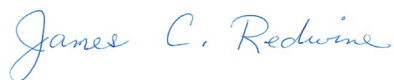December 2020

Semi-Annual Remedy Selection and Design Progress Report
Plant Gaston

Prepared for Alabama Power Company

December 2020

Semi-Annual Remedy Selection and Design Progress Report
Plant Gaston

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ABBREVIATIONS

ACM	Assessment of Corrective Measures
ADEM	Alabama Department of Environmental Management
Alabama Power	Alabama Power Company
CCR	coal combustion residuals
CEC	cation exchange capacity
CFR	Code of Federal Regulations
COI	constituent of interest
CSM	conceptual site model
EPA	U.S. Environmental Protection Agency
MNA	monitored natural attenuation
Site	Ash Pond at Gaston
SEM	scanning electron microscopy
SSE	selective sequential extraction
SSL	statistically significant level
USGS	U.S. Geological Survey
XRD	X-ray diffraction
XRF	X-ray fluorescence

1   Introduction

In accordance with the U.S. Environmental Protection Agency's (EPA's) coal combustion residuals (CCR) Rule 40 Code of Federal Regulations (CFR) § 257.97(a), the Alabama Department of Environmental Management's (ADEM's) Admin. Code r. 335-13-15-.06(8)(a), and Part C of Administrative Order No. 18-095-GW, this *Semi-Annual Remedy Selection and Design Progress Report* has been prepared for the Ash Pond at Plant Gaston (Site). Specifically, this report has been prepared to describe the progress made in evaluating the selected remedy and alternative remedies and designing a remedy plan in the second semi-annual period of 2020.

In June 2019, Alabama Power Company (Alabama Power) completed an Assessment of Corrective Measures (ACM; Anchor QEA 2019) to address the occurrence of arsenic, lithium, and molybdenum in groundwater at statistically significant levels (SSLs). In the ACM, the following remedies were considered feasible for corrective measures for groundwater:

- Monitored natural attenuation (MNA)
- Hydraulic containment (pump and treat)
- Geochemical manipulation via injections (i.e., enhanced natural attenuation)
- Permeation grouting

As required by the Administrative Order, MNA was proposed as the main groundwater corrective action remedy for the Site. Source control measures consisting of consolidation, dewatering, and capping of the ash (source) were already planned as part of pond closure.

Additional assessment work has been completed in 2020 to evaluate and demonstrate MNA and geochemical manipulation as corrective measures at the Site. Groundwater samples and solids (precipitates) were collected from select wells, and groundwater sampling results were used to perform geochemical modeling, which predicted attenuating species under Site geochemical conditions. Well solids were analyzed to determine attenuating phases for the constituents of interest (COI; arsenic, lithium, and molybdenum) at the Site. Solids analysis also provides insight into the stability of the attenuating mechanisms. The well solids were analyzed as follows:

- Elemental analysis by X-ray fluorescence (XRF) to determine the chemical composition of the matrix (e.g., iron compounds, aluminosilicates, and carbonates) and presence of COI
- X-ray diffraction (XRD) to determine crystalline mineral phases
- Scanning electron microscopy (SEM) and associated elemental analysis to confirm mineral phases and attenuating mechanisms
- Selective sequential extraction (SSE) to determine the association of COI with attenuating phases and the relative binding strength of attenuated COI, and to provide a sense of permanence

- Cation exchange capacity (CEC) and exchangeable COI concentrations for samples that contain clay minerals

In addition, concentration versus time and concentration versus distance graphs were created to help determine if attenuation is occurring with time and/or distance from the ash pond.

Any data obtained during on-site investigations or to evaluate corrective action alternatives will be included in the subsequent *Semi-Annual Groundwater Monitoring and Corrective Action Reports*.

2 Summary of Work Completed

Site investigations and preliminary design work have continued at the Site to support remedy selection and design. As discussed in the ACM (Anchor QEA 2019), completing a final long-term corrective action plan is often a multi-year process. Additional assessment work has been completed since June 2020, and laboratory work has been performed to support MNA and in situ geochemical manipulation as discussed in the ACM. MNA and geochemical manipulation are both geochemically based, such that site-specific geochemical data and analyses can be applied to both technologies.

Laboratory analysis of groundwater and precipitates (attenuating solids) was conducted to support MNA and geochemical manipulation. The major rationale for these investigations includes the following:

- Identifying attenuating mechanisms
- Gaining an understanding of the stability of the attenuating mechanisms
- Identifying potential geochemical manipulation approaches for COIs based on Site geochemical conditions and attenuation processes already occurring naturally

In the previous reporting period (January through June 2020), the following field and laboratory investigations were performed:

- Evaluated groundwater analytical data (primarily graphing) to look for evidence of natural attenuation occurring in space and time.
- Collected groundwater samples from background and impacted wells and performed a complete chemical analysis on the samples to enable groundwater geochemical modeling and the development of a geochemical conceptual site model (CSM).
- Performed geochemical modeling using the U.S. Geological Survey (USGS) computer program PHREEQC and Geochemist's Workbench.
- Collected precipitate samples from the bottom of monitoring wells.
- Analyzed precipitate samples by XRF and XRD.

The following investigations were begun in the previous reporting period but completed in the current reporting period:

- SEM to directly observe attenuating mineral phases
- SSE to determine association of COI with attenuating phases, determine relative strength of attenuation, and provide a sense of permanence
- CEC to assess ion exchange as an attenuation mechanism

The work performed since the completion of the June 2020 progress report includes the following:

- Sampling horizontal and vertical delineation wells
- Completing SEM, SSE, and CEC testing on well solids samples

- Analyzing and synthesizing the laboratory data described above to develop a geochemical CSM and to evaluate MNA and enhanced MNA via geochemical manipulation
- Conceptualizing other corrective action options in the context of site-specific conditions, should MNA or geochemical manipulation not perform as expected

2.1 Preliminary Data Analysis

Results from existing groundwater data analysis, geochemical modeling, and well solids analyses provide evidence for attenuation mechanisms for arsenic, lithium, and molybdenum, as summarized in Table 1. The attenuating mechanisms identified include sorption on amorphous iron oxides (arsenic and molybdenum), precipitation of arsenate and molybdate phases (arsenic and molybdenum, respectively), and cation exchange on clays and manganese oxides (lithium).

2.1.1 Concentration Versus Time and Concentration Versus Distance Graphs

Existing groundwater data were used to generate concentration versus time and concentration versus distance graphs to determine if attenuation is occurring over space and/or time and to assess natural attenuation occurrence and rates. Arsenic, lithium, and molybdenum were plotted on the y-axis. For the concentration versus distance graphs, the distance between the pond boundary and the monitoring well was plotted on the x-axis. No trends are apparent for the concentration versus distance graphs, though this could change as more data become available with continued monitoring. For the concentration versus time graphs, the time between sampling events (in days) was plotted on the x-axis. Figure 1 shows that molybdenum concentrations are decreasing with time in well GN-AP-MW-5,[1] which provides evidence for natural attenuation. Similar evidence from other wells is expected after closure, as closure activities cut off the source of COI to groundwater.

2.1.2 Laboratory Analyses

Well solids (precipitates) were previously collected and were analyzed as follows:

- XRF to determine the chemical composition of the matrix (e.g., iron compounds) and presence of COI
- XRD to determine mineral phases present
- SEM to directly observe attenuating phases and mechanisms
- SSE to determine association of COI with attenuating phases, determine relative strength of attenuation, and provide a sense of permanence
- CEC to assess ion exchange as a mechanism for attenuation

All samples with sufficient volume were analyzed by XRF. A select number of samples were chosen to be analyzed by XRD to determine predominant mineralogy. Samples for XRD analysis were selected

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[1] No arsenic or lithium SSL in well GN-AP-MW-5

by looking at a variety of data, including XRF data, well location, groundwater chemical analysis, field parameters, and recovered sample mass.

In solid samples collected from 13 monitoring wells, the XRF chemical analysis of the well solids (Table 2) showed a relationship of arsenic and molybdenum with iron, and possibly with other elements associated with natural attenuation (e.g., calcium and barium). Figure 2 shows a relationship between arsenic and iron, and Figure 3 shows a relationship between molybdenum and iron concentrations in the well solids. Iron oxide coatings on soil/aquifer particles may be attenuating arsenic and molybdenum. XRD identified quartz and calcite or dolomite as the major constituent minerals in the well solids. Muscovite-illite, a potential attenuating clay mineral phase, was identified as a minor component of only one sample (Table 3).

SEM and associated elemental mapping were conducted on select samples to confirm mineral phases and attenuating mechanisms. SEM results indicate that the solids collected from MS-11S[2] are predominantly silica (quartz) interspersed with occasional small feldspar and iron-rich grains. Some alteration, with dissolution pitting in some grains, coatings of aluminum and iron material on others, and small iron precipitates on still other grains were observed. SEM images show secondary mineral growth on quartz sand grains (Figure 4). These secondary minerals likely contain iron (red color shading on the top image of Figure 4). The colors in Figure 4 are not natural but are added to show the locations of the various elements analyzed. SEM results indicate that the solids collected from GN-AP-MW-20 are predominantly large (approximately 500 micrometer), rounded quartz grains interspersed with approximately 200-micrometer calcite and feldspar grains, and iron-rich (reddish) grains. Some alteration, with coatings of aluminum, calcium, and iron material on many grains, were observed.

Based on the results from the XRF and XRD analyses and sample volume, samples were selected for SSE. SSE targets a series of operationally defined mineral fractions. In SSE, samples are leached with increasingly aggressive solutions to determine the chemical associations and mechanisms of attenuation. Generally, COIs released in each successive step represent stronger sequestration and greater stability than the previous step. The fractions, from most to least environmentally available, are as follows:

- F1 – Water soluble
- F2 – Exchangeable (e.g., clay minerals)
- F3 – Reducible (e.g., poorly crystalline metal oxides such as iron oxides)
- F4 – Oxidizable (e.g., crystalline oxide and crystalline sulfide minerals)
- F5 – Residual (e.g., silicate phases)

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[2] MW-11 is an existing site monitoring well that is not part of the CCR monitoring network.

The F3, F4 and F5 fractions represent relatively stable (permanent) attenuating mechanisms, provided Site geochemical conditions do not change drastically.

Figure 5 shows the results of SSE for five samples from the Site. All three COI (arsenic, lithium, and molybdenum) are associated primarily with the F5 (residual) fraction, less with the F2 (exchangeable) fraction, and much less with the F1 (water soluble) fraction. The SSE detection limits for COI in fractions F3 and F4 are somewhat elevated due to the small sample masses.

Select samples with suspected clay content were submitted for CEC testing. CEC was variable but low, ranging from 7.4 to 221 milliequivalents per kilogram (Table 4), which reflects the minor clay mineralogy. Exchangeable lithium was detected in solids from downgradient wells, confirming attenuation by cation exchange but is likely limited by low clay content.

2.2   Geochemical Modeling

Geochemical equilibrium modeling was performed to help determine what phases may be controlling the solubility, mobility, and attenuation of arsenic, lithium, and molybdenum as well as the behavior of other species (such as iron, manganese, and aluminum) that influence the behavior of arsenic, lithium, and molybdenum.

The Geochemist's Workbench software was used to construct Pourbaix (Eh-pH) diagrams for COI, iron, and manganese based on Site groundwater chemistry, to assess the geochemical stability of phases potentially controlling COI concentrations under Site conditions (Figures 6 through 9). The blue shaded fields indicate conditions under which dissolved/mobile species are predicted to be more stable, while yellow fields indicate conditions where solid phases are stable. Eh-pH data from Site groundwater wells are also plotted to determine the most stable forms under Site conditions. The Pourbaix stability diagrams indicate the following:

- Iron concentrations appear to be controlled by amorphous iron oxides [$Fe(OH)_{3(a)}$] (Figure 6). Iron oxides are strong sorbents for many metals and metalloids including arsenic and molybdenum. Arsenic association with iron oxides is consistent with the arsenic-iron relationship shown in Figure 2 and the iron-rich coatings observed on quartz grains (Figure 4, top image).
- Arsenic is predominantly in the +5 valence state. In addition to sorption on iron oxides, arsenic concentrations may be controlled by a barium arsenate mineral phase (Figure 7).
- Lithium is often associated with manganese oxides. In Figure 8, this association is represented by the stability field of the mineral lithiophorite [$(Al,Li)MnO_2(OH)_2$]. The thermodynamic properties of lithiophorite and other Li-bearing manganese oxides are not well known, and the stability field is approximate. Site groundwater conditions plot close to the lithiophorite field but appear to be slightly more reducing than needed to stabilize Li in manganese oxides

(Figure 8). One downgradient location plots within the stability field of the manganese oxide mineral hausmannite [Mn_3O_4].

- Molybdenum concentrations likely controlled by the solubility of a calcium molybdate phase [$CaMoO_4$] (Figure 9).

Geochemical speciation-solubility calculations were also performed using PHREEQC with the WATEQ4F thermodynamic database (augmented with data for lithiophorite and molybdenum species from the MINTEQ database) to evaluate charge balance, calculate aqueous speciation, and determine the saturation state of groundwater samples with respect to possible mineral phases. Saturation index calculations can be useful in inferring potential solid phases present in an aquifer and controls on water chemistry and reactivity of an aqueous solution toward specific mineral phases. Geochemical modeling results indicate that groundwater with detectable iron is close to equilibrium with amorphous iron oxide [$Fe(OH)_{3(a)}$] and supersaturated with more crystalline iron oxides (goethite, hematite, and magnetite). Barite (barium sulfate) is close to equilibrium in all samples, and a barium arsenate phase is also predicted to be supersaturated. The mineral phase lithiophorite [$(Al,Li)MnO_2(OH)_2$] is supersaturated in samples with detectable aluminum and manganese. Molybdenum concentrations are close to saturation with respect to a calcium molybdate phase [$CaMoO_4$].

In summary, geochemical modeling evaluations indicate the following:

- Arsenic concentrations are likely controlled by adsorption on iron oxides and possibly a barium arsenate phase.
- Lithium concentrations are likely controlled by cation exchange. Note that SSE and CEC data indicate lithium is present in an exchangeable form, which is consistent with clay minerals and/or manganese oxides.
- Molybdenum concentrations are likely controlled by a calcium molybdate phase in addition to adsorption on iron oxides.

These mineral associations are well documented in the scientific literature as attenuation mechanisms for arsenic, lithium, and molybdenum.

2.3   Geochemical Conceptual Site Model

The investigations described previously and geochemical equilibrium modeling were used to develop an initial geochemical CSM, including probable attenuating mechanisms for arsenic, lithium, and molybdenum, and the relative permanence of those mechanisms. The initial CSM for the Site is as follows:

- Multiple lines of evidence for arsenic, lithium, and molybdenum attenuation
- Aerobic to suboxic, neutral to alkaline groundwater conditions
- Redox buffered by iron and/or manganese oxide equilibria

- Arsenic attenuation by sorption to iron oxides and possibly precipitation of barium arsenate
- Lithium attenuation by ion exchange on clay minerals and/or manganese oxides
- Molybdenum attenuation by adsorption to iron oxides and/or calcium molybdate

As supported by SSE results and the scientific literature, incorporation of arsenic into iron minerals, arsenic into barium arsenate, lithium into manganese minerals, and molybdenum into calcium minerals are relatively stable attenuation mechanisms.

3 Planned Activities and Anticipated Schedule

The following conceptual-level feasibility study activities are planned for the next reporting period (January to June 2021) to evaluate MNA, geochemical manipulation, and possibly other corrective action technologies:

- Continue to compare site-specific corrective actions to the evaluation criteria in the CCR Rule, with emphasis on deficiencies that could eliminate a corrective action from further consideration
- Continue to determine how corrective actions could be integrated with pond closure, such as dewatering and associated water treatment systems
- Develop plans for additional Site investigations and associated laboratory work to determine MNA capacity, rates, and stability; and plans for laboratory treatability and/or field pilot tests to determine the effectiveness of geochemical manipulation as needed

Section 2 describes substantial evidence for the occurrence of natural attenuation at the Site. The EPA's four phases (or tiers) of MNA (EPA 2015) are as follows:

- Phase 1 – Demonstrate area of impacts (plume) is stable or shrinking
- Phase 2 – Determine mechanisms and rates of attenuation
- Phase 3 – Determine system capacity and stability
- Phase 4 – Design performance monitoring program and identify alternative remedies

The MNA work performed at the Site to date primarily supports Phase 2 (specifically mechanisms) of attenuation, though some information has been collected that supports all four phases. To advance MNA at the Site, additional work needs to be performed with respect to rate, aquifer capacity, and stability (permanence) of MNA.

Though substantial evidence for natural attenuation exists for the Site, natural attenuation is expected to increase as source control measures are implemented (i.e., dewatering, consolidation, and capping). MNA will almost certainly be one component, if not the only component, of corrective action. MNA could be implemented immediately upon pond closure.

The longer-term schedule for developing a groundwater corrective action system at the Site is as follows:

- Collect additional soil and/or rock samples and perform associated laboratory work to determine MNA capacity, rates, and stability(first and second quarters 2021)
- Perform laboratory treatability studies and implement field pilot tests as needed (second and third quarters 2021)
- Prepare a Remedy Selection Report (fourth quarter 2021)
- Develop a Corrective Action Groundwater Monitoring Program (fourth quarter 2021)

During the next reporting period, other potential remedies identified in the ACM will continue to be evaluated with respect to technical feasibility, ability to attain target standards, and ease of implementation. Based on the site-specific evaluation, additional studies may be implemented.

The schedule of activities above is considered typical and will be affected by the pond closure activities and schedule. For example, some of the activities could be performed sooner, to enable integration of corrective action with pond closure. Similarly, pond closure activities might delay implementation of some of the items above.

Pursuant to 40 CFR 257.97(a) and ADEM Admin. Code r. 335-13-15-.06(8)(a), semi-annual status progress reports will continue to be finalized in June and December until a final remedy plan is developed. Upon developing a final remedy plan, the Remedy Selection Report will be prepared describing the remedy plan and how it demonstrably meets the requirements of § 257.97 and r. 335-13-15-.06(8). Details regarding adaptive management triggers and criteria will be included in the Corrective Action Groundwater Monitoring Program.

Alabama Power will continue groundwater monitoring at the Site and will submit the next *Semi-Annual Remedy Selection and Design Progress Report* by June 12, 2021.

4 References

Anchor QEA (Anchor QEA, LLC), 2019. *Assessment of Corrective Measures.* Plant Gaston Ash Pond. Prepared for Alabama Power Company. June 2019.

EPA (U.S. Environmental Protection Agency), 2015. *Use of Monitored Natural Attenuation for Inorganic Contaminants in Groundwater at Superfund Sites.* Office of Solid Waste and Emergency Response Directive 9283.1-36. August 2015.

Tables

Table 1
Lines of Evidence for Attenuation Mechanisms

Mechanism	Geochemical Modeling	XRF	XRD	SSE	CEC
Sorption on amorphous iron oxides (arsenic, molybdenum)	X	X	X	X	
Precipitation of arsenate and molybdate phases	X			X	
Cation exchange on clays and manganese oxides (lithium)	X		X		X

Notes:

CEC: cation exchange capacity

SSE: selective sequential extraction

XRD: X-ray diffraction

XRF: X-ray fluorescence

Table 2

Bulk Chemistry of Well Solids Samples by XRF

Well ID	Arsenic	Molybdenum	Iron	Manganese	Aluminum	Calcium	Magnesium	Potassium	Silicon	Sulfur	Barium
GN-AP-MW-5	20	3	19,000	ND	5,790	135,000	10,200	4,820	59,400	709	ND
GN-AP-MW-16	4	ND	10,800	ND	7,290	102,000	5,940	3,640	119,000	853	208
GN-AP-MW-17	ND	ND	2,140	ND	1,610	85,900	4,360	641	108,000	643	ND
GN-AP-MW-20	ND	8	6,860	ND	2,470	69,700	ND	789	164,000	2,275	146
MS-11S*	ND	8	163,000	1,590	10,500	5,460	ND	2,870	185,000	1,003	180
MW-1*	ND	3	43,300	ND	10,500	2,440	ND	2,100	243,000	481	51
MW-2D*	72	ND	217,000	1,570	6,700	54,500	ND	3,380	34,700	906	294
MW-3S*	38	3	69,800	ND	7,400	2,040	ND	1,610	194,000	11,899	ND
MW-4*	ND	ND	8,730	333	8,320	886	ND	1,970	227,000	437	128
MW-9*	ND	3	42,500	970	7,630	43,100	ND	5,820	219,000	132	245
MW-10*	ND	ND	15,900	ND	5,030	68,400	ND	4,390	192,000	113	149
MW-11*	14	ND	56,600	758	17,400	69,900	ND	8,830	152,000	2,823	303
MW-11S*	ND	ND	14,000	89	6,050	1,250	ND	1,310S	255,000	439	178

Notes:

Direct analysis of lithium is not possible with portable XRF due to X-ray physics limitations.

Units are in milligrams per kilogram

*: Existing site monitoring well that is not part of the Coal Combustion Residuals rule monitoring network

ND: below limit of detection

XRF: X-ray fluorescence

Table 3

Minerals Identified in Well Solids Samples by XRD[1]

Well ID	Quartz	Muscovite-illite	Calcite	Dolomite
GN-AP-MW-5	XXX	X	--	XX
GN-AP-MW-16	XXX	--	--	XX
GN-AP-MW-17	XXX	--	--	XX
GN-AP-MW-20	XXX	--	--	XX
MS-11S[*]	XXX	--	--	--
MW-1[*]	XXX	--	--	--
MW-2D[*]	XXX	--	--	--
MW-11[*]	88	--	12	--

Notes:

1: Estimated concentration (weight %) reported where available

*: Existing site monitoring well that is not part of the Coal Combustion Residuals rule monitoring network

--: not detected

X: <10%

XX: 10% to 50%

XXX: >50%

XRD: X-ray diffraction

Table 4
Cation Exchange Capacity of Well Solids Samples

Well ID	Aluminum	Boron	Calcium	Lithium	Magnesium	Potassium	Sodium	Sum
GN-AP-MW-16	<0.015	0.073 J	81	0.057 J	27	1.2	3.5	113
GN-AP-MW-20	0.056 J	0.23 J	204	0.054 J	16	0.38	1.4	221
MS-11S[*]	0.014	<0.0022	5.9	<0.0035	0.84	0.11	0.61	7.4

Notes:

Results are in milliequivalents per kilogram.

*: Existing site monitoring well that is not part of the Coal Combustion Residuals rule monitoring network

<: Indicates the compound was analyzed for but not detected

J: Detected but result is below the method reporting limit

Figures
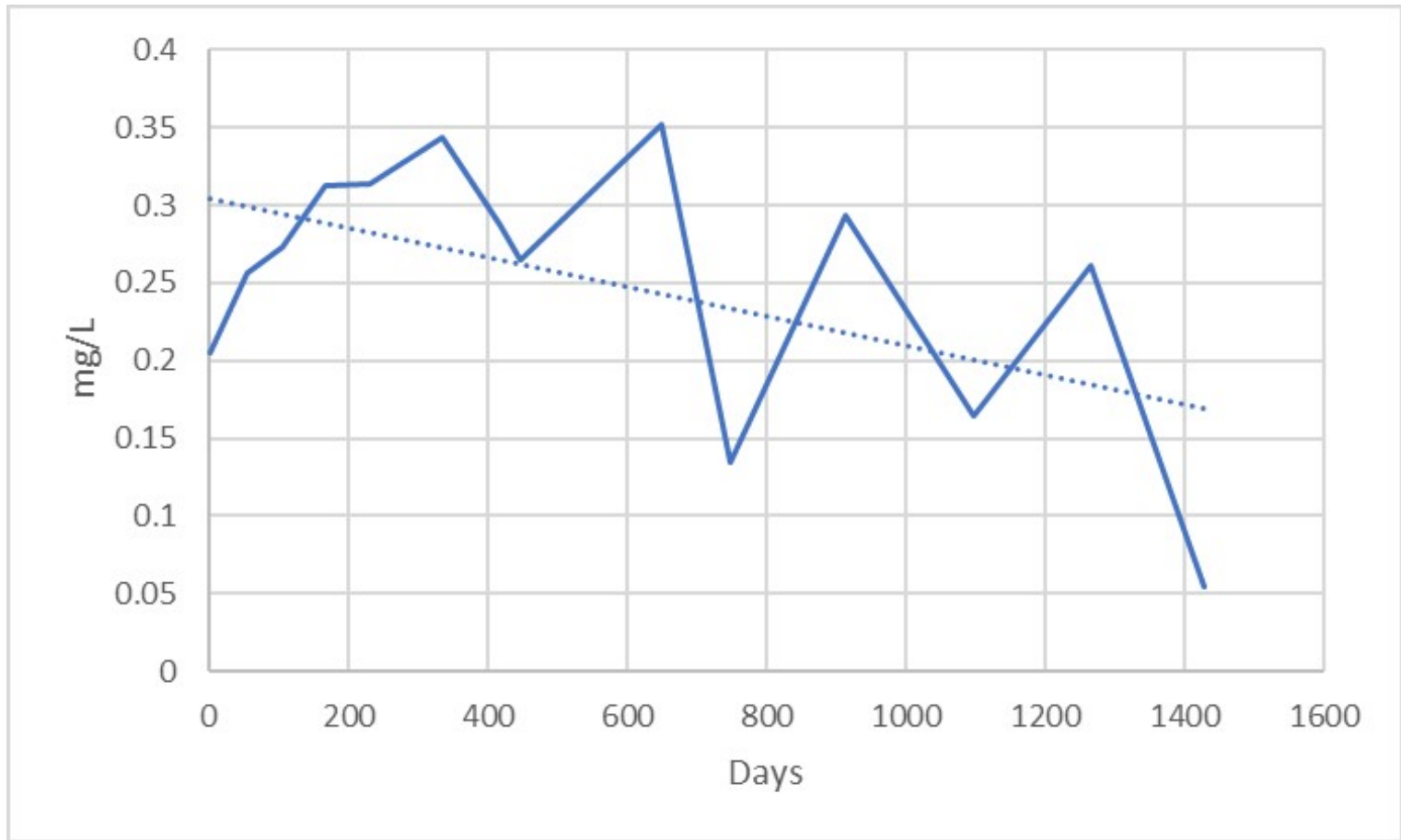
Note:
mg/L: milligrams per liter

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Figure 1
Molybdenum Concentration Versus Time in GN-AP-MW-5
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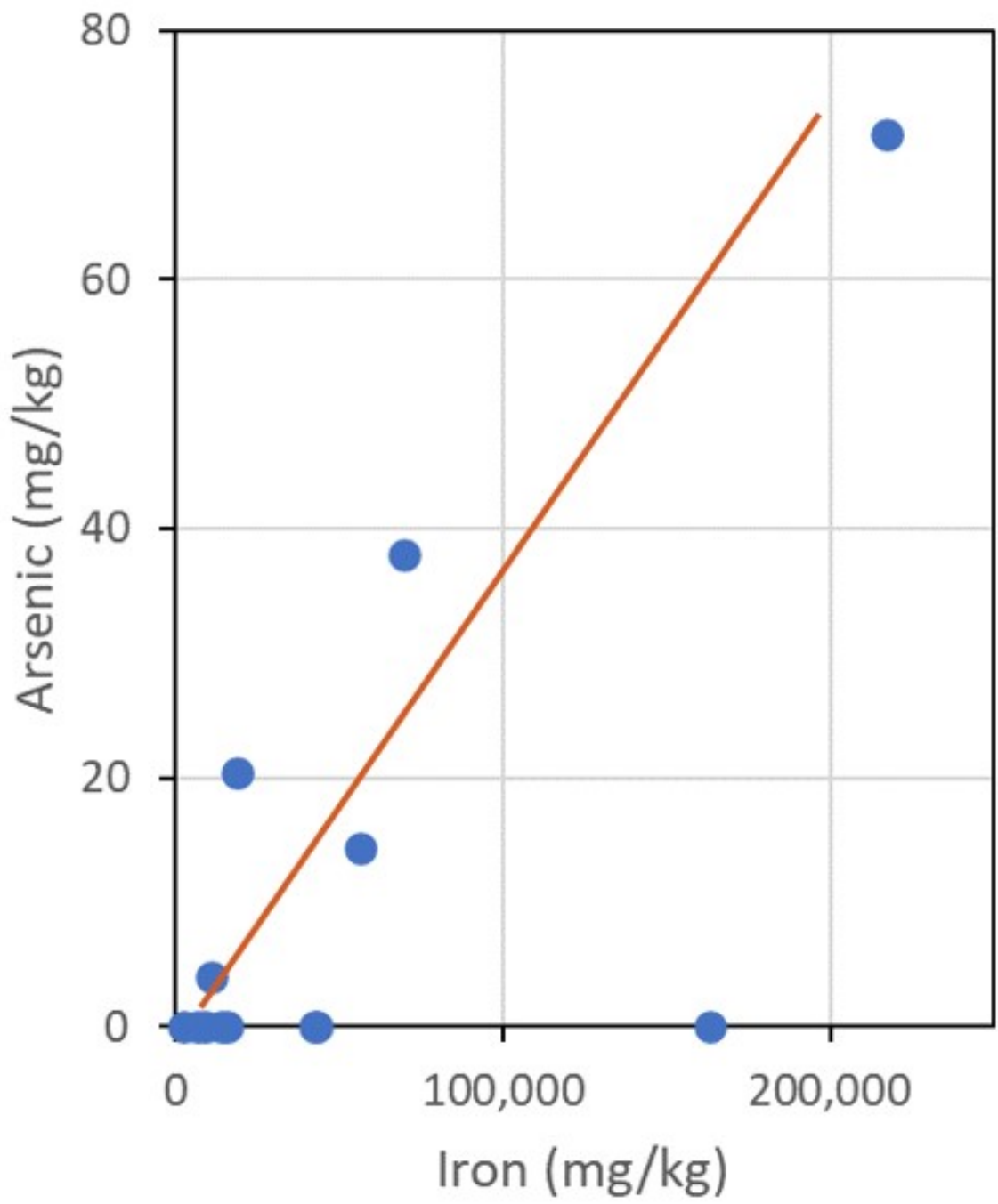
Figure 2
Bulk Chemistry Relationship Between Arsenic and Iron
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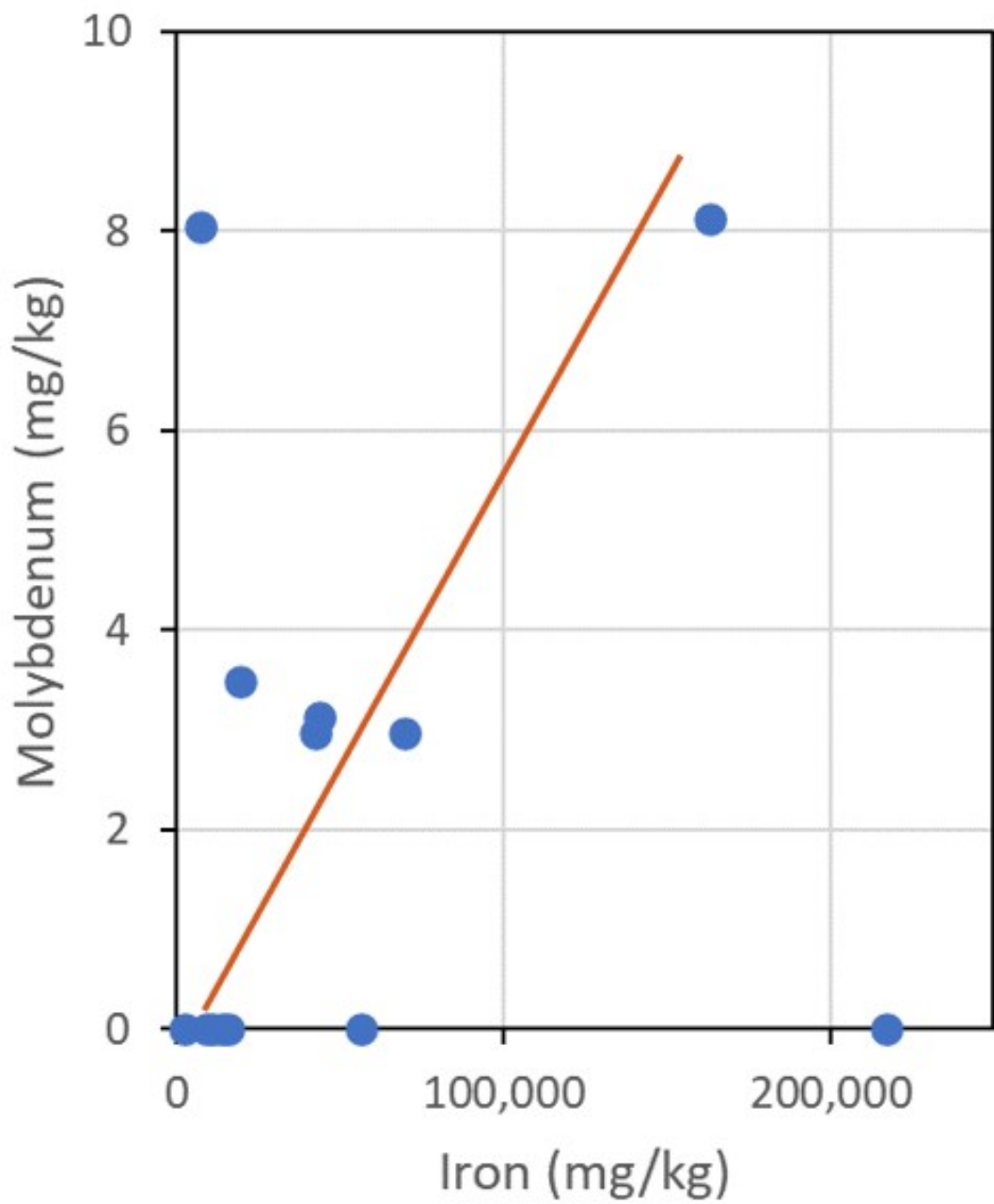
Figure 3
Bulk Chemistry Relationship Between Molybdenum and Iron
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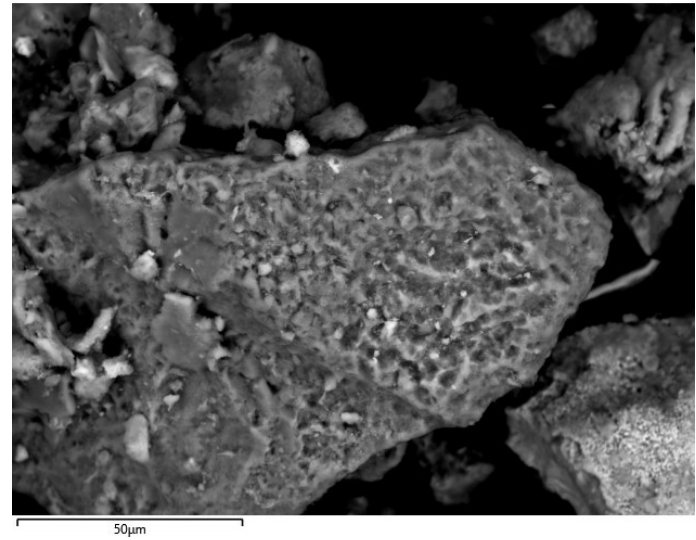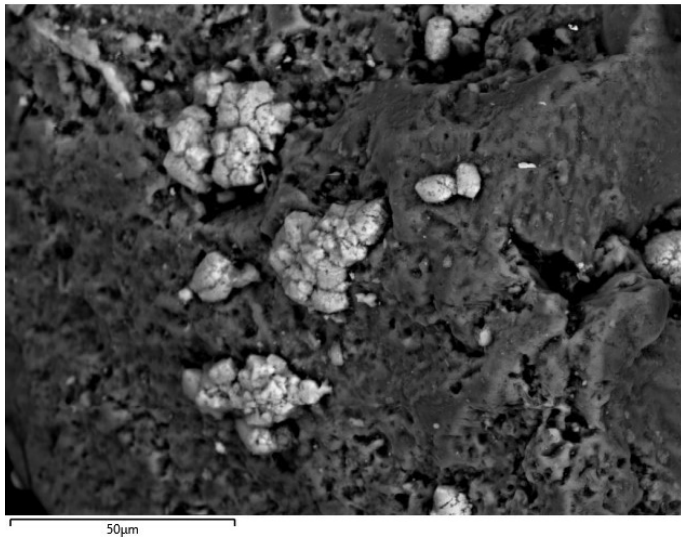
Note:
μm: micron

Figure 4
SEM Results for MS-11S
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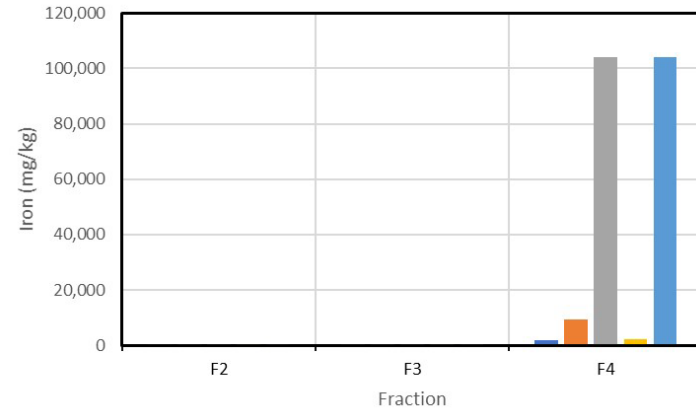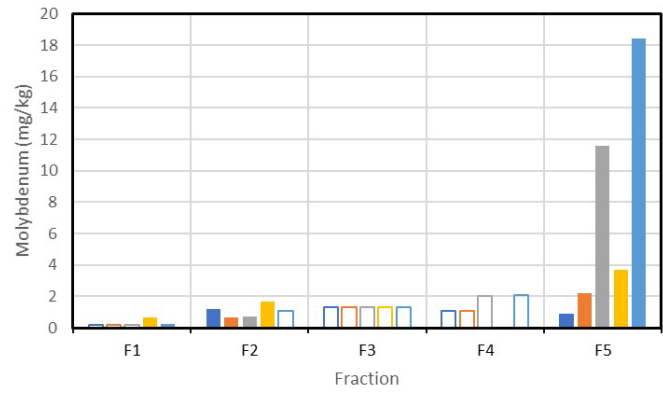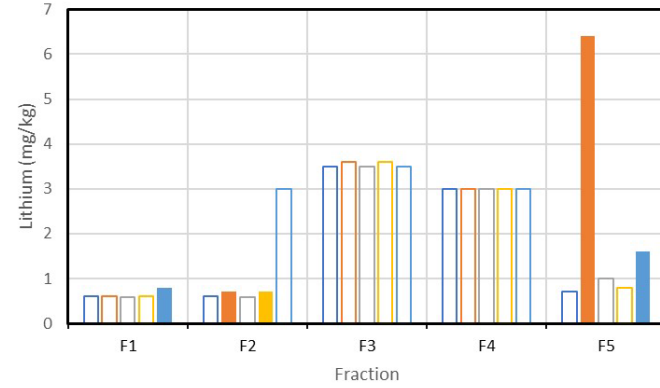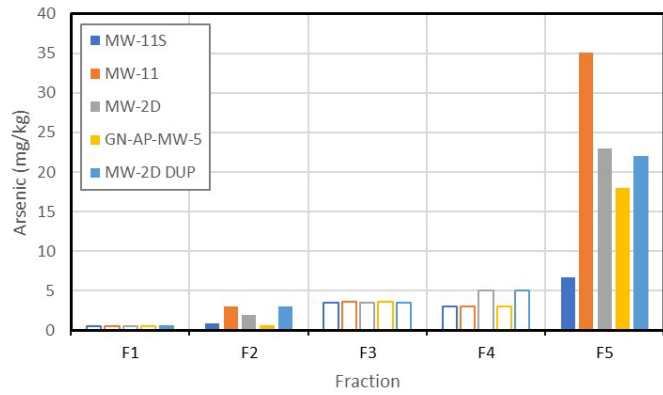
Notes:
Non-detect results shown as unfilled bars plotted at detection limit.
mg/kg: milligrams per kilogram
F1 – Water soluble
F2 – Exchangeable (e.g., clay minerals)
F3 – Reducible (e.g., poorly crystalline metal oxides such as iron oxides)
F4 – Oxidizable (e.g., crystalline oxide and crystalline sulfide minerals)
F5 – Residual (e.g., silicate phases)

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Figure 5
SSE Results for Well Solids
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Note:
Blue fields indicate dissolved/mobile species. Yellow fields indicate solid/attenuated species.

Note:
Blue fields indicate dissolved/mobile species. Yellow fields indicate solid/attenuated species.

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Figure 7
Eh-pH Stability Diagram for Dissolved and Solid Arsenic Phases
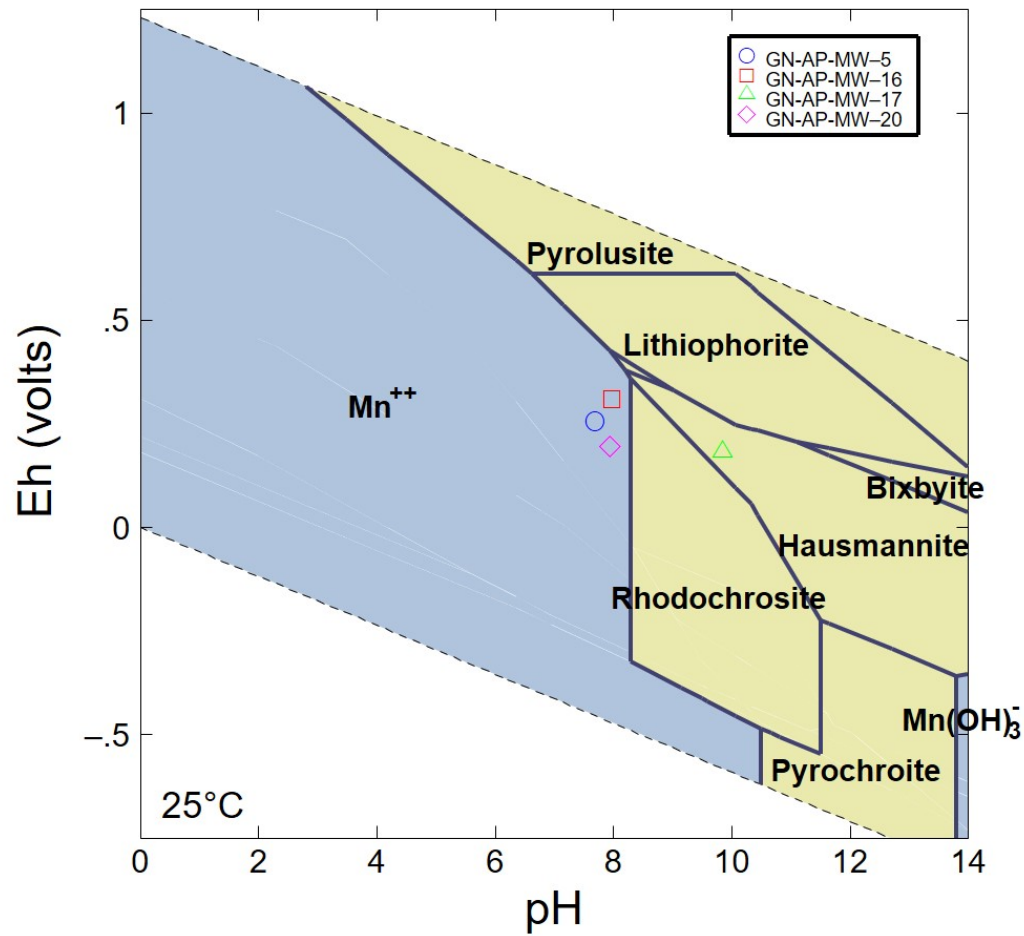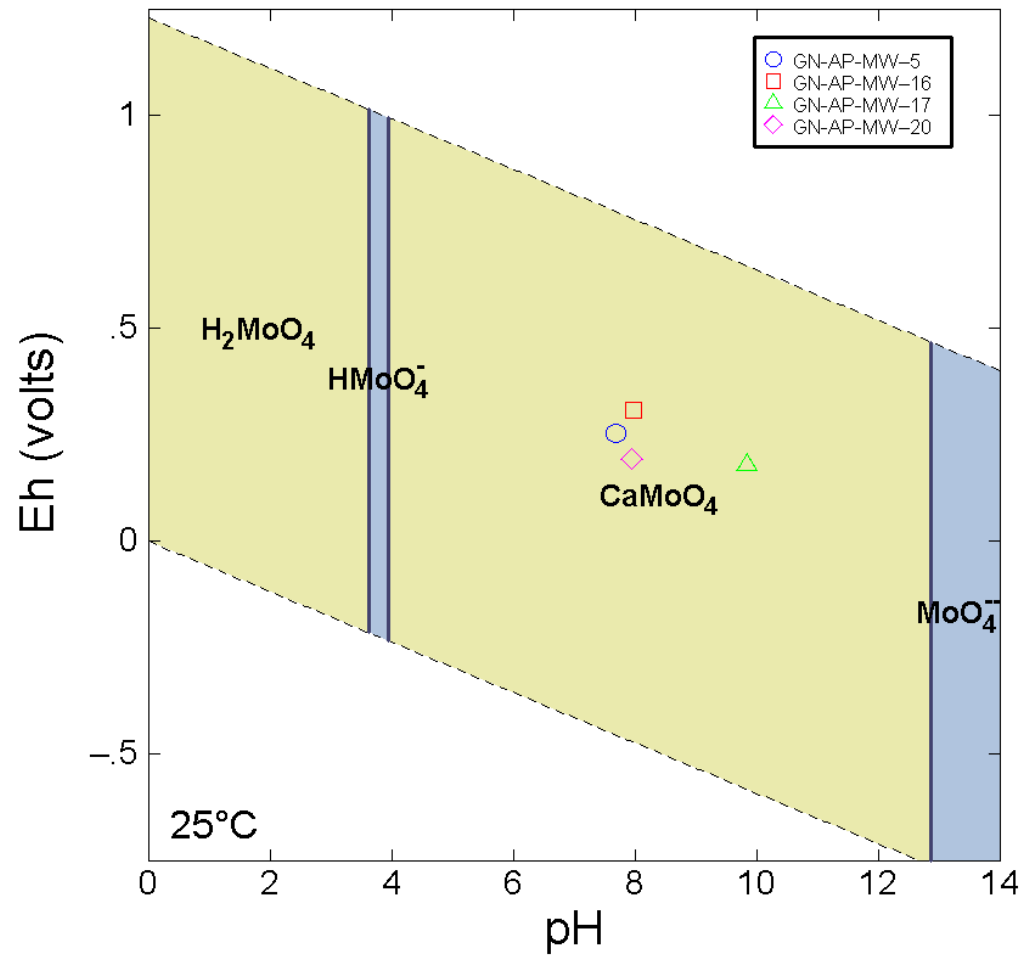Semi-Annual Remedy Selection and Design Progress Report
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Figure 8
Eh-pH Stability Diagram for Dissolved and Solid Manganese Phases
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Note:
Blue fields indicate dissolved/mobile species. Yellow fields indicate solid/attenuated species.

Note:
Blue fields indicate dissolved/mobile species. Yellow fields indicate solid/attenuated species.

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Figure 9
Eh-pH Stability Diagram for Dissolved and Solid Molybdenum Phases
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