Groundwater Treatability Pilot Study
Work Plan, Lot 3
Campus Bay, Richmond, California

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Prepared for
Cherokee Simeon Venture I, LLC,
Zeneca Inc., and
Bayer CropScience Inc.

Prepared by
LFR an Arcadis Company
1900 Powell Street, 12th Floor
Emeryville, California 94608

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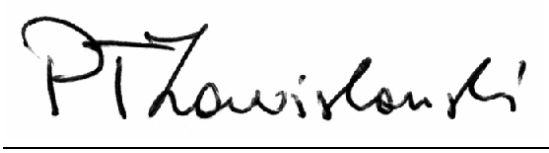
CERTIFICATION

All engineering information, conclusions, and recommendations in this document have been prepared under the supervision of and reviewed by an LFR Inc. California Professional Geologist.



September 24, 2009

Peter T. Zawislanski
Principal Geologist
California Professional Geologist (7210)
Certified Hydrogeologist (925)

Date

1.0 INTRODUCTION

LFR Inc. an ARCADIS company (LFR) has prepared this "Groundwater Treatability Pilot Study Work Plan" ("the Work Plan") for groundwater underlying Lot 3 at the former Zeneca Inc. facility, now known as Campus Bay, located at 1391 South 49th Street in Richmond, California ("the Site"; Figure 1). This Work Plan describes the procedures and methodologies for evaluating the effectiveness of in situ remediation technologies at decreasing the concentration of dissolved metals detected in localized areas of groundwater. The California Department of Toxic Substances Control (DTSC) required that this Work Plan be prepared in a letter dated June 16, 2009 ("the June 16, 2009 Letter"). LFR prepared the Work Plan in accordance with the requirements of the DTSC Site Investigation Order, Docket No. 04/05-006 ("the DTSC Order") on behalf of Cherokee Simeon Venture I, LLC (CSV), Zeneca Inc., and Bayer Crop Science Inc., collectively known as "the Respondents" to the DTSC Order[1].

1.1 Work Plan Objectives

Between 2003 and the present, concentrations of arsenic, copper, nickel, and zinc (contaminants of concern [COCs]) in groundwater have at times exceeded screening criteria at monitoring wells MW-10A, MW-10B, MW-11A, and MW-11B (Figure 2; the Study Area). Increasing trends in some of the COCs have been observed at these wells. Therefore, as discussed in the June 16, 2009 letter, the DTSC required that a work plan be developed with the procedures and methodologies for assessing the effectiveness of select in situ remedial alternatives at decreasing dissolved concentrations of arsenic, nickel, copper, and zinc detected in upper and lower horizon groundwater at the Study Area. Wells MW-10A and MW-11A represent upper horizon groundwater. Wells MW-10B and MW-11B represent lower horizon groundwater. The general approach of the pilot study described in this Work Plan was discussed in an August 5, 2009 conference call attended by representatives from CSV, the DTSC, and LFR. The general approach was memorialized in a memorandum prepared by LFR and submitted to the DTSC on August 21, 2009 (LFR 2009). As discussed previously with the DTSC, the objectives of this Work Plan are to:

1) Describe the procedures and methodologies for collecting grab groundwater samples for laboratory analysis. The additional groundwater analytical data will aid in the implementation of this pilot study and the design of the full scale remedial alternative.
2) Describe the procedures and methodologies for a groundwater treatability test, including bench scale and pilot testing, that will help evaluate the effectiveness of injecting calcium polysulfide (CaSx) to decrease the concentrations of divalent

[1] The Regents of the University of California is also listed as a respondent to the DTSC Order.

metals (e.g. nickel, copper, zinc) detected in groundwater at wells MW-11A, and MW-10B and MW-11B.

3) Describe the procedures and methodologies for laboratory bench and treatability tests that will evaluate various remediation approaches to decrease concentrations of arsenic, nickel, and zinc in the vicinity of well MW-10A (upper horizon groundwater).

1.2 Work Plan Organization

This Work Plan is organized as follows:

- **Section 2: Site Description -** Section 2 of the Work Plan provides a description of the Site and a summary of the site geology and hydrogeology. This section also provides a discussion of the dissolved metal concentrations detected in groundwater monitoring wells MW-10A, MW-10B, MW-11A, and MW-11B.
- **Section 3: Additional Grab Groundwater Sampling -** Section 3 of the Work Plan describes the procedures and methodologies for the collection and chemical analysis of additional grab groundwater samples. This section also discusses the applicable groundwater screening criteria.
- **Section 4: Groundwater Treatability Pilot Study –** Section 4 of the Work Plan describes the pilot test and quick-turnaround bench test that have been designed to assess the effectiveness of CaSx at reducing dissolved concentrations of copper, nickel and zinc detected in groundwater at wells MW-11A, MW-10B and MW-11B.
- **Section 5.0: Bench Scale Treatability Testing –** Section 5 of the Work Plan discusses the design for laboratory treatability tests to assess the effectiveness of various treatment technologies and their effect on dissolved arsenic and divalent metals concentrations detected in groundwater at well MW-10A.
- **Section 6.0: Data Analysis and Reporting –** Section 6 of the Work Plan discusses how the data will be documented and what reports will be prepared for submittal to the DTSC.
- **Section 7.0: Schedule –** Section 7 of the Work Plan provides an approximate schedule for the pilot testing activities.

2.0 SITE BACKGROUND INFORMATION

2.1 Site Description

Campus Bay is an approximately 86-acre Site that is located in the City of Richmond, California, in the South Shoreline area, just south of Interstate 580 between the Regatta and Bayview exits, two blocks west of the Bayview interchange (Figure 1). In accordance with the DTSC Order, the 86-acre Site has been divided into the following

six sub-areas referred to as Lot 1, Lot 2, Lot 3, Habitat Area 1, Habitat Area 2, and Southeast Parcel. The proposed Study Area is located within a small portion of Lot 3 and Habitat Area 1.

The Lot 3 parcel comprises approximately 60 acres and includes Building B-240, which is currently unoccupied. A paved road lies south and west of Building B-240. The remaining portion of Lot 3 consists of exposed soil surfaces or treated cinder material that is currently capped with Kuma Type II Hydroseal. The Study Area is generally located downgradient of the Biologically Active Permeable Barrier (BAPB) and upgradient of the East Stege Marsh (ESM) near MW-10A/B and MW-11A/B (Figure 2).

2.2 Site Geology

The site geology in the upper 100 ft below ground surface (bgs) comprises Late Pleistocene and Holocene estuarine and alluvial deposits. The estuarine units consist of fine-grained sediments including Bay Mud and Yerba Buena Mud. The coarse-grained alluvial deposits are locally continuous and inter-fingered in alternating layers with the estuarine units. The alluvial sediments were deposited from the Berkeley Hills, located east and northeast of the Site, and provide the significant water-bearing units beneath the Site. Sediments in the ESM were likely accumulated from runoff transported via Carlson Creek. Sediment deposits at ESM generally range from 2 to 8 ft in thickness. South of Lot 3, near the bay margin, Bay Sediments are present and continue to be deposited.

2.3 Site Hydrogeology

Shallow groundwater upgradient from and beneath ESM generally flows toward the Bay through the upper and lower horizons encountered beneath the fill. The upper horizon is a fine-grained zone containing laterally discontinuous sand and gravel units that range from approximately 1 to 3 ft thick, and is generally encountered at depth less than 20 feet bgs. The deeper water-bearing unit (lower horizon) is encountered above the Yerba Buena Mud at depths ranging from approximately 25 to 40 ft bgs. In most of the Study Area, depth to groundwater ranges from 5 to 6 feet bgs. Based on data from the tidal study (LFR 2007a), groundwater discharging into ESM is primarily from the shallower water-bearing unit.

2.4 Recent Groundwater Monitoring Results

As part of the quarterly groundwater monitoring activities currently conducted at the Site, concentration trends are assessed using a Mann-Kendall analysis for chemicals that exceed specific aquatic screening criteria in groundwater samples collected during groundwater monitoring at the Site. The analysis uses data collected over the last six to eight years and evaluates the data at a 95% confidence level. Statistical trend results and recent groundwater monitoring results for samples collected between February

2008 and May 2009 for the Study Wells are summarized in Table 1 and are briefly discussed below. The concentration versus time graphs for arsenic, copper, nickel and zinc are provided in Figures 3 through 6.

Well MW-10A: For samples collected between February 2008 and May 2009, concentrations of arsenic, nickel, and zinc ranged above the site-specific screening criteria for upper horizon groundwater in well MW-10A. The Mann-Kendall statistical analysis indicates an increasing arsenic trend. Nickel and zinc data do not exhibit a statistical trend at the 95% confidence level. Based on the concentration trend graphs, between February 2008 and May 2009 arsenic was detected above the site-specific screening criteria in only the February 2008 sample. Arsenic concentrations fluctuate seasonally, with higher concentrations detected during the wetter (higher precipitation) months of the year. Nickel and zinc concentrations also fluctuate seasonally, with the higher concentrations typically detected during the drier months of the year. Groundwater collected at well MW-10A exhibits slightly acidic and slightly reducing geochemical conditions (inferred from the presence of ferrous iron and negative to low oxidation-reduction potential [ORP]).

Well MW-11A: Between February 2008 and May 2009, the detected concentrations of copper and zinc ranged above the site-specific screening criteria for upper horizon groundwater in well MW-11A. The Mann-Kendall statistical analysis indicates an increasing copper trend. Zinc data do not exhibit a statistical trend at the 95% confidence level. At well MW-11A, nickel and zinc concentrations fluctuate seasonally, with the higher copper and zinc concentrations typically detected during the drier months of the year. Groundwater collected at well MW-11A exhibits slightly acidic to neutral and reducing geochemical conditions (as inferred from the absence of ferrous iron and low ORP).

Well MW-10B: Between February 2008 and May 2009, concentrations of copper, nickel, and zinc ranged above the site-specific screening criteria for lower horizon groundwater in well MW-10B. The Mann-Kendall statistical analysis indicates an increasing statistical trend for copper, nickel, and zinc. Groundwater collected at well MW-10B exhibits slightly acidic and slightly reducing geochemical conditions (as inferred from non-detect to low concentrations of ferrous iron and positive ORP).

Well MW-11B: Between February 2008 and May 2009, concentrations of copper, nickel, and zinc ranged above the site-specific screening criteria for lower horizon groundwater in well MW-11B. The Mann-Kendall statistical analysis indicates no trend at the 95% confidence level for arsenic, copper, nickel, or zinc. Groundwater collected at well MW-11B exhibits slightly acidic and slightly reducing geochemical conditions (as inferred from the presence of ferrous iron).

3.0 ADDITIONAL GRAB GROUNDWATER SAMPLING

The overall objective for the additional grab groundwater sampling is to provide an additional understanding of groundwater conditions that will aid in the implementation

of this pilot study and the design of a full-scale remedial alternative. The additional data will also serve to further characterize geochemical conditions in the Study Area. The field activities discussed in this Section of the Work Plan will be conducted in accordance with the procedures and methodologies set forth in the following LFR documents previously approved by the DTSC:

- "Lot 3 Field Sampling and Analysis Plan, Campus Bay Site, Former Zeneca, Inc., Richmond Facility, Richmond, California," dated November 2, 2005 ("the Lot 3 FSAP");
- "Revised Quality Assurance Project Plan Approval, Former Zeneca Property, Campus Bay Site," dated July 18, 2005; and
- "Revised Health and Safety Plan, Environmental and Associated Activities, Campus Bay Site, Former Zeneca, Inc., Richmond Facility, Richmond, California," (HSP) dated July 18, 2005.

The approximate locations of grab groundwater sampling are illustrated on Figure 7. Upper- and lower-horizon grab groundwater samples will be collected downgradient (San Francisco Bay side) from the BAPB. Upgradient from the BAPB, only lower-horizon samples will be collected. The upper-horizon data set previously collected as part of the remedial investigation activities completed from 2006 through 2007 has sufficiently characterized upper-horizon groundwater in this area for the purpose of this pilot study.

3.1 Pre-field Investigation Activities

3.1.1 Permitting

LFR will apply for the appropriate well installation permit(s) with the Contra Costa County.

3.1.2 Subsurface Utility Clearance

Potential locations of underground utilities will be determined before soil intrusive work is performed. The state underground utility notification authority, Underground Service Alert (USA), will be contacted prior to the start of intrusive field activities, in accordance with local notification requirements. Additionally, a qualified private underground utility locating contractor will be contracted to identify possible subsurface obstructions and utilities within a five foot radius of each sample location. If underground utilities are identified within approximately 5 feet of a proposed drilling location, LFR will revise the proposed location accordingly, and will repeat the underground utility clearance procedures as necessary. As an added precaution, individual borings will be started by hand augering to approximately 5 feet bgs to bypass potentially undetected shallow underground utilities.

3.2 Proposed Direct-Push Borings for Grab Groundwater Sampling

3.2.1 Cone Penetration Testing (CPT) Boring Advancement

In accordance with the procedures provided in the Lot 3 FSAP, a CPT rig will be used to advance a soil boring at each grab groundwater sample location identified in Figure 7. The objective of using the CPT rig is to identify permeable lithologic units in the subsurface. An instrumented probe will be attached to the end of hollow steel rods and advanced into the subsurface using direct push methodologies. As the rods progress into the subsurface, the instrumented probe will record the resistance of the soil along the tip of the probe, the frictional resistance along the cylindrical friction sleeve of the instrumented probe, and the pore-water pressure. Electronic signal processing equipment will relay these data in real time to a data acquisition, processing, and storage computer system located in the CPT rig. This computer system will correlate the data to provide the lithology encountered by the sensor probe as it is advanced into the subsurface.

The lithologic data generated from the CPT-instrumented probe will be evaluated to identify changes in subsurface lithology and aid in identifying an appropriate water-bearing zone for the collection of grab groundwater samples. As illustrated in Figure 7, grab groundwater samples will be collected from the upper and lower horizon at locations downgradient of the BAPB and upgradient of the ESM. Samples will be collected from up to three depth intervals selected from the surface to approximately 40 feet bgs to further delineate the vertical distribution of dissolved metals in groundwater. If feasible, grab groundwater samples will be collected from the approximate target depths of 10 to 20 feet bgs for the upper horizon and between 25 and 40 feet in the lower horizon.

In addition, as illustrated on Figure 7, grab groundwater samples will be collected from the lower horizon upgradient of the BAPB. Groundwater samples will be collected from up to two depth intervals between approximately 25 feet bgs and 40 feet bgs to further delineate the vertical and horizontal distribution of metals in lower horizon groundwater, as shown on Figure 7.

3.2.2 Grab Groundwater Sampling

In accordance with the grab groundwater sampling procedures described in the Lot 3 FSAP, the grab groundwater samples will be collected from a separate soil boring located adjacent to the CPT boring. The grab groundwater sample will be collected using a hollow-rod assembly with a 3-foot long stainless steel screen attached at the leading end of the assembly (Hydropunch). The screen will be advanced to the desired depth interval based upon the CPT-derived lithology. At the selected depths, the rod assembly will then be retracted exposing the screen. Grab groundwater samples will be collected using a disposable bailer lowered through the hollow-push rods. The groundwater will be field-filtered through a 0.45 micron filter prior to transfer into

clean laboratory-provided sample containers, stored in an ice-chilled cooler, and transported under chain-of-custody protocol to the laboratory for analysis.

Grab groundwater samples will be submitted to Curtis & Tompkins, Ltd., a state-certified laboratory. The analytical tests to be requested include the following:

- Title 22 Metals plus iron and manganese (EPA Method 6010/EPA Method 7470)
- Ferrous iron (SM 3500FeD)
- Sulfide (EPA Method 376.2)
- Major cations: calcium (Ca), magnesium (Mg), sodium (Na), potassium (K) (EPA Method 6010)
- Major anions: bromide (Br), chloride (Cl), sulfate (SO_4) (EPA Method 300.0)
- Alkalinity (total, carbonate, bicarbonate; EPA Method 310.1)

In addition, pH and oxidation reduction potential (ORP) will be measured in the field. The soil boring locations will be recorded by a California-licensed surveyor in accordance with the Lot 3 FSAP. Drilling and sampling equipment will be properly decontaminated in accordance with the procedures described in the Lot 3 FSAP. Down-hole drilling equipment, including drill rods will be decontaminated by steam-cleaning at a designated wash pad or within a portable containment unit. Groundwater samples will be collected using single-use disposable bailers and filters.

After groundwater sampling is complete, the soil borings will be abandoned using the procedures described in the Lot 3 FSAP. A neat cement slurry will be pressure grouted through the tubing or rod as it is slowly withdrawn from the hole, sealing the hole from the bottom up, to approximately 1 to 2 feet bgs.

The anticipated investigation-derived waste that will be generated during the field activities will be disposed of in accordance with the procedures described in the Lot 3 FSAP. Soil cuttings will be containerized in clean Department of Transportation-approved 55-gallon drums or similar. Used PPE and disposable sampling equipment will be placed in double plastic bags in drums or in an industrial disposal bin. An adhesive label will be affixed to each container, noting the following information: container number, waste type, location where the IDW was generated, and date of waste generation.

The containers storing the generated wastes will be temporarily stored at a centralized location at the site until the waste characterization results are received and disposal is arranged. If necessary for waste disposal, samples of the soil cuttings will be collected to evaluate appropriate disposal options.

3.2.3 Grab Groundwater Analytical Data Assessment

The additional grab groundwater data will be assessed to determine the vertical extent of the pilot test activities at the Study Area. In addition, to support the design of the full-scale remedial alternative, this additional groundwater analytical data will be assessed to identify the lateral and vertical extent of dissolved metals at concentrations that require treatment.

To delineate the vertical extent of the study area, the grab groundwater results will be compared to the applicable site-specific screening criteria. Due to the proximity of Lot 3 to East Stege Marsh and San Francisco Bay, groundwater data collected from Lot 3 for metals are compared to aquatic criteria with a location-specific dilution factor (DF) applied. The aquatic criteria are the more stringent of the 10x Human Consumption of Aquatic Organisms value and the Salt Water Aquatic Criteria value. An evaluation of DFs for the Site was developed as part of the Draft Feasibility Study and Remedial Action Plan ("Draft FS/RAP"; EKI 2008). The applicable aquatic criteria for arsenic, copper, nickel, and zinc in groundwater are included in Table 1. The following DFs for Lot 3 groundwater were developed in Appendix I of the Draft FS/RAP:

- Upper horizon groundwater in the habitat area near the biologically active permeable barrier (BAPB): 5
- Upper horizon groundwater in the upland portions of Lot 3: 40
- Lower horizon groundwater on Lot 3: 160

4.0 GROUNDWATER TREATABILITY PILOT STUDY

A remedial alternative for treating copper, nickel, and zinc in the vicinity of MW-10B, MW-11A, and MW-11B is in-situ treatment by CaSx injection to upper horizon and lower horizon groundwater. CaSx binds metals by precipitation as sulfides and also, to a lesser extent, as hydroxides. Due to the very low solubility of sulfide phases, metal sulfides are more stable than other precipitates, and are less affected by long-term pH changes. The objectives of the proposed pilot test injection of CaSx are:

- to confirm the effectiveness of treatment in the field in a different site location;
- to evaluate the radius of influence (ROI) of injection;
- to evaluate the ability to effectively distribute CaSx; and
- to measure the potential formation of unfavorable byproducts.

CaSx was previously (2002) applied in the upland parts of Lot 3 to treat dissolved metals in upper horizon groundwater (LFR 2003). Concentrations of copper, nickel, and zinc were reduced by about an order of magnitude. The treatment was especially effective in removing copper from groundwater. Given the previous successful application of CaSx, proof-of-concept laboratory testing is not required prior to field

application of CaSx for the treatment of divalent metals. However, direct injection has not been performed in areas downgradient from the BAPB, or in the lower horizon groundwater. Therefore, prior to the implementation of field injection, a quick-turnaround laboratory bench test will be performed to determine the optimal CaSx dosage for upper and lower horizon groundwater and soil in these areas.

The groundwater treatability pilot study will be implemented within a local area in the direct vicinity of wells MW-10B and MW-11A/B (Figure 8). Prior to implementation of the treatability pilot study, a memo documenting the results of the additional grab groundwater sampling and the proposed injection depth intervals for the treatability pilot study will be submitted for DTSC review and approval. Upon receipt of approval from the DTSC, three injection points will be advanced for the treatability pilot study to evaluate the use of in situ groundwater remediation to treat elevated concentrations of copper, nickel, and zinc detected in upper and lower horizon groundwater and meet regulatory requirements for metals concentrations. Performance monitoring will be completed at 15 monitoring wells (12 new wells and 3 existing monitoring wells) to evaluate the extent of the CaSx in the subsurface and to monitor the effectiveness of the CaSx in reducing dissolved concentrations of copper, nickel, and zinc in groundwater.

The data collected over the course of the pilot study will assist in the design of a full-scale injection system, if deemed appropriate for this localized area of the Site.

4.1 Calcium Polysulfide Laboratory Bench Test

A laboratory bench test will be performed on soil and groundwater samples collected from the upper and lower horizon to determine an appropriate concentration of CaSx solution to treat copper, nickel, and zinc in groundwater in the pilot study treatment area.

4.1.1 Soil and Groundwater Sample Handling, Preparation, and Storage

Groundwater for the bench test will be collected from wells MW-11A and MW-11B. Groundwater samples will be collected using low-flow groundwater sampling techniques in accordance with the Lot 3 Field Sampling and Analysis Plan (LFR 2005a) to collect accurate field parameters, particularly pH and ORP. Groundwater will be in-line filtered (0.45 micron) and collected in nitrogen-gas-purged containers. Following field filtration, approximately 5 liters of groundwater will be collected from each well.

Approximately 3 kilograms of soil will be collected from each of the upper and lower horizons. Soil will be obtained from a borehole located within 5 to 15 feet of wells MW-11A and MW-11B using direct-push sample methodology. One continuous core will be collected from approximately 5 ft bgs to 15 ft bgs (representing upper horizon soil). A second continuous core will be collected from approximately 25 ft bgs to 35 ft bgs (representing lower horizon soil). Soils will be collected using a hydraulic drill rig and a dual-tube sampling system. Soil cores will be collected in clear Lexan sleeves, which will be capped immediately after retrieval from the core barrels to minimize

contact with air. Soils will be described through the Lexan sleeve. Soil cores will be labeled, identifying the depth intervals. Soil cores will be frozen with dry ice, then preserved with blue ice and shipped overnight to a treatability laboratory, following chain-of-custody protocols. At the treatability lab, the soil will be processed in an anaerobic chamber. The first centimeter of soil on either end of each core segment will be discarded to eliminate the portion of the soil that is most likely to have been oxidized during sampling. The remainder of each core from each depth interval will be thoroughly homogenized, using a soil chopper or blade. Prior to the initiation of the treatability study, soil samples will be kept on dry ice.

Field duplicates of soil and water samples will not be collected because the purpose of the sample collection is to provide material for treatability testing and not site characterization or routine monitoring.

4.1.2 Calcium Polysulfide Batch Testing

All soil and groundwater handling, and pH and ORP measurement will be performed in an anaerobic chamber. In each test, 250 grams of soil and 500 ml of groundwater will be placed in a 1-liter, acid-rinsed and distilled-water-rinsed glass jar. CaSx will be added to each jar at a prescribed dosage (Table 2). The range of dosages for CaSx was based on direct experience with this additive and on similar tests presented in the technical literature. The same range of dosages will be applied for each of the two soil-groundwater combinations, one representing upper horizon conditions and the other representing lower horizon conditions.

The mixture will be shaken vigorously for approximately 1 minute, either by hand or on a laboratory shaker, to obtain a well-mixed slurry. After 15 minutes of equilibration, pH and ORP will be measured, using calibrated electrodes. The jars will then be placed on a mechanical shaker table to maintain the soil and groundwater in contact with each other. The mixtures will be mechanically mixed for 24 hours. pH and ORP will be measured once again after equilibration.

Following the treatment, each sample will be decanted, centrifuged (if needed), and filtered through a 0.45-micron filter. The pH, ORP, and conductivity of the filtrate will be measured immediately. The remaining soil will be placed in labeled glass jars in refrigerated storage, pending potential future testing. The filtrate will be submitted to a certified analytical laboratory for the analysis of the following constituents:

- Metals: arsenic, copper, cadmium, iron, lead, manganese, mercury, nickel, selenium, and zinc (EPA Method 6010/EPA Method 7470)
- Ferrous Fe (SM 3500FeD)
- Sulfide (EPA Method 376.2)
- Major cations: Ca, Mg, Na, K (EPA Method 6010)
- Major anions: Cl, SO_4 (EPA Method 300.0)

- Alkalinity (total, carbonate, bicarbonate; EPA Method EPA 310.1)

4.1.3 Data Evaluation

The analytical results from the quick-turnaround bench test will be received from the analytical laboratory in 5 days. The data will be evaluated to determine the optimal CaSx dosage to be applied in the pilot test. The relative percentage of metals immobilized and the presence or absence of unfavorable byproducts are the two key factors that will be used to assess treatment and dosage effectiveness.

4.2 General Approach for Treatability Pilot Test

The CaSx injection will be performed by a subcontractor specializing in the delivery of fluids to the subsurface. The CaSx solution will be prepared to the desired concentration and will then be injected using a dedicated delivery system that is capable of providing specified pressures and flow rates at the injection point at the desired volumes based on the subsurface lithology. Pressure, flow rate, and reagent concentration will be adjusted as needed during the injection.

A conservative tracer (bromide, as potassium bromide) will be injected along with the CaSx solution to evaluate the radius of influence of the pressure injection and the time lag between the conservative tracer (bromide) and the non-conservative indicators (pH, ORP, and sulfide). This time lag can be used to calculate a retardation factor for the CaSx solution, which is effectively a measure of the rate at which the CaSx reactivity is depleted in the groundwater treatment zone.

4.3 Pre-Injection Field Activities

4.3.1 Pre-Field Activities

Pre-field investigation activities described under Section 3.1 will also be conducted prior to implementation of the injection pilot study, including permitting and subsurface utility clearance. LFR will inquire with Contra Costa County and the City of Richmond whether any additional permits would be required specific to conducting the proposed injection pilot test.

Additionally, the existing HSP will be amended as necessary to incorporate the most recent groundwater monitoring data, and to address health and safety concerns specific to the field procedures associated with CaSx groundwater injection. Health and safety meetings will be conducted in the field at the start of the project and each day before beginning fieldwork. All fieldwork will be monitored according to the HSP to ensure that appropriate health and safety procedures are followed. A copy of the HSP will be kept on site during field work activities.

4.3.2 Installation of Injection Points and Monitoring Wells

Pilot study injection points will be installed approximately 5 feet upgradient of existing groundwater monitoring wells MW-10B and MW-11A/B to evaluate the radius of influence (ROI) for in situ remediation and injection within the Study Area (Figure 8). The proposed strategy is to conduct direct injection using a Geoprobe boring. However, in the event that field implementation of the injection point demonstrates that the direct-push injection technology is not feasible within the Study Area due to low injection rates, excessive back-pressure, and/or surfacing of the reagent, LFR will install injection wells instead. The target depth for the injection points (or wells) will be based on the results of the additional grab groundwater sampling.

The injection monitoring wells (IMWs) will be installed at the approximate locations illustrated on Figure 8. The IMWs will be designed so that the screen interval extends from approximately the same depth as the injection treatment interval. Four IMWs will be installed near each injection point to observe the effects of CaSx injection to groundwater within the treatment areas both downgradient and cross-gradient of the injection points, and to monitor the influence of CaSx injections in the Study Area. The existing monitoring wells MW-10B and MW-11A/B will also be monitored. Monitoring wells will be spaced approximately 5 feet in the downgradient and cross-gradient direction of each injection point/well. The spacing of the monitoring wells is based on the known lithology in the study area and on hydraulic characteristics of the upper and lower horizon groundwater zones.

The injection will be followed by a 3-month-long monitoring period during which groundwater samples will be periodically collected to evaluate the CaSx distribution and treatment effectiveness.

4.3.2.1 Injection Point Installation

Direct push technology will be used to advance a 1.5-to-2-inch-diameter injection tool to the bottom of the injection zone. The injection depth interval will depend on the results of the additional groundwater characterization. Once the total depth is reached, an injection cap/manifold will be secured to the top of the tool string.

4.3.2.2 Drilling Methodology

The proposed temporary IMWs (and injection wells, if necessary) will be installed using hollow-stem auger (HSA) drilling technology with continuous-core barrel for lithologic data collection, in accordance with the procedures discussed in the Lot 3 FSAP. LFR will subcontract a California-certified drilling contractor to drill and install the proposed IMWs (and injection wells) under supervision of LFR field staff working under the direction of an LFR California Professional Geologist.

During drilling, a 5-foot-long continuous core barrel will be used to collect a continuous soil core, as feasible, at each proposed monitoring well location. The soil

core will be examined and the lithology will be logged by an LFR field geologist using the USCS. Boring logs will be prepared for each of the borings under the direction of a California Professional Geologist using these data.

4.3.2.3 Well Construction Details

IMWs and injection wells to be installed for the treatability pilot study will be constructed of 2-inch-diameter Schedule 40 polyvinyl chloride (PVC). The depth of the screened interval for the treatability pilot study treatment zones is nominally estimated to be from 8 to 13 feet bgs for the upper horizon and between 25 to 35 ft bgs for lower horizon. These depth intervals were selected to provide increased vertical coverage through the affected saturated interval.

Wells will be installed using the following methodology designed to limit the potential for short-circuit pathways to form due to well construction. Due to their different purposes, the construction details of the monitoring and injection wells will differ.

Monitoring Well Construction Details

After the desired depth of the boreholes is reached, the augers will then be slowly removed from the borehole as the monitoring well casing, sand, bentonite, and grout are added from the bottom up. Approximately 10 feet of 0.010-inch slotted well screen will be installed in each IMW. As the augers are being removed, the annular space between the well screen and the formation will be filled with No. 2/12 sand to a depth of approximately 1 foot above the screened interval. The well screen will be positioned within the boring to screen across the in situ treatment area.

Injection Well Construction Details

In the event that injection wells are deemed necessary for pilot study implementation, the following well construction details will be followed. The screened interval of the injection wells will be placed fully below the groundwater table, to prevent reagent short-circuiting through the vadose zone. The screened section of the injection wells will be constructed of PVC Circumslot casing, which is a PVC equivalent of wire-wound screen, and which has a much higher intake area than standard slotted pipe design. It is anticipated that either 5- or 10-foot lengths of 0.010-inch slotted well screen will be installed in each well, depending on the results of the groundwater characterization study.

The injection wells will be installed using the following methodology designed to maximize injection flow rates and limit the potential for short-circuit pathways to form due to well construction. As the augers are being removed, the annular space between the well screen and the formation will be filled with No. 3 sand to a depth of approximately 1 foot above the screened interval. The sand filter pack around the screened interval will be constructed of coarse sand that will extend from 1/2 foot

below to 1 foot above the screened interval. The coarse sand will be overlain by an approximate 1-foot thick layer of ultra-fine sand, which will extend above the water table; the ultra-fine sand transition zone separates the bentonite seal from the injected reagent, and will reduce the likelihood of the seal being compromised by the reactive chemicals and the heat they generate.

Injection and Monitoring Well Seal Construction Details

Approximately 3 feet of bentonite chips will be placed above the sand pack and hydrated to form a coherent seal. Due to the shallow depth of the wells, the bentonite seal will be dropped down the annulus from the surface. A tamping device will be used to prevent bridging of the bentonite material. The bentonite seal will be placed in three lifts of approximately 1 foot each. Each lift will be hydrated with potable water in such a way as to prevent the displacement of the bentonite material. The bentonite seal will be allowed to hydrate in accordance with the manufacturer's recommendations. The remaining annular space above the bentonite will be filled using a low-shrink cement grout, which is less likely to crack during curing. This is necessary because cracks may potentially provide short-circuit pathways for the injected reagents. A locking well cap will be placed on top of the well casing, and the well will be completed using a traffic-rated Christy box installed approximately 0.25 inch above grade.

4.3.3 Well Development

The newly installed IMWs (and injection wells, if necessary) will be developed to remove sediment from around the screen and to enhance hydraulic communication with the surrounding formation. The grout installed within the annular seal for the monitoring wells will be allowed to cure for a minimum of 72 hours before initiating well development activities. The wells will be developed using a combination of surging and pumping techniques. Observations of indicator parameters, including pH, temperature, specific conductance, quantity, and clarity, will be recorded onto water-quality data sheets after each well volume is purged. In the event that a well recovers slowly, the well will be purged dry and then allowed to recover to approximately 80 percent of its static water level before being purged dry again. The wells will be developed until a minimum of six well casing volumes are removed, relatively sediment-free water is produced, or indicator parameters stabilize in accordance with the following criteria:

Parameter	pH	Conductivity	ORP	Turbidity	DO
Stabilization Criterion	±0.1 units	±3%	±10 mV	±10%	±10%

Notes:
DO = dissolved oxygen
mV = millivolts
ORP = oxidation reduction potential

Previous well development activities at the Site suggest that indicator parameters will stabilize after approximately 10 well volumes are evacuated from the monitoring well. Groundwater samples will be collected at a minimum of 24 to 48 hours after well development is complete and the water-quality parameters have stabilized during purging.

4.3.4 Surveying of Injection Points and IMWs

The elevation, northing, and easting of each newly installed injection well and IMW will be surveyed by a California-licensed surveyor. Elevations of groundwater monitoring wells will be surveyed to the nearest 0.01 foot relative to the 1929 National Geodetic Vertical Datum. These data will allow for the measurement of groundwater elevations, the assessment of groundwater flow direction, and the response of the groundwater table to injection.

4.3.5 Baseline Groundwater Monitoring

In addition to groundwater analytical data already collected as part of the quarterly monitoring, all wells to be used in the evaluation of the treatability pilot test will be sampled prior to the CaSx injection. The initial sampling will provide baseline values to evaluate the effectiveness of the remedial technology.

Groundwater monitoring will be completed using low-flow groundwater sampling techniques in accordance with the Lot 3 Field Sampling and Analysis Plan (LFR 2005a). A slight modification may be implemented to include the use of dedicated Teflon tubing and peristaltic pump instead of dedicated bladder pumps. Groundwater samples will be field-filtered and then submitted to Curtis & Tompkins, Ltd. For the following analyses:

- Title 22 Metals plus iron and manganese (EPA Method 6010/EPA Method 7470)
- Ferrous iron (SM 3500FeD)
- Sulfide (EPA Method 376.2)
- Major cations: calcium (Ca), magnesium (Mg), sodium (Na), potassium (K) (EPA Method 6010)
- Major anions: bromide (Br), chloride (Cl), sulfate (SO_4) (EPA Method 300.0)
- Alkalinity (total, carbonate, bicarbonate; EPA Method 310.1)

In addition, pH and ORP will be measured in the field.

4.4 Calcium Polysulfide Injection

The concentration and volume of CaSx will be estimated based on the results of the bench test (described in Section 4.1), previous experience with in situ injection

remediation projects at the site, and geochemical and hydrogeologic conditions present in the targeted zone of influence for each injection well. The concentrations and volume estimates will be based on the following assumptions:

- The ROI for injection will be approximately 10 feet;
- The CaSx will be diluted approximately 5-fold through advection, dispersion, and diffusion in groundwater;
- The total treatment interval is initially assumed to be 5 feet in the upper horizon groundwater zone and 10 feet in the lower horizon groundwater zone; and
- The porosity of the upper and lower horizon aquifer material is 0.25.

Based on these assumptions, the estimated volume of the surrounding aquifer to be targeted by injection at each injection well is approximately 3,000 gallons in the upper horizon and 6,000 gallons in the lower horizon. The specific treatment locations and depth intervals will be selected based on the results of the additional groundwater characterization. Initial injections will be completed by feeding the CaSx mixture into the injection well at low pressure (approximately 5 psi).

Additional equipment may be used to inject the CaSx mixture at different pressures or flow rates depending on the results of initial injection activities. Records of the volume and strength of the mixture injected into each point will be kept for evaluation and included in a final report to the DTSC.

4.4.1 Injection Procedure

The CaSx solution will be shipped to the Site in concentrated form in U.S. Department of Transportation-approved drums or other containers. The additive will be diluted to the desired concentration on Site, using a transfer pump and a dilution tank. The bromide tracer will be added in solid form to achieve a 1,000 mg/L concentration, equivalent to 0.4 kilograms of bromide for every 100 gallons injected. CaSx is corrosive and needs to be handled in accordance with the handling procedures described in the HSP and the MSDS.

The aboveground equipment will consist of storage tanks, a transfer pump, pneumatic double-diaphragm pumps, ¾-inch-diameter reinforced tubing (minimum 200 pounds per square inch [psi] working pressure rating), valves, and cam-lock connectors. Transfer of the reagents from the storage and/or mixing containers to the point of injection will be performed via double-diaphragm pumps. The reagent will be separately conveyed through ¾-inch diameter reinforced tubing and connected to the injection point with a wellhead containing ball valves, fittings, and a pressure gauge. Injection pressures are expected to range from 5 psi to 50 psi.

CaSx will be injected into the subsurface at the Site using direct-push technology, if possible. The injection casing for the injection point will be raised in 1-foot intervals. One-foot injection zones will be targeted to provide consistent vertical distribution of

CaSx throughout the injection zone. At least 5 feet of the injection casing at each location will remain in the borehole to provide a seal and help prevent surfacing of the injected CaSx. Once the injection is completed in the area, the injection borehole will be pressure-grouted using a neat cement slurry and then patched at the surface to match existing surface material. Alternately, delivery of the additives will occur through specially constructed injection wells.

At the injection point or well, the injection contractor will attach a two-way injection manifold. The manifold will be valved to allow for the independent opening or closing of the additive flow stream. The manifold and the connection between the manifold and the injection well will have a pressure rating of at least 100 psi. The injection contractor will attach chemical-resistant hoses to the other remaining fittings. One hose will lead to the additive, and the other to an open and empty drum or bucket, to serve as a bleed.

The reagent injection process will take place as follows:

1. Prior to injecting reagents, the entire pressurized system will be tested with potable water to check for potential leaks.
2. The additive will then be injected through air-operated diaphragm pumps through a manifold with a pressure relief valve prior to connection to the wellhead. The diaphragm pumps will include flow measurement to provide for accurate tracking of injected reagent.
3. At the completion of reagent injection, a final potable water injection (approximately 50 gallons) will be used to flush the reagent from the injection equipment.

4.4.2 Injection Safety

Prior to pilot-scale test field activities, LFR will update the HSP to address issues related to the injection process. The main hazards associated with in-situ treatment by injection are:

- handling and storage of chemicals
- elevated pressure at injection points
- surfacing of reagent due to the formation of short-circuit pathways in the vadose zone and along the annulus of the injection casing
- standard hazards associated with the operation of heavy equipment

The chemical handling procedures will be developed based on the material safety data sheet for the given chemical and past experience. The MSDSs for the proposed additives are included as Appendix D of this Work Plan. The updated HSP will be reviewed and approved by LFR's Director of Health and Safety, a Certified Industrial Hygienist.

4.5 Performance Monitoring

Performance monitoring analytical data will be collected to evaluate the effectiveness of the injection and assess whether additional injections are warranted. Performance monitoring will be completed over a three-month period. IMWs will be sampled prior to the injection and approximately one day, one week, one month, and three months following the injection event. This injection and monitoring scheme will allow an evaluation of treatment effectiveness after the CaSx reacts with the soil and groundwater and is dispersed with groundwater movement. Injection points or wells will not be sampled.

Groundwater monitoring will be completed using low-flow groundwater sampling techniques described in Section 4.3.5. Field measurements of pH, ORP, and bromide will be used to assess whether the injection front has reached the sampling location. An IMW will not be sampled if changes in pH, ORP, and bromide do not indicate the presence of the injected additive at the IMW.

The list of proposed analyses to be performed on collected groundwater samples will remain consistent with the ongoing study, including monitoring the following analytes:

- pH
- ORP
- Title 22 Metals plus iron and manganese (EPA Method 6010/EPA Method 7470)
- Ferrous iron (SM 3500FeD)
- Sulfide (EPA Method 376.2)
- Major cations: calcium (Ca), magnesium (Mg), sodium (Na), potassium (K) (EPA Method 6010)
- Major anions: bromide (Br), chloride (Cl), sulfate (SO_4) (EPA Method 300.0)
- Alkalinity (total, carbonate, bicarbonate; EPA Method 310.1)

Collected groundwater samples will be submitted to Curtis & Tompkins, Ltd. As monitoring results are obtained, concentrations of COCs in the treated groundwater will be compared to baseline concentrations.

5.0 BENCH-SCALE TREATABILITY TESTING – WELL MW-10A

As described in Section 2.4, arsenic, nickel, and zinc have been detected at or above the site-specific screening criteria for upper horizon groundwater in well MW-10A. Bench-testing of potential remedial technologies for the treatment of arsenic and divalent metals in the well MW-10A area is necessary prior to field application, for the following two key reasons:

- the effectiveness of the remedial approach needs to be tested for multiple COCs; and
- the potential formation of unfavorable by-products as a result of treatment needs to be evaluated (e.g. increase concentrations of divalent metals or arsenic).

The rationale and technical approach for the proposed bench testing are presented below.

5.1 Remediation Approaches for Arsenic and Divalent Metals

Differences in chemistry between arsenic and divalent metals affect remediation design for co-contaminated media. The most common forms of arsenic under environmentally relevant conditions are inorganic oxyanions of trivalent arsenite [As(III)] and pentavalent arsenate [As(V)], and, due to their predominantly negative charge, arsenic solubility increases with pH (Smedley and Kinniburgh 2002).

Strongly oxidizing conditions are generally more favorable for arsenic remediation because arsenate has a greater affinity for surface sorption than arsenite (Manning and Goldberg 1997). Arsenic remediation strategies often rely on sorption and co-precipitation, largely onto and with iron oxides, under oxidized conditions. On the other hand, remediation approaches for divalent metals, such as nickel and zinc, have generally focused on precipitation of metal sulfides under reducing conditions and of metal hydroxides under high-pH conditions. Consequently, the optimal geochemical regimes for the remediation of arsenic and divalent metals are different, necessitating deliberate planning and bench-scale testing prior to field application.

5.2 Groundwater Geochemistry in Well MW-10A

Temporal trends in arsenic, nickel, and zinc concentrations, and in the key geochemical parameters (pH, ferrous iron, and sulfate) are shown on Figure 9. The data exhibit seasonal trends, most likely resulting from seasonally rising and falling groundwater levels. In general, arsenic and ferrous iron concentrations are high in the spring, when the groundwater table is high, whereas nickel, zinc, and sulfate concentrations are highest in the summer and fall, when the groundwater table is low. This pattern is suggestive of redox-controlled processes. Specifically, the correlation of high arsenic with high ferrous iron suggests that arsenic is being solubilized due to reductive dissolution of iron oxyhydroxides. The concurrent decreases in sulfate concentrations are an indication of sulfate reduction and further support the presence of reducing conditions. Conversely, the correlation of high nickel and zinc concentrations with high sulfate and low ferrous iron concentrations suggests that nickel and zinc are being solubilized under more oxidizing conditions due to the oxidation of reduced metal sulfide species.

These trends highlight the differences in the dependence of arsenic, nickel and zinc solubility on redox conditions.

5.3 Evaluation of Potential Treatment Additives

Several treatment additives were evaluated as potential options for the treatment of groundwater in the well MW-10A area. This evaluation is presented in Table 3. The potential treatment approaches are discussed below.

5.3.1 Oxidative Technologies

Chemical oxidants can be used to promote the oxidation of arsenite to arsenate and the precipitation of iron oxyhydroxides. Both of these processes reduce arsenic solubility, primarily through the adsorption of arsenic onto iron oxyhydroxide surfaces (Manning and Goldberg 1997). Additives that have been applied to promote iron and arsenic oxidation include oxygen and ozone (Kim and Nriagu 2000), permanganate (Jazdanian et al. 2004), and hydrogen peroxide (Hug and Leupin 2003). Arsenic treatment with hydrogen peroxide has also been coupled with the addition of iron compounds, such as ferric chloride, to enhance the available iron (Slater et al. 2006). The oxidative approach may be effective for increasing sorption of divalent metals by creating new sorption surfaces; however, it also has the potential to increase metal solubility due to metal-sulfide oxidation.

Hydrogen peroxide was previously applied (in 2004) at the Campus Bay site for the treatment of volatile organic compounds in the vicinity of well MW-20. The injection of hydrogen peroxide coincidentally removed arsenic from groundwater in well MW-20 and no rebound in arsenic concentrations has been observed to date (LFR 2009) Concentrations of divalent metals did not increase in well MW-20 as a result of the hydrogen peroxide injections and have remained low.

5.3.2 Reductive Technologies

Divalent metals and arsenic can be removed from solution under strongly reducing conditions due to co-precipitation with low-solubility sulfide phases (Brown et al. 1998; Kirk et al. 2004; Keimowitz et al. 2007), such as amorphous iron sulfides, metal-sulfides, and arsenic-sulfides. Sulfidic conditions for the purpose of metal remediation can be created biologically, by stimulating sulfate reduction (Suthersan and Payne 2005) or abiotically, through the introduction of sulfide compounds, such as sodium bisulfide (Brown et al. 1998) or calcium polysulfide (Zawislanski et al. 2004; Miller et al. 2006).

Calcium polysulfide was previously injected in the upper horizon groundwater in the upland portion of Lot 3 in 2002 (LFR 2003). The goal of that injection was the removal of copper, nickel, and zinc and the buffering of low-pH in groundwater. Concentrations of copper, nickel, and zinc were reduced by about an order of magnitude. Arsenic was not a target COC for that injection; on average, arsenic concentrations in upland groundwater were low before the injection and have remained low following the injection.

The solubility of arsenic under reducing conditions is the subject of ongoing investigations. Arsenic can be precipitated with sulfides under strongly reducing conditions (Smedley and Kinniburgh 2002). However, under sulfidic conditions there is potential for the formation of soluble arsenic-sulfide complexes (thioarsenites) (Wilkin et al. 2003). The presence of high concentrations of reactive iron may limit thioarsenite formation (O'Day et al. 2004). Recent studies indicate that thioarsenite solubility is inversely proportional to the ratio of reactive iron to free sulfide (Lee et al. 2005). High concentrations of iron may explain the absence of arsenic increases in upper horizon groundwater following treatment with calcium polysulfide.

5.3.3 Zero-Valent Iron Technologies

Zero-valent iron (ZVI) has been used extensively to treat arsenic in soil and groundwater (Su and Puls 2001; Manning et al. 2002). ZVI is reactive and able to release electrons to react with contaminants and water. ZVI reacts with water as described below:

In the presence of oxygen: $Fe^0 + ½O_2 + H_2O = Fe^{2+} + 2OH^-$

In the absence of oxygen: $Fe^0 + 2H_2O = Fe^{2+} + H_2 + 2OH^-$

The resultant ferrous iron (Fe^{2+}) will precipitate in the form of iron oxyhydroxides, which is beneficial for the immobilization of arsenic and metals through sorption or coprecipitation (Lien and Wilkin 2004; Melitas et al. 2002). Corrosion products include oxidized iron minerals such as ferrihydrite, goethite, carbonate green rust and magnetite (Wilkin and Puls 2003). Ferrihydrite has a very high specific surface area given its small particle size (nanoparticulate [approximately 2-6 nm]; Michel et al., 2007) and therefore has a high capacity to sorb arsenic and lead. Oxidation of ZVI to ferrous iron results in pH increases, which can help immobilize divalent metals through precipitation as metal hydroxides. Divalent metals can also be immobilized by precipitation with iron sulfides and carbonate mineral phases. Therefore, ZVI can be effective under both aerobic and anaerobic conditions, and may be less susceptible to seasonal groundwater table fluctuations.

5.3.4 Selection of Treatment Additives

The selection of treatment additives to be tested in the bench-scale treatability study was based on the pros and cons of each additive presented in Table 3 and the discussion presented in Sections 5.3.1 through 5.3.3. The following treatment additives will be evaluated in the bench-scale tests:

- ***oxygen (air)***

  Ambient air (21% oxygen [O_2], by volume) will be used to sparge soil and groundwater in the treatability study. Air was selected from among the oxidants because of better control of distribution relative to hydrogen peroxide, lower

potential for the formation of unfavorable byproducts (bromate, chromate) relative to ozone, and lower likelihood of oxidizing metal sulfides. The application of air would not require a rigorous oxidant demand measurement because it will not aggressively react with reduced organic matter the way that hydrogen peroxide and ozone do.

- ***calcium polysulfide***

  CaSx was selected as a reducing additive. CaSx, also known as "lime sulfur," is a mixture of calcium polysulfides formed by reacting calcium hydroxide with sulfur. The aqueous solution is reddish-yellow in color and strongly alkaline (pH 11). The concentrated CaSx solution (29% solution by weight) will be diluted to target concentrations.

- ***zero-valent iron***

  ZVI, in the form of iron filings, will be tested as a sorptive and reducing additive. The exact type of ZVI to be used for the study will be determined based on availability and price. Two grades of ZVI will be tested, one within a grain size range of 0.05 to 0.5 mm, for potential use in direct injection, and another in a grain size range of 1.0 to 2.0 mm, for potential in situ mixing or permeable reactive barrier installation.

5.4 General Approach

The three selected treatment additives – air, calcium polysulfide, and ZVI – will be tested as part of this groundwater treatability study ("treatability study"), to evaluate their ability to reduce dissolved concentrations of arsenic, nickel, and zinc in groundwater from well MW-10A.

Groundwater for treatability testing will be collected from well MW-10A. Soil will be collected from a location within 5 feet of well MW-10A from a depth ranging from 5 to 15 feet bgs, and corresponding to the vertical extent of the screened interval of well MW-10A. Duplicate samples of groundwater and soil will be analyzed for COCs and key geochemical parameters.

Groundwater and soil will be treated in the laboratory, using a range of dosages of the selected additives, in batch tests. The treated media will be analyzed for COCs and key geochemical parameters. The most effective reagent/dosage combinations will be tested further for chemical stability by exposing the treated media to a range of geochemical conditions, similar to those that can be expected in site groundwater.

5.5 Treatability Study Evaluation Criteria

The purpose of the treatability study is to determine if the treatment additives described in Section 5.2.4 are capable of treating COCs to levels protective of water quality

criteria. Water quality criteria to be used in the evaluation of treatability study results are based on the DTSC-approved aquatic screening criteria provided in Table 1.

5.6 Sample Handling, Preparation, Storage, and Analysis

Approximately 10 kilograms of soil will be collected from a location within 5 feet of monitoring well MW-10A. A continuous core will be collected from depths below the groundwater table (approximately 5 ft bgs) to 10 feet below the groundwater table (approximately 15 ft bgs). Soils will be collected using a hydraulic drill rig and a dual-tube sampling system. Soil cores will be collected in clear Lexan sleeves, which will be capped immediately after retrieval from the core barrels to minimize contact with air. Soils will be described through the Lexan sleeve. Soil cores will be labeled, identifying the depth intervals. Soil cores will be frozen with dry ice, then preserved with blue ice and shipped overnight to a treatability laboratory, following chain-of-custody protocols. At the treatability lab, the soil will be processed in an anaerobic chamber. The first centimeter of soil on either end of the core will be discarded to eliminate the portion of the soil that is most likely to have been oxidized during sampling. The remainder of the core will be thoroughly homogenized, using a soil chopper or blade. Prior to the initiation of the treatability study, soil samples will be kept on dry ice.

Groundwater for the bench test will be collected from well MW-10A using low-flow groundwater sampling techniques in accordance with the Lot 3 FSAP (LFR 2005a) to collect field parameters, particularly pH and ORP. Approximately 20 liters of groundwater will be collected from well MW-10A. Groundwater will be in-line filtered (0.45 μm) and collected in nitrogen-gas-purged containers. Groundwater samples will be labeled, placed in an ice-chilled cooler, and delivered to a treatability laboratory following chain-of-custody protocols. Prior to the initiation of the treatability study, groundwater samples will be kept in refrigerated storage.

Field duplicates of soil and water samples will not be collected because the purpose of the sample collection is to provide material for treatability testing and not site characterization or compliance monitoring.

5.6.1 Preliminary Analysis

Prior to initiation of testing, duplicate subsamples of filtered groundwater will be analyzed for the following analytes:

- pH
- ORP
- Metals: arsenic, copper, cadmium, iron, lead, manganese, mercury, nickel, selenium, and zinc (EPA Method 6010/EPA Method 7470)
- Arsenic speciation (ion-chromatography-inductively coupled plasma spectrophotometry-mass-spectrometry [IC-ICP-MS])

- Ferrous iron (SM 3500FeD)
- Sulfide (EPA Method 376.2)
- Nitrite/Nitrate (EPA Method 353.2)
- Major cations: calcium (Ca), magnesium (Mg), sodium (Na), potassium (K) (EPA Method 6010)
- Major anions: chloride (Cl), sulfate (SO4) (EPA Method 300.0)
- Alkalinity (total, carbonate, bicarbonate; EPA Method 310.1)

Triplicate subsamples of soil will be analyzed for the following analytes:

- pH (saturation paste)
- Total organic carbon (Walkley-Black method)
- Metals -- Title 22 metals plus iron and manganese (EPA Method 6010/EPA Method 7470)

In addition, the fractionation of arsenic (As) on soil in the area of well MW-10A will be evaluated using sequential soil extractions. Sequential or selective extraction techniques provide information on the associations of As with soil fractions. This information is useful in evaluating the relative solubility and potential leachability of As from soil into groundwater. Furthermore, data from As fractionation performed before and after treatment provide supporting information regarding the geochemical reactions that lead to As immobilization and effective treatment.

Three soil samples will be collected from the area of well MW-10A, from a depth interval of approximately 5 to 14 feet bgs (within the screen interval of MW-10A). The samples will be frozen with dry ice, then preserved with blue ice and shipped overnight to a treatability laboratory, following chain-of-custody protocols. At the treatability lab, the soil will be processed in an anaerobic chamber. Each sample will be thoroughly homogenized, using a soil chopper or blade. Prior to the initiation of the treatability study, soil samples will be kept on dry ice.

The sequential extraction consists of six separate extractions, as shown in the Table below:

Sequential Extractions for MW-10A soil:

Step	Soil Fraction	Extractants
1	Ionically Bound / Exchangeable	1 M $MgCl_2$ (pH 7.0) 1 h, 25C, continuous agitation. Two reps + one water wash. Prior to contact with sample material, the solutions will be stripped of O_2 by flushing with He gas.
		Wash 15 minutes with 4mL DI water, centrifuge and add to Mg Chloride extract. Prior to contact with sample material, the wash water will be stripped of O_2 by flushing with He gas.
2	Organic Matter	0.1 M NaOH, 4 h, continuous shaking. Prior to contact with sample material, the NaOH solution will be stripped of O_2 by flushing with He gas.
		Wash 15 minutes with 4mL DI water, centrifuge and add to Sodium Hydroxide extract. Prior to contact with sample material, the wash water will be stripped of O_2 by flushing with He gas.
3	Metals absorbed / coprecipitated with amorphous Fe hydroxides	A0D. 0.2 M ammonium oxalate / oxalic acid, pH 3.0, 2 h, 25C in dark (wrapped in Al foil); one rep + one water wash.
		Wash 15 minutes with 4mL DI water, centrifuge and add to Oxalate Extract.
4	Metals coprecipitated with crystalline Fe/Mn hydroxides	CBD. 0.3 M Na-citrate, 0.2 M Na-bicarbonate, 1 g/g soil Na-dithionite. May require more that one rep.
		Wash 15 minutes with 4mL DI water, centrifuge and add to CBD Extract.
5	Metals coprecipitated with pyrite and amorphous sulfides	16 N HNO_3, 4h, shake, 25C; one reps + one water wash.
		Wash 15 minutes with 4mL DI water, centrifuge and add to Nitric Acid extract.
6	Residual (crystalline oxides and silicates)	Microwave acid digestion SW-846 Method 3052.

5.7 Phase 1 Treatability Tests

The purpose of the Phase 1 treatability tests is to identify the optimal additives and additive dosage to reduce the concentration of COCs in treated groundwater. Additives that effectively reduce COC concentrations will be carried forward to Phase 2 testing at their optimal dosage.

5.7.1 Phase 1 Batch Testing – Calcium Polysulfide and ZVI

Soil and groundwater handling, and pH and ORP measurement will be performed in an anaerobic chamber. In each test, 250 grams of soil and 500 ml of groundwater will be placed in a 1-liter, acid-rinsed and distilled-water-rinsed glass jar. CaSx and ZVI will be added to each jar at a prescribed dosage (Tables 4 and 5). The range of dosages for CaSx and ZVI was based on direct experience with these additives and on similar tests presented in the technical literature.

The mixture will be shaken for approximately 1 minute, either by hand or on a laboratory shaker, to obtain a well-mixed slurry. After 15 minutes of equilibration, pH and ORP will be measured, using calibrated electrodes. The jars will then be placed on a mechanical shaker table to maintain the soil and groundwater in contact with each other. The mixtures will be mechanically mixed for 24 hours. pH and ORP will be measured once again after equilibration.

Following the treatment, each sample will be decanted, centrifuged (if needed), and filtered through a 0.45-micron filter. The pH, ORP, and conductivity of the filtrate will be measured immediately. The remaining soil will be placed in labeled glass jars in refrigerated storage, pending potential future testing. The filtrate will be submitted to a certified analytical laboratory for the analysis of the following constituents:

- Metals: arsenic, copper, cadmium, iron, lead, manganese, mercury, nickel, selenium, and zinc (EPA Method 6010/EPA Method 7470)
- Arsenic speciation (ion-chromatography-inductively coupled plasma spectrophotometry-mass-spectrometry [IC-ICP-MS])
- Ferrous Fe (SM 3500FeD)
- Sulfide (EPA Method 376.2)
- Major cations: Ca, Mg, Na, K (EPA Method 6010)
- Major anions: Cl, SO_4 (EPA Method 300.0)
- Alkalinity (total, carbonate, bicarbonate; EPA Method EPA 310.1)

In addition, soil from the CaSx tests will be analyzed for:

- Acid-volatile sulfides (AVS) and simultaneously extracted metals (SEM) (EPA Method 376.3)

Duplicates representing 10 percent of all samples will be submitted for analysis.

5.7.2 Phase 1 Batch Testing – Air-Sparging

The air-sparging tests will be performed in custom-built microcosms, consisting of a glass jar and modified lid. The lid of each jar will be modified by installing two gas ports, one for influx and one for efflux of sparging air. The ports will accommodate two polyethylene tubes. The influx tube will have a stainless-steel fritted end, which will be pushed into the soil-groundwater slurry, and to the bottom of the jar. The end of the efflux tube will be just below the jar lid. This configuration will enhance the movement of sparge air through the soil-groundwater slurry.

Similar to the CaSx and ZVI tests, a soil-groundwater slurry will be prepared by mixing 250 grams of soil with 500 ml of groundwater in a 1-liter, acid-rinsed and distilled water-rinsed glass jar. The mixture will be shaken vigorously for approximately 1 minute, either by hand or on a laboratory shaker, to obtain a well-mixed slurry. After 15 minutes of equilibration, pH and ORP will be measured, using calibrated electrodes. The jar will then be fitted with the modified lid and sparging tubes.

An air compressor will be connected to the influx tube and will deliver ambient air at rates ranging from 0.1 to 10 L/hour (Table 6). These rates cover a wide range of flow rates and are based in part on information from the technical literature (Kim and Nriagu 2000; Nishimura and Umetsu 2001). However, the flow rates may be adjusted during the test, depending on back-pressure build-up and observations of dissolved oxygen (DO) and ORP. The air-sparging tests are expected to be run for approximately 5 days (120 hours). Small (25 mL) subsamples of the treated water will be collected after 1 day (24 hours) and 3 days (72 hours). The subsamples will be analyzed, under expedited turnaround time, for dissolved arsenic, nickel, and zinc. At the same time as the subsamples are being collected, pH, DO, and ORP will be measured directly in the microcosms. If COC concentrations in subsamples collected from certain microcosms during the 24-hour and 72-hour sampling are substantially below treatment goals, then those microcosm tests will be terminated. Conversely the duration of the tests may be extended beyond 5 days if the rates of COC concentration decreases are relatively low.

Following the treatment, each sample will be decanted, centrifuged (if needed), and filtered through a 0.45-micron filter. The pH, DO, ORP, and conductivity of the filtrate will be measured immediately. The remaining soil will be placed in labeled glass jars in refrigerated storage, pending potential future testing. The filtrate will be submitted to a certified analytical laboratory for the analysis of the following constituents:

- Metals: arsenic, copper, cadmium, iron, lead, manganese, mercury, nickel, selenium, and zinc (EPA Method 6010/EPA Method 7470)
- Arsenic speciation (ion-chromatography-inductively coupled plasma spectrophotometry-mass-spectrometry [IC-ICP-MS])

- Ferrous Fe (SM 3500FeD)
- Major cations: Ca, Mg, Na, K (EPA Method 6010)
- Major anions: Cl, SO_4 (EPA Method 300.0)
- Alkalinity (total, carbonate, bicarbonate; EPA Method EPA 310.1)

Duplicates representing 10 percent of all samples will be submitted for analysis.

5.8 Phase 2 Treatability Tests

Additives which effectively reduce COC concentrations will be carried forward to Phase 2 testing at their optimal dosage. The purpose of Phase 2 treatability testing is to evaluate the stability of the treatment under varying redox conditions that have been observed at the Site. Specifically, the DO and ORP will be modified in a direction opposite to the original treatment. For instance, if the Phase 1 CaSx treatment, which is a reductive treatment, proves to be effective, then the treated soil and groundwater will be exposed to slightly oxidizing conditions, similar to the most oxidizing conditions observed in the field.

Phase 2 testing will involve no more than three tests (each additive at its optimal dosage). However, Phase 2 testing will not be implemented if none of the Phase 1 treatments effectively treat the COCs.

5.8.1 Phase 2 Stability Testing – Calcium Polysulfide

If CaSx proves to be effective in Phase 1 testing, then the treatment with the most effective CaSx dosage will be repeated, following the procedures presented in Section 5.7.1. After 24 hours of mixing, a small sample of the treated groundwater will be collected and analyzed for arsenic, nickel, zinc, and ferrous iron. At the same time as the subsamples are being collected, pH, DO, and ORP will be measured directly in the jar.

Subsequently, the treated soil and groundwater will be transferred to a sparging microcosm, which is described in Section 5.7.2, fitted with a custom lid with air-sparging tubes.

An air compressor will be connected to the influx tube and will deliver ambient air at a rate which will be determined based on the results of the air-sparging test described in Section 5.7.2. The microcosm will be air-sparged for 24 hours, after which the pH, DO, and ORP will be measured directly in the microcosm. The results of this measurement will be compared with the historical data collected in well MW-10A. Adjustments to the air flow rate will be made accordingly, in an attempt to match the lab parameters to field parameters. The additional duration of air-sparging will be determined based on the evaluation of these parameters.

Following the treatment, each sample will be decanted, centrifuged (if needed), and filtered through a 0.45-micron filter. The pH, DO, ORP, and conductivity of the filtrate will be measured immediately. The remaining soil will be placed in labeled glass jars in refrigerated storage, pending potential future testing. The filtrate will be submitted to a certified analytical laboratory for the analysis of the following constituents:

- Metals: arsenic, copper, cadmium, iron, lead, manganese, mercury, nickel, selenium, and zinc (EPA Method 6010/EPA Method 7470)
- Arsenic speciation (ion-chromatography-inductively coupled plasma spectrophotometry-mass-spectrometry [IC-ICP-MS])
- Ferrous Fe (SM 3500FeD)
- Sulfide (EPA Method 376.2)
- Sulfate (EPA Method 300)
- Alkalinity (total, carbonate, bicarbonate; EPA Method EPA 310.1)

In addition, soil from the CaSx tests will be analyzed for:

- Acid-volatile sulfides (AVS) and simultaneously extracted metals (SEM) (EPA Method 376.3)

Duplicates representing 10 percent of all samples will be submitted for analysis.

5.8.2 Phase 2 Stability Testing – ZVI

If ZVI proves to be effective in Phase 1 testing, then the treatment with the most effective ZVI dosage will be repeated, following the procedures presented in Section 5.7.1. After 24 hours of mixing, a small sample of the treated groundwater will be collected and analyzed for arsenic, nickel, zinc, and ferrous iron. At the same time as the subsamples are being collected, pH, DO, and ORP will be measured directly in the jar.

Subsequently, the treatment effectiveness will be tested to determine the stability of the sorbed/precipitated arsenic and metals under fluctuating redox conditions. Initially, anaerobic conditions will be created by the addition of easily metabolized organic carbon. The jar containing treated groundwater and soil will be transferred to an anaerobic glove box and purged with nitrogen. In order to stimulate anaerobic microbial activity, acetate will be added in the form of sodium acetate (for a final concentration of 100 mg/L). Sample bottles will be capped and incubated at room temperature in the gloved box for 5 days. At the end of 5 days, sample bottles will be opened and pH, DO, and ORP will be measured directly in the jar, and groundwater will be collected for acetate, arsenic, nickel, zinc, and ferrous iron (Hach Kit). Based on these results (if acetate metabolism is confirmed), the full suite of analyses will be performed as follows:

- Metals: arsenic, copper, cadmium, iron, lead, manganese, mercury, nickel, selenium, and zinc (EPA Method 6010/EPA Method 7470)
- Arsenic speciation (ion-chromatography-inductively coupled plasma spectrophotometry-mass-spectrometry [IC-ICP-MS])
- Ferrous Fe (SM 3500FeD)
- Sulfide (EPA Method 376.2)
- Sulfate (EPA Method 300)
- Alkalinity (total, carbonate, bicarbonate; EPA Method EPA 310.1).

The soil and groundwater will then be exposed to aerobic conditions, as described in Section 5.8.1. Groundwater samples will be collected and analyzed for the same analytes as shown in Section 5.8.1.

5.8.3 Phase 2 Stability Testing – Air-Sparging

If air-sparging proves to be effective in Phase 1 testing, then the treatment with the most effective air-sparge flow-rate/total flow/sparge duration will be repeated, following the procedures presented in Section 5.7.2. After treatment, a small sample of the treated groundwater will be collected and analyzed for arsenic, nickel, zinc, and ferrous iron. At the same time as the subsamples are being collected, pH, DO, and ORP will be measured directly in the jar.

Subsequently, the treatment effectiveness will be tested to determine the stability of the sorbed/precipitated arsenic and metals when conditions shift from aerobic to anaerobic. Anaerobic conditions will be created by the addition of easily metabolized organic carbon. The treatment, sampling, and analytical approach will be the same as described in Section 5.8.2.

6.0 DATA ANALYSIS AND REPORTING

Sampling, analytical quality control, decontamination, and waste management procedures will follow procedures presented in the DTSC-approved Quality Assurance Project Plan (LFR 2005b).

6.1 Field Documentation

All relevant field activities will be appropriately documented using the following forms as appropriate: field logs of soil borings, well development forms, groundwater sampling forms, sample labels, chain-of-custody forms, waste management and hazardous waste labels, pilot test injection details and ongoing monitoring. All field forms will be kept on file at LFR and will be available upon request. Copies of relevant field forms will be included in a summary report.

6.2 Report Submittals

Two interim reports are scheduled to document the progress of the additional groundwater characterization study and initial injection monitoring results. The interim groundwater characterization study report will include isoconcentration maps for arsenic, copper, nickel, and zinc, and a graphical interpretation of metals distribution with depth, and the proposed injection well and IMW layout for the CaSx pilot injection test.

Upon completion of the treatability bench tests, a final report will be prepared that will document implementation of the Work Plan. The final report will describe the procedures used, observations, results, discussion, and recommendations for further evaluation, if needed.

7.0 SCHEDULE

The DTSC requested that this pilot study be completed outside of the Clapper Rail breeding season and prior to the onset of the local “rainy” season, which limits the potential implementation period to September through October.

Following DTSC approval of this Work Plan, LFR will begin the additional groundwater characterization study immediately. A preliminary schedule has been developed based on the assumption that DTSC approval of this Work Plan is received by September 14.

- Groundwater characterization and laboratory samples will be collected the week of September 21.
- Laboratory analytical tests, CaSx bench tests, data review, and technical analyses will require approximately two weeks.
- LFR will submit the interim groundwater characterization report to the DTSC by October 2.
- Bench scale treatability testing will begin in mid-October and will likely be completed by mid-January.
- LFR will begin installing the proposed CaSx injection wells and IMWs within one week following DTSC approval of the CaSx pilot injection test layout. This task will possibly be completed by October 23.
- During the week of October 26, LFR will implement the CaSx first injection of CaSx.

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Table 1
Range of Detected Metals in Groundwater and Geochemical Parameters
February 2008 Through May 2009
Groundwater Treatability Pilot Study Area
Lot 3, Campus Bay Site, Richmond, California

Analyte	Units	Upper Horizon Groundwater					Lower Horizon Groundwater				
		MW-10A		MW-11A		Screening Criteria	MW-10B		MW-11B		Screening Criteria
		Range	Trend	Range	Trend		Range	Trend	Range	Trend	
Arsenic	(μg/L)	74 to **180**	increasing	2.6 to 11	decreasing	180	<5 to 21	increasing	<5 to 11	no trend	5,800
Copper	(μg/L)	<5.0	nc	**92** to **690**	increasing	16	**850** to **2,000**	increasing	**4,100 to 5,200**	no trend	500
Nickel	(μg/L)	6.3 to **810**	no trend	7.4 to 17	no trend	41	1,100 to **1,600**	increasing	1,200 to **1,500**	no trend	1,300
Zinc	(μg/L)	<20 to **2,000**	no trend	140 to **2,300**	no trend	410	**13,000 to 20,000**	increasing	**21,000 to 25,000**	no trend	13,000
pH	SU	5.10 to 6.35	--	6.61 to 7.15	--	na	5.38 to 6.23	--	3.77 to 4.84	--	na
ORP	mV	-32.6 to 61.9	--	48.1 to 325.7	--	na	101.1 to 329.4	--	203 to 382.4	--	na
Ferrous Iron	mg/L	31 to 700	--	<0.10	--	na	0.86 to 4.5	--	79 to 120	--	na

Abbreviations:
ORP = oxidation reduction potential
μg/L = micrograms per liter
SU = standard units
mV = millivolts
mg/L = milligrams per liter
nc = not calculated because of insufficient number of detections (<15%)

Notes:
Values denoted in bold highlight concentrations that exceed the site-specific screening criteria.
Site-specific screening criteria for upper horizon groundwater is based on 5x the Aquatic Criteria.
Site-specific screening criteria for lower horizon groundwater is based on 160x the Aquatic Criteria.
Mann-Kendall analysis was performed on data collected from January 1, 2003 (or first date well was sampled if constructed after January 1, 2003) through current reporting period.
Consistent with reference documents (Gilbert 1987), non-detect samples are represented with one-half the lowest reporting limit for Mann-Kendall analysis.
The 0.05 confidence level is used to evaluate the trend.

Table 2
Proposed Experimental Setup --
Calcium Polysulfide Batch Treatment Test for Copper, Nickel, and Zinc
Groundwater Treatability Pilot Study
Lot 3, Campus Bay Site, Richmond, California

Batch Test #	Volume of Groundwater (mL)	Mass of Soil (g)	Calcium Polysulfide (mL)	Calcium Polysulfide (% by volume rel. to groundwater)	Calcium Polysulfide (g/L)
Control	500	250	0.00	0.0%	0.0
CaSx-1			12.5	2.5%	31.3
CaSx-2			25.0	5.0%	62.5
CaSx-3			37.5	7.5%	93.8
CaSx-4			50.0	10%	125.0
CaSx-5			75.0	15%	187.5

Notes:
mL = milliliter
g = grams
g/L = grams per liter
Each batch test will be run in duplicate.

Table 3
Mechanisms, Pros, and Cons of Arsenic Treatment Technologies for Proposed Treatability Pilot Study
Lot 3, Campus Bay Site, Richmond, California

Technology	Mechanism(s)	Pros	Cons
Air-sparging	Oxidation of Fe(II) to precipitate ferric hydroxides for As to sorb onto. May also directly oxidize As(III) to less soluble As(V).	Potentially better distribution than liquid.	May be less effective in Fe(II) oxidation than ozone or hydrogen peroxide.
		Less aggressive oxidant than ozone (less metal oxidation).	Requires aboveground infrastructure to supply air over periods of weeks to months.
		Low cost.	
Ozone sparging	Oxidation of Fe(II) to precipitate ferric hydroxides for As to sorb onto. Oxidation of As(III) to less soluble As(V).	Potentially better distribution than liquid.	Potential for metal mobilization from soil.
		Faster oxidation than air.	Requires aboveground infrastructure to supply air over periods of weeks.
		Moderately low cost.	Could oxidize bromide and trivalent chromium to produce bromate and hexavalent chromium.
Hydrogen peroxide	Oxidation of Fe(II) to precipitate ferric hydroxides for As to sorb onto. Oxidation of As(III) to less soluble As(V).	Potentially shorter treatment duration.	Less control over delivery and distribution than gas phase.
		Does not require aboveground infrastructure.	Potential for surfacing, including in the adjacent marsh.
		Shown effective in Lot 3.	Surfacing can damage flora.
		Moderately low cost.	

Table 3
Mechanisms, Pros, and Cons of Arsenic Treatment Technologies for Proposed Treatability Pilot Study
Lot 3, Campus Bay Site, Richmond, California

Technology	Mechanism(s)	Pros	Cons
ZVI	Sorption and co-precipitation onto FeOOH.	Effective for both As(III) and As(V).	Difficult to inject. May have to be trenched in or large-diameter auger mixed.
		Should not affect metals concentrations.	Difficult to control delivery (during injection).
		Can be emplaced as barrier.	High cost.
CaSx	Precipitation of As-sulfides.	Proven effective on site for divalent metals.	Less effective for As than oxidation methods due to potential formation of soluble thioarsenite complexes.
		Better injectability than ZVI.	Less control over delivery and distribution than gas phase.
		Less damaging to plants in case of surfacing than oxidants.	Potential for surfacing.

Table 4
Proposed Experimental Setup --
Calcium Polysulfide Batch Treatment Test for Arsenic, Nickel, and Zinc
Groundwater Treatability Pilot Study
Lot 3, Campus Bay Site, Richmond, California

Batch Test #	Volume of Groundwater (mL)	Mass of Soil (g)	Calcium Polysulfide (mL)	Calcium Polysulfide (% by volume rel. to groundwater)	Calcium Polysulfide (g/L)
Control	500	250	0.00	0.00%	0.0
CaSx-1			0.40	0.08%	1.0
CaSx-2			1.00	0.20%	2.5
CaSx-3			4.00	0.80%	10.0
CaSx-4			10.0	2.00%	25.0
CaSx-5			40.0	8.00%	100.0

Notes:
mL = milliliter
g = grams
g/L = grams per liter
Each batch test will be run in duplicate.

Table 5
Proposed Experimental Setup --
Zero-Valent Iron Batch Treatment Test for Arsenic, Nickel, and Zinc
Groundwater Treatability Pilot Study
Lot 3, Campus Bay Site, Richmond, California

Batch Test #	Volume of Groundwater (mL)	Mass of Soil (g)	ZVI (g)	ZVI (% mass rel. to soil)	ZVI (g/L)
ZVI-1	500	250	0.25	0.10%	0.5
ZVI-2			1.00	0.40%	2.0
ZVI-3			2.50	1.00%	5.0
ZVI-4			10.00	4.00%	20.0
ZVI-5			25.00	10.00%	50.0

Notes:
mL = milliliter
g = grams
g/L = grams per liter
Each batch test will be run in duplicate.

Table 6
Proposed Experimental Setup --
Air Sparge Treatment Test for Arsenic, Nickel, and Zinc
Groundwater Treatability Pilot Study
Lot 3, Campus Bay Site, Richmond, California

Sparge Test #	Volume of Groundwater (mL)	Mass of Soil (g)	Air flow rate (L/hour)
O2-1	500	250	0.10
O2-2			0.50
O2-3			1.0
O2-4			5.0
O2-5			10

Notes:
mL = milliliter
g = grams
L/hour = liters per hour

SOURCE: THOMAS BROS MAP - Bay Area 2001

Approximate Campus Bay Property Boundary

Approximate HEA Boundary

0 .5 mile

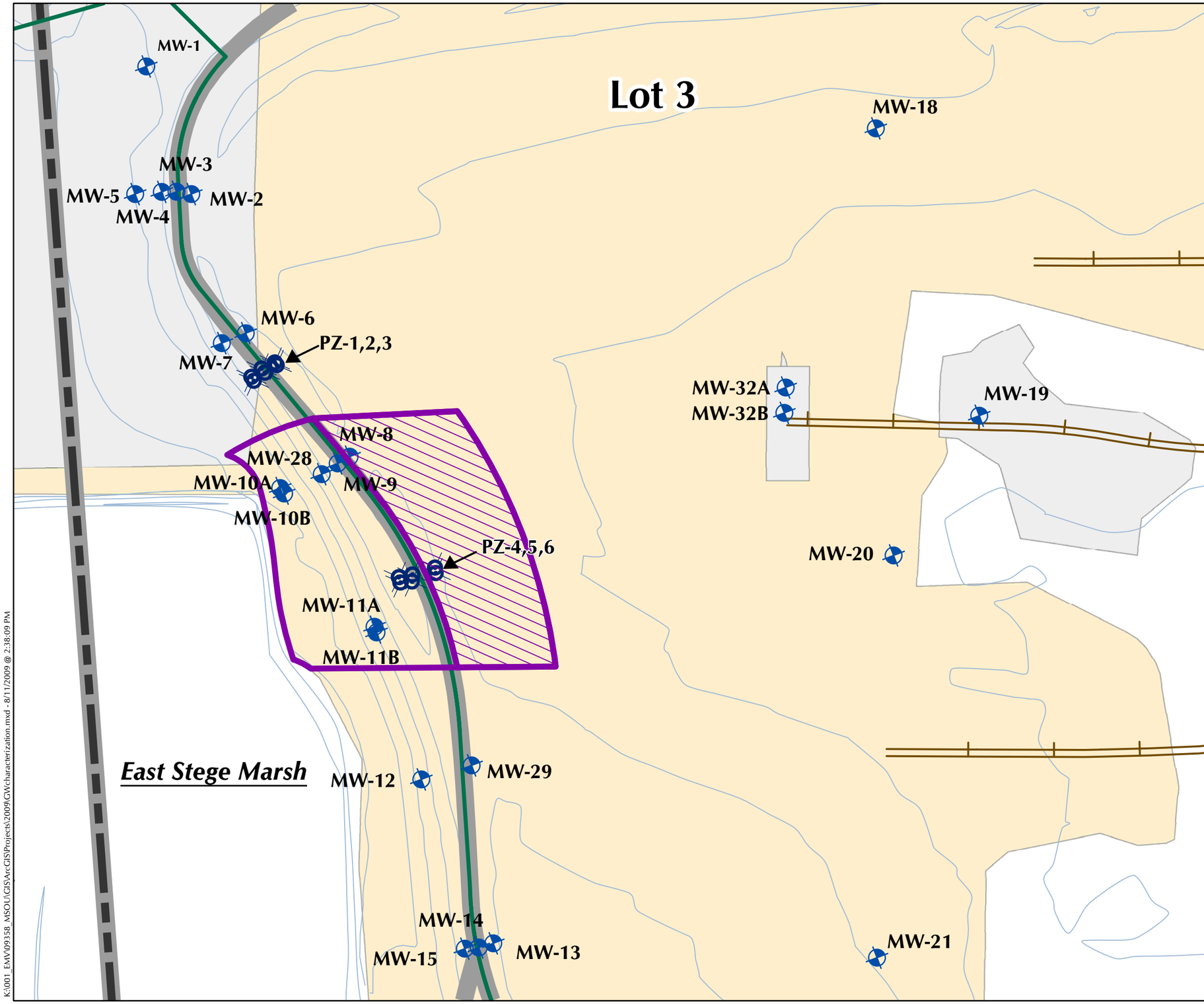
Site Vicinity Map

Campus Bay, Richmond, California

Figure 1

LFR an ARCADIS company

DESIGN\001\09358\Campus Bay Site Vicinity Map.CDR 120203



LEGEND

- MW-10A — Approximate location of monitoring well
- PZ-1 — Approximate location of piezometer
- Habitat enhancement area boundary
- Railroad spurs removed
- Property boundary
- Subarea boundary
- Previous cinder excavation area
- Previous excavation area
- 2-foot contour interval
- Approximate boundary of grab groundwater sampling to delineate upper and lower horizon study area
- Approximate boundary of grab groundwater sampling to delineate lower horizon study area

N

70 0 70 Feet

Site Plan with Approximate Study Area

Campus Bay, Richmond, California

LFR

Figure 2

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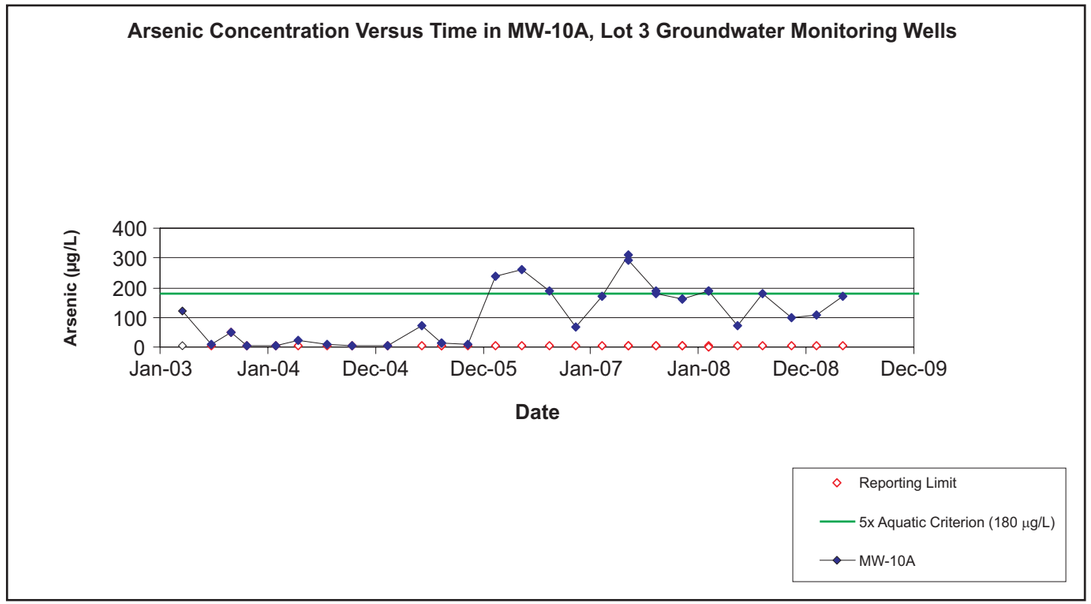
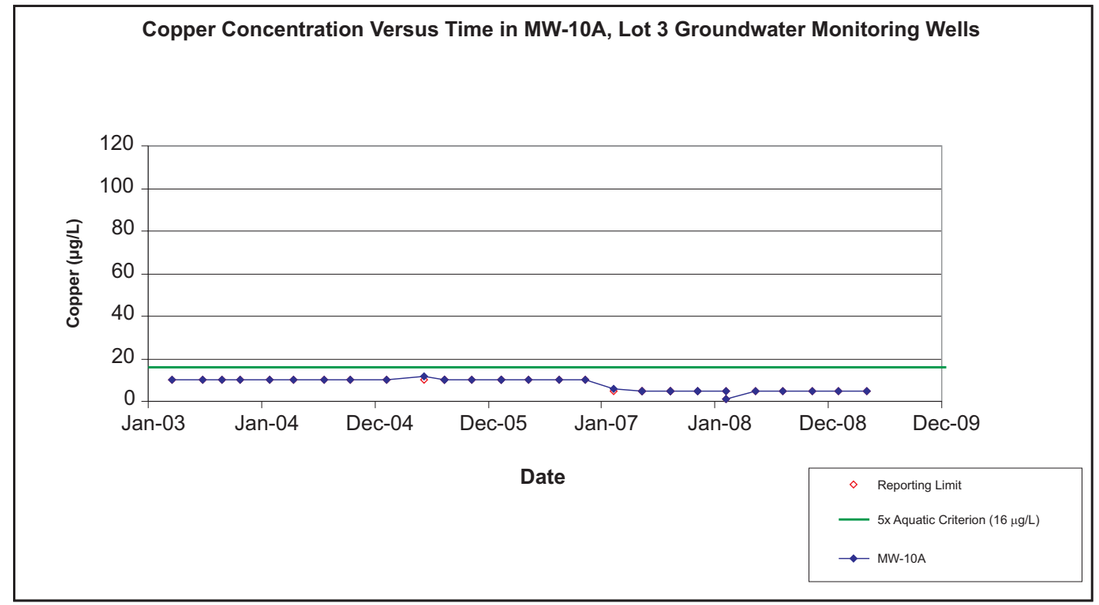
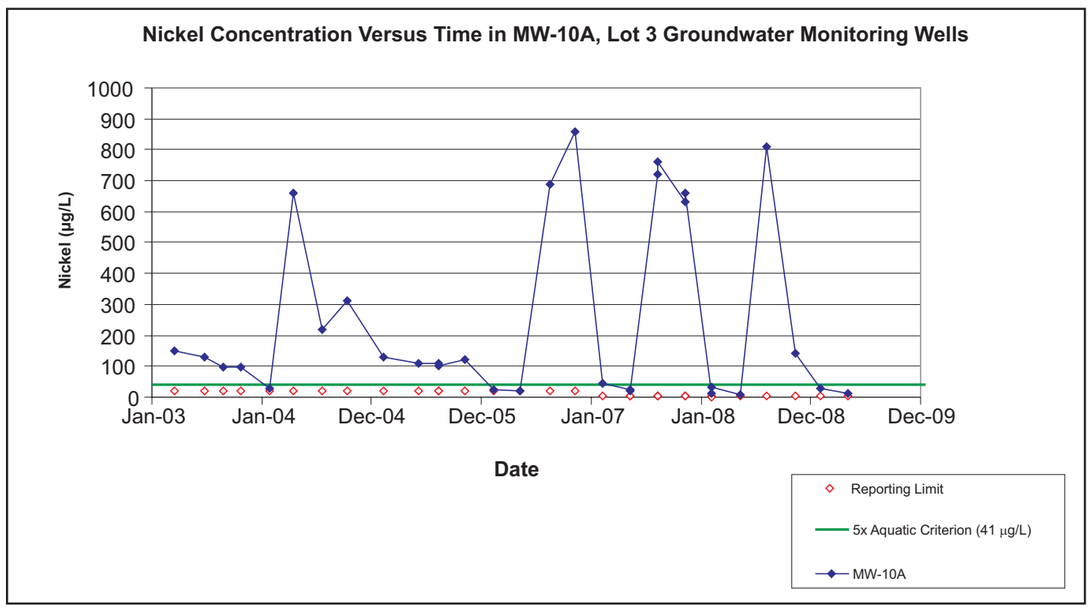
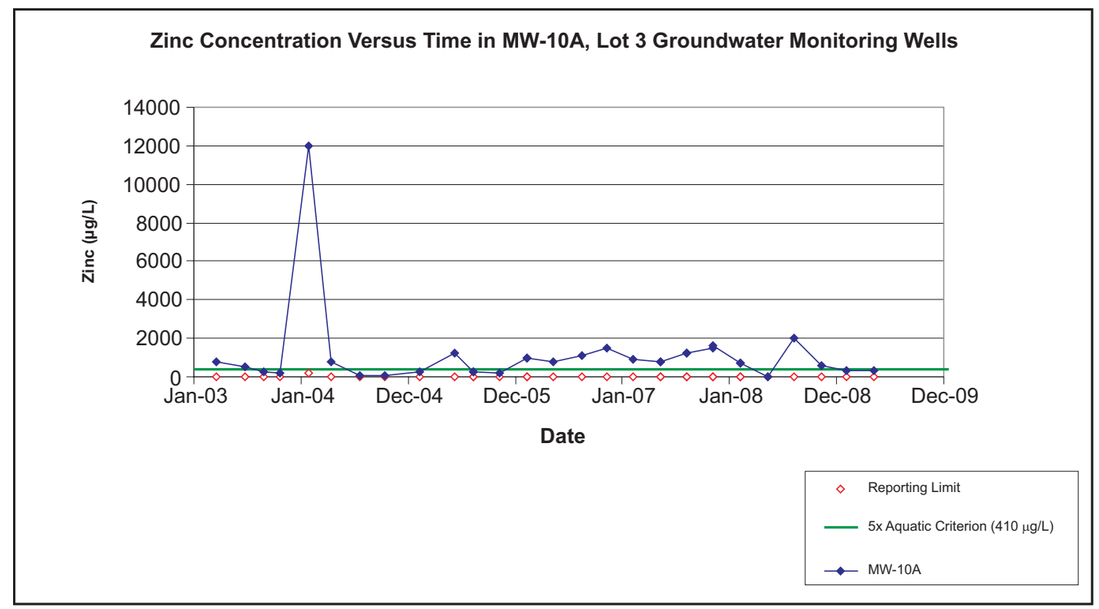








NOTES:

µg/L = micrograms per liter

Site-specific screening criteria for upper horizon groundwater is based on 5x the Aquatic Criteria.

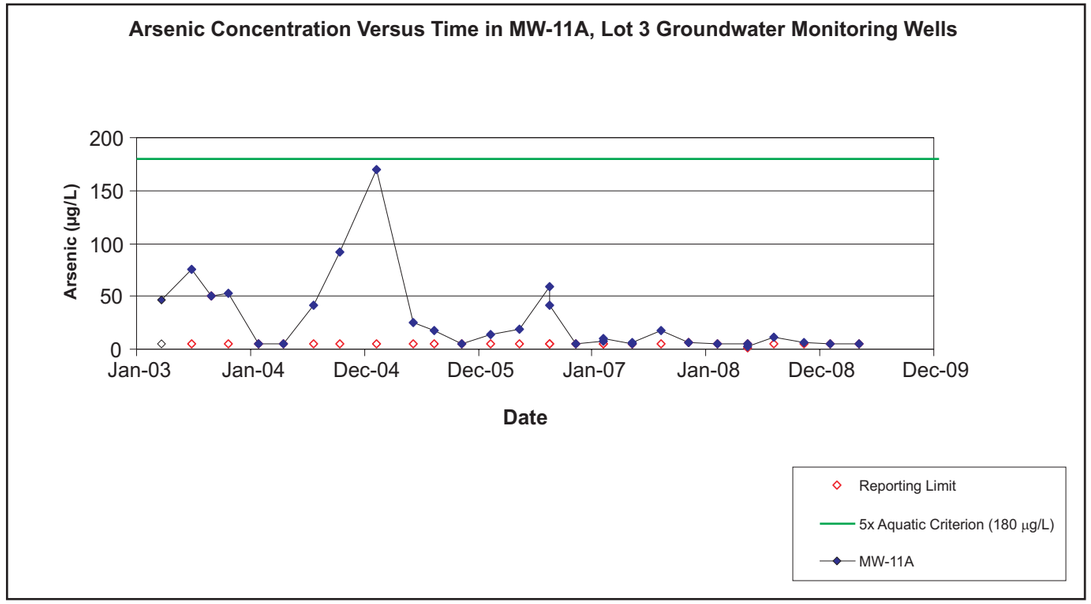
Time Trends in Arsenic, Copper, Nickel, and Zinc Concentrations in Well MW-10A

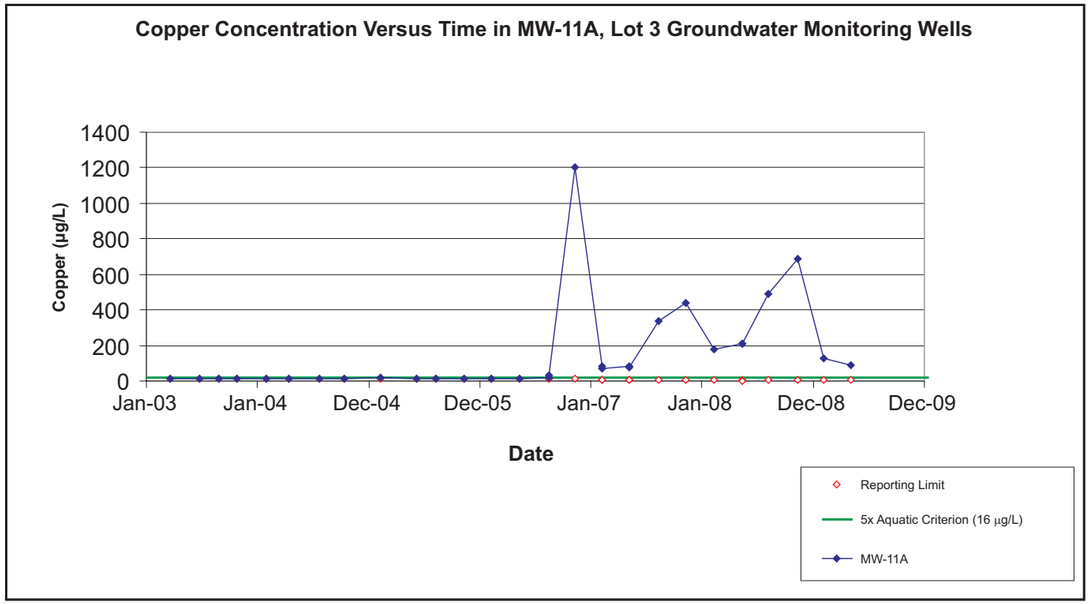
Campus Bay, Richmond, California

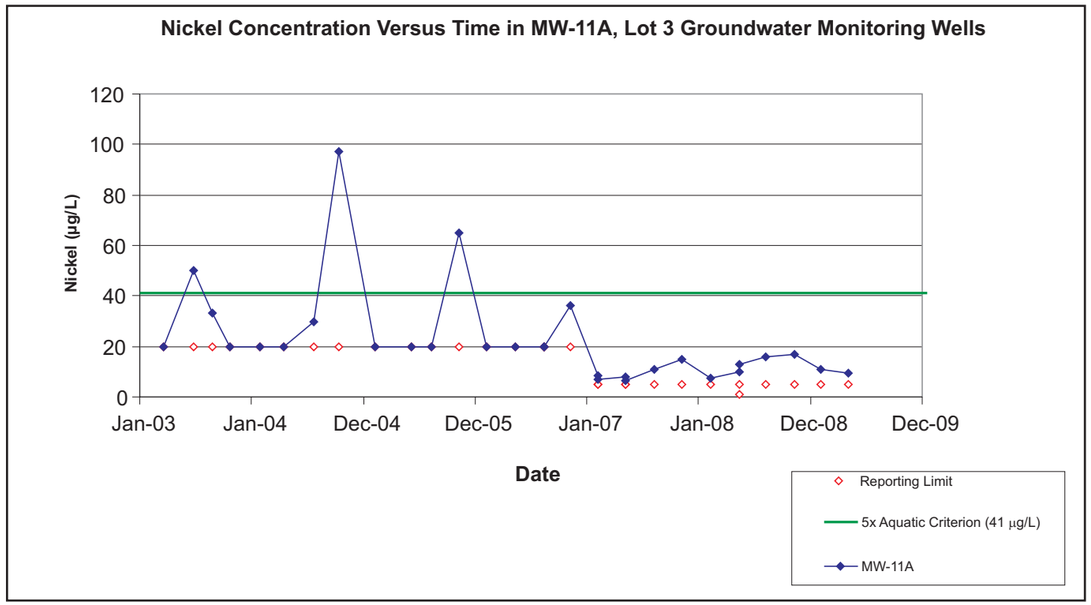
Figure 3

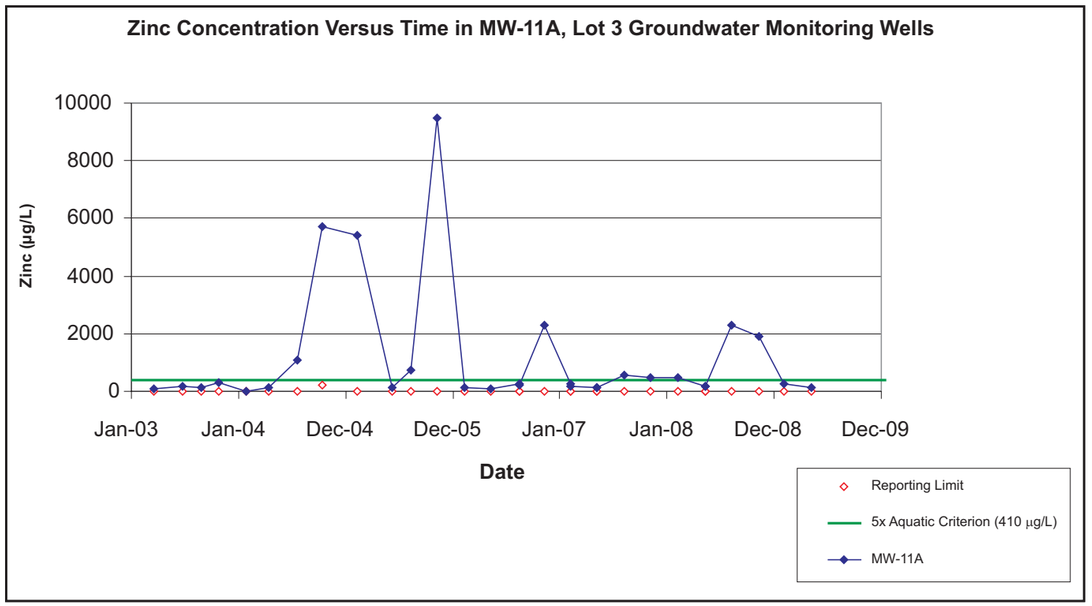
LFR an ARCADIS company

DESIGN\001\09359\56\Time Trend Concentrations in MW-10A 10B 11A 11B.cdr









NOTES:

µg/L = micrograms per liter

Site-specific screening criteria for upper horizon groundwater is based on 5x the Aquatic Criteria.

Time Trends in Arsenic, Copper, Nickel, and Zinc Concentrations in Well MW-11A

Campus Bay, Richmond, California

Figure 4

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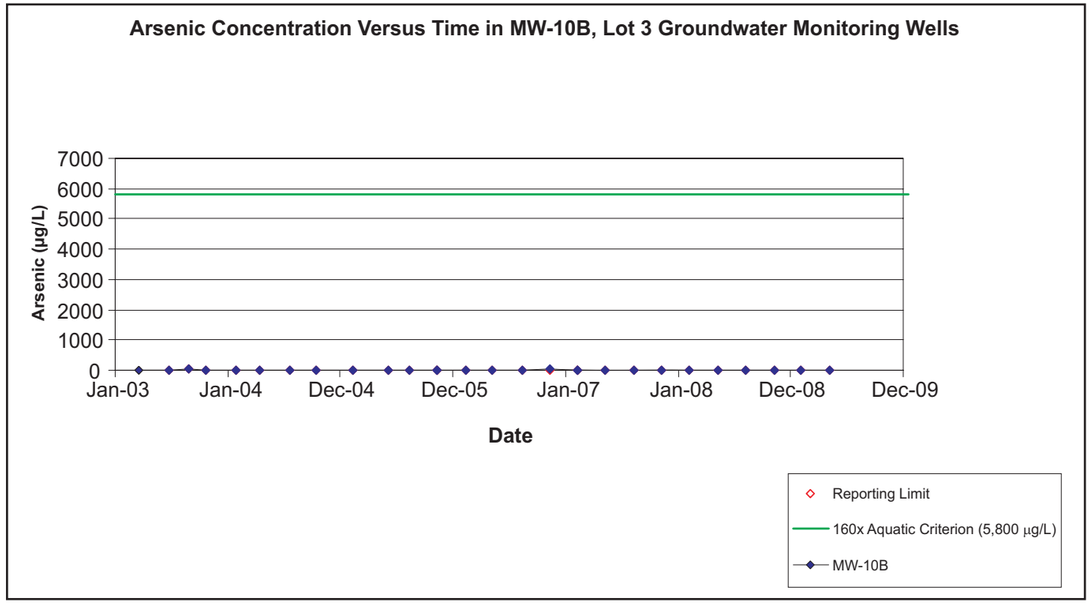
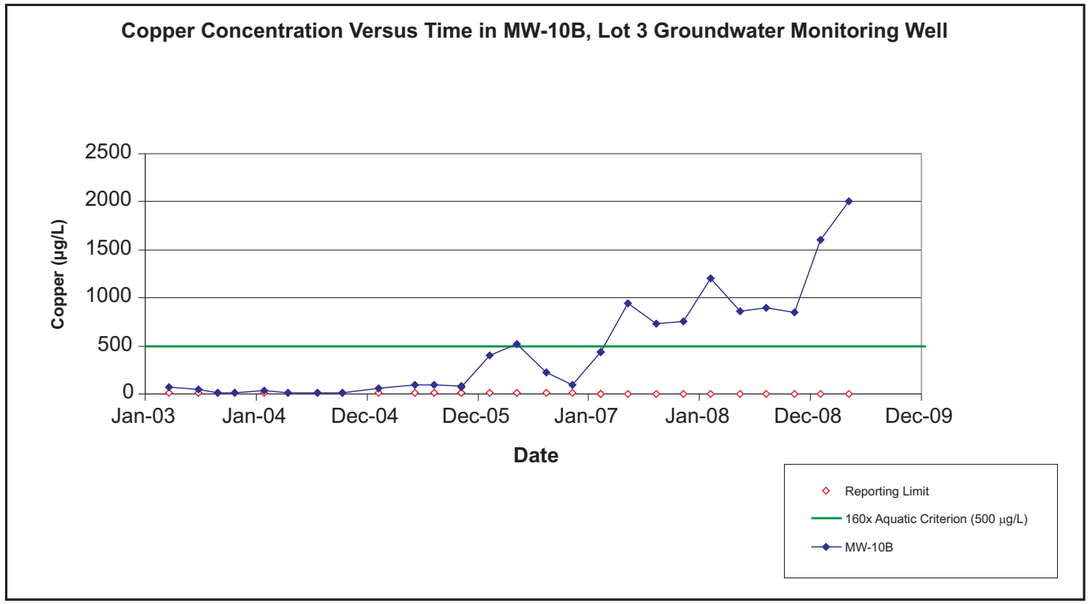
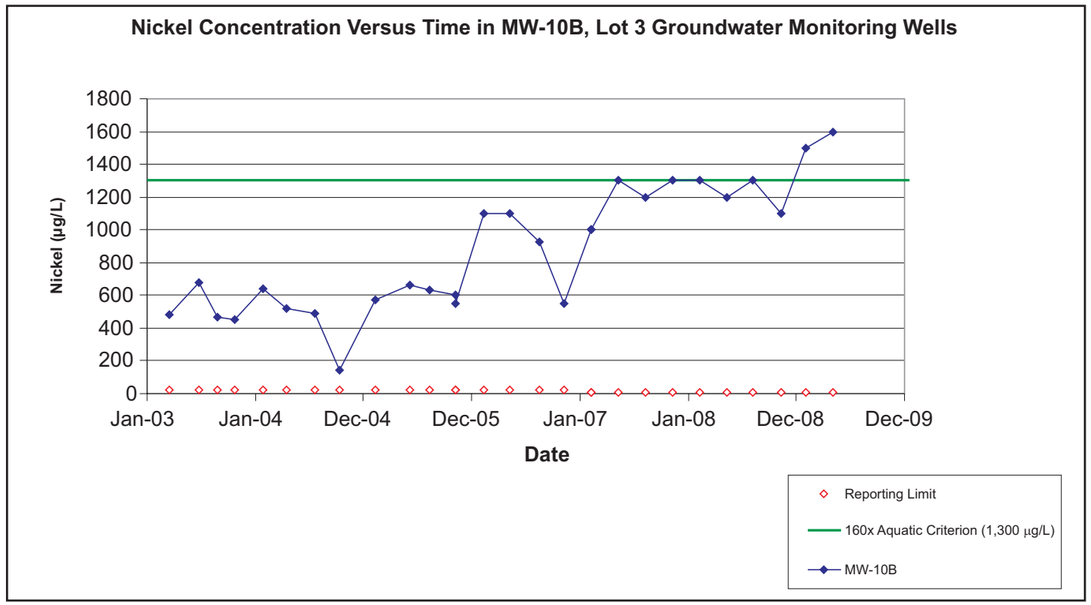
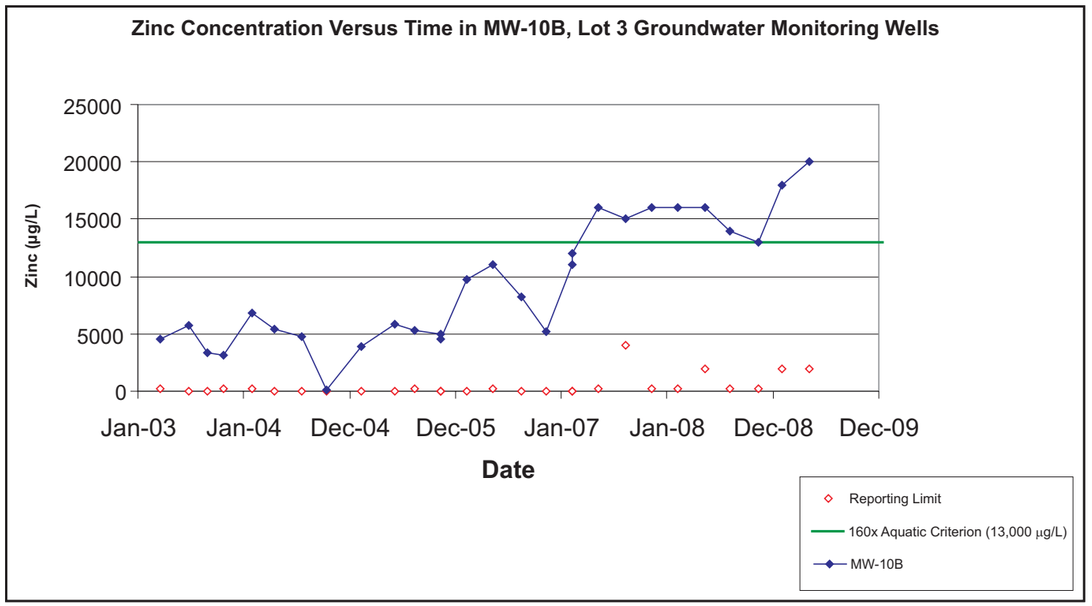
DESIGN\001\09359\56\Time Trend Concentrations in MW-10A 10B 11A 11B.cdr









NOTES:

µg/L = micrograms per liter

Site-specific screening criteria for lower horizon groundwater is based on 160x the Aquatic Criteria.

Time Trends in Arsenic, Copper, Nickel, and Zinc Concentrations in Well MW-10B

Campus Bay, Richmond, California

Figure 5

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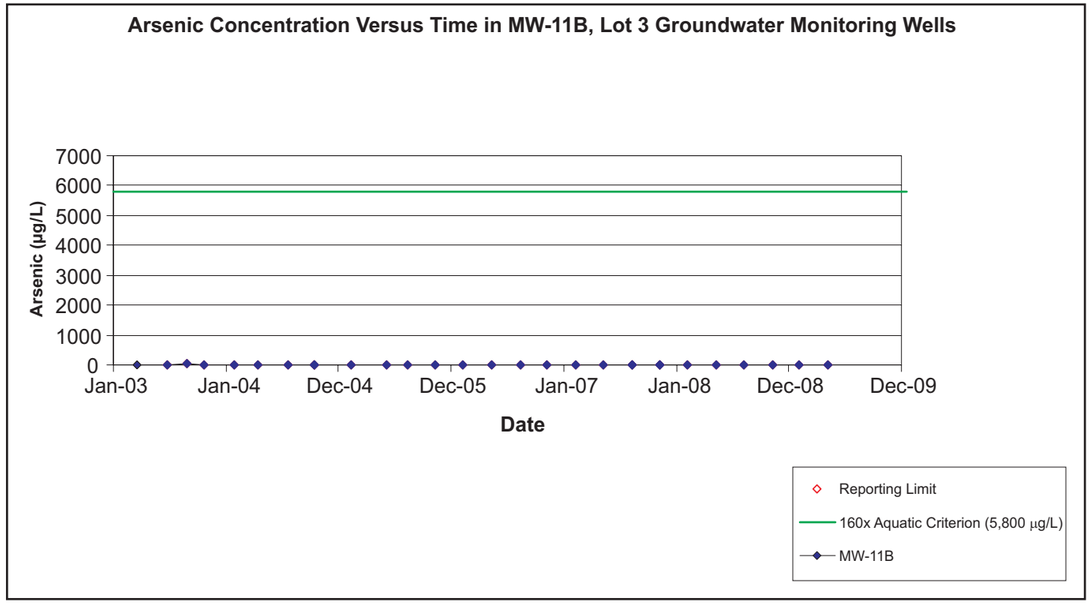
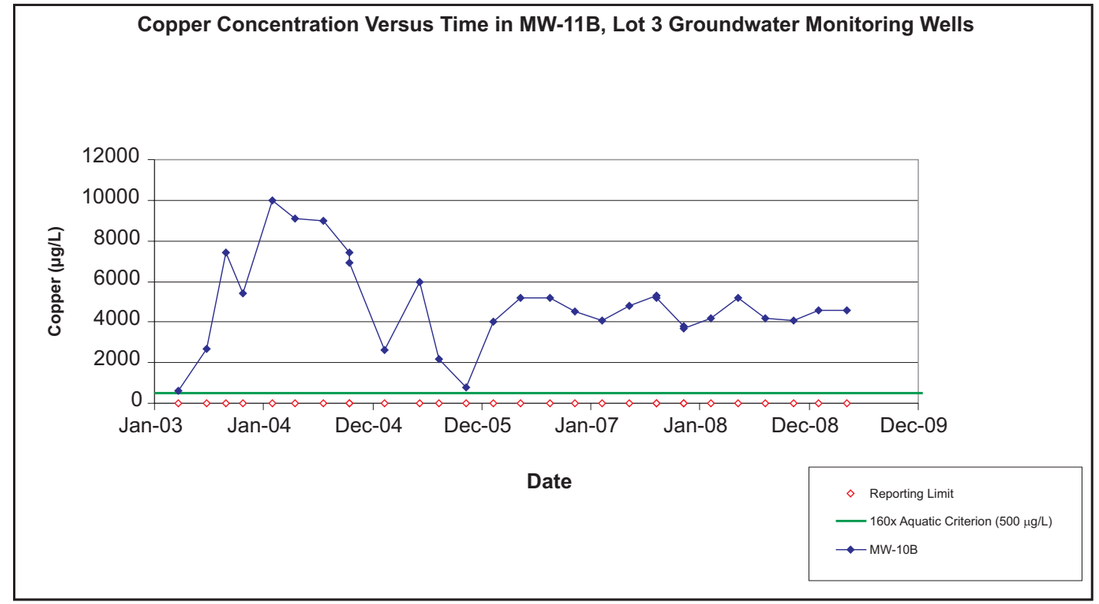
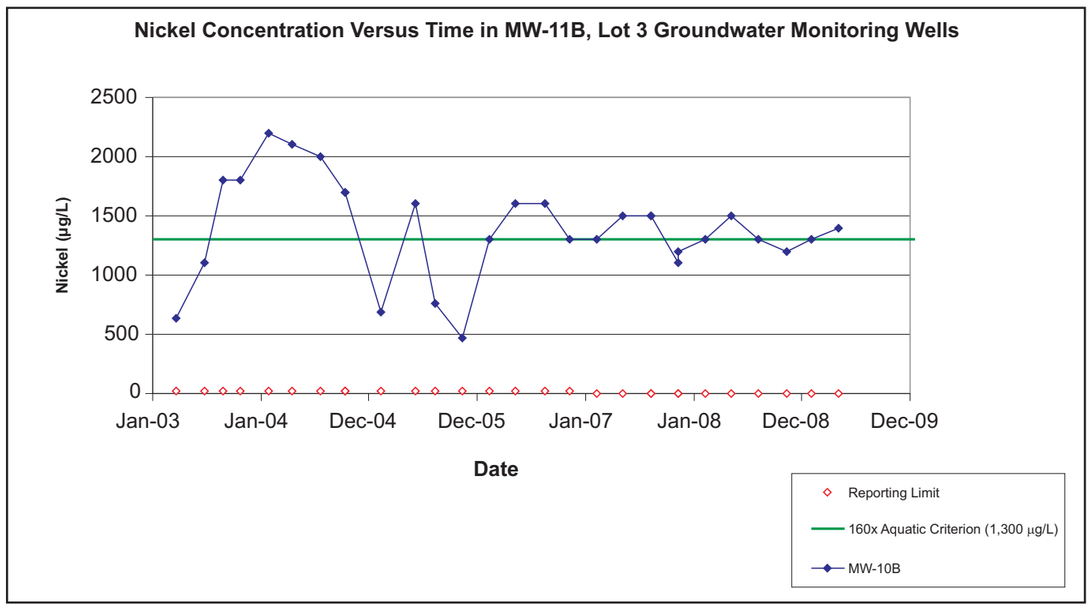
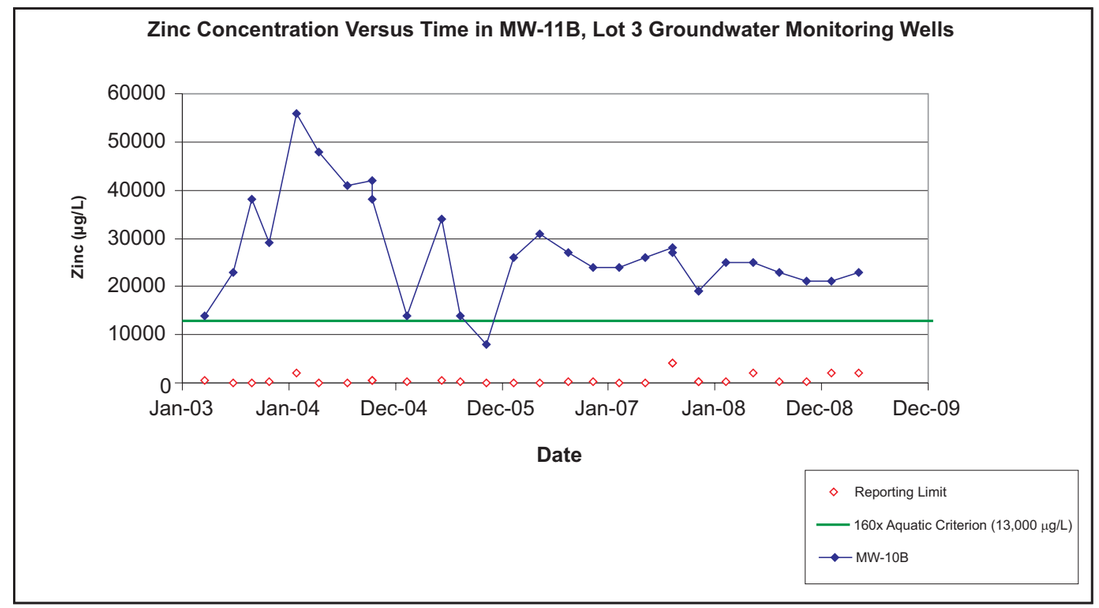
DESIGN\001\093559\56\Time Trend Concentrations in MW-10A 10B 11A 11B.cdr









NOTES:

µg/L = micrograms per liter

Site-specific screening criteria for lower horizon groundwater is based on 160x the Aquatic Criteria.

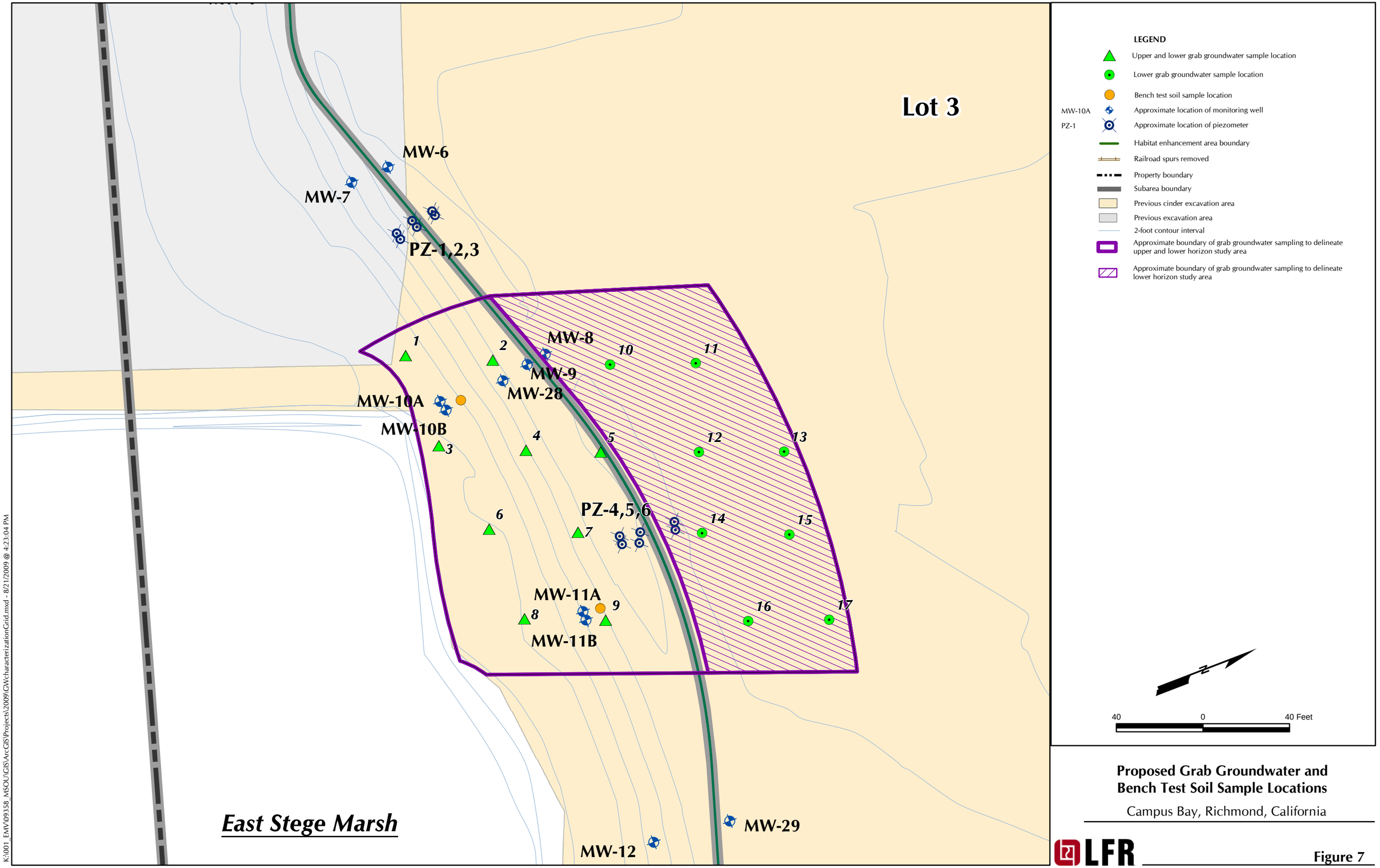
Time Trends in Arsenic, Copper, Nickel, and Zinc Concentrations in Well MW-11B

Campus Bay, Richmond, California

Figure 6

LFR an ARCADIS company

DESIGN\001\09359\56\Time Trend Concentrations in MW-10A 10B 11A 11B.cdr



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Proposed Grab Groundwater and Bench Test Soil Sample Locations

Campus Bay, Richmond, California

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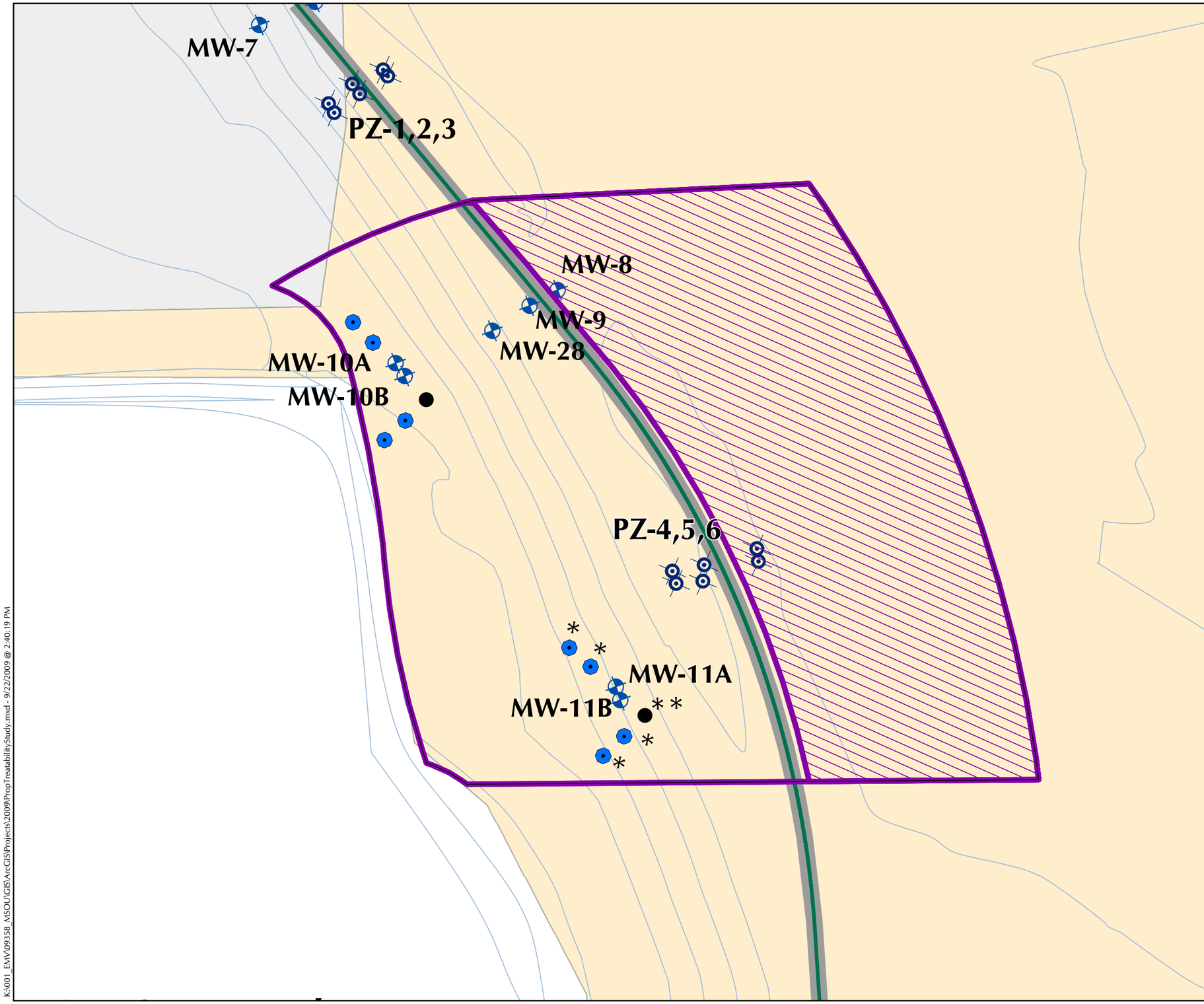
Figure 7



LEGEND

- IMW (injection monitoring well)
- IP (injection point)
- MW-10A — Approximate location of monitoring well
- PZ-1 — Approximate location of piezometer
- Habitat enhancement area boundary
- Railroad spurs removed
- Property boundary
- Subarea boundary
- Previous cinder excavation area
- Previous excavation area
- 2-foot contour interval
- Approximate boundary of grab groundwater sampling to delineate upper and lower horizon study area
- Approximate boundary of grab groundwater sampling to delineate lower horizon study area
- * Denotes upper and lower horizon well pair to monitor upper and lower horizon injection.
- ** Denotes upper and lower horizon injection point.

N

30 0 30 Feet

Proposed Groundwater Treatability Pilot Study Injection Point and IMW Locations

Campus Bay, Richmond, California

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Figure 8

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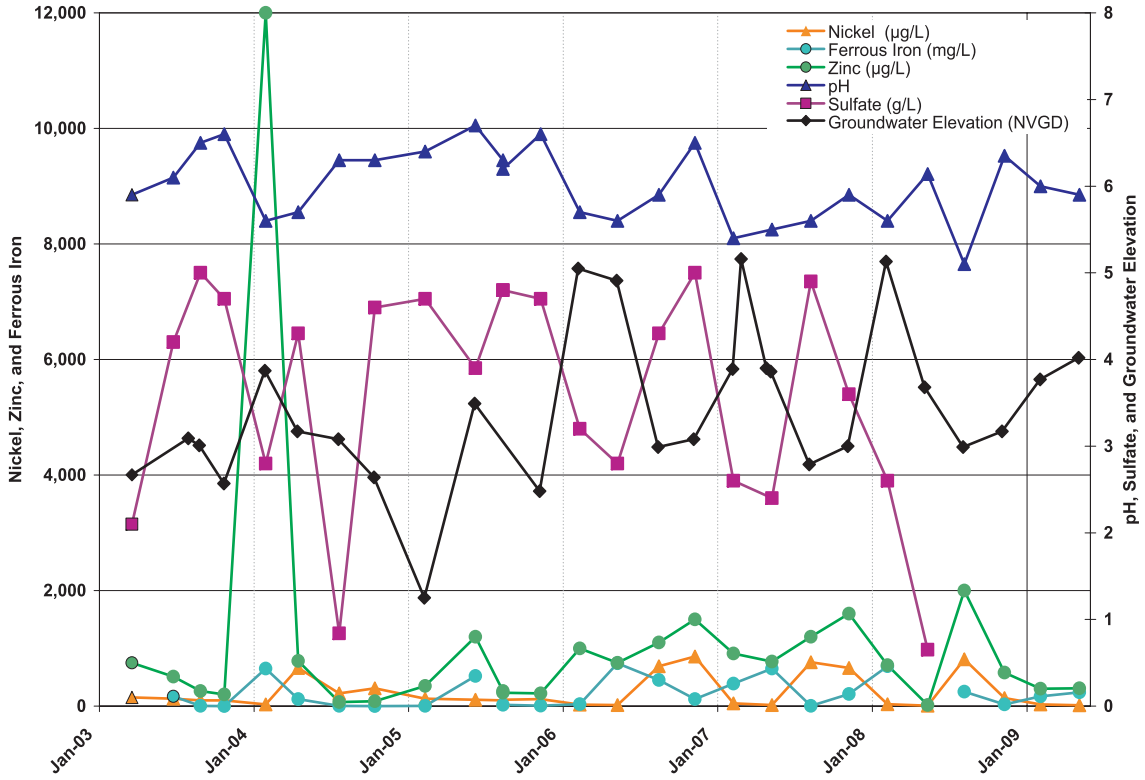

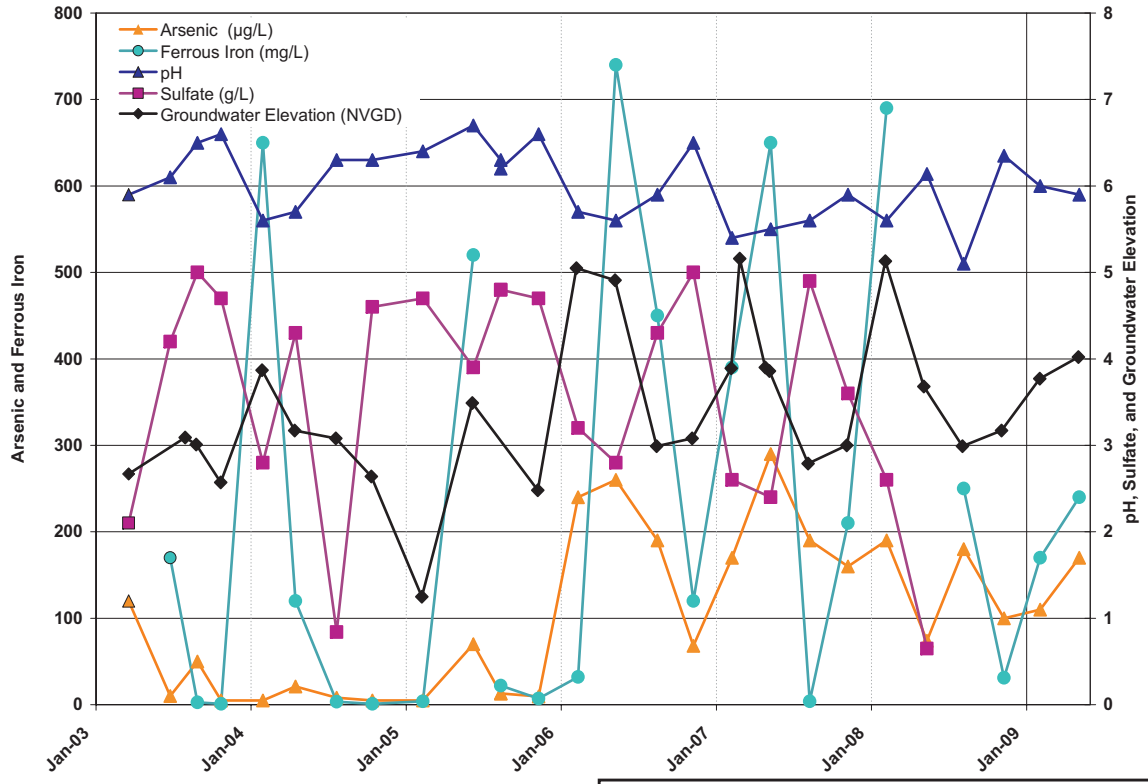

Arsenic, Nickel, and Zinc Temporal Trends and Geochemical Parameters at Well MW-10A

Campus Bay, Richmond, California

Figure 9

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DESIGN\001\09359\56\Graphs\Arsenic Iron Nickel Zinc MW-10a.cdr