Play Area Groundwater Treatment Interim Action Work Plan

Gas Works Park Site
Seattle, Washington

for
Puget Sound Energy

August 1, 2017

GeoEngineers
Earth Science + Technology

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Plaza 600 Building
600 Stewart Street, Suite 1700
Seattle, Washington 98101
206.728.2674

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Prepared for:

Puget Sound Energy
PO Box 97034 PSE-12
Bellevue, Washington 98009

Attention: John Rork

Prepared by:

GeoEngineers, Inc.
Plaza 600 Building
600 Stewart Street, Suite 1700
Seattle, Washington 98101
206.728.2674

Chris Bailey

Chris L. Bailey, PE
Project Engineer

Sandy Smith

Sandra Smith, PE, LG
Project Manager

Dan M. Baker, LG, LHG
Principal, Program Manager

CLB:SMS:DMB:leh

cc: David Graves
City of Seattle
Department of Parks and Recreation

Pete Rude
Seattle Public Utilities

GeoEngineers

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1.0 SUMMARY

The primary objective of the Play Area Groundwater Treatment Interim Action (Treatment Interim Action) described in this Work Plan is to reduce dissolved phase arsenic concentrations in the subsurface, below the Play Area. The Treatment Interim Action complements an interim action completed in June 2017 that consisted of the installation of remediation infrastructure within the Play Area. The Treatment Interim Action is expected to begin in Fall 2017, prior to construction of the Play Area renovation project.

A geochemical evaluation conducted on Play Area soil and groundwater found that elevated concentrations of arsenic in subsurface groundwater are related to local geochemical conditions. The general approach for the Treatment Interim Action is to inject treatment reagent—a dilute solution of ferrous sulfate—into the remediation infrastructure, consisting of multiple injection wells screened across the fill and outwash groundwater units. The injected reagent will react with groundwater and modify geochemical conditions to reduce dissolved arsenic concentrations and sequester arsenic in a solid phase.

The Treatment Interim Action will consist of pre-treatment confirmation of baseline conditions, reagent injection, performance monitoring, and post-treatment confirmation monitoring. The baseline sampling event will be used to evaluate pre-treatment Play Area groundwater conditions and refine treatment parameters. Reagent injection will be performed by a qualified remediation contractor using common reagent injection pumps, tanks, and mixing equipment during a one to two-week period.

Performance monitoring for the Treatment Interim Action will include short-term and treatment monitoring. Short-term monitoring will monitor hydraulic and chemical effects of reagent injection for a 2-week period. Treatment monitoring will evaluate the effectiveness of the injected reagent at reducing dissolved arsenic concentrations at approximately one month following completion of reagent injection. The treatment performance monitoring will include analysis of groundwater samples for arsenic to directly evaluate treatment performance, as well as analysis of iron, sulfate, and sulfide to evaluate distribution of reagent.

Confirmation monitoring will be performed following the completion of all interim action treatment to evaluate the overall performance of the Treatment Interim Action and to characterize post-treatment conditions.

2.0 INTRODUCTION

This Play Area Groundwater Treatment Interim Action Work Plan (Work Plan) outlines the proposed completion of groundwater treatment interim action in the Play Area of the Gas Works Park Site for the purpose of reducing the mobility of arsenic present in upland groundwater in the Play Area. The purpose of this work plan is to provide details of the proposed groundwater treatment. The work described in this Work Plan will be conducted under the March 18, 2005, Agreed Order DE 2008 between Puget Sound Energy (PSE), the City of Seattle (City), and the Washington State Department of Ecology (Ecology) for the Gas Works Park Sediment Site modified in 2013 to expand the area of investigation to include the upland. The 2005 Agreed Order was amended (second amendment) in March 2017 to authorize installation of the groundwater treatment infrastructure and groundwater monitoring wells that will be used to complete the Interim Action described in this Work Plan. This Work Plan describes the completed installation of the treatment infrastructure and the planned in-situ treatment using the installed infrastructure for the treatment of arsenic in groundwater in the vicinity of the Play Area.

2.1. Site Background

Gas Works Park is a twenty-acre park located at 1801 North Northlake Way (Figure 1) mostly owned and operated by Seattle Parks and Recreation (SPR). Gas Works Park is bounded by Lake Union to the south and east, Seattle Harbor Patrol to the west, and North Northlake Way to the north. The Play Area is in the eastern portion of the Park, along the shoreline of Lake Union (Figure 2).

Gas Works Park is located on the site of a former manufactured gas plant, and more specifically the Play Area is located in an area where hydrogen sulfide was removed from the manufactured gas stream using the Thylox process. The Thylox process used a sodium thioarsenate solution to remove hydrogen sulfide from the manufactured gas. The hydrogen sulfide captured in the Thylox process was recovered as elemental sulfur during regeneration of the Thylox solution by aeration in a slurry-settling tank. The detection of elevated arsenic in soil and groundwater in this area likely reflects past releases of Thylox solutions, probably from leaks and accidental spills at the tower vessel, piping, slurry-settling tank, Kelly filter, and/or during loading and unloading of trucks.

2.2. Play Area Arsenic Conditions

In 2013, Agreed Order DE 2008 was amended to include upland properties in the area of investigation in order to evaluate the upland to sediment pathway. In March 2013, Ecology approved the Supplemental Investigation Work Plan (GeoEngineers, 2013), which outlined the scope of additional soil and groundwater sampling to characterize potential arsenic sources in the Play Area, in addition to other site-wide investigation activities. During the supplemental investigation (SI), elevated concentrations of arsenic were measured in soil and groundwater samples collected from the vicinity of the Play Area and eastern shoreline. In response to these findings, the 2014 Play Area investigation (PAI) was conducted to evaluate the nature and extent of arsenic in soil and groundwater, arsenic groundwater geochemistry and arsenic leaching from soil to groundwater. The PAI, conducted in Winter 2014, obtained further data to evaluate the vertical and lateral extent of arsenic impacted soil and groundwater, including characterization sampling through arsenic speciation. The PAI included a geochemical evaluation of site soil and groundwater to understand arsenic leachability (or conversely, arsenic sequestration) through sequential extraction testing and characterization of arsenic species (Anchor QEA, 2015).

In 2016 Play Area Supplemental Investigation was performed to evaluate the vertical and lateral extent of dissolved arsenic impacts in the vicinity of the Play Area to inform the lateral and vertical placement of injection infrastructure and monitoring wells for treatment and performance monitoring. In addition to the characterization of arsenic in soil and groundwater, the 2016 SI included the completion of several hydraulic profile tool tests to estimate hydraulic conductivity of soil within the estimated Interim Action treatment area. The hydraulic conductivity test results were used to estimate the groundwater flow behavior within the Play Area and expected response to injected reagent.

Arsenic-impacted soil and groundwater had been identified in the vicinity of the former Thylox process area during the 2013 SI. The highest concentrations of arsenic encountered in the Play Area are located within the fill unit at the approximate depth of the water table and below the limits of soil excavation conducted in the 1970s (GeoEngineers, 2016). The results of the 2014 PAI, including the geochemical evaluation, are included with the Play Area 2016 Supplemental Investigation Data Report, submitted to Ecology in August 2017 (GeoEngineers, 2017).

Figure 3 presents the dissolved arsenic concentrations in groundwater samples collected within the shallow fill soil unit. Dissolved arsenic concentrations detected in fill groundwater samples collected during the 2016 SI ranged from 140 micrograms per liter (µg/L) to 10,500 µg/L. Figure 4 presents the dissolved arsenic concentrations in deeper outwash groundwater samples. Dissolved arsenic concentrations detected in outwash groundwater samples collected during the 2016 SI ranged from 39 µg/L to 23,400 µg/L. The geochemical evaluation found that elevated concentrations of arsenic in soil reflect precipitation of arsenic sulfides within the soil matrix and elevated arsenic concentrations in groundwater are related to local geochemical conditions that stabilize thioarsenate species in groundwater. Additional details of the groundwater sample analyses are presented in the Play Area 2016 Supplemental Investigation Data Report (GeoEngineers, 2017).

2.3. Interim Action Objectives

The primary objective of the Interim Action is to reduce dissolved phase arsenic concentrations in the vicinity of the Play Area by implementing in-situ treatment methods. Infrastructure for the Interim Action was installed prior to the planned Play Area renovation project. After Play Area renovation, access to treat groundwater beneath the Play Area will be limited to existing wells. This Interim Action is planned to be completed as ongoing remedial investigation and feasibility study (RI/FS) activities continue. Additional action for the groundwater to sediment pathway may be conducted following determination of the final cleanup action.

3.0 INTERIM ACTION APPROACH

The Interim Action will implement an in-situ arsenic treatment technology that was determined through treatability testing to be an effective method of reducing dissolved concentrations of arsenic in Play Area groundwater. The proposed approach for the Interim Action involves the use of injectable treatment reagent solutions to react in-situ within zones of elevated dissolved arsenic, resulting in conditions that promote the precipitation and adsorption of dissolved arsenic. Results of treatability testing for groundwater indicate that elevated arsenic concentrations in groundwater can likely be reduced by applying iron-containing amendments that act to decrease the soluble arsenic fraction in groundwater. The iron-containing amendments work by reducing the groundwater pH and sulfide concentrations, which results in arsenic sequestration within the soil matrix. Treatability testing indicates that a dilute solution of ferrous sulfate (FeSO4) is compatible with site conditions and is capable of significant reduction of dissolved arsenic in groundwater. Appendix A presents the results of the treatability testing and recommendations for implementation of in-situ treatment of arsenic in groundwater.

The Interim Action approach also involves the ability to perform the selected treatment under the Play Area without interfering with the activities at the Play Area or damaging the new Play Area surface, liner, and drain system after completion of the renovation project. An injection well network consisting of permanent, vertical injection wells designed to deliver reagent to the selected treatment zone was designed and installed during Spring 2017. Construction as-built drawings for the injection well network are included in Appendix B. Injection wells were installed across the footprint of the Play Area, completed below grade, and piped to vaults to allow injection from outside the Play Area. This approach will allow delivery of reagent to injection wells within the Play Area while avoiding above-ground infrastructure and disruption to park users.

3.1. Interim Action Treatment Infrastructure Approach and Layout

The infrastructure installed to facilitate the in-situ treatment Interim Action was designed to accommodate the planned construction and future configuration of the Play Area and to best distribute injected reagent into the targeted groundwater zones. Vertically oriented injection wells were selected to mitigate the effect of lateral heterogeneities on uniform distribution of reagent and deliver reagent to lower hydraulic conductivity areas, albeit at lower flow rates.

The injection infrastructure consists of shallow injection wells screened in the lower saturated portion of the fill unit and deep injection wells screened in outwash. The layout of the reagent injection system was based on the results of analysis of groundwater chemistry data, Hydraulic Profiling Tool (HPT) data, and geology observed at Play Area soil borings. The injection well system is two-layered consisting of 22 injection wells screened in the fill unit and 13 injection wells screened in the outwash unit. The layout of the injection wells within the Play Area is based on the distribution of dissolved arsenic plumes in the fill and outwash units, understanding of groundwater flow patterns based on geologic and hydrogeologic data, and the practicality of installing wells in an area with many above-ground and subsurface obstructions. Injection wells were laid out in rows with individual wells generally spaced 20 feet on center in the cross-gradient direction (north to south). The injection rows were generally spaced 30 feet apart. The injection wells are connected below grade to conveyance piping trenched to utility vaults located outside the Play Area footprint to allow injection from outside the Play Area after the Play Area renovation is complete. Figures 5 and 6 present the layout of the completed injection well system.

The treatment area was selected primarily based on the extent of dissolved arsenic in either the fill groundwater and outwash groundwater. The selected fill groundwater treatment area corresponds with the areas of fill groundwater with dissolved arsenic above approximately 1,000 μg/L within and south of the Play Area renovation footprint (Figure 3). The selected outwash groundwater treatment area corresponds with the area of outwash groundwater with dissolved arsenic concentrations above approximately 1,000 μg/L beneath and southwest of the Play Area renovation footprint (Figure 4). Additional outwash injection wells (Figure 6, injection wells C11 and C12) were installed outside the 1,000 μg/L footprint presented on Figure 4, in the area upgradient of well MW-36D—an outwash well where the highest arsenic concentrations in the vicinity of the Play Area have been observed. The treatment areas include the majority of the accessible Play Area footprint for fill groundwater, plus approximately the eastern (downgradient) half of the Play Area for outwash groundwater.

The area between the Play Area and the shoreline of Lake Union was not selected for treatment during the Interim Action. The area between the Play Area and the shoreline is outside of the footprint of the current Play Area renovation project. In addition, maintaining this buffer between the groundwater treatment area and the shoreline allows monitoring of downgradient treatment performance and potential movement of unreacted reagent toward Lake Union.

The vertical extent of treatment is based on the same groundwater arsenic results used to select the areal extent of treatment, with additional considerations for the vertical extent of groundwater within the proposed treatment areas and subsurface obstructions within the fill zone. Fill groundwater is generally proposed to be treated from the seasonal high water table down to either the underlying silt unit or, in areas where the silt unit is not present, the top of the outwash unit. Treatment thickness in the fill unit ranges from less than 3 feet (west) to 10 feet (east). Outwash groundwater is proposed to be treated across the full vertical extent of outwash soil within the aerial extent described above to the extent practicable. Treatment thickness in the outwash unit ranges from 6.5 feet to 12 feet.

3.2. Interim Action Treatment Approach

The general approach for the Interim Action is to inject a treatment reagent—a dilute solution of ferrous sulfate—into the injection wells screened across the fill and outwash groundwater units to neutralize the alkaline pH of groundwater and provide excess dissolved iron to induce precipitation and adsorption of dissolved arsenic and reduce the potential for groundwater within the Play Area to act as a source of arsenic to Lake Union. The reagent solution will be injected at low flow rates and low pressures at multiple injection wells simultaneously. Reagent will be injected at the fill and outwash treatment wells installed during the infrastructure installation, shown on Figures 5 and 6. The injection vaults installed outside the Play Area footprint, where piping connected to each injection well is terminated, will allow connection to individual injection wells separately or inject into several wells at once using an injection manifold.

Completion of the Interim Action treatment will consist of pre-treatment confirmation of baseline conditions, reagent injection, performance monitoring, and post-treatment confirmation monitoring. Pre-treatment baseline sampling will be completed prior to initiation of the treatment to provide data to characterize groundwater conditions prior to initiating treatment, primarily dissolved arsenic concentrations, as well as other factors that may affect treatment such as sulfide concentration and pH. Unexpected conditions observed during baseline sampling may result in minor alteration of treatment procedures.

Testing data collected during development of the injection wells suggests that the expected injection flow rates and required pressures will vary significantly across the expected fill and outwash groundwater treatment areas. Drawdown testing of fill unit injection wells in the A and B lines indicated significantly lower conductivity than the fill unit C and D wells reflecting the highly granular soil matrix present in the fill zone in the downgradient (eastern) portion of the Play Area. The deeper outwash injection wells are also expected to receive injected reagent at a low flower rate due to the lower conductivity of the outwash soil relative to downgradient fill soil. Injection well flow and pressure conditions will be tested at the beginning of injection. The injection testing will be conducted by injecting reagent solution at several individual wells representative of the various conditions observed during installation of the injection wells and will consist of gradually increasing the injection pressure to achieve a consistent flow.

The Interim Action treatment will consist of performing the reagent injection using the injection parameters determined during the injection testing phase. Based on the testing, and the capacity of the injection system, injection will be performed simultaneously at multiple wells with similar characteristics (e.g., upgradient, low flow fill wells) to maximize the efficiency of the injection process. Based on the results of the performance monitoring, additional treatment phases may be performed. If necessary, additional treatment would be expected to be performed using the same general procedures of the first treatment event.

3.3. Interim Action Monitoring Approach

Monitoring performed for the Interim Action will generally follow the Model Toxics Control Act (MTCA) requirements outlined in Washington Administrative Code (WAC) 173-340-410 for compliance monitoring to be completed during cleanup action or interim actions. Compliance monitoring, as described in MTCA, includes protection, performance, and confirmation monitoring. Protection monitoring is primarily associated with worker health and safety during construction and operation activities and will be addressed in a Health and Safety Plan developed separate from this Work Plan. The majority of the monitoring performed during the Interim Action is considered performance monitoring. Performance monitoring is used to evaluate the performance of the action during remedy implementation, and includes quality control measurements and short-term monitoring of treatment effectiveness. Confirmation monitoring is long-term monitoring used to evaluate continued or sustained achievement of remediation goals by the interim action.

A monitoring well network was developed and installed during Spring 2017 as a component of the injection infrastructure installation to allow sampling to evaluate the performance of the in-situ treatment. The infrastructure installation included 15 new monitoring wells to supplement the two existing monitoring wells (MW-36S and MW-36D) providing a 17-well monitoring network. The monitoring well network is presented on Figures 5 and 6, with the fill and outwash dissolved arsenic extent, respectively. The rationale for each monitoring well is presented in Table 1. The monitoring well network documented in the December 19, 2016 memorandum titled *"Gas Works Park Site, Play Area Injection Infrastructure Groundwater Monitoring Well Network"* (GeoEngineers, 2017b) was approved by Ecology. The monitoring network consists of:

- Nine performance monitoring wells located within the expected area of influence of the in-situ treatment (six wells screened in the fill unit and three wells screened in the outwash unit),
- Two upgradient monitoring wells (one well screened in the fill unit and one well screened in the outwash unit), and
- Six downgradient monitoring wells near the shoreline (two wells screened in the fill unit and four wells screened in the outwash unit).

The Interim Action performance monitoring approach consists of performing short-term injection monitoring and post-treatment performance monitoring. Confirmation monitoring completed at a later date will evaluate the long-term results of the Interim Action.

Short-term injection performance monitoring is intended to evaluate the conditions during reagent injection, including injection flow conditions and conditions at monitoring wells near the injection wells. Injection well flow conditions (pressure and flow rate) will be monitored during injection to evaluate hydraulic properties of the area surrounding the injection well. The effect of reagent injection on nearby groundwater elevation and chemistry and will be measured at monitoring wells near the active injection wells during and for a short period immediately following injection to evaluate the immediate influence of reagent injection at various distances away from the injection wells.

Performance monitoring will be conducted following completion of a complete injection event across the monitoring well network to evaluate the performance of the treatment process. Performance monitoring will include sampling of shoreline monitoring wells included in the monitoring well network that are expected to be beyond the limits of treatment effectiveness. These shoreline wells will be monitored to evaluate the potential for downgradient effects of injected reagent as well as the potential for reduction of arsenic concentrations beyond the expected treatment area. Post-injection performance monitoring results will be compared to results observed during baseline sampling to evaluate treatment performance.

Confirmation monitoring will be conducted several months after completing the Interim Action treatment to evaluate the sustained performance of the treatment. Confirmation monitoring will include sampling of monitoring wells within and immediately downgradient of the treatment area and results will be compared to post-treatment performance sampling to determine the long-term behavior of arsenic in groundwater after treatment.

Further details of the Interim Action monitoring are presented in Section 6.

4.0 TREATMENT TECHNOLOGY BACKGROUND

This section describes the general conditions of dissolved arsenic at the Play Area, the results of the treatability testing to select an effective treatment technology, and application of the selected technology to conditions present at the Play Area.

4.1. Treatment Technology Selection

Treatability testing was performed during 2016 to evaluate potential reduction of Play Area dissolved arsenic concentrations using in-situ treatment methods. The treatment methods that were evaluated primarily rely on the interaction between iron and arsenic and the ability of iron to remove dissolved arsenic from groundwater through precipitation of dissolved arsenic as well as adsorption of dissolved arsenic. The procedures and results of the treatability testing are presented in Appendix A. The treatment mechanisms for iron-based arsenic treatment that were evaluated in the treatability testing include:

- Reaction of ferrous iron with dissolved sulfide to form an iron sulfide. This mechanism reduces sulfide concentrations, thus reducing arsenic solubility, and creates an iron precipitate capable of adsorption of dissolved arsenic.
- Neutralization of alkaline pH by injecting slightly acidic (ferrous sulfate) to moderately acidic (ferric chloride) solutions, which results in slightly acidic conditions conducive to precipitation of arsenic.
- Adsorption of dissolved arsenic on iron oxides formed by the precipitation of iron in injected reagent and present on corroding solid iron amendments. Solid iron amendments (i.e., zero-valent iron) were evaluated for application outside the Play Area and were not considered for this Interim Action.

During the treatability study, the performance of two (2) injectable liquid reagents (ferrous sulfate and ferric chloride) and two (2) solid reagents (zero-valent iron and siderite) were evaluated. The Play Area Interim Action is designed around the use of a liquid reagent that can be injected using injection wells. Ferric chloride and ferrous sulfate were both determined to be successful at reducing dissolved arsenic concentrations in bench tests. However, ferrous sulfate was observed to more strongly sequester arsenic in the solid phase following treatment (i.e., a larger percentage of arsenic was present in more stable forms as a result of ferrous sulfate treatment, relative to ferric chloride treatment). Ferrous sulfate is also expected to result in moderately increased acidity (reduced pH) during treatment relative to the strongly acidic ferric chloride. The result of the ferric chloride reaction appeared to be too acidic, resulting in reduced effectiveness relative to the mildly-acidic to neutral conditions from ferrous sulfate reactions. The treatability study (Appendix A) also determined that ferrous sulfate was capable of breaking down the thioarsenate form of arsenic prevalent in Play Area groundwater to more treatable forms of arsenic. Therefore, ferrous sulfate was identified as the preferred liquid reagent for arsenic treatment at the Play Area based on reduction in dissolved arsenic concentrations during the bench-scale test, less potential for arsenic re-dissolution to groundwater, and resultant geochemical conditions most similar to existing groundwater on site.

4.2. Treatment Technology Application

The selected treatment technology consists of injecting a solution containing the selected reagent into groundwater targeted for treatment. The reagent solution is injected across the treatment area at locations designed to achieve sufficient distribution of reagent, in this case using dedicated injection wells screened across the treatment zone. Figure 7 presents a conceptual schematic cross section of the Play Area groundwater treatment performed by injecting ferrous sulfate solution into injection wells installed under the Play Area.

The treatability testing performed to support Interim Action planning (Appendix A) evaluated reagent concentrations that considered arsenic and sulfide concentrations, as well as the groundwater pH. The treatability test evaluated arsenic reduction performance for multiple reagent concentrations, and the results of this evaluation were used to develop an in-situ concentration of the chosen reagent that would be expected to achieve similar results for the Interim Action. The resulting concentration of ferrous sulfate reagent determined to be effective under the conditions present within the Interim Action treatment area was determined to be 1 gram per liter (g/L), measured as the commonly available heptahydrate form of ferrous sulfate.

In order to achieve the 1 g/L in-situ reagent concentration goal[1] in the treatment area, a higher concentration solution of ferrous sulfate heptahydrate is injected into the existing injection wells, up to a 5 percent (50 g/L) solution. Injection of a higher solution concentration (e.g., 50:1 ratio of injected solution concentration to in-situ reagent concentration goal) accounts for mixing of injected solution with groundwater surrounding the injection well and the reactivity of the reagent. Upon injection, the reagent solution will mix with groundwater and react, resulting in a slightly acidic to neutral pH (i.e., 6 to 6.5), as determined during treatability testing (Appendix A). The direct effects of the injected ferrous sulfate solution (reduced pH and elevated dissolved iron and sulfate concentrations) are expected to be limited to the immediate vicinity of the injection wells (i.e., the treatment zone—see Figure 7). The monitoring well network described in Sections 3.3 and 6.0 will allow monitoring of downgradient effects, the results of which will be used to evaluate performance (reagent distribution and treatment).

The arsenic treatment using ferrous sulfate solution relies on the reagent being an acidic solution, designed to neutralize the alkaline conditions in Play Area groundwater to facilitate arsenic precipitation. This requires equipment to be compatible with acidic solutions. A health and safety plan that addresses reagent hazards will be prepared for worker and park user safety prior to performing reagent injection.

5.0 INTERIM ACTION IMPLEMENTATION

The specific tasks associated with completion of the Interim Action at the Play Area are described in this section and include the following activities:

- Regulatory Approval
- Site preparation;
- Injection system setup; and,
- Reagent injection.

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[1] The 1 g/L is the concentration of ferrous sulfate heptahydrate reagent needed to achieve a stoichiometric ratio of ½:1 based on dissolved arsenic, sulfide, and pH conditions in groundwater in the treatment area calculated using the equation developed by Anchor QEA (2017) during treatability testing. Treatability testing determined a reagent stoichiometric ratio of ½:1 effectively reduced dissolved arsenic concentrations in groundwater from monitoring well MW-36D. The stoichiometric ratio represents the balance between ferrous sulfate heptahydrate and a combination of arsenic, sulfide, and pH conditions in groundwater.

5.1. Regulatory Approval

The Play Area Interim Action will be conducted under a modification of the March 18, 2005, Agreed Order DE 2008 between PSE, the City, and Ecology for the Gas Works Park Sediment Site. Injection wells are typically regulated by Ecology under the requirements of WAC 173-218 (Underground Injection Control [UIC] Program). The injection wells being used for the Interim Action are considered Class V injection wells per WAC 173-218-040(5)(a)(x). Because the injection wells are being used as a component of an interim cleanup action under a MTCA agreed order, the injection wells do not need a permit but do need to be registered with the Ecology UIC program per WAC 173-218-060(5)(b) prior to being used for remediation. Injection wells are generally subject to the UIC non-endangerment standard WAC 173-218-080. However, as injection wells for remediation at a cleanup site under a MTCA order, the injection wells proposed for the Play Area infrastructure installation are considered to automatically meet the non-endangerment standard in accordance with WAC 173-218-100, and are registered using the registration form titled “Underground Injection Control (UIC) Well Registration Form for Class V UIC Wells that Automatically Meet the Nonendangerment Standard”. The UIC registration forms are included in this Work Plan as Appendix C.

5.2. Site Preparation

Mobilization for performing Interim Action treatment will be coordinated with SPR staff to determine the placement of equipment required to complete the treatment. The specific equipment required for the injection, and the associated footprint required, will be determined by the injection contractor, but is expected to consist of truck-mounted injection equipment (pumps, gauges, hoses, etc.) and reagent tanks for mixing and storage of the treatment reagent. The area surrounding the two injection vaults will be fenced off during the duration of the reagent injection period to create an exclusion zone prohibiting access by park users and to secure the equipment during off-hours.

5.3. Baseline Groundwater Sampling

Prior to performing reagent injection for the Interim Action, a baseline sampling event will be completed to evaluate pre-treatment Play Area groundwater conditions. Groundwater samples will be collected from each of the fill and outwash monitoring wells in the Interim Action monitoring well network to evaluate baseline dissolved arsenic concentrations as well as concentrations of other chemical parameters that may impact treatment. The results of the baseline sampling will be compared to existing groundwater data to verify and finalize the planned injection protocol. In the event that the groundwater conditions with the greatest effect on reagent usage (arsenic, sulfide, and pH) differ significantly from expected conditions, the injection parameters such as reagent concentration and volume, may be revised.

Samples will be collected from each of the wells listed on Table 1. Samples will be collected and analyzed in accordance with the sampling and analysis plan (SAP) and quality assurance project plan (QAPP) in the 2013 Supplemental Investigation Work Plan (GeoEngineers, 2013) and an addendum to the SAP and QAPP (Addendum 3) that is attached to this Work Plan as Appendix E.

Groundwater sampling will include low-flow well purging while collecting field parameters. The final field parameter measurements collected at each well will also be used to evaluate chemical conditions of the groundwater to be sampled. The SAP/QAPP further outlines sampling procedures.

The following field parameters will be measured during sample collection:

- Dissolved oxygen concentration;
- Oxidation/reduction potential (ORP);
- Specific conductance;
- Turbidity;
- Temperature; and
- pH.

Following measurement of field parameters, groundwater samples will be collected for laboratory analysis by a Washington-certified laboratory. The laboratory will analyze all groundwater samples for the following analytes:

- Total and dissolved arsenic by U.S. Environmental Protection Agency (EPA) Method 200.8. Dissolved arsenic samples will be field-filtered.
- Total and dissolved iron by EPA Method SW6010. Dissolved iron samples will be field-filtered.
- Sulfide by EPA Method SM4500-S2-D.
- Sulfate by EPA Method 300.0

In addition to the analyses listed above that will be performed for each baseline groundwater sample, additional analyses will be performed for samples collected from within the treatment footprint to evaluate the baseline conditions for the various arsenic species. The arsenic speciation will be performed by Brooks Applied Labs using an IC-ICP-MS method. This laboratory and method was used to evaluate the species of arsenic during the geochemical evaluation performed on Play Area groundwater and summarized in the November 2015 memorandum titled *"Former Thylox Process Area Geochemical Evaluation"* prepared by Anchor QEA. (Anchor QEA, 2015). Speciation analysis will be performed on fill and outwash monitoring wells within the immediate treatment area, including the following monitoring wells:

- Fill Groundwater Monitoring Wells – MW-42S, MW-43S, MW-45S, and MW-46S.
- Outwash Groundwater Monitoring Wells – MW-45D, MW-46D, and MW-48D.

Table 2 presents a sampling matrix for baseline groundwater samples.

5.4. Reagent Injection

This section describes the anticipated steps to perform the reagent injection for the Interim Action. Reagent mixing and injection will be subcontracted to an experienced remediation contractor equipped to complete on-site mixing and injection of reagent solutions. The procedures described are general and may be adjusted based on the specific injection methods and capabilities of the selected injection contractor.

5.4.1. Reagent Handling and Mixing

The ferrous sulfate reagent will be purchased as a solid, granular product in the heptahydrate form and delivered to and securely stored at the off-site facility of the selected contractor. The product to be used is a QC Corporation brand granular ferrous sulfate heptahydrate, or equivalent product. Direct contact hazards associated with the solid ferrous sulfate product are described in the safety data sheet provided as Appendix D. The ferrous sulfate product will only be handled by personnel who have had safety data sheet training (i.e., Occupational Safety and Health Administration [OSHA] 40-hour Hazardous Waste Operations and Emergency Response [HAZWOPER]) and have reviewed the safety information for the ferrous sulfate product being used. Material storage and mixing will be conducted in an exclusion zone off-limits to unqualified personnel. Additional safety procedures for workers and to protect park users will be described in a health and safety plan to be prepared for the injection activities.

Field personnel will set up a central temporary mixing system on site to allow safe mixing of the reagent. The mixing tank(s) will include temporary secondary containment to allow collection of spilled reagent. A water supply is located adjacent to the injection vaults and will be metered to allow accurate measurement of water volume added to the mixing tank(s). The mixing tank(s) will include components to automatically mix the reagent to facilitate complete dissolution of the solid product, including recirculation pumps and/or powered paddle mixers. All mixing equipment that comes into contact with the ferrous sulfate solution will be constructed of materials compatible with the ferrous sulfate, as the solution is corrosive and can damage common materials like carbon steel.

The ferrous sulfate reagent solution will be mixed at a concentration of up to 5 percent, measured by weight of heptahydrate form of ferrous sulfate. For a 1000-gallon batch of reagent, 415 pounds of ferrous sulfate heptahydrate product is mixed to create a reagent concentration of 5 percent. Data collected during baseline sampling may indicate that a 5 percent solution is not needed and a more dilute solution will be used.

5.4.2. Reagent Injection

The injection contractor will use a temporary delivery system to transfer the reagent solution from a mixing tank to the selected injection wells at controlled and measured pressures and flow rates. The delivery system will consist of a transfer pump, manifold, distribution hoses, and fittings to connect to multiple injection wells simultaneously. The delivery system will include a flow meter to measure the total injection flow rate and volume. A manifold will be used to split the injection flow into multiple streams to allow injection into multiple wells simultaneously. The manifold will include pressure gauges and flow meters to measure flow conditions for each stream (i.e., injection well). Injection equipment will be constructed of materials compatible with the dilute ferrous sulfate solution being injected.

Injection pressures and flow rates will be evaluated at the injection wells. Flow data collected during development of the injection wells indicated that the injection wells generally fall in three categories; low conductivity upgradient fill wells, high conductivity downgradient fill wells, and outwash wells. The injection pressures planned for fill wells are relatively low due to the shallow depth of the well screens. Guidance provided in “Remediation Hydraulics” by Payne, et. al. (Payne, 2008) led to the conclusion that fill injection pressure be limited to approximately 6 pounds per square inch (psi; at the well) to increase the probability that injected solution is primarily distributed laterally. For fill injection wells located in areas of low conductivity soil (injection well lines A and B in the western portion of the Play Area), and to a lesser degree line C (Figure 5), this low pressure is expected to generate a low injection flow rate. The high conductivity conditions in downgradient fill wells, primarily associated with fill wells on line D (Figure 5), are expected to achieve significantly higher flow rates under equivalent pressure limitations. The injection process at these wells will likely be flow limited rather than pressure limited.

The outwash injection wells were also observed to be relatively low conductivity and are expected to behave similarly to the low conductivity fill injection wells during injection. However, due to the depth of the outwash injection well screens, a higher injection pressure of approximately 10 psi is planned to be used for outwash injection wells.

The reagent solution injection will be initiated by performing flow testing at each injection well to determine the resulting flow rates at pressures up to the anticipated maximum pressure. The results of this procedure will be used to determine injection protocol specifics such as the number of wells to inject simultaneously and the anticipated injection duration, expected to be approximately 1 to 2 weeks.

6.0 INTERIM ACTION MONITORING PLAN

The Interim Action will consist of several monitoring elements that will be used to determine the performance of the arsenic treatment. As describe in Section 3.3, the Interim Action monitoring approach generally follows the requirements for cleanup action compliance monitoring as outlined by MTCA in WAC 173-340-410. The compliance monitoring performed for a cleanup action generally consists of protection, performance, and confirmation monitoring. This section presents the Interim Action Monitoring Plan and focusses on performance monitoring and confirmation monitoring. Protection monitoring will be addressed in a Health and Safety Plan prepared for personnel performing the Interim Action.

Performance monitoring will consist of baseline sampling to evaluate pre-treatment conditions across the site, collecting data during the reagent injection period to evaluate immediate influence of injection, and collecting post-injection samples to evaluate treatment performance at the end of the expected treatment duration. Confirmation monitoring will be performed at an extended period following treatment to evaluate longer-term performance and stability of the arsenic treatment. Additional details for the Interim Action monitoring are presented in the sections below.

6.1. Interim Action Performance Monitoring

Performance monitoring of a cleanup action under MTCA, including an interim action, is used to evaluate the performance of the action during construction or operation of the action, and includes quality control measurements and short-term evaluation of treatment effectiveness. The performance monitoring data will be evaluated to determine the lateral influence of injected reagent, the resulting influence on groundwater chemistry at varying distances away from the injection locations, and the resulting reduction of dissolved arsenic concentrations. If appropriate, the results of the data analysis will be used to develop a plan for additional reagent injection and performance monitoring. Performance monitoring will be reevaluated and likely reduced if additional rounds of reagent injection are needed. The performance monitoring planned for the Interim Action is described in the following sections.

6.1.1. Short-Term Injection Performance Monitoring

Short-term injection performance monitoring is intended to collect injection pressure and flow data during reagent injection and to evaluate immediate influence of reagent injection at nearby monitoring wells. The short-term data will be used to evaluate and potentially adjust injection parameters and protocol.

The reagent delivery system used for the Interim Action will be configured in a way that allows the measurement of flow and pressure to each injection well. During injection, the pressure and flow rate at wells being injected will be measured and recorded regularly (at least every 15 minutes) to evaluate pressure and flow stability and monitor the total injection volume at each well.

Monitoring wells located within the immediate vicinity of the injection well network will be monitored during injection to determine the hydraulic effect of injection at short distances away from the injection wells. During injection, groundwater elevation will be measured hourly at the five fill groundwater zone monitoring wells (MW-42S, -43S, -44S, -45S, and -47S) and the two outwash groundwater monitoring wells (MW-45D and MW-48D) located near the operating injection wells.

Following injection, sampling will be conducted twice weekly for 2 weeks at the five fill wells and two outwash wells listed above to evaluate the immediate chemical effects from injected reagent. Sampling using low flow sampling procedures described in the SAP/QAPP will be used to measure the same field parameters that are proposed for baseline sampling as described in Section 5.3 above and to collect samples to perform field screening using iron and sulfate test kits. Table 2 presents a sampling matrix for short-term injection performance monitoring.

The short-term injection performance monitoring described above for the initial reagent injection event will be reevaluated if additional reagent injection is performed. The assumption is that short-term injection performance monitoring for additional injection events (if required) would consist of flow, pressure, and well head measurements, but not post-injection short-term twice weekly sampling.

6.1.2. Treatment Performance Monitoring

The objective of the treatment performance monitoring is to evaluate the effectiveness of the ferrous sulfate reagent injection on dissolved arsenic concentrations within the footprint of the treatment layout, and to evaluate downgradient effects of the treatment in the form of reduced dissolved arsenic as well as direct chemical influence from the injected reagent (i.e., pH and increased iron or sulfate concentrations). Following completion of the first full round of reagent injection and the short-term monitoring (Section 6.1.1), performance monitoring will consist of performing one round of groundwater sampling at wells within and surrounding the injection system footprint, approximately 1 month following completion of the first round of reagent injection.

The treatment performance monitoring groundwater samples will be collected from all of the monitoring wells in the Play Area Interim Action monitoring network, in accordance with the SAP/QAPP Addendum included as Appendix E. Table 2 provides a list of wells and analytes for the treatment performance monitoring.

6.2. Interim Action Confirmation Monitoring

The Interim Action will include confirmation monitoring. Confirmation monitoring will be performed following the completion of all treatment associated with the Interim Action, and will be performed after an extended period (3 months or more) following reagent injections to evaluate post-treatment conditions.

Confirmation monitoring will consist of completing one round of groundwater sampling at fill and outwash monitoring wells located within the immediate footprint of the treatment. Table 2 includes a sampling matrix for confirmation groundwater samples. The results of performance monitoring conducted during the Interim Action may result in altering the scope of confirmation monitoring. Confirmation groundwater sampling will be conducted in accordance with the SAP/QAPP Addendum included as Appendix E.

7.0 SCHEDULE

Installation of the infrastructure associated with the Interim Action was completed during Spring and Summer 2017. The reagent injection component of the Interim Action is expected to begin in Fall 2017, prior to construction of the Play Area renovation project or Winter/Spring 2018 following construction of the Play Area renovation project. A single round of reagent injection is expected to take 1 to 2 weeks, which would be immediately followed by performance monitoring as described above. Additional treatment may be performed based on the results of performance monitoring, but would be scoped and scheduled based on monitoring results as well as the schedules for construction or other activities planned by SPR at the Play Area.

8.0 REFERENCES

Anchor QEA 2015. Former Thylox Process Area Geochemical Evaluation.

Anchor QEA, 2017. Email communication “FeSO4 _demand_GWP_20161111”, November 11, 2016.

GeoEngineers, Inc. 2013. Supplemental Investigation Work Plan, Gas Works Park Site, Seattle, Washington.

GeoEngineers, Inc. 2016. Agency Review Draft Site-wide Remedial Investigation/Feasibility Study, Gas Works Park Site, Seattle, Washington.

GeoEngineers, Inc. 2017a. Play Area 2016 Supplemental Investigation Data Report, Gas Works Park Site, Seattle, Washington.

GeoEngineers, Inc. 2017b. Gas Works Park Site, Play Area Injection Infrastructure Groundwater Monitoring Well Network.

Washington State Department of Ecology. 2005. Agreed Order DE 2008—Gas Works Park Sediment Site issued to the City of Seattle and Puget Sound Energy. State of Washington Superior Court.

TABLES

Table 1

Proposed Play Area Groundwater Monitoring Network

Play Area Interim Action Work Plan
Gas Works Park Site
Seattle, Washington

No.	Well ID	Unit	Type	Purpose/Rationale
1	MW-36S	Fill	Downgradient	Part of existing shoreline network to monitor groundwater quality downgradient of Play Area injection system. Sampling optional.
2	MW-36D	Outwash	Downgradient	Part of existing shoreline network to monitor groundwater quality downgradient of Play Area injection system.
3	MW-41S	Fill	Upgradient	Characterize groundwater entering the treatment area. Upgradient of injection wells to avoid treatment effects.
4	MW-41D	Outwash	Upgradient	Characterize groundwater entering the treatment area. Upgradient of injection wells to avoid treatment effects.
5	MW-42S	Fill	Performance	Monitor groundwater within treatment area downgradient of injection lateral A.
6	MW-43S	Fill	Performance	Monitor groundwater within treatment area downgradient of injection lateral B.
7	MW-44S	Fill	Performance	Monitor groundwater within treatment area downgradient of injection lateral C -- closer to injection well.
8	MW-45S	Fill	Performance	Monitor groundwater within treatment area downgradient of injection lateral C -- farther from injection well.
9	MW-45D	Outwash	Performance	Monitor groundwater within treatment area downgradient of injection lateral C.
10	MW-46S	Fill	Performance	Monitor groundwater near downgradient edge of treatment area along plume centerline (higher concentration area).
11	MW-46D	Outwash	Performance	Monitor groundwater near downgradient edge of treatment area along plume centerline.
12	MW-47S	Fill	Performance	Monitor groundwater within treatment area downgradient of injection lateral D south of plume centerline (lower concentration area).
13	MW-48D	Outwash	Performance	Monitor groundwater within treatment area downgradient of injection laterals C and D.
14	MW-49D	Outwash	Downgradient	Part of shoreline network to monitor groundwater quality downgradient of Play Area injection system -- southern well.
15	MW-50D	Outwash	Downgradient	Part of shoreline network to monitor groundwater quality downgradient of Play Area injection system -- central well.
16	MW-51S	Fill	Downgradient	Part of shoreline network to monitor groundwater quality downgradient of Play Area injection system and centerline of plume.
17	MW-52D	Outwash	Downgradient	Part of shoreline network to monitor groundwater quality downgradient of Play Area injection system -- northern well.

Notes:

1. Monitoring well locations are shown on Figures 5 and 6.

Table 2

Interim Action Monitoring Matrix

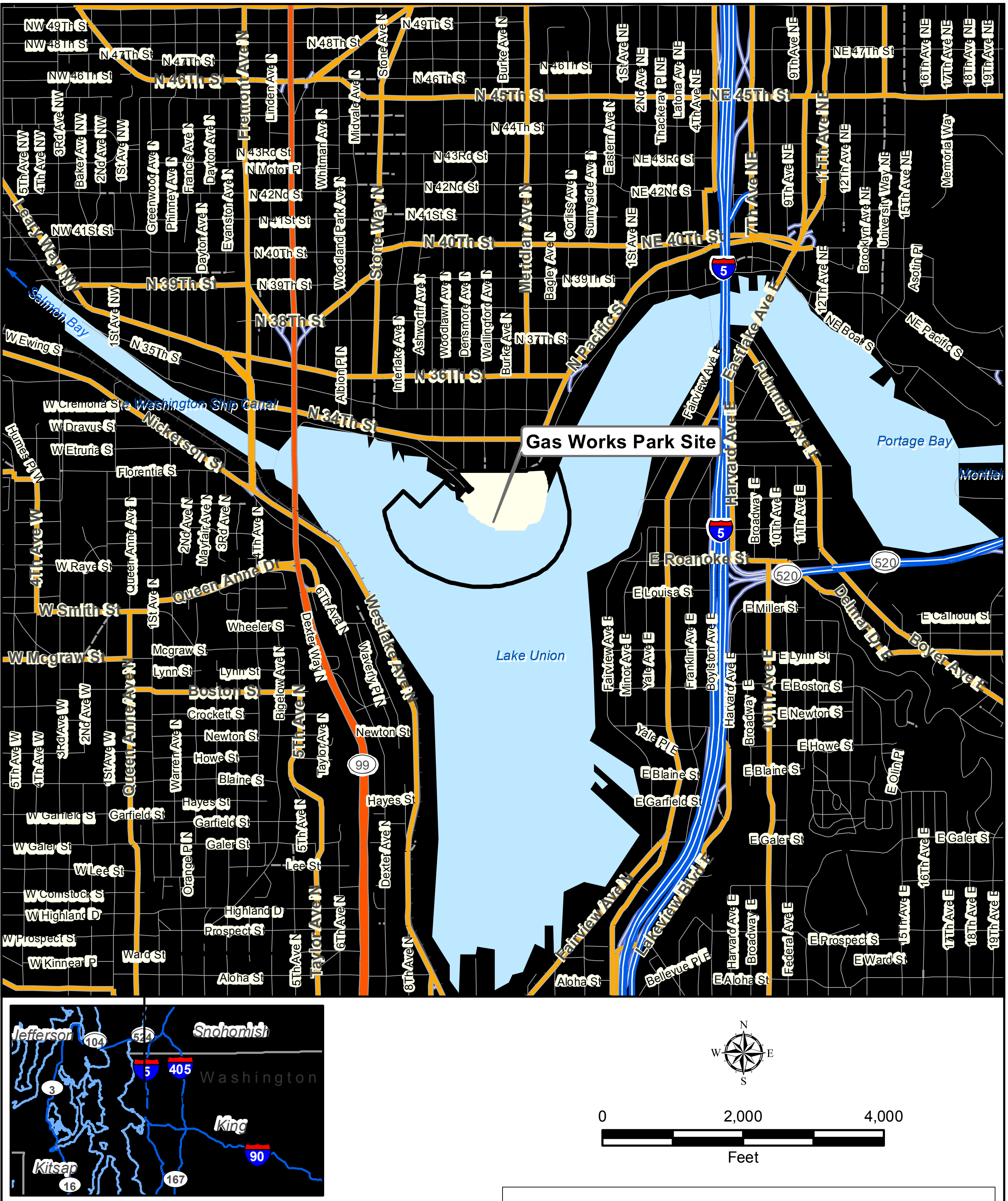
Play Area Interim Action Work Plan
Gas Works Park Site
Seattle, Washington

Well ID	Well Screen Geologic Unit	Well Type	Baseline Sampling						Performance Monitoring									Confirmation Monitoring	
									Short-Term Performance Monitoring (During and following Injection)				Treatment Performance Monitoring					At least 3 months after final injection	
			Prior to beginning injection						Hourly during injection	Two times per week following injection[4]			1 month after end of injection						
			Field Parameters[1]	Arsenic[2] (200.8)	Arsenic Speciation (IC-ICP-MS)	Iron[3] (SW6010)	Sulfide (SM4500-S2-D)	Sulfate (300.0)	Water Levels	Field Parameters[1]	Iron[5]	Sulfate[6]	Field Parameters[1]	Arsenic[2] (200.8)	Iron[3] (SW6010)	Sulfide (SM4500-S2-D)	Sulfate (300.0)	Field Parameters[1]	Arsenic[2] (200.8)
MW-36S	Fill	Downgradient	X	X		X	X	X					X	X	X	X	X		
MW-36D	Outwash	Downgradient	X	X		X	X	X					X	X	X	X	X		
MW-41S	Fill	Upgradient	X	X		X	X	X					X	X	X	X	X		
MW-41D	Outwash	Upgradient	X	X		X	X	X					X	X	X	X	X		
MW-42S	Fill	Performance	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
MW-43S	Fill	Performance	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
MW-44S	Fill	Performance	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X
MW-45S	Fill	Performance	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
MW-45D	Outwash	Performance	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
MW-46S	Fill	Performance	X	X	X	X	X	X					X	X	X	X	X	X	X
MW-46D	Outwash	Performance	X	X	X	X	X	X					X	X	X	X	X	X	X
MW-47S	Fill	Performance	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X
MW-48D	Outwash	Performance	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
MW-49D	Outwash	Downgradient	X	X		X	X	X					X	X	X	X	X		
MW-50D	Outwash	Downgradient	X	X		X	X	X					X	X	X	X	X		
MW-51S	Fill	Downgradient	X	X		X	X	X					X	X	X	X	X		
MW-52D	Outwash	Downgradient	X	X		X	X	X					X	X	X	X	X		

Notes:

1. Field parameters include: water level, dissolved oxygen, oxidation/reduction potential, specific conductance, turbidity, temperature, and pH.
2. Total and dissolved arsenic. Dissolved arsenic sample to be field filtered.
3. Total and dissolved iron. Dissolved iron sample to be field filtered.
4. Sample twice weekly for 2 weeks following reagent injection.
5. Iron by colorimetric field test kit. Hach IR-18 or equivalent.
6. Sulfate by colorimetric field test kit. Hach SF-1 or equivalent.

FIGURES



Vicinity Map

Gas Works Park Site
Seattle, Washington

[redacted]

Figure 1

Notes:

1. Gas Works Park Site boundary is equivalent to the Gas Works Park Sediment Site boundary documented in the 2013 Amendment of Agreed Order DE2008.
2. Reference: basemap provided by Esri.
3. The locations of all features shown are approximate.
4. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

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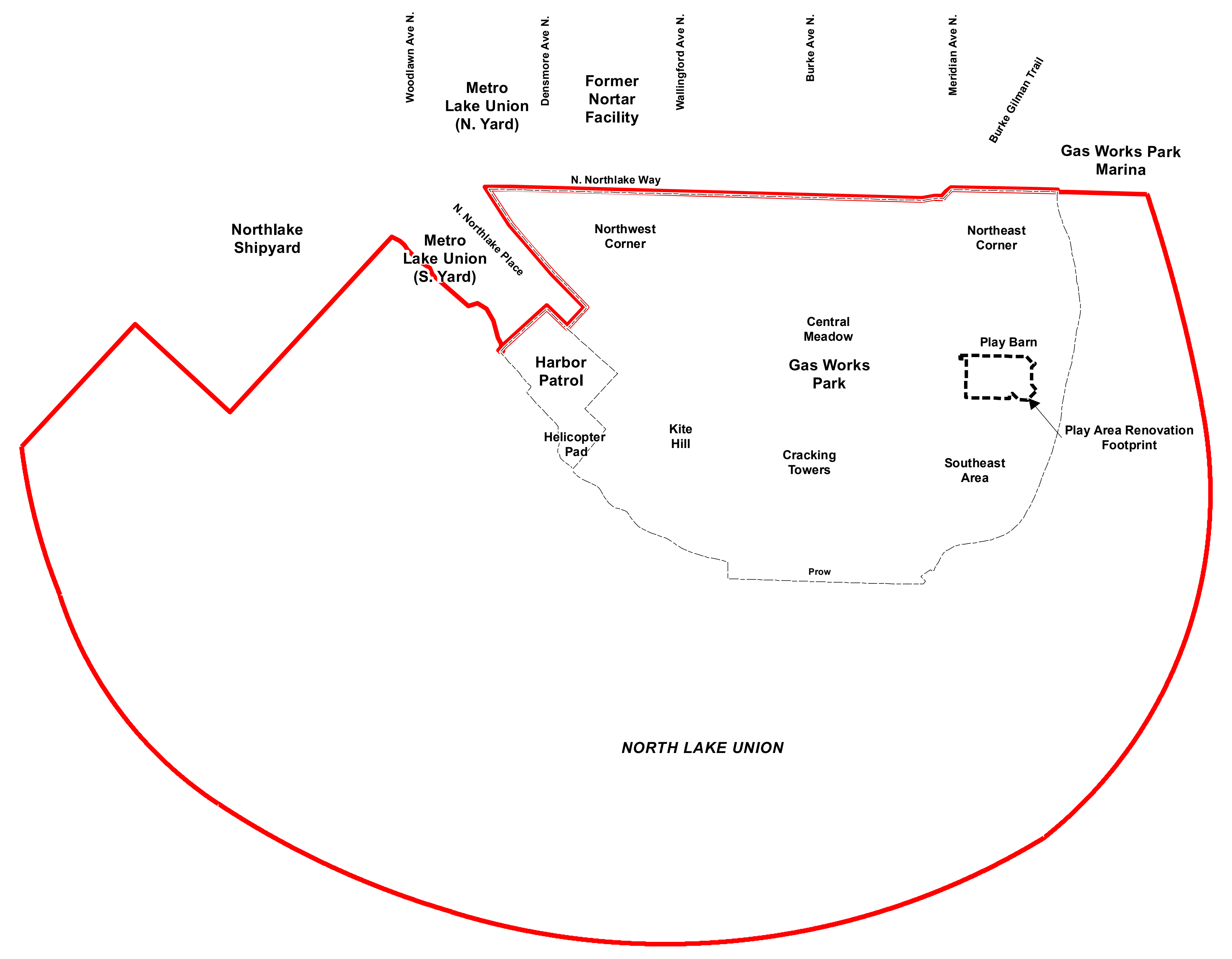


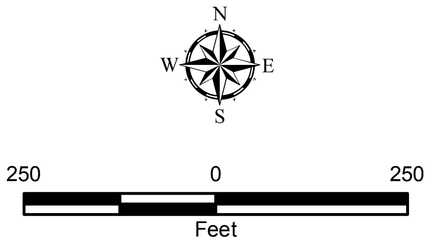
Legend

🟥 Area of Investigation (AOI) (Ecology 2013)

- - - Consent Decree Boundary (Ecology 1999)

⬚ Play Area Renovation Footprint

Notes:
1. The AOI is equivalent to the Gas Works Park Sediment Site boundary documented in the 2013 Amendment of Agreed Order DE 2008 (Ecology 2013).
2. The Uplands Consent Decree boundary is equivalent to the Site boundary documented in Exhibit A of the Final Consent Decree 99-2-52532-9SEA (Ecology 1999).
3. The locations of all features shown are approximate.
4. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.



Site Plan

Gas Works Park Site
Seattle, Washington

[redacted]

Figure 2

Path: P:\0\0186846\GIS\MXD\Phase01\T1804\018684601_T1804S06_F02_Site Plan.mxd Map Revised: 15 August 2017 syi

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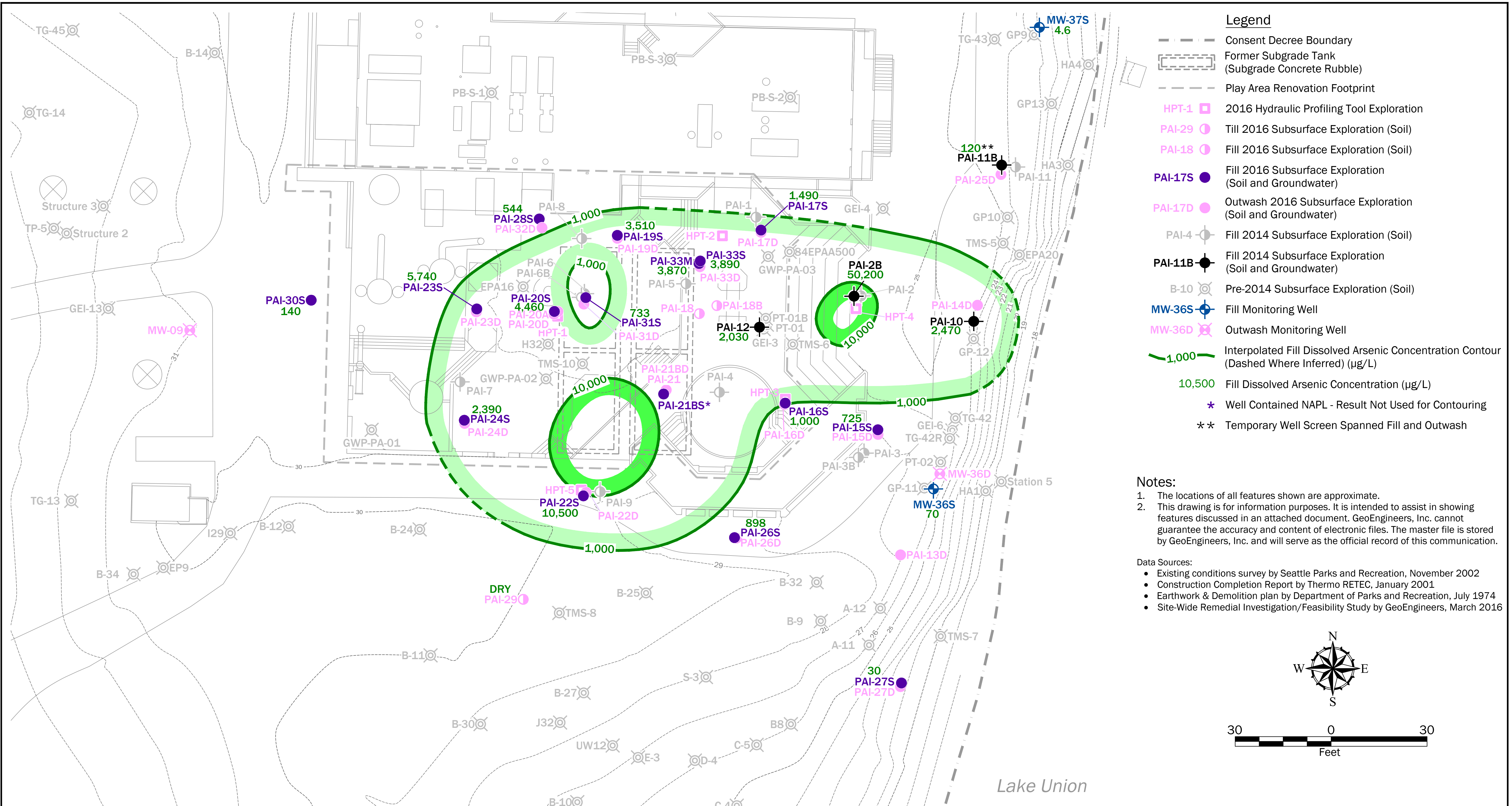


Legend

- Consent Decree Boundary
- Former Subgrade Tank (Subgrade Concrete Rubble)
- Play Area Renovation Footprint

HPT-1	2016 Hydraulic Profiling Tool Exploration
PAI-29	Till 2016 Subsurface Exploration (Soil)
PAI-18	Fill 2016 Subsurface Exploration (Soil)
PAI-17S ●	Fill 2016 Subsurface Exploration (Soil and Groundwater)
PAI-17D ●	Outwash 2016 Subsurface Exploration (Soil and Groundwater)
PAI-4	Fill 2014 Subsurface Exploration (Soil)
PAI-11B	Fill 2014 Subsurface Exploration (Soil and Groundwater)
B-10	Pre-2014 Subsurface Exploration (Soil)
MW-36S	Fill Monitoring Well
MW-36D	Outwash Monitoring Well
1,000	Interpolated Fill Dissolved Arsenic Concentration Contour (Dashed Where Inferred) (µg/L)
10,500	Fill Dissolved Arsenic Concentration (µg/L)
*	Well Contained NAPL - Result Not Used for Contouring
**	Temporary Well Screen Spanned Fill and Outwash

Notes:

1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Data Sources:

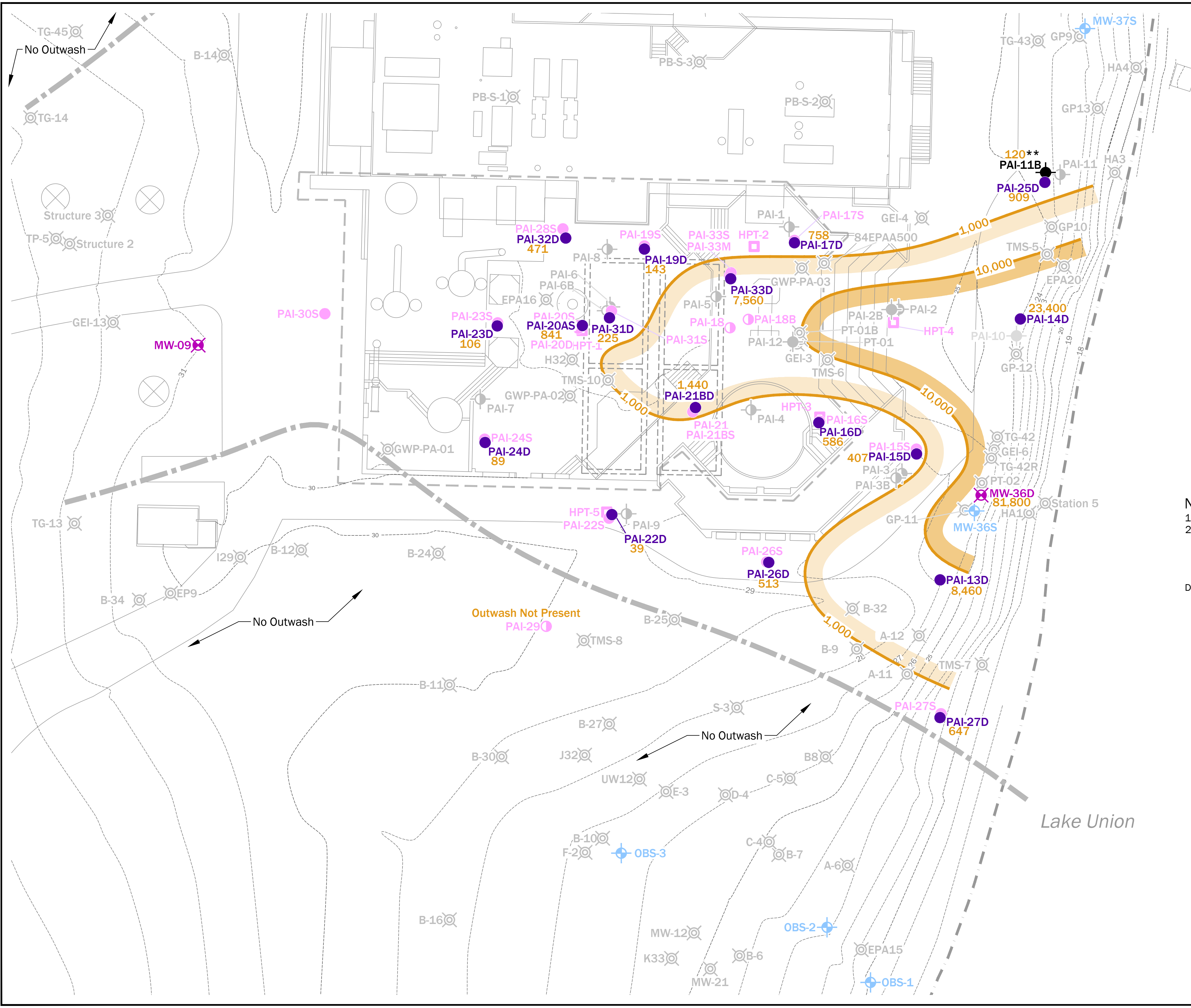
- Existing conditions survey by Seattle Parks and Recreation, November 2002
- Construction Completion Report by Thermo RETEC, January 2001
- Earthwork & Demolition plan by Department of Parks and Recreation, July 1974
- Site-Wide Remedial Investigation/Feasibility Study by GeoEngineers, March 2016

Fill Dissolved Arsenic

Gas Works Park Site
Seattle, Washington

GEOENGINEERS

Figure 3



Legend

▬ · ▬	Consent Decree Boundary
▭	Former Subgrade Tank (Subgrade Concrete Rubble)
- - -	Play Area Renovation Footprint
HPT-1 ▫	2016 Hydraulic Profiling Tool Exploration
PAI-29 ◑	Till 2016 Subsurface Exploration (Soil)
PAI-18 ◑	Fill 2016 Subsurface Exploration (Soil)
PAI-17D ●	Outwash 2016 Subsurface Exploration (Soil and Groundwater)
PAI-17S ●	Fill 2016 Subsurface Exploration (Soil and Groundwater)
PAI-4 ◑	Fill 2014 Subsurface Exploration (Soil)
PAI-11B ●	Outwash 2014 Subsurface Exploration (Soil and Groundwater)
PAI-2B ●	Fill 2014 Subsurface Exploration (Soil and Groundwater)
B-10 ⊗	Pre-2014 Subsurface Exploration (Soil)
MW-36S ⌖	Fill Monitoring Well
MW-36D ⊗	Outwash Monitoring Well
1,000	Interpreted Outwash Dissolved Arsenic Concentration Contour (µg/L)
10,500	Outwash Dissolved Arsenic Concentration (µg/L)
**	Temporary Well Screen Spanned Fill and Outwash
▬ · ▬	Estimated Lateral Extent of Outwash

Notes:

1. The locations of all features shown are approximate.
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Data Sources:

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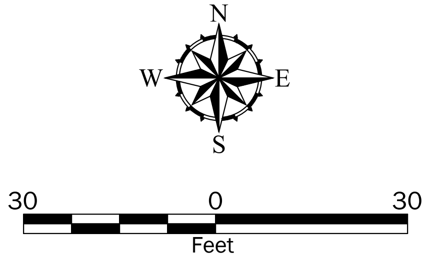

Outwash Dissolved Arsenic

Gas Works Park Site
Seattle, Washington

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Figure 4

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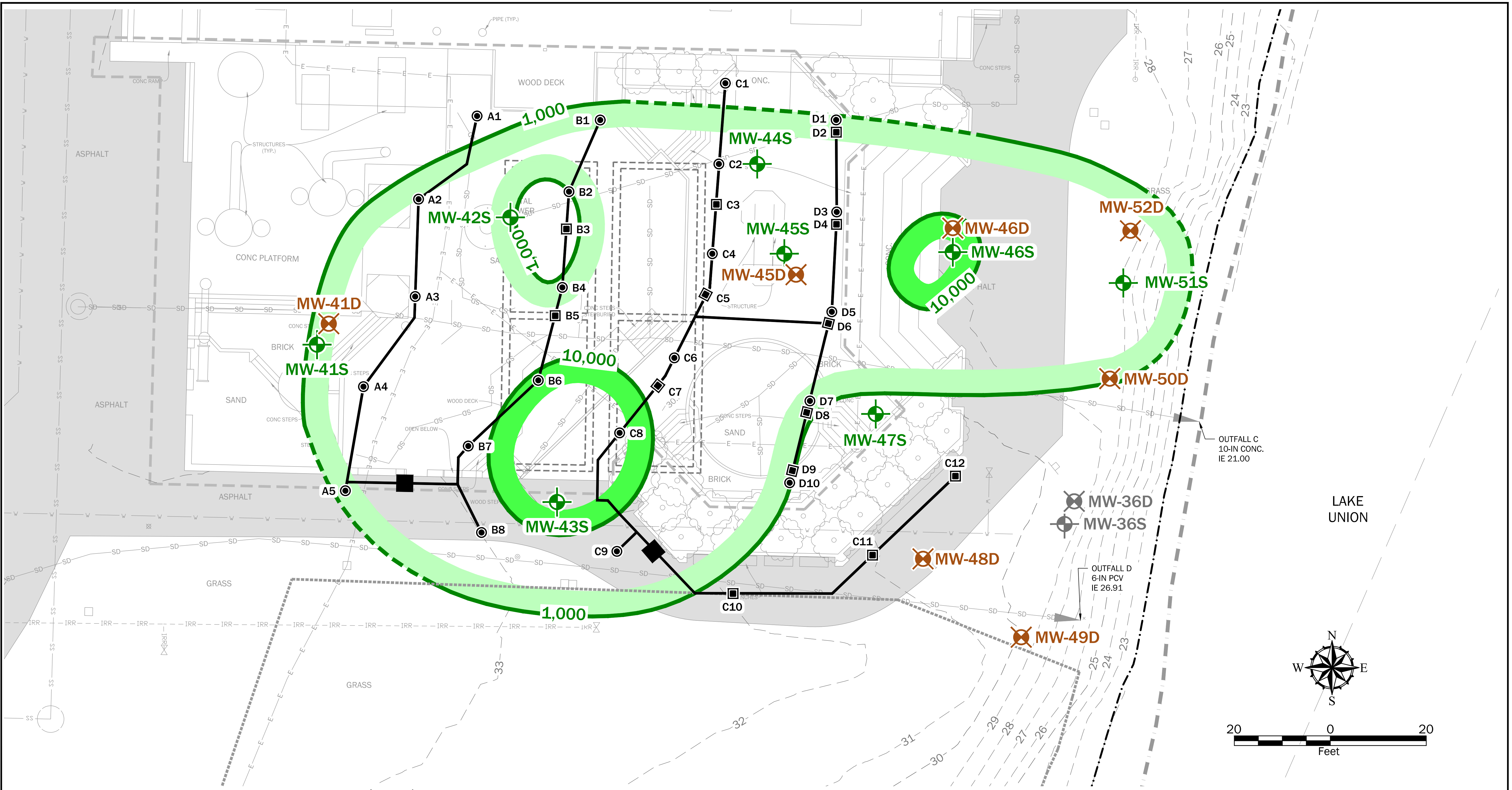

Notes:

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Data Source:

- Existing conditions survey by Seattle Parks and Recreation, November 2002
- Construction Completion Report by Thermo RETEC, January 2001
- Outfall C and D based on APS Survey, December 2014

Legend

---30---	Existing Contour (USACOE)
--SD--	Existing Stormdrain
--W--	Existing Water
--E--	Existing Electrical
— — —	Play Area Renovation Footprint
·······	Approximate Edge of Existing Impermeable Liner
▨	Existing Asphalt, Gravel, and/or Concrete
⊕	Existing Monitoring Well - Fill
⊗	Existing Monitoring Well - Outwash
1,000	Interpreted Fill Dissolved Arsenic Concentration Contour (Dashed where inferred) (µg/L)
-·-·-	Ordinary High Water

Proposed Injection Infrastructure and Monitoring Wells

A1 ◉	Injection Well - Fill
B3 ■	Injection Well - Outwash
—■—	Trenched Injection Pipe and System Vault
MW-46S ⊕	Monitoring Well - Fill
MW-46D ⊗	Monitoring Well - Outwash

Injection Infrastructure and Monitoring Well Network - Fill Dissolved Arsenic

Gas Works Park Site
Seattle, Washington

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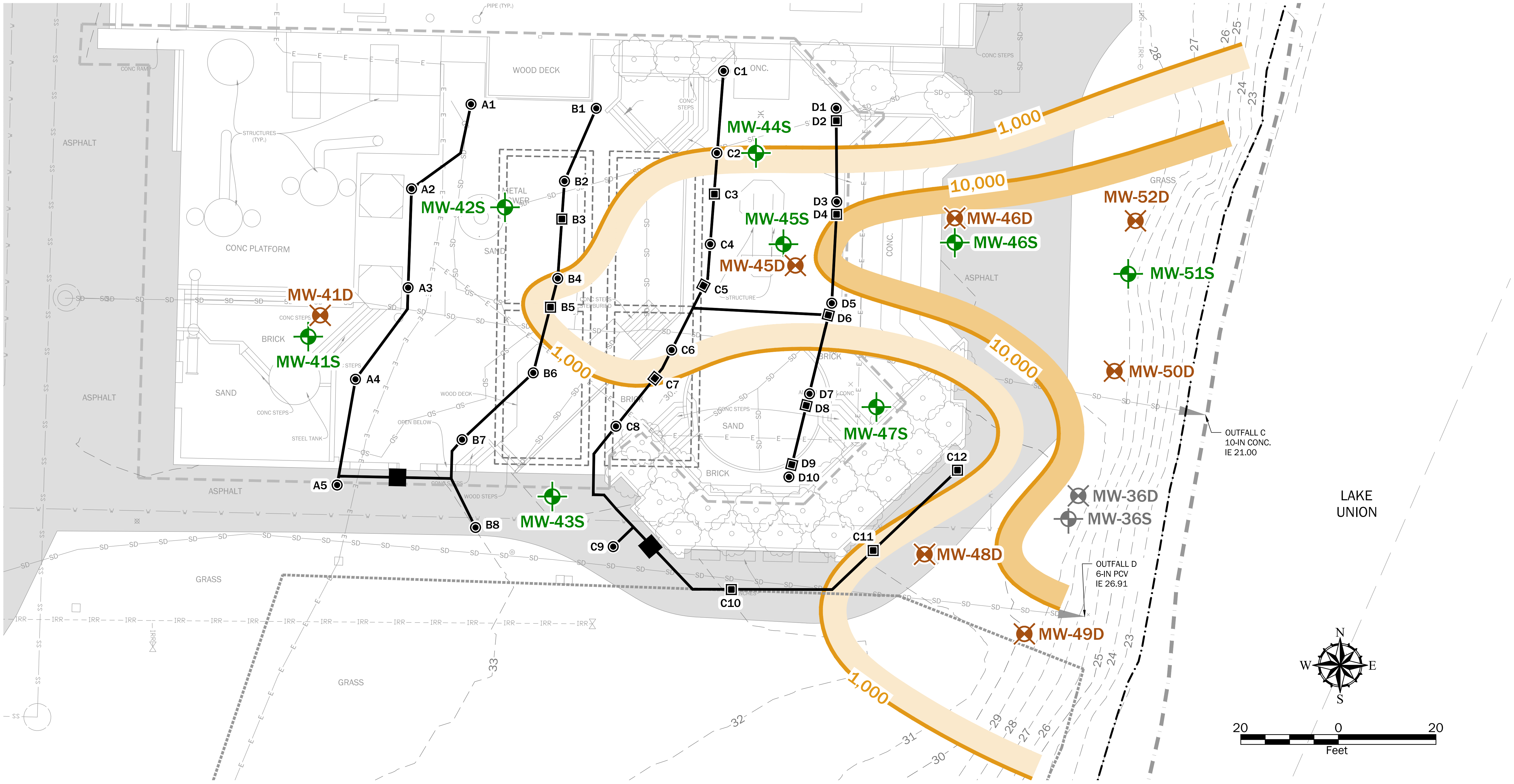
Figure 5

P:\0\0186846\01\CAD\Task 1804 2017 Play Area IA\Work Plan\0186846 01_T1804S06_F05-F06 Injection Infrastructure and MW Well Networks Fill and Outwash Dissolved Arsenic.dwg TAB:F05 Date Exported: 08/15/17 - 11:58 by syi



Notes:

1. The locations of all features shown are approximate.
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Data Source:

- Existing conditions survey by Seattle Parks and Recreation, November 2002
- Construction Completion Report by Thermo RETEC, January 2001
- Outfall C and D based on APS Survey, December 2014

Legend

---30---	Existing Contour (NAVD88)
—SD—	Existing Stormdrain
—W—	Existing Water
—E—	Existing Electrical
— —	Play Area Renovation Footprint
▪▪▪▪	Approximate Edge of Existing Impermeable Liner
▨	Existing Asphalt, Gravel, and/or Concrete
⌖	Existing Monitoring Well - Fill
⊗	Existing Monitoring Well - Outwash
1,000	Interpreted Outwash Dissolved Arsenic Concentration Contour (µg/L)
—·—	Ordinary High Water

Proposed Injection Infrastructure and Monitoring Wells

A1 ◉	Injection Well - Fill
B3 ▣	Injection Well - Outwash
—■	Trenched Injection Pipe and System Vault
MW-46S ⌖	Monitoring Well - Fill
MW-46D ⊗	Monitoring Well - Outwash

Injection Infrastructure and Monitoring Well Network - Outwash Dissolved Arsenic

Gas Works Park Site
Seattle, Washington

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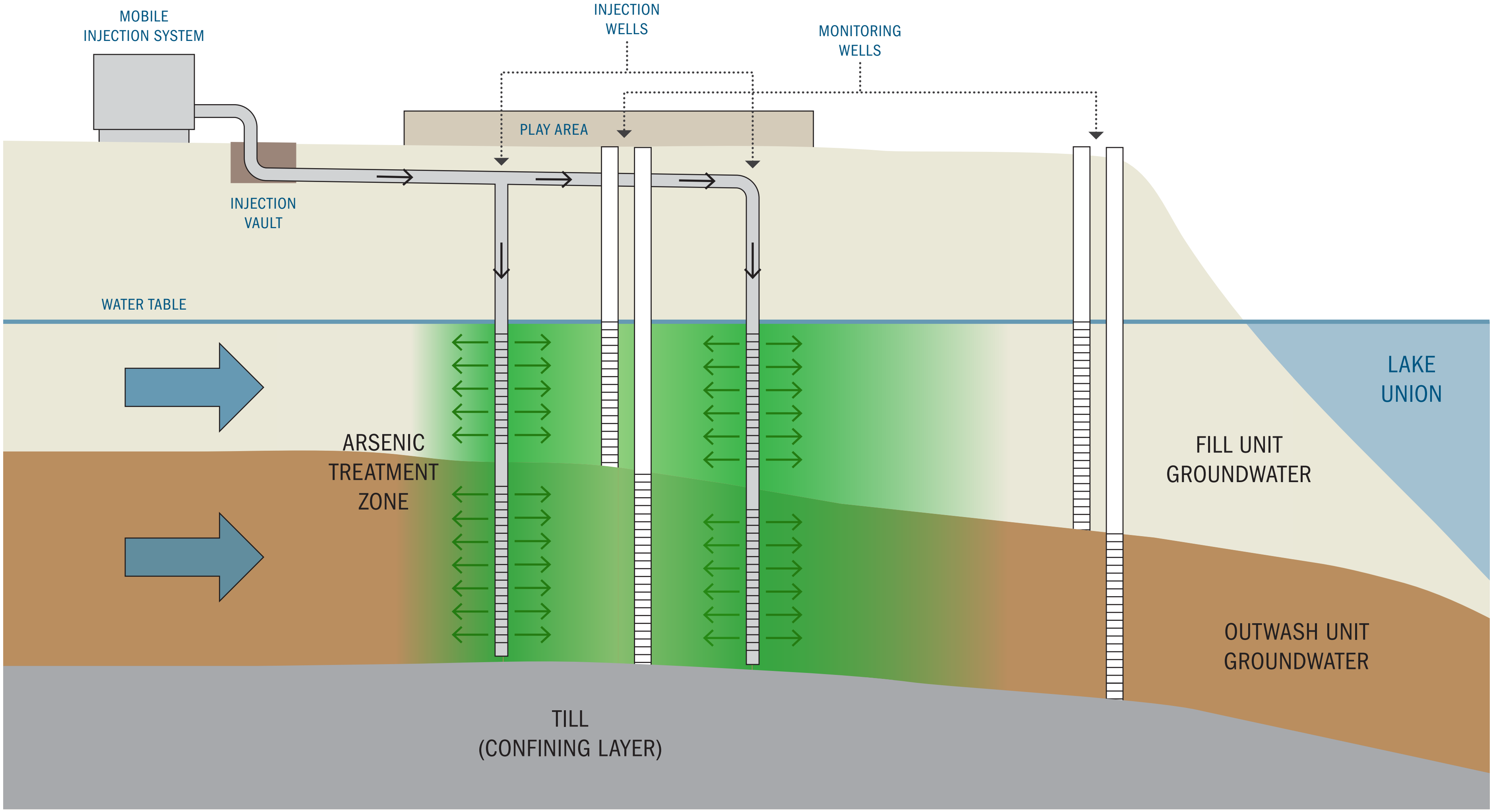
Figure 6



Play Area Groundwater Treatment Schematic

Gas Works Park Site
Seattle, WA

GeoEngineers

Figure 7

Notes:

1. The location of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc.and will serve as the official record of this communication.

APPENDICES

APPENDIX A
Arsenic Treatability Study Report, Gas Works Park

ARSENIC TREATABILITY STUDY REPORT GAS WORKS PARK

Prepared for

GeoEngineers, Inc.

Prepared by

Anchor QEA, LLC
421 SW Sixth Avenue, Suite 750
Portland, Oregon 97204

December 2016

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LIST OF ACRONYMS AND ABBREVIATIONS

ARI	Analytical Resources, Inc.
Brooks	Brooks Applied Labs
DO	dissolved oxygen
EGL	Environmental Geochemistry Laboratory
mg/L	milligrams per liter
ORP	oxidation-reduction potential
QC	quality control
RPD	relative percent difference
SSE	selective sequential extraction

1 INTRODUCTION

This report presents results and recommendations of groundwater treatability testing for arsenic contamination at the Gas Works Park Site in Seattle, Washington. Dissolved arsenic concentrations are elevated in groundwater in the eastern portion of the site, where the Thylox process equipment was formerly located. Arsenic is a contaminant of concern for site soil and groundwater discharging to surface water.

Iron amendments can remove arsenic from groundwater through one or more the following mechanisms:

- Ferrous iron reacts with dissolved sulfide to form an insoluble iron sulfide precipitate (FeS or mackinawite); removal of dissolved sulfide from groundwater also reduces the solubility of arsenic under sulfidic conditions.
- Soluble iron compounds such as ferrous sulfate and ferric chloride are acidic and have been used for neutralization of alkaline pH; arsenic solubility under sulfidic conditions present at the site decreases with decreasing pH.
- Arsenic attenuation is also provided by adsorption on iron oxides that form within an iron-based reactive barrier or downgradient of the point of injection of soluble iron amendments.

The objective of the treatability study is to provide empirical bench-scale data for the performance of iron-based amendments to aid in selection of suitable amendments and doses for in situ removal of arsenic from site groundwater.

Treatability testing was performed in Anchor QEA's Environmental Geochemistry Laboratory (EGL) in Portland, Oregon, following procedures outlined in the *Treatability Study Work Plan* (Anchor QEA 2016a).

2 SAMPLE COLLECTION

Site groundwater and aquifer solids for treatability testing were provided to Anchor QEA by GeoEngineers. Site groundwater was collected from monitoring well MW-36D. Groundwater samples were collected in 5 gallon cubitainers with zero headspace, and packed in Mylar barrier bags containing oxygen adsorbents to preserve anaerobic conditions during transport to EGL. Aquifer soil materials from the Fill and Outwash units were obtained from archived samples collected by GeoEngineers during the Play Area Investigation in 2014. Soils were also packaged in Mylar zip-seal bags with oxygen absorbent packets for transport to EGL.

3 TREATABILITY TESTING RESULTS

The in situ treatment approaches that were evaluated target manipulation of geochemical conditions to reduce arsenic solubility and mobility under site conditions.
Iron-based amendments that were tested included soluble iron compounds that can be injected into groundwater, as well as sparingly soluble iron amendments that can be emplaced in a reactive barrier or as a reactive component of a sediment cap to treat groundwater in situ prior to discharge to Lake Union. The following iron-based amendments were evaluated for dissolved arsenic removal (and sequestration) from site groundwater:

- Soluble amendments for implementation by in situ injection
  - Ferrous sulfate [$FeSO_4 \cdot 7H_2O$]
  - Ferric chloride [$FeCl_3 \cdot 4H_2O$]
- Solid phase amendments for implementation in a reactive barrier
  - Siderite [$FeCO_3$]
  - Zero-valent iron [Fe^0]

The iron-based amendments used for treatability testing were obtained from commercial suppliers. Ferrous sulfate and ferric chloride were obtained from GFS Chemicals (www.gfschemicals.com), zero-valent iron was obtained from Connelly-GPM, Inc. (www.connellygpm.com), and siderite was obtained from SidCo Minerals.

3.1 Treatability Groundwater and Soil Sample Characterization

Geochemical characterization of site groundwater and aquifer solids (soil) was performed to support the design and interpretation of the treatability testing. Groundwater and soil samples were composited and homogenized under a nitrogen atmosphere. The homogenized materials were subsampled in duplicate and submitted for analysis at EGL, Analytical Resources, Inc. (ARI), and Brooks Applied Labs (Brooks), as described in Anchor QEA (2016). Initial groundwater and soil characterization data are presented in Tables 1 and 2.

The dissolved arsenic speciation in MW-36D groundwater consists of a mixture of arsenite (As(III), 54 %), arsenate (As(V), <2 %) and a significant proportion of species tentatively identified as thioarsenates (AsS_xO_{4-x}, 45 %).

The fill unit soil is predominantly coarse sand to gravel with a pH of 8.6, while the outwash unit soil is predominantly fine sand to silt with a pH of 8.4.

3.2 Groundwater pH Titration

Geochemical investigations conducted at the site found that dissolved arsenic concentrations in groundwater decrease with decreasing pH (Anchor QEA 2015); therefore, pH neutralization is a potentially important process for arsenic removal from groundwater. The solubility of arsenic as a function of pH was determined by acid titration of site groundwater from its initial native pH of 8.65 to a final pH of 3, with collection of aliquots for determination of dissolved arsenic concentration (and selected samples for arsenic speciation) at intervals of approximately 0.5 to 1.0 pH units. The acid titration was performed twice with samples submitted at each neutralization step for total and dissolved arsenic and iron concentration, as well as arsenic speciation. The first titration experiment (Titration 1) was performed in a 4 liter Erlenmeyer flask set on a stirring plate. Nitric acid was added stepwise under ambient conditions, and sample aliquots were collected at each target pH. For the second titration experiment (Titration 2), individual bottles were prepared for each target pH, and the reaction was performed under anaerobic conditions. Titration test results are summarized in Tables 3 and 4. The pH titration curves are shown in Figure 1, and the dissolved arsenic concentrations measured at different pH values are shown in Figure 2.

The acid titration test results confirmed that decreasing groundwater pH also reduces dissolved arsenic concentrations. However, pH neutralization alone decreased the dissolved arsenic concentration of MW-36D groundwater by nearly 90 % to a final concentration of approximately 9 milligrams per liter (mg/L). A yellowish precipitate observed to form following acidification is most likely an arsenic sulfide such as orpiment (As_2S_3). Arsenic concentrations were lower in Titration 2 because the closed and anaerobic conditions prevented hydrogen sulfide volatilization and/or oxidation, and enhanced the precipitation of arsenic sulfides.

Arsenic speciation results for the Titration 2 test samples indicated that although arsenate and arsenite were removed from solution with decreasing pH, the unknown species, likely thioarsenates based on prior site characterization, were not completely degraded and persisted in solution to pH as low as 3 (Figure 3).

3.3 Groundwater Batch Tests

A series of batch tests were performed to determine arsenic removal efficiency and removal rate from MW-36D groundwater by the 4 amendments evaluated. In reacting with site groundwater, the iron amendments which ultimately produce iron hydroxide, carbonate, and/or sulfide precipitates which produce acidity. For soluble amendments, a stoichiometric dose was calculated from the amount of acid required to bring the groundwater pH to 5 (based on the Titration 2 test data) and the acidity of the amendments, as described in Appendix A. For siderite and zero-valent iron, a nominal dose based on an iron to arsenic ratio of 1,000 was used.

Groundwater and amendments were added to test bottles in a glove box under a nitrogen atmosphere. The nominal doses used in the groundwater batch tests are given in Table 5. Replicate test bottles were set up for the nominal doses, and additional batch tests were set up at one half and twice the nominal doses to bracket the test conditions.

Test bottles were allowed to react anaerobically for 48 hours prior to sampling. Dissolved arsenic concentrations decreased in all treatments but were still elevated relative to the controls. Batch tests were therefore allowed to react for an additional 14 days at which time they were sampled again. Batch tests results are summarized in Table 6, and dissolved arsenic concentrations for the different treatments as a function of reaction time are plotted in Figures 4 to 7. After the additional reaction period, all the treatments had greater than 90% arsenic removal compared to the control. A black precipitate, likely iron sulfide, formed in all the ferrous sulfate treatments and in the lowest (1/2) dose of the ferric chloride treatment. A reddish-brown precipitate, likely iron oxyhydroxide, formed in the nominal and higher dose ferric chloride treatments.

Based on the previous experience with the acid titration tests, the extended time needed to achieve 90% dissolved arsenic removal by the iron-based amendments was somewhat unexpected. Thioarsenates are known to be poorly adsorbed to iron oxides and sulfides (Couture et al. 2013). It was therefore hypothesized that the amendments, which have long been used for arsenic removal from groundwater, were not as effective as the acid used in the titrations in promoting rapid decomposition of thioarsenates. To test this hypothesis, an additional set of batch tests was conducted in which groundwater was pretreated with a strong oxidant (potassium permanganate or hydrogen peroxide) to degrade the thioarsenate species and convert them to arsenate:

$$AsS_xO_{4-x}^{3-} + OX \rightarrow AsO_4^{3-} + x\ SO_4^{2-}$$

where OX is the oxidant. The pretreated groundwater was then allowed to react with the amendments (added at ½ the nominal dose for ferric chloride and ferrous sulfate and the nominal dose for siderite and zero-valent iron) for 48 hours and sampled. The results (Table 7) showed that arsenic removal was greatly improved by the pretreatment, confirming that the observed performance in the previous batch tests (48-hour reaction time without thioarsenate pretreatment) was due to the slow decomposition of thioarsenates present in groundwater.

3.4 Groundwater-Soil Slurry Sequential Batch Uptake Tests

Based on the results of the batch test, it was decided to proceed with a 2-pronged approach for the batch uptake tests. Accelerated (short cycle) uptake tests for the ferric chloride and ferrous sulfate treatments with peroxide pretreated groundwater were performed to provide sufficient data on amendment performance to support a decision regarding implementing in situ injection as an interim action. The accelerated laboratory timeframe allowed for infrastructure construction to be performed in coordination with other planned construction at the site but also introduced some uncertainty on the representativeness of the results for site-specific conditions. A second set of uptake tests was also performed for all 4 amendments with longer reaction cycles (2 weeks) and without groundwater pretreatment to generate treatability data under more realistic site-specific conditions to reduce uncertainties regarding treatment effectiveness and permanence in selecting the preferred amendments.

3.4.1 Short Cycle Uptake Tests with Pretreated Groundwater

Aquifer solids (fill and outwash soil) were reacted with amended groundwater (pre-treated with peroxide) at a liquid-to-solid ratio of 10 for 48 hours. At the end of the reaction period, groundwater was decanted for sampling, and a new aliquot of amended groundwater was reacted with the amended solids for 48 hours. This was repeated for a total of four cycles. Controls (soil only) and duplicate tests were also set up in accordance with the work plan (Anchor QEA 2016a). At the end of each reaction cycle, specific conductance, pH, and oxidation-reduction potential (ORP) were measured in the reacted groundwater, and a sample was collected for dissolved arsenic and iron analysis. Results for outwash soil are presented in Table 8 and results for fill soil are presented in Table 9.

The fill soil controls showed some reduction in dissolved arsenic concentrations during the first and second cycles but little removal thereafter (Figure 8). The outwash soil control showed even less removal and the final dissolved arsenic concentration at the end of the fourth cycle was slightly greater than the initial groundwater concentration, indicating a net release of arsenic from the solids by the fourth cycle (Figure 9). Consequently, the calculated cumulative arsenic uptake from the groundwater test solutions by the unamended soils was generally low (Figures 10 and 11).

The multiple uptake cycles with ferric chloride treatment consistently resulted in average dissolved arsenic concentrations around 0.3 mg/L representing 3 orders of magnitude reduction compared to the controls (Figures 8 and 9). The cumulative arsenic uptake by the ferric chloride treated soils was essentially 100 % of the arsenic loading (Figures 10 and 11).

No visible precipitates formed with ferric chloride treatment; however, the solutions turned reddish-brown in color. Dissolved iron concentrations remained similar or slightly lower than in the controls, indicating that the added iron was largely precipitated as colloidal iron oxides and coatings on the soil grains.

The ferrous sulfate treatments consistently resulted in average dissolved arsenic concentrations of 0.02 mg/L or 4 orders of magnitude reduction compared to the controls (Figures 8 and 9). The cumulative arsenic uptake by the ferrous sulfate treated soils was essentially 100 % of the arsenic loading (Figures 10 and 11). Residual dissolved iron concentrations were in the 100-200 mg/L range, representing 10-20 % of the iron added, the remainder having precipitated. A rust colored precipitate formed in the slurry test bottles with ferrous sulfate. The lower dissolved arsenic concentrations coupled with elevated iron suggest that a ferrous arsenate such as symplesite may have precipitated in these test bottles in addition to iron oxides.

The calculated cumulative arsenic uptake from the groundwater test solutions by the ferric chloride and ferrous sulfate amended soils was high and close to the maximum possible uptake based on the cumulative arsenic loading to the test bottles (Figures 10 and 11).

3.4.2 Long Cycle Uptake Tests with Anoxic Groundwater

Aquifer solids (fill and outwash soil) were reacted with amendments and anoxic groundwater at a liquid-to-solid ratio of 10 for 14 days. At the end of the reaction period, groundwater was decanted for sampling, and a new aliquot of groundwater was added to each test bottle and allowed to react with the amended solids for an additional 14 days. This procedure was repeated for a total of four cycles. Controls (soil only) and duplicate tests were also set up in accordance with the work plan (Anchor QEA 2016a). At the end of each reaction cycle, specific conductance, pH, and oxidation-reduction potential (ORP) were measured, and water samples were collected for dissolved arsenic and iron analysis. For each soil/amendment combination, one replicate was submitted for analysis and the second was archived. Results for outwash soil are presented in Table 10 and results for fill soil are presented in Table 11.

The purpose of the long cycle uptake tests was to evaluate cumulative arsenic uptake by a single dose of amendments, therefore amendments were initially only added to the soil at the beginning of the first cycle. For the soluble iron amendments (ferric chloride and ferrous sulfate), however, arsenic uptake was significantly reduced at the end of the second cycle. Although not entirely unexpected because the dosing of the soluble amendments was based on stoichiometric considerations, ferrous sulfate and ferric chloride were added again at the beginning of the third cycle in an attempt to increase the cumulative arsenic uptake on the soil. Amendments were added to both of the test bottle replicates, one at the initial dose and the other at twice the initial dose to assess the effect of a higher dose on arsenic uptake. Water samples from both replicate bottles were analyzed at the end of cycle 3. Although the additional amendment dose improved the arsenic removal, the higher dosage did not result in significant additional removal (Tables 10 and 11). For the fourth and final cycle, ferrous sulfate and ferric chloride were therefore added again to both replicates at the initial dose rate. For uptake tests with the solid phase amendments (siderite and ZVI), no additional doses were added after the initial dose.

3.4.2.1 Untreated Soil Controls

Arsenic removal from solution by the fill and outwash soil controls was initially modest to low and decreased in subsequent cycles, with negative uptake (i.e. small net release of arsenic from solids) by the final cycle (Figures 12 and 13). The cumulative arsenic uptake by the fill was 14 % of the total arsenic loading with an estimated arsenic uptake capacity of approximately 760 mg/kg (Figure 14). The cumulative arsenic uptake by the outwash soil was 3 % of the arsenic loading with an estimated arsenic uptake capacity of approximately 130 mg/kg (Figure 15). The low uptake by the untreated soils is partly due to weaker adsorption of arsenic at alkaline pH, which remained above 8 in all cycles. The higher arsenic uptake capacity of the fill is likely attributable to the higher sulfide content relative to the outwash soil (Table 2).

3.4.2.2 Ferric Chloride

The ferric chloride treatments achieved 70 to 88 % arsenic removal by the fill and 79 to 86 % by outwash soil for cycles when ferric chloride was added (cycles 1, 3, and 4) but only 35 % and 31 %, respectively, during cycle 2 when groundwater was replaced without addition of ferric chloride (Figures 12 and 13). The cumulative arsenic uptake was 67 % of the total arsenic loading for fill (Figure 14) and 70 % for outwash soil (Figure 15). Solution pH was generally reduced below 7 when ferric chloride was added with values as low as 3.1 recorded. A reddish brown precipitate was observed in the bottles indicative of iron oxides.

3.4.2.3 Ferrous Sulfate

The ferrous sulfate treatments resulted in 51 to 78 % arsenic removal by the fill and 64 to 79 % by outwash soil for cycles when ferrous sulfate was added (cycles 1, 3, and 4) but only 39 % and 35 %, respectively, during cycle 2 when groundwater was replaced without addition of ferrous sulfate (Figures 12 and 13). The cumulative arsenic uptake was 58 % of the total arsenic loading for fill (Figure 14) and 62 % for outwash soil (Figure 15). Solution pH was consistently reduced to 6.5±0.2 when ferrous sulfate was added. Dark brown precipitates were observed in the bottles indicating a mixture of iron sulfides and oxides.

3.4.2.4 Siderite

Arsenic removal by outwash soil amended with siderite decreased from 40 % during the first cycle to 4 % by the fourth cycle (Figure 13). The cumulative arsenic uptake was 19 % of the total arsenic loading (Figure 15). Solution pH remained slightly elevated at around 8.0±0.2.

3.4.2.5 Zero-valent Iron

Arsenic removal by outwash soil amended with zero-valent iron decreased from 83 % during the first cycle to 61 % by the fourth cycle (Figure 13). The cumulative arsenic uptake was 71 % of the total arsenic loading (Figure 15). Solution pH increased slightly to 9.3±0.2.

3.5 Selective Sequential Extraction

Following completion of the sequential batch uptake tests, the solid residues were recovered and subjected to selective sequential extraction (SSE) to evaluate the extent of arsenic sequestration and to assess the potential for arsenic remobilization from the treated solids. SSE fractionates the arsenic in the solid residues into 5 operationally defined pools, F1 through F5, which require increasingly aggressive chemical reagents to extract. F1 represents readily soluble arsenic. F2 is extracted with a mildly acidic concentrated phosphate solution. F2 targets arsenic present in forms that are soluble in mild acid (pH 5) or can be exchanged by phosphate. F3 is an acidic (pH 2) solution containing hydroxylamine which reduces ferric iron and solubilizes associated arsenic. F4 is concentrated nitric acid and solubilizes most of the arsenic associated with organic matter or bound in crystalline phases that are recalcitrant to the previous extraction steps. F5 represents the residual arsenic that is not released by the sequential extraction procedure.

3.5.1 Short Cycle Uptake Tests

SSE results for fill and outwash soil residues from the short cycle uptake tests with pretreated groundwater are summarized in Table 12 and Figures 16 and 17, respectively.

For fill soil, the ferric chloride treatment had a marginally higher total arsenic uptake than the control (Table 12). However, the soluble F1 arsenic fraction was greatly reduced and a higher proportion of the bound arsenic was sequestered in the F3 fraction (Figure 16). The increase in the F3 fraction is consistent with adsorption and co-precipitation of arsenic with iron oxides formed on addition of ferric chloride. The ferrous sulfate treatment resulted in approximately twice the arsenic uptake of the control with reductions in the relative proportions of the soluble F1 arsenic fraction and increases in the recalcitrant F3 and F4 arsenic fractions. The higher arsenic concentration in the F2 fraction and very low dissolved arsenic concentrations observed in the ferrous sulfate treatments relative to control and ferric chloride treatments (Figure 8) are consistent with precipitation of symplesite, a ferrous arsenate solid phase which is expected to be stable under the test conditions with pretreated groundwater.

For the outwash soil, the ferric chloride treatment increased total arsenic uptake by an order of magnitude relative to the control (Table 12). The soluble F1 arsenic fraction was reduced and a greater proportion of the arsenic was sequestered in the more recalcitrant F2, F3, and F4 fractions (Figure 11). The increases in the F2 and F3 fractions are consistent with adsorption and co-precipitation of arsenic with iron oxides formed on addition of ferric chloride. The ferrous sulfate treatment resulted in approximately 20 times the arsenic uptake of the control and twice the uptake of the ferric chloride treatment. The mass of soluble arsenic was reduced by approximately 60 percent as a result of the ferrous sulfate treatment, resulting in a shift in the proportion of arsenic in the F1 fraction from 33 percent for the control sample to less than 1 percent. Proportions of the more recalcitrant F2, F3, and F4 fractions also increased due to sequestration of the added arsenic. The higher proportion of arsenic in F2 and very low dissolved arsenic concentrations observed in the ferrous sulfate treatments (Figure 9) are also consistent with precipitation of symplesite under the short cycle test conditions with pretreated groundwater.

3.5.2 Long Cycle Uptake Tests

SSE results for fill and outwash soil residues from the long cycle uptake tests are summarized in Table 13 and Figures 18 and 19, respectively.

In the fill control sample, arsenic was predominantly distributed in the F2, F4 and F1 fractions in order of decreasing proportion, while for the outwash control sample, F2 and F1 were the dominant arsenic pools. The ferric chloride treatment resulted in an increase in proportion of the F2 fraction at the expense of F1 in both soils, consistent with arsenic uptake by adsorption on newly formed iron oxide precipitates. In the ferrous sulfate treated soils, the soluble F1 arsenic fraction decreased in both soils and the F2 and F4 fractions increased, consistent with arsenic sequestration in sulfide precipitates.

The siderite amended outwash soil also showed increases in both F2 and F4 fractions consistent with arsenic uptake by iron oxides and sulfides, but had the lowest cumulative arsenic uptake of the amendments tested. The zero-valent iron amended outwash soil had a higher total arsenic uptake which was largely taken up in the F4 fraction suggesting strong sequestration of arsenic in sulfide phases formed by the anaerobic corrosion of iron metal.

4 AMENDMENT RANKING

All the amendments tested were successful at decreasing dissolved arsenic concentrations in groundwater to varying degrees. In groundwater batch tests, both ferric chloride and ferrous sulfate achieved an order of magnitude reduction in dissolved concentrations. Slurry tests showed slightly higher arsenic uptake with ferric chloride than ferrous sulfate treatment, however sequential extraction data showed that ferrous sulfate sequestered arsenic more strongly in the solid phase. Ferrous sulfate is therefore the preferred amendment for groundwater remediation by in situ injection at the site.

In groundwater batch tests, both siderite and zero-valent iron were also effective at reducing dissolved arsenic concentrations by an order of magnitude or more. Slurry tests showed much higher arsenic uptake by zero-valent iron than siderite, however, and sequential extraction data showed that arsenic was sequestered more strongly by zero-valent iron. Zero-valent iron is therefore the preferred media for a reactive barrier or as a reactive component of a sediment cap to remove arsenic from groundwater prior to discharge to Lake Union at the site.

5 SUMMARY AND RECOMMENDATIONS

- The geochemical investigation (Anchor QEA 2015) revealed that a significant proportion of the dissolved arsenic in site groundwater was in the form of thioarsenate species. Sulfide and pH were identified as key factors controlling the subsurface mobility of arsenic at the site.
- It was also recognized that the potential effectiveness of in situ treatment was uncertain due to limited prior knowledge with thioarsenates. A treatability testing program was designed, focusing on manipulating pH and sulfide using iron-based amendments that could either be injected or emplaced as a permeable reactive barrier or as a reactive component of a sediment cap to remove arsenic from groundwater prior to discharge to Lake Union. Treatability testing was performed with MW-36D groundwater which represents the “worst case” scenario (highest arsenic, pH, and sulfide concentrations).
- Groundwater pH titrations confirmed that dissolved arsenic concentration (initially 76.4 mg/L) could be reduced by lowering pH from 9 to 6, however the lowest concentration achieved was 8 mg/L (89% removal). This was found to be due to the persistence of thioarsenate species.
- Groundwater batch testing assessed the addition of iron amendments (ferrous sulfate, ferric chloride, siderite, and zero-valent iron) to reduce both pH and sulfide levels which is expected to degrade the thioarsenates. The tests showed that arsenic concentrations could be reduced by up to 99% but the reaction was slow (2 weeks). This presented a challenge to completing remaining tests and making recommendations for the in situ

injection system within the aggressive schedule imposed by upcoming site construction activities.

- An accelerated test protocol was designed, in which groundwater was pretreated with an oxidant to degrade sulfide and thioarsenate species, to assess the likely long-term endpoint for treatments with the injectable amendments (ferric chloride and ferrous sulfate). The accelerated tests showed that >99% arsenic removal (<200 µg/L) could be achieved by ferric chloride and >99.9% (<30 µg/L) could be achieved by ferrous sulfate after groundwater pretreatment with peroxide.
- Uptake test results with groundwater slurries containing either fill or outwash soil, indicated that the soil matrix does not adversely impact treatment effectiveness. Sequential extraction analysis of the treated soils showed that treatment sequestered arsenic by reducing the readily soluble arsenic fraction and increasing the amount of arsenic bound up in less soluble reactive fractions.
- Longer duration uptake tests under conditions more representative of the site (i.e. without groundwater pretreatment) showed slower arsenic uptake due to the persistence of recalcitrant thioarsenate species. In the field, it is anticipated that thioarsenates would break down over a longer period of time, subsequent to in situ treatment, to arsenite and arsenate, which would then be removed more rapidly. The longer duration uptake test results also document stronger sequestration of arsenic by the ferrous sulfate than the ferric chloride treatment.
- Slurry testing also demonstrated higher arsenic uptake and stronger sequestration by zero-valent iron than siderite.
- Based on testing conducted with MW-36D groundwater, it is concluded that injection of ferrous sulfate can reduce arsenic concentrations in groundwater by an order of magnitude, and perhaps more over time as thioarsenate species are destabilized.
- Ferrous sulfate injection is expected to be more effective in areas where sulfide, dissolved arsenic, and/or thioarsenate species concentrations are lower than at MW-36D.
- The potential for arsenic remobilization post-treatment depends on the geochemistry of upgradient groundwater that will flow through the treated area. Review of supplemental groundwater characterization data collected in September and October 2016 (GeoEngineers 2016) indicates that groundwater conditions in the fill and outwash upgradient of the area targeted for in situ treatment are generally low in dissolved arsenic and sulfide, and higher in dissolved iron concentrations, with near-neutral pH. These

conditions are compatible with iron and arsenic sulfides that would precipitate within the treatment area and also favorable for arsenic adsorption, therefore the potential for arsenic remobilization is considered very low.

- In situ treatment of groundwater using ferrous sulfate injection for arsenic removal is recommended as an early action at the site.

6 REFERENCES

Anchor QEA, 2015. *Former Thylox Process Area Geochemical Evaluation Technical Memorandum*. Gas Works Park. November 23, 2015.

Anchor QEA, 2016a. *Treatability Study Work Plan*. Prepared for GeoEngineers. Gas Works Park. April 2016.

Couture, RM, J Rose, N Kumar, K Mitchell, D Wallschlager and P Van Cappellen, 2013. Sorption of Arsenite, Arsenate, and Thioarsenates to Iron Oxides and Iron Sulfides: A Kinetic and Spectroscopic Investigation. *Environmental Science & Technology* 47(11):5652-5659.

GeoEngineers, 2016. Play Area Treatment Infrastructure Monitoring Well Network. *Technical Memorandum to Ching-Pi Wang, Washington State Department of Ecology*. November 9, 2016.

TABLES

Table 1
MW-36D Groundwater Chemistry

Parameter	Result[1]	Units
Arsenic, total	86,700 (5,400)	µg/L
Arsenic, dissolved	76,400 (6,300)	µg/L
Arsenite [As(III)]	51,300 (200)	µg/L
Arsenate [As(V)]	1,850 (10)	µg/L
Monomethylarsonic Acid [MMAs]	<20	µg/L
Dimethylarsinic Acid [DMAs]	<20	µg/L
Arsenic, Unidentified Species[2]	42,600 (1,400)	µg/L
Iron	1.53 (0.04)	mg/L
Manganese	0.035 (0.001)	mg/L
Calcium	2.85 (0.31)	mg/L
Magnesium	2.16 (0.37)	mg/L
Sodium	945 (13)	mg/L
Potassium	2.91 (0.19)	mg/L
Chloride	12.9 (0.2)	mg/L
Sulfate	599 (32)	mg/L
Nitrate	<0.1	mg/L as N
Phosphate	1.8 (0.1)	mg/L as P
Silicon	19.8 (0.4)	mg/L
Alkalinity	941 (7)	mg/L as $CaCO_3$
Sulfide	158 (13)	mg/L
Total Organic Carbon	135 (1)	mg/L
Total Dissolved Solids	2,810 (14)	mg/L

Notes:

1. Average of 2 replicate samples. Standard deviation in parentheses. The samples were field-filtered.
2. Based on the chromatographic retention time and previous speciation studies (Anchor QEA 2015), the unidentified species were tentatively identified as thioarsenates.

µg/L = micrograms per liter
mg/L = milligrams per liter

Table 2
Fill and Outwash Soil Characterization

Parameter	Result[1]		Units
	Outwash	Fill	
Arsenic	16.4 (2.3)	179 (55)	mg/kg
Iron	10,500 (300)	11,800 (500)	mg/kg
Sulfide	27.8 (2.7)	593 (458)	mg/kg
Total Organic Carbon	0.125 (0.011)	4.79 (6.76)	wt %
Total Solids	89.3 (1.1)	77.5 (2.8)	wt %
Grain Size Distribution			
>2mm	11.8	50.3	wt %
1 - 2 mm	7.4	8.3	wt %
0.5 - 1 mm	10.0	8.0	wt %
0.25 - 0.5 mm	21.4	12.2	wt %
0.125 - 0.25 mm	14.0	10.1	wt %
0.074 - 0.125 mm	13.9	4.4	wt %
<0.125 mm	21.5	6.8	wt %

Notes:

1. Average of 2 replicate samples. Standard deviation in parentheses.

mg/kg = milligrams per kilogram
TOC = total organic carbon
wt % = weight percent

Table 3
MW-36D Groundwater pH Titration Test 1 Results

Acid Added (meq/L)	Final pH	Arsenic, total (µg/L)	Arsenic, dissolved (µg/L)	Arsenic Removal (%)	Iron, total (µg/L)	Iron, dissolved (µg/L)
0.0	8.72	86,700	76,400	0	--	1,530
0.5	8.46	79,900	75,400	1	1,050	1,170
1.0	8.07	78,600	75,900	1	1,000	1,200
2.1	7.50	82,600	73,800	3	1,080	1,160
4.1	7.05	76,500	72,400	5	1,030	1,130
8.7	6.52	78,300	71,000	7	1,060	1,160
14.1	6.04	79,300	55,000	28	1,040	1,170
18.6	5.47	75,500	37,200	51	1,170	1,140
20.5	5.00	76,200	30,100	61	1,350	1,300
22.4	3.45	65,600	19,800	74	1,210	1,120
24.5	3.10	80,300	14,800	81	1,220	1,320

Notes:
meq/L = milliequivalents per liter
µg/L = micrograms per liter

Table 4
MW-36D Groundwater pH Titration Test 2 Results

Acid Added (meq/L)	Final pH	Arsenic, total (µg/L)	Arsenic, dissolved (µg/L)	Arsenic Removal (%)	Iron, total (µg/L)	Iron, dissolved (µg/L)
0.0	8.72	86,700	76,400	0	--	1,530
0.5	8.42	69,700	77,600	0	1,700	1,570
1.3	7.88	77,300	77,800	0	1,700	1,520
2.0	7.52	81,300	69,400	9	1,650	1,590
3.7	7.09	81,800	73,600	4	1,690	1,510
8.6	6.50	84,600	48,500	37	1,660	1,570
13.3	6.05	83,900	29,500	61	1,640	1,500
17.6	5.54	87,300	18,000	76	1,590	1,520
18.2	5.21	83,100	13,800	82	1,550	1,490
18.8	4.64	85,000	11,900	84	1,590	1,500
19.5	4.25	85,700	11,000	86	1,610	1,500
20.3	3.37	48,500	9,370	88	1,650	1,520
21.5	2.89	14,200	8,630	89	1,620	1,500

Notes:
meq/L = milliequivalents per liter
µg/L = micrograms per liter

Table 5

Nominal Amendment Doses for Groundwater Batch Tests

Amendment [Formula]	Calculated Dose (g/L)
Ferric Chloride [$FeCl_3 \cdot 4H_2O$]	2.0
Ferrous Sulfate [$FeSO_4 \cdot 7H_2O$]	5.1
Siderite [$FeCO_3$]	154[1]
Zero-valent Iron [Fe^0]	75

Note:

1. Adjusted for 80% purity and 2% moisture content based on vendor specifications g/L = grams per liter

Table 6
Groundwater Batch Test Results

Treatment	Dose	Reaction Time (days)	pH	ORP (mV)	Arsenic (mg/L)	Iron (mg/L)	Arsenic Removal (%)
Control	--	2	8.78	-217	63.4	1.54	27
		16	8.30	-129	95.3	1.55	-10
Control Duplicate	--	2	8.78	-216	65.9	1.51	24
		16	8.15	-123	87.8	1.54	-1
Ferric Chloride	½	2	6.83	-147	37.8	59.6	56
		16	7.25	-133	18.3	6.10	79
	1	2	5.63	-32	16.5	132	81
		16	5.60	18	7.43	134	91
	2	2	2.11	474	18.3	333	79
		16	2.15	465	25.1	561	71
Ferric Chloride Duplicate	1	2	5.72	-54	13.2	148	85
		16	5.68	-3	7.61	123	91
Ferrous Sulfate	½	2	6.93	-220	49.2	291	43
		16	5.96	-153	8.40	1,320	90
	1	2	6.65	-200	53.7	625	38
		16	6.12	-150	7.75	820	91
	2	2	6.64	-207	51.6	1,680	40
		16	6.01	-163	9.97	1,000	89
Ferrous Sulfate Duplicate	1	2	6.71	-202	51.2	703	41
		16	6.04	-144	7.64	837	91
Siderite	½	2	7.53	-173	59.7	1.63	31
		16	7.12	-45	11.1	0.83	87
	1	2	7.19	-156	56.0	1.79	35
		16	6.90	-44	4.95	0.53	94
	2	2	7.03	-135	37.5	1.78	57

Treatment	Dose	Reaction Time (days)	pH	ORP (mV)	Arsenic (mg/L)	Iron (mg/L)	Arsenic Removal (%)
		16	6.47	24	0.19	0.42	99.8
Siderite Duplicate	1	2	7.17	-147	54.3	1.55	37
		16	6.78	-33	3.62	0.75	96
Zero-valent Iron	½	2	9.31	-254	40.5	1.57	53
		16	8.91	-161	12.4	1.24	86
	1	2	9.36	-285	40.7	1.52	53
		16	9.49	-103	6.3	0.92	93
	2	2	9.55	-262	42.4	1.49	51
		16	9.66	-186	4.42	1.08	95
Zero-valent Iron Duplicate	1	2	9.38	-271	42.8	1.36	51
		16	9.56	-159	7.3	0.94	92

Notes:

1. Arsenic removal calculated relative to initial groundwater concentration (86.7 mg/L)

Dose = relative to the nominal amendment doses listed in Table

mV = millivolts

mg/L = milligrams per liter

ORP = oxidation-reduction potential

Table 7
Batch Test Results for Pretreated Groundwater

Pretreatment	Treatment	Dose	Arsenic (mg/L)	Iron (mg/L)	Arsenic Removal (%)
Potassium Permanganate	Ferric Chloride	½	0.157	1.66	99.7
	Ferrous Sulfate	½	0.035	184	99.9
	Siderite	1	33.0	1.46	32
	Zero-valent Iron	1	20.6	2.46	58
	Control	--	48.6	1.45	--
Hydrogen Peroxide	Ferric Chloride	½	0.224	1.50	99.8
	Ferrous Sulfate	½	0.023	42.2	99.98
	Siderite	1	68.5	1.50	29
	Zero-valent Iron	1	17.9	0.63	82
	Control	--	96.7	1.49	--

Notes:

1. Arsenic removal calculated relative to the applicable pretreated groundwater control.

Dose = relative to the nominal amendment doses listed in Table 5

mg/L = milligrams per liter

Table 8
Short Cycle Sequential Uptake Test Results for Outwash Soil with Pretreated Groundwater

Treatment	Replicate	Cycle	pH	ORP (mV)	SC (µS/cm)	Arsenic (mg/L)	Iron (mg/L)	Arsenic Removal (%)
Control	1	1	7.47	178.6	4,120	84.2	1.45	6
		2	7.48	78.9	4,211	86.2	1.47	3
		3	8.12	66.5	4,200	75.9	1.57	15
		4	7.90	64.2	4,376	91.0	1.43	-2
	2	1	7.30	206.3	4,137	84.7	1.45	5
		2	7.39	98.1	4,210	88.5	1.42	1
		3	7.75	105.9	4,224	93.5	1.52	-5
		4	7.86	82.6	4,388	101	1.41	-13
Ferric Chloride	1	1	6.22	209.6	4,509	0.297	1.32	99.7
		2	6.81	125.1	4,605	0.323	1.29	99.6
		3	6.57	156.6	4,725	0.203	1.45	99.8
		4	6.18	164.2	4,797	0.254	1.17	99.7
	2	1	6.45	214.4	4,413	0.740	1.45	99.2
		2	6.87	130.5	4,601	0.396	1.26	99.6
		3	6.88	175.8	4,709	0.309	1.37	99.7
		4	6.28	158.8	4,849	0.380	1.07	99.6
Ferrous Sulfate	1	1	6.11	-53.7	5,141	0.025	187	99.97
		2	4.74	198.7	4,722	0.033	0.473	99.96
		3	5.82	85.5	4,775	0.004	108	99.99
		4	6.23	-39.3	4,886	0.005	226	99.99
	2	1	6.21	-52.1	4,433	0.009	218	99.99
		2	4.85	203.1	4,662	0.020	0.505	99.98
		3	5.90	66.7	4,762	0.010	113	99.99
		4	6.22	-55.6	4,976	0.007	206	99.99

Notes:
µS/cm = microseimens per centimeter
mg/L = milligrams per liter
mV = millivolts
ORP = oxidation-reduction potential
SC = specific conductance

Table 9

Short Cycle Sequential Uptake Test Results for Fill Soil with Pretreated Groundwater

Treatment	Replicate	Cycle	pH	ORP (mV)	SC (µS/cm)	Arsenic (mg/L)	Iron (mg/L)	Arsenic Removal (%)
Control	1	1	7.62	127.8	4,061	63.5	1.86	29
		2	7.35	157.4	4,166	75.0	1.82	16
		3	8.31	100.3	4,265	94.4	1.75	-6
		4	8.08	114.2	4,389	95.3	1.68	-7
	2	1	7.65	122.1	4,163	63.8	1.91	28
		2	7.39	187.1	4,190	79.1	1.90	11
		3	8.37	107.5	4,266	95.6	1.71	-7
		4	8.17	111.8	4,434	97.6	1.65	-9
Ferric Chloride	1	1	6.65	62.3	3,992	0.374	0.676	99.6
		2	6.33	233.1	4,499	0.376	1.04	99.6
		3	7.25	184.4	4,688	0.369	0.820	99.6
		4	6.55	178.5	4,898	0.362	0.860	99.6
	2	1	6.65	48.8	4,320	0.684	0.867	99.2
		2	6.31	238.1	4,531	0.204	0.988	99.8
		3	6.84	216.3	4,681	0.300	0.860	99.7
		4	6.23	181.7	4,797	0.206	0.710	99.8
Ferrous Sulfate	1	1	6.29	-36.5	4,733	0.038	166	99.96
		2	5.49	98.8	4,434	0.042	0.523	99.95
		3	6.17	20.6	4,790	0.014	133	99.98
		4	6.36	-61.4	4,975	0.025	186	99.97
	2	1	6.38	-59.2	4,805	0.042	194	99.95
		2	5.38	96.5	4,717	0.031	0.394	99.97
		3	6.13	31	4,769	0.008	102	99.99
		4	6.30	-58.4	5,006	0.014	155	99.98

Notes:
µS/cm = microseimens per centimeter
mg/L = milligrams per liter
mV = millivolts
ORP = oxidation-reduction potential
SC = specific conductance

Table 10

Long Cycle Sequential Uptake Test Results for Outwash Soil with Anoxic Groundwater

Treatment	Replicate	Cycle	pH	ORP (mV)	SC (µS/cm)	Arsenic (mg/L)	Iron (mg/L)	Arsenic Removal (%)
Control	1	1	8.52	47.8	3,913	81.0	1.74	9
		2	8.45	23.2	3,833	88.2	1.49	1
		3	8.31	93.8	4,055	87.4	1.71	2
		4	8.24	17.4	4,039	90.7	1.73	-1
	2	1	8.69	42.4	4,001	NA	NA	NA
		2	8.39	14.7	3,840	NA	NA	NA
		3	8.38	17.8	3,880	87.3	1.69	1
		4	8.33	18.7	4,017	NA	NA	NA
Ferric Chloride	1	1	6.14	-22.3	4,994	12.9	155	86
		2	7.81	-124.0	3,821	61.8	4.87	31
		3	6.18	-55.6	4,809	17.2	125	81
		4	5.68	28.6	4,867	14.5	119	84
	2	1	6.21	-30.7	5,063	NA	NA	NA
		2	7.69	-148.3	3,773	NA	NA	NA
		3	3.12	381.2	6,353	19.0	386	79
		4	5.39	47.8	5,076	NA	NA	NA
Ferrous Sulfate	1	1	6.41	-142.8	5,229	18.8	637	79
		2	7.53	-140.2	3,771	58.1	7.36	35
		3	6.53	-150.2	5,260	32.4	632	64
		4	6.58	-177.0	5,091	25.9	613	71
	2	1	6.52	-150.6	5,362	NA	NA	NA
		2	7.60	-175.4	3,744	NA	NA	NA
		3	6.36	-137.2	6,610	29.0	1,490	68
		4	6.51	-153.8	5,292	NA	NA	NA
Zero-valent Iron	1	1	9.52	45.4	3,973	14.9	1.13	83
		2	9.15	-180.0	3,797	25.9	1.20	71
		3	9.26	-140.6	4,031	27.9	1.53	69
		4	9.18	-119.2	3,968	34.9	1.59	61
	2	1	9.50	66.0	3,992	NA	NA	NA
		2	9.15	-151.7	3,794	NA	NA	NA
		3	9.31	-125.1	4,042	24.2	1.47	73
		4	9.20	-131.3	4,029	NA	NA	NA
Siderite	1	1	7.81	17.4	3,910	53.9	1.40	40
		2	8.12	-118.8	3,719	72.1	1.58	19
		3	8.12	-143.3	4,017	78.7	1.74	12
		4	8.15	-26.7	3,939	85.5	1.85	4
	2	1	7.92	35.9	3,866	NA	NA	NA

Treatment	Replicate	Cycle	pH	ORP (mV)	SC (µS/cm)	Arsenic (mg/L)	Iron (mg/L)	Arsenic Removal (%)
		2	8.09	-118.3	3,726	NA	NA	NA
		3	8.10	-149.6	4,041	79.4	1.71	11
		4	8.01	-57.2	4,006	NA	NA	NA

Notes:
µS/cm = microseimens per centimeter
mg/L = milligrams per liter
mV = millivolts
NA = not analyzed
ORP = oxidation-reduction potential
SC = specific conductance

Table 11

Long Cycle Sequential Uptake Test Results for Fill Soil with Anoxic Groundwater

Treatment	Replicate	Cycle	pH	ORP (mV)	SC (µS/cm)	Arsenic (mg/L)	Iron (mg/L)	Arsenic Removal (%)
Control	1	1	8.27	-198.6	3,881	66.3	3.69	26
		2	8.23	-33.5	3,813	64.9	1.89	27
		3	8.02	-60.4	4,046	78.3	1.90	12
		4	8.16	-105.1	3,909	98.5	1.73	-10
	2	1	8.44	-187.2	3,920	NA	NA	NA
		2	8.31	-3.5	3,830	NA	NA	NA
		3	8.16	-43.9	4,018	79.9	1.97	11
		4	8.21	-91.9	3,954	NA	NA	NA
Ferric Chloride	1	1	6.43	-107.3	5,034	10.3	110	88
		2	7.79	-74.0	3,785	58.2	2.83	35
		3	6.32	-92.7	4,840	26.9	111	70
		4	6.26	-66.9	4,963	23.0	147	74
	2	1	6.48	-90.7	4,992	NA	NA	NA
		2	7.66	-88.9	3,817	NA	NA	NA
		3	3.93	223.8	6,081	18.1	370	80
		4	5.35	30.8	5,233	NA	NA	NA
Ferrous Sulfate	1	1	6.41	-145.7	5,282	20.0	535	78
		2	7.19	-163.5	3,829	54.2	16.7	39
		3	6.57	-162.7	5,166	44.2	587	51
		4	6.68	-173.5	4,859	30.0	465	66
	2	1	6.66	-156.4	5,168	NA	NA	NA
		2	7.23	-158.2	3,775	NA	NA	NA
		3	6.47	-165.1	6,403	33.4	1,370	63
		4	6.52	-161.8	5,545	NA	NA	NA

Notes:
µS/cm = microseimens per centimeter
mg/L = milligrams per liter
mV = millivolts
NA = not analyzed
ORP = oxidation-reduction potential
SC = specific conductance

Table 12
Selective Sequential Extraction Results for Short Cycle Uptake Tests

Soil	Treatment	F1 Soluble (mg/kg)	F2 Exchangeable (mg/kg)	F3 Reducible (mg/kg)	F4 Oxidizable (mg/kg)	F5 Residual (mg/kg)	Sum (mg/kg)
Fill	Control	56	516	48	155	17	792
	Ferric Chloride	6.1	542	206	171	13.6	939
	Ferrous Sulfate	0.7	927	220	333	17.1	1,498
Outwash	Control	16	27	0.8	2.1	2.7	49
	Ferric Chloride	12.8	344	87.5	39	2.8	486
	Ferrous Sulfate	6.7	598	147	152	4.3	908
		7.4	565	158	116	3.2	850

Notes:
mg/kg = milligrams per kilogram
F1 = 1 M magnesium chloride, pH 8
F2 = 1 M sodium phosphate, pH 5
F3 = 0.1 M hydroxylamine hydrochloride, pH 2
F4 = 16 N nitric acid
F5 = residual solids after F4 extraction

Table 13
Selective Sequential Extraction Results for Long Cycle Uptake Tests

Soil	Treatment	F1 Soluble (mg/kg)	F2 Exchangeable (mg/kg)	F3 Reducible (mg/kg)	F4 Oxidizable (mg/kg)	F5 Residual (mg/kg)	Sum (mg/kg)
Fill	Control	37.6	98.1	7.8	55.4	25.2	224
	Ferric Chloride	3.5	2,130	73.7	184	55.8	2,450
	Ferrous Sulfate	2.1	731	101	793	101	1,728
Outwash	Control	10.7	17.0	0.6	1.9	3.4	33.6
	Ferric Chloride	7.8	1,350	44.4	115	16.9	1,530
	Ferrous Sulfate	5.9	356	34.4	205	30.4	632
	ZVI	15.5	109	22.2	1,280	40.2	1,470
		16.5	129	28.7	1,130	132	1,440
	Siderite	10.4	95.6	5.2	55.0	45.2	211.4

Notes:
mg/kg = milligrams per kilogram
F1 = 1 M magnesium chloride, pH 8
F2 = 1 M sodium phosphate, pH 5
F3 = 0.1 M hydroxylamine hydrochloride, pH 2
F4 = 16 N nitric acid
F5 = residual solids after F4 extraction

FIGURES

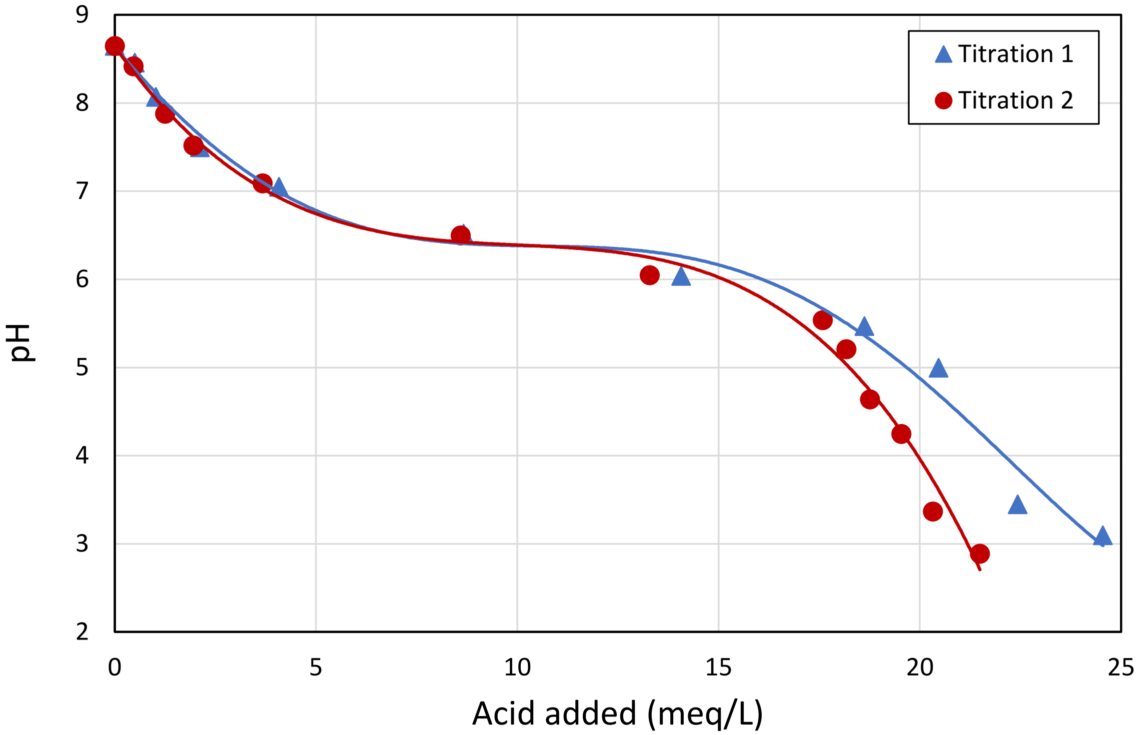


Figure 1 Titration Curves for MW-36D Groundwater

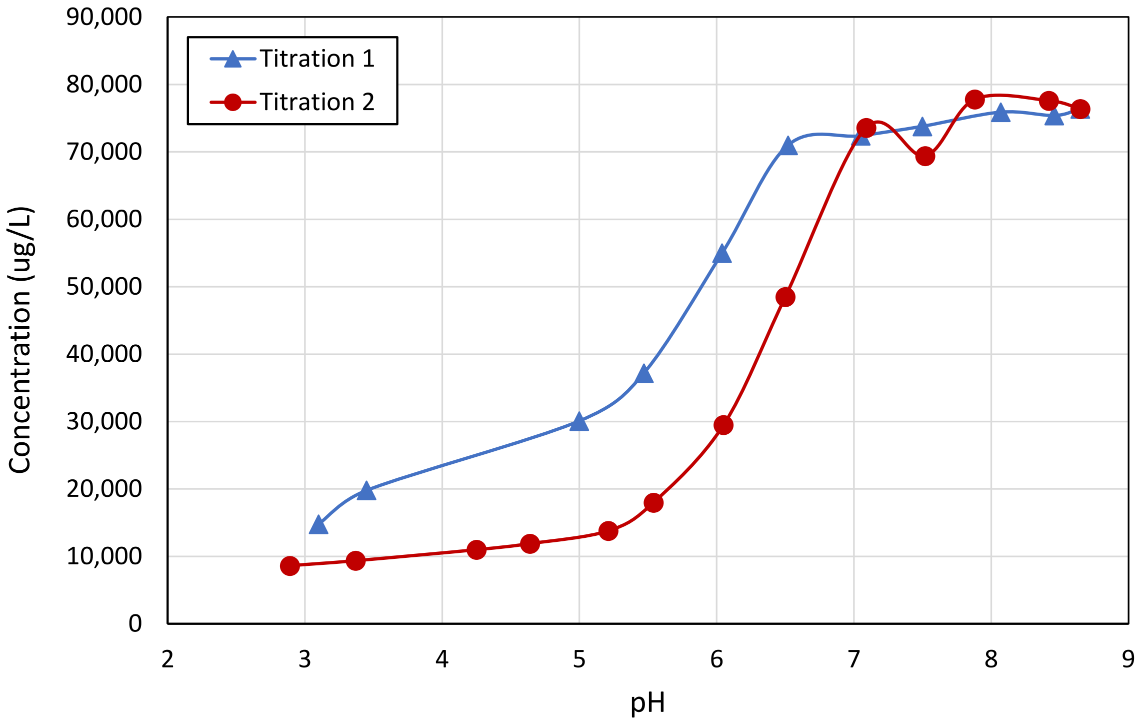


Figure 2 Dissolved Arsenic Concentrations During pH Titration of MW-36D Groundwater

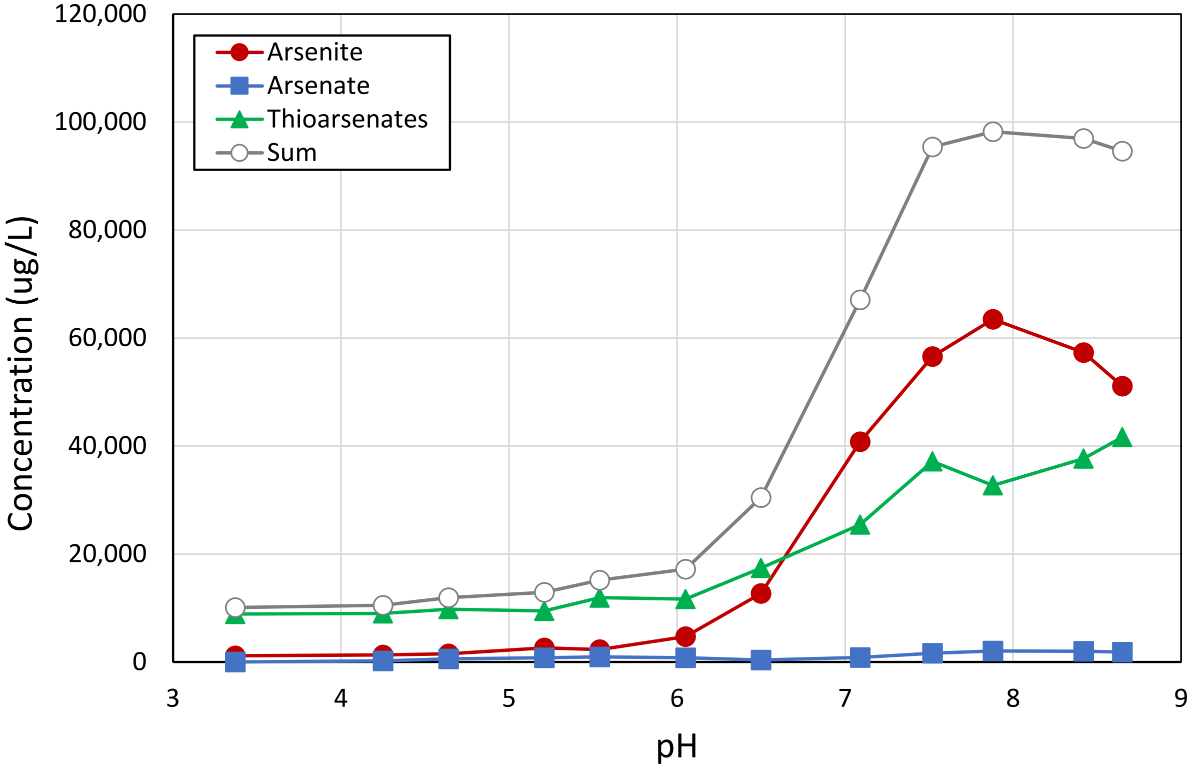


Figure 3 Arsenic Speciation Changes During pH Titration of MW-36D Groundwater

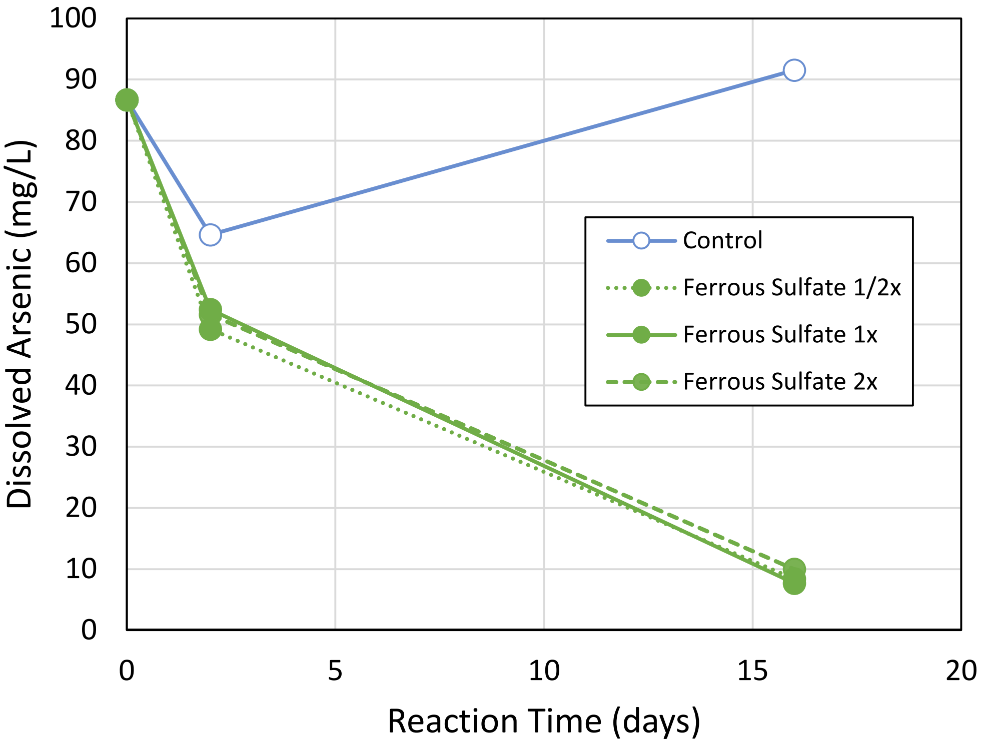


Figure 4 **Dissolved Arsenic Concentrations in Ferrous Sulfate Batch Tests**

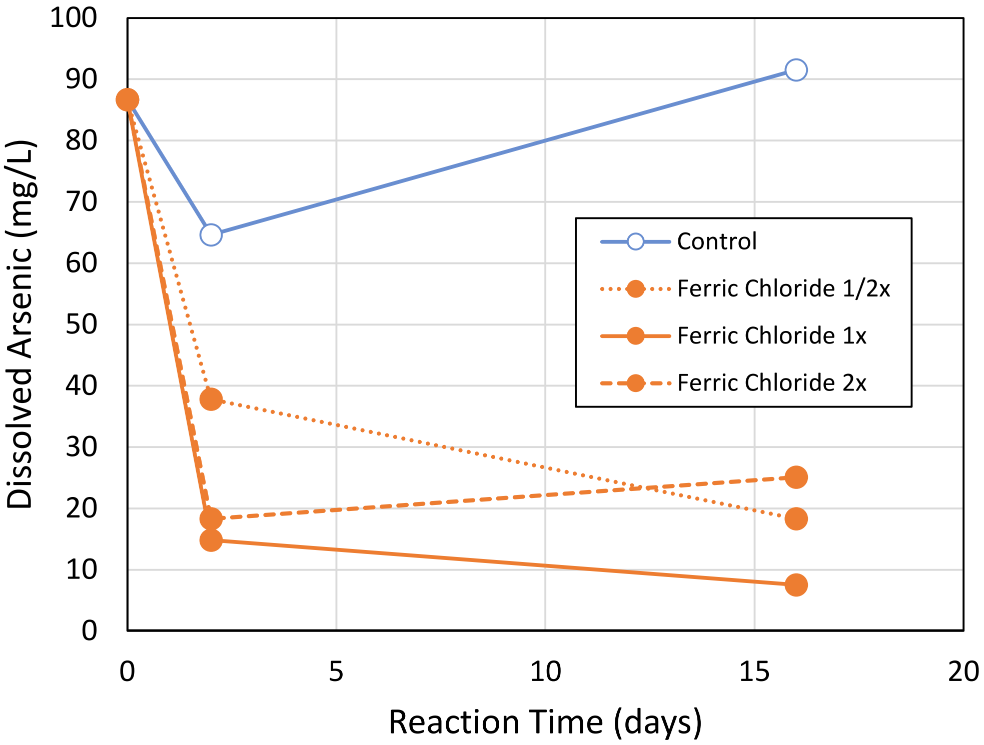


Figure 5 **Dissolved Arsenic Concentrations in Ferric Chloride Batch Tests**

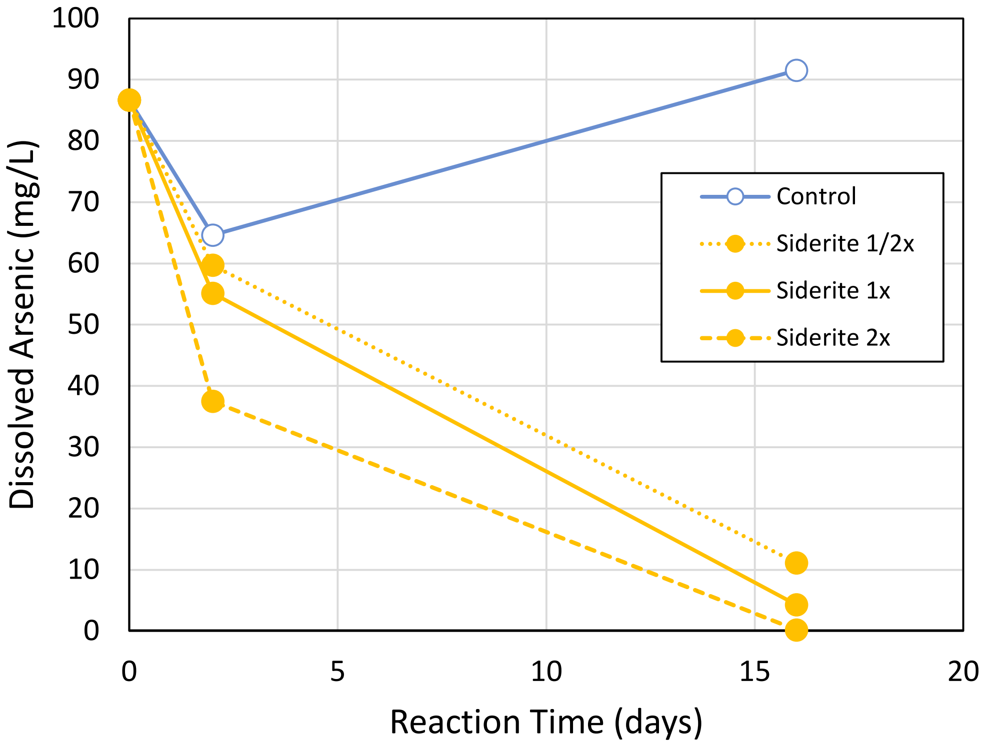


Figure 6 **Dissolved Arsenic Concentrations in Siderite Batch Tests**

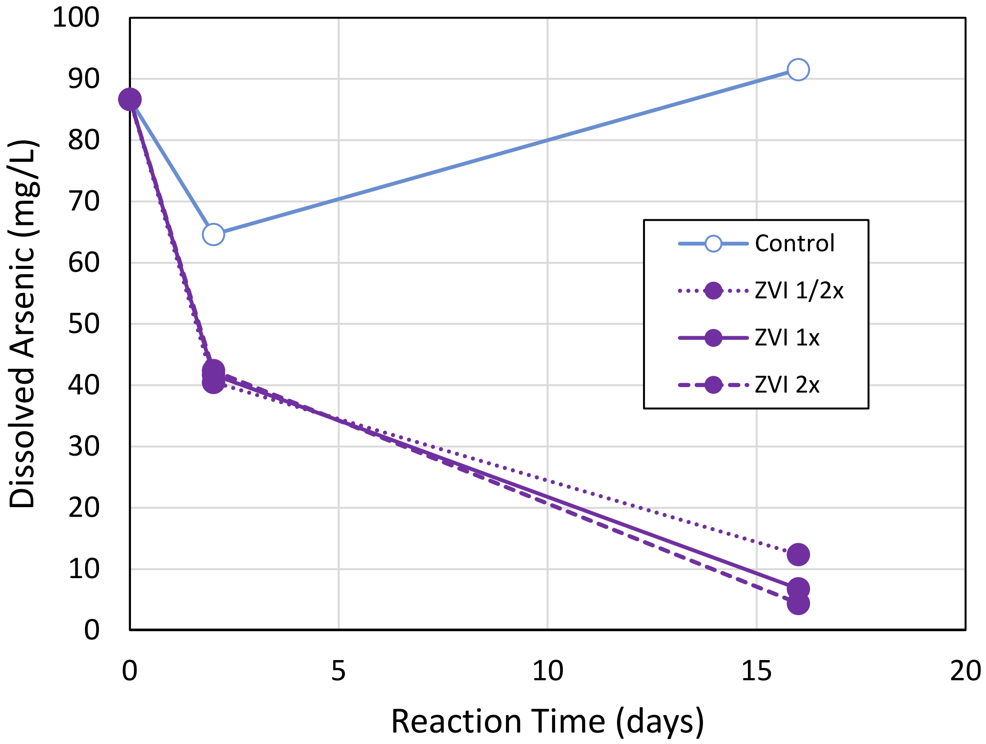


Figure 7 **Dissolved Arsenic Concentrations in Zero-valent Iron Batch Tests**

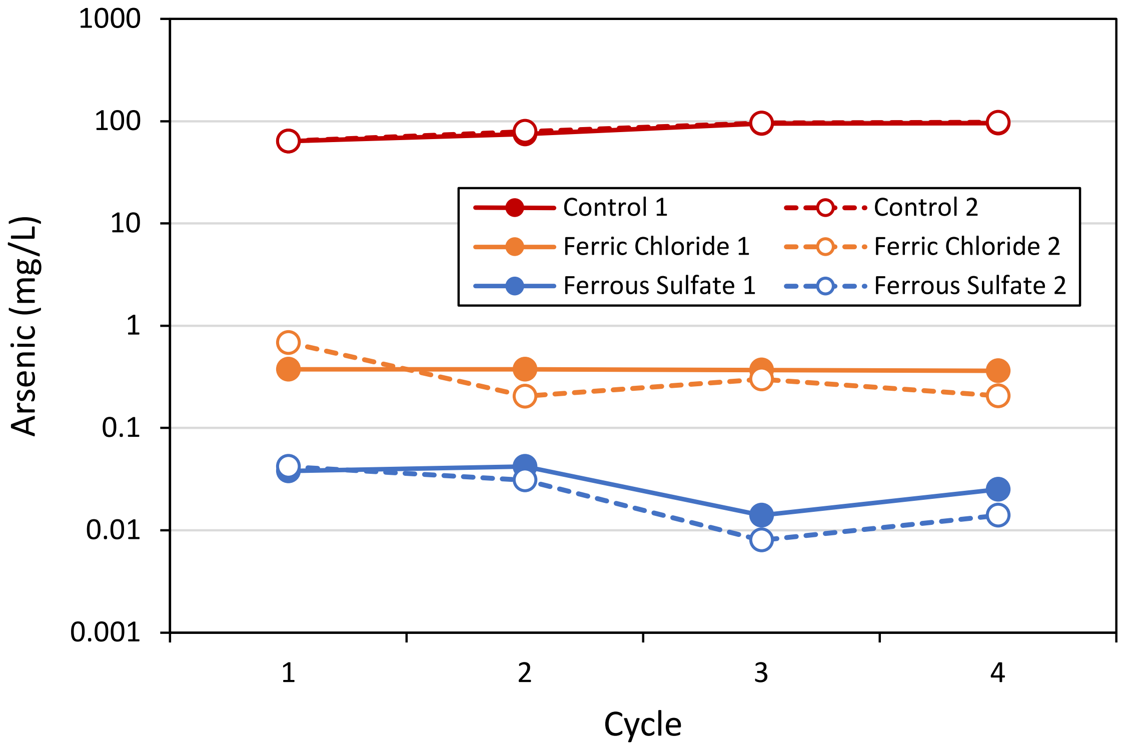


Figure 8 Dissolved Arsenic Concentrations in Short Cycle Uptake Tests with Fill Soil

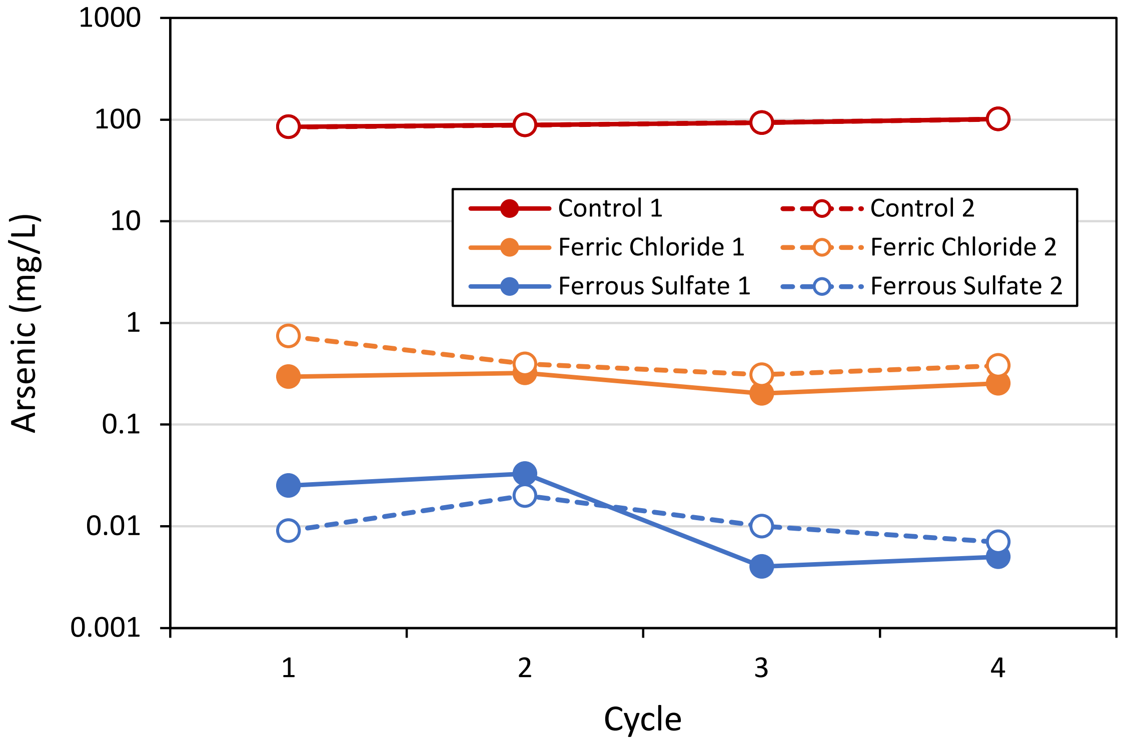
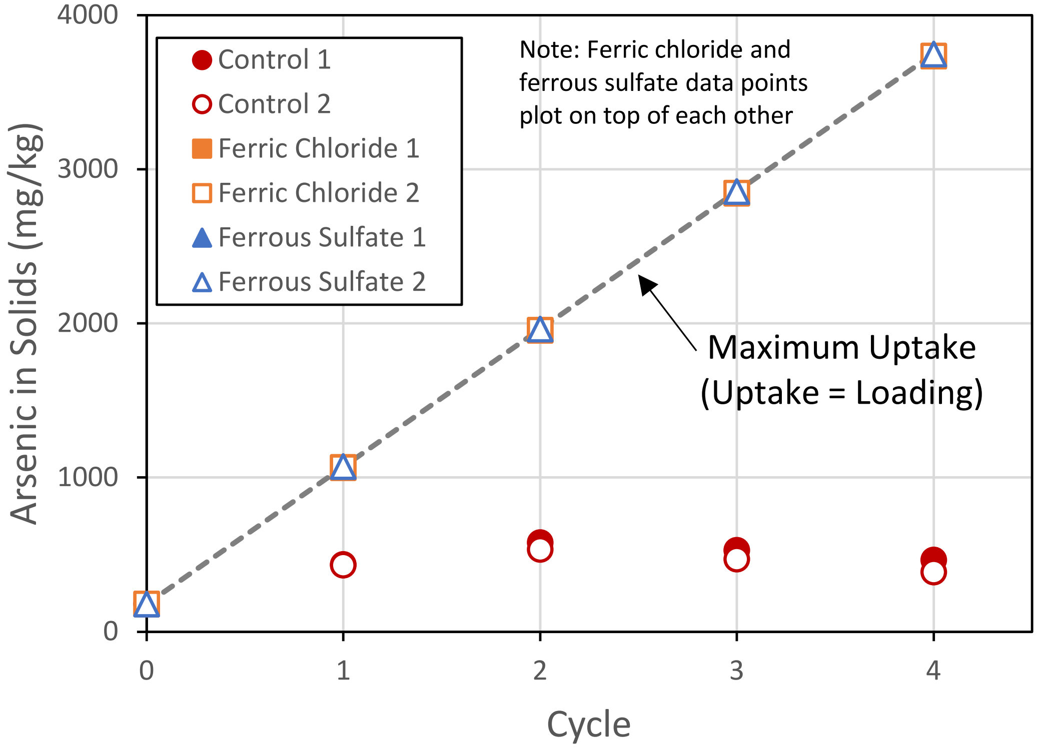
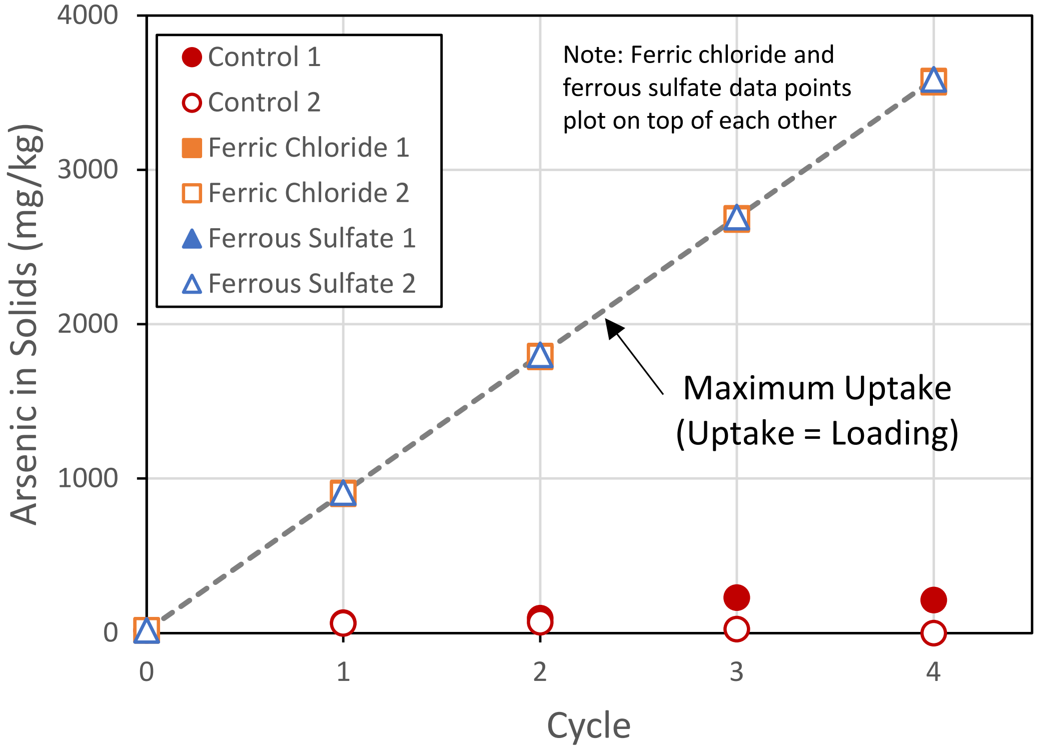


Figure 9 Dissolved Arsenic Concentrations in Short Cycle Uptake tests with Outwash Soil



Note: Ferric chloride and ferrous sulfate data points plot on top of each other

Figure 10 Calculated Arsenic Uptake by Solids in Short Cycle Tests with Fill Soil



Note: Ferric chloride and ferrous sulfate data points plot on top of each other

Figure 11 Calculated Arsenic Uptake by Solids in Short Cycle Tests with Outwash Soil

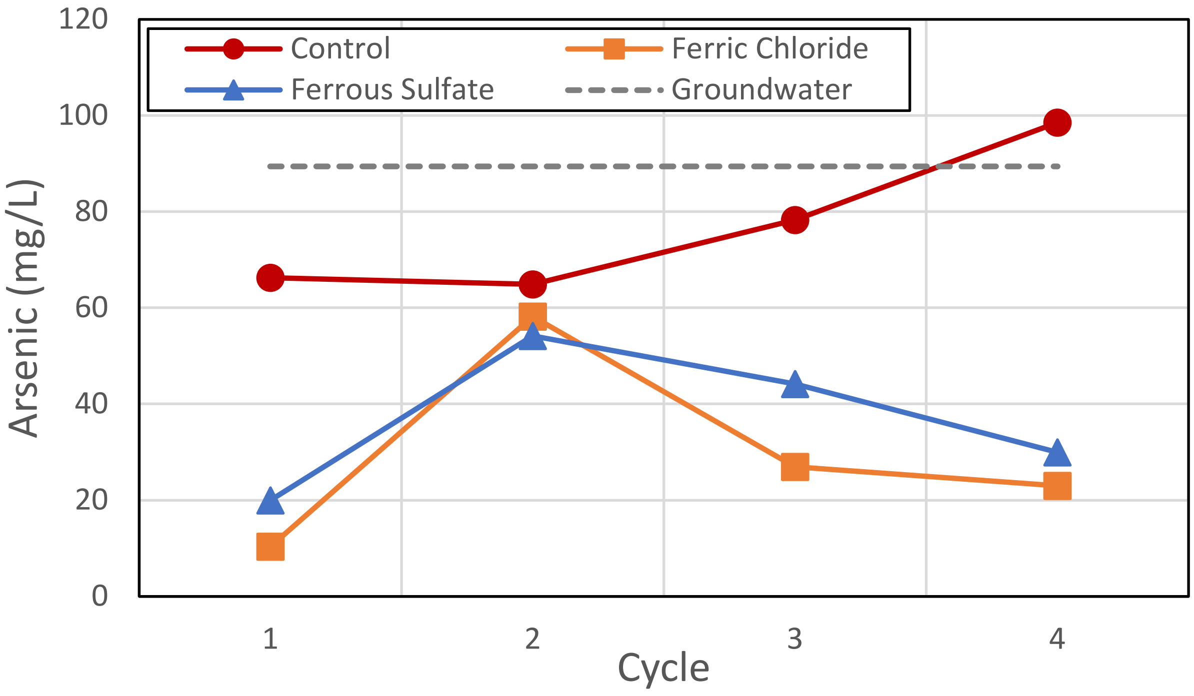


Figure 12 Dissolved Arsenic Concentrations in Long Cycle Uptake Tests with Fill Soil

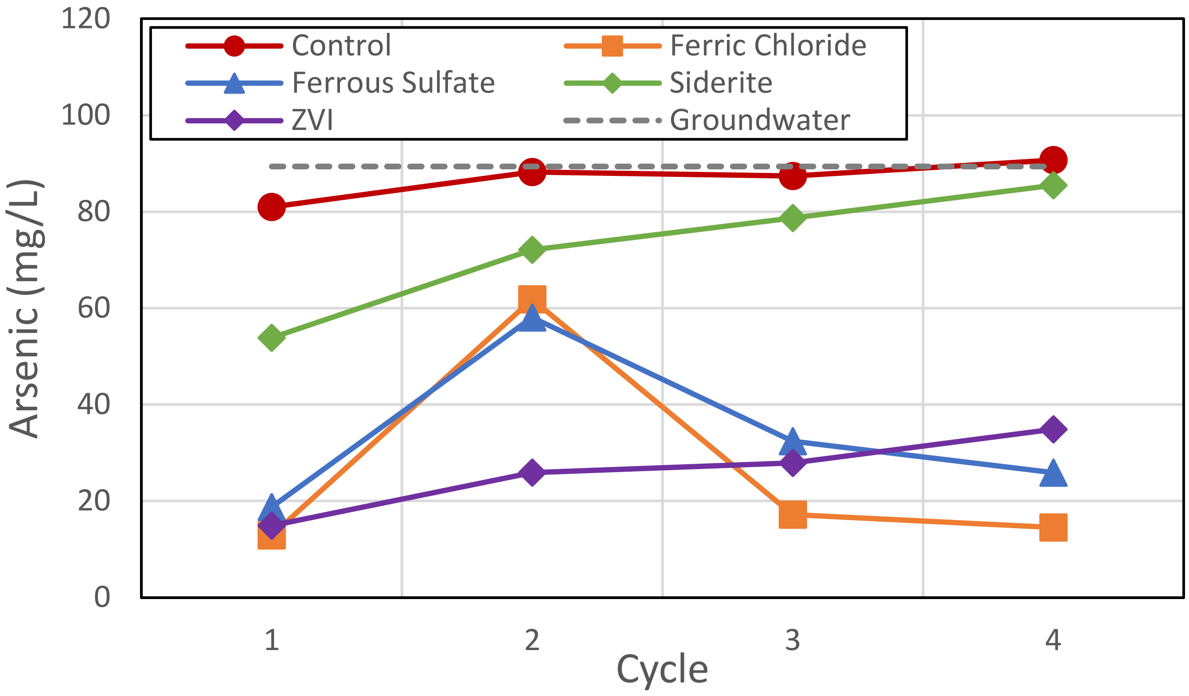


Figure 13 Dissolved Arsenic Concentrations in Long Cycle Uptake Tests with Outwash Soil

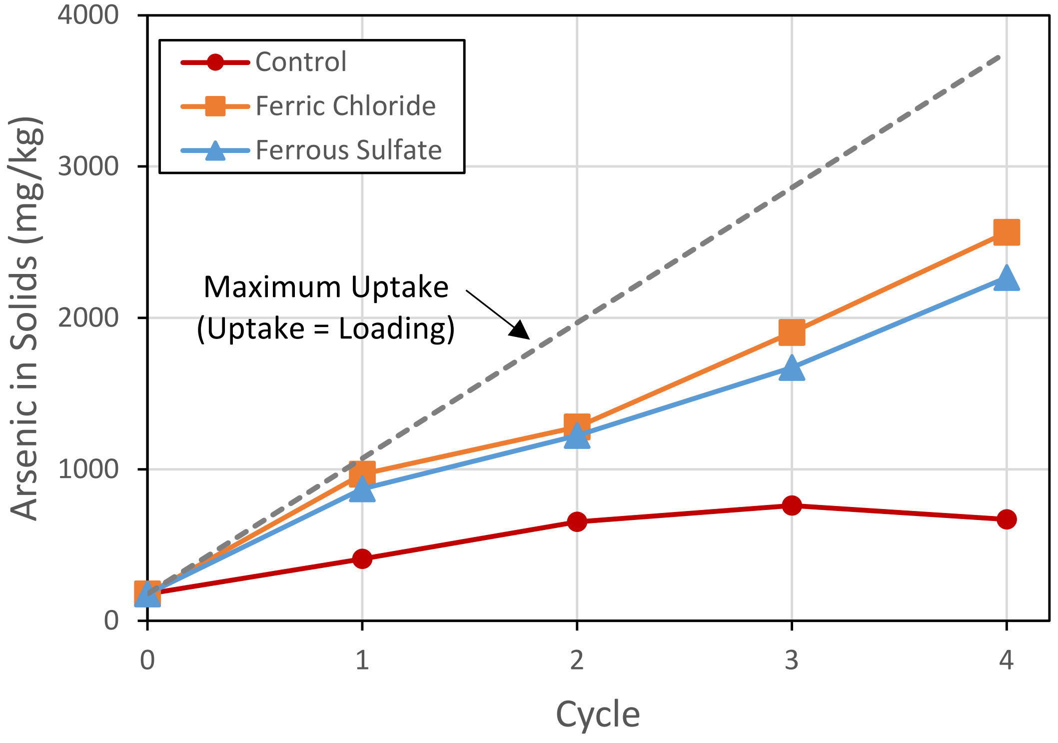


Figure 14 Calculated Arsenic Uptake by Solids in Long Cycle Tests with Fill Soil

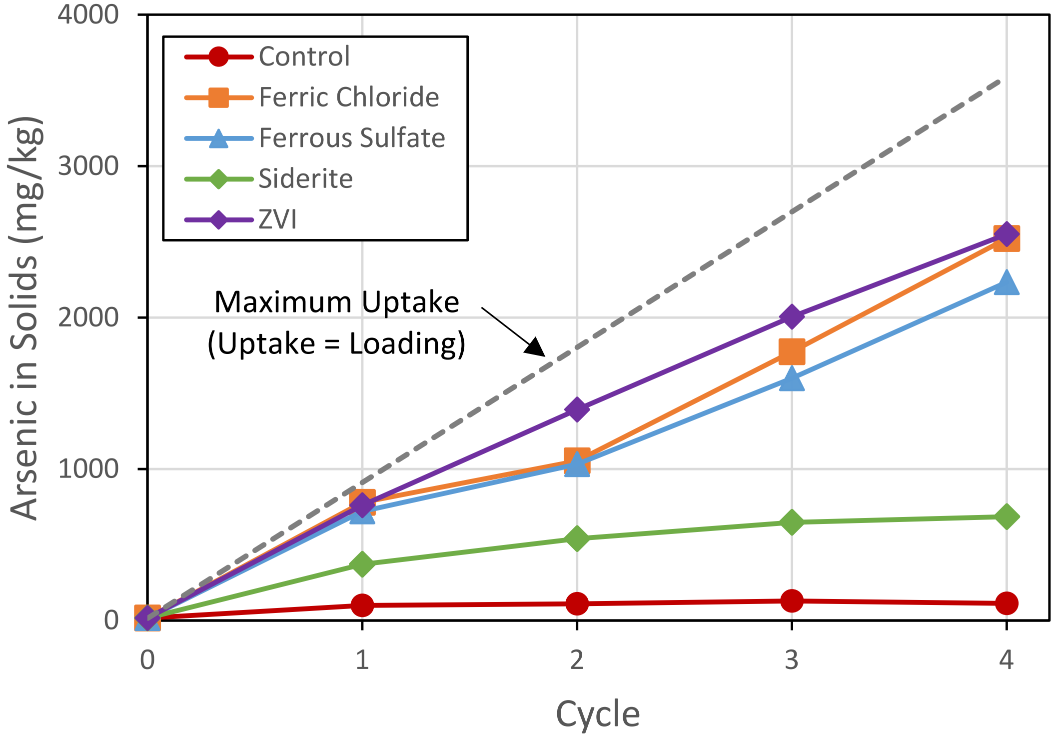


Figure 15 Calculated Arsenic Uptake by Solids in Long Cycle Tests with Outwash Soil

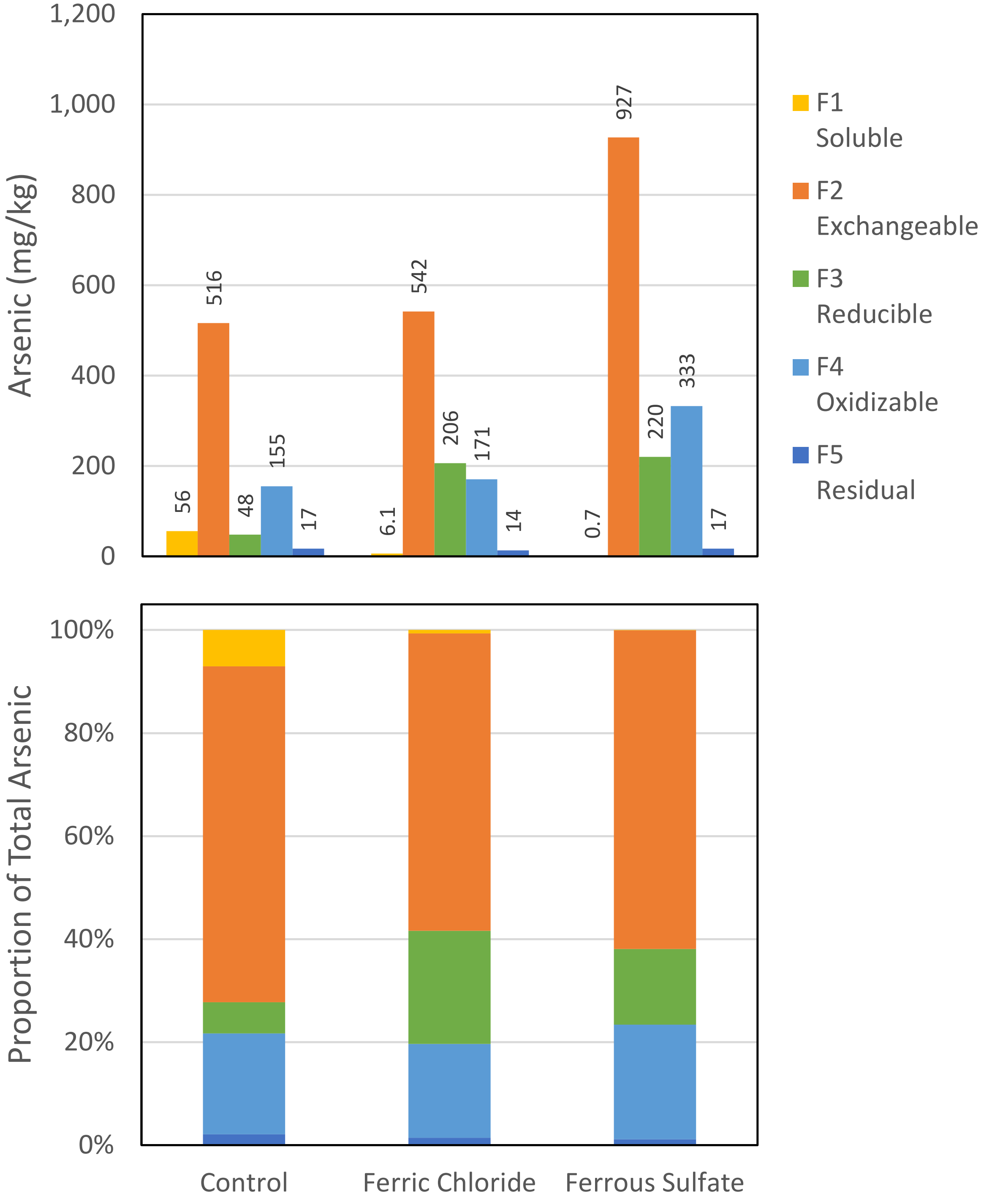


Figure 16 **Arsenic Fraction Distributions in Short Cycle Uptake Tests with Fill Soil**

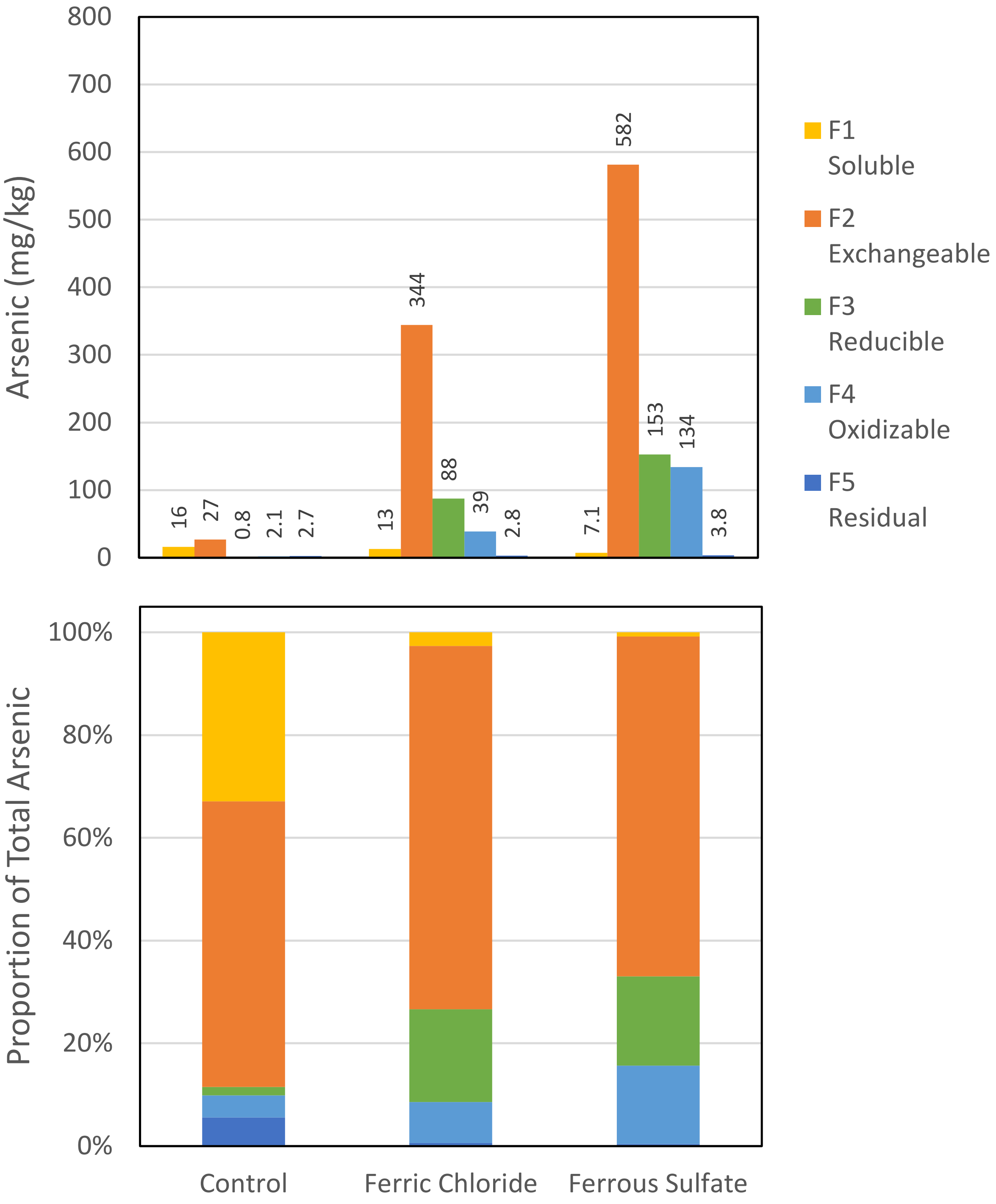


Figure 17 **Arsenic Fraction Distributions in Short Cycle Uptake Tests with Outwash Soil**

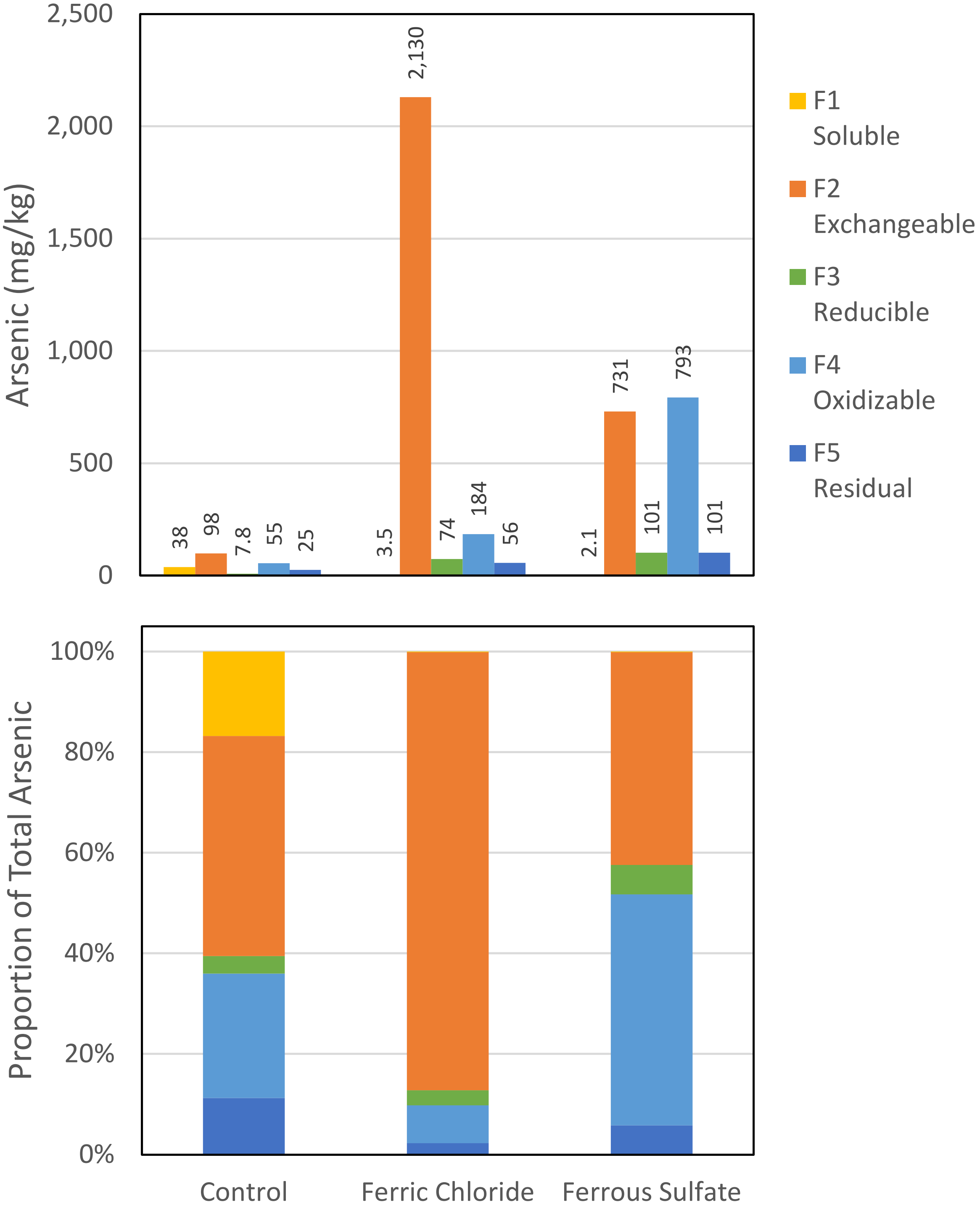


Figure 18 Arsenic Fraction Distributions in Long Cycle Uptake Tests with Fill Soil

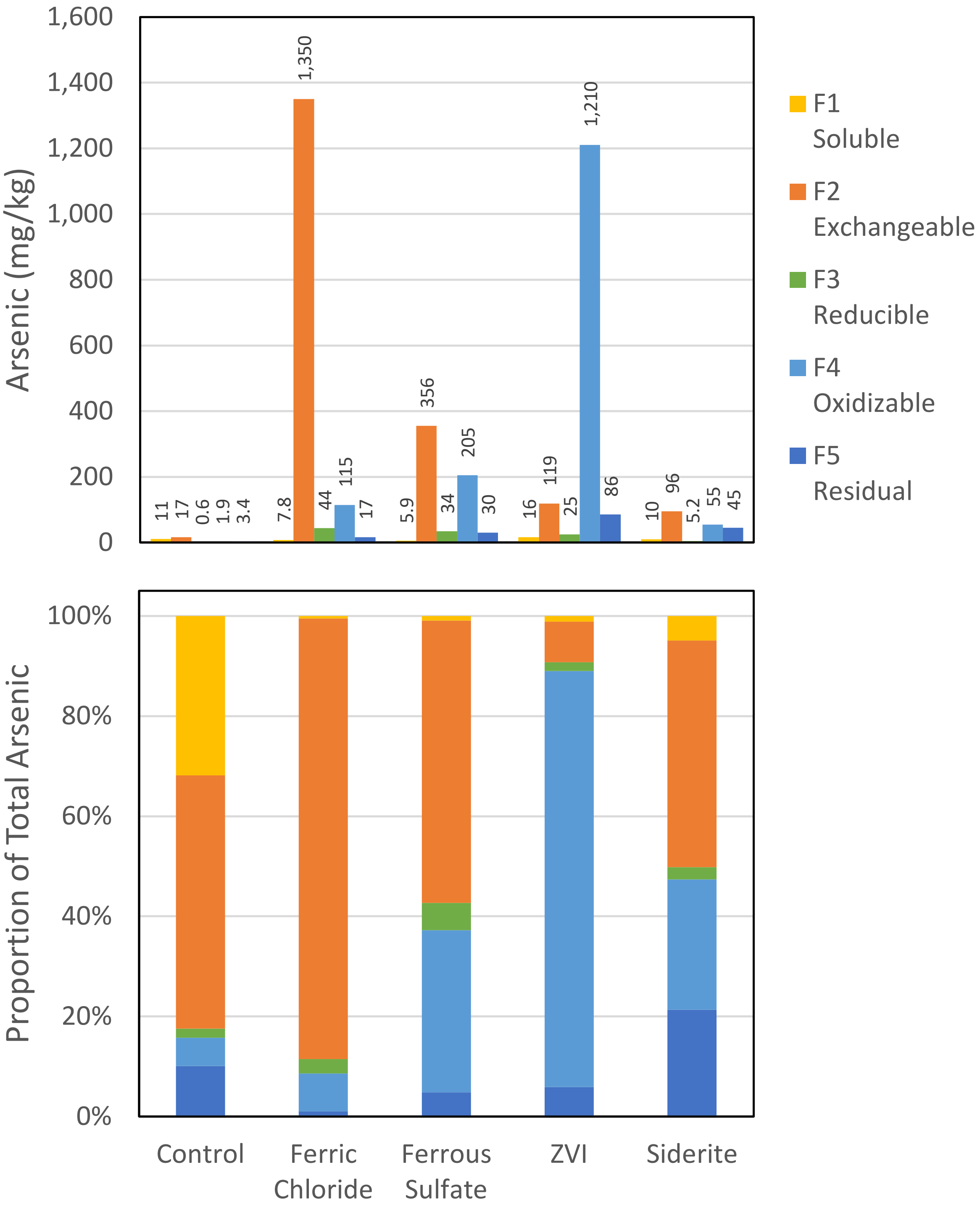


Figure 19 **Arsenic Fraction Distributions in Long Cycle Uptake Tests with Outwash Soil**

APPENDIX A

AMENDMENT DOSE CALCULATIONS

1 INTRODUCTION

Amendment doses for in situ treatment are calculated based on the acid neutralizing capacity (ANC) of groundwater, which represents the net stoichiometric balance from acid-consuming and acid-producing constituents (including the target contaminant species) that react with the amendment constituents. For iron-based amendments, these constituent are mainly represented by bisulfide (HS^-), bicarbonate (HCO_3^-), and hydroxyl (OH^-) ions. The accompanying decrease in pH also destabilizes thioarsenate species ($H_xAsO_yS_z^{5+x-2(y+z)}$) which decompose to produce additional bisulfide and ultimately arsenite (H_3AsO_3). With increasing concentrations of arsenite and sulfide, groundwater eventually becomes saturated with and precipitates arsenic sulfide (As_2S_3). Injectable amendment doses are therefore calculated based on the acid neutralizing capacity (ANC) of site groundwater. The acidity required to neutralize MW-36D groundwater with pH 8.65 to a target pH endpoint of 5.0 (to maximize decomposition of thioarsenates) is 18.2 milli-equivalents per liter (meq/L) as determined from the titration experiment.

2 FERROUS SULFATE

Potential reactions of ferrous sulfate are listed in Table A-1.

Table A-1

Potential Acidity Producing Reactions for Ferrous Sulfate Amendment

No	Reaction	Stoichiometry	Reaction Rate
1	Dissolution	$FeSO_4 \Rightarrow Fe^{2+} + SO_4^{2-}$	Rapid
2	Iron sulfide precipitation	$Fe^{2+} + HS^- \Rightarrow FeS(s) + H^+$	Rapid
3	Carbonate precipitation	$Fe^{2+} + HCO_3^- \Rightarrow FeCO_3(s) + H^+$	Slow

Each mole of ferrous sulfate dissolved produces 1 mole of ferrous iron (reaction 1). Ferrous iron reacts with sulfide to precipitate iron sulfide and produce 1 equivalent (eq) of acid. Ferrous iron can also react with bicarbonate (reaction 3) although carbonate precipitation is relatively slow and as a first approximation can be neglected. When sulfide is present, ferrous sulfate will produce a net of 1 eq of acid per mole. This value was assumed in calculating the nominal stoichiometric dose:

Stoichiometric dose = (ANC) / (net acidity/mole)
= (18.2 meq/L) / (1 eq/mole)
= 18.2 mmol/L
= 5.1 g [$FeSO_4 \cdot 7H_2O$]/L

3 FERRIC CHLORIDE

Potential reactions of ferric chloride are listed in Table A-2.

Table A-2

Potential Acidity Producing Reactions for Ferric Chloride Amendment

No	Reaction	Stoichiometry	Reaction Rate
1	Dissolution	$FeCl_3 \Rightarrow Fe^{3+} + 3\ Cl^-$	Rapid
2	Hydrolysis	$Fe^{3+} + 3\ H_2O \Rightarrow Fe(OH)_3(s) + 3\ H^+$	Rapid
3	Sulfide oxidation	$Fe^{3+} + 0.125\ HS^- + 0.5\ H_2O \Rightarrow Fe^{2+} + 0.125\ SO_4^{2-} + 1.125\ H^+$	Rapid
4	Iron sulfide precipitation	$Fe^{2+} + HS^- => FeS(s) + H^+$	Rapid
5	Organic matter oxidation	$4\ Fe^{3+} + CH_2O + 2\ H_2O \Rightarrow 4\ Fe^{2+} + HCO_3^- + 5\ H^+$	Slow
6	Carbonate precipitation	$Fe^{2+} + HCO_3^- => FeCO_3(s) + H^+$	Slow

Each mole of ferric chloride dissolved can potentially produce 3 eq of acidity (reactions 1 and 2); however the actual amount will be less if other reactive constituents such as sulfide are present. Each mole of sulfide consumes 8 moles of ferric iron to produce 8 moles of ferrous iron of sulfate and 9 eq of acidity (reaction 3). Each mole of ferrous iron produced will also react with 1 mole of sulfide to precipitate iron sulfide and produce 1 additional eq of acid (reaction 4). Reactions 5 and 6 can generally be neglected as a first approximation because they are very slow. Therefore, when sulfide is present, ferric chloride will only produce a net of 2.125 eq of acid per mole. This value was assumed in calculating the nominal stoichiometric dose:

Stoichiometric dose = (ANC) / (net acidity/mole)
= (18.2 meq/L) / (2.125 eq/mole)
= 8.6 mmol/L
= 2.0 g [$FeCl_3 \cdot 4H_2O$]/L

4 SIDERITE AND ZERO-VALENT IRON

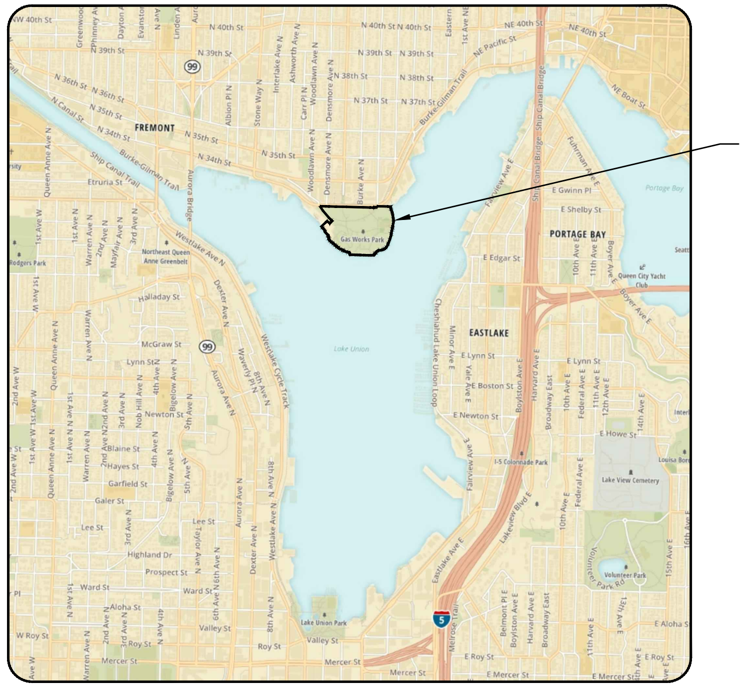
The nominal dose calculated for siderite and zero-valent iron were based on a molar iron to arsenic concentration in groundwater ratio of 1,000. The arsenic concentration in MW-36D groundwater is 1.02 mmol/L. The nominal dose for siderite and zero-valent iron is 1.02 mol/L or 118 g [$FeCO_3$]/L and 57 g [Fe]/L.

APPENDIX B

Play Area Groundwater Infrastructure Installation As-Built Drawings

GAS WORKS PARK SITE

PLAY AREA GROUNDWATER INFRASTRUCTURE INSTALLATION



VICINITY MAP

SCALE: NTS

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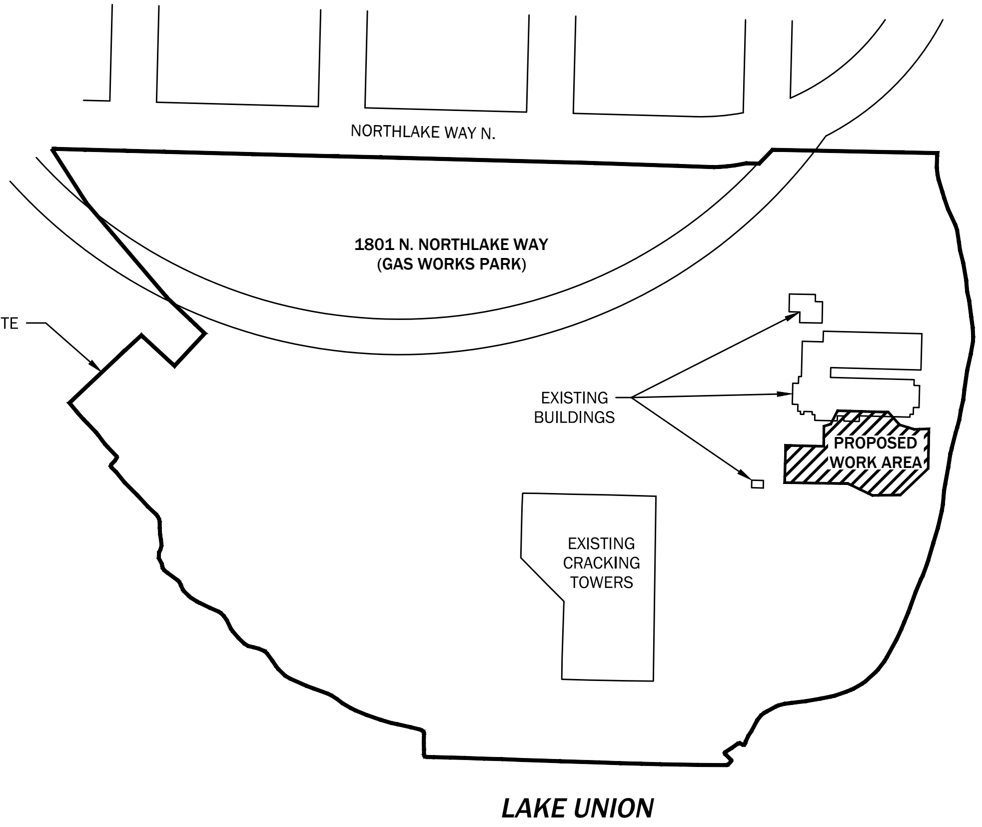

SITE MAP

SCALE: NTS

N

SHEET INDEX:

1.0	COVER SHEET
~~2.0~~	~~GENERAL NOTES~~
~~2.1~~	~~CONSTRUCTION NOTES~~
3.0	PRE-CONSTRUCTION CONDITIONS
3.1	EXISTING SURVEY CONTROL
4.0	INJECTION SYSTEM LAYOUT
4.1	INJECTION SYSTEM ELEVATIONS
5.0	TRENCHING AND INJECTION SYSTEM DETAILS
6.0	MONITORING WELL SURFACE COMPLETION CONSTRUCTION SEQUENCING - BRICK PLAZA
7.0	MONITORING WELL SURFACE COMPLETION CONSTRUCTION SEQUENCING - PLAYGROUND
8.0	WELL CONSTRUCTION SCHEMATIC DETAILS

DATUM:

VERTICAL = NAVD88

HORIZONTAL = NAD 83/91

PROPERTY INFO:

ZONE: IB/U45

KING CO. ASSESSOR PARCEL NO.: 124970-0005

OWNER: SEATTLE PARKS & RECREATION

SITE ADDRESS: 1801 N NORTHLAKE WAY, SEATTLE, WA 98103

LEGAL DESCRIPTION: BURKES 1ST ADD ALL BLKS 1 & 2 4 THRU 6 & 9 THRU 11 ALSO BLKS 42 THRU 44 LAKE UNION SHORELANDS ALSO BLK 3 LLEWELLYN'S SUPL BLK 3 BURKES 1ST ALSO BLK 43A LAKE UNION SD LDS 2ND SUPL TGW POR VAC STS ADJ LESS ST & TGW POR VAC N NORTHLAKE PL ADJ AS VAC BY SEATTLE ORD NO 112955

CONTACTS:

OWNER:
PUGET SOUND ENERGY
PO BOX 90868, PSE-12
BELLEVUE, WA 98009
CONTACT: JOHN RORK
(425) 456-2228

PROPERTY OWNER (GAS WORKS PARK):
SEATTLE PARKS AND RECREATION
800 MAYNARD AVENUE SOUTH, 3RD FLOOR
SEATTLE, WA 98134
CONTACT: DAVID GRAVES
(206) 684-7048

ENGINEER:
GEOENGINEERS, INC.
600 STEWART STREET #1700
SEATTLE, WA 98101
CONTACT: CHRIS BAILEY
(206) 728-2674

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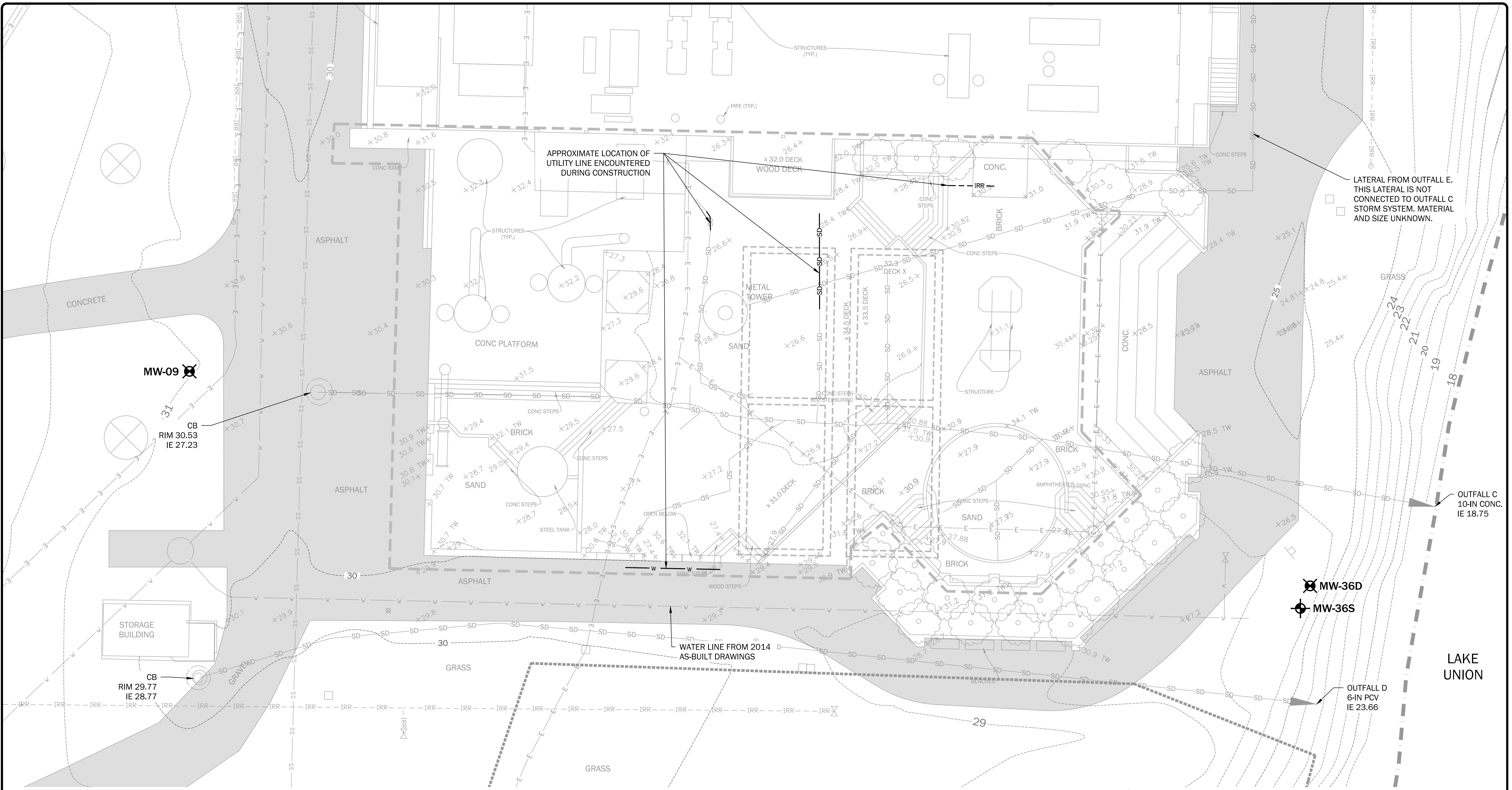
COVER SHEET

DRAWN: CFS	PROJ NO: 0186-846-01
DESIGN: SMS	SHEET 1 OF 9
CHECKED: CLB	DATE: 08.30.2017
SHEET NO. 1.0	

AS-BUILT



NOTES:
1. VERTICAL DATUM NAVD88.
2. EXISTING CONDITIONS FROM SEATTLE PARKS AND RECREATION 11-06-02 AS BUILT DRAWINGS LAST REVISED MARCH 2014.
3. OUTFALL C AND D BASED ON APS DECEMBER 5, 2014 SURVEY.

LEGEND

---30---	EXISTING CONTOUR (NAVD88)
—SD—	EXISTING STORMDRAIN
—W—	EXISTING WATER
—E—	EXISTING ELECTRICAL
– – IRR –	EXISTING IRRIGATION
⊏⊐	FORMER SUBSURFACE CONCRETE TANKS
▬ ▬	PLAY AREA RENOVATION FOOTPRINT
▪▪▪▪▪▪	APPROXIMATE EDGE OF EXISTING IMPERMEABLE LINER
▨	EXISTING ASPHALT, GRAVEL, AND/OR CONCRETE PATHS
⌖	EXISTING MONITORING WELL - FILL
⊠	EXISTING MONITORING WELL - OUTWASH

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PRE-CONSTRUCTION CONDITIONS

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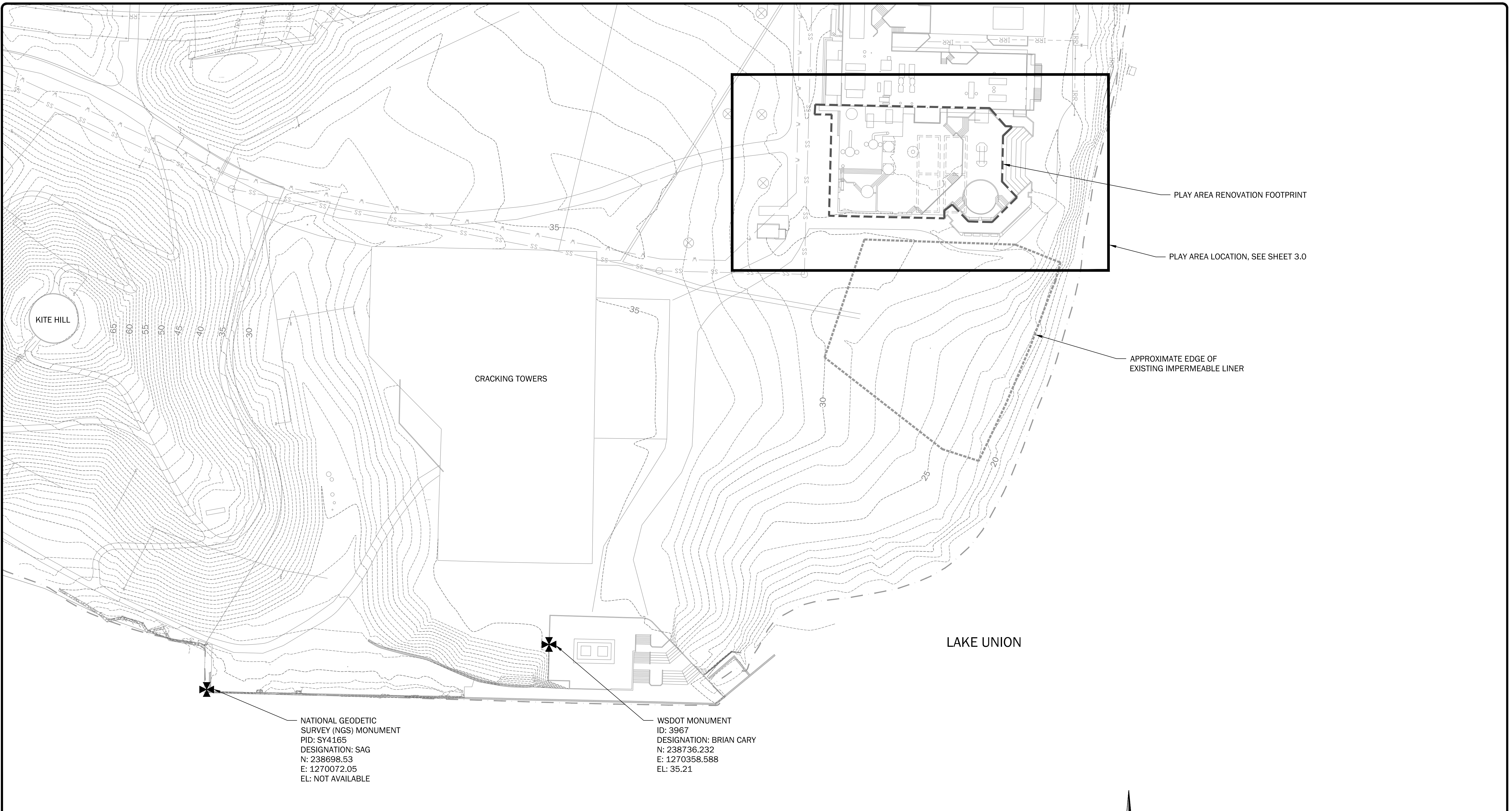
CHECKED: CLB	DATE: 08.30.2017
SHEET NO. 3.0	

AS-BUILT



NOTES:

1. HORIZONTAL DATUM: WASHINGTON STATE PLANE, NAD83, NORTH ZONE, US FOOT
   VERTICAL DATUM: NAVD88
2. EXISTING CONDITIONS FROM SEATTLE PARKS AND RECREATION 11-06-02 AS BUILT DRAWINGS LAST REVISED MARCH 2014.
3. SURVEY CONTROL PROVIDED BY TRUE NORTH LAND SURVEYING, INC.

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EXISTING SURVEY CONTROL

DRAWN: CFS	PROJ NO: 0186-846-01
DESIGN: SMS	SHEET 3 OF 9
CHECKED: CLB	DATE: 08.30.2017
SHEET NO. 3.1	

AS-BUILT

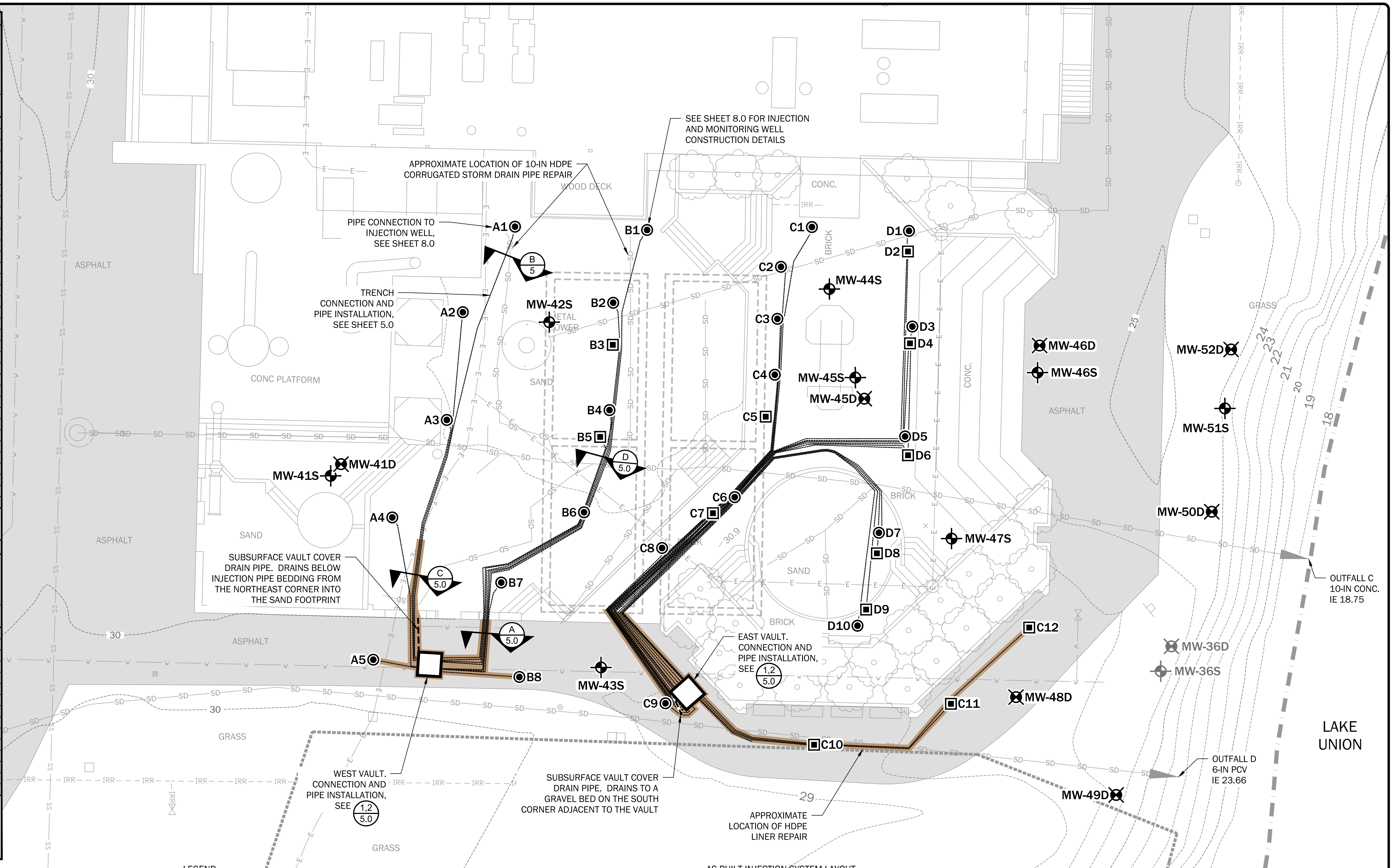
INJECTION WELLS				
WELL ID	NORTHING	EASTING	GROUND SURFACE AT TIME OF INSTALLATION (MARCH - APRIL 2017)	TOP OF 90° ELBOW[A]
	WA STATE PLANE, NORTH ZONE, NAD83, US FT		ELEVATION FT (NAVD88)	
A1	239171.14	1270661.05	26.75	25.04
A2	239154.91	1270651.15	26.87	24.92
A3	239134.46	1270648.11	26.99	25.50
A4	239115.96	1270637.76	27.44	25.58
A5	239088.96	1270634.15	29.38	26.86
B1	239170.51	1270686.12	26.83	24.19
B2	239156.70	1270679.68	26.64	24.40
B3	239148.72	1270679.61	26.61	24.18
B4	239136.33	1270678.98	26.76	24.38
B5	239131.24	1270677.21	26.76	24.31
B6	239116.94	1270674.15	27.00	24.50
B7	239103.60	1270658.44	27.33	24.69
B8	239085.68	1270661.88	29.44	26.44
C1	239171.07	1270717.40	31.11	25.87
C2	239163.52	1270711.53	30.81	25.92
C3	239153.65	1270710.85	30.80	26.03
C4	239143.04	1270710.36	30.69	26.37
C5	239135.08	1270708.63	30.73	26.14
C6	239119.81	1270702.75	30.90	26.30
C7	239116.76	1270698.62	30.87	26.30
C8	239110.16	1270688.96	30.88	26.39
C9	239080.68	1270689.61	28.96	26.50
C10	239072.82	1270717.81	28.30	25.67
C11	239080.59	1270743.78	27.45	24.73
C12	239095.06	1270758.65	27.43	24.51
D1	239170.34	1270735.83	30.77	25.97
D2	239166.43	1270735.63	30.56	25.82
D3	239152.19	1270736.47	30.33	25.80
D4	239149.00	1270736.02	30.44	25.95
D5	239131.33	1270735.09	30.41	26.01
D6	239127.76	1270735.17	30.56	25.94
D7	239113.05	1270730.11	27.99	25.63
D8	239109.15	1270729.73	28.03	25.48
D9	239098.48	1270727.69	27.82	25.19
D10	239095.41	1270726.05	27.88	25.29

A. TOP OF 90° ELBOW IS THE HIGHEST POINT ON THE INJECTION WELLS. SEE SHEET 8.0 FOR WELL SCHEMATIC.

MONITORING WELLS				
WELL ID	NORTHING	EASTING	TOP OF MONUMENT[A]	TOP OF PVC CASING
	WA STATE PLANE, NORTH ZONE, NAD83, US FT		ELEVATION FT (NAVD88)	
MW-41S	239123.85	1270626.07	B	29.02
MW-41D	239126.07	1270628.03	B	29.19
MW-42S	239153.02	1270667.56	B	27.82
MW-43S	239087.49	1270677.38	29.37	29.03
MW-44S	239159.31	1270720.72	B	30.29
MW-45S	239142.50	1270725.64	B	30.74
MW-45D	239138.49	1270727.34	B	30.00
MW-46S	239143.44	1270760.23	25.41	24.84
MW-46D	239148.59	1270760.61	25.40	24.92
MW-47S	239111.94	1270743.90	B	29.80
MW-48D	239081.86	1270756.15	27.27	26.80
MW-49D	239063.29	1270775.15	26.75	26.15
MW-50D	239117.04	1270793.29	25.52	25.06
MW-51S	239136.65	1270795.79	25.74	25.37
MW-52D	239147.84	1270796.96	25.76	25.31

A. TOP OF MONUMENT IS THE HIGHEST POINT ON THE MONITORING WELLS. THE WELL MONUMENTS ARE FLUSH WITH GROUND SURFACE. SEE SHEET 8.0 FOR WELL SCHEMATIC.

B. WELL DOES NOT CURRENTLY HAVE A FINISHED MONUMENT AND IS IN CONSTRUCTION SEQUENCING STAGES DESCRIBED IN SHEET 6.0 OR 7.0 AND MONUMENT COMPLETION WILL FOLLOW SPR CONSTRUCTION.



LEGEND

- ----30---- EXISTING CONTOUR (NAVD88)
- ——SD—— EXISTING STORMDRAIN
- —— W —— EXISTING WATER
- ——E—— EXISTING ELECTRICAL
- [⊏⊐] EXISTING SUBSURFACE CONCRETE TANKS
- ▬ ▬ PLAY AREA RENOVATION FOOTPRINT
- ▪▪▪▪▪▪▪▪ APPROXIMATE EDGE OF EXISTING IMPERMEABLE LINER
- ▒ EXISTING ASPHALT, GRAVEL, AND/OR CONCRETE
- ⌖ EXISTING MONITORING WELL - FILL
- ⊗ EXISTING MONITORING WELL - OUTWASH

AS-BUILT INJECTION SYSTEM LAYOUT

- A1 ◉ INJECTION WELL - FILL
- B3 ▣ INJECTION WELL - OUTWASH
- MW-46S ⌖ MONITORING WELL - FILL
- MW-46D ⊗ MONITORING WELL - OUTWASH
- ------------ TRENCHED INJECTION PIPE
- □ SYSTEM VAULT
- 🟫 APPROXIMATE LOCATION OF CONTROLLED DENSITY FILL (CDF) BACKFILL AREAS

N

0 10 20
SCALE IN FEET

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NOTE:
INJECTION SYSTEM SURVEY INFORMATION PROVIDED BY TRUE NORTH LAND SURVEYING INC. AUGUST 14, 2017. VERTICAL DATUM IS NAVD88.

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INJECTION SYSTEM LAYOUT

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DESIGN: SMS	SHEET 4 OF 9
CHECKED: CLB	DATE: 08.30.2017
SHEET NO. 4.0	

AS-BUILT

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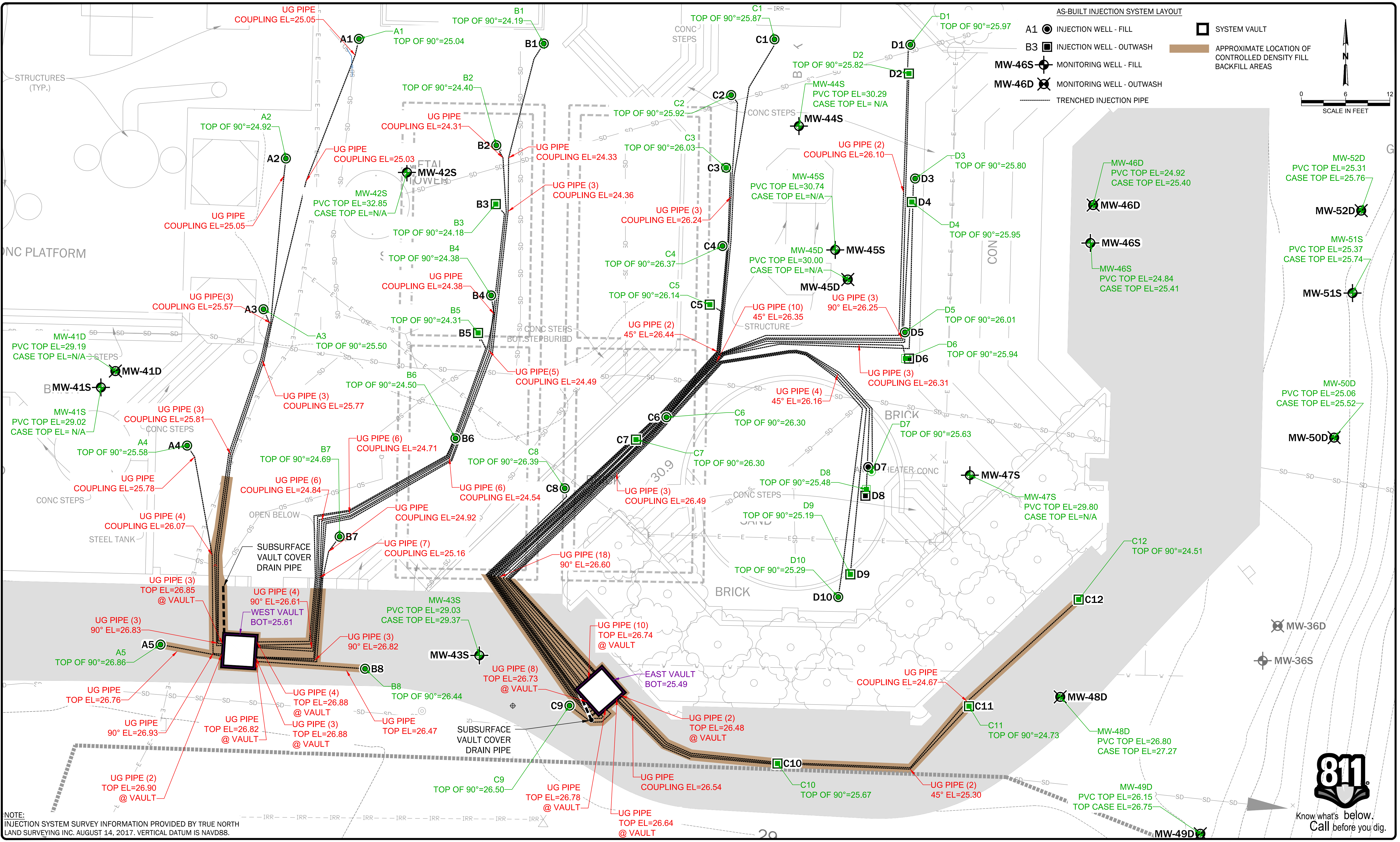

NOTE:
INJECTION SYSTEM SURVEY INFORMATION PROVIDED BY TRUE NORTH LAND SURVEYING INC. AUGUST 14, 2017. VERTICAL DATUM IS NAVD88.

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INJECTION SYSTEM ELEVATIONS

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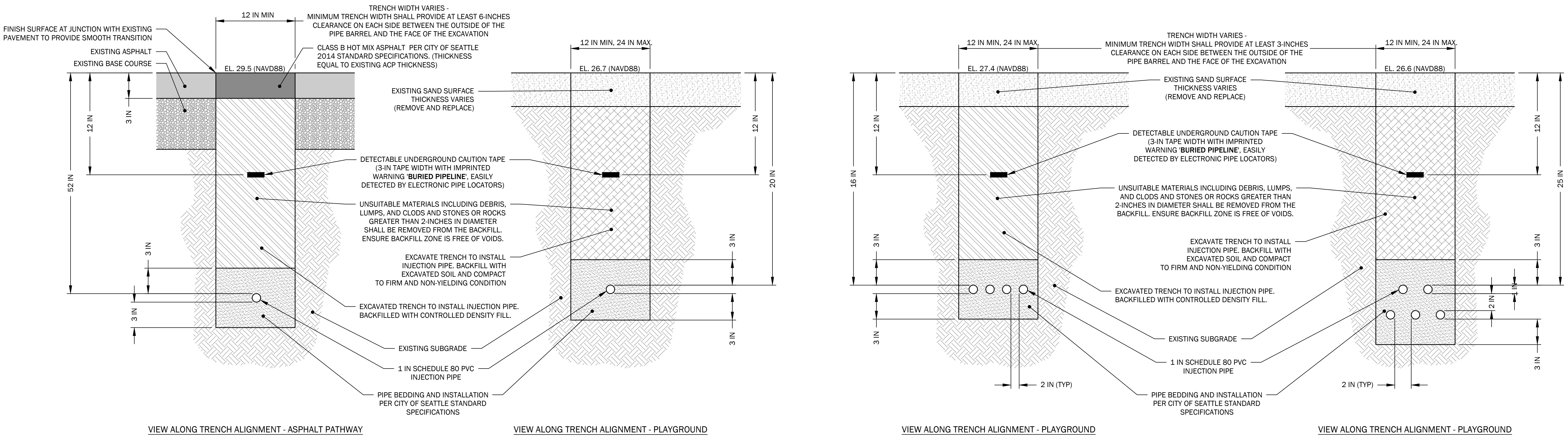
DESIGN: SMS	SHEET 5 OF 9
CHECKED: CLB	DATE: 08.30.2017
SHEET NO. 4.1	

AS-BUILT



CROSS-SECTION A-A' A
SCALE: NOT TO SCALE 5.0

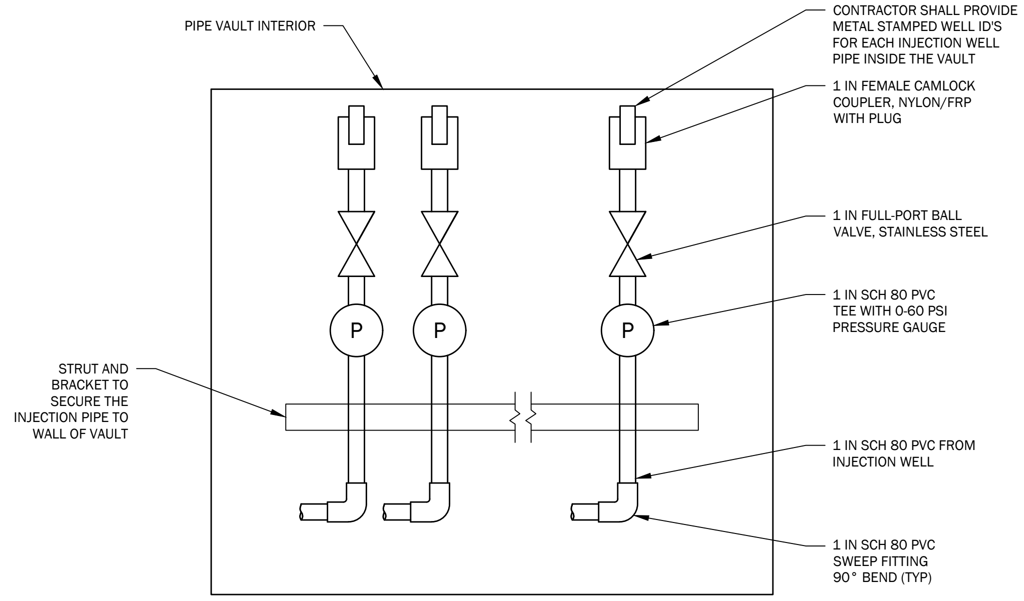
CROSS-SECTION B-B' B
SCALE: NOT TO SCALE 5.0

CROSS-SECTION C-C' C
SCALE: NOT TO SCALE 5.0

CROSS-SECTION D-D' D
SCALE: NOT TO SCALE 5.0

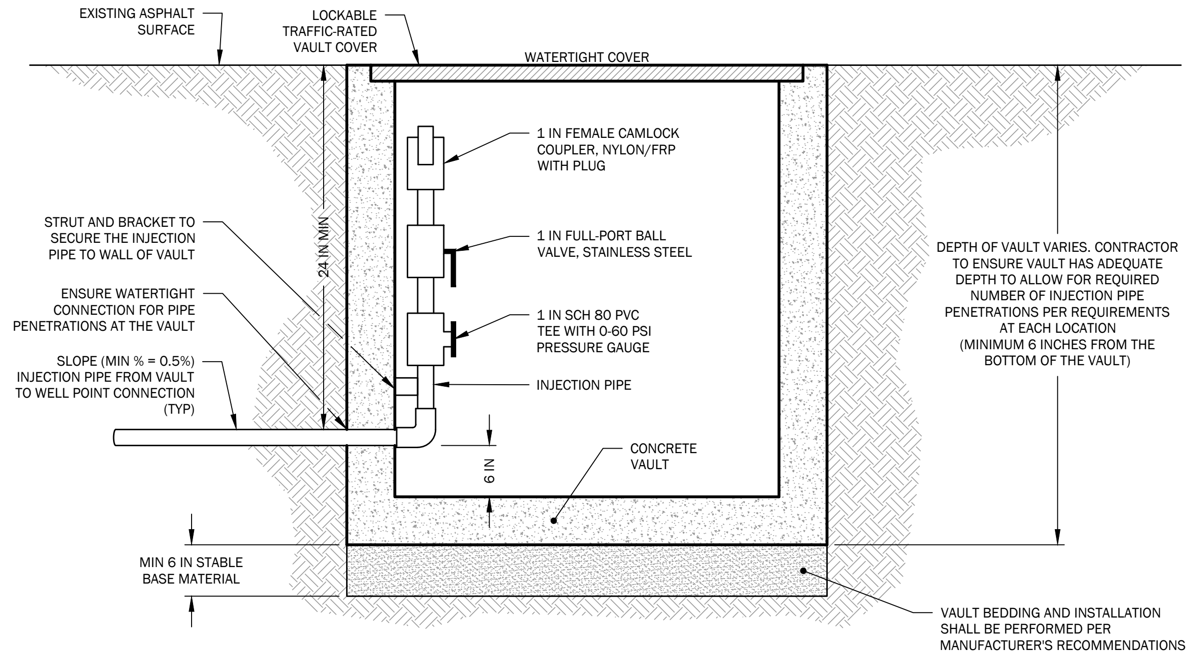
INJECTION PIPING AND TRENCH DETAIL -

SCALE: NOT TO SCALE 5.0



VAULT PIPING DETAIL 1

SCALE: NOT TO SCALE 5.0



WEST VAULT
CONTRACTOR INSTALLED OLDCASTLE PRECAST VAULT MODEL 444-LA AND WATER TIGHT LID

EAST VAULT
CONTRACTOR INSTALLED OLDCASTLE PRECAST VAULT MODEL 504-LA AND WATER TIGHT LID

INJECTION SYSTEM VAULT DETAIL 2

SCALE: NOT TO SCALE 5.0

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SEATTLE, WASHINGTON

TRENCHING AND INJECTION SYSTEM DETAILS

DRAWN: CFS	PROJ NO: 0186-846-01
DESIGN: SMS	SHEET 6 OF 9
CHECKED: CLB	DATE: 08.30.2017
SHEET NO. 5.0	

AS-BUILT

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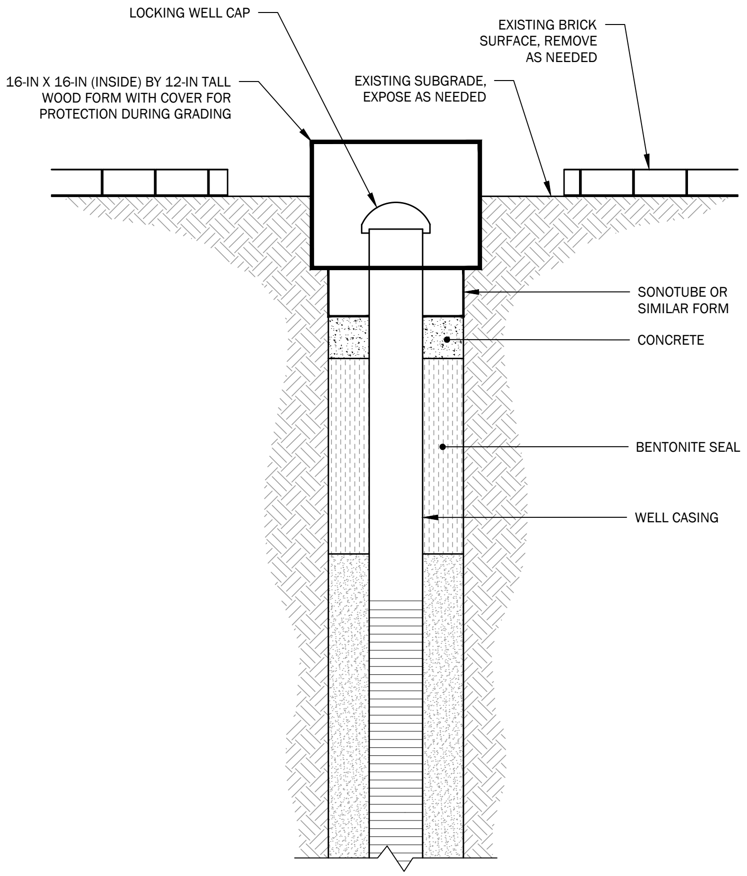
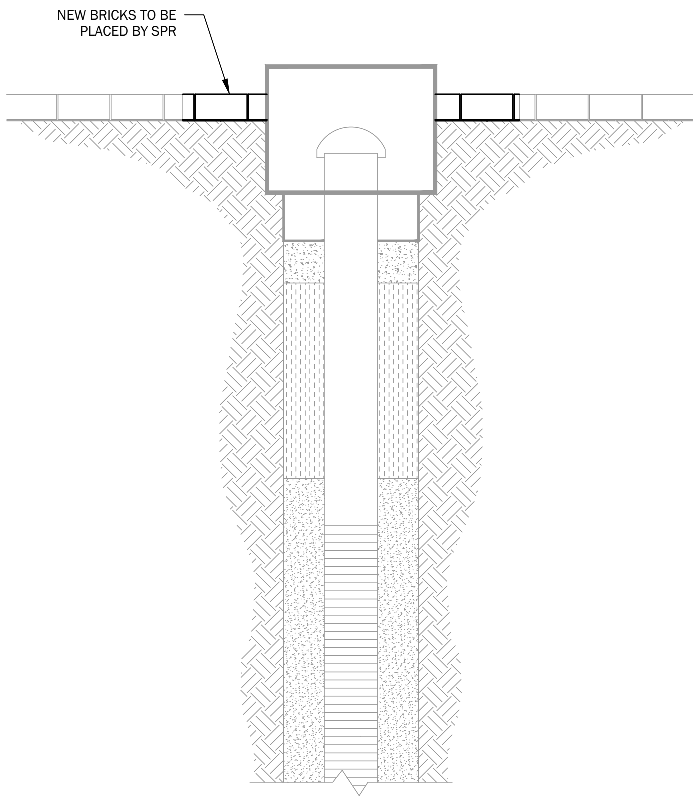


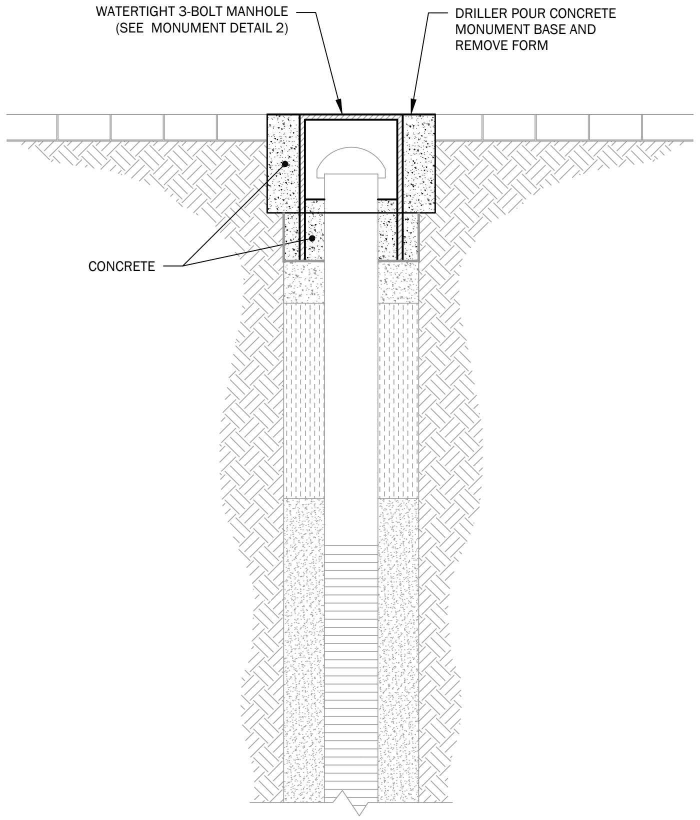
WELL CONDITION DURING CONSTRUCTION (STAGE 1)
COMPLETED

NOTES:
1. MONITORING WELL INSTALLATION COMPLETED BY LICENSED WELL DRILLER PRIOR TO MOBILIZATION BY SPR RENOVATION CONTRACTOR.
2. MONITORING WELL PROTECTION INSTALLED BY WELL DRILLER.
3. TEMPORARY WELL PROTECTION COMPLETED BY WELL DRILLERS JUNE 2017.



WELL CONDITION DURING CONSTRUCTION (STAGE 2)
TO BE COMPLETED

NOTES:
1. SPR RENOVATION CONTRACTOR COMPLETES BACKFILL AND BRICK LAYING AROUND PROTECTED MONITORING WELL. CONTRACTOR TO EXERCISE CAUTION DURING BACKFILLING OPERATIONS AND PROTECT THE MONITORING WELL FROM DAMAGE.
2. SPR RENOVATION CONTRACTOR TO NOTIFY GEOENGINEERS AFTER COMPLETION OF BRICK LAYING ACTIVITIES.
3. ALLOW APPROXIMATELY 90-180 DAYS FOR BRICK INSTALLATION BY SPR.

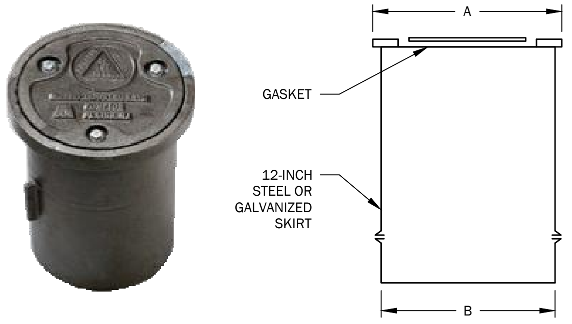


FINAL WELL CONDITION (STAGE 3)
TO BE COMPLETED

NOTES:
1. LICENSED WELL DRILLER TO INSTALL WELL MONUMENT AT REQUIRED ELEVATION BASED ON SURROUNDING BRICK SURFACE. WELL DRILLER TO REMOVE WOOD FORM AND POUR CEMENT MONUMENT BASE FLUSH WITH SURROUNDING BRICK.

MONITORING WELL SURFACE COMPLETION CONSTRUCTION SEQUENCING - BRICK FINAL SURFACE 1 / 6.0

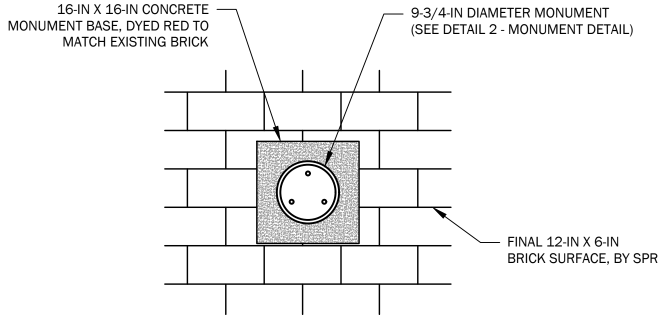
SCALE: NOT TO SCALE



DIMENSIONS		
SIZE	A	B
8-IN MANHOLE	9-3/4 IN	8-5/8 IN

MONUMENT DETAIL 2 / 6.0

SCALE: NOT TO SCALE



MONITORING WELL SURFACE COMPLETION IN BRICK SURFACE 3 / 6.0

SCALE: NOT TO SCALE

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39963
8/30/17

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PLAY AREA GROUNDWATER INFRASTRUCTURE INSTALLATION AS-BUILT
SEATTLE, WASHINGTON

**MONITORING WELL SURFACE COMPLETION
CONSTRUCTION SEQUENCING
BRICK PLAZA**

DRAWN: CFS
DESIGN: SMS
CHECKED: CLB
PROJ NO: 0186-846-01
SHEET 7 OF 9
DATE: 08.30.2017
SHEET NO. 6.0

AS-BUILT

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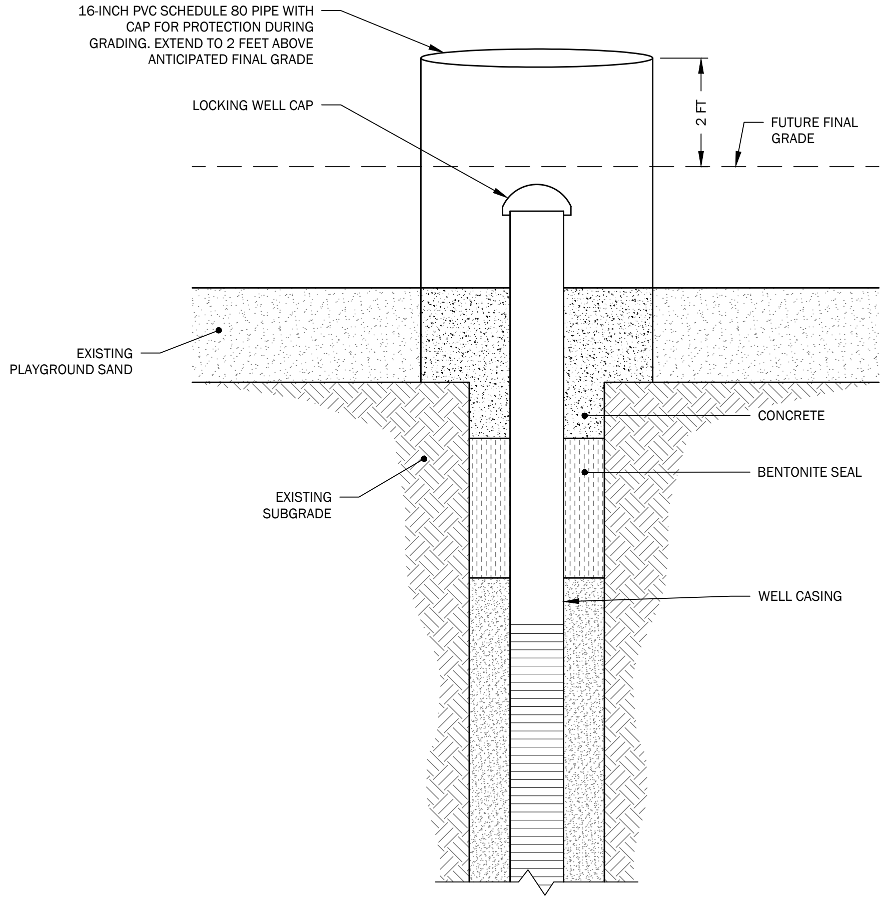
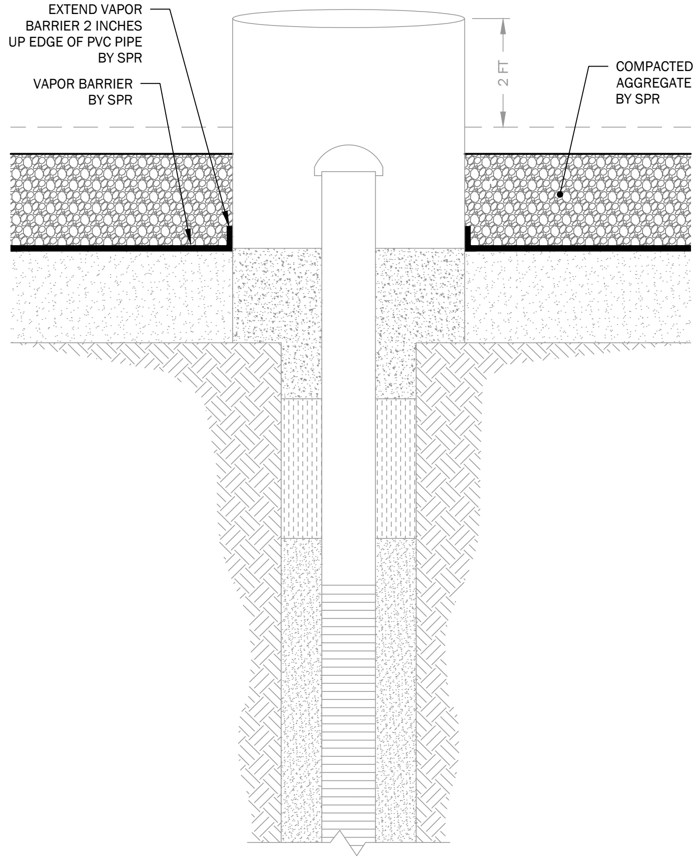


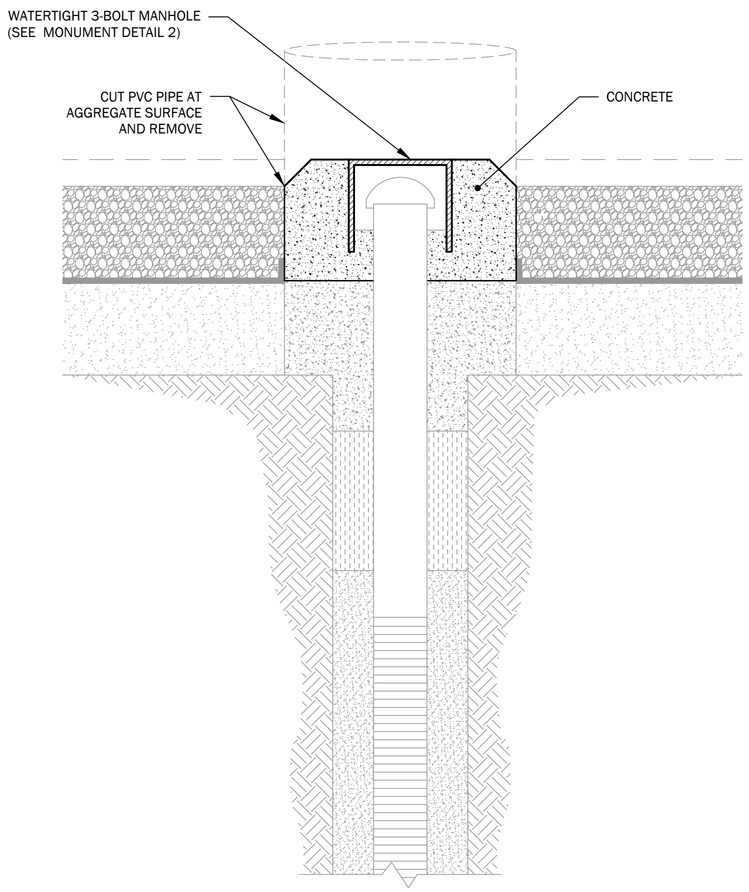
WELL CONDITION DURING CONSTRUCTION (STAGE 1)
COMPLETED

NOTES:
1. MONITORING WELL INSTALLATION SHALL BE COMPLETED BY LICENSED WELL DRILLER PRIOR TO MOBILIZATION BY SPR RENOVATION CONTRACTOR.
2. MONITORING WELL PROTECTION SHALL BE INSTALLED BY WELL DRILLER.
3. TEMPORARY WELL PROTECTION COMPLETED BY WELL DRILLERS JUNE 2017.



WELL CONDITION DURING CONSTRUCTION (STAGE 2)
TO BE COMPLETED

NOTES:
1. SPR RENOVATION CONTRACTOR WILL COMPLETE AGGREGATE BACKFILLING AND GRADING TO PVC PROTECTION PIPE. CONTRACTOR TO EXERCISE CAUTION DURING BACKFILLING OPERATIONS AND PROTECT THE MONITORING WELL FROM DAMAGE.
2. SPR RENOVATION CONTRACTOR WILL NOTIFY GEOENGINEERS AFTER BACKFILLING.
3. ALLOW APPROXIMATELY 90-180 DAYS FOR INSTALLATION BY SPR.

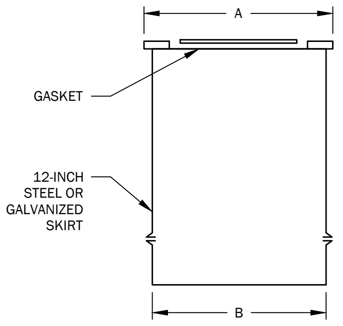


WELL CONDITION DURING CONSTRUCTION (STAGE 3)
TO BE COMPLETED

NOTES:
1. LICENSED WELL DRILLER TO SET MANHOLE AND CONCRETE BASE AT PROPOSED ELEVATION OF PIP SURFACE TO BE INSTALLED BY SPR.
2. AFTER CONCRETE BASE SETS, LICENSED WELL DRILLER TO CUT PVC PIPE FORM WITH SURROUNDING AGGREGATE SURFACE AND REMOVE.
3. SPR CONTRACTOR TO INSTALL PIP SURFACE FLUSH WITH WELL MONUMENT,

MONITORING WELL SURFACE COMPLETION CONSTRUCTION SEQUENCING - POURED IN PLACE FINAL SURFACE 1 7.0

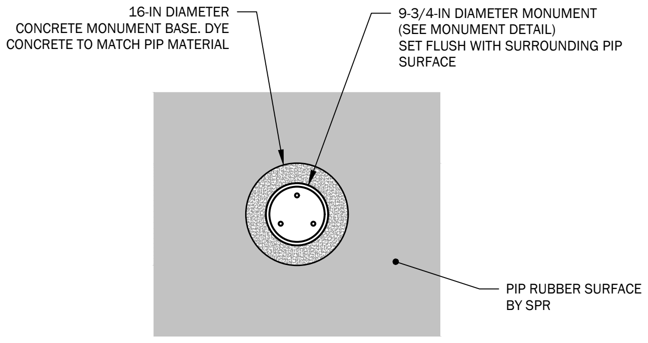
SCALE: NOT TO SCALE



DIMENSIONS		
SIZE	A	B
8-IN MANHOLE	9-3/4 IN	8-5/8 IN

MONUMENT DETAIL 2 7.0

SCALE: NOT TO SCALE



MONITORING WELL SURFACE COMPLETION IN POURED-IN-PLACE (PIP) RUBBER SURFACE 3 7.0

SCALE: NOT TO SCALE

811
Know what's below.
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NO.	DATE	BY	REVISION

GEOENGINEERS
600 STEWART ST : SUITE 1700 : SEATTLE, WA 98101 : 206-728-2674 : WWW.GEOENGINEERS.COM

CHRISTOPHER LEWIS BAILEY
39963
8/30/17

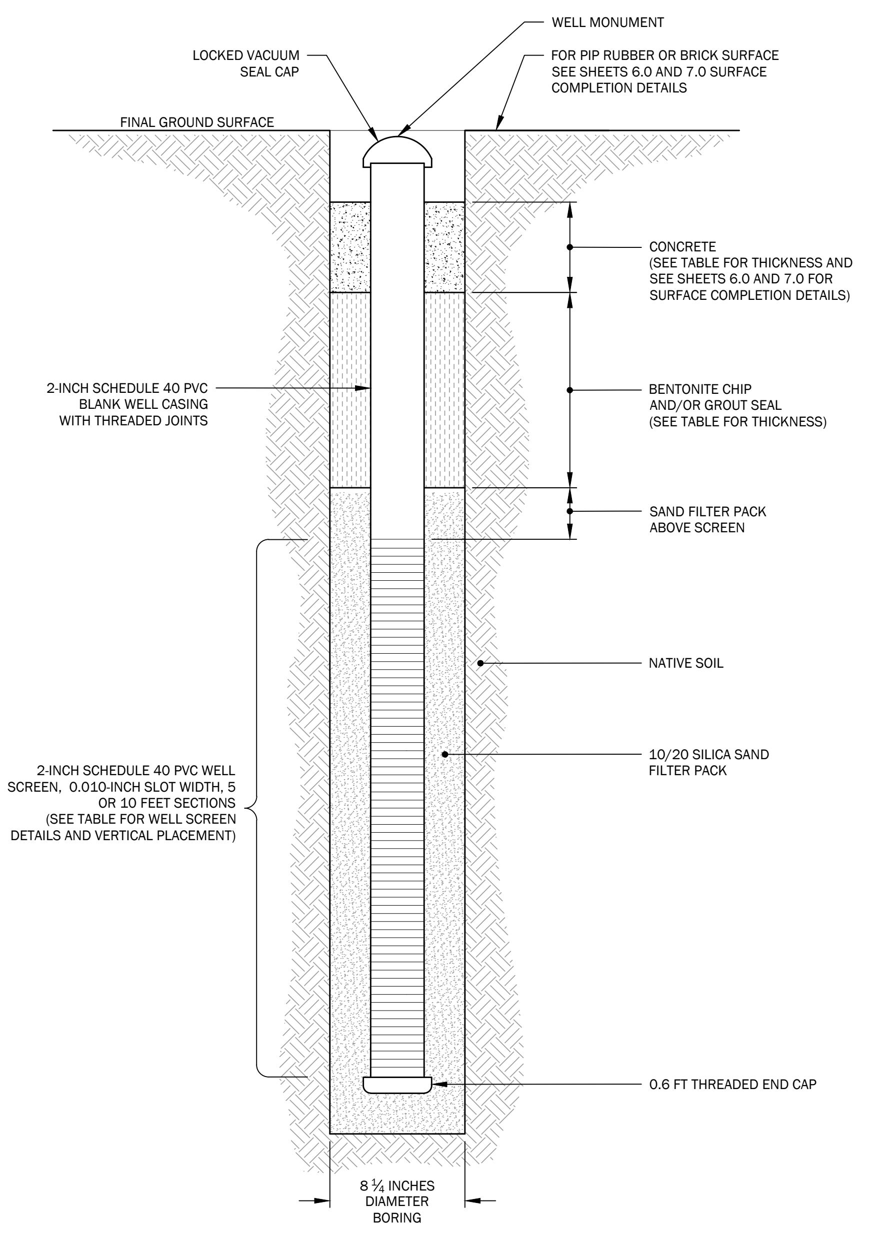
GAS WORKS PARK SITE
PLAY AREA GROUNDWATER INFRASTRUCTURE INSTALLATION AS-BUILT
SEATTLE, WASHINGTON

MONITORING WELL SURFACE COMPLETION
CONSTRUCTION SEQUENCING
PLAYGROUND

DRAWN: CFS	PROJ NO: 0186-846-01
DESIGN: SMS	SHEET 8 OF 9
CHECKED: CLB	DATE: 08.30.2017
SHEET NO. 7.0	

AS-BUILT

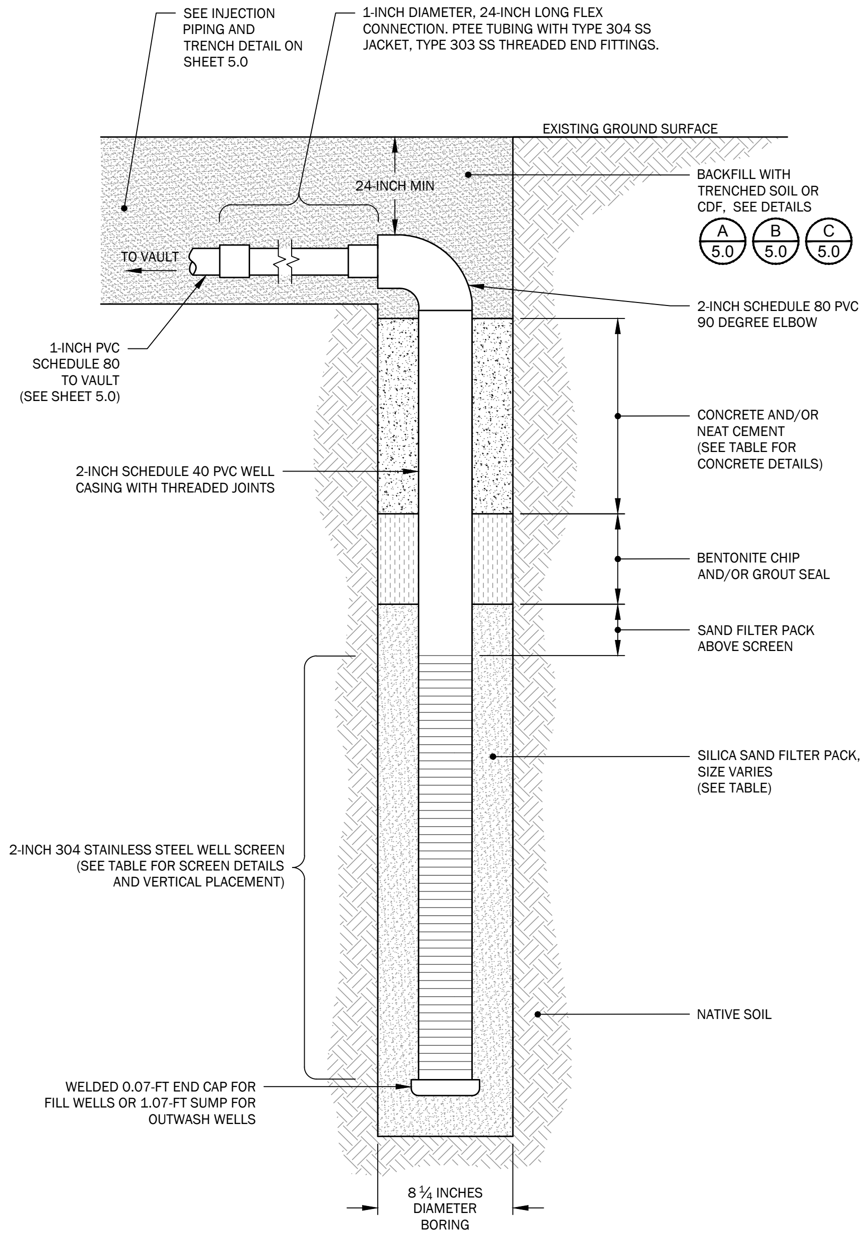
Plotted: 08/29/2017, 21:03 | cstickel P:\0\0186846\01\CAD\Task 1803 Play Area Action\Interim Action Design\R03 [Asbuilt]\018684601_Sht 07 - Sht 08_6.0 & 7.0 [Well Head Details].dwg



MONITORING WELL SCHEMATIC

SCALE: NOT TO SCALE

1
8.0



INJECTION WELL SCHEMATIC

SCALE: NOT TO SCALE

2
8.0

WELL ID	WELL SCREEN GEOLOGIC UNIT	ELEVATION FEET (NAVD88)						DEPTH (FEET BELOW GROUND SURFACE AT TIME OF INSTALLATION)		SCREEN LENGTH (FEET)	THICKNESS (FEET)				SAND FILTER PACK	SLOT SIZE^B
		TOP OF CONCRETE	TOP OF NEAT CEMENT	TOP OF BENTONITE CHIP/ GROUT SEAL	TOP OF SAND	SCREEN START	SCREEN END	SCREEN START	SCREEN END		CONCRETE	NEAT CEMENT	BENTONITE CHIP/ GROUT SEAL	SAND FILTER PACK ABOVE SCREEN		
INJECTION WELLS																
A1	FILL	24.6	22.5	22.5	21.5	20.5	15.0	6.3	11.8	5.5	2.1 A	0.0	1.0	1.0	6/9	50
A2	FILL	24.3	23.2	23.2	22.2	21.2	15.7	5.7	11.2	5.5	1.1 A	0.0	1.0	1.0	6/9	50
A3	FILL	25.0	22.9	22.9	21.9	20.9	15.9	6.1	11.1	5.0	2.1 A	0.0	1.0	1.0	6/9	50
A4	FILL	25.1	23.3	23.3	22.3	21.3	17.8	6.2	9.7	3.5	1.8 A	0.0	1.0	1.0	6/9	50
A5	FILL	26.5	24.8	24.8	23.8	23.3	18.3	6.1	11.1	5.0	1.7	0.0	1.0	0.5	6/9	50
B1	FILL	23.7	22.3	22.3	21.3	20.3	10.8	6.5	16.0	9.5	1.4 A	0.0	1.0	1.0	6/9	50
B2	FILL	24.0	21.8	21.8	20.8	19.8	10.8	6.9	15.9	9.0	2.2 A	0.0	1.0	1.0	6/9	50
B3	OUTWASH	23.5	21.5	11.0	10.0	9.0	2.5	17.6	24.1	6.5	2.0	10.5	1.0	1.0	10/20	20
B4	FILL	23.9	21.9	21.9	20.9	19.9	13.4	6.9	13.4	6.5	2.0	0.0	1.0	1.0	6/9	50
B5	OUTWASH	23.8	21.8	11.3	10.3	9.3	2.3	17.5	24.5	7.0	2.0	10.5	1.0	1.0	10/20	20
B6	FILL	24.0	22.4	22.4	21.4	20.4	13.9	6.6	13.1	6.5	1.6	0.0	1.0	1.0	6/9	50
B7	FILL	24.3	22.4	22.4	21.4	20.4	15.4	7.0	12.0	5.0	1.9 A	0.0	1.0	1.0	6/9	50
B8	FILL	25.9	23.9	23.9	22.9	21.9	16.4	7.5	13.0	5.5	2.0	0.0	1.0	1.0	6/9	50
C1	FILL	25.4	22.8	22.8	21.8	20.8	13.3	10.3	17.8	7.5	2.6	0.0	1.0	1.0	6/9	50
C2	FILL	25.4	22.8	22.8	21.8	20.8	12.8	10.0	18.0	8.0	2.6	0.0	1.0	1.0	6/9	50
C3	OUTWASH	25.5	21.8	10.8	9.8	8.8	0.8	22.0	30.0	8.0	3.7	11.0	1.0	1.0	10/20	20
C4	FILL	25.9	23.2	23.2	22.2	21.2	15.7	9.5	15.0	5.5	2.7	0.0	1.0	1.0	6/9	50
C5	OUTWASH	25.6	21.4	9.4	8.4	7.4	0.4	23.3	30.3	7.0	4.2	12.0	1.0	1.0	10/20	20
C6	FILL	25.9	22.1	21.6	20.6	19.6	16.6	11.4	14.4	3.0	3.8	0.5	1.0	1.0	6/9	50
C7	OUTWASH	25.8	24.8	12.2	11.2	10.2	3.2	20.7	27.7	7.0	1.0	12.6	1.0	1.0	10/20	20
C8	FILL	25.9	23.6	23.6	22.6	21.6	16.1	9.3	14.8	5.5	2.3	0.0	1.0	1.0	6/9	50
C9	FILL	26.0	22.7	22.7	21.7	20.7	15.7	8.3	13.3	5.0	3.3	0.0	1.0	1.0	6/9	50
C10	OUTWASH	25.2	23.0	13.5	12.5	11.5	0.5	16.8	27.8	11.0	2.2	9.5	1.0	1.0	10/20	20
C11	OUTWASH	23.9	22.4	10.9	9.9	8.9	-3.1	18.6	30.6	12.0	1.5	11.5	1.0	1.0	10/20	20
C12	OUTWASH	24.0	21.2	5.2	4.2	3.2	-5.8	24.2	33.2	9.0	2.8	16.0	1.0	1.0	10/20	20
D1	FILL	25.5	21.7	20.7	19.7	18.7	12.7	12.1	18.1	6.0	3.8	1.0	1.0	1.0	4/8	90
D2	OUTWASH	25.3	21.8	12.8	11.8	10.8	1.3	19.7	29.2	9.5	3.5	9.0	1.0	1.0	10/20	20
D3	FILL	25.3	21.5	20.5	19.5	18.5	11.5	11.8	18.8	7.0	3.8	1.0	1.0	1.0	4/8	90
D4	OUTWASH	25.3	20.3	9.3	8.3	7.3	-1.7	23.1	32.1	9.0	5.0	11.0	1.0	1.0	10/20	20
D5	FILL	25.6	22.4	21.4	20.4	19.4	9.4	11.1	21.1	10.0	3.2	1.0	1.0	1.0	4/8	90
D6	OUTWASH	25.4	21.5	9.5	8.5	7.5	-2.5	23.0	33.0	10.0	3.9	12.0	1.0	1.0	10/20	20
D7	FILL	24.9	21.3	21.3	20.3	19.3	12.3	8.7	15.7	7.0	3.6	0.0	1.0	1.0	4/8	90
D8	OUTWASH	24.6	19.6	11.0	10.0	9.0	-3.0	19.1	31.1	12.0	5.0	8.6	1.0	1.0	10/20	20
D9	OUTWASH	24.6	22.6	11.6	10.6	9.6	-2.4	18.2	30.2	12.0	2.0	11.0	1.0	1.0	10/20	20
D10	FILL	24.7	21.1	21.1	20.1	19.1	14.1	8.8	13.8	5.0	3.6	0.0	1.0	1.0	4/8	90
MONITORING WELLS																
MW-41S	FILL	27.6	–	26.1	24.6	24.1	19.1	5.5	10.5	5.0	1.5	0.0	1.5	0.5	10/20	10
MW-41D	OUTWASH	26.5	–	25.0	12.2	10.7	0.7	18.8	28.8	10.0	1.5	0.0	12.8	1.5	10/20	10
MW-42S	FILL	26.6	–	25.6	24.1	23.1	18.1	3.8	8.8	5.0	1.0	0.0	1.5	1.0	10/20	10
MW-43S	FILL	28.5	–	26.8	23.0	21.5	16.5	7.8	12.8	5.0	1.7	0.0	3.8	1.5	10/20	10
MW-44S	FILL	30.2	–	28.3	24.8	23.4	13.4	7.4	17.4	10.0	1.9	0.0	3.5	1.4	10/20	10
MW-45S	FILL	29.3	–	27.8	25.8	24.0	14.0	6.8	16.8	10.0	1.5	0.0	2.0	1.8	10/20	10
MW-45D	OUTWASH	29.8	–	28.3	7.3	5.2	0.2	25.6	30.6	5.0	1.5	0.0	21.0	2.1	10/20	10
MW-46S	FILL	24.4	–	23.0	20.5	18.0	8.0	7.5	17.5	10.0	1.4	0.0	2.5	2.5	10/20	10
MW-46D	OUTWASH	24.4	–	23.4	2.9	0.9	-4.1	24.5	29.5	5.0	1.0	0.0	20.5	2.0	10/20	10
MW-47S	FILL	29.3	–	28.0	19.5	15.7	10.7	14.8	19.8	5.0	1.3	0.0	8.5	3.8	10/20	10
MW-48D	OUTWASH	26.2	–	24.7	5.7	4.7	-5.3	22.5	32.5	10.0	1.5	0.0	19.0	1.0	10/20	10
MW-49D	OUTWASH	25.6	–	22.2	3.7	2.1	-7.9	24.6	34.6	10.0	3.4	0.0	18.5	1.6	10/20	10
MW-50D	OUTWASH	24.5	–	23.0	-1.0	-4.1	-9.1	29.6	34.6	5.0	1.5	0.0	24.0	3.1	10/20	10
MW-51S	FILL	24.8	–	23.2	19.7	18.8	8.8	6.9	16.9	10.0	1.6	0.0	3.5	0.9	10/20	10
MW-52D	OUTWASH	24.8	–	20.8	-1.7	-4.0	-9.0	29.8	34.8	5.0	4.0	0.0	22.5	2.3	10/20	10

A. CONCRETE DIAMETER FOR A1 AND A2 IS 20 INCHES. CONCRETE DIAMETER FOR A3, A4, B1, B2 AND B7 IS 18 INCHES.
B. SLOT SIZES: 10 = 0.010-INCH OPENINGS. 20 = 0.020-INCH OPENINGS. 50 = 0.050-INCH OPENINGS. 90 = 0.090-INCH OPENING

NOTES:
1. REFER TO SHEETS 6.0 AND 7.0 FOR SURFACE COMPLETION IN BRICK AND PIP RUBBER. SURFACE COMPLETION IN ASPHALT AND GRASS TO MATCH EXISTING CONDITIONS PRIOR TO DRILLING. 12-INCH MONUMENT SKIRT LENGTH SHALL BE USED FOR MONITORING WELL COMPLETIONS.
2. WELL DETAILS BASED ON FIELD MEASUREMENTS.

811
Know what's below.
Call before you dig.

Plotted: 08/29/2017, 17:56 | cstickel P:\0\0186846\01\CAD\Task 1803 Play Area Action\Interim Action Design\R03 [Asbuilt]\0186846-01_Sht 09_8.0 [Well Construction Schematic Details].dwg

NO.	DATE	BY	REVISION

GEOENGINEERS
600 STEWART ST : SUITE 1700 : SEATTLE, WA 98101 : 206-728-2674 : WWW.GEOENGINEERS.COM

CHRISTOPHER LEWIS BAILEY
39963
8/30/17

GAS WORKS PARK SITE
PLAY AREA GROUNDWATER INFRASTRUCTURE INSTALLATION AS-BUILT
SEATTLE, WASHINGTON

WELL CONSTRUCTION SCHEMATIC DETAILS

DRAWN: CFS	PROJ NO: 0186-846-01
DESIGN: SMS	SHEET 9 OF 9
CHECKED: CLB	DATE: 08.30.2017
SHEET NO. 8.0	

AS-BUILT

APPENDIX C

UIC Form

Underground Injection Control (UIC) Well Registration Form for Class V UIC Wells that Automatically Meet the Nonendangerment Standard

The purpose of this form is to register with the Washington State Department of Ecology UIC wells that automatically meet the non endangerment standard in accordance with WAC 173-218-100.

A. Facility Name and Location

Facility Name ______________________________

Facility Address ______________________________

City ____________ State ________ ZIP __________

Phone at the facility ______________________________

County ______________________________

Township, Range, Section, Quarter-Quarter ______________________________

____

B. Contact Information

Well Owner

Name ______________________________

Organization ______________________________

Address ______________________________

City ____________ State ________ ZIP __________

Phone ______________________________

Email _ ______________________________

Property Owner

Same as Well Owner: ☐

If not the same, complete below:

Name ______________________________

Organization ______________________________

Address ______________________________

City ____________ State ________ ZIP __________

Technical Contact Person (Engineer, Contractor, Consultant)

Name ______________________________

Organization ______________________________

Address ______________________________

City ____________ State ________ ZIP __________

Phone ______________________________

Email _ ______________________________

If the UIC well is used at a remediation site or is a septic system and located in a water supply well's one year time of travel or a surface water intake protection area you must notify the water utility of the project. Please visit Washington State Department of Health's wellhead protection tool to identify well head and surface water intake areas in the county you are working in: https://fortress.wa.gov/doh/eh/dw/swap/maps/.

C. Type of Class V Well that this form may be used for (see WAC 173-218-070 and WAC 173-218-100)

Use the number from the following list to fill in the "Number of UIC Well Type from Section C" in the well table:

1. **Well used for Subsidence Control:** UIC wells which inject fluids that meet Chapter 173-200 WAC, Water quality Standards for Ground Waters of the State of Washington, to control subsidence.
2. **Extraction/dewatering well maintenance:** UIC wells that temporarily inject fluids or other material for the purpose of maintaining a properly functioning extraction well or dewatering well. Water must meet the Water Quality Standards for Ground waters of the State of Washington, Chapter 173-200 WAC.
3. **Receives unpolluted stormwater:** UIC wells receiving stormwater from nonpollutant-generating surfaces. See number four for roof runoff. Some examples of a non pollutant generating surface are paved bicycle pathways and sidewalks that are separate from the road and fenced fire lanes. Sidewalks frequently treated with salt or other deicing chemicals are considered a pollutant generating surface. If the land surface has any vehicle traffic, then stormwater is considered polluted (must use different UIC registration form).
4. **Receives Inert roof runoff:** UIC wells that only receive runoff from a roof coated with an inert, nonleachable material and a roof that is **not** subject to venting of manufacturing, commercial, or other indoor pollutants.

   UIC wells receiving roof runoff at an **industrial facility** must complete the Underground Injection Control (UIC) Well Registration Form for Industrial or Commercial Facilities instead of this form.

For the following UIC well types, please also fill in permit information in the well table:

5. **Aquifer recharge and storage wells** that meet the requirements in Chapter 173-157 WAC underground artificial storage and recovery.
6. **Reclaimed Water:** UIC wells used as part of a reclaimed water project that meet the requirements of the water reclamation and reuse standards as authorized by RCW 90.46.042.
7. **Septic systems that serve twenty or more people per day** and either receive operating permits, meet the requirements and are permitted in accordance with Chapter 246-272B WAC large on-site sewage system regulations, or meet the requirements of Chapter 246-272A WAC on-site sewage systems.
8. **Geothermal:** UIC wells used for geothermal fluid return flow into the same aquifer and that meet Chapter 173-200 WAC Water Quality Standards for Ground Waters of the State of Washington, Chapter 173-216 WAC state waste discharge permit program requirements and RCW 79.76 geothermal resources.
9. **NPDES Individual Permit** that covers the UIC wells on-site, except for UIC wells used to manage stormwater.
10. **State Waste Discharge Permit** that covers the UIC wells on-site, except for UIC wells used to manage stormwater.
11. **CERCLA or RCRA cleanup site:** Permit ID is the EPA site ID.
12. **MTCA – Cleanup site under a MTCA order or consent decree:** Permit ID is the state site ID.

This form does NOT apply to MTCA Voluntary Cleanup Sites. Use the UIC Registration form for Voluntary Cleanup Sites.

C. UIC well information

	1	2	3	4	5	6	7
Owner's ID Name or Number							
Number of UIC Well Type from Section C							
Construction Date							
EPA Well Type (see below)							
Status (Active, Unused, Closed, Proposed)							
Depth of UIC well							
Latitude (decimal degrees)							
Longitude (decimal degrees)							
UIC Wells with Permits (see Section C and table of permit types below):							
Permit Type							
Permit ID							
Permit Issuer							

EPA Class V Well Types

5A19 Cooling Water Return	5A6 Geothermal Heat	5W11 Septic System (gen)	5X26 Aquifer Remediation
5D2 Stormwater	5R21 Aquifer Recharge	5W20 Industrial Process Water	5X27 Other Wells
5D4 Industrial Storm Runoff	5W9 Untreated Sewage	5W31 Septic System (well disposal)	5X28 Motor Vehicle Waste
5G30 Special Drainage Water	5W10 Cesspool	5W32 Septic System (drainfield)	

Permit Types for use with this registration form (See also WAC 173-218-070(g))

Abbreviation	Permit Type
ASR	Aquifer Recharge Wells under WAC 173-157
LOSS	Large Septic Systems under WAC 246-272A
GRF	Geothermal Fluid Return Flow under WAC 173-216
RW	Reclaimed Water under RCW 90.46.0042
NPDES	NPDES Individual Permit that covers the UIC wells on-site (except stormwater wells)
SWD	State Waste Discharge permit that includes the UIC wells on-site (except stormwater wells)
EPA	CERCLA or RCRA cleanup site – Permit ID is the EPA site ID
MTCA	State oversight of cleanup site – Permit ID is the state site ID

If your UIC well is in a Well Head Protection Area, Critical Aquifer Recharge Area, or other ground water protection area, your local government may have additional ordinances or requirements.

Please contact your local city or county for more information.

D. Signature of authorized representative

I hereby certify that the information contained in this registration is true and correct to the best of by knowledge.

Name of legally authorized representative	Title
Signature of legally authorized Representative	Date:

For Department Use Only	
Site ID:	
Date received:	
Date acknowledged:	
Date Entered:	
Final Disposition:	

Please send completed form to:

UIC Coordinator
Water Quality Program,
Washington Department of Ecology
P.O. Box 47600
Olympia, WA 98504-7600

To request ADA accommodation including materials in a format for the visually impaired, call the Water Quality Program at 360-407-6600. Persons with impaired hearing may call Washington Relay Service at 711. Persons with a speech disability may call 877-833-6341.

Instructions to Complete the UIC Registration Form for Class V UIC Wells that Automatically Meet the Nonendangerment Standard

A. Facility Name and Location: Provide the name, address, and phone number of the facility where the UIC wells are or will be located. Provide the township, range and section for the facility.

B. Contact Information

Well Owner: Provide the well owner's name, organization, address, phone number and email address.
Property Owner: Complete if different from the well owner

Technical Contact: Provide the name, organization, address, telephone number and email address of the person to contact in case there are any questions about this registration.

C. UIC Well information

- Owners ID: Provide a well identification name or number you create.
- The number of the UIC well type found in section C of this form.
- Construction Date: Provide the approximate date the well was installed.
- EPA well type: EPA well types are listed in the table within section C.
- Status: Active if the well is in use; unused if well is not in use, closed, or proposed if the well is in the design phase.
- Well depth: Provide the approximate well depth.

- Latitude and longitude: Enter the latitude and longitude in decimal form for each UIC well. Visit http://ww4.doh.wa.gov/scripts/esrimap.dll?Name=geoview&Cmd=Map and type the address in at the bottom of the screen. Locational information including, latitude and longitude, will be found in a table below the map.

Permits: Provide permit type, ID number and agency that issued the permit.

For more information contact:

Underground Injection Control
Washington Dept. of Ecology
P.O. Box 47600
Olympia, WA 98504-7600
Phone: (360) 407-6143
E-mail: maha461@ecy.wa.gov
http://www.ecy.wa.gov/programs/wq/grndwtr/uic/index.html

To request ADA accommodation including materials in a format for the visually impaired, call the Water Quality Program at 360-407-6600. Persons with impaired hearing may call Washington Relay Service at 711. Persons with a speech disability may call 877-833-6341.

APPENDIX D
Ferrous Sulfate Safety Data Sheet

Safety Data Sheet

1. IDENTIFICATION OF THE SUBSTANCE/PREPARATION AND OF THE COMPANY/UNDERTAKING

Product identifier

Product Name: Ferrous Sulfate Heptahydrate (Moist or Dried)
CAS-No.: 7782-63-0

Other means of identification

Synonyms: Copperas, Iron (II) Sulfate

Recommended use of the chemical and restrictions on use

Recommended Use: Laboratory chemicals, manufacture of substances

Uses advised against: No information available

Details of the supplier of the safety data sheet

Supplier Name: QC LLC
Supplier Address: 5566 Nash Rd
Cape Girardeau, MO 63701
Supplier Phone Number: 800-666-4766 Fax: 573-335-2308
Contact Phone: 573-335-6700
Supplier Email: info@qccorporation.com

Emergency telephone number CHEMTREC (800) 424-9300

2. HAZARDS IDENTIFICATION

Classification

Acute Toxicity, Oral	Category 4
Skin irritation	Category 2
Eye Irritation	Category 2A

GHS Label elements, including precautionary statements

Pictogram:

Signal word: Warning

Hazard statement(s):
Harmful if swallowed.
Causes skin irritation.
Causes serious eye irritation.

Precautionary statement(s):
Wash skin thoroughly after handling.
Do not eat, drink, or smoke when using this product.
Wear protective gloves/eye protection/face protection.

IF SWALLOWED: Call a POISON CENTER or doctor/ physician if you feel unwell.
IF ON SKIN: Wash with plenty of soap and water.
IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.
Specific treatment (see supplemental first aid instructions on this label).
Rinse mouth.
If skin irritation occurs: Get medical advice/ attention.
If eye irritation persists: Get medical advice/ attention.
Remove contaminated clothing and wash before reuse.
Dispose of contents/container to an approved waste disposal plant.

Hazards not otherwise classified (HNOC): None

3. COMPOSITION/INFORMATION ON INGREDIENTS

Substances

Synonyms:	Ferrous Sulfate Heptahydrate
Formula:	$FeSO_4 \cdot 7H_2O$
Molecular Weight:	278.01 g/mol
CAS-No.:	7782-63-0
Weight %:	100%

Hazardous components

Component:	Classification:
Ferrous Sulfate Heptahydrate	Acute Tox. 4; Skin Irrit. 2; Eye Irrit. 2A; H302, H315, H319

4. FIRST AID MEASURES

Description of first aid measures

General advice: Consult a physician. Show this safety data sheet to the doctor in attendance. Move out of dangerous area.

If inhaled: If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact: Wash off with soap and plenty of water. Consult a physician.

In case of eye contact: Rinse thoroughly with plenty of water for at least 15 minutes and consult a physician.

If swallowed: Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

Most important symptoms and effects, both acute and delayed: The most important known symptoms and effects are described in the labelling (see Section 2.2) and/or in Section 11.

Indication of any immediate medical attention and special treatment needed: No data available.

5. FIREFIGHTING MEASURES

Extinguishing media

Suitable extinguishing media: Use extinguishing measures that are appropriate to local circumstances and the surrounding environment.

Special hazards arising from the substance or mixture: Sulphur oxides, Iron oxides.

Advice for firefighters: Wear self-contained breathing apparatus for firefighting if necessary.

Further information: The product itself does not burn.

6. ACCIDENTAL RELEASE MEASURES

Personal precautions, protective equipment and emergency procedures: Use personal protective equipment. Avoid dust formation. Avoid breathing vapors, mist, or gas. Ensure adequate ventilation. Avoid breathing dust. For personal protection see Section 8.

Environmental precautions: Do not let product enter drains.

Methods and materials for containment and cleaning up: Pick up and arrange disposal without creating dust. Sweep up and shovel. Keep in suitable, closed containers for disposal.

Reference to other sections: For disposal see Section 13.

7. HANDLING AND STORAGE

Precautions for safe handling: Avoid contact with skin and eyes. Avoid formation of dust and aerosols. Provide appropriate exhaust ventilation at places where dust is formed. For precautions see Section 2.

Conditions for safe storage, including any incompatibilities: Keep container tightly closed in a dry and well-ventilated place. Air sensitive. Store under inert gas. Hygroscopic.

Specific end use(s): Apart from the uses mentioned in Section 1 no other specific uses are stipulated.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

Control Parameters

Components with workplace control parameters

Component	CAS-No.	Value	Control parameters	Basis
Ferrous sulfate Heptahydrate	7782-63-0	TWA	1 mg/m^3	USA. ACGIH Threshold Limit Values (TLV)
	Remarks	Upper Respiratory Tract & skin irritation varies		
		TWA	1 mg/m^3	USA. OSHA - TABLE Z-1 Limits for Air Contaminants - 1910.1000
		TWA	1 mg/m^3	USA. NIOSH Recommended Exposure Limits

Exposure Controls

Appropriate engineering controls: Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

Personal Protective Equipment

Eye/face protection: Safety glasses with side-shields.

Skin protection: Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Body protection: Complete suit protecting against chemicals, the type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection: For nuisance exposures use a particle respirator. For higher level protection use type, wear NIOSH approved air-purifying respirator with cartridges/canisters.

Control of environmental exposure: Do not let product enter drains.

9. PHYSICAL AND CHEMICAL PROPERTIES

Physical and Chemical Properties

Physical State:	Solid	
Appearance:	Blue Green crystals	Odor: No data available
Color:	Blue-Green	Odor Threshold: No data available

Property	**Values**
pH	3.0 – 4.0 @ 50 g/l @ 25º C (77º F)
Melting/freezing point	Melting point/range: 64º C (147º F)
Flash Point	No data available
Evaporation Rate	No data available
Flammability (solid, gas)	No data available
Flammability Limit in Air	
Upper flammability limit	No data available
Lower flammability limit	N/A
Vapor pressure	No data available
Vapor density	No data available
Specific Gravity	No data available
Water solubility	No data available

Property	**Values**
Solubility in other solvents	No data available
Partition coefficient: n-octanol/water	No data available
Autoiginition temperature	No data available
Decomposition temperature	No data available
Kinematic viscosity	No data available
Dynamic viscosity	No data available
Explosive properties	No data available
Oxidizing properties	No data available

Other Information

Bulk density	1,300 kg/m^3

10. STABILITY AND REACTIVITY

Reactivity: No data available.

Chemical Stability: Stable under recommended storage conditions.

Possibility of Hazardous Reactions: No data available.

Hazardous: Polymerization: No data available.

Conditions to Avoid: No data available.

Incompatible Materials: Strong oxidizing agents.

Hazardous Decomposition Products: Other decomposition products – no data available. In the event of a fire see Section 5.

11. TOXICOLOGICAL INFORMATION

Information on likely routes of exposure

Product information	Inhalation	No data available
	Eye contact	No data available
	Skin contact	No data available
	Ingestion	Harmful if swallowed

Component Information

Information on toxicological effects

Symptoms	No data available

Delayed and immediate effects as well as chronic effects from short & long-term exposure

Sensitization:	No data available.
Mutagenic effects:	No data available.
Carcinogenicity:	No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.
STOT-single exposure:	No data available.
STOT-repeated exposure:	No data available.
Chronic toxicity:	No data available.
Target organ exposure:	No data available.
Aspiration hazard:	No data available.

Numerical measure of toxicity product information

The following values are calculated based on Section 3 of the GHS document: No data available.

12. ECOLOGICAL INFORMATION

Ecotoxicty:	No data available.
Persistence and Degradability:	No data available.
Bioaccumulation:	No data available.
Other adverse effects:	No data available.

13. DISPOSAL CONSIDERATIONS

Waste treatment methods

Disposal methods	Offer surplus and non-recyclable solutions to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material.
Contaminated packaging	Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)	UN Number: 3077 Class: 9 Packing group: III
Proper shipping name	Environmentally hazardous substance, solid, n.o.s. (Ferrous Sulfate Heptahydrate) Reportable Quantity (RQ): 1,000 lbs Marine pollutant: No Poison Inhalation Hazard: No
IMDG	Not dangerous goods.
IATA	Not dangerous goods.

15. REGULATORY INFORMATION

INTERNATIONAL INVENTORIES

TSCA:	CAS# 7782-63-0 is not on the TSCA Inventory because it is a hydrate. It is considered to be listed if the CAS# for the anhydrous form is on the inventory (40CFR720.3(u)(2)). CAS# 7720-78-7 is listed on the TSCA Inventory.
DSL:	CAS# 7720-78-7 is listed on Canada’s DSL List.

US Federal Regulations

SARA 313:	SARA 313: This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA + Title III, Section 313.
SARA 311/312 Hazard Categories:	Acute health hazard Chronic health hazard
CWA (Clean Water Act)	Section 311 Hazardous Substances (40 CFR 117.3) Sulfuric acid, Iron (2) salt (1:1), Heptahydrate Reportable quantity: 1000 lbs.
CERCLA	(40 CFR 302.4) Sulfuric acid, Iron (2) salt (1:1), Heptahydrate Reportable quantity: 1000 lbs.

US State Regulations

California Prop. 65 Components	This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

US State Right-to-Know Regulations

Massachusetts Right-to-Know Components:

Ferrous Sulfate Heptahydrate	CAS-No. 7782-63-0	Revision Date: 1993-04-24

Pennsylvania Right-to-Know Components:

Ferrous Sulfate Heptahydrate	CAS-No. 7782-63-0	Revision Date: 1993-04-24

New Jersey Right-to-Know Components:

Ferrous Sulfate Heptahydrate	CAS-No. 7782-63-0	Revision Date: 1993-04-24

International Regulations

Canada **WHMIS Hazard Class:** Uncontrolled product; Disclosure at 1%.

16. OTHER INFORMATION

NFPA Rating	Health hazard: 2	Fire Hazard: 0	Reactivity Hazard: 0
HMIS Rating	Health hazard: 2 Physical Hazard 0	Chronic Health Hazard: Flammability: 0	

Further information

This SDS summarizes to the best of our knowledge at the date of issue, the chemical health and safety hazards of the material and general guidance on how to safely handle the material in the workplace. Since QC LLC cannot anticipate or control the conditions under which the product may be used, each user must, prior to usage, assess and control the risks arising from its use of the material. The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. QC LLC and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.qccorporation.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Issuing Date New

Revision Date 25, Mar - 2015

Revision Number 1

APPENDIX E

Supplemental Investigation Work Plan
SAP/QAPP, Addendum 3

Sampling and Analysis Plan and Quality Assurance Project Plan
Addendum No. 3

Play Area Groundwater Treatment Interim Action Work Plan
Gas Works Park Site
Seattle, Washington

for
Puget Sound Energy

August 1, 2017

GeoEngineers
Earth Science + Technology

Sampling and Analysis Plan and Quality Assurance Project Plan
Addendum No. 3

Play Area Groundwater Treatment Interim Action
Work Plan
Gas Works Park Site
Seattle, Washington

for
Puget Sound Energy

August 1, 2017

GeoEngineers

Plaza 600 Building
600 Stewart Street, Suite 1700
Seattle, Washington 98101
206.728.2674

Sampling and Analysis Plan and Quality Assurance Project Plan

Addendum No. 3

Play Area Groundwater Treatment Interim Action Work Plan

Gas Works Park Site

Seattle, Washington

File No. 0186-846-01

August 1, 2017

Prepared for:

Puget Sound Energy
P.O. Box 90868, PSE 12
Bellevue, Washington 98009-0868

Attention: John Rork

Prepared by:

GeoEngineers, Inc.
Plaza 600 Building
600 Stewart Street, Suite 1700
Seattle, Washington 98101
206.728.2674

Claudia De La Via
Environmental Engineer

Dan Baker, LG, LHG
Principal

CDV:DMB:leh

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ATTACHMENTS

1.0 INTRODUCTION

This document is the third addendum to the sampling and analysis plan (SAP) and quality assurance project plan (QAPP) for the Supplemental Investigation at the Gas Works Park Site (GWPS) in Seattle, Washington. This SAP and QAPP Addendum No. 3 (SAP-QAPP addendum) presents additional investigation methods that will be used for groundwater monitoring during Play Area Interim Action groundwater treatment, and serves as the primary guide for the integration of quality assurance (QA) and quality control (QC) functions into field activities. This SAP-QAPP addendum has been prepared in general accordance with the Model Toxics Control Act (MTCA), Chapter 173-340-820 of the Washington Administrative Code (WAC). Unless specifically noted in this SAP-QAPP addendum, the activities described in this addendum will be conducted under the March 2013 *Supplemental Investigation Work Plan* (GeoEngineers, 2013) including the Sampling and Analysis Plan (Appendix A) and Quality Assurance Project Plan (Appendix B), approved by the Washington State Department of Ecology (Ecology) on March 11, 2013. The *Supplemental Investigation Work Plan* described an environmental investigation designed to meet the data needs for completing the RI. Data collected during that investigation were summarized in the Agency Review Draft Site-Wide Remedial Investigation Report (GeoEngineers, 2016).

Elevated concentrations of arsenic were detected in soil and groundwater samples collected from beneath the Play Area during the 2013 supplemental upland investigation (GeoEngineers, 2016). Additional information regarding the nature and extent of arsenic in soil and groundwater was obtained during investigations of the Play Area in 2014 and 2016 (GeoEngineers, 2016 [Appendix Y]; GeoEngineers, 2017 [in progress]). An arsenic treatability study performed in 2016 indicated dissolved arsenic concentrations could likely be reduced by application of iron amendments (Anchor QEA, 2016). Groundwater injection infrastructure was installed in spring 2017 to facilitate in-situ treatment of arsenic in groundwater beneath the Play Area.

Groundwater monitoring activities summarized in this third SAP-QAPP addendum, will be used to document baseline groundwater conditions before treatment, and evaluate the effectiveness and permanence of in-situ treatment of dissolved arsenic.

Groundwater monitoring during the Play Area Interim Action will consist of the following:

- Baseline monitoring to evaluate pre-treatment conditions at the Play Area,
- Short-term performance monitoring during reagent injection to evaluate the immediate influence of the injection,
- Post-injection performance monitoring to evaluate treatment performance approximately one month after injection, and
- Confirmation monitoring after an extended period (3 months or more) following treatment to evaluate long-term performance and stability of the arsenic treatment.

Groundwater sample numbering will follow the sample numbering convention included in the 2013 SAP.

2.0 GROUNDWATER MONITORING

This section presents field sampling methods that are not contained in the 2013 SAP and QAPP or that deviate from the methods described therein. Play Area monitoring well locations are shown on Interim Action Work Plan Figures 5 and 6. Monitoring well construction and groundwater elevation information are summarized in Table E-1. A summary of the proposed groundwater samples and analyses is presented in Table E-2. The following sections describe the activities to be conducted during each groundwater monitoring event. Unless noted, groundwater samples will be collected using the procedures presented in the 2013 SAP including:

- Groundwater depth measurements,
- Light and dense nonaqueous phase liquid (LNAPL and DNAPL) depth measurements (if present), and
- Groundwater sampling using low-flow/low-turbidity methods.

Groundwater monitoring activities will be recorded in field reports and on groundwater sampling forms as described in the 2013 SAP.

2.1. Baseline Groundwater Monitoring

One groundwater monitoring event will be performed to obtain chemical analytical data to document groundwater conditions before in-situ treatment (baseline). Groundwater samples will be collected from the 17 Play Area monitoring wells, and analyzed for field parameters, total and dissolved arsenic, total and dissolved iron, sulfide and sulfate (Table E-2). Samples from selected monitoring wells, as shown in Table E-2, will be collected for arsenic speciation analysis using the anoxic sampling methodology described in SAP-QAPP Attachment E-1. Standard low-flow sampling procedures will be used to obtain groundwater samples during the baseline event. The volume of water purged from each monitoring well before sampling will be measured and recorded, and used as the purge volume to be removed from each monitoring well during subsequent sampling events.

2.2. Short-Term Performance Monitoring

Short-term performance monitoring will be performed to document groundwater conditions during and shortly after reagent injection. Groundwater samples will be collected from the seven monitoring wells within the targeted treatment area (Table E-2). Short-term performance monitoring will include hourly measurements of depth-to-groundwater during reagent injection; and monitoring of field parameters, iron, and sulfate approximately twice per week for two weeks after reagent injection. Iron and sulfate concentrations will be measured in the field using colorimetric field tests; Hach IR-18 for iron (range: 0 to 4 milligrams per liter [mg/L]) and Hach SF-1 for sulfate (range: 50 to 200 mg/L), or equivalent, following manufacturer's instructions. Some groundwater samples may be submitted to the analytical laboratory for iron and sulfate analysis to be sure the detection range of the field test kits are acceptable for detecting the anticipated concentrations of iron and sulfate in the groundwater samples. Iron and sulfate test kit information and operating instructions are included in Attachment E-2.

2.3. Post-Injection Performance Monitoring

Post-injection performance monitoring is anticipated to be completed approximately 1 month following injection. Like the baseline monitoring event, groundwater samples will be collected from the 17 Play Area monitoring wells, and analyzed for field parameters, total and dissolved arsenic, total and dissolved iron, sulfide and sulfate (Table E-2). Unlike the baseline event, samples will not be collected for arsenic speciation analysis.

2.4. Confirmation Monitoring

Confirmation monitoring is anticipated to be completed at least three months after final reagent injection. Groundwater samples will be collected from 11 selected Play Area monitoring wells, and analyzed for field parameters and total and dissolved arsenic (Table E-2).

3.0 LABORATORY ANALYTICAL METHODS

The analytical methods to be used for sample analysis, as well as details regarding containers, sample preservatives, and sample holding times, are listed in Table E-3.

Table E-4 lists the field quality control (QC) samples to be collected during this investigation. Field QC samples will consist of equipment rinsate blanks, trip blanks, and field duplicates, and will be documented in field reports. As discussed in the 2013 QAPP, field QC samples will be used to evaluate the effectiveness of equipment decontamination procedures, potential cross-contamination of samples during transport to the laboratory, reproducibility of laboratory results, and sample heterogeneity.

4.0 FIELD DOCUMENTATION, INVESTIGATION DERIVED WASTE, AND SAMPLE HANDING PROCEDURES

Unless noted here field documentation, investigation-derived waste management, and sampling handling procedures will be performed using the procedures presented in the 2013 SAP including:

- Daily field reports including groundwater monitoring forms,
- Sample labels, and
- Laboratory Chain-of-Custody forms.

5.0 REFERENCES

Anchor QEA, 2016a. Draft Arsenic Treatability Study Report, Gas Works Park, prepared by Anchor QEA, LLC, for GeoEngineers, Inc., December 2016.

GeoEngineers, Inc. 2013. Final Supplemental Investigation Work Plan, Gas Works Park Site, Seattle, Washington.

GeoEngineers, Inc. 2014. Final Supplemental Investigation Work Plan, Gas Works Park Site, Seattle, Washington.

GeoEngineers, Inc. March 1, 2016. Agency Review Draft Site-Wide Remedial Investigation Feasibility Study Report, Gas Works Park Site, Seattle, Washington.

GeoEngineers 2017, *In progress*. Draft Play Area 2016 Supplemental Investigation Data Report, last revised June 30, 2016.

Table E-1

Play Area Monitoring Well Construction Summary

SAP-QAPP Amendment 3

Gas Works Park Site

Seattle, Washington

Well ID	Well Location		Top of Casing Elevation[1,2]	Screen Interval Depth Below Ground Surface at Time of Installation		Geologic Unit of Screen Interval
	Northing	Easting		Top	Bottom	
Play Area						
MW-36S	239086.77	1270783.61	26.37	8.0	22.8	Fill
MW-36D	239091.49	1270785.63	26.30	29.3	33.8	Outwash
MW-41S	239123.85	1270626.07	29.02	5.3	10.3	Fill
MW-41D	239126.07	1270628.03	29.19	18.3	28.3	Outwash
MW-42S	239153.02	1270667.56	32.85	3.8	8.8	Fill
MW-43S	239087.49	1270677.38	29.03	7.4	12.4	Fill
MW-44S	239159.31	1270720.72	30.29	7.5	17.5	Fill
MW-45S	239142.50	1270725.64	30.74	6.8	16.8	Fill
MW-45D	239138.49	1270727.34	30.00	25.8	30.8	Outwash
MW-46S	239143.44	1270760.23	24.84	7.3	17.3	Fill
MW-46D	239148.59	1270760.61	24.92	30.0	25.0	Outwash
MW-47S	239111.94	1270743.90	29.80	15.0	20.0	Fill
MW-48D	239081.86	1270756.15	26.80	22.4	32.4	Outwash
MW-49D	239063.29	1270775.15	26.15	24.9	34.9	Outwash
MW-50D	239117.04	1270793.29	25.06	28.5	33.5	Outwash
MW-51S	239136.65	1270795.79	25.37	6.4	16.4	Fill
MW-52D	239147.84	1270796.96	25.31	29.9	34.9	Outwash

Notes:

1. Elevations are relative to NAVD88 vertical datum.
2. Top-of-casing elevations for monitoring wells MW-41S, MW-41D, MW-42S, MW-44S, MW-45S, and MW-45D (shaded cells) are interim elevations. Permanent, flush-mounted protective monuments have not yet been installed. Monuments will be installed and top-of-casing elevations will be surveyed after Play Area renovations are complete.

Table E-2

Play Area Groundwater Sample Summary

SAP-QAPP Addendum 3
Gas Works Park Site
Seattle, Washington

Well ID	Well Screen Geologic Unit	Well Type	Baseline Sampling						Performance Monitoring										Confirmation Monitoring	
									Short-Term Performance Monitoring				Treatment Performance Monitoring							
			Prior to beginning injection						Hourly during injection	Two times per week following injection[4]			1 month after end of injection						At least 3 months after final injection	
			Field Parameters[1]	Arsenic[2] (200.8)	Arsenic Speciation (IC-ICP-MS)	Iron[3] (SW6010)	Sulfide (SM4500-S2-D)	Sulfate (300.0)	Water Levels	Field Parameters[1]	Iron[5]	Sulfate[6]	Field Parameters[1]	Arsenic[2] (200.8)	Iron[3] (SW6010)	Sulfide (SM4500-S2-D)	Sulfate (300.0)	Field Parameters[1]	Arsenic[2] (200.8)
MW-36S	Fill	Downgradient	X	X		X	X	X					X	X	X	X	X		
MW-36D	Outwash	Downgradient	X	X		X	X	X					X	X	X	X	X		
MW-41S	Fill	Upgradient	X	X		X	X	X					X	X	X	X	X		
MW-41D	Outwash	Upgradient	X	X		X	X	X					X	X	X	X	X		
MW-42S	Fill	Performance	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
MW-43S	Fill	Performance	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
MW-44S	Fill	Performance	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X
MW-45S	Fill	Performance	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
MW-45D	Outwash	Performance	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
MW-46S	Fill	Performance	X	X	X	X	X	X					X	X	X	X	X	X	X
MW-46D	Outwash	Performance	X	X	X	X	X	X					X	X	X	X	X	X	X
MW-47S	Fill	Performance	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X
MW-48D	Outwash	Performance	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
MW-49D	Outwash	Downgradient	X	X		X	X	X					X	X	X	X	X		
MW-50D	Outwash	Downgradient	X	X		X	X	X					X	X	X	X	X		
MW-51S	Fill	Downgradient	X	X		X	X	X					X	X	X	X	X		
MW-52D	Outwash	Downgradient	X	X		X	X	X					X	X	X	X	X		

Notes:

1. Field parameters include: water level, dissolved oxygen, oxidation/reduction potential, specific conductance, turbidity, temperature, and pH.
2. Total and dissolved arsenic. Dissolved arsenic sample to be field filtered.
3. Total and dissolved iron. Dissolved iron sample to be field filtered.
4. Sample twice weekly for 2 weeks following reagent injection.
5. Iron by colorimetric field test kit. Hach IR-18 or equivalent.
6. Sulfate by colorimetric field test kit. Hach SF-1 or equivalent.

Table E-3

Test Methods, Sample Containers, Preservatives and Holding Times

SAP-QAPP Addendum No. 3
Gas Works Park Site
Seattle, Washington

Analysis	Method	Minimum Sample Size	Sample Containers	Sample Preservatives	Sample Holding Times[1]
		Water	Water	Water	Water
Arsenic	EPA 200.8 (water)	500 mL	500 mL HDPE	Cool <6 °C, HNO_3 to pH < 2 (Dissolved metals preserved after filtration)	180 days to digestion, 180 days to analysis
Iron	SW6010 (water)				
Sulfide	SM 4500-S2-D-0 (water)	500 mL	500 mL HDPE	Cool <6 °C, Zinc Acetate (NaOH added in lab), pH > 9	7 days
Sulfate	EPA 300.0 (water)	500 mL	500 mL HDPE	Cool <6 °C	28 days
Arsenic Speciation	EPA 6800M (modified) (IC-ICP-MS) (water)	5 mL	125 mL HDPE	Cool 0-4° C, prepreserved with EDTA/acetic acid, minimal headspace, keep dark*	28 days

Notes:

1. Holding times are based on elapsed time from date of sample collection.

g = gram
°C = degrees Celsius
EDTA = ethylenediaminetetraacetic acid
EPA = U.S. Environmental Protection Agency
HDPE = High density polyethylene
HNO_3 = nitric acid
H_2SO_4 = Sulfuric acid
mL = milliliter
NaOH = Sodium hydroxide
pH = potential of hydrogen
* Field-filtration recommened, especially for samples with high levels of solids.

Table E-4

Quality Control Sample Types and Minimum Frequency

SAP/QAPP Addendum No. 3

Gas Works Park Site

Seattle, Washington

		Field QC Samples			Laboratory QC Samples			
Parameter	**Reporting Limit**	**Field Duplicates**	**Trip Blanks**	**Equipment Rinsate Blanks**	**Method Blanks**	**Blank Spike, LCS or OPR**	**MS/MSD**	**Lab Duplicates**
Arsenic	0.2 µg/L	1 per 20 primary groundwater samples	NA	1	1 per batch*	1 per batch*	1 MS only per batch*	1 per batch*
Total Iron	0.05 mg/L							
Sulfide	0.05 mg/L							
Sulfate	0.1 mg/L							
Arsenic Speciation	0.2 µg/L	1 (minimum) or 1 per 20 primary groundwater samples	NA	none				

Notes:

*An analytical batch is defined as a group of samples taken through a preparation procedure and sharing a method blank, LCS, and MS/MSD (or MS and lab duplicate). No more than 20 field samples are contained in one batch.

LCS = Laboratory control sample

MS = Matrix spike

MSD = Matrix spike duplicate

NA = Not applicable

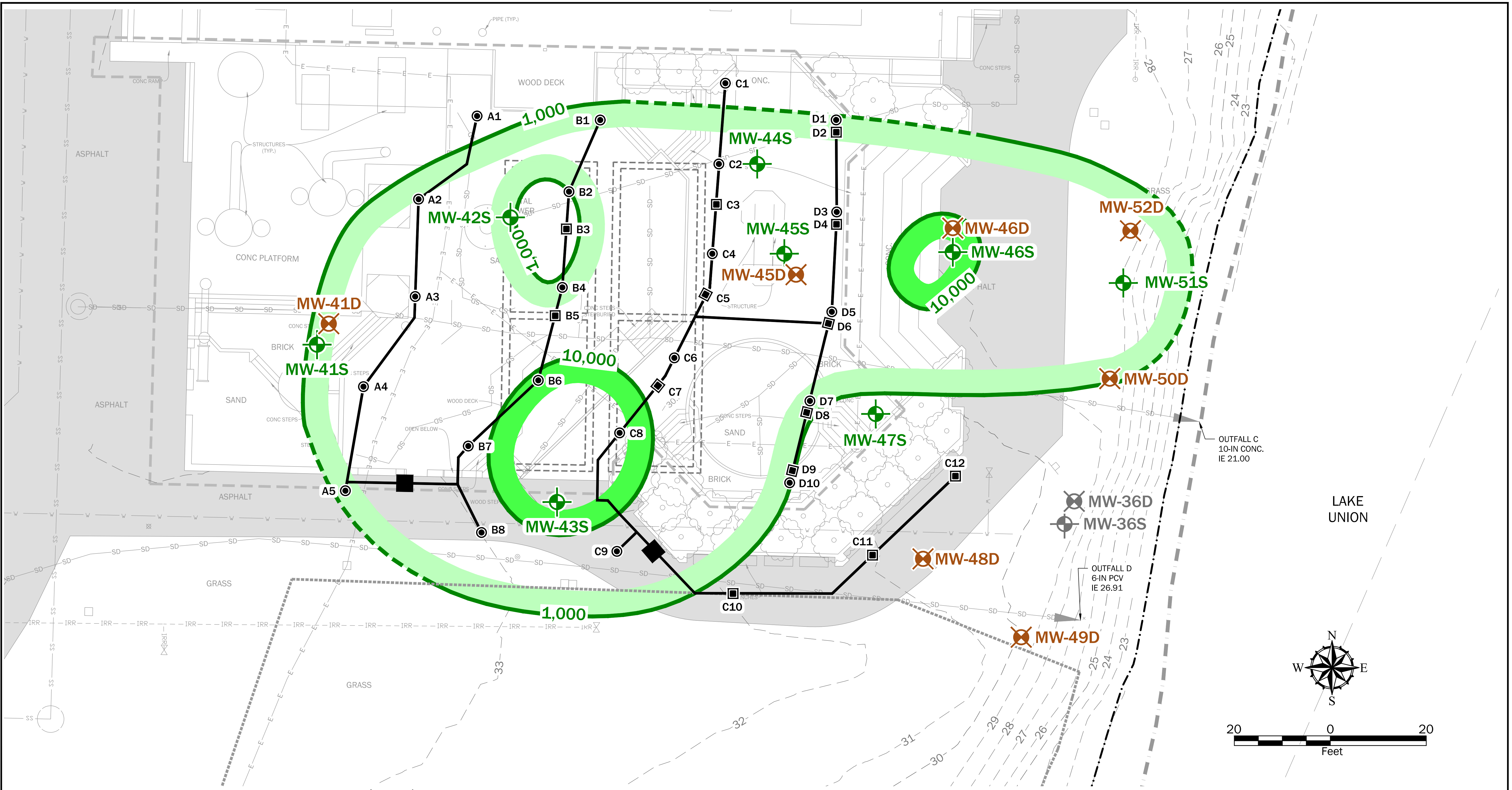
OPR = Ongoing precision and recovery

µg/L = micrograms per liter

mg/L = milligrams per liter

FIGURES

GEOENGINEERS



Notes:

1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Data Source:

- Existing conditions survey by Seattle Parks and Recreation, November 2002
- Construction Completion Report by Thermo RETEC, January 2001
- Outfall C and D based on APS Survey, December 2014

Legend

---30---	Existing Contour (USACOE)
---SD---	Existing Stormdrain
---W---	Existing Water
---E---	Existing Electrical
▬ ▬	Play Area Renovation Footprint
┈┈┈	Approximate Edge of Existing Impermeable Liner
▨	Existing Asphalt, Gravel, and/or Concrete
⌖	Existing Monitoring Well - Fill
☒	Existing Monitoring Well - Outwash
1,000	Interpreted Fill Dissolved Arsenic Concentration Contour (Dashed where inferred) (µg/L)
-·-·-	Ordinary High Water

Proposed Injection Infrastructure and Monitoring Wells

A1 ◉	Injection Well - Fill
B3 ▣	Injection Well - Outwash
━■	Trenched Injection Pipe and System Vault
MW-46S ⌖	Monitoring Well - Fill
MW-46D ☒	Monitoring Well - Outwash

Injection Infrastructure and Monitoring Well Network - Fill Dissolved Arsenic

Gas Works Park Site
Seattle, Washington

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Figure 5

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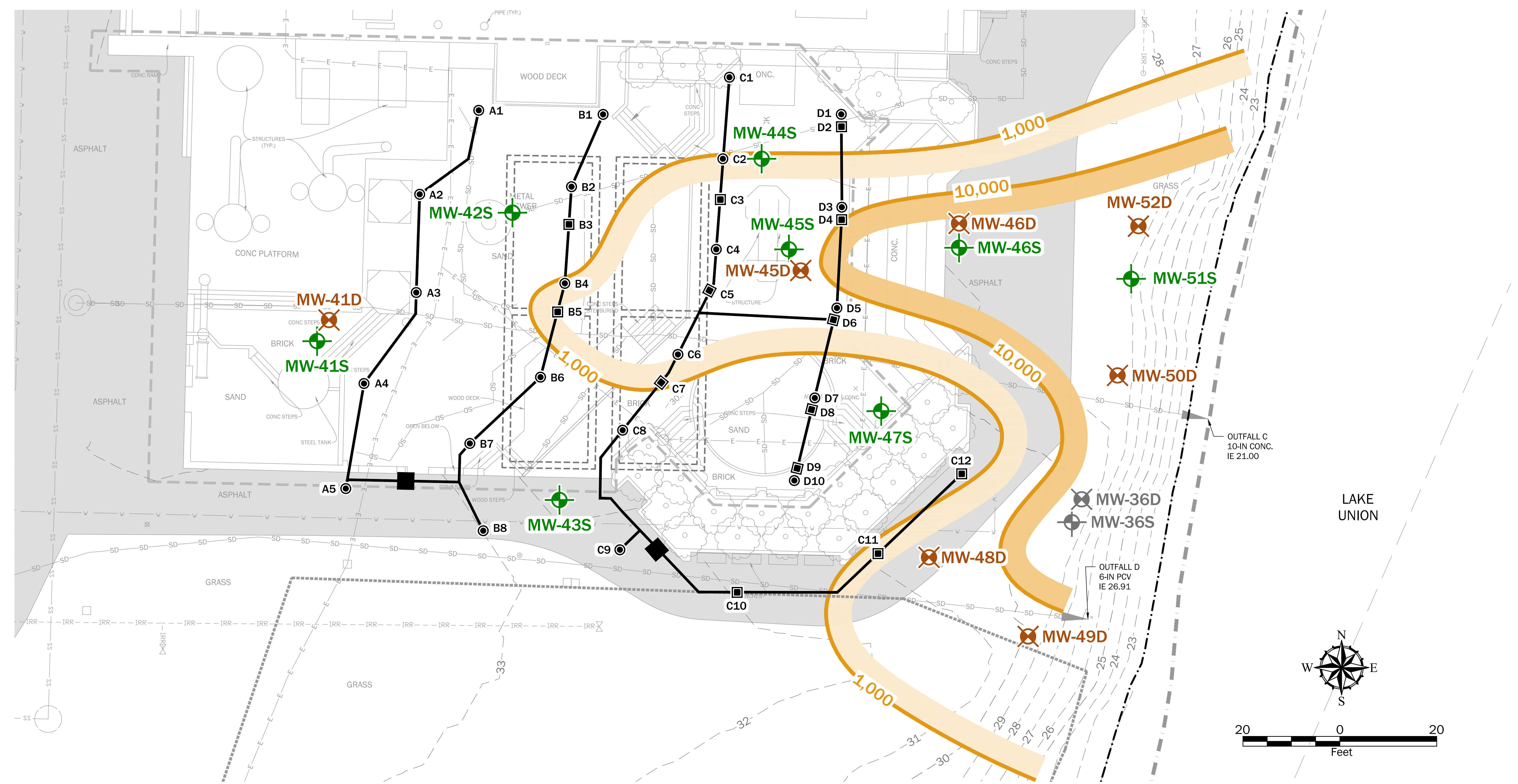

Notes:

1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Data Source:

- Existing conditions survey by Seattle Parks and Recreation, November 2002
- Construction Completion Report by Thermo RETEC, January 2001
- Outfall C and D based on APS Survey, December 2014

Legend

- - -30- - - Existing Contour (NAVD88)

— SD — Existing Stormdrain

— W — Existing Water

— E — Existing Electrical

- - - Play Area Renovation Footprint

····· Approximate Edge of Existing Impermeable Liner

▨ Existing Asphalt, Gravel, and/or Concrete

⊕ Existing Monitoring Well - Fill

⊗ Existing Monitoring Well - Outwash

~1,000~ Interpreted Outwash Dissolved Arsenic Concentration Contour (µg/L)

-·-·- Ordinary High Water

Proposed Injection Infrastructure and Monitoring Wells

A1 ◉ Injection Well - Fill

B3 ▣ Injection Well - Outwash

—■— Trenched Injection Pipe and System Vault

MW-46S ⊕ Monitoring Well - Fill

MW-46D ⊗ Monitoring Well - Outwash

Injection Infrastructure and Monitoring Well Network - Outwash Dissolved Arsenic

Gas Works Park Site
Seattle, Washington

GeoEngineers

Figure 6

ATTACHMENTS

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ATTACHMENT E-1

Arsenic Speciation - Anoxic Field Sample Technique

ATTACHMENT E-1

Arsenic Speciation - Anoxic Field Sample Technique

Safety

This method uses a surgical steel needle. Use caution to avoid injury with the needle.

Materials (see Figure 1)

15 mL Syringe barrel with Luer-lock fitting
Luer-lock 25-gauge surgical steel needle
Luer-lock 0.45 µm filter
Evacuated sample vial with septum – non-preserved or EDTA-coated
Sharps container

Method

Water samples collected for arsenic speciation analysis are sensitive to redox changes. The purpose of this groundwater sampling technique is to mimic anoxic conditions—minimizing the exposure to oxygen. Follow these procedures after low flow purging is complete, groundwater parameters are stabilized and the monitoring flow through cell (YSI) has been disconnected.

1. Label the sample vial before sampling.
2. Allow for a segment of silicon (Tygon, Masterflex, or equivalent) tubing, approximately 6-inches long, on the discharge end of the peristaltic or submersible pump.
3. Remove any air within the syringe barrel. Attach the surgical needle to the barrel.
4. Point the needle against the current of the groundwater, insert the needle into the silicon tubing. Puncture tube about 3 inches from the end, this punctured segment will need to be cut to minimize spillage when filling subsequent bottle ware.
5. Draw approximately 15 millileters (mL) of water into the barrel. To minimize the amount of oxygen in the barrel, draw water slowly. Water may flow into the barrel by itself, displacing the small amount of air in the barrel. Be careful not to pull the plunger out of the barrel.
6. Extract the syringe from the tubing. Detach the needle from the barrel. Hold the syringe needle side up, gently flick the barrel to dislodge bubbles from the walls within, and slowly depress the syringe plunger to expel any air pockets.
7. Attach the Luer-lock 0.45 micrometer (µm) filter onto the barrel (fits only in one direction). Attach the needle on the filter.
8. Gently depress the plunger to expel a small amount of water through the filter and needle, this will hydrate the filter and the needle. Be sure to retain approximately 6 mL to fill each vial.
9. Insert the needle through the septum of the evacuated sample vial. Gently depress the plunger to fill the vial with water. Note it is normal for the vacuum in the vial to pull some water into the vial. Do not fill the vial completely, instead try to “balance” the vial without over pressurizing it, the plunger will resist. The vial will contain a small amount of headspace.

10. Remove the needle from the evacuated sample vial.
11. Place the vial in a plastic bag, seal the bag, and place the sample in a cooler with ice.
12. Discard the syringe into an appropriate “sharps” disposal container when finished.

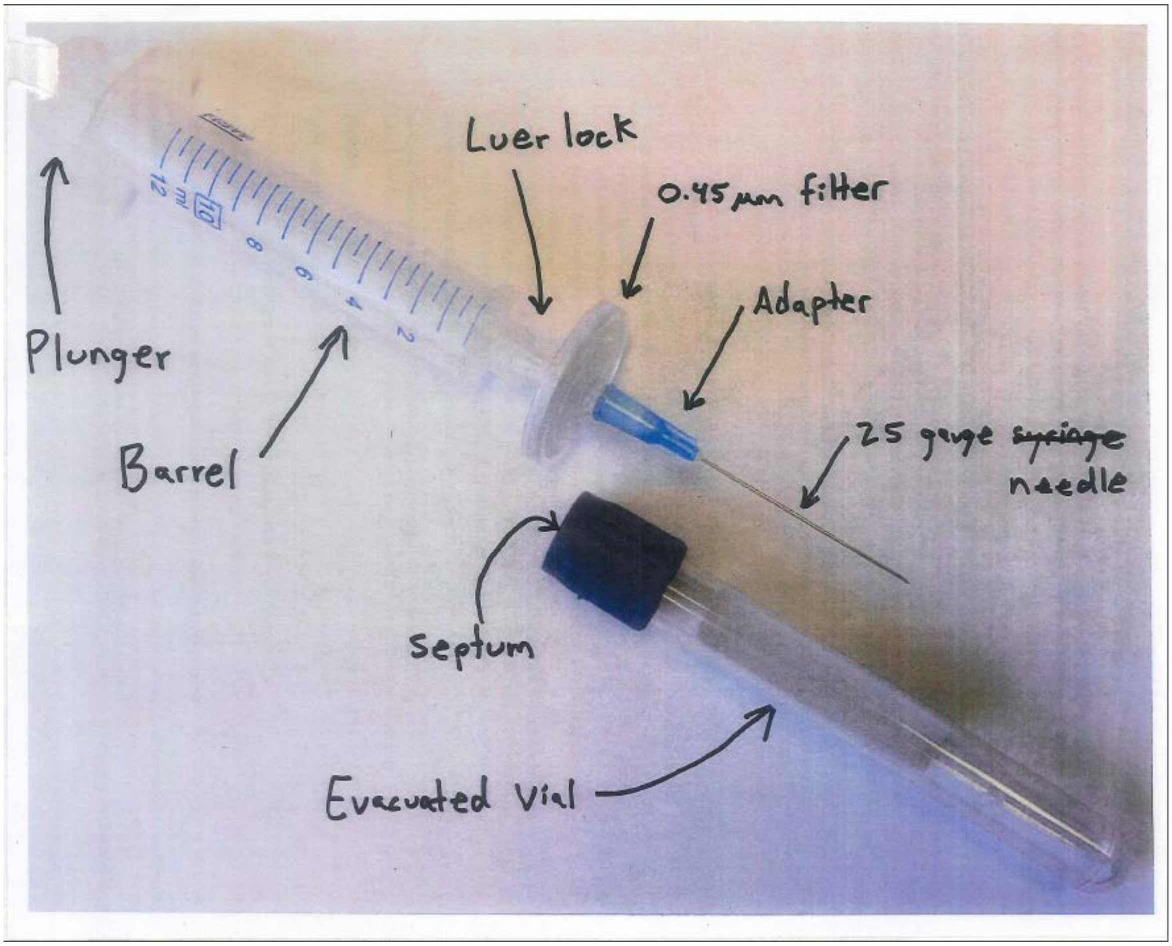


Figure 1
Groundwater Arsenic Speciation Sample Collection Materials

ATTACHMENT E-2

Field Test Kit Information and Instructions (Iron and Sulfate)

Iron Test Kit

IR-18 (146400)

DOC326.98.00042

Test preparation

CAUTION:* ⚠ *Review the Safety Data Sheets (MSDS/SDS) for the chemicals that are used. Use the recommended personal protective equipment.

- Put the color disc on the center pin in the color comparator box (numbers to the front).
- Use the indoor light color disc when the light source is fluorescent light. Use the outdoor light color disc when the light source is sunlight.
- Rinse the tubes with sample before the test. Rinse the tubes with deionized water after the test.
- If the color match is between two segments, use the value that is in the middle of the two segments.
- If the color disc becomes wet internally, pull apart the flat plastic sides to open the color disc. Remove the thin inner disc. Dry all parts with a soft cloth. Assemble when fully dry.
- Undissolved reagent does not have an effect on test accuracy.
- To verify the test accuracy, use a standard solution as the sample.
- If the sample contains rust or precipitated iron, fully mix the sample and then fill the tubes. Wait 2–5 minutes after the reagent is added. Dissolved iron develops a color immediately.
- Samples that contain more than 4 mg/L iron can give low results. If high iron levels are possible, dilute the sample as follows. Use a 3-mL syringe to add 2.5 mL of sample to each tube. Dilute the sample to the 5-mL mark with deionized water. Use the diluted sample in the test procedure and multiply the result by 2. Use the syringe to add 1 mL of sample to each tube. Dilute the sample to the 5-mL mark with deionized water. Use the diluted sample in the test procedure and multiply the result by 5.

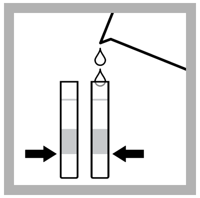
Replacement items

Description	Unit	Item no.
FerroVer® Iron Reagent Powder Pillows, 5 mL	100/pkg	92799
Color disc, iron, indoor light, 0–4 mg/L	each	9262400
Color disc, iron, outdoor light, 0–4 mg/L	each	9263800
Color comparator box	each	173200
Plastic viewing tubes, 18 mm, with caps	4/pkg	4660004

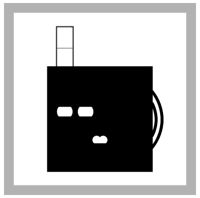
Optional items

Description	Unit	Item no.
Caps for plastic viewing tubes (4660004)	4/pkg	4660014
Water, deionized	500 mL	27249
Glass viewing tubes, glass, 18 mm	6/pkg	173006
Iron standard solution, 1 mg/L Fe	500 mL	13949
Stoppers for 18-mm glass tubes and AccuVac Ampuls	6/pkg	173106
Syringe, Luer-Lok® Tip, 3 mL	each	4321300

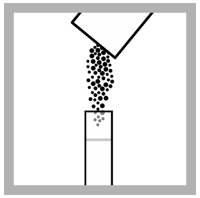
Test procedure—Iron (0–4 mg/L Fe)



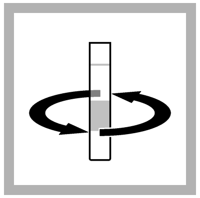
1. Fill two tubes to the first line (5 mL) with sample.



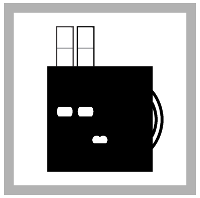
2. Put one tube into the left opening of the color comparator box.



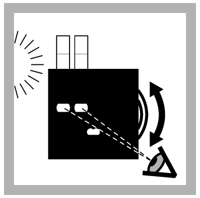
3. Add one FerroVer Iron Reagent Powder Pillow to the second tube.



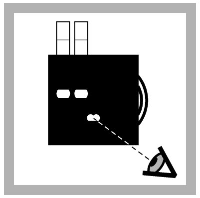
4. Swirl to mix. An orange color develops.



5. Put the second tube into the color comparator box.



6. Hold the color comparator box in front of a light source. Turn the color disc to find the color match.



7. Read the result in mg/L in the scale window.

12/2015, Edition 1

SULFATE TEST KIT
Model SF-1
Cat. No. 2251-00

HACH

To ensure accurate results, please read carefully before proceeding.

The sample mixing bottle, graduated cylinder and dipstick should be cleaned thoroughly after each use. If this is not done, a white film will form on the wall of the apparatus.

Test Instructions:

1 Fill the sample mixing bottle to the 25-mL mark.

WARNING: The chemical in this kit may be hazardous to the health and safety of the user if inappropriately handled. Please read all warnings before performing the tests and use appropriate safety equipment.

2. Use the clippers to open one SulfaVer® 4 Powder Pillow. Add the contents of the pillow to the mixing bottle. Press the cap on tightly and shake the bottle for 15 seconds.

3. A white turbidity will appear if sulfate is present.

4. Allow the sample to stand five minutes.

5. Invert the bottle to mix any solids left on the bottom. Remove the cap on the mixing bottle and slowly pour the contents into the clean 25 mL graduated cylinder

6. Hold the cylinder in a vertical position. While looking straight down into the cylinder slowly insert the sulfate dipstick down into the cylinder until the black dot disappears completely Hold the dipstick in that position and rotate the cylinder so you view the scale on the dipstick through the non-graduated portion of the cylinder

7 Read the concentration by looking across the surface of the sample to the scale on the dipstick. The number on the dipstick scale that meets with the surface of the sample corresponds to mg/L of sulfate in the sample.

8. If the black dot disappears before the first test mark (200 mg/L), the concentration of sulfate is greater than 200 mg/L. If the black dot does not disappear after the dipstick is inserted to the cylinder bottom, the sulfate concentration is less than 50 mg/L.

Replacements

Cat. No.	Description	Unit
12065-66	SulfaVer 4 Powder Pillows	pkg/50
46814-00	Dipstick, Sulfate Measure	each
24102-00	Bottle, mixing, plastic	pkg/2
968-00	Clippers	each
2172-40	Cylinder, graduated, polymethylpentene	each

SulfaVer is a Hach Company trademark.

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