 43938 5 OF THE 5 SITE INF 5 T) FIPS 3 R - MIN 2022	9 STATE DNR RI/FS. SEE THE FRASTRUCTURE. 9401 IMUM
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LEG	END				
•	COLLUVIAI	SOIL		Mn Co	oncentration (µg/L)
•	INTERFLO	N			0
	LOWER PI	ITSBURGH			500
	PERCHED	BEDROCK			1000
.	REGIONAL	BEDROCK			1500
	SITE SURF	ACE WATER			2000
	UNDER CO	DAL ZONE			2500
	UPPER CA	SSELMAN			3500
•	VALLEY FIL	L			4000
	EXISTING F	FACILITY			4500
	EXISTING	ON-SITE ACCESS ROAD			5000
	COUNTY R	OAD			5500
	FENCE LIN	E			6000
	CREEK FLC	WC			
	RIVER MILI	E MARKER AND LABEL			
	CROSS CR	EEK			
	AEP IRAN				
└ <u></u> J	EXISTING	RAILROAD			
	FORMER R	AIL SPUR/LOW RAIL SPUR			
	EXISTING	SLURRY PIPELINE			
	MAJOR DR	AINAGE DITCH			
	STORM PIF	PELINE			
	INTERMITT	ENT JURISDICTIONAL WATERS	OF THE U.S. (CORPS)		
	PERENNIA	L JURISDICTIONAL WATERS OF	THE U.S. (CORPS)		
	ISOLATED	WETLANDS (OEPA JURISDICTIO	N)		
		ER (NON-JURISDICTIONAL)			
	CONTOUR	(10 FT INTERVAL)			
NOTE 1. BAS OFFIC DATUI MEAS 2. PRO 2006. 3. WE	(S) SE TOPOGR SE. HORIZO M: NAVD88 UREMENTS OPERTY BO TLANDS DE URCES. IN(0 150 300 RAPHY DATED 2003 PROVIDE DNTAL DATUM: NAD 1983, STA (EST. 1991). ADDITIONAL TO S. DUNDARY BY BONAR SURVEY ELINEATION PERFORMED IN 2	600 FEET D BY JEFFERSON COU ATE PLANE OHIO NOR POGRAPHY BASED ON YING, BERGHOLZ, OHI 2015 AND 2016, PROVI	JNTY, O TH (FT) I N FIELD O, DATE DED BY	HIO, ENGINEER'S FIPS 3401. VERTICAL OBSERVATIONS AND D OCTOBER 17, WESTLAND
4. THE WEBS	RIVER MIL	LE MARKERS SHOWN FOR C	ROSS CREEK ARE FRO		O STATE DNR
5. SITI	EADDRESS	S: 4243 COUNTY ROAD 74, MI	NGO JUNCTION, OH 4	3938 OF THE	
INTER		REPORT FOR MORE RECEN	T MODIFICATIONS TO	SITE INI	FRASTRUCTURE.
REFE	RENCE(S)				
1. JEF)		
2. BUI 3. WE	STLAND RE	SOURCES, INC. (WETLANDS	, 2013)		2404
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	RUS AN				
SAI	RALLUI	REIVIEDIAL INVEST	IGATION		
_					
TITLE					
DISS	SOLVED	MANGANESE IN G	ROUNDWATER	- MA	XIMUM
CONS	ULTANT		YYYY-MM-DD	2022	-05-17
			DESIGNED	BVJ	
		GOLDER	PREPARED	TH	
		MEMBER OF WSP		 RI	
				וט	

FIGURE

PROJECT NO. 1239330902

PHASE 600

APPROVED

LH

REV. 1



◆◆				
-	COLLUVIAL SOIL		Mn Concentration (µg/L))
T	INTERFLOW		0	
	LOWER PITTSBURGH		1000	
•	PERCHED BEDROCK		2000	
•	REGIONAL BEDROCK		4000	
•	SITE SURFACE WATER		5000	
	UNDER COAL ZONE		6000	
	UPPER CASSELMAN		7000	
•	VALLEY FILL		8000	
	EXISTING FACILITY		9000	
	EXISTING ON-SITE ACCESS ROAD		10000	
	COUNTY ROAD		11000	
			12000	
			13000	
	CROSS CREEK		15000	
	AEP TRANSMISSION LINE		16000	
	EXISTING PROPERTY BOUNDARY		17000	
	INHOLDING PROPERTY BOUNDARY			
	EXISTING RAILROAD			
	FORMER RAIL SPUR/LOW RAIL SPUR			
	EXISTING SLURRY PIPELINE			
	MAJOR DRAINAGE DITCH			
	ISOLATED WETLANDS (OEDA HUDISDICT)	- THE U.S. (CURPS) ON)		
	OPEN WATER (NON-ILIRISDICTIONAL)			
	CONTOUR (50 FT INTERVAL)			
	CONTOUR (10 FT INTERVAL)			
NOTE(S	5) E TOPOGRAPHY DATED 2003 PROVID E. HORIZONTAL DATUM' NAD 1983 ST	ED BY JEFFERSON COU	INTY, OHIO, ENGINEER H (FT) FIPS 3401 VFR	'S TICA
	:. הסגובטא ואב מאוטא: NAD 1983, ST ו: NAVD88 (EST. 1991). ADDITIONAL T(DPOGRAPHY BASED ON	ロ(「」)「PS 3401. VER I FIELD OBSERVATIONS	S AN
MEASU 2. PRO	REMENTS. PERTY BOUNDARY BY BONAR SURVE	EYING, BERGHOLZ. OHIO	D, DATED OCTOBER 17	,
2006. 3 ₩FT				
RESOU				
4. THE WEBSI	TE, JUNE 2012.	JRUSS UKEEK ARE FRC		
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a leg	END			
•	COLLUVIAL SOIL		Mn Co	oncentration (μg/L)
	INTERFLOW		_	0
	LOWER PITTSBURGH			2000
	PERCHED BEDROCK			4000
•	REGIONAL BEDROCK			8000
~	SITE SURFACE WATER			10000
	UNDER COAL ZONE			12000
	UPPER CASSELMAN			14000
•	VALLEY FILL			16000
	EXISTING FACILITY			18000
	EXISTING ON-SITE ACCESS ROAD			20000
	COUNTY ROAD			22000
				24000
	RIVER MILE MARKER AND LABEL			26000
	CROSS CREEK			30000
	AEP TRANSMISSION LINE			32000
	EXISTING PROPERTY BOUNDARY			
	INHOLDING PROPERTY BOUNDARY			
	EXISTING RAILROAD			
	FORMER RAIL SPUR/LOW RAIL SPUR			
	EXISTING SLURRY PIPELINE			
	PERENNIAL JURISDICTIONAL WATERS OF	THE U.S. (CORPS)		
	ISOLATED WETLANDS (OEPA JURISDICTIC	N)		
	OPEN WATER (NON-JURISDICTIONAL)			
<u> </u>	CONTOUR (50 FT INTERVAL)			
	CONTOUR (10 FT INTERVAL)			
NOTE 1. BAS OFFIC DATUI MEAS 2. PRC 2006. 3. WE RESO 4. THE WEBS 5. SITH 6. SITH 1. JEF 2. BON 3. WE 4. COO CLIEN CYP	(S) SE TOPOGRAPHY DATED 2003 PROVIDE E. HORIZONTAL DATUM: NAD 1983, ST/ VI: NAVD88 (EST. 1991). ADDITIONAL TO UREMENTS. DPERTY BOUNDARY BY BONAR SURVE TLANDS DELINEATION PERFORMED IN URCES, INC. E RIVER MILE MARKERS SHOWN FOR C SITE, JUNE 2012. E ADDRESS: 4243 COUNTY ROAD 74, M E INFRASTRUCTURE IS DEPICTED AS E MACTION REPORT FOR MORE RECEN RENCE(S) FERSON COUNTY (TOPOGRAPHY, 2003 VAR SURVEYING (PROPERTY BOUNDAI STLAND RESOURCES, INC. (WETLANDS ORDINATE SYSTEM: NAD 1983, STATE F	D BY JEFFERSON CO ATE PLANE OHIO NO POGRAPHY BASED (YING, BERGHOLZ, OF 2015 AND 2016, PRO ROSS CREEK ARE FI INGO JUNCTION, OH XISTING AT THE TIME IT MODIFICATIONS TO () RY, 2006) 5, 2013) LANE OHIO NORTH (OUNTY, O RTH (FT) I ON FIELD HIO, DATE VIDED BY ROM OHIO 43938 E OF THE O SITE INI	HIO, ENGINEER'S FIPS 3401. VERTICAL OBSERVATIONS AND D OCTOBER 17, WESTLAND O STATE DNR RI/FS. SEE THE FRASTRUCTURE.
PROJ	ECT			
SAT	RALLOY REMEDIAL INVES	FIGATION		
TITLE	AL MANGANESE IN GROU	NDWATER - M/	AXIMU	Μ
TITLE TOT	CAL MANGANESE IN GROU	NDWATER - MA	AXIMU 2022	M -05-17
TITLE TOT	AL MANGANESE IN GROU	NDWATER - MA	AXIMU 2022 BVJ	M -05-17
TITLE TOT		NDWATER - MA	AXIMU 2022 BVJ TH	M -05-17

FIGURE

PROJECT NO. 1239330902

PHASE 600

APPROVED

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REV. 1





H: G:\GIS\Sites\Satralloy\1239330902_600_005_Sulfate_concentration.mxd

+	COLLOVIAL SOIL			
•	INTERFLOW			100
•	PERCHED BEDROCK			200
•	REGIONAL BEDROCK			300
	SITE SURFACE WATER			500
	UNDER COAL ZONE			600
	UPPER CASSELMAN			700
•	VALLEY FILL			800 - 1900
	EXISTING FACILITY			
	EXISTING ON-SITE ACCESS ROAD			
	COUNTY ROAD			
	RIVER MILE MARKER AND LABEL			
	CROSS CREEK			
	AEP TRANSMISSION LINE			
	EXISTING PROPERTY BOUNDARY			
	INHOLDING PROPERTY BOUNDARY			
+-+	EXISTING RAILROAD			
	FORMER RAIL SPUR/LOW RAIL SPUR			
	EXISTING SLURRY PIPELINE			
	PERENNIAL JURISDICTIONAL WATERS	F THE U.S. (CORPS)		
	ISOLATED WETLANDS (OEPA JURISDICT	ON)		
	OPEN WATER (NON-JURISDICTIONAL)			
	CONTOUR (50 FT INTERVAL)			
	CONTOUR (10 FT INTERVAL)			
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I F THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI D







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LE	GEND				
-	► Valley Fill			Min ORP (mV)	
7	EXISTING FA	CILITY		-450	
	EXISTING ON	I-SITE ACCESS ROAD		-400	
	COUNTY RO	AD		-350	
	FENCE LINE			-250	
				-200	
				-150	
				-100	
				-50	
1 i-		PROPERTY BOUNDARY		0	
	+ EXISTING RA	ILROAD		50	
	- FORMER RA	L SPUR/LOW RAIL SPUR		100	
	- EXISTING SL	URRY PIPELINE		150	
	MAJOR DRAI	NAGE DITCH		200	
	— STORM PIPE	LINE		250	
		NT JURISDICTIONAL WATERS	OF THE U.S. (CORPS)	300	
	PERENNIAL	IURISDICTIONAL WATERS OF	THE U.S. (CORPS)	350	
	ISOLATED W	ETLANDS (OEPA JURISDICTIO	DN)	400	
	OPEN WATE	R (NON-JURISDICTIONAL)		450	
	— CONTOUR (5	0 FT INTERVAL)			
	CONTOUR (1	0 FT INTERVAL)			
+					
4					
		0 Г	150 300	600	
2					
				FEEI	
OF DA ME 2. F 200 3. V RE 5. S 6. S INT RE 3. V 4. O CL C C PR	FICE. HORIZON TUM: NAVD88 (E ASUREMENTS. PROPERTY BOU)6. VETLANDS DEL SOURCES, INC. THE RIVER MILE BSITE, JUNE 20 SITE ADDRESS: SITE INFRASTRU ERIM ACTION R FERENCE(S) VESTLAND RES COORDINATE SY VESTLAND RES COORDINATE SY VESTLAND RES COORDINATE SY VESTLAND RES COORDINATE SY	ITAL DATUM: NAD 1983, ST ST. 1991). ADDITIONAL TO NDARY BY BONAR SURVE INEATION PERFORMED IN MARKERS SHOWN FOR O 12. 4243 COUNTY ROAD 74, M JCTURE IS DEPICTED AS E EPORT FOR MORE RECEI UNTY (TOPOGRAPHY, 2003 ING (PROPERTY BOUNDA OURCES, INC. (WETLANDS (STEM: NAD 1983, STATE F AX MINERALS COI	ATE PLANE OHIO NO POGRAPHY BASED YING, BERGHOLZ, C 2015 AND 2016, PRC ROSS CREEK ARE F INGO JUNCTION, OF EXISTING AT THE TIM NT MODIFICATIONS T 3) RY, 2006) S, 2013) PLANE OHIO NORTH WPANY	ORTH (FT) FIPS 3401 ON FIELD OBSERV/ OHIO, DATED OCTOR OVIDED BY WESTLA FROM OHIO STATE I 4 43938 IE OF THE RI/FS. SI TO SITE INFRASTRU (FT) FIPS 3401	I. VERTICAL ATIONS AND BER 17, ND DNR EE THE JCTURE.
	TLE RP OF VAL NSULTANT	LEY FILL AQUIFE	R GROUNDWA	TER - MINIMU 2022-05-03	JM
5			DESIGNED	BVJ	
2		GOLDER	PREPARED	TH	
		MEMBER OF WSP	REVIEWED	BI	
			APPROVED	LH	
PR	0JECT NO.	PHASE 600	RE 1	EV.	FIGURE
. 175		000	I		



*	END				
🔶 '	Valley Fill			Min pH	
ł	EXISTING FAC	CILITY			0
[EXISTING ON	-SITE ACCESS ROAD			4.5
(COUNTY ROA	D			5
— F	FENCE LINE				5.5
					6.5
		IARKER AND LABEL			7
					7.5
	EXISTING PR	OPERTY BOUNDARY			8
	INHOLDING P	ROPERTY BOUNDARY			8.5
I	EXISTING RAI	LROAD			9
— I	FORMER RAIL	SPUR/LOW RAIL SPUR			9.5
<u> </u>	EXISTING SLU	JRRY PIPELINE			10
— I	MAJOR DRAIN	IAGE DITCH			10.5
	STORM PIPEL	INE			11
		IT JURISDICTIONAL WATER	RS OF THE U.S. (CORPS)	11.5
			DF THE U.S. (CORPS)		
			IUN)		
(CONTOUR (10) FT INTERVAL)			
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			0 150 300	600	
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DATUM: MEASUI 2. PROF 2006. 3. WETL RESOUI 4. THE F WEBSIT 5. SITE INTERIM REFERE 1. JEFFI 2. BON/ 3. WES	INDERIZON NAVD88 (ES REMENTS. PERTY BOUN LANDS DELII RCES, INC. RIVER MILE TE, JUNE 207 ADDRESS: 4 INFRASTRU MACTION RI ENCE(S) ERSON COL AR SURVEYI TLAND RESO	INCEDENTION. INAD 1983, S ST. 1991). ADDITIONAL T NDARY BY BONAR SURV NEATION PERFORMED I MARKERS SHOWN FOR 12. 1243 COUNTY ROAD 74, CTURE IS DEPICTED AS EPORT FOR MORE REC INTY (TOPOGRAPHY, 20 NG (PROPERTY BOUND DURCES, INC. (WETLAN)	OPOGRAPHY BASED (EYING, BERGHOLZ, ON N 2015 AND 2016, PR CROSS CREEK ARE MINGO JUNCTION, O EXISTING AT THE TH ENT MODIFICATIONS 03) ARY, 2006) DS, 2013)	ON FIELD OF OHIO, DATED OVIDED BY W FROM OHIO S H 43938 ME OF THE RI TO SITE INFR	OCTOBER 17, ESTLAND STATE DNR /FS. SEE THE ASTRUCTURE.
CLIENT	RUS AMA	X MINERALS CO	OMPANY		
CLIENT CYPF PROJEC SATR	RUS AMA CT RALLOY F	X MINERALS CO REMEDIAL INVES	OMPANY STIGATION R GROUNDWAT	ER - MIN	MUM
CLIENT CYPF PROJEC SATR TITLE pH O	RUS AMA CT RALLOY F	X MINERALS CO REMEDIAL INVES	OMPANY STIGATION R GROUNDWAT	ER - MIN	MUM
CLIENT CYPF PROJEC SATR TITLE PH O CONSUI	RUS AMA CT RALLOY F	X MINERALS CO REMEDIAL INVES	DMPANY STIGATION R GROUNDWAT	ER - MIN 2022-03	I MUM 5-03
CLIENT CYPF PROJEC SATR TITLE pH O CONSUI	RUS AMA	X MINERALS CO REMEDIAL INVES	DMPANY STIGATION R GROUNDWAT	TER - MIN 2022-03 BVJ	I MUM 5-03
CLIENT CYPF PROJEC SATR TITLE pH O CONSUI	RUS AMA	S MINERALS CO REMEDIAL INVES	DMPANY STIGATION R GROUNDWAT	ER - MIN 2022-03 BVJ TH	I MUM 5-03
CLIENT CYPF PROJEC SATR TITLE pH O	RUS AMA	X MINERALS CO REMEDIAL INVES	DMPANY STIGATION R GROUNDWAT R GROUNDWAT DESIGNED PREPARED REVIEWED	ER - MIN 2022-03 BVJ TH BI	MUM 5-03
CLIENT CYPF PROJEC SATR TITLE pH O CONSUI	RUS AMA	AX MINERALS CO REMEDIAL INVES EY FILL AQUIFER GOLDER MEMBER OF WSP	DMPANY STIGATION R GROUNDWAT PREPARED PREPARED REVIEWED APPROVED	TER - MIN 2022-03 BVJ TH BI LH	MUM 5-03

