CVOC PILOT STUDY WORK PLAN

W4 Group - Site Unit 1

Prepared for: West of 4th Group

Project No. 050067 • December 21, 2017 Final

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Acronyms

ABP	Art Brass Plating
AO	Agreed Order
ARI	Analytical Resources Inc.
Aspect	Aspect Consulting, LLC
AS/SVE	air-sparge/soil vapor extraction
bgs	below ground surface
BDC	Blaser Die Casting
CI	Capital Industries
COCs	constituents of concern
CSM	conceptual site model
CUL	cleanup level
CVOC	chlorinated volatile organic compounds
CWA	Clean Water Act
DCE	cis-1,2 Dichlorethene
DP	direct-push
DR	dose response
EAnb	Enhanced Anaerobic Biodegradation
Ecology	Washington Department of Ecology
EPA	U.S. Environmental Protection Agency
FS	Feasibility Study
ft	feet
ft/day	feet per day
HASP	Health and Safety Plan
HSA	hollow-stem auger
IDW	investigative-derived waste
ISCR	*In-Situ* Chemical Reduction
mg/L	milligrams per liter
µg/L	micrograms per liter

MHHW	mean higher high water
MLLW	mean lower low water
MNA	monitored natural attenuation
MTCA	Model Toxics Control Act
O&M	operation and maintenance
OUL	Ozark Underground Laboratory
PCE	perchloroethylene
PCULs	proposed cleanup levels
PLPs	potentially liable parties (the W4 Group)
PVC	polyvinyl chloride
QAPP	Quality Assurance Project Plan
RAOs	Remedial Action Objectives
redox	reduction/oxidation
RI	Remedial Investigation
RI/FS	Remedial Investigation/Feasibility Study
ROI	radius of influence
ROWs	right-of-ways
SDS	safety data sheet
Stericycle	Burlington Environmental, LLC
SU1	W4 Group Site Unit 1
SU2	W4 Site Unit 2
TCE	trichloroethene
VC	vinyl chloride
W4	west of 4th
W4 Site	west of 4th site
WAC	Washington Administrative Code
the Waterway	the Duwamish Waterway
Work Plan	Pilot Study Work Plan
ZVI	zero valent iron

1 Introduction

1.1 Purpose

The W4 Group Site Unit 1 (SU1) chlorinated volatile organic compounds (CVOC) Pilot Study Work Plan (Work Plan) has been prepared by Aspect Consulting, LLC (Aspect) on behalf of potentially liable parties (PLPs) [Art Brass Plating (ABP), Blaser Die Casting (BDC), Capital Industries (CI), and Burlington Environmental) [1],] identified by the Washington State Department of Ecology (Ecology) in Agreed Order (AO) No. DE10402 for the West of 4th (W4) Site (the Site). The AO requires the four PLPs (the W4 Group) to complete a Feasibility Study (FS), and prepare a Draft Cleanup Action Plan for the W4 Site.

The W4 Site has been divided into two site units, Site Unit 1 (SU1; ABP and Stericycle) and Site Unit 2 (SU2; BDC, CI and Stericycle), as described in the AO. Figure 1 shows the ABP Facility locations of the four PLPs and the SU1 and SU2 boundaries.

The SU1 FS (Aspect, 2016) developed and evaluated remedial alternatives to address contaminated media at SU1 in accordance with Washington Administrative Code (WAC) 173-340-350(8). Ecology did not agree with the preferred remedy identified in the SU1 FS. Upon further discussion with Ecology, pilot testing of technologies was determined to be an appropriate step to reduce the uncertainties associated with treatment of CVOCs in downgradient groundwater and evaluating the ability of different treatment approaches, including *In-Situ* Chemical Reduction (ISCR) and Enhanced Anaerobic Biodegradation (EAnB), to achieve Remedial Action Objectives (RAOs). The First Amendment to the AO effective on November 20, 2017 (AO Amendment), identifies the pilot study scope of work and schedule of deliverables. After pilot study completion, the AO Amendment requires that the PLPs submit a SU1 Focused FS Report Addendum which selects the preferred cleanup action.

This Work Plan describes the pilot study activities proposed to evaluate the *in-situ* treatment of the downgradient trichloroethene (TCE) Plume. The pilot study location is shown on Figure 2. Pilot testing will assess the effectiveness and cost of using ISCR and EAnB to treat CVOCs in groundwater west of East Marginal Way. The pilot study results will be used to refine the description and evaluation of remedial alternatives presented in the SU1 FS and to define the preferred remedy, to be presented in the SU1 Focused FS Report Addendum

1.2 Report Organization

This report is organized as follows:

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[1] Burlington Environmental, LLC, is a wholly owned subsidiary of PSC Environmental Services, LLC, which is a wholly owned subsidiary of Stericycle Environmental Solutions, Inc., hereafter referred to in this document as “Stericycle” for simplicity.

- **Section 1** describes the purpose and organization of the Work Plan.
- **Section 2** contains background information about SU1 relevant to pilot testing, description of the Site, proposed cleanup and remediation levels (Aspect, 2016), and technology screening.
- **Section 3** presents a conceptual site model (CSM) as a basis for pilot testing design including geology, hydrogeology, nature and extent of CVOC contamination, and groundwater biogeochemistry in the vicinity of the pilot study location.
- **Section 4** describes the objectives and approach of the pilot study.
- **Section 5** describes the activities that will be completed prior to pilot testing including locating utilities, obtaining access agreements, obtaining an underground injection authorization, installing monitoring wells and conducting baseline monitoring.
- **Section 6** describes the conceptual pilot study design. The final pilot study design details will be reported separately in a Field Implementation Work Plan.
- **Section 7** presents the project organization and plans required for the pilot study.
- **Section 8** presents the schedule and reporting of pilot study activities.
- **Section 9** provides references used in the preparation of this report.

The text is followed by tables and figures that support the text and illustrate the proposed pilot testing activities.

Appendices to this report provide supporting information referenced within the text. These include CVOC concentration and geochemistry trends in groundwater wells in the vicinity of the pilot study, a typical well construction diagram, and historical groundwater analytical results.

2 Background

2.1 Site Description

SU1 is located in the Georgetown neighborhood of Seattle. SU1 extends from 4th Avenue South to the Duwamish Waterway (the Waterway), a distance of about 2,200 feet, and is generally flat with a gradual slope to the west. SU1 includes a mixture of commercial, industrial, and residential land uses.

A remedial investigation (RI) was completed to characterize SU1 conditions and collect the information needed to prepare this FS, as documented in the *Remedial Investigation Report, Art Brass Plating* (hereafter: ABP RI Report; Aspect, 2012). Additional characterization data for SU1 and SU2 are available in the RI reports prepared by CI (Farallon, 2012), BDC (PGG, 2012), and Stericycle (PSC, 2003). Exploration locations from these activities are depicted on Figure 2. The *Site Conceptual Model Technical Memo* (SCM; Aspect, 2014b) identifies the sources of constituents of concern (COCs), nature and extent of contamination, and known and potential exposure pathways and receptors. COCs in SU1 include CVOCs, plating metals, and non-plating metals (redox-sensitive metals).

This Work Plan focuses on CVOCs in groundwater downgradient (west) of East Marginal Way. The nature and extent of CVOCs in the pilot study location is discussed further in Section 3.3.

2.2 Proposed Cleanup Levels

The W4 joint deliverable, *Revised Preliminary Site Cleanup Standards* (Farallon, 2014) outlined the preliminary cleanup standards for the Site. The proposed cleanup levels (PCULs) for COCs are based on potential exposure pathways. Since 2014, PCULs have been updated as standards change. The most recent update is based on revisions to the Clean Water Act (CWA) for protection of human health promulgated by the U.S. Environmental Protection Agency (EPA) in November 2016. This recent update resulted in edits to the PCULs for tetrachloroethylene (PCE), TCE, cis-1,2 Dichloroethene (DCE), and vinyl chloride (VC). As presented in the Final FS, Site groundwater is not considered a current or potential future drinking water source; therefore, drinking water standards are not included in PCULs. Table 1 provides the PCULs, as updated and submitted to Ecology on January 27, 2017.

2.3 Remediation Levels

The Model Toxics Control Act (MTCA) recognizes that a cleanup action may involve a combination of cleanup action components and provides that remediation levels may be used to identify concentrations (or other methods of identification) of hazardous substances at which different cleanup action components will be used (WAC 173-340-355). Remediation levels are concentration thresholds above which particular cleanup action components may be applied, and are usually specific to a particular remediation technology. Remediation levels may be applied if it is not practicable to achieve cleanup levels (CULs) at the standard point of compliance within a reasonable restoration time frame.

Potential remediation levels for TCE and VC are identified in the SU1 FS based on concentrations that are predicted (using conservative modeling assumptions) to be protective of the surface water pathway (i.e., they would not result in concentrations exceeding the surface water CUL at the mudline in the Waterway). As discussed in the Final FS, application of these remediation levels depends in part on a practicability analysis of achieving shorter restoration time frames. The remediation levels identified in the SU1 FS for South Fidalgo Street (the pilot study location) are 4.0 micrograms per liter (µg/L) for TCE, 5.0 for DCE, and 1.6 µg/L for VC as shown in Table 2. However, these remediation levels were determined before the current PCULs were last updated as described above.

Remediation levels from the SU1 FS are provided herein for reference and were not revised for this Work Plan. The revision of remediation levels for a preferred remedy would consider pilot testing results and may also include updated modeling or other analysis. Revised remediation levels, if developed, and their basis would be presented in the SU1 Focused FS Report Addendum. Evaluating the ability of the EAnB and ISCR technologies to achieve potential remediation levels is a primary objective of the pilot study and discussed further in Section 4.3.

3 Conceptual Site Model

Remedial investigation activities conducted at the Site to date have focused on Site-wide objectives and completing the Remedial Investigation (RI) Report (Aspect, 2012), and subsequently identified data gaps summarized in the *Site Conceptual Model Technical Memorandum* (Aspect, 2014b). This section summarizes the CSM related to CVOCs in the Downgradient TCE area to develop the basis of design for pilot testing. As additional data are collected during pilot study activities, this CSM will be revisited and updated as necessary.

3.1 Geology

The geologic units encountered in borings completed in the vicinity of ABP include a Younger Alluvium and Older Alluvium. The upper portion of the Younger Alluvium has been modified and is referred to as the Fill Unit. A description of these units is provided below. A simplified one-dimensional (1-D) section is presented in Figure 3 to illustrate the geologic units and hydrostratigraphy in the pilot study location. Available boring logs from the pilot study vicinity are included in Appendix D.

Fill Unit

The Fill unit consists of heterogeneous layers of gravelly sand, silt, and silty sand with scattered bits of inert debris such as glass shards or brick fragments. This unit extends up to a depth of 8 feet. In some cases, the boundary between the Fill Unit and the Younger Alluvium is difficult to distinguish. Therefore, these units are generally grouped together.

Younger Alluvium

The Younger Alluvium (Qyal) represents channel and overbank/floodplain deposits from the Duwamish River (Booth and Herman, 1998). Based on borings in the vicinity of the ABP Facility, the Younger Alluvium consists of two subunits, a sandy silt or silty sand unit overlying slightly silty fine-medium sand unit. Scattered bits of wood and organic debris are also present. This unit is typically found within a few feet above or below the current sea level and extends to a depth of approximately 25 to 30 feet beneath the Facility. West of the Facility (starting near 2nd Avenue South) and in the pilot study location, the Younger Alluvium extends to a depth of approximately 55 feet.

The upper sandy silt/silty sand unit typically extends to a depth of 8 to 12 feet and includes a silt unit observed to be 2 feet thick (and up to 6 feet thick) at MW-24-50 (Figure 3). The sand in the underlying slightly silty sand unit has a characteristic ‘salt and pepper’ appearance. This lower portion of the Qyal also includes silt stringers that range in thickness up to a few inches thick.

Older Alluvium

The Older Alluvium (Qoal) represents materials deposited in an estuarine and deltaic environment. Based on borings in the vicinity of the ABP Facility, the Older Alluvium consists of interbedded sequences of silty fine sand and sandy silt. While not observed in ABP borings, this unit can also contain discontinuous gravel lenses and locally abundant shells and some wood (Booth and Herman, 1998).

A silt aquitard—likely a subunit of the Older Alluvium—and bedrock have been identified in deeper borings east of 4th Avenue (PSC, 2003). Neither the silt aquitard nor bedrock was encountered in borings located in the vicinity of the pilot study location, where the deepest boring was advanced to 70 feet (CG-140-70). Based on a review of the Duwamish Valley cross sections available in Booth and Herman (1998), it is expected that the silt aquitard and bedrock are present at a depth greater than 150 feet.

3.2 Hydrogeology

Groundwater at the Site is encountered at a depth of 3 to 10 feet below grade. Groundwater flow is towards the Waterway, which is west-southwest of the ABP Facility.

3.2.1 Hydrostratigraphy

A nomenclature for hydrostratigraphic units has been adopted for Site characterization (groundwater monitoring and sampling intervals) and directly corresponds to the lithologic units described in Section 2.3 (PSC, 2003). This nomenclature is maintained in describing groundwater at the Site and consists of:

- **Water Table Interval.** This interval includes monitoring wells screened above 20 feet below ground surface (bgs) and reconnaissance groundwater samples collected above 20 feet bgs.
- **Shallow Interval.** This interval includes monitoring wells screened below 20 feet and above 40 feet bgs, and reconnaissance groundwater samples collected between 21 feet and 40 feet bgs.
- **Intermediate Interval.** This interval includes monitoring wells and reconnaissance groundwater samples screened below 40 feet bgs.

As discussed in subsequent sections, the focus of the pilot study is the high TCE concentrations in the Shallow Interval of the Downgradient TCE Plume west of East Marginal Way.

3.2.2 Aquifer Properties

The discussion below provides a characterization of aquifer characteristics based on the data collected during the RI (Aspect, 2012) and provides a basis of design for the pilot study.

Groundwater Flow Direction and Gradients

The W4 Group completed multiple coordinated water level measurements during the RI (Aspect, 2012). The events completed between May 2010 and August 2012 represent a comprehensive data set for the W4 Group. The August 2012 groundwater elevation contours, which includes tidally averaged water level data for wells near the Waterway, are included in CVOC Figures 4, 5, 6, and 7, by sampling interval. Findings from these comprehensive water level monitoring events completed May 2010 through August 2012 indicate the following:

- **Water Table Interval.** The approximate direction of groundwater flow was southwest. The horizontal hydraulic gradient for the Water Table Interval ranges from 0.0004 to 0.0016 feet per foot;

- **Shallow Interval.** The approximate direction of groundwater flow is west-southwest. The horizontal hydraulic gradient for the Shallow Interval ranges from 0.0013 to 0.0021 feet per foot; and
- **Intermediate Interval.** The approximate direction of groundwater flow is west-southwest. The horizontal hydraulic gradient for the Intermediate Interval ranges from 0.0007 to 0.0018 feet per foot.

Vertical hydraulic gradients vary across the Site. In the upgradient portions of the Site (east of Marginal Way), a downward vertical gradient is observed from the Water Table Interval to the Shallow and Intermediate Intervals. West of Marginal Way, groundwater is tidally-influenced and vertical gradients vary with time between upward and downward gradients. Strong upward gradients exist at wells adjacent to the Waterway (Aspect, 2012). Tidal influences in the pilot study location are discussed further in Section 3.2.2.1.

Hydraulic Conductivity Estimates

Hydraulic conductivity values were estimated based on slug tests completed at multiple wells for each sampling interval during the RI (Aspect, 2012). The following provides a summary of the data:

- **Water Table Interval.** Estimates from 6 wells ranged from 2.8 (MW-10) to 49 (PSC-138-WT) feet per day (ft/day). The geometric mean of all estimates is 8.6 ft/day;
- **Shallow Interval.** Estimates from 8 wells ranged from 20 (MW-8-30) to 111 (MW-24-30) feet per day (ft/day). The geometric mean of all estimates is 52.7 ft/day; and
- **Intermediate Interval.** Estimates from 8 wells ranged from 0.4 (MW-16-75) to 49.7 (MW-21-50) feet per day (ft/day). The geometric mean of all estimates is 5.5 ft/day.

The hydraulic conductivity estimates from Shallow and Intermediate Interval monitoring wells in SU1 are consistent with values from the other W4 Group investigations.

3.2.2.1 Tidal Influence

ABP has completed four tidal studies during the following periods: May/June 2010, October 2010, January 2011, and August 2012; these are reported in the RI (Aspect, 2012). Water levels in the Waterway are influenced by river flow and tidal effects from Elliott Bay. The typical tidal range in Elliott Bay is approximately 11 feet, based on the difference between mean higher high water (MHHW) and mean lower low water (MLLW).[2] Monitoring wells completed near the Waterway in the Shallow and Intermediate Intervals (MW-22-30/-50, MW-23-30/-50 and, PSC-CG-151-25) had a tidal range of 6 to 8 feet. Monitoring wells in the same interval but 300 feet from the Waterway (MW-24-30/-50) had a recorded tidal range of approximately 3 feet. Tidal influences on water levels diminish to 0.5 feet or less east of East Marginal Way, approximately 800 feet east of the Waterway. The hydraulic efficiencies calculated as the

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[2] http://tidesandcurrents.noaa.gov

ratio of groundwater elevation change to surface water elevation change in the Waterway are presented on Figure 8.

Further, high tides result in localized groundwater flow gradient reversal, although the time-averaged net-groundwater-flow direction is still toward the Waterway (Booth and Herman, 1998 and Aspect, 2012). The occurrence of localized and transient flow reversals is consistent with site characterization data collected at other similar sites in the Waterway, and with the ABP RI data.

In the two nearshore well clusters (MW-22-30/-50 and MW-23-30/-50), the tidally-averaged vertical gradients were slightly upward: +0.004 at MW-22 and +0.008 at MW-23. This slightly upward gradient is consistent with the regional flow path of groundwater discharge from adjacent uplands into the Waterway. The relatively dense saline water wedge that occurs in and below the Waterway results in an upward gradient of groundwater discharge into the river.

3.2.2.2 Groundwater Flow Rates

Estimates of groundwater flow rates are critical to pilot study design parameters—reagent washout rates, injection frequencies, downgradient monitoring well locations, and monitoring durations. The pilot study will include measurement of the groundwater flow rate which is critical to understanding the performance of a barrier remedial approach.

Previous work has included estimates of groundwater seepage velocities, including most recently in Appendix C of the SU1 FS (Aspect, 2016) for the purpose of estimating restoration timeframes. Estimates presented in this Work Plan vary from those estimates given that parameters local to the planned pilot study area presented in previous sections are used. Groundwater flow rate estimates are calculated using Darcy's Law:

$V = Ki/n$; where

V = average groundwater velocity, in ft/day;

K = hydraulic conductivity, in ft/day;

i = horizontal hydraulic gradient, in feet per foot; and,

n = effective porosity, in percent.

As mentioned previously and discussed further in Section 3.3, pilot study activities will be focused on the Shallow Interval groundwater in South Fidalgo Street near MW-24-30. Therefore, a range in hydraulic conductivity is used: the geomean of 52.7 ft/day and the estimate at MW-24-30 of 111 ft/day. The average horizontal hydraulic gradient in the Shallow Interval of 0.0017 ft/ft is used. As discussed in Payne et al. (2008), the use of a mobile porosity is recommended for estimating the actual groundwater velocity, plume migration rates and clean water transport rates for *in-situ* remediation. An estimated mobile porosity of 10 percent is used, based on soil type in the pilot study area. Based on these parameters, a groundwater flow rate of 0.9 to 1.9 ft/day is estimated in the Shallow Interval in the pilot study location. These estimates represent an average groundwater flow velocity (or seepage velocity) for just groundwater; Section 3.3.1 estimates transport rates for the target COCs. The pilot study includes tracer testing to further evaluate groundwater flow rate in the pilot study area.

3.3 Nature and Extent of CVOC Contamination

Suspected sources of CVOCs in SU1 groundwater include the ABP Facility as well as other area sources. TCE was used at the ABP Facility for vapor degreasing from approximately 1983 to February 2004. The primary CVOC is TCE; however, under certain conditions, TCE can undergo reductive dechlorination and form the less-chlorinated ethenes dichloroethenes (cis-1,2 DCE, 1,1-DCE, trans-DCE) and VC, which are also COCs in groundwater. The extent of TCE; cis-1,2 DCE; VC; and total chlorinated ethenes in groundwater are presented in Figures 4 through 7. If multiple grab samples were collected within a given sampling interval, the highest reported value for that location is depicted on the figure. At locations where both a well sample and grab sample were collected, the well sample is included on the figure. Trend charts for CVOCs and key biogeochemical indicators are included in Appendix A.

The RI Report (Aspect, 2012) discusses the nature and extent of all COCs in detail; however, this Work Plan is focused on the nature and extent of CVOCs in the Downgradient TCE Plume where the pilot study is planned. West of East Marginal Way, the highest TCE concentrations are observed in the Shallow Interval (Figure 4). Given the suspected source location, and the attenuation distance downgradient from the suspected source areas of TCE (greater than 2,000 feet), high concentrations of daughter products cis-1,2 DCE and vinyl chloride in the Shallow Interval are also observed in the pilot study location (Figures 6 and 7).

More recent investigations conducted by ABP (post-2010) have utilized permanent monitoring wells for monitoring CVOC concentrations in groundwater. However, older investigations conducted by PSC (2002) and other companies (2005) west of East Marginal Way utilized temporary groundwater samples collected from direct-push borings. This investigation method allows greater vertical discretization of CVOC concentrations. The TCE concentrations from discrete vertical intervals are presented on Figure 9. Recognizing that temporary groundwater sampling methods can result in biased-high concentrations (primarily due to turbid samples) and the age of these data (12 and 15 years old), these data still yield the following key CSM insights:

- The high magnitude of TCE concentrations (greater than 500 µg/L) observed at PSC-Q32, PSC-Q32-B, PSC-Q32-D, STG-GP-6, PSC-Q32-A, and STG-GP-7 indicate this area is the predominant CVOC transport pathway in groundwater to the Waterway.
- The highest TCE concentration at all temporary borings is observed between 20 and 30 feet (ft) bgs. Further, the TCE concentration gradient between vertical sample intervals is steep, indicating that the contamination exists in a relatively thin vertical interval of the aquifer. For example, the maximum concentration of 6,580 µg/L TCE in the 21-25 ft bgs interval is greater than one order of magnitude than the 17-21 ft bgs sample interval (307 µg/L TCE) and two orders of magnitude greater than the 25-29 ft bgs sample interval (13.4 µg/L TCE).

The following observations from the temporary groundwater sample results are made regarding concentrations of degradation products, cis-1,2 DCE and VC:

- Concentrations of cis-1,2-DCE greater than 200 µg/L were observed at STP-GP-6, PSC-Q32-F, and PSC-Q32-G at depth intervals ranging from 16-18 to 25-29 ft bgs sample intervals. The highest concentration of 1,040 µg/L cis-1,2-DCE was observed at PSC-Q32-F in the 20-22 ft bgs interval.
- Concentrations of VC greater than 50 µg/L were observed at STG-GP-5, STG-GP-6, STG-GP-7, PSC-Q32-A, PSC-Q32-B, PSC-Q32C, and PSC-Q32-G at depth intervals ranging from 15-19 to 28-30 ft bgs sample intervals. The highest concentration of 110 µg/L VC was detected at PSC-GP-6 in the 25-29 ft bgs interval.

The observed maximum concentrations of degradation products, cis-1,2 DCE and vinyl chloride, are not co-located with maximum concentrations of TCE. This is expected because TCE is transformed into its degradation products, and increased concentrations of degradation products typically are associated with decreased concentrations of the parent compound. Based on this discussion, the pilot study will be conducted in the vicinity of temporary boring locations PSC-Q32 and PSC-Q32-D in the Shallow Interval. This will allow existing monitoring wells MW-24-30 and MW-24-50 to be used as performance monitoring locations. While elevated concentrations of CVOCs (and maximum concentrations of degradation products) have been observed downgradient of this location, the selected area for the pilot study provides a greater attenuation distance to the Waterway. Further, the highest mass transport zone represents the greatest risk of discharge to the Waterway and therefore, the pilot testing targets the zone of highest mass transport.

3.3.1 Contaminant Transport Rate

An average groundwater flow rate of 0.9 – 1.9 ft/day was estimated using Darcy's Law was in previous Section 3.2.2.2. Transport rates for contaminants are less than average groundwater flow rates because of sorption behavior. A sorption retardation (Rfoc) of 2.1 and 1.2 are calculated for TCE and VC in the Final FS using measured soil fraction organic carbon (foc) of 0.002 (Aspect, 2016). Therefore, based on the Darcy's Law estimated average groundwater flow rate of 0.9 – 1.9 ft/day transport rates range 0.4 – 0.9 and 0.8 – 1.6 ft/day are estimated for TCE and VC, respectively.

3.4 Groundwater Geochemistry

Previous investigation activities related to groundwater geochemistry have primarily focused on evaluating metals attenuation mechanisms and CVOC plume attenuation (Aspect, 2012; 2014b; 2015a). This section describes the current understanding of groundwater chemistry in the pilot study area. Groundwater geochemical conditions across the Site have been previously reported to be mildly to moderately reducing (Aspect, 2015a). To better understand groundwater geochemistry conditions in the pilot testing location, a closer evaluation of available dissolved gases (ethene, ethane, and methane) and reduction/oxidation (redox) indicators (e.g., dissolved iron and sulfate) is performed in this section. Dissolved gases in the pilot study vicinity are presented on Figure 10 and redox indicators on Figure 11.

Under iron-reducing conditions, relatively-insoluble and naturally-occurring ferric iron (Fe3+) is reduced to ferrous iron (Fe2+), which is more soluble; therefore, greater dissolved Fe concentrations in groundwater indicate iron-reducing conditions. Sulfate reduction, based on thermodynamic potential, occurs under more reducing conditions than iron reduction, and is indicated by reduced sulfate concentrations. Methanogenesis, occurs under similar reducing conditions to sulfate reduction and is indicated by elevated methane concentrations in groundwater.

Elevated dissolved iron in groundwater wells MW-26-40 and MW-26-50 upgradient of East Marginal Way indicate iron-reducing conditions; however, significantly lower dissolved iron concentrations are observed at MW-24-30 and MW-24-50 in South Fidalgo Street. The presence of sulfate-reducing conditions is less clear based on the observed sulfate concentrations, which vary widely both in horizontal and vertical extent (Figure 11). Similarly, methane concentrations also vary widely. Methanogenesis is clearly occurring at locations where >10,000 µg/L methane is observed (MW-24-50, MW-22-50, and MW-25-75).

A more direct indication of groundwater redox geochemistry is the concentrations of less chlorinated TCE daughter products (cis-1,2 DCE and VC) and non-toxic end products (ethene and ethane) that indicate complete dechlorination. Cis-1,2 DCE and VC are detected at all locations in the pilot study location, in some cases closer to the Waterway, these daughter products are observed in much higher concentrations than the parent compound, TCE (e.g., MW-22-30, PSC-CG-151-25, PSC-140-40; see Appendix A). The CVOC trends at these locations are a sharp contrast to locations MW-25-50, MW-26-40 and MW-26-55 where TCE concentrations are much higher (>1 milligrams per liter [mg/L]) than daughter compound concentrations. These spatial differences in CVOC concentrations indicate greater attenuation further downgradient. However, attenuation is not entirely a function of distance and could also be attributed to the availability of organic carbon, the degree of reducing conditions, and/or hydrogeologic heterogeneities and corresponding transport rates.

The most direct indication of redox conditions (relative to attenuation of CVOCs in groundwater) is the presence of dechlorination end products ethene and ethane. The elevated concentrations of ethene and ethane at monitoring locations confirm the presence of a native microbial community capable of completely dechlorinating TCE to non-toxic end products (Figure 10). Additional monitoring for methane, ethane, and ethene, including within and outside the CVOC plume area, are proposed for the pilot study performance monitoring in Section 6.2.

3.5 CSM Summary

This CSM presents a focused understanding of conditions in the pilot study area and establishes basis of design for the pilot study. The following summarizes the key CSM conclusions and associated pilot study design implications:

- A range in average groundwater flow rates is estimated as 0.9 to 1.9 ft/day and transport rate of 0.4 to 0.9 and 0.8 to 1.6 ft/day for TCE and VC, respectively. These rates are considered when designing the monitoring well locations and sampling frequency, and the distance of the pilot study from the Waterway. Further, this rate is critical to understanding the performance of a technology applied as barrier, which relies on advective groundwater flow for downgradient improvements in water quality. Given this importance, directly measuring the groundwater flow rate through use of an applied tracer in pilot testing is proposed in Section 6.

- Significant hydraulic tidal influences complicate the evaluation of *in-situ* remediation technologies through increased dilution/dispersion and variable groundwater flow directions. The pilot study is planned far enough upgradient of the Waterway to avoid significant hydraulic tidal influences. Tidal effects will be monitored with pressure transducers for continuous water-level measurements during the pilot study, as outlined in Section 6.2.
- All available CVOC investigation results from South Fidalgo Street indicate the highest mass concentrations and transport occur in the 20 to 30 ft bgs depth. This will be confirmed during pre-pilot study activities discussed in Section 5, and is expected to be the target interval of pilot study activities.
- Dissolved iron and methane concentrations indicate mild to moderate reducing conditions in groundwater downgradient of East Marginal Way. Ethene and ethane concentrations confirm that complete reductive dechlorination is naturally occurring, although not at MW-24-30 and MW-24-50, the closest monitoring wells to the pilot study location. The pre-pilot study activities are designed to refine this understanding within the pilot study area and to be considered in the final pilot study design, to be submitted in the Field Implementation Work Plan.

4 Proposed Pilot Study

The success of any remedial technology relies on the Site characterization and an understanding of conditions that ultimately control the performance of the remedy technology. The CSM presented in the previous sections justifies revisiting remedial technologies selected for addressing the Downgradient TCE Plume.

4.1 Remedial Technologies

The Final FS (Aspect, 2016) assembled remedial alternatives using the retained technologies from the *Revised Technology Screening Memo* (PGG, 2015). In the Downgradient TCE Plume, air-sparge/soil vapor extraction (AS/SVE), EAnB, and ISCR were incorporated into FS alternatives (Aspect, 2016). ISCR and EAnB are both considered effective and implementable in areas of somewhat limited access (e.g., the operating ABP facility and street right-of-ways [ROWs]). These technologies were generally preferred to AS/SVE in the Downgradient TCE plume area because restoration time frame modeling indicates that AS/SVE systems may need to be operated for an extended period, and AS/SVE would require much more extensive infrastructure and operation and maintenance (O&M) demands. AS/SVE was identified in several alternatives as a possible remedial action next to the Waterway due to concerns about impacts to the Waterway from EAnB/ISCR reagents[3] and reduced effectiveness of EAnB/ISCR in that area. A pilot test for AS/SVE is not proposed at this stage of design because the application and effectiveness of those technologies, which rely on physical removal rather than biogeochemical transformations, is more reliably predicted.

This Work Plan further evaluates the potential use of ISCR and EAnB in the South Fidalgo Street area. The following sections expand on technology descriptions in the *Revised Technology Screening Memo* (PGG, 2015) and provide a comparative evaluation of the two technologies based on the CSM presented in Section 3.

4.1.1 Enhanced Anaerobic Bioremediation (EAnB)

In anaerobic conditions, microorganisms degrade PCE and TCE to ethene/ethane, limited amounts of carbon dioxide, and trace amounts of hydrogen gas. In these reactions, bacteria use the chlorinated COCs as electron acceptors, removing chlorine atoms that are replaced with hydrogen. Nitrate, ferric iron, manganese, sulfate, carbon dioxide, oxidized metals, or other organic compounds also replace oxygen as an electron acceptor/energy source to fuel the reaction and growth of beneficial bacteria. The source of hydrogen is the fermentation of native organic carbon material in the subsurface that serves as a food source, or electron donor.

During anaerobic biodegradation of chlorinated COCs, chloride ions are sequentially removed. The more highly chlorinated (more oxidized) compounds, such as PCE and TCE, are degraded more readily than the less chlorinated (less oxidized) compounds, such as DCE isomers and VC, which require more energy and a more highly anaerobic

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[3] An objective of the pilot study is to determine the impact of amendments on groundwater quality and the downgradient extent of those impacts.

environment to support the bacterial strains capable of complete reductive dechlorination to ethene and ethane. The CSM (Section 3) confirms that naturally-occurring complete reductive dechlorination is occurring in the Downgradient TCE Plume, although the extent and rate of dechlorination varies widely.

The EAnB technology involves enhancing microorganisms in contaminated groundwater through injection of an electron donor to sustain or increase reducing conditions and enhance the naturally occurring reductive dechlorination process. Electron donors include substances such as simple sugars (molasses), lactate, vegetable oils, or engineered reagents specifically designed to promote EAnB. Electron donor solutions can be injected using injection points constructed as a conventional well, temporary direct push probes, or groundwater recirculation systems.

In some cases, the microbial community required to support complete reductive dechlorination of DCE and VC may not be present at sufficient quantities and augmentation is necessary. However, based on the groundwater geochemistry discussion in Section 3.4, bioaugmentation is not considered necessary for EAnB in the proposed pilot study location because microbes capable of fully dechlorinating CVOCs are already present based on ethene/ethane detections (although to be confirmed in planned pilot study area before final pilot study design). Additionally, microbiological analysis will be conducted to inform final pilot study design.

Degradation rates in EAnB systems are well demonstrated to be greater for parent compounds, PCE and TCE, than for daughter products, cis-1,2 DCE and VC. This is evident by the persistent daughter product concentrations in the Downgradient TCE Plume and would be a careful consideration in designing an EAnB remediation approach.

EAnB may temporarily increase certain metals concentrations in groundwater such as arsenic, ferrous iron, and manganese, from reductive dissolution of native minerals in the aquifer matrix (Suthersan et al., 2008). This effect is temporary, as dissolved metals conditions would be expected to return to baseline levels as the organic carbon is exhausted and the redox returns to the background conditions, referred to as the redox recovery zone (Figure 12). Identifying the redox recovery zone and confirming protection of the Waterway are objectives of the downgradient performance monitoring. To ensure protection of the Waterway, a Contingency Plan (Section 6.2) includes performance monitoring triggers for redox-sensitive metals at monitoring locations downgradient of the injection transect (in areas expected to show redox recovery) and associated contingency actions.

Additional considerations for the implementation of the EAnB technology are the (desired) methane generation in the reactive zone, which has the potential to accumulate in the vadose zone and present a risk to occupants of nearby structures. These secondary effects of the EAnB technology are not considered to be of significant risk given the reducing and methanogenic conditions already present in the Downgradient TCE Plume, however they are evaluated further in Section 4.1.3. While not considered a significant risk, the Contingency Plan includes methane concentration triggers and contingency actions, if conditions warrant (see Section 6.2).

4.1.2 In-Situ *Chemical Reduction (ISCR)*

While biologically-mediated reductive dechlorination continues to be a significant focus of CVOC remediation, there has been an increased focus on abiotic reductive processes as remediation approaches, referred to as *in-situ* chemical reduction (ISCR). Indirect contaminant reduction via biologically-mediated processes can also play a role in ISCR technology, including EAnB, which is described in the previous section. Reducing agents used for ISCR include zero valent iron (ZVI), ferrous iron, sodium dithionite, sulfide salts, and hydrogen sulfide. These reductants can cause the rapid establishment of highly reducing conditions in the aquifer, resulting in degradation or destruction of CVOCs. The primary abiotic reaction pathway is beta-elimination, resulting in acetylene reaction products (as opposed to ethenes in biologically-mediated reduction). Conventional ISCR methods (e.g., PRBs constructed through trenching and emplacing granular iron) are not considered feasible in the Downgradient TCE Plume Area due to access constraints. However, ISCR can also be implemented by injecting products *in-situ*.

There are a number of products available on the market that utilize ISCR technology, primarily containing various forms of reduced iron and carbon substrates. A key consideration for the implementation of injection-based ISCR is given the insoluble iron component of ISCR reagents, the achievable distribution in the subsurface is limited and typically requires high-pressure injections and intentional fracturing of the formation to achieve design injection volumes/reagent loadings.

4.1.3 Comparative Evaluation

ISCR is considered potentially more effective at minimizing VC generation compared to EAnB, and ISCR amendments have potentially greater longevity (i.e., less frequent injections are needed). However, EAnB can be distributed through wells or direct-push borings (while ISCR requires direct-push injection) and typically uses cheaper amendments. Both of these technologies can significantly alter groundwater geochemistry in the vicinity of treatment by creating highly reducing conditions that can mobilize naturally occurring redox metals (e.g., iron, manganese, and arsenic). Therefore, neither are considered to be applied directly adjacent to the Waterway.

Both EAnB and ISCR technologies are considered effective for the Downgradient TCE Plume Area and a comparative evaluation is presented. The technologies are comparatively evaluated based on four key considerations:

1) **Treatment Effectiveness & Mechanisms:** Both the ISCR and EAnB technologies are effective for the target CVOCs (TCE, cis-1,2 DCE, vinyl chloride). ISCR relies more heavily on abiotic degradation but also enhances biologically-mediated EAnB through hydrogen generation (and the addition of organic carbon to some ISCR reagents). EAnB relies more heavily on biologically-mediated processes however recent research indicates that abiotic processes can contribute meaningful amount of treatment in EAnB systems (Suthersan et al, 2013). One key difference between the technologies is the sequential degradation of TCE in an EAnB system resulting in greater cis-1,2 DCE and vinyl chloride generation.

2) **Delivery & Distribution:** The success of all *in-situ* remediation technologies relies on the ability to deliver and distribute reagent to the target zone in the subsurface. EAnB is typically implemented with soluble reagents which can be delivered under low, non-fracturing pressures resulting in more uniform and predictable porous distribution. ISCR, however, typically requires injection under higher pressure for delivery resulting in fractured emplacement which is largely unpredictable and unrepeatable. An ISCR reagent would require careful injection considerations to avoid delivery to the target zone and in general, more dense point spacing.

3) **Secondary Effect Management**: Both EAnB and ISCR result in reducing conditions which can mobilize redox-sensitive metals such as iron, manganese, and arsenic, which must be monitored and managed. The degree of temporary metals mobilization is expected to be higher with EAnB. Unlike ISCR, EAnB is expected to generate methane, which could require monitoring to evaluate potential impacts on the adjacent structures.

4) **Longevity and Access:** The pilot study location in South Fidalgo Street is a high traffic area requiring significant access coordination/limitations and health and safety considerations. In order to establish an *in-situ* treatment barrier through injections, more-frequent access would be required with the EAnB technology.

Based on this comparative evaluation, the primary differences are the reagent chemistry relative to the groundwater chemistry and the delivery method. A proposed pilot test approach is discussed in the next Section. Based on the existing data, a combined ISCR and EAnB approach is considered likely. However, depending on the baseline monitoring results, which will include geochemical, and microbiological characterization, EAnB could be a preferable option. Therefore, this work plan provides a general pilot study approach with additional details to be identified after baseline monitoring in the subsequent Field Implementation Work Plan.

4.2 Pilot Study Approach

A field-scale pilot study will be conducted in the Downgradient TCE Plume Area in South Fidalgo Street. The injection reagent will be delivered through an array of injection points to create a continuous transect and reactive zone in the Shallow Interval (targeting 20 to 30 ft. bgs) and spanning the width of access within the ROW as shown in Figure 13. This location was selected based on 1) previously achieved access and safe operations in this area, 2) the ability to use existing monitoring well MW-24-30 as a downgradient performance monitoring well, 3) the elevated concentrations and relatively thin vertical impacted interval observed at temporary groundwater samples, and 4) the distance of 300 feet from the Waterway to allow recovery of geochemical changes within the reactive zone and avoid hydraulic and geochemical tidal influences.

The Final FS (Aspect, 2016) conceptualized active treatment along the entire length of S. Fidalgo Street which is oriented more parallel to groundwater flow than orthogonal. The pilot study injection transect is oriented orthogonal to groundwater flow. This orientation maximizes the treatment downgradient of the injection transect (i.e., advectioncontrolled, physical flushing via a clean-water front generated within the reactive zone; Figure 13).

At this time, and based on the comparative evaluation (Section 4.1.3) and the current CSM (Section 3), the following reagents have been identified as the most likely for potential use in the pilot test:

- Peroxychem EHC ® Liquid Reagent – includes a soluble iron compound and ELS™ microemulsion that are mixed and diluted on-Site for injection. This is an ISCR reagent that is more soluble than a ZVI-based ISCR reagent.
- EOS Remediation EOS Pro – an enriched emulsified vegetable oil in a concentrated emulsion that is diluted on Site for injection.
- EOS Remediation EOS ZVI – an enriched emulsified vegetable containing micro-scale ZVI. This is an insoluble ISCR reagent.

Additional information regarding these three reagents is included in Appendix E, including vendor product sheets and Safety Data Sheets (SDSs). The makeup and treatment mechanisms associated with these three reagents are representative of all reagents being considered. A list of other commercially-available reagents is also provided in Appendix E. These amendments contain similar components with similar characteristics (iron and/or organic carbon source) and are expected to have a similar effect on groundwater geochemistry as the three reagents identified.

If the baseline groundwater biogeochemistry indicates that the system is reducing, yet is limited by the availability of carbon (as an electron donor) for more reducing conditions necessary for the biologically-mediated reduction of CVOCs, a EAnB reagent (e.g. EOS Pro) will be selected. A reagent with an ISCR component (e.g. EHC Liquid or EOS ZVI) will be selected if the baseline groundwater results indicate concentrations of total CVOCs (specifically TCE) greater than observed at MW-24-30. The final injection design (including reagent selection, dosing, and delivery approach) will be presented under separate cover, a Field Implementation Work Plan, discussed in Section 8.

The application of *in-situ* remediation technologies requires the careful management of non-target, secondary reactions and effects that require monitoring and contingency actions, if conditions warrant. Monitoring and contingency actions are discussed in Section 6.2.

4.3 Pilot Study Objectives

The Final FS (Aspect, 2016) discussed the need for pilot testing of technologies to select and design the final cleanup action. The pilot study is designed to assess the effectiveness and cost of using *in-situ* ISCR or EAnB to treat CVOCs in groundwater west of East Marginal Way, to refine remedial alternatives presented in the SU1 FS and select a preferred remedy. This pilot study is designed based on the following objectives:

1) **Evaluate the ability to deliver and distribute reagent in Shallow Interval groundwater.** This objective will be evaluated based on the ability to achieve targeted injection volumes and reagent dosing, observe reagent breakthrough, and

establish a continuous transect (barrier) through an array of injection points. This objective also includes logistical considerations of access, a safe work space in high traffic areas, and utility locations.

2) **Reduce CVOC concentrations at rates greater than monitored natural attenuation (MNA) process.** MNA processes are occurring at the Site and to evaluate effectiveness, post-injection CVOC trends at wells influenced by injections will be compared to trends in wells not influenced by injections.

3) **Estimate design parameters for implementing the technology.** This includes the longevity of the desired biogeochemical change and associated injection frequency required to maintain the reactive barrier. Other design parameters include radius of influence (ROI)/injection volume relationship, injection specific capacity (relationship of injection rate and water level increase), and injection pressure thresholds. The injection pressure thresholds will vary dependent on the reagent selection. (i.e. greater injection pressures and fracture emplacement are required for ISCR; low-pressure, porous distribution for soluble EAnB reagents).

4) **Evaluate performance downgradient of the reactive zone.** Downgradient of the reactive zone in the direction of the Waterway, CVOC concentrations are reduced through physical flushing via a clean-water front. This will be evaluated using downgradient analytical monitoring and directly measuring groundwater flow rates using an applied, conservative tracer.

5) **Evaluate ability to manage secondary effects.** With both the EAnB and ISCR technologies, inherent to the desired change in CVOC concentrations are secondary effects that should be expected and managed. These include the reductive dissolution of redox sensitive metals, the generation and potential accumulation of methane, and potential short-circuiting of injection solution. The design in this Work Plan includes management elements of a redox recovery zone, a buffer between buildings and injection points, and monitoring of these secondary effects.

These objectives will serve as the basis for performance evaluation during the pilot study. The following sections described the planned pilot study activities.

5 Pre-Pilot Study Activities

This section describes the planned activities prior to initiating the remediation phase of the field pilot study. A key objective of pre-pilot study activities is to refine the CSM presented in Section 3. Specific CSM elements to be refined are the extent and current concentrations of CVOCs in groundwater. The relative molar concentrations of TCE, cis-1,2 DCE, VC, and ethene/ethane are a key component of the final pilot study design. This final pilot design, along with the results of all pre-pilot study activities will be included in the Field Implementation Work Plan described later in Section 8.

5.1 Utility Clearance

Prior to initiation of any subsurface work, a comprehensive utility survey will be performed. At a minimum, this utility survey will include a public utility locate (i.e., “one-call”), a private utility locate, and a review of available public and/or private as-built drawings. Prior to the locates, the proposed locations of the new monitoring wells and injection transect will be identified at the Site. If necessary, a vacuum truck will be mobilized to “clear” proposed boring locations to a shallow depth prior to drilling.

5.2 Well Installation

Additional groundwater monitoring wells are necessary for pilot study performance monitoring in the planned pilot study area. A total of seven new monitoring wells are proposed to be installed and sampled for baseline conditions prior to the beginning of pilot testing. The proposed locations are shown in Figure 13 and consist of three categories:

- **Dose-response (DR) monitoring wells.** Two dose-response monitoring wells are proposed and will be installed approximately 5 to 8 feet downgradient of the injection points. The location of the DR wells is intended to provide monitoring data during the injection operation; specifically, breakthrough of the injection solution at the DR well would be targeted. Observing breakthrough during injection allows verification of distribution and calibration of other key design parameters, including the relationship between injection volume and ROI.

- **Downgradient performance monitoring wells**. An additional four monitoring wells will be installed to monitor the reactive zone further downgradient through changes in water quality. Three of these locations will be located approximately 20 ft downgradient of the injection points. Two of these three locations will be approximately in the same flow path as a corresponding DR well. The fourth location will be installed approximately 50 ft downgradient of the injection points, the same distance downgradient as existing locations MW-24-30 and MW-24-50, which will also be utilized as downgradient performance monitoring wells.

  The distances of these downgradient monitoring wells correspond to an estimated average groundwater travel time of 11-22 days (at wells 20 feet downgradient) and 26-56 days (at wells 50 feet downgradient). This estimated range serves as a basis of performance monitoring frequency discussed later in Section 6.2.2.

- **Upgradient monitoring well.** One additional well will be installed to evaluate upgradient CVOC and geochemical conditions in groundwater entering the pilot study area. This well will be located 15-20 feet upgradient of the injection transect.

All proposed new monitoring wells will be screened in the Shallow Interval between approximately 20 and 30 ft. bgs based on the nature and extent discussion in Section 3.3. Existing monitoring well, MW-24-50, will provide monitoring data in the Intermediate Interval during pilot study activities.

With the exception of DR-1, all proposed new monitoring wells will be constructed of 2-inch Schedule 40 polyvinyl chloride (PVC) and 10-slot PVC 10-foot screened sections. DR-1 will be constructed of using a 4-inch PVC casing and 4-inch stainless-steel wire-wrapped 10-foot screened section to allow potential use as an injection well. The use of this well as an injection point, if determined necessary, would be described in the Field Implementation Work Plan.

Monitoring wells will be installed by a WA-licensed driller using hollow-stem auger (HSA) drilling methods. Monitoring wells will be installed as outlined above, consistent with project field procedures outlined in the Remedial Investigation Work Plan (Aspect, 2008). Locations, as shown on Figure 13, are subject to access based on the field locates and utility clearance. As-built monitoring well construction details, locations, and drilling observations will be summarized in the Field Implementation Work Plan. Investigative-derived waste (IDW) generated during drilling will be containerized and transported from the pilot study location to the ABP Facility for temporary storage and, ultimately, characterized and disposed at an approved off-Site disposal facility.

All proposed well locations are within South Fidalgo Street and the associated ROW. A City of Seattle street use permit will be obtained, and although no access agreements are anticipated, the business owner/operators in this busy corridor will be notified of planned activities. A traffic control plan will likely be required to obtain the street use permit and will be implemented diligently to ensure worker safety and minimize disruptions to local traffic and businesses.

5.3 Baseline Groundwater Sampling

Groundwater monitoring data will be collected to inform the final pilot study injection design and serve as baseline conditions for performance evaluation. This monitoring event will include baseline groundwater elevation gauging, and samples will be collected for the analytes presented in Table 3. This groundwater sampling will occur after the installation of the seven new monitoring wells and include all new wells in addition to existing wells, MW-24, MW-24-30 and MW-24-50 (Table 4). A second baseline event that includes the seven new monitoring wells will occur immediately before injection to allow for more than one data point for evaluating performance and because there may be several months between the first event and the start of the field test.

Additionally, PSC-142-40 will be sampled during this baseline event to represent biogeochemical conditions outside of the CVOC plume and allow comparison of general chemistry parameters to results from pilot study monitoring wells and refinement of the groundwater geochemistry CSM element. Additionally, microbiological analysis will be performed at PSC-142-40 for comparison with pilot test area wells and ultimately, the final pilot test design to be presented in the FIWP.

Samples will be collected using low-flow sampling methods in accordance with project standard operating procedures (Pacific Groundwater Group, 2017; Aspect, 2008) and analyzed by Analytical Resources Inc. (ARI) Laboratories in Tukwila, WA.

5.4 Underground Injection Authorization

The proposed injection points are considered Class V underground injection wells that are subject to the Underground Injection Control Program, WAC 173-218. The Site is being managed pursuant to Agreed Order No. DE10402, between Ecology and the W4 Group. In accordance with WAC 173-218-060(5)(b), a permit is not required when injection activity is performed under an agreed order. However, the injection points will be registered with Ecology’s UIC program using their online registration tool.

6 Pilot Study Design

This section presents a conceptual design for the pilot study. The final pilot study design will be presented in a Field Implementation Work Plan to be submitted after the pre-pilot study activities.

6.1 Reagent Injections

6.1.1 Injection Transect

An injection transect will be created through an array of injection points to create a continuous barrier in the Shallow Interval (targeting 20 to 30 ft bgs) and spanning the width of access (approximately 60 ft) within the ROW as shown in Figure 13. The basis for this location is discussed in Section 4.2. It is expected that direct-push (DP) technology will be used to implement the injections, regardless of the final reagent design, given the proven ability to advance to the target depths (up to 30 ft bgs), and the limited temporary access on South Fidalgo Street.

DP injections also allow using headers to inject multiple points at the same time and increase overall efficiency, which will be critical to minimizing the disruption to businesses and traffic on South Fidalgo Street. There are different methods of conducting injections using DP technology, including:

- **Conventional screen points.** This method uses standard direct push tooling for groundwater sampling. A concealed screen and an expendable point are fixed to the bottom of the drill rods. The rods are driven to the desired depth and then retracted, exposing a stainless steel screen. This screen allows the borehole to stay open across the injection interval, providing increased surface area for reagent delivery. Standard drive points are available in either 4- or 5-foot screen lengths; the effective length of the screen point can potentially be extended by pulling the rods up during injection at a given location. This approach is typically used with soluble injection materials (delivery of slurries could be limited by straining of particles through the screen slots).
- **Modified screen points.** Some vendors and drilling contractors have developed a modified screen point approach to provide a longer screened interval. Larger diameter direct-push rods fitted with an expendable drive point are driven to the desired depth, but before the rods are retracted, a well screen is inserted in the drill rods to the base of the rods. The rods are then retracted and the screen is exposed. The injection line is connected to the direct-push rods, but the well screen allows the reagent to travel down the well screen and be delivered into the formation. This method works well when the target injection interval is 10 feet or less; however, once deployed, the screen cannot be retracted to inject across a shallower interval. As with the conventional screen point method described above, this approach is typically used with soluble injection materials.
- **Nozzle drive point.** This method uses specialized drive points designed for direct-push injection incorporating lateral injection ports or “nozzles.” These devices are typically equipped with a foot valve that opens to allow fluid flow

into the surrounding formation through several ports on the side of the drive point. If the opening at the foot valve is sufficiently large to prevent straining, this approach can be used with soluble or slurried injection materials.

- **Open-bottom rods.** This injection point uses standard direct-push tooling, outfitted with an expendable drive point affixed to the downhole end of the rods. The rods are driven to the bottom of the injection interval and then retracted back a predetermined distance to remove the expendable point so that fluid can be injected into the subsurface. This method is frequently used; however, the open borehole beneath the tooling may collapse, reducing the surface area for the material to be delivered and inhibiting delivery. This method can be used with either soluble or slurried injection materials.

All of these methods will be considered based on the final reagent selection and targeted dosing to identify the most appropriate DP tooling and method. Regardless, given the high hydraulic conductivity of the target interval, injection under low (non-fracturing) pressures results in a more predictable and uniform porous distribution and prevent risk associated with short-circuiting is preferred.

As discussed in Section 4.1.3, the estimated ROI for a soluble EAnB reagent is greater than for an insoluble ISCR reagent. A minimum ROI of 3 feet and maximum of 5 feet are estimated based on the different reagents considered for pilot testing and the planned use of DP technology. The ROI dictates the required point spacing to construct the continuous treatment barrier of 60 ft and based on this range, point spacings of 5 to 8 ft are planned allowing some overlap to ensure complete distribution.

These details are presented as a conceptual design and illustrate the parameters for *in-situ* design; however, final injection design details are subject to the final reagent selection and targeted dosing which will be determined based on the pre-pilot study activities. This final injection design will be presented in the Field Implementation Work Plan.

6.1.2 Applied Conservative Tracer

An applied tracer will be added to the injection solution to support evaluation of pilot study objectives identified in Section 4.3. The tracer will be conservative (i.e., nonreactive in the Site groundwater and injection solution) and provide a “signature” to the injection solution to indicate breakthrough at monitoring wells. Specifically, the tracer breakthrough will be monitored during the operational monitoring (discussed in Section 6.2.1) to measure distribution and during post-injection performance monitoring (Section 6.2.2) to refine hydrogeologic properties.

The final applied tracer design will be specified in the Field Implementation Work Plan. There are generally three categories of applied tracers used in *in-situ* remediation: ionic (salt), isotopic, and fluorescent. A fluorescent tracer is planned for pilot testing because of the benefit of visual detection (observing breakthrough in field and reducing number of analytical samples), demonstrated and ease of use in *in-situ* applications and low detection limits (<0.01 µg/L). Ozark Underground Laboratory (OUL) in Protem, Missouri is a recognized leader in the use of applied tracers for hydrogeologic investigations and will be used as the supplier of tracer and analytical testing. OUL uses dyes (common name) of fluorescein, eosine, rhodamine WT, and sulforhodamine B, and analyzes fluorescent intensity of all tracers using a Shimadzu spectrofluorophotometer (model RF-5301). Additionally, passive charcoal samplers can be deployed down-hole and analyzed for peak concentrations.

The applied tracer element of field pilot test is designed to prevent discharge of fluorescent water to the Waterway. An applied tracer concentration of 40 mg/L is common in injection solutions and gives six orders of magnitude resolution for analytical detection (relative to detection limit of <0.01 µg/L). Another key consideration is the sorptive losses of tracer observed in high TDS water and some injection reagent solutions (Chua et al., 2007 and Richardson et al., 2004).

Numerous studies (Stockton et al, 2011; Marking, 1969; Walthall and Stark, 1999; and Smart, 1984) have looked at the aquatic toxicity of fluorescent tracers. Of these studies, the lowest reported (Smart, 1984) toxic concentration was 1 mg/L for blue mussels (*Mytilus edulis*). The tracer selection and dosing will be finalized when the reagent and dosing is selected and presented in the Field Implementation Work Plan. However, based on these literature and protection of potential Waterway aquatic receptors, a maximum injected tracer concentration of 10 mg/L is planned. At least 50% dilution at the dose-response monitoring wells is assumed, therefore the estimated maximum *in-situ* concentration in groundwater would be 5 mg/L at the DR monitoring wells, approximately 300 ft. from the Waterway (Figure 13). The aquifer volume between the injection transect and the Waterway for the target interval is at least 10 times greater than the anticipated injection volume, and therefore any tracer concentration reaching the water would be significantly below the 1 mg/L concentration (by dilution alone), if detected at all. Contingency measures to ensure protection of the Waterway are described in 6.2.3.

6.2 Monitoring

The monitoring program in this section is designed to evaluate the pilot study objectives presented in Section 4.3. Baseline monitoring will be performed as a pre-pilot study activity and is necessary for final pilot study design. Additional monitoring consists of two different monitoring programs and objectives, operational monitoring and performance monitoring, which are described in the following sections.

6.2.1 Operational Monitoring

Operational monitoring will be conducted during the injections to guide the injection operations and modify as necessary. The operational monitoring elements and objectives consist of:

- **Injection rate, volume and pressure.** The injection rate and pressure will be monitored and recorded continuously (approximately hourly frequency) throughout the injections. Injection rate will be measured individually at each injection point and pressure measured at the injection point wellhead. Injection pressures will be managed to achieve reasonable injection rates and avoid formation fracturing, if possible. The total injection volume per point (and per depth interval) will also be recorded.

- **Reagent dosing.** At least one sample will be collected from the injection solution and submitted to verify design dosing. The type of analysis to verify dosing will be specified in the Field Implementation Work Plan. A sample will also be submitted to OUL for tracer analysis to verify tracer source concentration.
- **Water level monitoring.** The primary means of fluid accommodation in the subsurface is vertical displacement (mounding); therefore, water level monitoring of DR monitoring wells and any injection points not being actively injected will be performed. Sudden and significant increases in water levels at wells during injections can indicate formation failure and/or short-circuiting to the well, and can be avoided and prevented through low-pressure injections. Manual water level monitoring will also be conducted approximately twice a day during the active injections at all PSW wells, MW-24-30, and MW-24-50.

  Additionally, pressure transducers will be deployed in two DR wells to record water levels every 10 minutes to assess response to the injections. These pressure transducers will remain deployed after the injection event for longer-term monitoring of water levels and tidal influences in the pilot test area.
- **Breakthrough monitoring.** Breakthrough monitoring at the DR monitoring wells will consist of a one-well volume purge (given the high frequency of sampling) and a grab sample. The grab sample will be field-screened against visual standards (to estimate tracer strength). Based on field screening, samples will be submitted to OUL for laboratory analysis of tracer to develop breakthrough curves. Additionally, samples may also be collected for general chemistry parameters (e.g., TOC) to estimate reagent breakthrough—this detail will be specified in the Field Implementation Work Plan based on the final reagent selection and dosing. Tracer monitoring details (e.g., collection frequency, laboratory analyses) will be included in the Field Implementation Work Plan.

These operational monitoring activities will be conducted in accordance with project standard operating procedures (Pacific Groundwater Group, 2017; Aspect, 2008), with any exceptions noted herein.

6.2.2 Performance Monitoring

Performance monitoring will be initiated at the end of the pilot study injections to evaluate the objectives described in Section 4.3. The analytes to be evaluated are listed in Table 3 and the locations and frequency presented in Table 4. The monitoring frequency is based on the average groundwater and TCE transport velocities calculated in Section 3. The performance monitoring schedule may be modified if observations warrant a change. Any modifications to the schedule in Table 4 will be discussed with Ecology. The performance monitoring program consists of:

- **Short-term monitoring.** Samples will be collected from DR monitoring wells immediately following injection completion (0 days elapsed), Week 1, Week 2, Week 4, Month 2, and Month 3 (Table 4). At Week 4, in addition to the DR wells, the three new performance monitoring wells will also be sampled. At

Month 2, the fourth new performance monitoring well and wells MW-24-30 and MW-24-50 will be sampled. This progression of monitoring locations downgradient during the first quarter of monitoring is based on the expected movement of changes in geochemical and CVOC concentration changes resulting from injections.

- **Longer-term monitoring.** Following the first quarter, the monitoring frequency will be reduced to quarterly (Months 6, 9, and 12) at all monitoring locations (Table 4). Continued monitoring beyond one year may be necessary for complete evaluation of pilot study objectives – this need will be determined during the planned longer-term monitoring and discussed with Ecology.

Monitoring methods will be performed in accordance with project standard operating procedures (Pacific Groundwater Group, 2017; Aspect, 2008). This performance monitoring plan is not expected to be modified significantly based on the pre-pilot study activities and final reagent selection and dosing. However, it will be included in the Field Implementation Work Plan to identify any changes.

6.2.3 Contingency Plan

The application of *in-situ* remediation technologies requires the careful management of non-target, secondary reactions and effects that require monitoring and contingency actions, if conditions warrant. The secondary effects associated with the planned field pilot test are described in Section 4. The pilot test is designed at a scale to minimize the secondary effect footprint and to provide information necessary for full-scale design, if selected (see Pilot Test Objectives in Section 4.3). This pilot test carefully considers design parameters such as planned injection transect length, dosing, and distance from Waterway to prevent any exposure risk to aquatic receptors. However, a Contingency Plan is developed to outline actions to take during the field pilot test if monitoring results indicate a potential exposure risk.

The existing monitoring well, MW-24-30, as the most downgradient performance monitoring well, is proposed to trigger contingency actions (Figure 13). The monitoring well MW-24-30 is located approximately 32 to 67 days of groundwater travel time downgradient of the injection transect based on the estimated average groundwater seepage velocity presented in Section 3. The Waterway, the exposure point this Contingency Plan is designed to protect, is 160 to 335 days of groundwater travel time downgradient of the injection transect. These travel time estimates show that monitoring conditions at well MW-24-30 provides adequate time for contingency response actions protective of the Waterway.

The planned monitoring of MW-24-30 is outlined in Table 4. The monitoring results will be compared to the following triggers for contingency actions:

Redox-sensitive metals: Arsenic and manganese have PCULs protective of surface water of 5 and 100 ug/L, respectively (Table 1). Additionally, as reducing conditions already exist, historical results indicate baseline manganese concentrations above PCULs (Appendix D) – therefore, the trigger is any redox-sensitive metal concentration above PCULs and at least 2x greater than the baseline concentration.

Fluorescent tracer: Triggered by a measured tracer concentration of greater than the 1 mg/L aquatic toxicity threshold discussed in Section 6.1.2.

Methane: The generation of methane is a desired condition for enhanced reductive dechlorination. There are no relevant aquatic toxicity data for methane. However, the potential to accumulate in the vadose zone in the vicinity of structures is an explosive hazard that warrants a contingency trigger. The methane trigger is a measured methane concentration of 10x greater the baseline concentration. Given this trigger is to protect structures and not the Waterway, this condition will be triggered based on a result from any PSW monitoring location (Table 4).

If any of these conditions are observed, the following sequence of contingency actions would be implemented:

1) If the next monitoring event is not within one month per Table 4, an additional monitoring event will be conducted within one month to verify the condition. If the condition is verified, proceed to next action.

2) a) Establish appropriate sampling to continue monitoring the observed condition. This contingency monitoring would be proposed to and approved by Ecology and would include more frequent monitoring of the observed condition, at a minimum.

   b) Evaluate the aquatic exposure risk of the observed condition at the Waterway. This evaluation would include an estimate of the attenuation observed in the pilot test area and applying this estimate to the groundwater pathway from the pilot test area to the Waterway. If this evaluation indicates there is a potential risk, proceed to the next action.

3) Given the estimated groundwater travel time to the Waterway and the next downgradient Shallow Interval monitoring wells are adjacent to the Waterway (PSC-CG-151-25, MW-22-30, MW-23-30) – an additional Shallow Interval monitoring well would be installed in the vicinity of MW-24 for contingency monitoring. The contingency monitoring at this new location would be consistent with that approved in Step 2) a) above.

4) If the observed contingency condition is observed at the new monitoring well, an appropriate contingency action would be proposed to Ecology in a contingency action plan submitted to Ecology for approval within 10 days of receiving the analytical result. The next contingency action would be designed to address the specific condition and actions could include pumping to establish hydraulic control, oxidation to offset a condition created by reducing conditions, or passive (or active) vapor relief to address a methane concern.

An update to this contingency plan will be provided in the FIWP with installed monitoring well locations, baseline concentrations and associated trigger concentrations.

7 Project Organization and Plans

7.1 Project Organization

The project organization is led by Aspect who will engage the necessary subcontractors to complete the planned activities. All team members are responsible for execution of work in accordance with the final Work Plan and Field Implementation Work Plan; key individuals and their roles on this project are as follows:

- **Project Manager – Jeremy Porter.** The project manager is responsible for the successful completion of all aspects of this project, including day-to-day management, production of reports, liaison with party and regulatory agencies, and coordination with the project team members. The project manager is also responsible for resolution of non-conformance issues, is the lead author on project plans and reports, and will provide regular, up-to-date progress reports and other requested information to project team and Ecology.
- **Field Manager – Adam Griffin.** The field manager is responsible for overseeing the pilot study outlined in this plan, including oversight and management of field personnel and subcontractors, ensuring conformance with final Work Plan and the Field Implementation Memo. The field manager will manage procurement of necessary field supplies, assure that monitoring equipment is operational and calibrated in accordance with the specifications provided herein, and act as the Site Health and Safety Officer.
- **Subcontractors.** Numerous subcontractors are necessary to complete the activities described in this Work Plan and the Field Implementation Work Plan, including analytical laboratories (ARI Laboratories and OUL), driller for well installation and injections, IDW disposal, and a reagent vendor (to be determined in Field Implementation Memo). The subcontractors are responsible for conforming to the final Work Plan and the agreed to scope with Aspect.

7.2 Quality Assurance Project Plan

Monitoring and activities described in this Work Plan will be conducted in accordance with the Ecology-approved Quality Assurance Project Plan (QAPP) presented in the RI Work Plan (Aspect, 2008) and the Supplemental QAPP presented in the RI Data Gaps and Supplemental Work Plan (Aspect, 2014a). A pilot study-specific QAPP will be presented in the FIWP that references the existing QAPPs (Aspect, 2008; Aspect, 2014a), but includes specific QA/QC elements unique to the pilot test including the applied tracer sampling and QA/QC that relates to the selected injection reagent.

7.3 Health and Safety Plan

Work and public safety are of paramount importance during the planned pilot test activities and will be performed in accordance with the existing Health and Safety Plan (HASP). A subsequent update of the HASP will be presented in the Field Implementation Work Plan to include safety data sheets (SDSs) for the reagent and tracer.

8 Schedule and Reporting

A detailed estimated schedule of pilot study activities is presented in Figure 14. Ecology issued an AO amendment and the draft of this Work Plan for public comment in October 2017. The pre-pilot activities are planned to be implemented after the public comment period and estimated to occur December 2017/January 2018, following Ecology approval of the final Work Plan and the Field Implementation Work Plan to be final in Q2 2018. The field pilot study activities would be initiated in Q3 2018 and the completion of one year of performance monitoring in Q3 2019. If performance monitoring beyond one year post-injection is determined necessary, monitoring would be conducted beyond Q3 2019.

As required by the Amended AO, pilot test deliverables will consist of this Work Plan, a Field Implementation Work Plan, and a Pilot Study Completion Report. Data collected during the pilot study, including injection results and post-injection monitoring, and recommendations for modifications to the monitoring program if warranted, will be included in quarterly progress reports. This Work Plan presents a CSM for the pilot study area, pilot study approach and a conceptual design. The final pilot study design will be submitted in the Field Implementation Work Plan and will include the following:

- Results of pre-pilot testing activities described in Section 5 including well construction logs and baseline monitoring results.
- Based on the results of the pre-pilot testing activities, an updated CSM, with focus on the extent and current concentrations of CVOCs in groundwater. The relative molar concentrations of TCE, cis-1,2 DCE, vinyl chloride, and ethene/ethane and an evaluation of ongoing ERD.
- Selection of a preferred treatment chemistry and reagent for pilot testing (EAnB or ISCR) based on improved understanding of groundwater geochemistry.
- A comprehensive Sampling and Analysis Plan and the supplemental QAPP;
- Injection design details, including:
    - Injection point configuration and spacing, targeted ROI and injection volumes, and tracer selection and dosing.
    - The point configuration and design ROIs comprising the Injection transect will be illustrated on a figure.
    - Injection operation procedures.
- Any modifications to the monitoring program based on the final injection design.
- An updated Contingency Plan, and
- An updated HASP.

The Pilot Study Completion Report will be prepared and submitted draft to Ecology within 45 days of receiving all analytical data. The Pilot Study Completion Report will include conclusions regarding the pilot testing and the potential effectiveness of the technology for the final cleanup action.

9 References

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10 Limitations

Work for this project was performed for the West of 4th Group (Client), and this report was prepared in accordance with generally accepted professional practices for the nature and conditions of work completed in the same or similar localities, at the time the work was performed. This report does not represent a legal opinion. No other warranty, expressed or implied, is made.

All reports prepared by Aspect Consulting for the Client apply only to the services described in the Agreement(s) with the Client. Any use or reuse by any party other than the Client is at the sole risk of that party, and without liability to Aspect Consulting. Aspect Consulting's original files/reports shall govern in the event of any dispute regarding the content of electronic documents furnished to others.

TABLES

Table 1 - Proposed Cleanup Levels

Art Brass Plating 050067

		Preliminary Cleanup Levels													
		Soil					Groundwater				Air		Surface Water		Sediment
Constituent of Concern	Carcinogen or Non-Carcinogen	Puget Sound Background Concentrations for Metals[1]	Soil Cleanup Level Protective of Direct Contact Pathway (Unrestricted Land Use)[2]	Soil Cleanup Level Protective of Direct Contact Pathway (Industrial Land Use)[2]	Soil Cleanup Level Protective of Air Quality based on Protection of Groundwater as Potable Drinking Water[3]	Soil Cleanup Level Protective of Groundwater Concentrations Protective of Surface Water Quality[4]	Groundwater Cleanup Level Protective of Air Quality Water Table Zone (Unrestricted Land Use)[5]	Groundwater Cleanup Level Protective of Air Quality Water Table Zone (Industrial Land Use)[5]	Groundwater Cleanup Level Protective of Surface Water[6]	Groundwater Cleanup Level Protective of Sediment[7]	Air Cleanup Level Protective of Inhalation Pathway (Unrestricted Land Use)[2]	Air Cleanup Level Protective of Inhalation Pathway (Industrial Land Use)[2]	Surface Water Cleanup Level Protective of Human Health[8]	Surface Water Cleanup Level Protective of Aquatic Life	Sediment Cleanup Level[9]
		(Milligrams/kilogram)					(Micrograms/liter)				(Micrograms/cubic meter)		(Micrograms/liter)		(Milligrams/kilogram)
Tetrachloroethene	Carcinogen	--	476	21,000	0.08	0.04	116	482	2.9	36,000	9.6	40	2.9	--	190
Trichloroethene	Carcinogen	--	12	1,750	0.03	0.006	6.9	37	0.7	4,760,000	0.37	2	0.7	194 [12]	8,950
cis-1,2-Dichloroethene	Non-Carcinogen	--	160	7,000	--	--	--	--	--	--	--	--	--	--	--
trans-1,2-Dichloroethene	Non-Carcinogen	--	1,600	70,000	0.59	6	559	1,224	1,000	--	27.4	60	1,000	--	--
1,1-Dichloroethene	Non-Carcinogen	--	4,000	175,000	0.055	0.025	538	1,176	3.2	--	91.4	200	3.2	--	--
Vinyl chloride	Carcinogen	--	0.67	87.5	0.002	0.001	1.3	12.7	0.18	543,000	0.28	2.8	0.18	210 [13]	202
1,4-Dioxane	Carcinogen	--	10	1,310	0.004	0.32	2,551	25,510	78	--	0.5	5	78	--	--
Arsenic	Carcinogen	20	20	87.5	Not Applicable	0.082	Not Applicable	Not Applicable	0.14 / 5 [10]	241	Not Applicable	Not Applicable	0.14 / 5 [10]	36 [14]	7
Barium	Non-Carcinogen	--	16,000	700,000	Not Applicable	824	Not Applicable	Not Applicable	--	--	Not Applicable	Not Applicable	--	--	--
Cadmium	Non-Carcinogen	1	80	3,500	Not Applicable	1.2	Not Applicable	Not Applicable	8.8	760	Not Applicable	Not Applicable	--	8.8 [15]	5.1
Copper	Non-Carcinogen	36	3,200	140,000	Not Applicable	1.1	Not Applicable	Not Applicable	3.1 [11]	18,000	Not Applicable	Not Applicable	--	3.1 [15]	390
Iron	Non-Carcinogen	58,700	58,700	2,450,000	Not Applicable	--	Not Applicable	Not Applicable	--	--	Not Applicable	Not Applicable	1,000	--	--
Manganese	Non-Carcinogen	1,200	11,200	490,000	Not Applicable	--	Not Applicable	Not Applicable	100	--	Not Applicable	Not Applicable	100	--	--
Nickel	Non-Carcinogen	48	1,600	70,000	Not Applicable	11	Not Applicable	Not Applicable	8.2	2,200	Not Applicable	Not Applicable	100	8.2 [15]	15.9
Zinc	Non-Carcinogen	85	24,000	1,050,000	Not Applicable	101	Not Applicable	Not Applicable	81	6,600	Not Applicable	Not Applicable	1,000	81 [15]	410

NOTES:

Preliminary cleanup levels presented represent the most stringent cleanup levels for the constituent of concern listed in the media indicated.

-- indicates no value is available. In the case of ARARs, the reference sources do not publish values for the noted chemicals. In the case of calculated values, one or more input parameters are not available.

"Not Applicable" is used where the constituent of concern will not affect the media of potential concern due to an incomplete pathway.

[1] Background metals values from Ecology Publication No. 94-115, Natural Background Soil Metals Concentrations in Washington State. Arsenic background from MTCA, Table 740-1 Method A Soil Cleanup Levels for Unrestricted Land Uses.

[2] Cleanup level is based on standard Washington State Model Toxics Control Act Cleanup Regulation (MTCA) Method B (unrestricted land use) or Method C (industrial land use) values from the Cleanup and Risk Calculations tables (CLARC).

[3] Soil cleanup levels for protection of air quality are calculated using MTCA Equation 747-1 where the potable Method B groundwater cleanup level was used as Cw. Concentrations of hazardous substances in soil that meet the potable groundwater protection standard currently are considered sufficiently protective of the air pathway for unrestricted and industrial land uses.

[4] Soil cleanup levels for protection of surface water quality are calculated using MTCA Equation 747-1 where the groundwater cleanup level protective of surface water in this table was used as Cw.

[5] Groundwater cleanup levels protective of the air pathway for unrestricted land use (residential and commercial sites) and industrial land use were derived using the following equation: GWcul = Aircul/GIVF.

[6] Human health and marine aquatic ecologic receptors were considered. Refer to the Surface Water Cleanup Levels Protective of Human Health and Aquatic Life in this table. The more stringent value of the two receptors has been listed for the Groundwater Cleanup Level Protective of Surface Water.

[7] Groundwater screening levels based on the transfer of contaminants from groundwater to sediment were calculated by dividing the sediment screening level by the associated partition coefficients. Koc and Kd values are from MTCA. Fraction of carbon assumed at 0.02 based on Lower Duwamish Waterway Feasibility Study (AECOM, 2012).

[8] The most stringent exposure pathway for human health receptors are for consumption of fish. Listed values are based on ARARs listed in CLARC except: (1) 1,4-dioxane is derived from MTCA Method B default values and values; (2) PCE, TCE, trans-DCE, vinyl chloride, nickel and zinc are based on EPA's revised CWA Human Health Criteria - Organism Only dated 11/15/16.

[9] Sediment has not been confirmed to be affected by groundwater discharge to surface water. Sediment cleanup levels were derived from the Lower Duwamish Waterway Superfund Site Record of Decisions (EPA, 2014), which does not contain values for nickel, TCE, PCE, or vinyl chloride. These constituents are not listed in the Sediment Management Standards (WAC 173-204) either. EPA Region 3 BTAG Marine

[10] Arsenic Cleanup level of 5 ug/L based on background concentrations for state of Washington (MTCA Table 720-1).

[11] The surface water cleanup level for copper had previously been tabulated as 2.4ug/L; however this value is based on an approach using site-specific water effects ratio which has not been determined. We have replaced this with 3.1 ug/L, National Recommended Water Quality Criteria published by EPA under 304 of the Federal Clean Water Act - Aquatic Life Criteria Table

[12] Oak Ridge Nation Laboratory (ORNL) Toxicological Benchmarks for Screening Potential Contaminants of Concern for Effects on Aquatic Biota

[13] Peer Review Literature - DeRooij et al., 2004, *Euro Chlor Risk Assessment for the Marine Environment OSPARCOM Region – North Sea – Environmental Monitoring and Assessment*

[14] WAC- 173-201A-240

[15] National Recommended Water Quality Criteria published by EPA under 304 of the Federal Clean Water Act - Aquatic Life Criteria Table

Table updated August 14, 2015 based on revisions to AWQC; July 20, 2016 based on Ecology comments on the Draft FS Reports for SU1 and SU2 (clarify footnotes, add sediment values, add surface water CULs protective of aquatic life); and January 17, 2017 based on EPA's revisions to the Clean Water Act Human Health criteria (dated 11/15/16).

Table 2 - Proposed Remediation Levels for cVOCs by Location

Art Brass Plating 050067

	Remediation Level in µg/L		
Location	**TCE**	**DCE**	**VC**
ABP Facility	1,380	1,620	162
Second Avenue	430	68	7
First Avenue	90	10	2
E Marginal Way S	30	4	2
S Fidalgo Street	4	5	1.6
Surface Water CUL	*7*	*4,000*	*1.6*

Note:

Remediation Levels derived using BIOCHOLOR modeling and are non-unique solutions for combinations of TCE, DCE, and VC. Remediation levels can be less than cleanup levels due to conversion of TCE or DCE to VC. Refer to Appendix C for details.

Table 3 - Monitoring Program - Analyte List

Art Brass Plating 050067

Analyte	Analytical Method	Purpose
CVOCs and Degradation Products		
Volatile Organic Compounds (VOCs)	EPA 8260B	
Dissolved gases; ethane, ethene, methane	RSK-175	Degradation end-product (ethene and ethane; redox indicator (Methane)
General Chemistry		
Total Organic Carbon (TOC)	EPA 415.1 (or SW-846 Method 9060)	Electron donor
Chloride	EPA 300.1	ERD reaction product
Sulfate	EPA 300.0	Electron acceptor/ Redox Indicator
Nitrate, Nitrite (both as N)	EPA 300.0	Electron acceptor/ Redox Indicator
Iron (Dissolved)[2]	EPA 6020 or 6010B	Electron acceptor/redox indicator
Redox-Sensitive Metals		
Arsenic, Barium, and Manganese (Dissolved)	EPA 6020 or 6010B	Redox-sensitive COCs
Microbiological Analysis		
Phospholipids fatty acids	PLFA - Biotrap	Microbiological community indicator
CENSUS- Dehalococcodies	CENSUS - Biotrap	Microbiological community indicator
Field Parameters		
Fe(II)/Fe(III)[1]	Hach ferrous iron kit, in field	Electron acceptor/Redox Indicator
Total Dissolved Solids	Multimeter	Field parameter
Specific conductance	Multimeter	Field parameter
Dissolved oxygen	Multimeter	Field parameter
pH	Multimeter	Field parameter
ORP	Multimeter	Field parameter
Turbidity	Turbidometer	Field parameter

1. Fe(III) is a calculated value from the difference between total iron and ferrous iron.

ERD - Enhanced Reductive Dechlorination

N - Nitrogen

2. Dissolved metals analysis will be field-filtered using a 0.45 micron filter.

Table 4 - CVOC Pilot Study Groundwater Monitoring Program

Art Brass Plating 050067

	Baseline		Performance Monitoring (time elapsed post-injection)								
	Pre-Pilot	Before Injection	0 days	Week 1	Week 2	Week 4	Month 2	Month 3	Month 6	Month 9	Month 12
DR-1	1,2,3,4,5,6	1,2,3	1,2,3,4,5	1,2,3,4	1,2,3,4	1,2,3,4,5	1,2,3,4	1,2,3,4,5	1,2,3,4,5	1,2,3,4	1,2,3,4,5
DR-2	1,2,3,4,5	1,2,3	1,2,3,4,5	1,2,3,4	1,2,3,4	1,2,3,4,5	1,2,3,4	1,2,3,4,5	1,2,3,4,5	1,2,3,4	1,2,3,4,5
PSW-1	1,2,3,4,5	1,2,3				1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4,5	1,2,3,4	1,2,3,4,5
PSW-2	1,2,3,4,5	1,2,3				1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4,5	1,2,3,4	1,2,3,4,5
PSW-3	1,2,3,4,5	1,2,3				1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4,5	1,2,3,4	1,2,3,4,5
PSW-4	1,2,3,4,5	1,2,3					1,2,3,4	1,2,3,4	1,2,3,4,5	1,2,3,4	1,2,3,4,5
PSW-5 (upgradient)	1,2,3,4,5	1,2,3				1,2,3		1,2,3	1,2,3	1,2,3	1,2,3
MW-24	1, 3							1, 3	1, 3	1, 3	1, 3
MW-24-30	1,2,3,4,5,6						1,2,3,4	1,2,3,4	1,2,3,4,5	1,2,3,4	1,2,3,4,5
MW-24-50	1,2,3,4,5						1,2,3,4	1,2,3,4	1,2,3,4,5	1,2,3,4	1,2,3,4,5
PSC-142-40	1,2,3,6										

Analytes (see Table 3):

1 - CVOCs and Dissolved Gases
2 - General Chemistry Parameters
3 - Field Parameters
4 - Applied Tracer
5 - Redox Sensitive Metals
6 - Microbiological Analysis

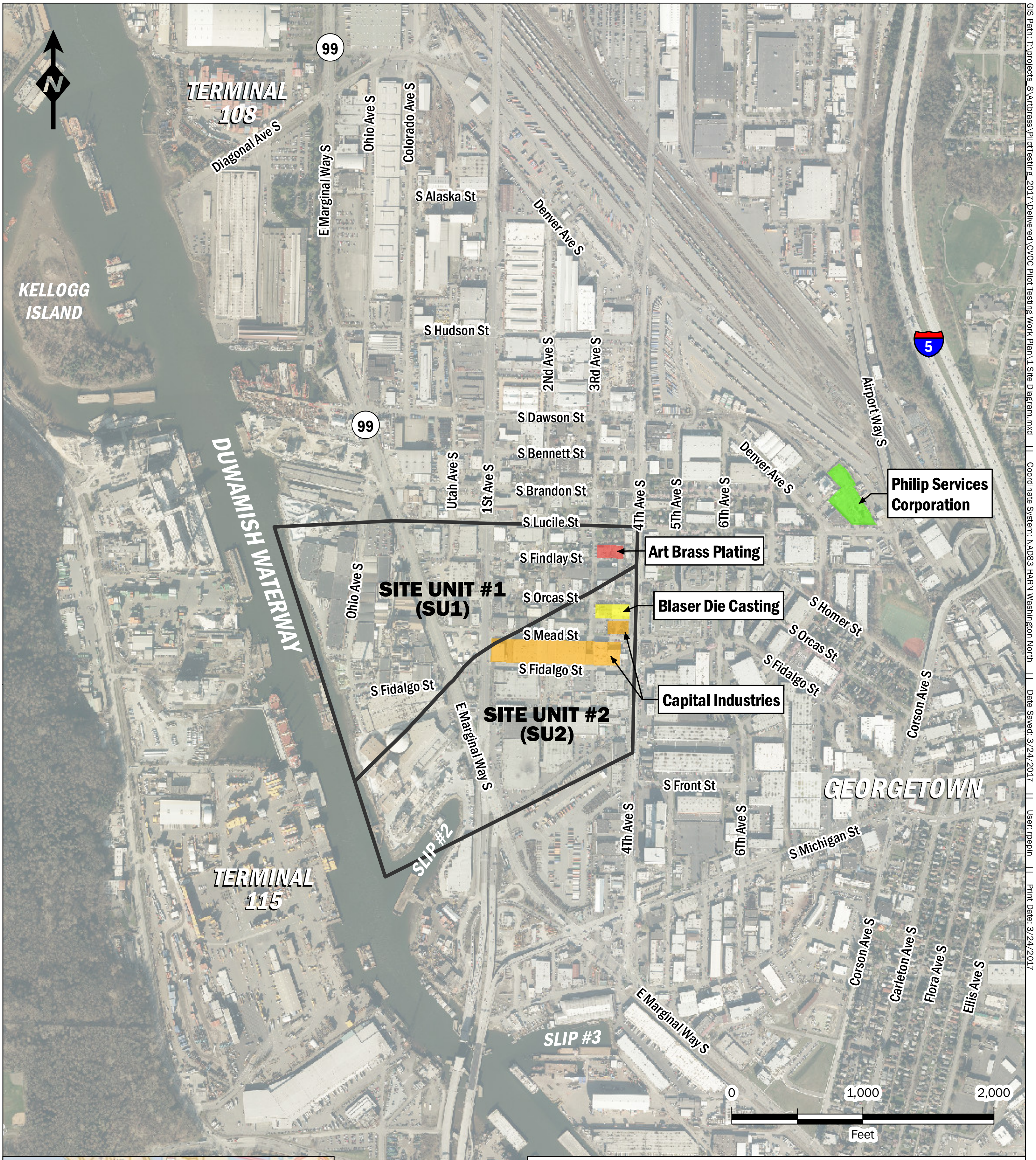
Notes:

The first baseline monitoring results will be reported in the *Field Implementation Memo* in addition to any changes to this Performance Monitoring Program

DR - dose-response monitoring wells

PSW - pilot monitoring wells

FIGURES



Site Diagram

CVOC Pilot Study Work Plan
Art Brass Plating
Seattle, Washington

Aspect CONSULTING

MAR-2017	BY: PPW	FIGURE:	
PROJECT NO. 050067	REVISED BY: DIM / RAP		1

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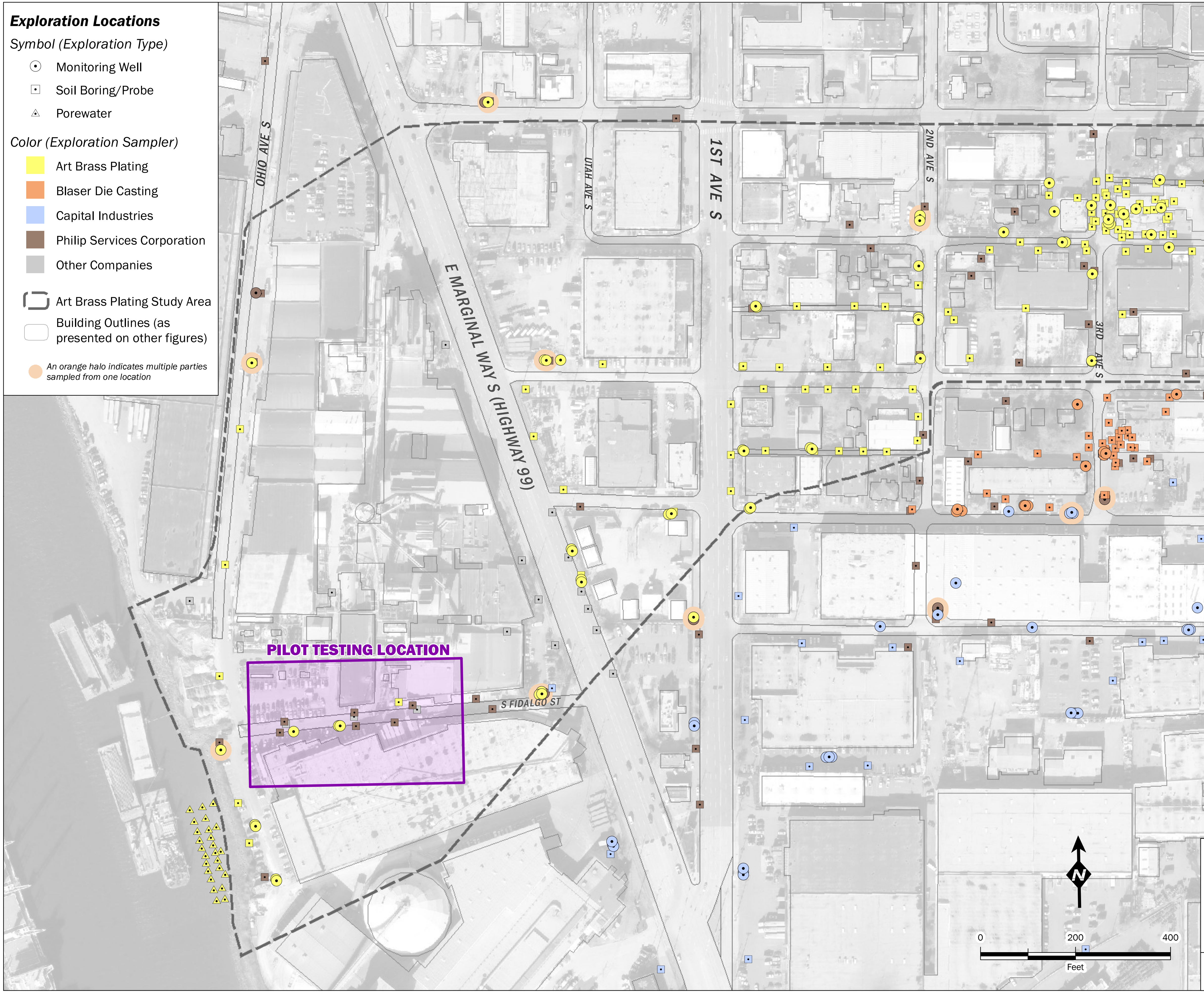
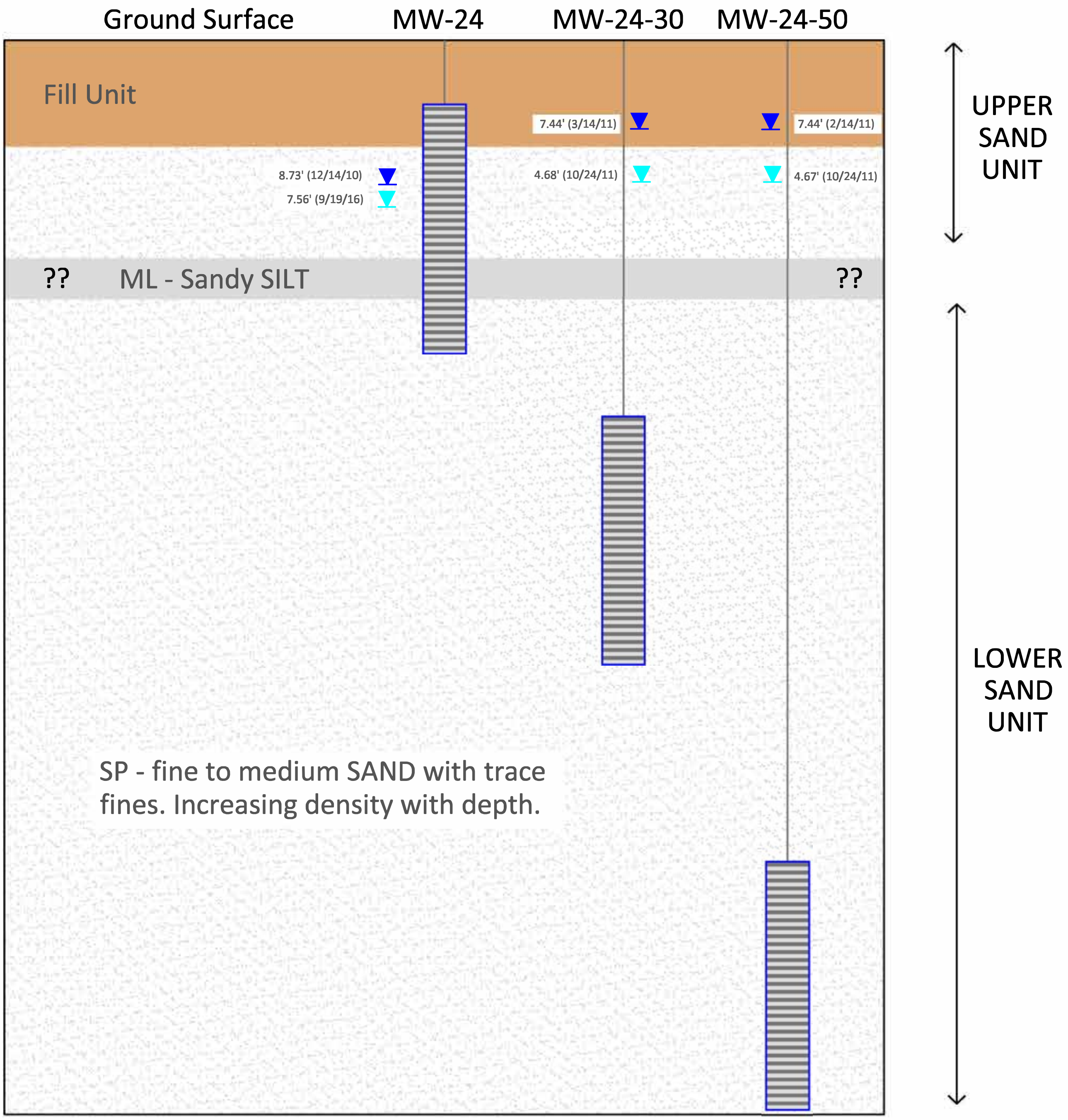


Site Map - Exploration Locations

CVOC Pilot Study Work Plan
Art Brass Plating
Seattle, Washington

Aspect CONSULTING

MAR-2017	BY: EAH	FIGURE NO. 2
PROJECT NO. 050067	REVISED BY: DIM / RAP	



Legend

▼ Maximum Groundwater Elevation Observed

▼ Minimum Groundwater Elevation Observed

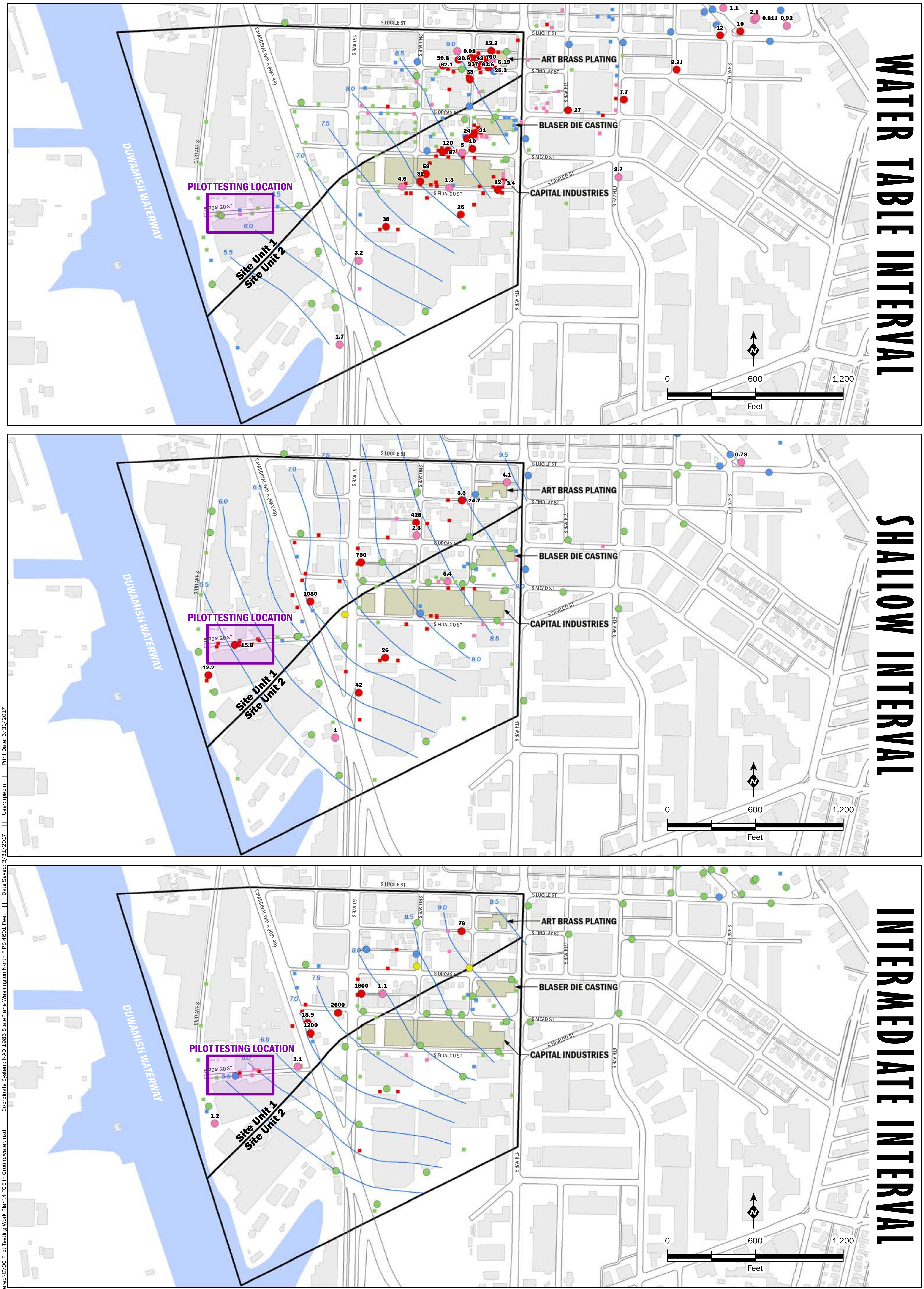
Note: Well Screen Locations and Groundwater Elevations are Not to Scale.

1-D Hydrostratigraphy Section

CVOC Pilot Study Work Plan
Art Brass Plating
Seattle, Washington

Aspect CONSULTING	Mar-2017	BY: TAD/ACG	FIGURE NO.
	PROJECT NO. 050067-14J	REVISED BY: SCC	3

CAD Path: Q:\Art Brass Plating\050067 Art Brass\2017-03 Pilot Study\Figure 3.dwg Figure 3 || Date Saved: Mar 24, 2017 10:52am || User: rpepin



GIS Path: T:\projects_8\ArtbrassPilotTesting_2017\Delivered\CVOC Pilot Testing Work Plan\4 TCE in Groundwater.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 3/31/2017 || User: rpepin || Print Date: 3/31/2017

Groundwater Sample Locations:
● Well ■ Geoprobe
⊗ Well without data for analyte/interval

Sample Location Symbol Color:
🟥 Detected at > 10x CUL
■ Detected Above CUL
🟦 Detected Below CUL
🟨 Not Detected (Reporting Limit Above CUL)
🟩 Not Detected

Geoprobe data shown on this map reflects the maximum concentration detected at that sample location in the given interval.

Well data shown on this map reflects the most recent sample at that well collected through 2016 for SU1 and 2014 for SU2.

Well locations with CUL exceedances are labeled with the most recent concentration:

55 ● ← *Trichloroethene (TCE) Concentration (in µg/L)*

8.0 ∼ Half-foot Groundwater Elevation Contours from August, 2012 Site-Wide Monitoring Event (NAVD88 Vertical Datum)

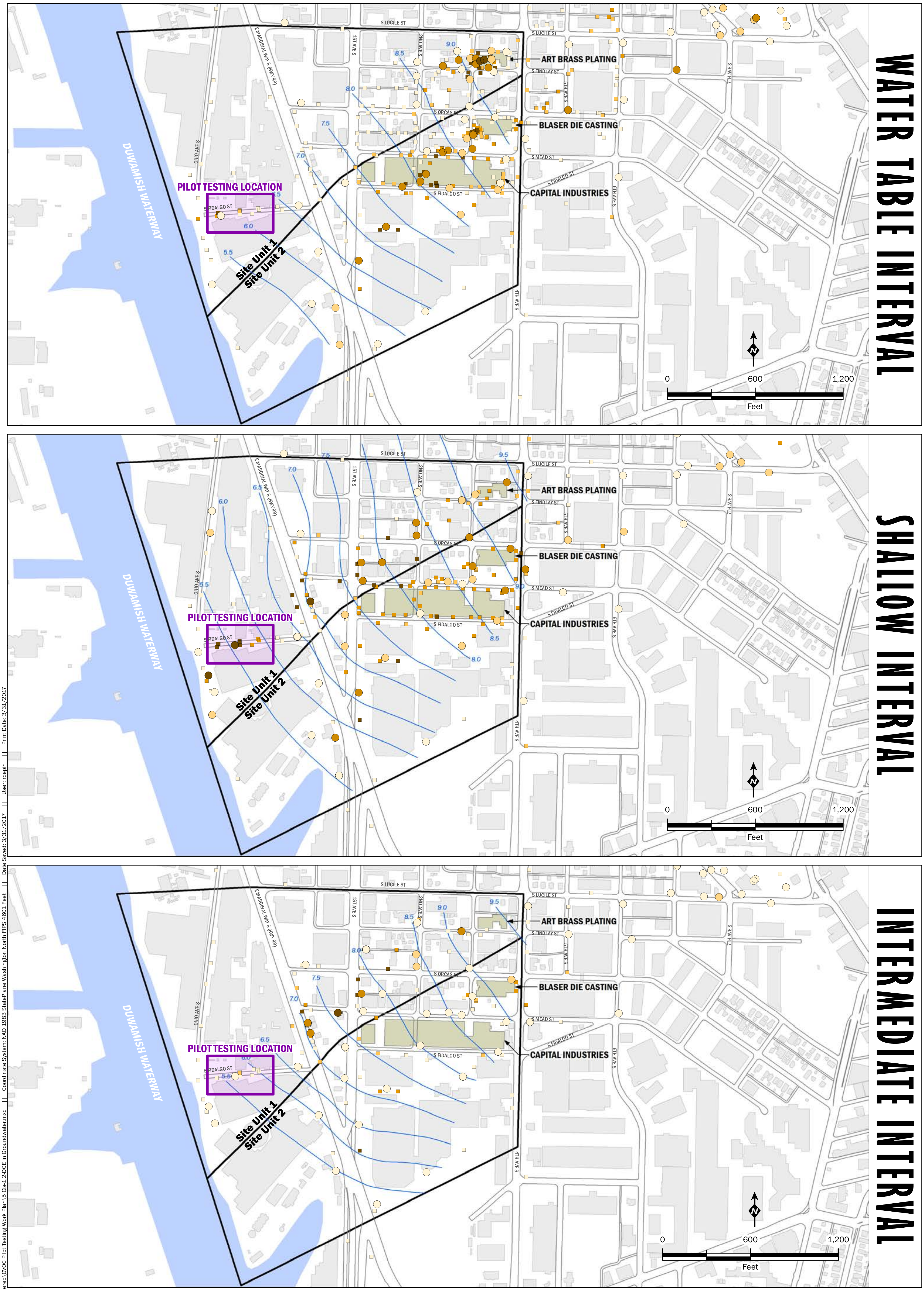
The Groundwater Cleanup Level (CUL) Protective of Surface Water Quality for Trichloroethene (TCE) is 0.7 µg/L.

Trichloroethene (TCE) in Groundwater

CVOC Pilot Study Work Plan
Art Brass Plating
Seattle, Washington

Aspect CONSULTING

MAR-2017	BY: PPW	FIGURE NO.
PROJECT NO. 050067	REVISED BY: DIM / RAP	4



Groundwater Sample Locations:

- ● Well
- ⊗ Well without data for analyte/interval
- ■ Geoprobe

Sample Location Symbol Color:

- ■ >100 µg/L
- ■ 10 - 100 µg/L
- ■ 1 - 10 µg/L
- □ < 1 µg/L

8.0 〜 Half-foot Groundwater Elevation Contours from August, 2012 Site-Wide Monitoring Event (NAVD88 Vertical Datum)

Well data shown on this map reflects the most recent sample at that well collected through 2016 for SU1 and 2014 for SU2.

There is no groundwater cleanup level for Cis-1,2 Dichloroethene and the concentrations scale presented on this figure is arbitrary and for illustration

Cis-1,2 Dichloroethene (DCE) in Groundwater

CVOC Pilot Study Work Plan
Art Brass Plating
Seattle, Washington

Aspect CONSULTING

MAR-2017

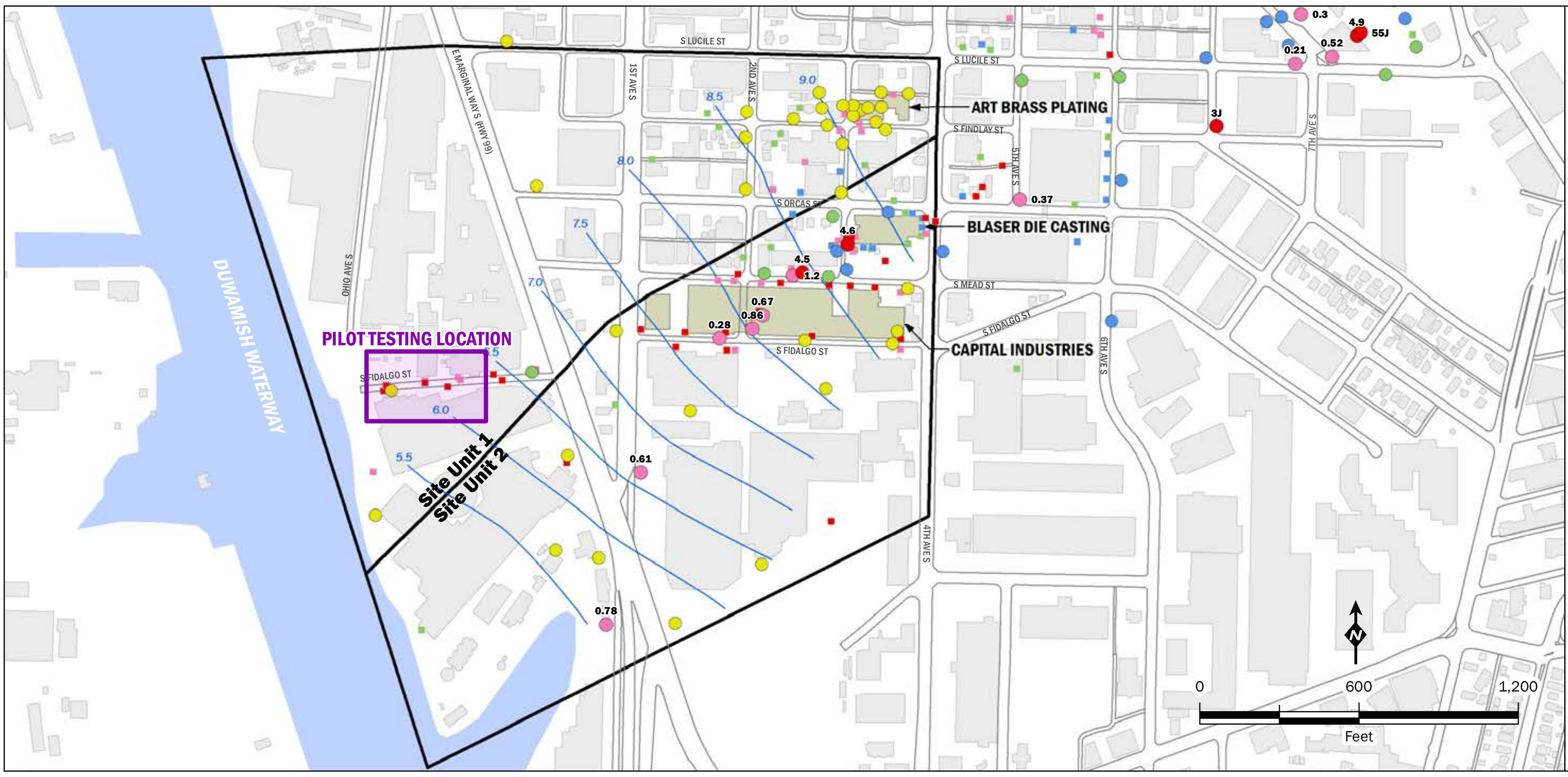
BY: PPW

PROJECT NO. 050067

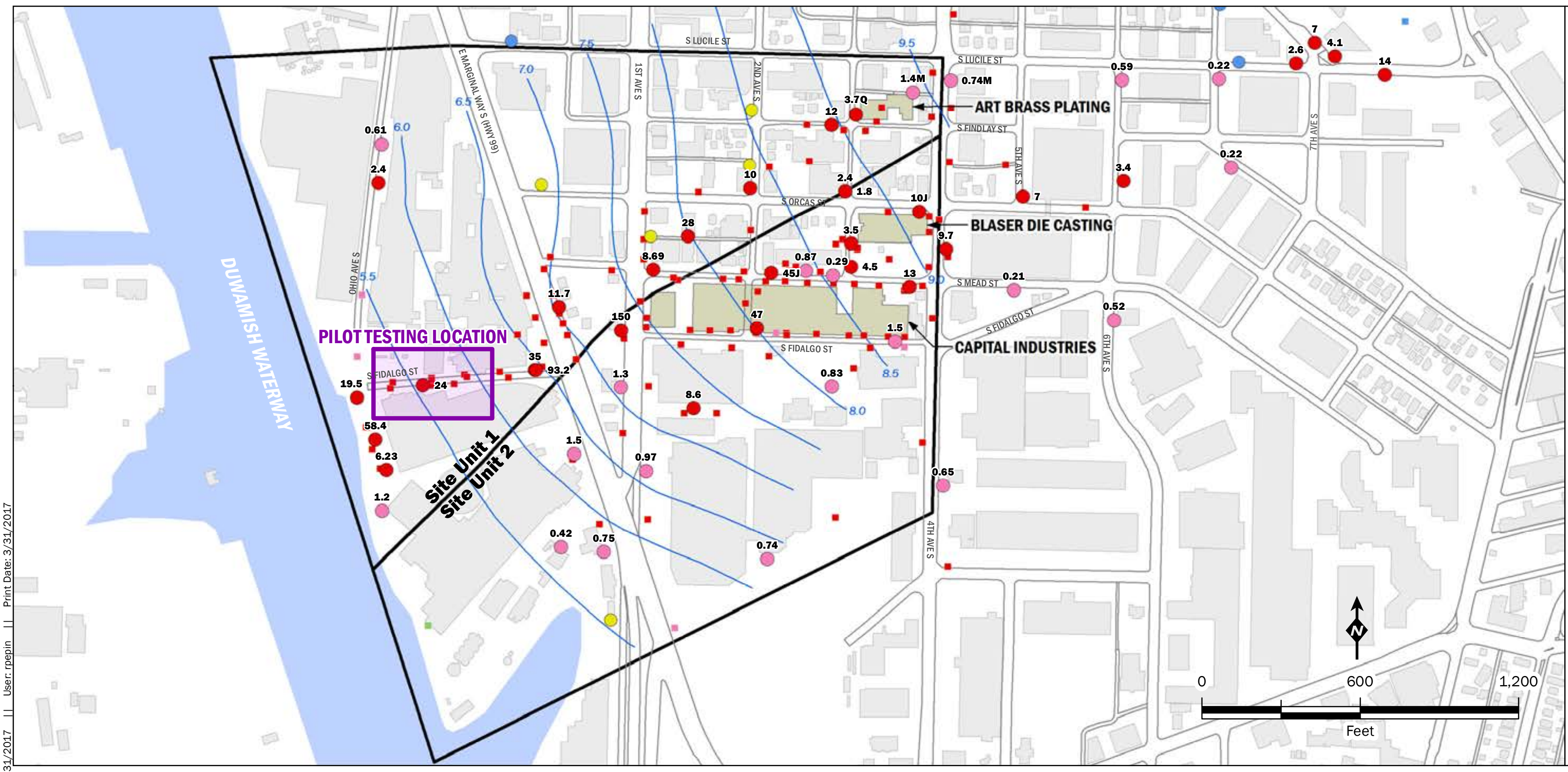
REVISED BY: DIM / RAP

FIGURE NO. 5

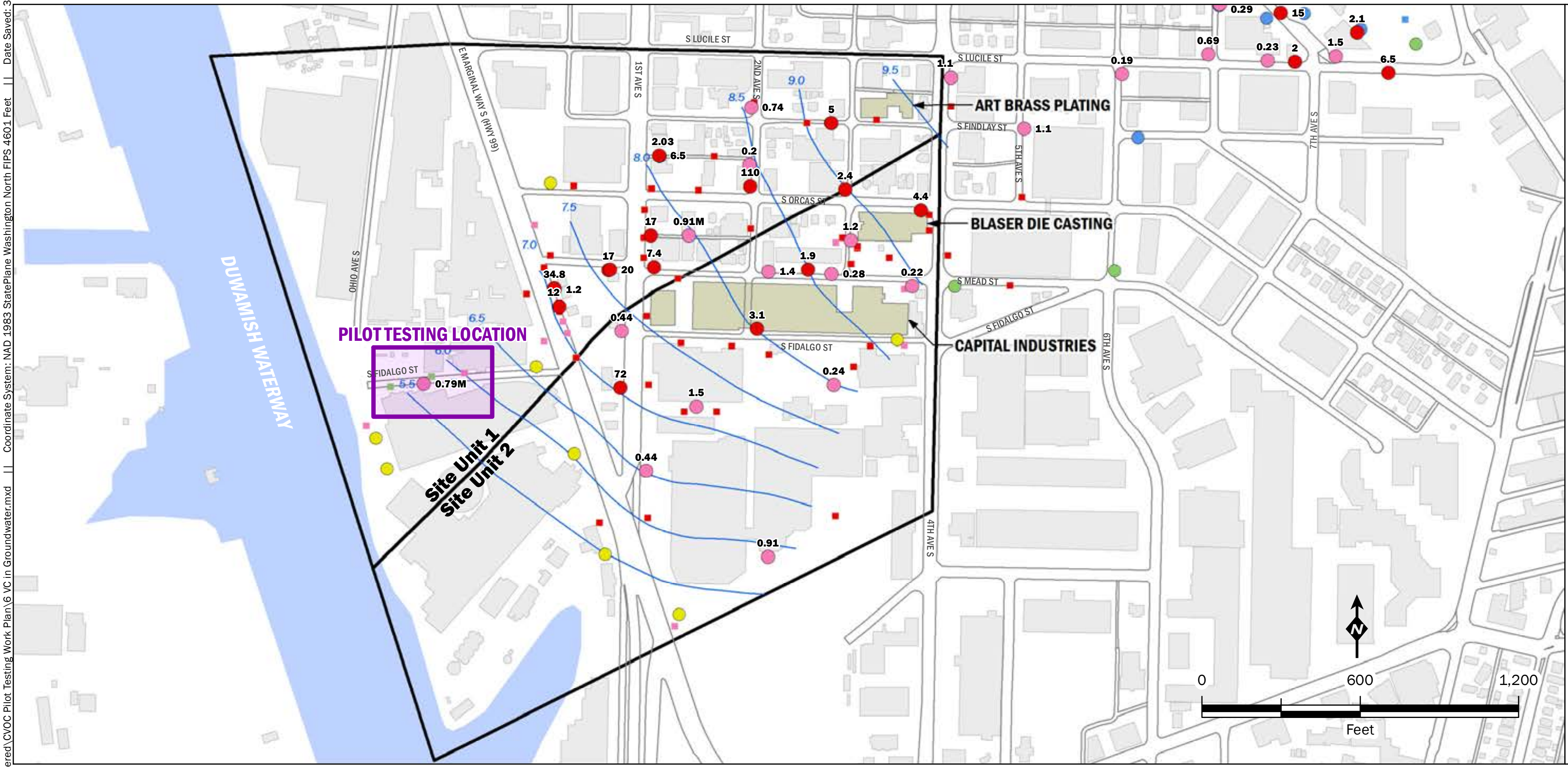
GIS Path: T:\projects_8\Artbrass\PilotTesting_2017\Delivered\CVOC Pilot Testing Work Plan\5 Cis-1,2-DCE in Groundwater.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 3/31/2017 || User: rpepin || Print Date: 3/31/2017



WATER TABLE INTERVAL



SHALLOW INTERVAL



INTERMEDIATE INTERVAL

GIS Path: T:\projects_8\Artbrass\PilotTesting_2017\Delivered\CVOC Pilot Testing Work Plan\6 VC in Groundwater.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 3/31/2017 || User: rpepin || Print Date: 3/31/2017

Groundwater Sample Locations:
- ● Well ■ Geoprobe
- ⊗ Well without data for analyte/interval

Sample Location Symbol Color:
- 🟥 Detected at > 10x CUL
- 🟥 Detected Above CUL
- 🟦 Detected Below CUL
- 🟨 Not Detected (Reporting Limit Above CUL)
- 🟩 Not Detected

Geoprobe data shown on this map reflects the maximum concentration detected at that sample location in the given interval.

Well data shown on this map reflects the most recent sample at that well collected through 2016 for SU1 and 2014 for SU2.

Well locations with CUL exceedances are labeled with the most recent concentration:

55 ● ← *Vinyl chloride Concentration (in µg/L)*

"M" indicates a result flagged as estimated by lab.

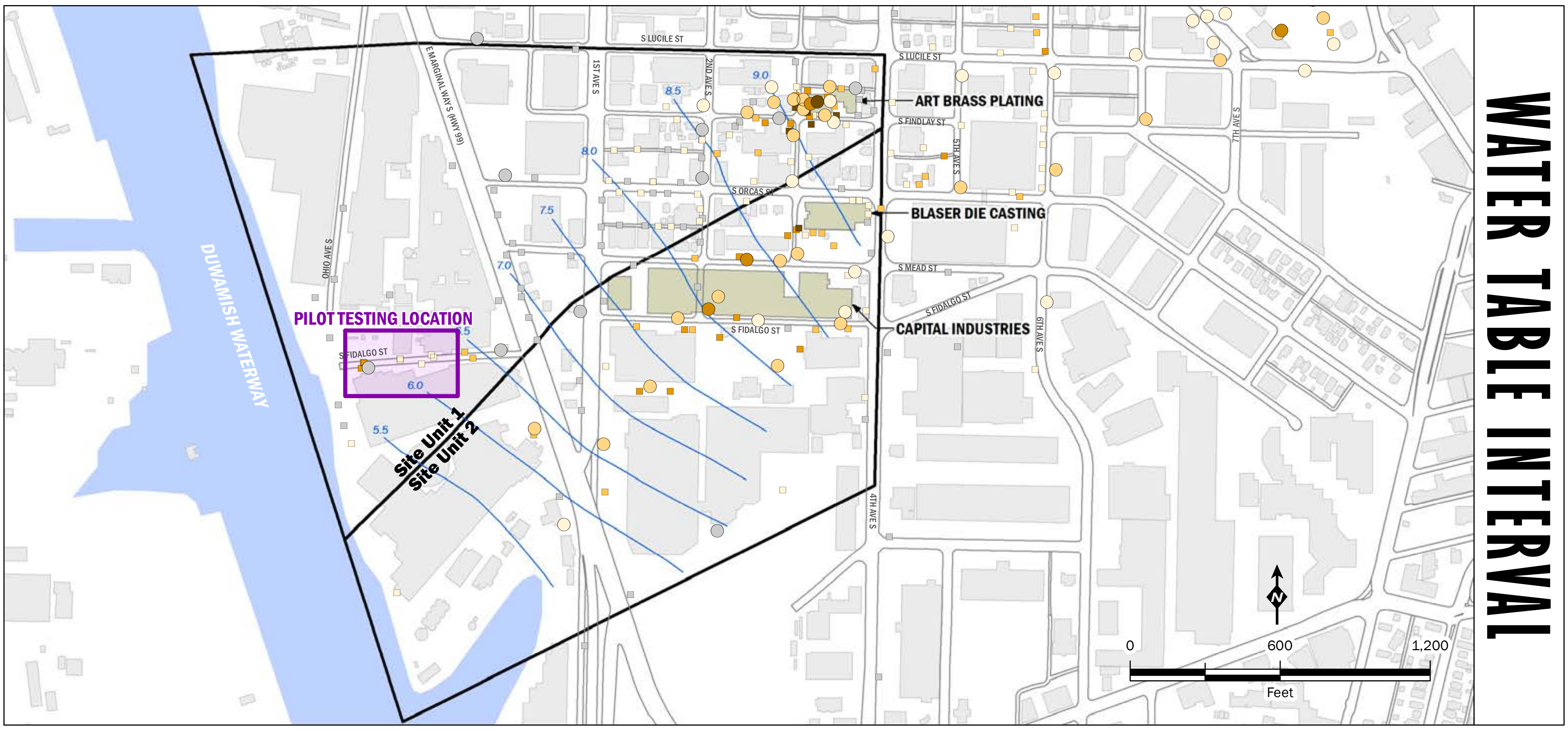
8.0 Half-foot Groundwater Elevation Contours from August, 2012 Site-Wide Monitoring Event (NAVD88 Vertical Datum)

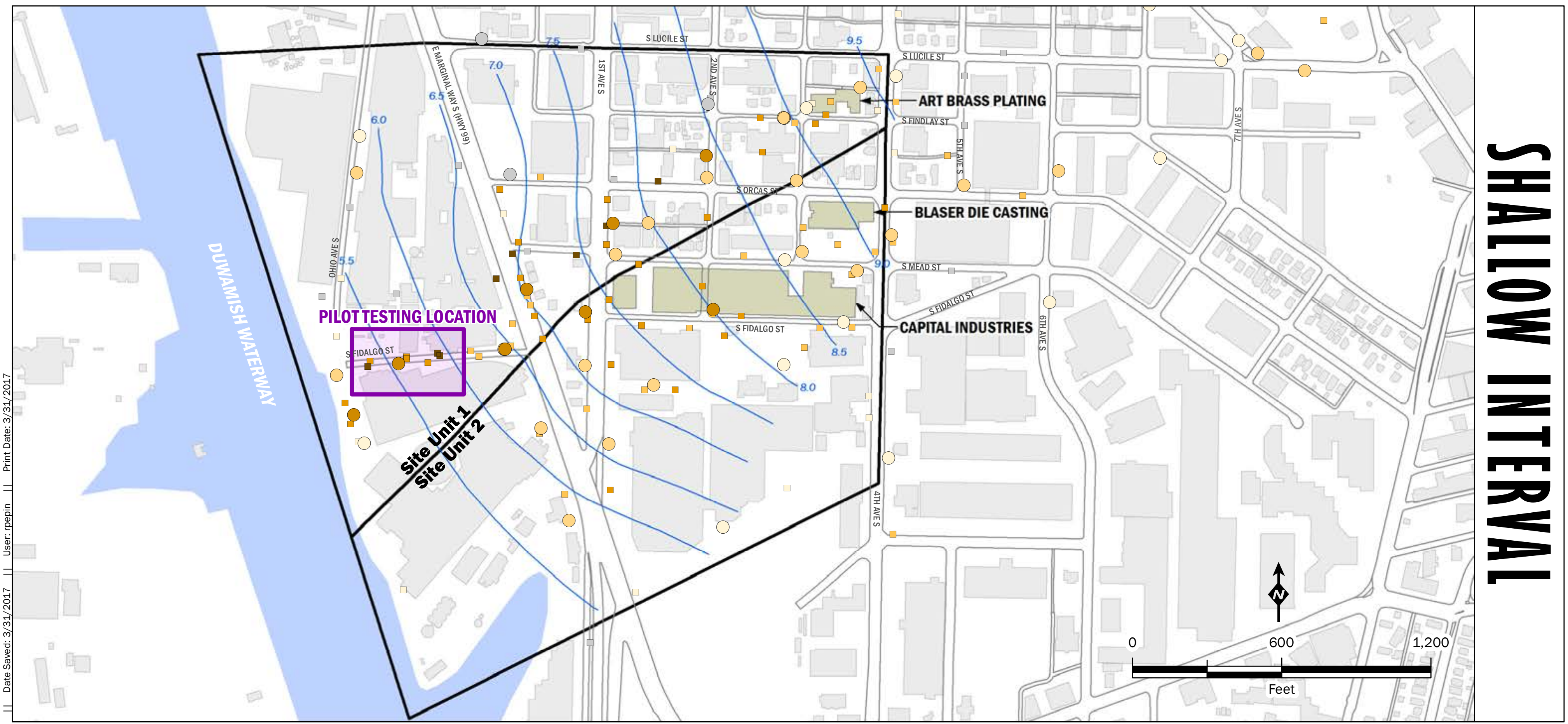
The Groundwater Cleanup Level (CUL) Protective of Surface Water Quality for Vinyl chloride is 0.18 µg/L.

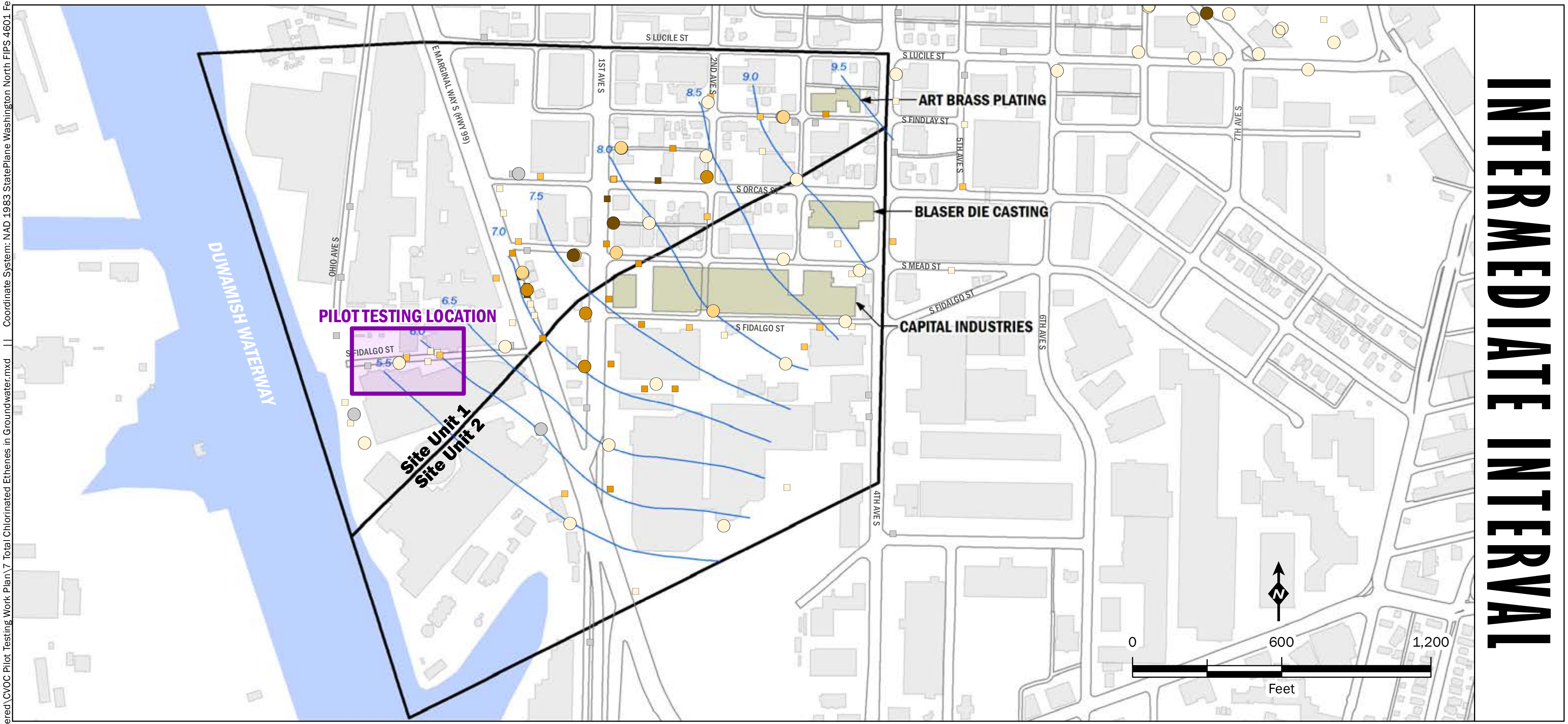
Vinyl Chloride in Groundwater

CVOC Pilot Study Work Plan
Art Brass Plating
Seattle, Washington

Aspect CONSULTING	MAR-2017	BY: PPW	FIGURE NO.
	PROJECT NO. 050067	REVISED BY: DIM / RAP	6







GIS Path: T:\projects_8\Artbrass\PilotTesting_2017\Delivered\CVOC Pilot Testing Work Plan\7 Total Chlorinated Ethenes in Groundwater.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 3/31/2017 || User: rpepin || Print Date: 3/31/2017

Groundwater Sample Locations:

- ● Well
- ⊗ Well without data for analyte/interval
- ■ Geoprobe

Sample Location Symbol Color:

- 🟫 >10 µmol/L
- 🟧 1 - 10 µmol/L
- 🟨 0.1 - 1 µmol/L
- ⬜ 0.001 - 0.1 µmol/L
- ⬜ < 0.001 µmol/L

8.0 ∼ Half-foot Groundwater Elevation Contours from August, 2012 Site-Wide Monitoring Event (NAVD88 Vertical Datum)

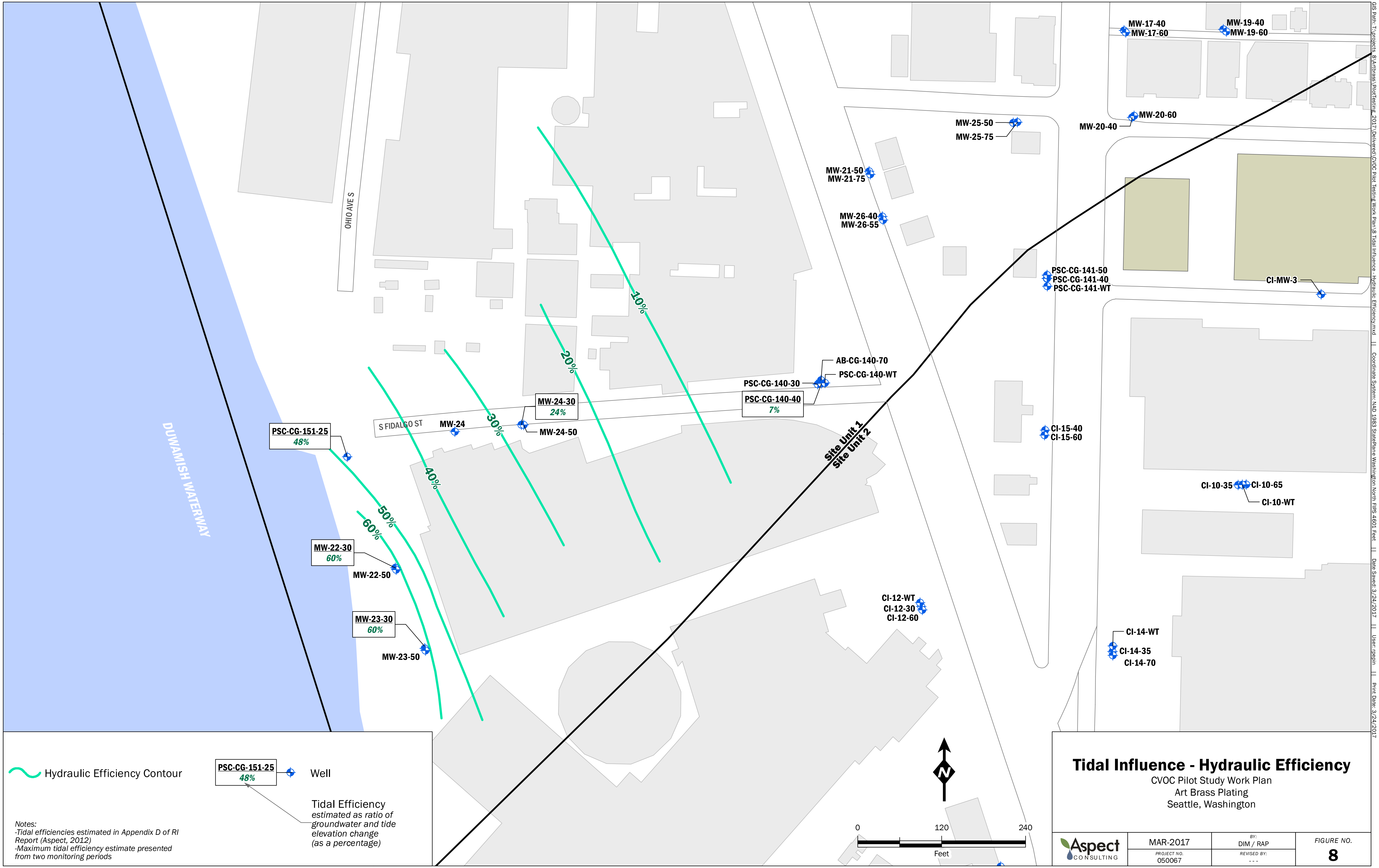
Well data shown on this map reflects the most recent sample at that well collected through 2016 for SU1 and 2014 for SU2.

There is no groundwater cleanup level for Total Chlorinated Ethenes and the concentrations scale presented on this figure is arbitrary and for illustration

Total Chlorinated Ethenes in Groundwater

CVOC Pilot Study Work Plan
Art Brass Plating
Seattle, Washington

Aspect CONSULTING	MAR-2017	BY: PPW	FIGURE NO.
	PROJECT NO. 050067	REVISED BY: DIM / RAP	7



Notes:
-Tidal efficiencies estimated in Appendix D of RI Report (Aspect, 2012)
-Maximum tidal efficiency estimate presented from two monitoring periods

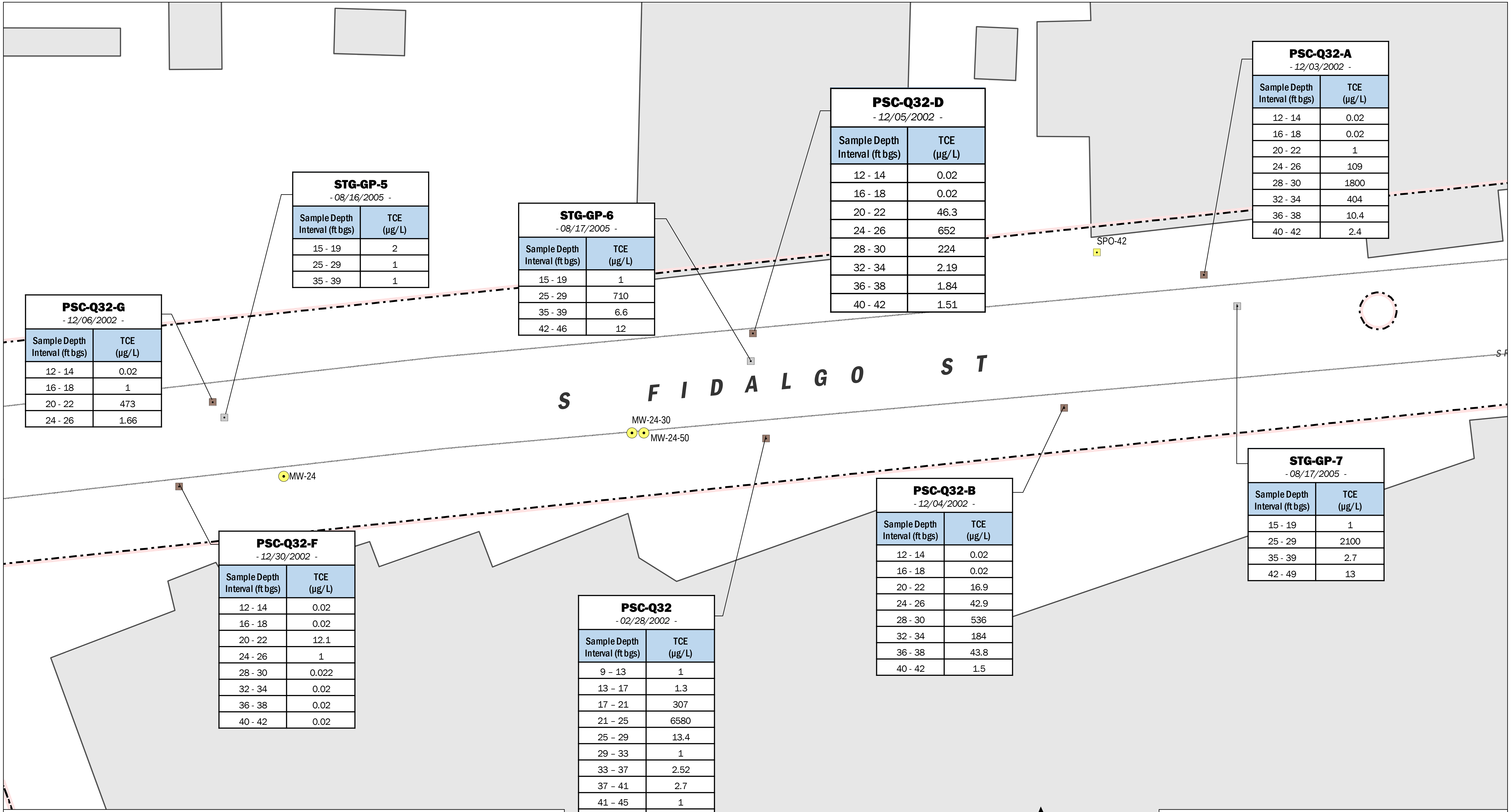
Tidal Influence - Hydraulic Efficiency

CVOC Pilot Study Work Plan
Art Brass Plating
Seattle, Washington

Aspect
CONSULTING

MAR-2017	BY: DIM / RAP	FIGURE NO. 8
PROJECT NO. 050067	REVISED BY: - - -	

GIS Path: T:\projects_8\Artbrass\PilotTesting_2017\Delivered\CVOC Pilot Testing Work Plan\8 Tidal Influence - Hydraulic Efficiency.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 3/24/2017 || User: rpepin || Print Date: 3/24/2017



PSC-Q32-A
- 12/03/2002 -

Sample Depth Interval (ft bgs)	TCE (µg/L)
12 - 14	0.02
16 - 18	0.02
20 - 22	1
24 - 26	109
28 - 30	1800
32 - 34	404
36 - 38	10.4
40 - 42	2.4

PSC-Q32-D
- 12/05/2002 -

Sample Depth Interval (ft bgs)	TCE (µg/L)
12 - 14	0.02
16 - 18	0.02
20 - 22	46.3
24 - 26	652
28 - 30	224
32 - 34	2.19
36 - 38	1.84
40 - 42	1.51

STG-GP-5
- 08/16/2005 -

Sample Depth Interval (ft bgs)	TCE (µg/L)
15 - 19	2
25 - 29	1
35 - 39	1

STG-GP-6
- 08/17/2005 -

Sample Depth Interval (ft bgs)	TCE (µg/L)
15 - 19	1
25 - 29	710
35 - 39	6.6
42 - 46	12

PSC-Q32-G
- 12/06/2002 -

Sample Depth Interval (ft bgs)	TCE (µg/L)
12 - 14	0.02
16 - 18	1
20 - 22	473
24 - 26	1.66

STG-GP-7
- 08/17/2005 -

Sample Depth Interval (ft bgs)	TCE (µg/L)
15 - 19	1
25 - 29	2100
35 - 39	2.7
42 - 49	13

PSC-Q32-B
- 12/04/2002 -

Sample Depth Interval (ft bgs)	TCE (µg/L)
12 - 14	0.02
16 - 18	0.02
20 - 22	16.9
24 - 26	42.9
28 - 30	536
32 - 34	184
36 - 38	43.8
40 - 42	1.5

PSC-Q32-F
- 12/30/2002 -

Sample Depth Interval (ft bgs)	TCE (µg/L)
12 - 14	0.02
16 - 18	0.02
20 - 22	12.1
24 - 26	1
28 - 30	0.022
32 - 34	0.02
36 - 38	0.02
40 - 42	0.02

PSC-Q32
- 02/28/2002 -

Sample Depth Interval (ft bgs)	TCE (µg/L)
9 – 13	1
13 – 17	1.3
17 – 21	307
21 – 25	6580
25 – 29	13.4
29 – 33	1
33 – 37	2.52
37 – 41	2.7
41 – 45	1
60 - 64	1

Exploration Locations

Symbol (Exploration Type)	*Color (Exploration Sampler)*
⊙ Monitoring Well	🟨 Art Brass Plating
⊡ Soil Boring/Probe	🟫 Philip Services Corporation
	⬜ Other Companies

- ▭ Building
- ┈ Road Edge
- ▭ King County Tax Parcel

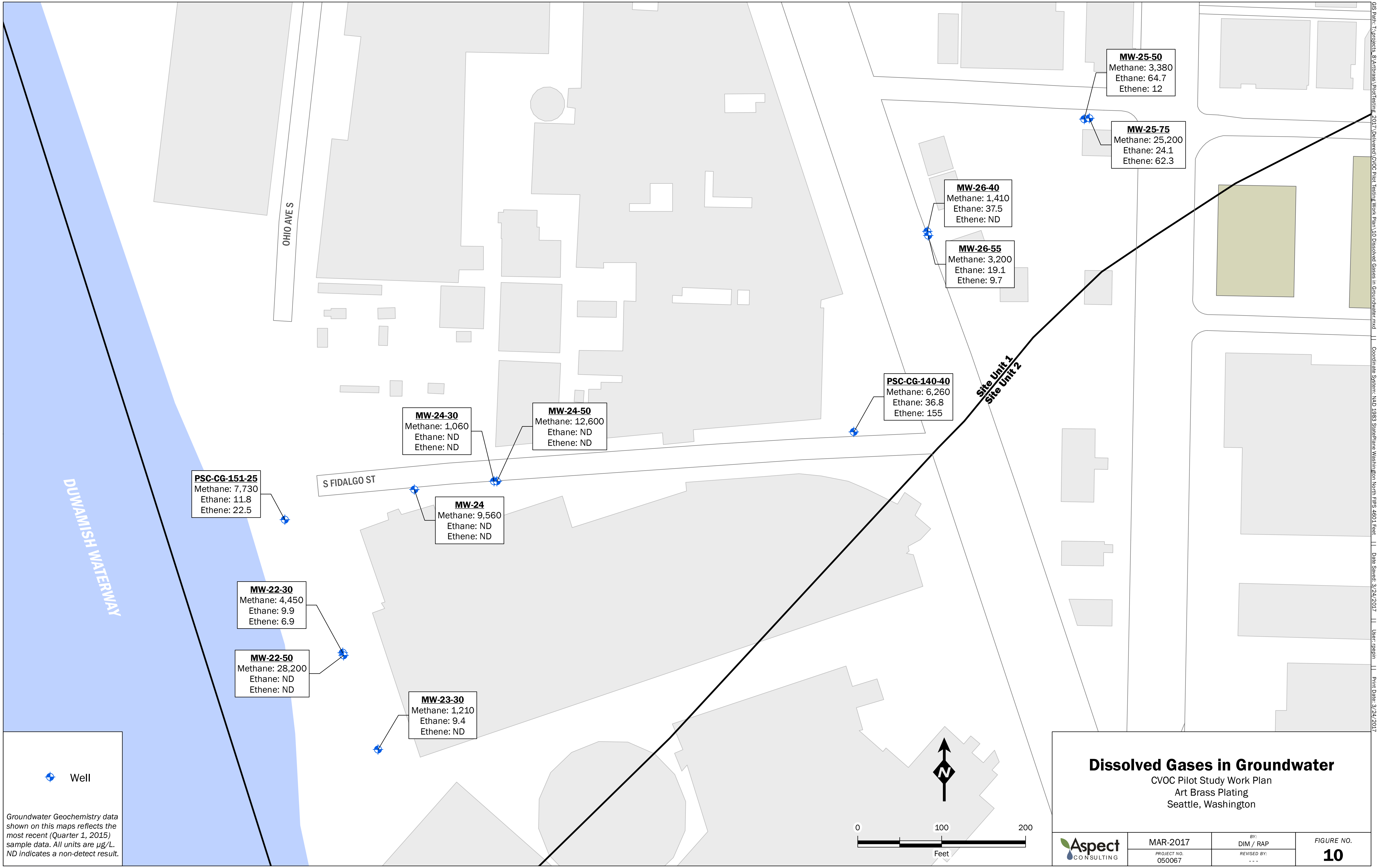
ft bgs = feet below ground surface

TCE Concentrations in Temporary Groundwater Samples

CVOC Pilot Study Work Plan
Art Brass Plating
Seattle, Washington

Aspect CONSULTING

MAR-2017	*BY:* EAH	*FIGURE NO.*
PROJECT NO. 050067	*REVISED BY:* DIM / RAP	**9**



⌖ Well

Groundwater Geochemistry data shown on this maps reflects the most recent (Quarter 1, 2015) sample data. All units are µg/L. ND indicates a non-detect result.

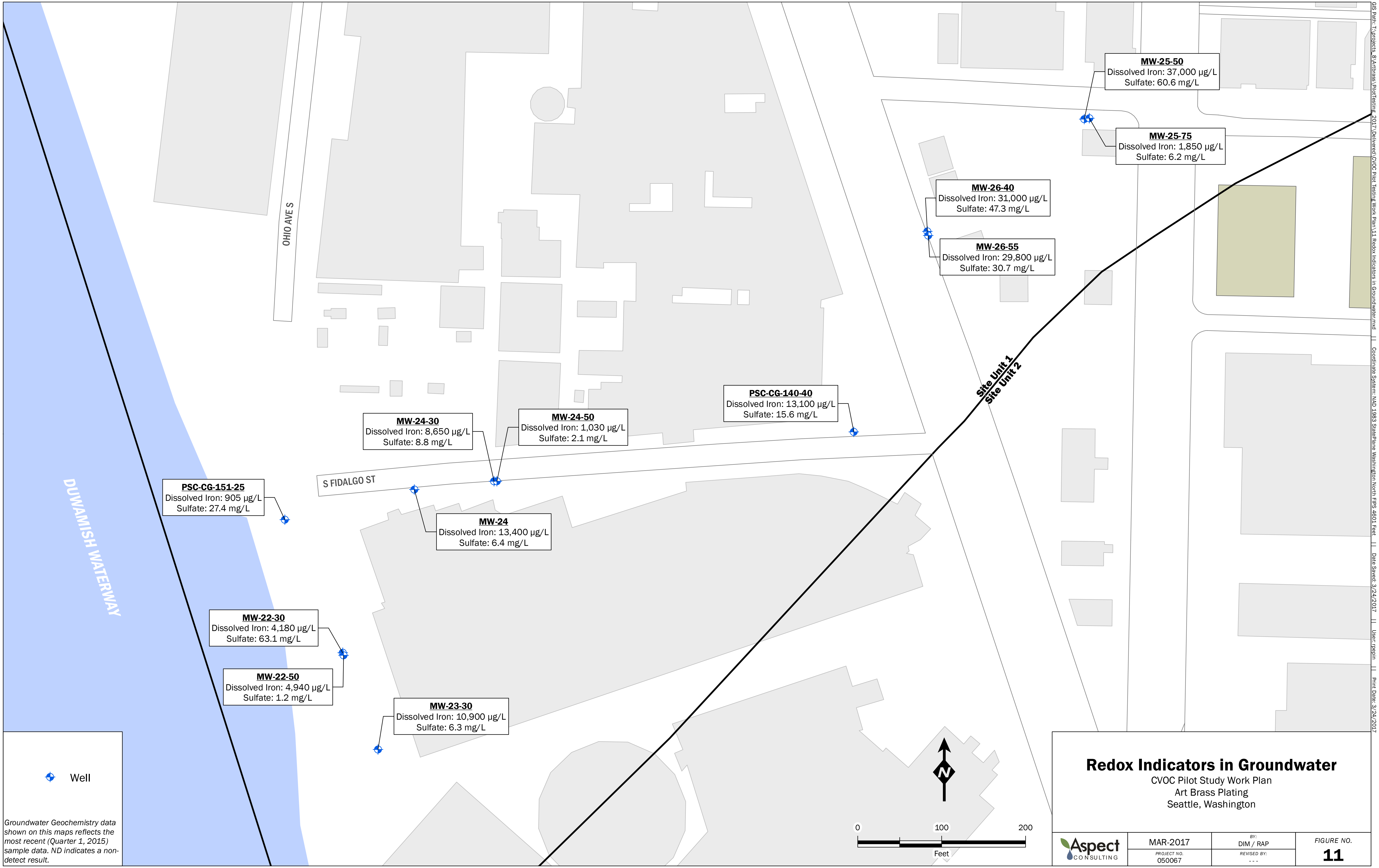
Dissolved Gases in Groundwater

CVOC Pilot Study Work Plan
Art Brass Plating
Seattle, Washington

Aspect CONSULTING

MAR-2017	BY: DIM / RAP	FIGURE NO.
PROJECT NO. 050067	REVISED BY: - - -	10

GIS Path: T:\projects_8\ArtBrass\PilotTesting_2017\Delivered\CVOC Pilot Testing Work Plan\10 Dissolved Gases in Groundwater.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 3/24/2017 || User: rpepin || Print Date: 3/24/2017



Groundwater Geochemistry data shown on this maps reflects the most recent (Quarter 1, 2015) sample data. ND indicates a non-detect result.

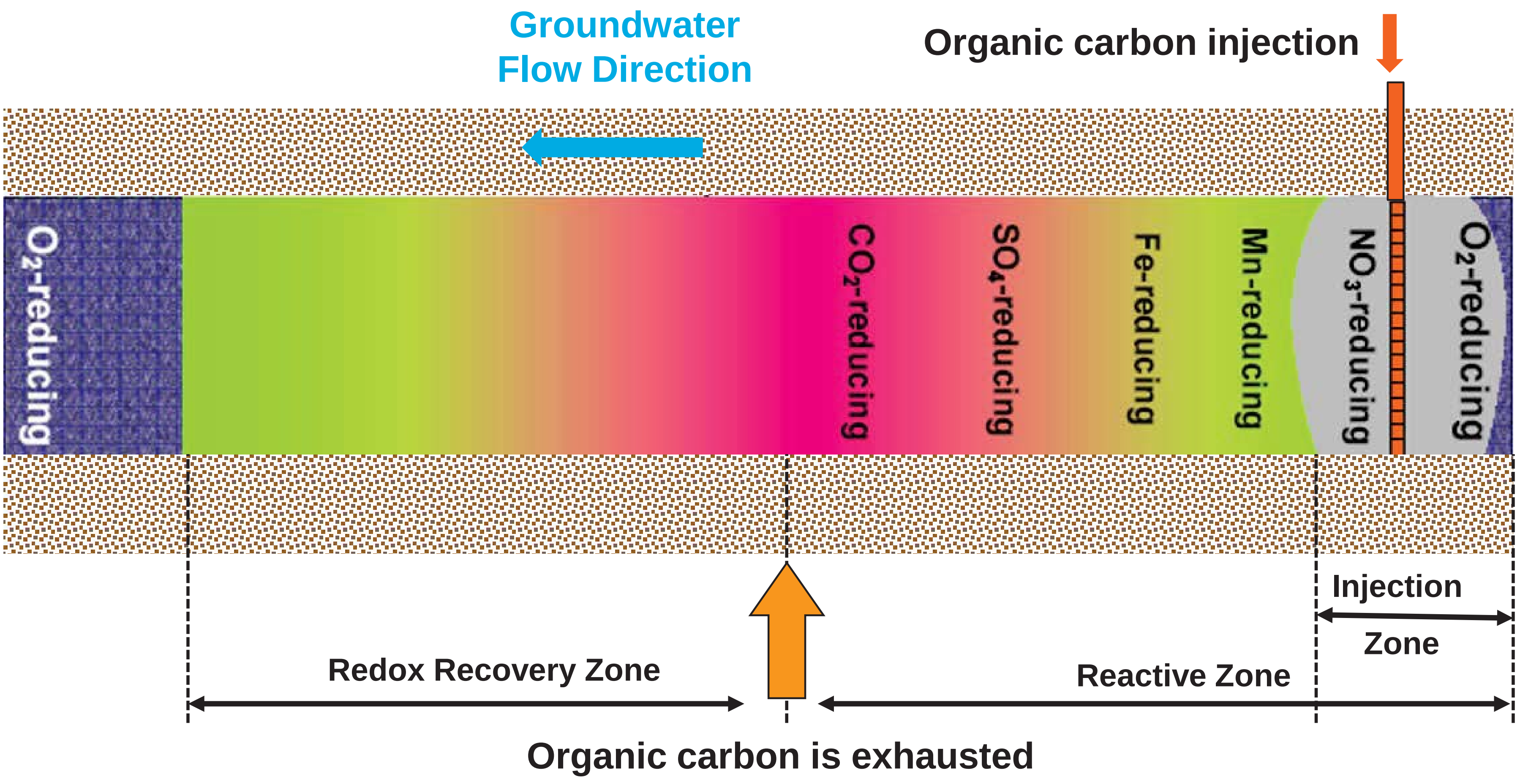
Redox Indicators in Groundwater

CVOC Pilot Study Work Plan
Art Brass Plating
Seattle, Washington

Aspect CONSULTING

MAR-2017	BY: DIM / RAP	FIGURE NO. **11**
PROJECT NO. 050067	REVISED BY: - - -	

GIS Path: T:\projects_8\Artbrass\PilotTesting_2017\Delivered\CVOC Pilot Testing Work Plan\11 Redox Indicators in Groundwater.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 3/24/2017 || User: rpepin || Print Date: 3/24/2017



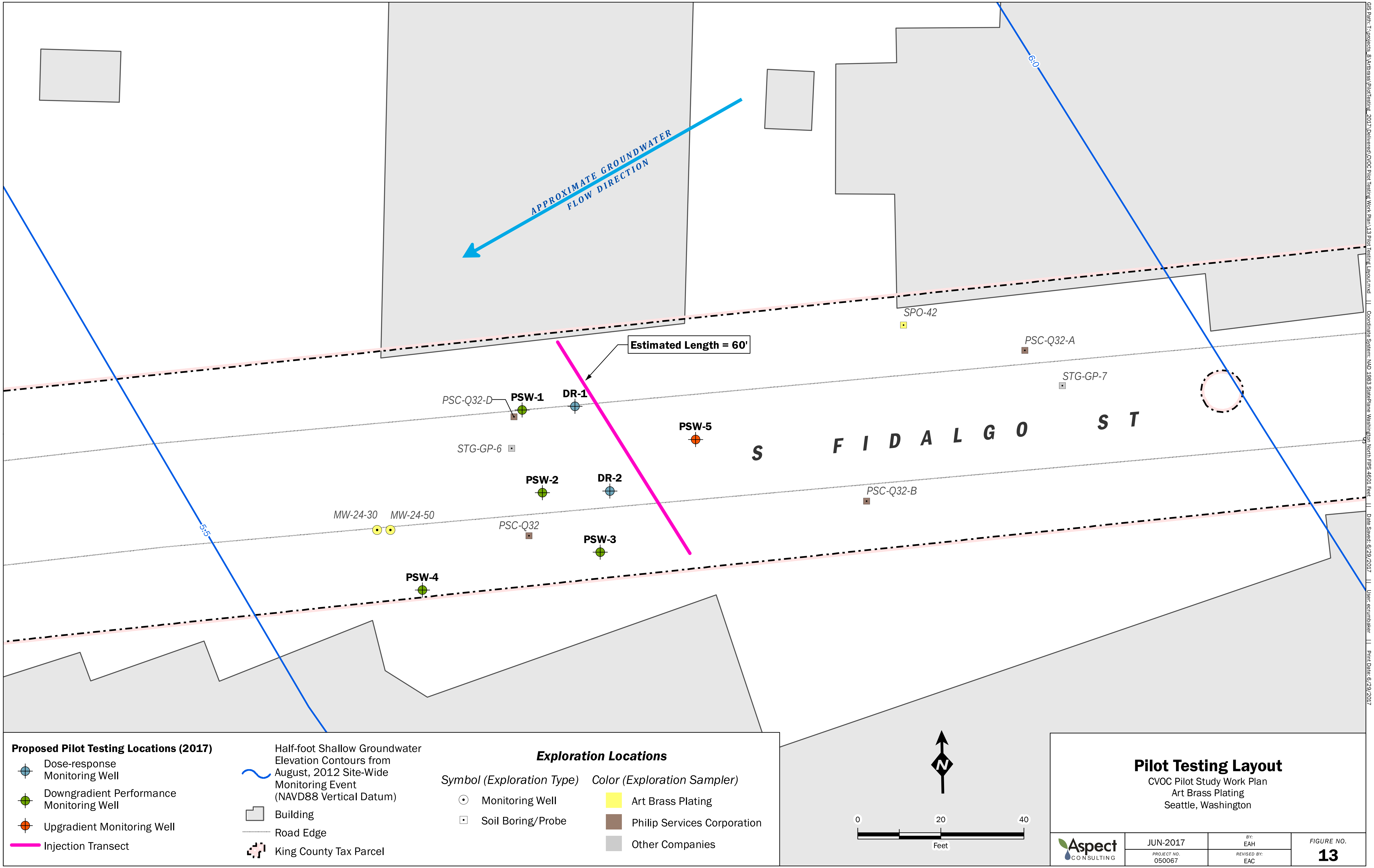
Adapted from Suthersan, 2005.
Suthersan, S.S., Payne F.C.. 2005. In Situ Remediation Engineering,
511 Boca Raton FL: CRC Press, Lewish Publishers.

Enhanced Reductive Dechlorination
In Situ Reactive Zone

CVOC Pilot Study Work Plan
Art Brass Plating
Seattle, Washington

Aspect CONSULTING	MAR-2017	BY: ACG / EAC	FIGURE NO.
	PROJECT NO. 050067	REVISED BY: RAP	12

GIS Path: T:\projects_8\Artbrass\PilotTesting_2017\Delivered\CVOC Pilot Testing Work Plan\12 Enhanced Reductive Dechlorination.mxd || Coordinate System: || Date Saved: 3/24/2017 || User: rpepin || Print Date: 3/24/2017



Proposed Pilot Testing Locations (2017)

- ⊕ Dose-response Monitoring Well
- ⊕ Downgradient Performance Monitoring Well
- ⊕ Upgradient Monitoring Well
- ▬ Injection Transect

Half-foot Shallow Groundwater Elevation Contours from August, 2012 Site-Wide Monitoring Event (NAVD88 Vertical Datum)

▢ Building

Road Edge

King County Tax Parcel

Exploration Locations

Symbol (Exploration Type)	*Color (Exploration Sampler)*
⊙ Monitoring Well	🟨 Art Brass Plating
⊡ Soil Boring/Probe	🟫 Philip Services Corporation
	⬜ Other Companies

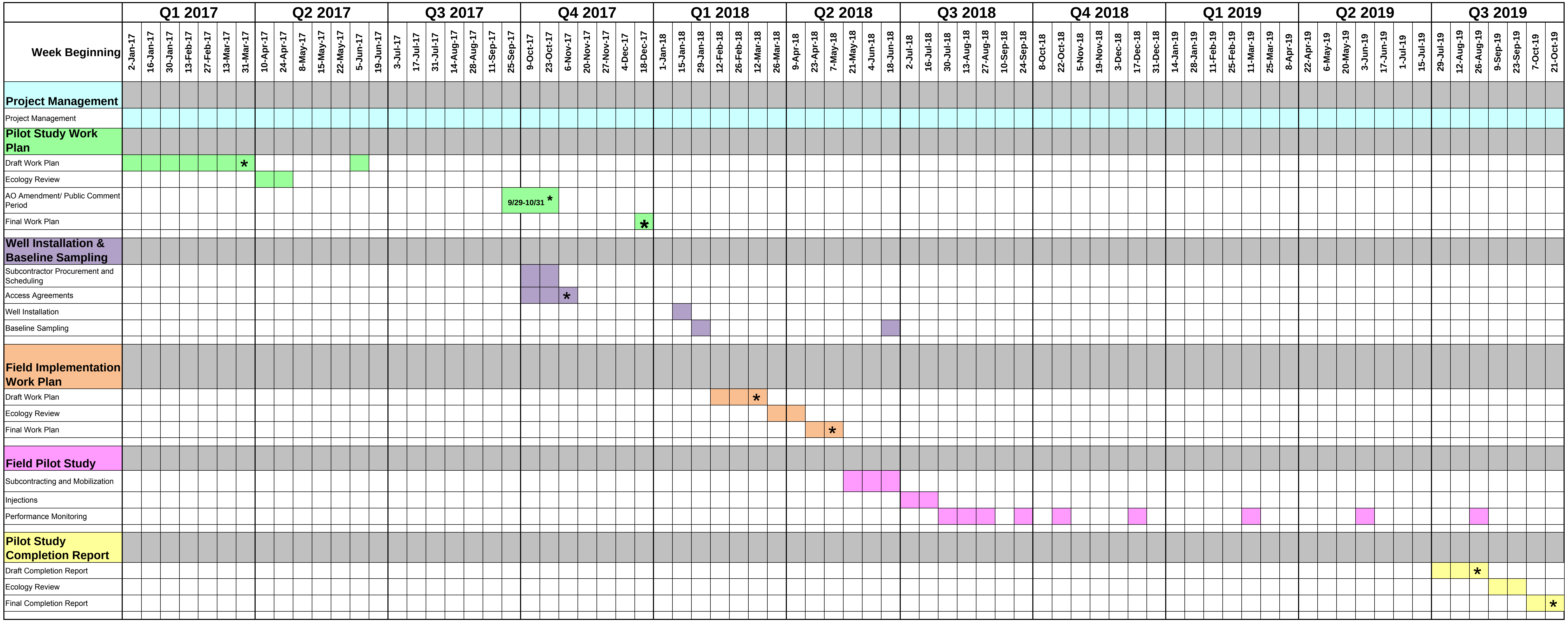
Pilot Testing Layout

CVOC Pilot Study Work Plan
Art Brass Plating
Seattle, Washington

Aspect CONSULTING

JUN-2017	BY: EAH	FIGURE NO.
PROJECT NO. 050067	REVISED BY: EAC	13

GIS Path: T:\projects_8\Artbrass\PilotTesting_2017\Delivered\CVOC Pilot Testing Work Plan\13 Pilot Testing Layout.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 6/29/2017 || User: ecrumbaker || Print Date: 6/29/2017



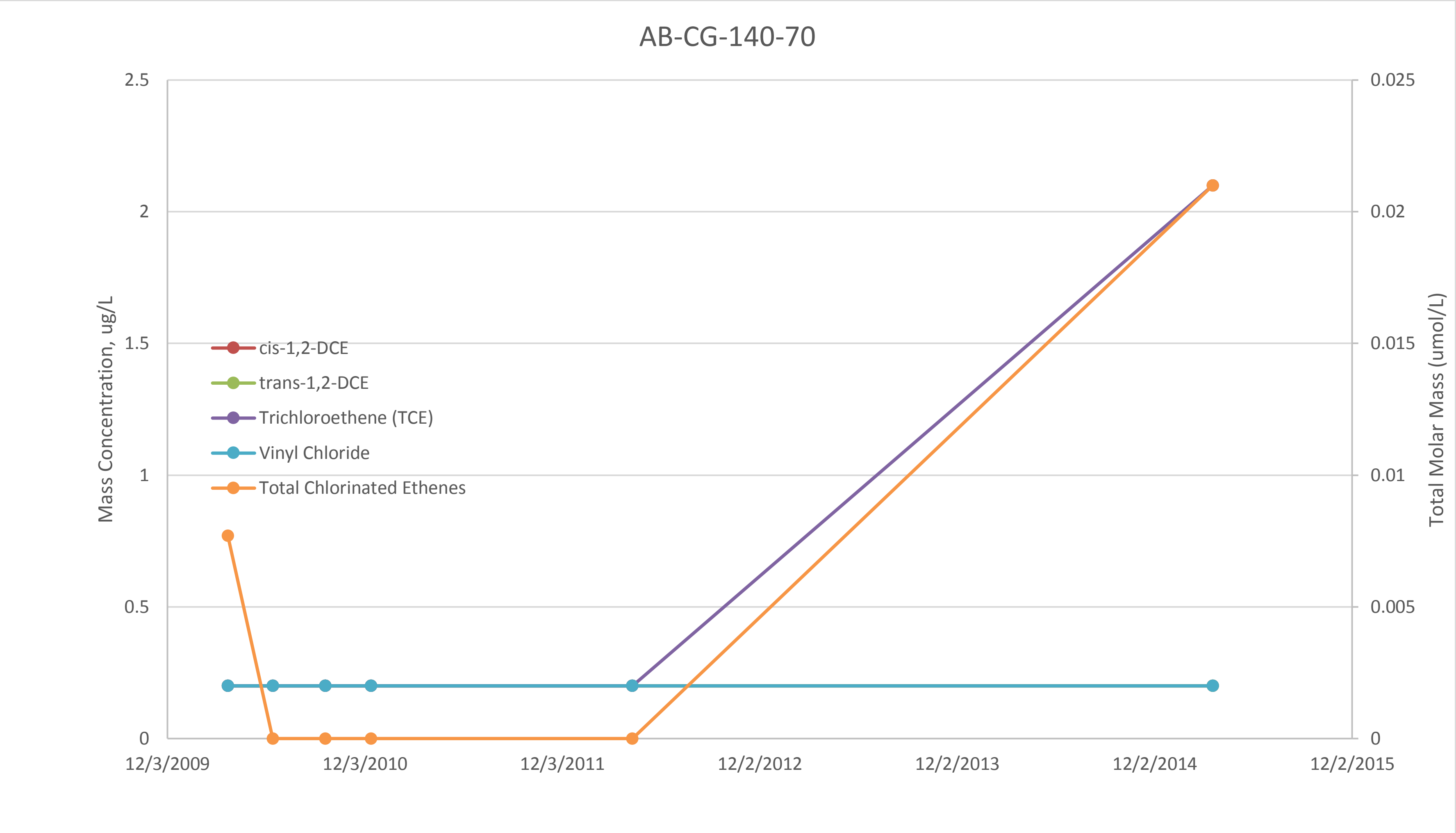
* - Indicates Project Milestone

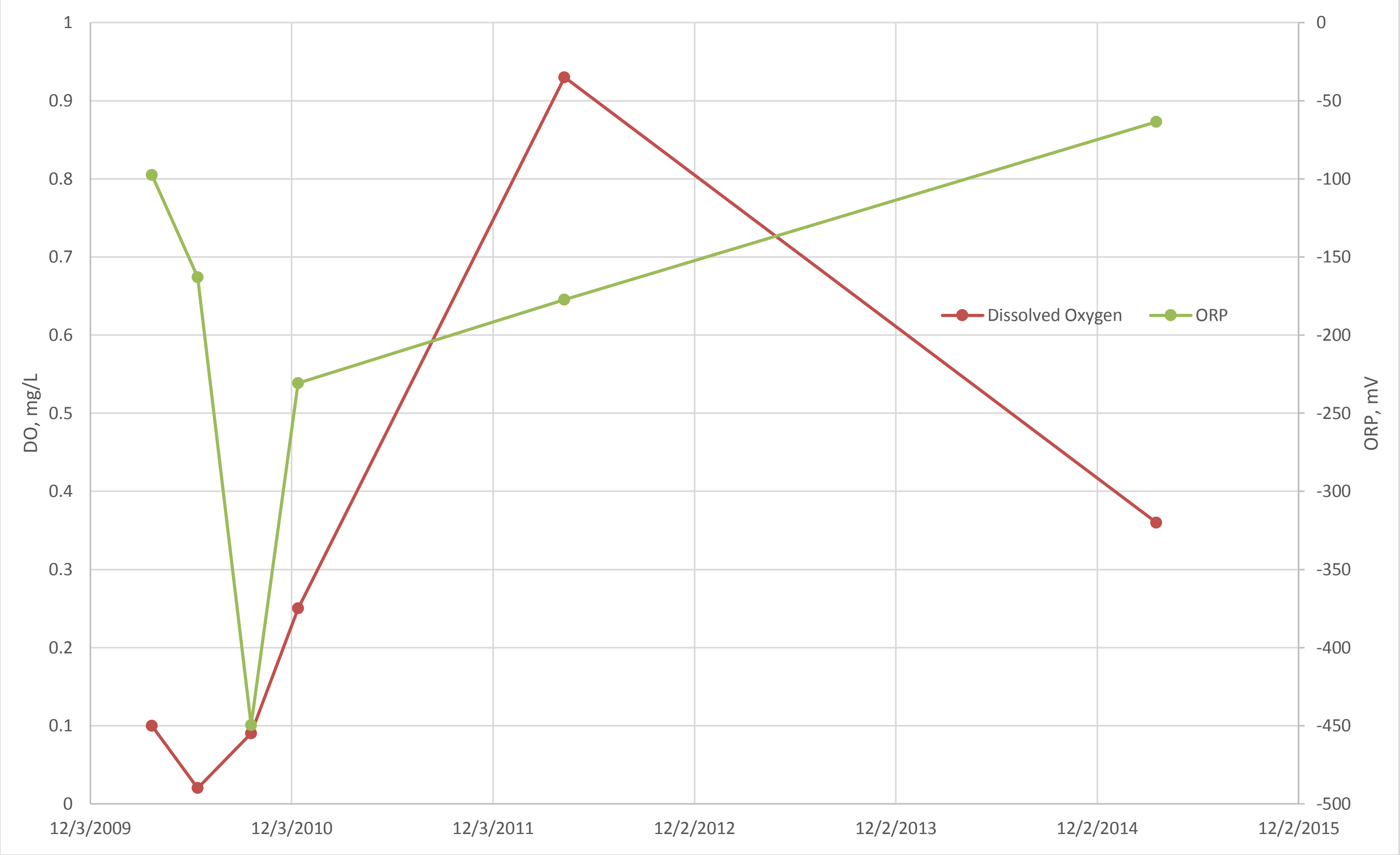
Aspect Consulting
12/21/2017
V:\050067 Art Brass Plating\Pilot Study\CVOCs\Pilot Test Work Plan\Final\Figures\Figure 14 Schedule_rev120617.xlsx

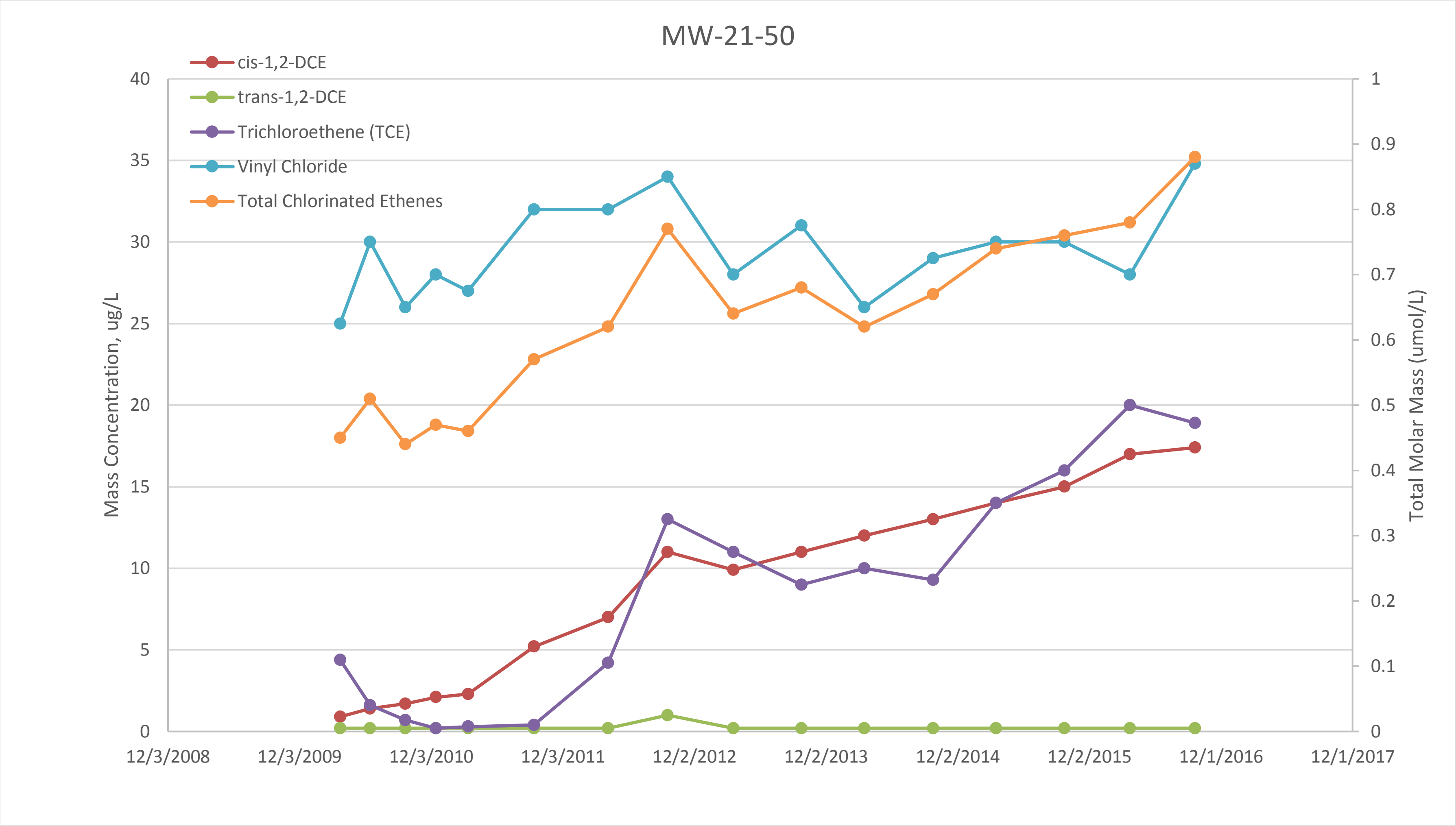
Figure 14
Anticipated Pilot Testing Schedule
CVOC Pilot Test Study
Art Brass Plating, Seattle, WA

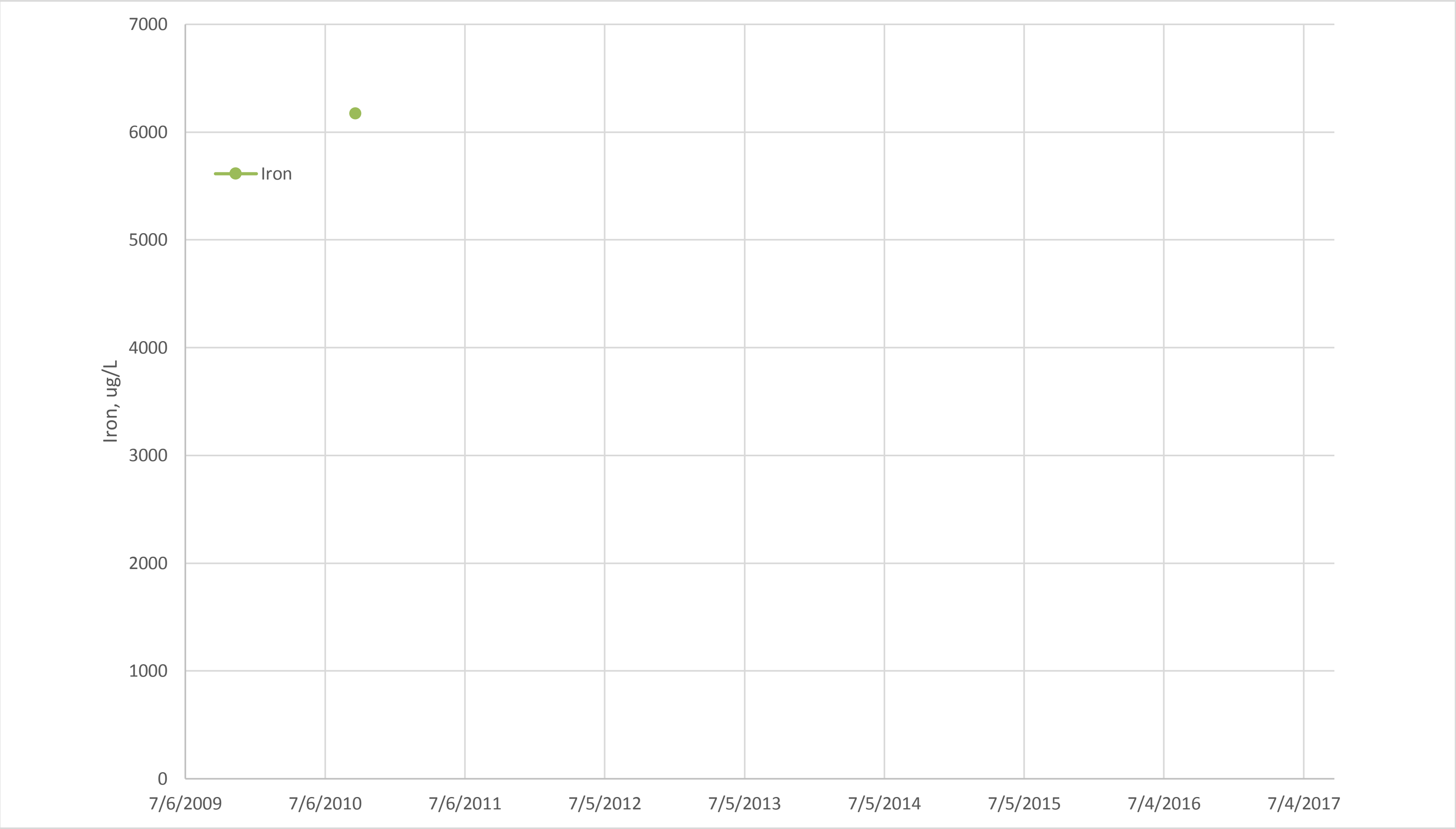
APPENDIX A

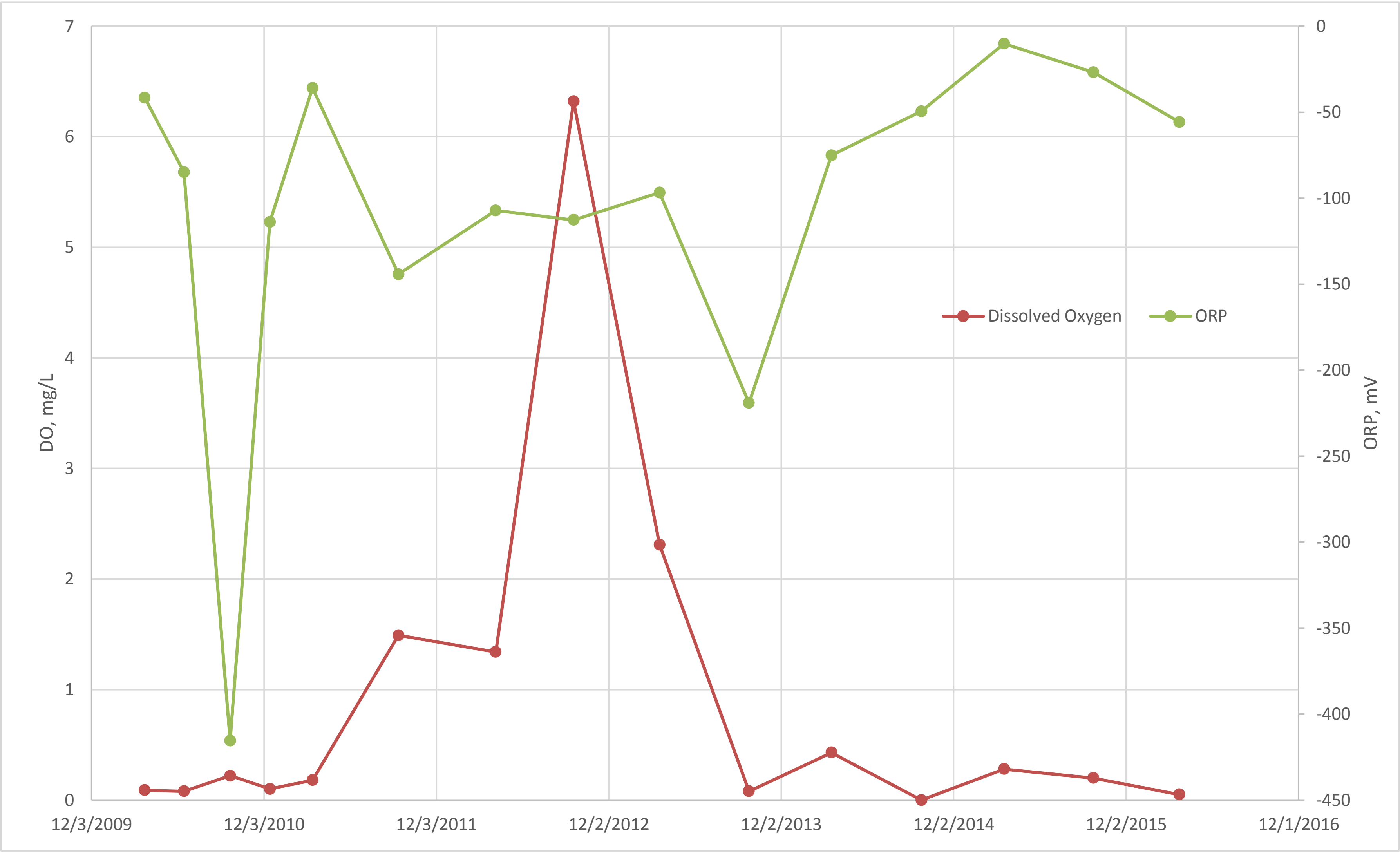
Groundwater CVOC Trend Charts


AB-CG-140-70
Mass Concentration, ug/L
Total Molar Mass (umol/L)
2.5
2
1.5
1
0.5
0
0.025
0.02
0.015
0.01
0.005
0
12/3/2009
12/3/2010
12/3/2011
12/2/2012
12/2/2013
12/2/2014
12/2/2015
cis-1,2-DCE
trans-1,2-DCE
Trichloroethene (TCE)
Vinyl Chloride
Total Chlorinated Ethenes

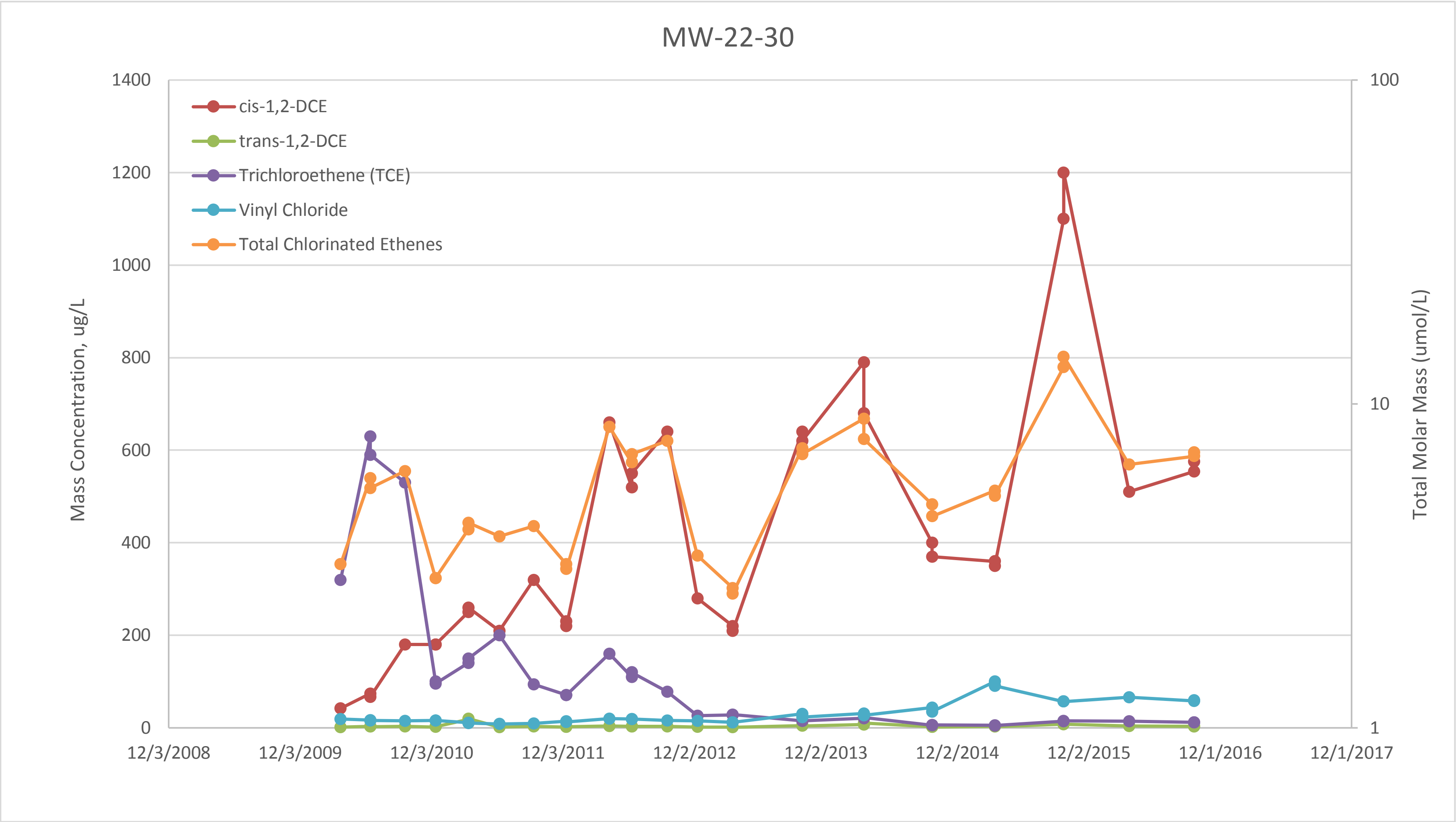

DO, mg/L
ORP, mV
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
-50
-100
-150
-200
-250
-300
-350
-400
-450
-500
12/3/2009
12/3/2010
12/3/2011
12/2/2012
12/2/2013
12/2/2014
12/2/2015
Dissolved Oxygen
ORP

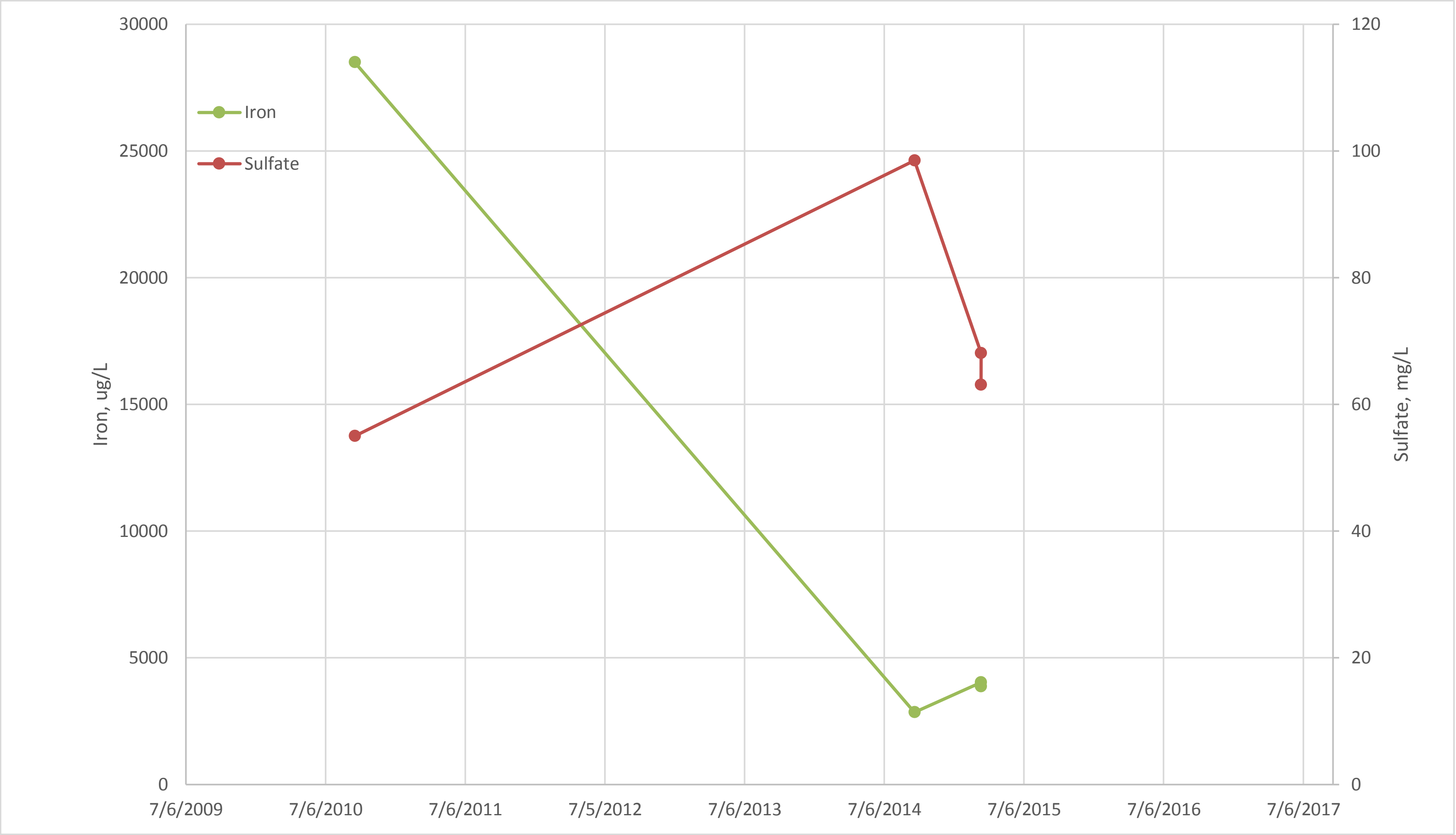

MW-21-50
cis-1,2-DCE
trans-1,2-DCE
Trichloroethene (TCE)
Vinyl Chloride
Total Chlorinated Ethenes
Mass Concentration, ug/L
Total Molar Mass (umol/L)
0
5
10
15
20
25
30
35
40
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
12/3/2008
12/3/2009
12/3/2010
12/3/2011
12/2/2012
12/2/2013
12/2/2014
12/2/2015
12/1/2016
12/1/2017

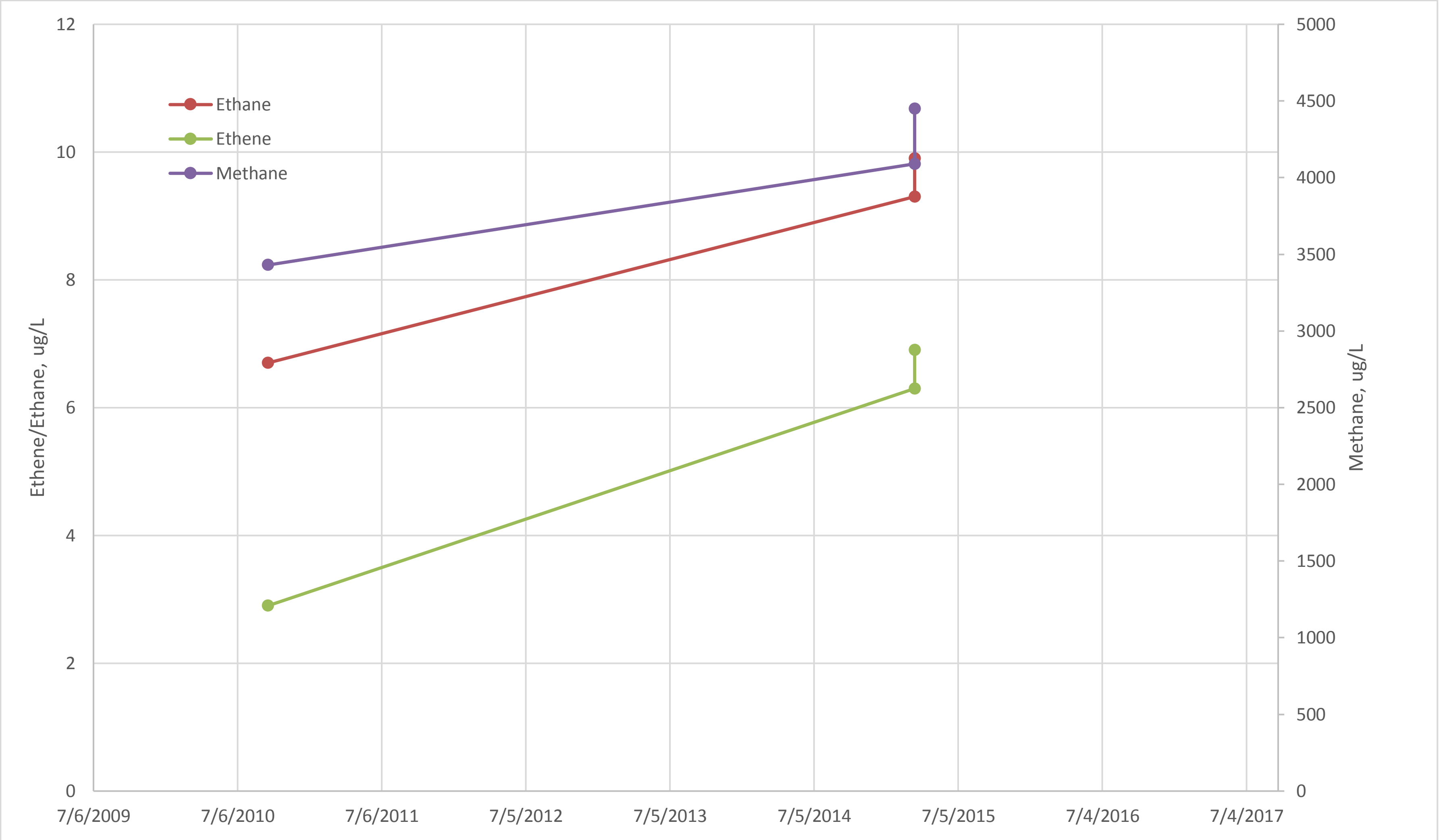

Iron
Iron, ug/L
0
1000
2000
3000
4000
5000
6000
7000
7/6/2009
7/6/2010
7/6/2011
7/5/2012
7/5/2013
7/5/2014
7/5/2015
7/4/2016
7/4/2017



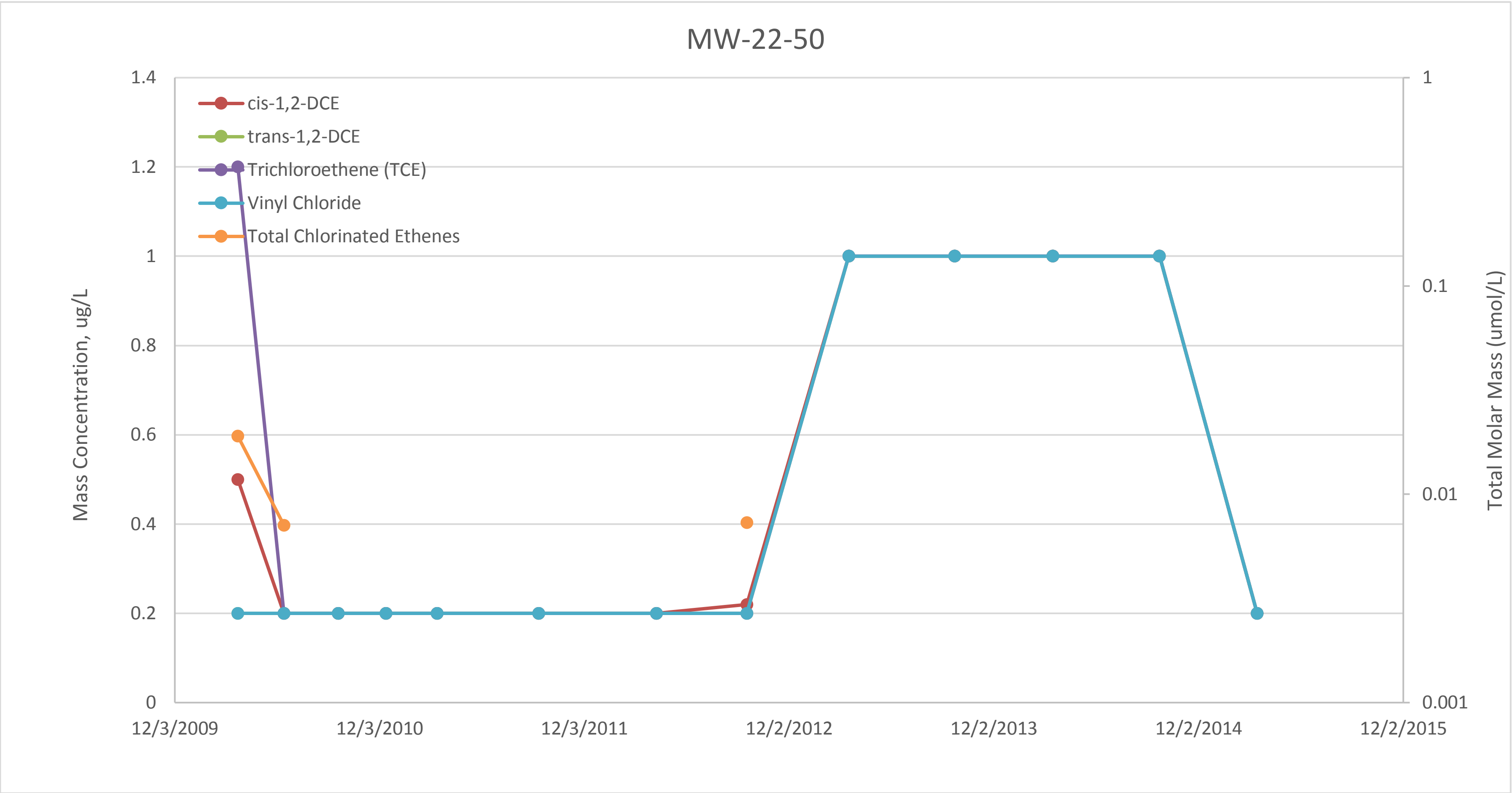
DO, mg/L
7
6
5
4
3
2
1
0
ORP, mV
0
-50
-100
-150
-200
-250
-300
-350
-400
-450
12/3/2009
12/3/2010
12/3/2011
12/2/2012
12/2/2013
12/2/2014
12/2/2015
12/1/2016
Dissolved Oxygen
ORP

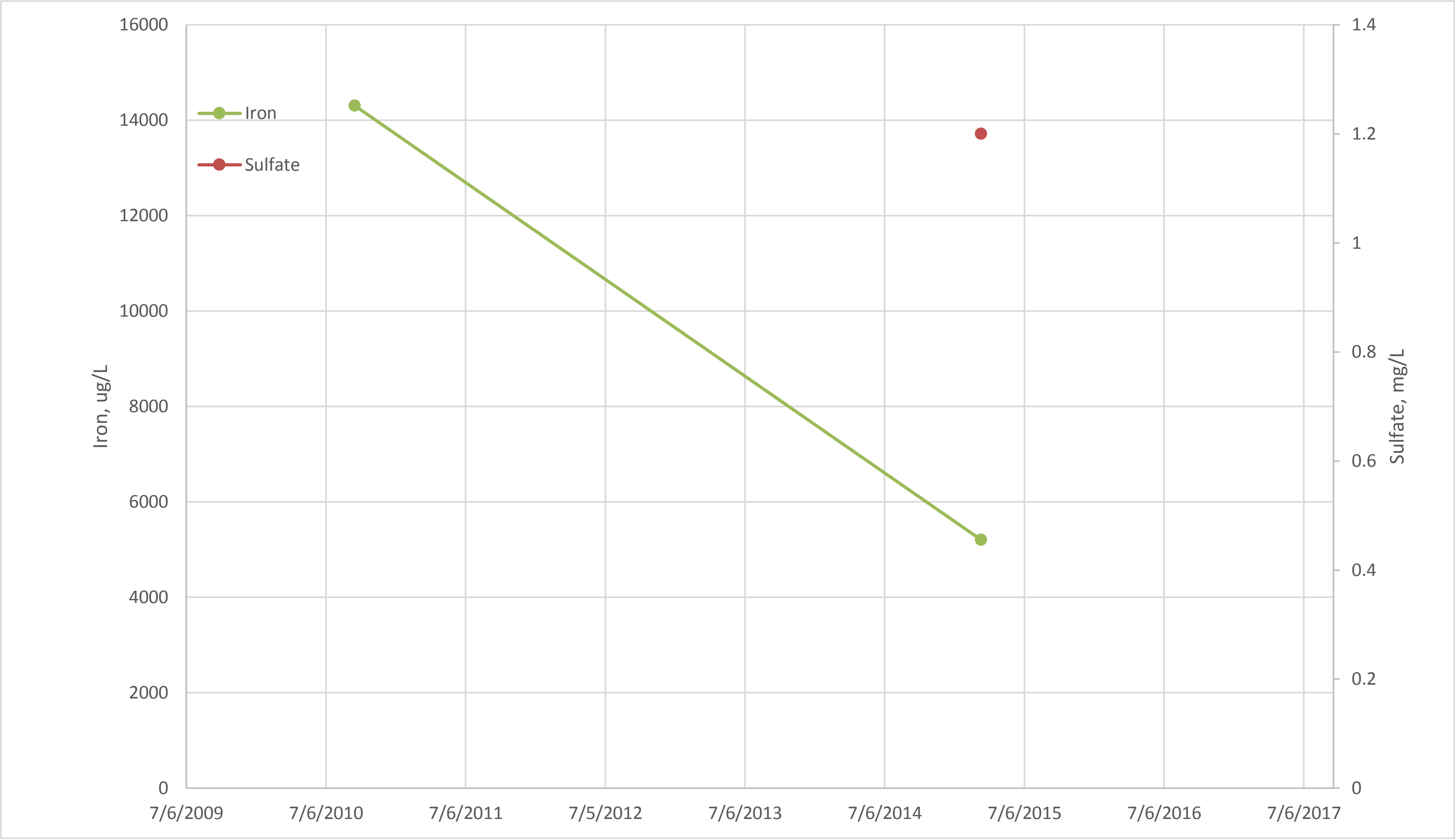

MW-22-30
cis-1,2-DCE
trans-1,2-DCE
Trichloroethene (TCE)
Vinyl Chloride
Total Chlorinated Ethenes
Mass Concentration, ug/L
Total Molar Mass (umol/L)
1400
1200
1000
800
600
400
200
0
100
10
1
12/3/2008
12/3/2009
12/3/2010
12/3/2011
12/2/2012
12/2/2013
12/2/2014
12/2/2015
12/1/2016
12/1/2017

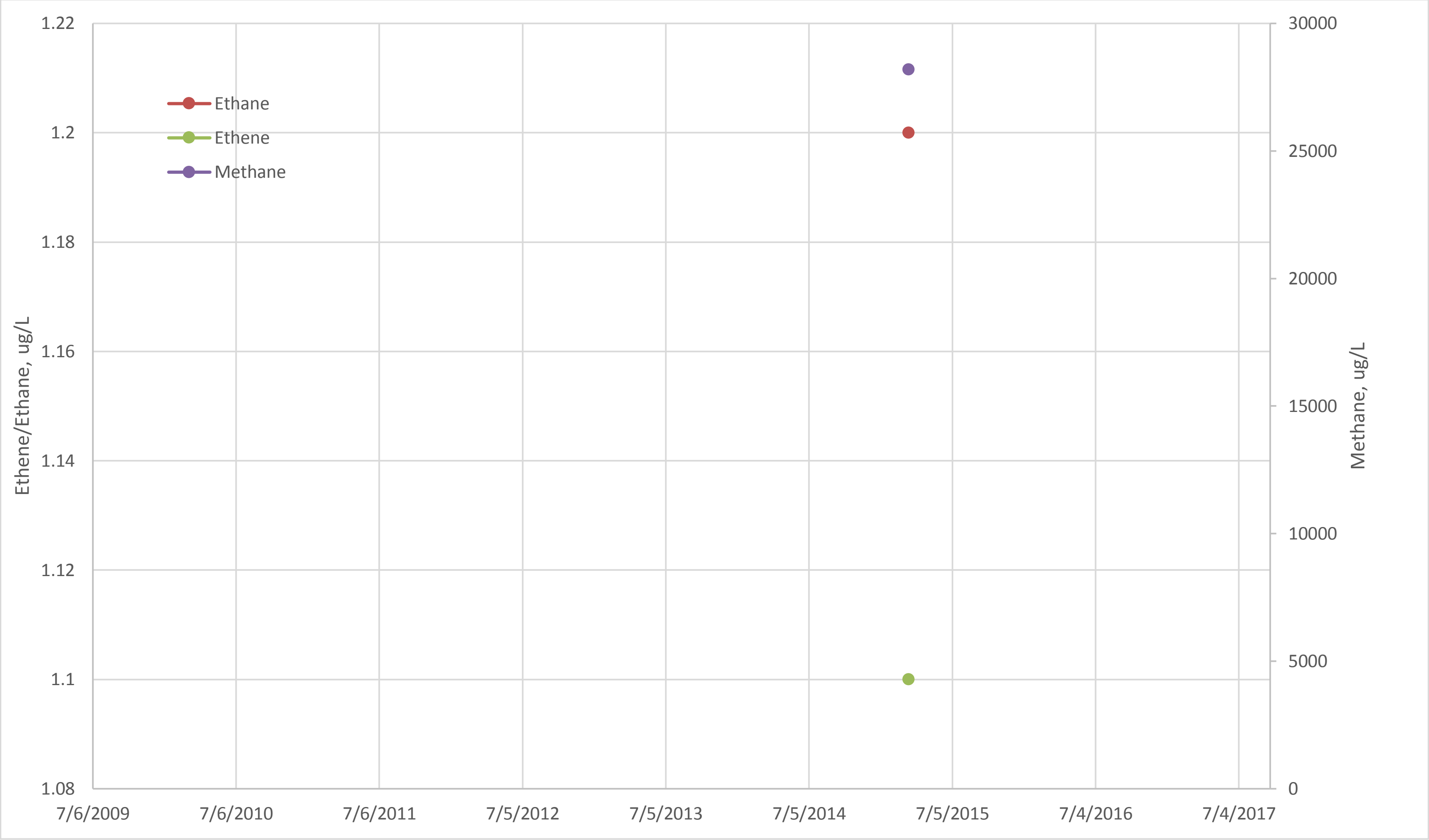

Iron
Sulfate
Iron, ug/L
Sulfate, mg/L
30000
25000
20000
15000
10000
5000
0
120
100
80
60
40
20
0
7/6/2009
7/6/2010
7/6/2011
7/5/2012
7/6/2013
7/6/2014
7/6/2015
7/6/2016
7/6/2017

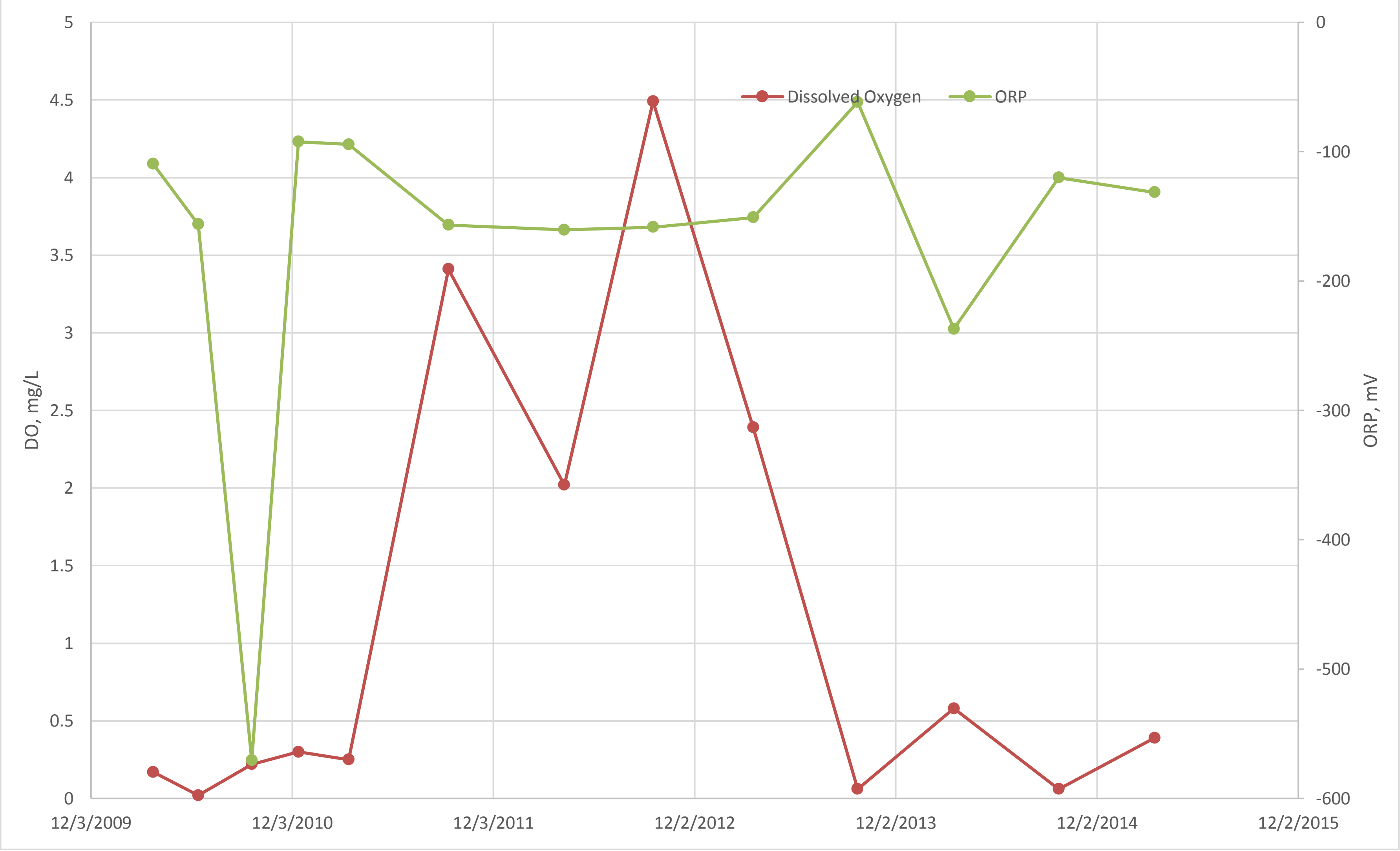

Ethane
Ethene
Methane
Ethene/Ethane, ug/L
Methane, ug/L
12
10
8
6
4
2
0
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
7/6/2009
7/6/2010
7/6/2011
7/5/2012
7/5/2013
7/5/2014
7/5/2015
7/4/2016
7/4/2017

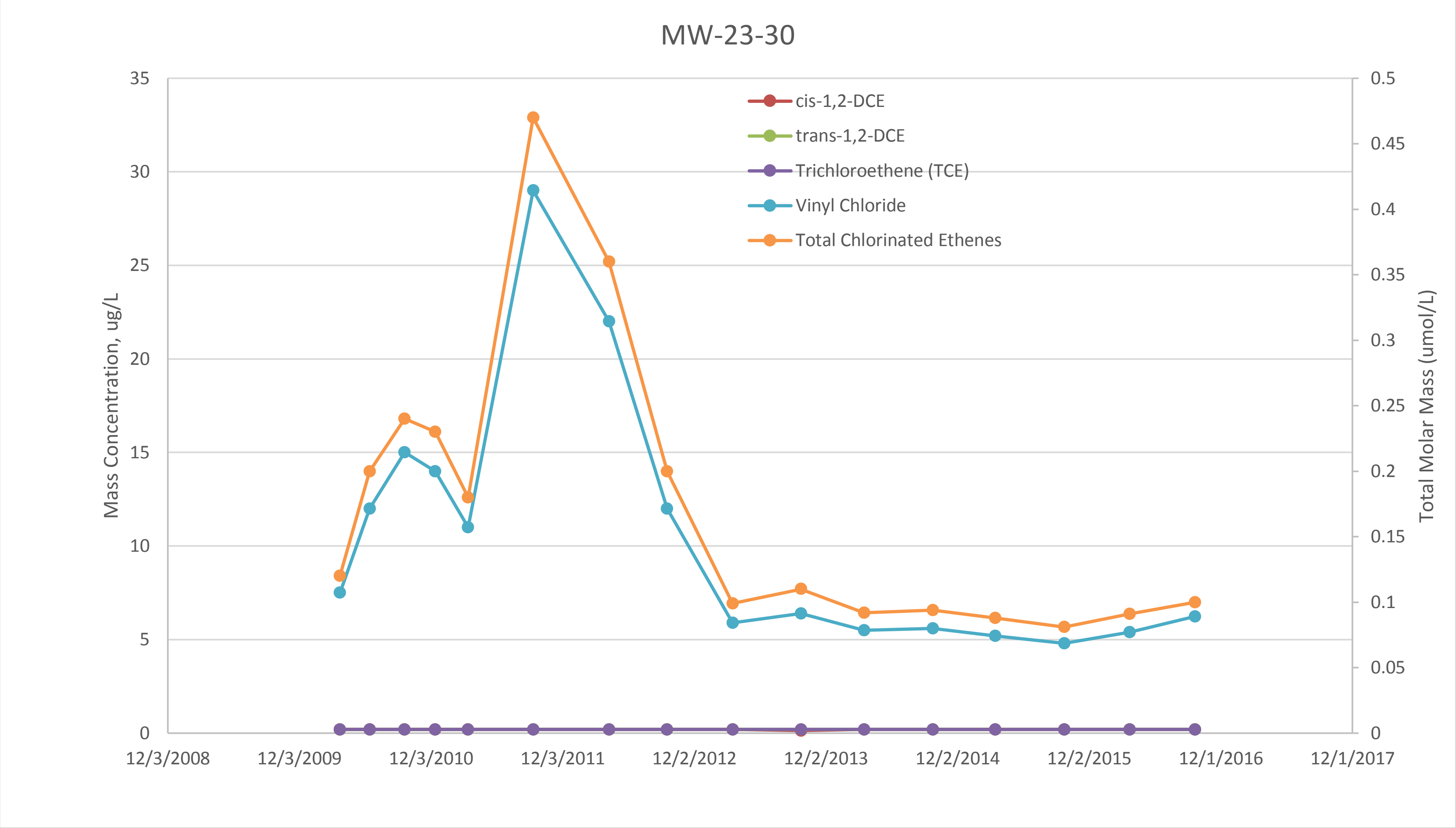

Dissolved Oxygen
ORP
DO, mg/L
ORP, mV
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
100
0
-100
-200
-300
-400
-500
-600
-700
12/3/2009
12/3/2010
12/3/2011
12/2/2012
12/2/2013
12/2/2014
12/2/2015
12/1/2016

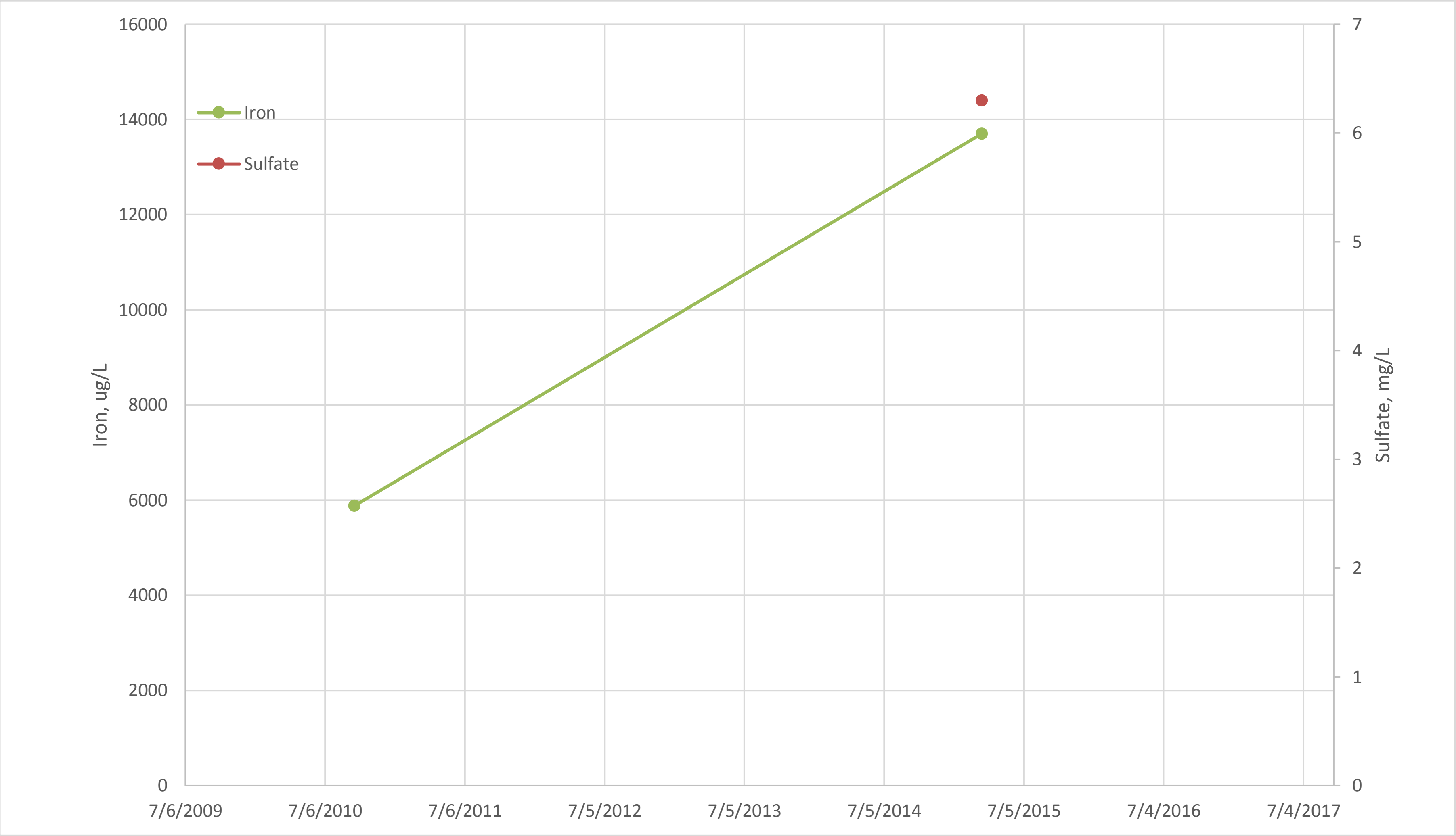

MW-22-50
Mass Concentration, ug/L
Total Molar Mass (umol/L)
cis-1,2-DCE
trans-1,2-DCE
Trichloroethene (TCE)
Vinyl Chloride
Total Chlorinated Ethenes
0
0.2
0.4
0.6
0.8
1
1.2
1.4
0.001
0.01
0.1
1
12/3/2009
12/3/2010
12/3/2011
12/2/2012
12/2/2013
12/2/2014
12/2/2015

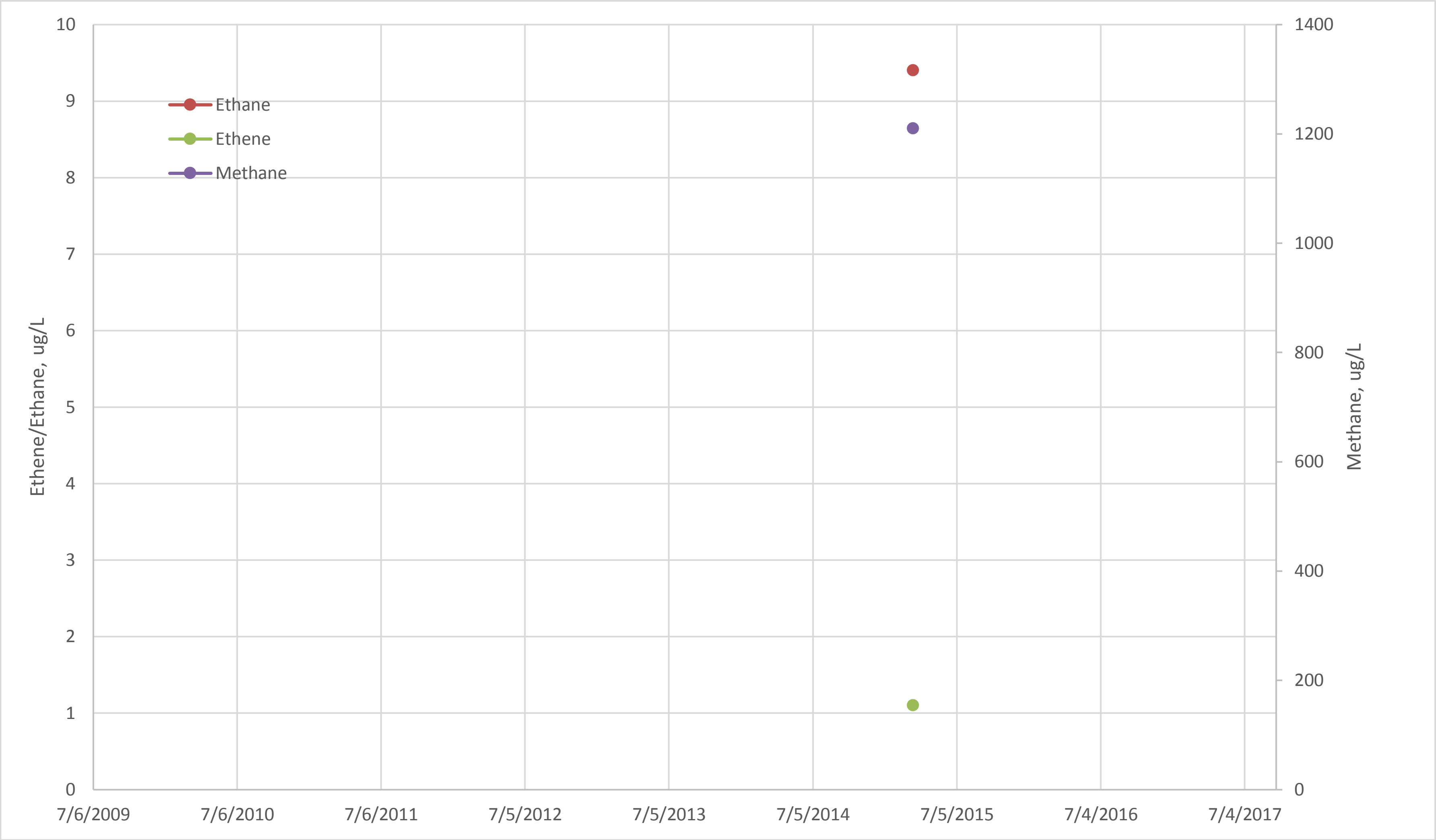

Iron, ug/L
Sulfate, mg/L
Iron
Sulfate
0
2000
4000
6000
8000
10000
12000
14000
16000
0
0.2
0.4
0.6
0.8
1
1.2
1.4
7/6/2009
7/6/2010
7/6/2011
7/5/2012
7/6/2013
7/6/2014
7/6/2015
7/6/2016
7/6/2017

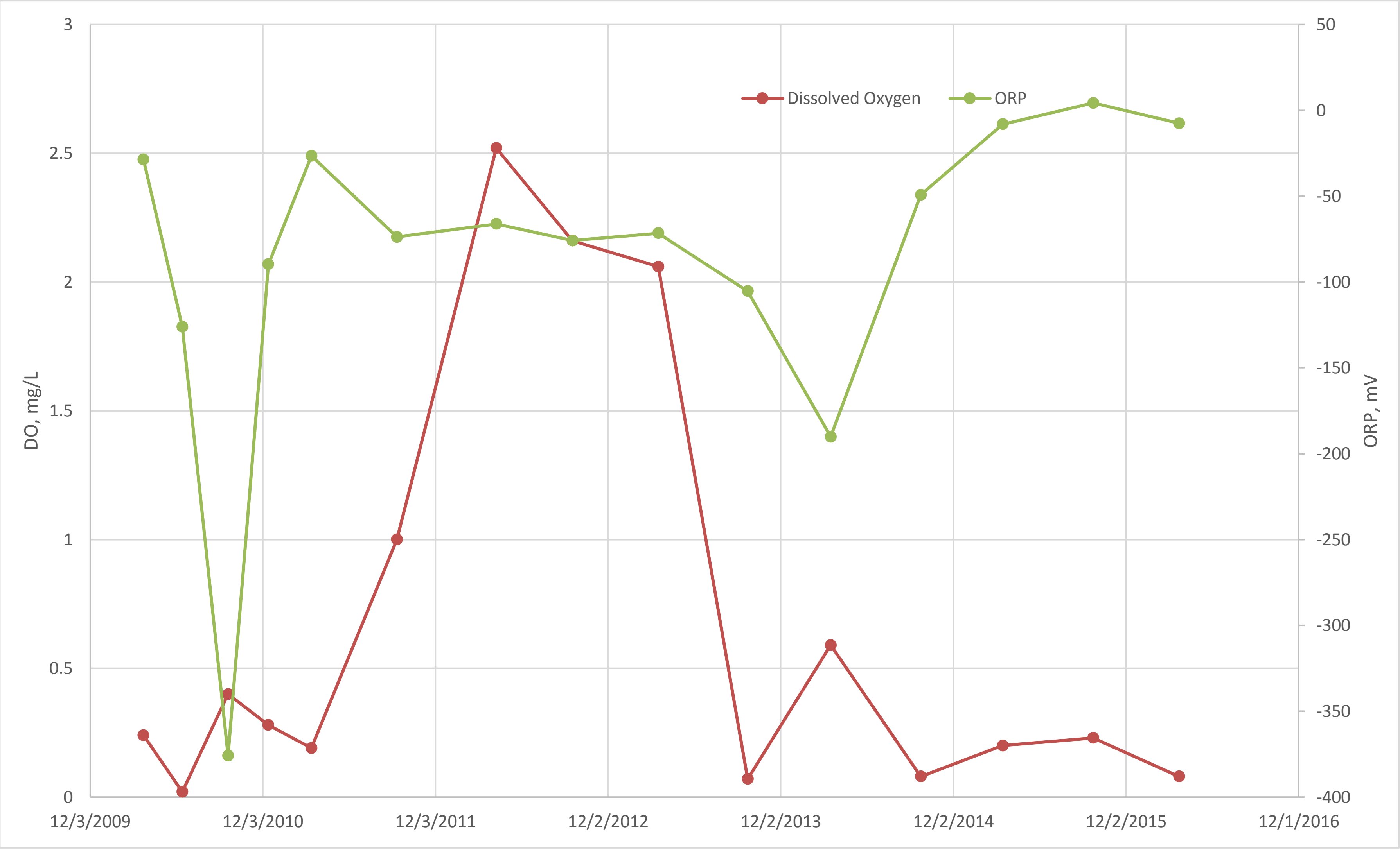

Ethene/Ethane, ug/L
Methane, ug/L
Ethane
Ethene
Methane
1.08
1.1
1.12
1.14
1.16
1.18
1.2
1.22
0
5000
10000
15000
20000
25000
30000
7/6/2009
7/6/2010
7/6/2011
7/5/2012
7/5/2013
7/5/2014
7/5/2015
7/4/2016
7/4/2017

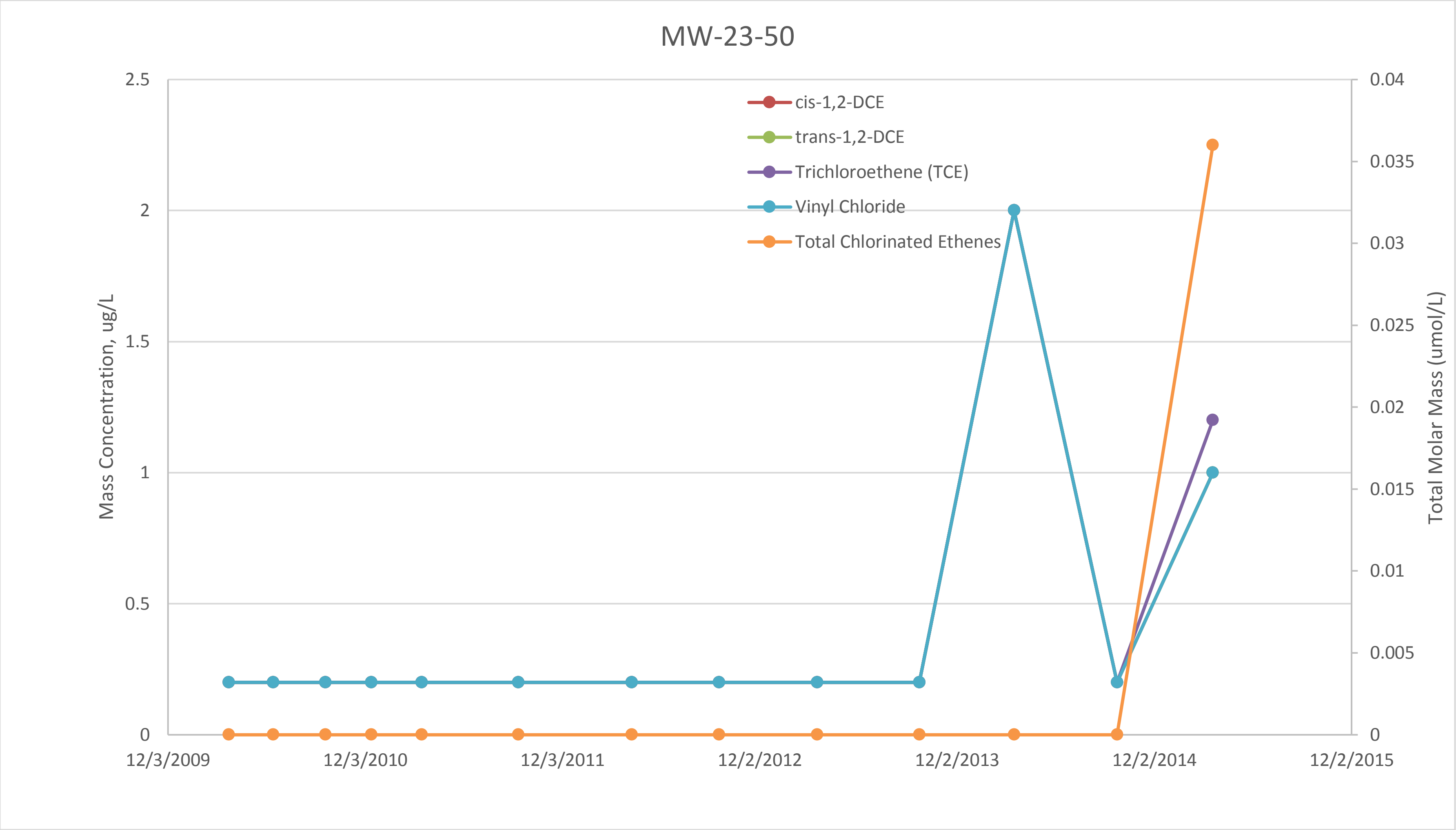

DO, mg/L
ORP, mV
Dissolved Oxygen
ORP
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
-100
-200
-300
-400
-500
-600
12/3/2009
12/3/2010
12/3/2011
12/2/2012
12/2/2013
12/2/2014
12/2/2015


MW-23-30
Mass Concentration, ug/L
Total Molar Mass (umol/L)
35
30
25
20
15
10
5
0
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
12/3/2008
12/3/2009
12/3/2010
12/3/2011
12/2/2012
12/2/2013
12/2/2014
12/2/2015
12/1/2016
12/1/2017
cis-1,2-DCE
trans-1,2-DCE
Trichloroethene (TCE)
Vinyl Chloride
Total Chlorinated Ethenes

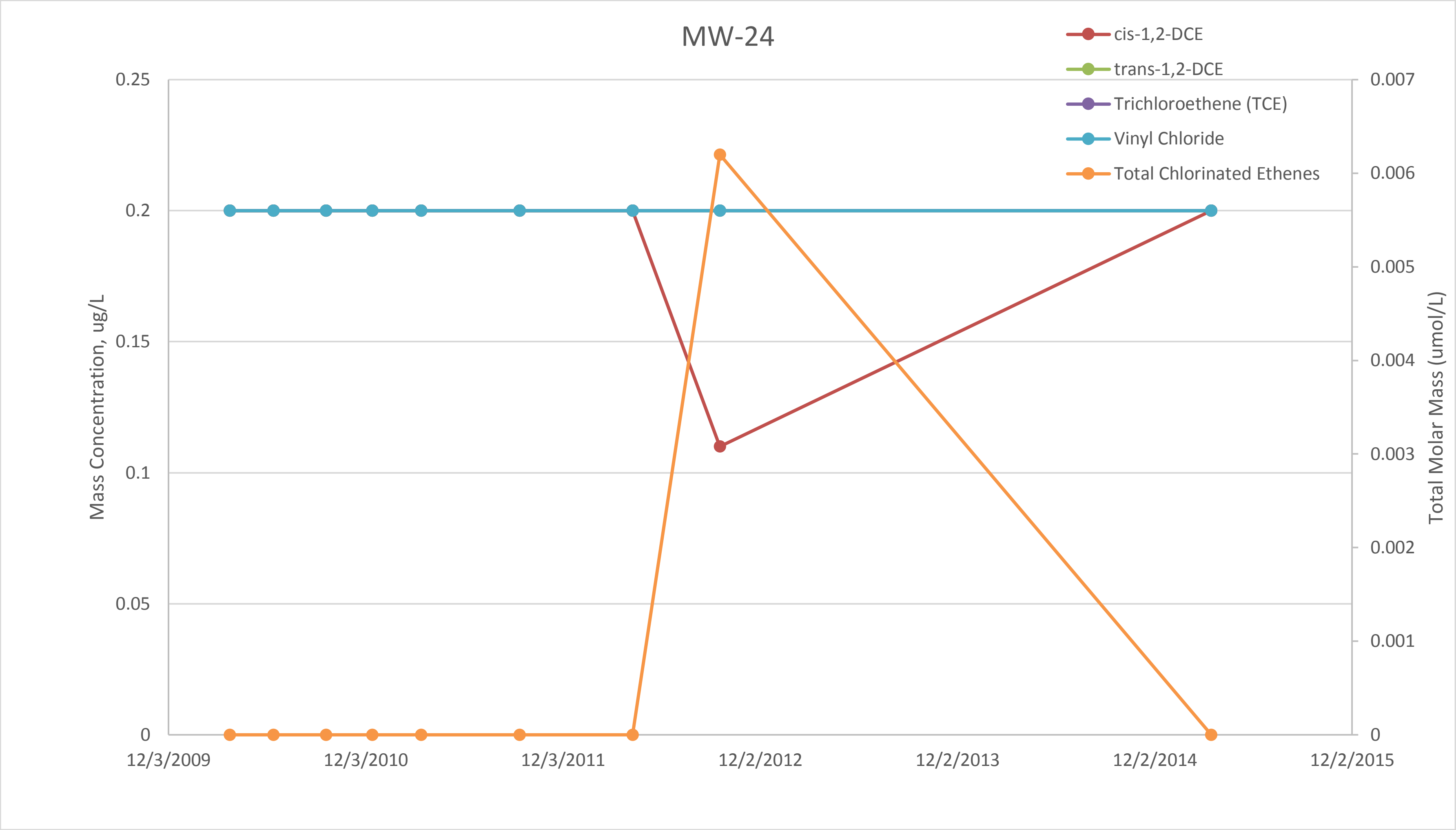

Iron, ug/L
Sulfate, mg/L
16000
14000
12000
10000
8000
6000
4000
2000
0
7
6
5
4
3
2
1
0
7/6/2009
7/6/2010
7/6/2011
7/5/2012
7/5/2013
7/5/2014
7/5/2015
7/4/2016
7/4/2017
Iron
Sulfate


Ethane
Ethene
Methane
Ethene/Ethane, ug/L
Methane, ug/L
10
9
8
7
6
5
4
3
2
1
0
1400
1200
1000
800
600
400
200
0
7/6/2009
7/6/2010
7/6/2011
7/5/2012
7/5/2013
7/5/2014
7/5/2015
7/4/2016
7/4/2017

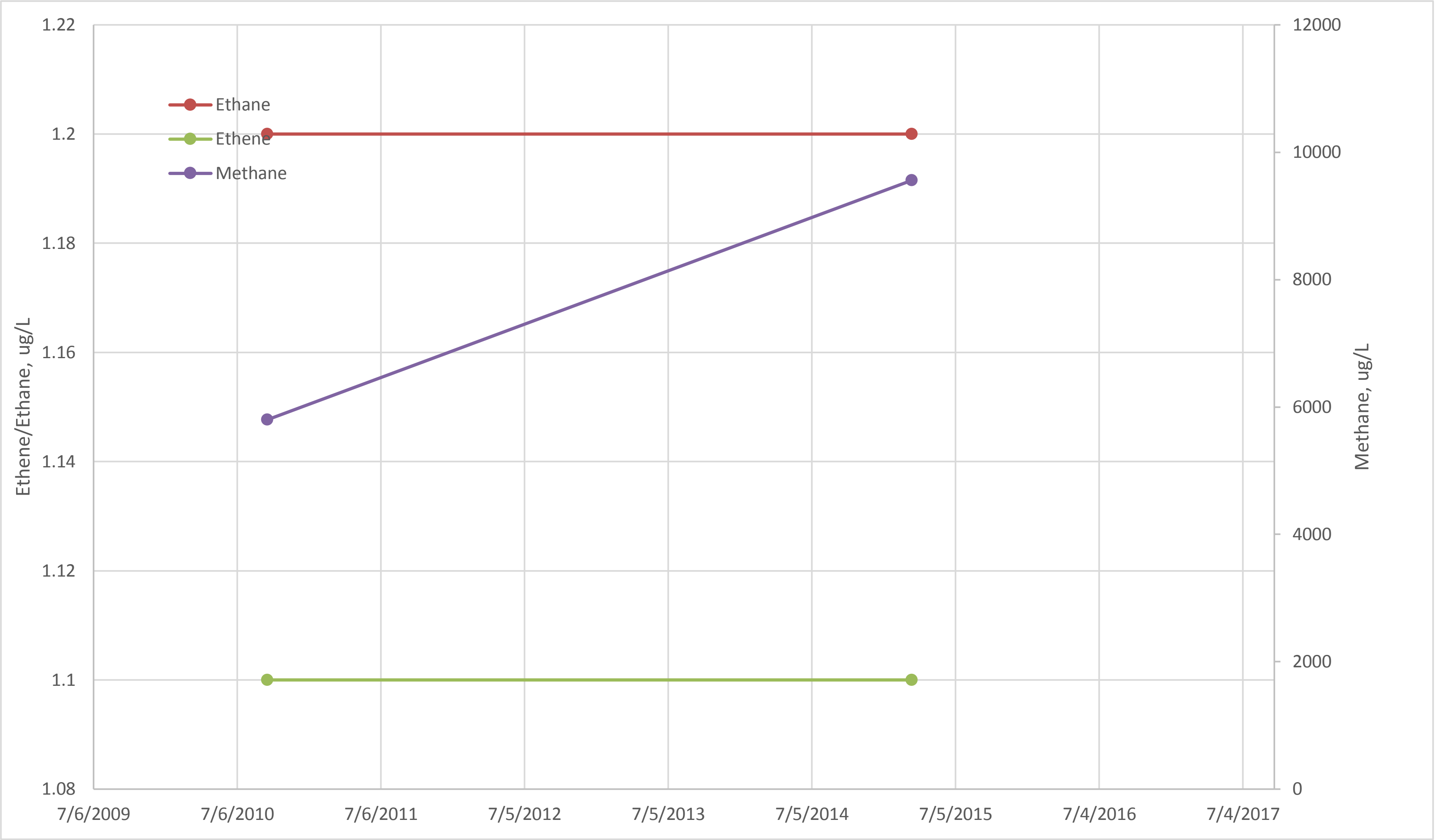

Dissolved Oxygen
ORP
DO, mg/L
ORP, mV
3
2.5
2
1.5
1
0.5
0
50
0
-50
-100
-150
-200
-250
-300
-350
-400
12/3/2009
12/3/2010
12/3/2011
12/2/2012
12/2/2013
12/2/2014
12/2/2015
12/1/2016


MW-23-50
cis-1,2-DCE
trans-1,2-DCE
Trichloroethene (TCE)
Vinyl Chloride
Total Chlorinated Ethenes
Mass Concentration, ug/L
Total Molar Mass (umol/L)
2.5
2
1.5
1
0.5
0
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
12/3/2009
12/3/2010
12/3/2011
12/2/2012
12/2/2013
12/2/2014
12/2/2015

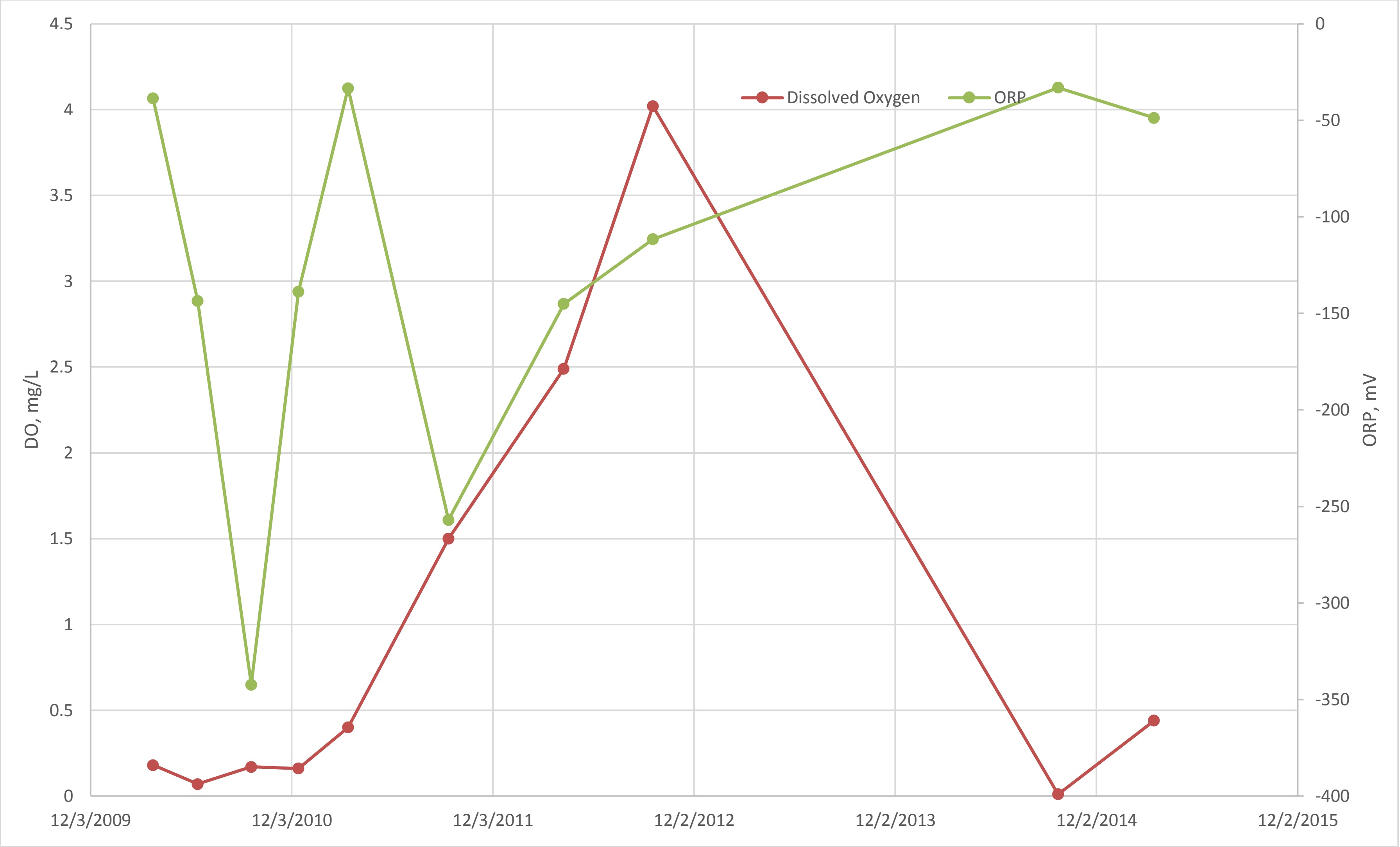

Dissolved Oxygen
ORP
DO, mg/L
ORP, mV
3
2.5
2
1.5
1
0.5
0
0
-50
-100
-150
-200
-250
-300
-350
-400
-450
-500
12/3/2009
12/3/2010
12/3/2011
12/2/2012
12/2/2013
12/2/2014
12/2/2015


MW-24
cis-1,2-DCE
trans-1,2-DCE
Trichloroethene (TCE)
Vinyl Chloride
Total Chlorinated Ethenes
Mass Concentration, ug/L
Total Molar Mass (umol/L)
0.25
0.2
0.15
0.1
0.05
0
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
12/3/2009
12/3/2010
12/3/2011
12/2/2012
12/2/2013
12/2/2014
12/2/2015

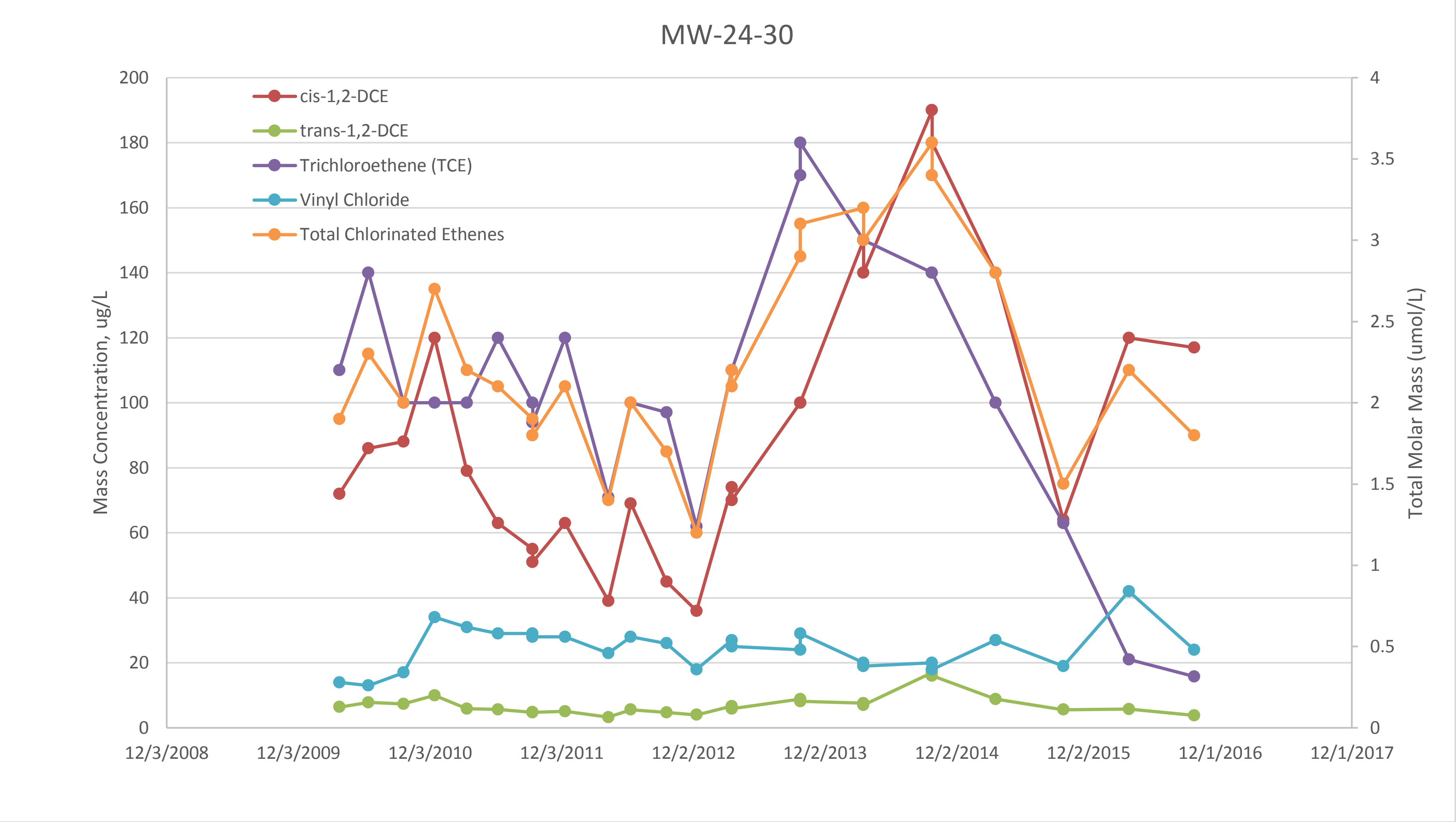

Iron
Sulfate
Iron, ug/L
Sulfate, mg/L
14000
12000
10000
8000
6000
4000
2000
0
6.65
6.6
6.55
6.5
6.45
6.4
6.35
7/6/2009
7/6/2010
7/6/2011
7/5/2012
7/5/2013
7/5/2014
7/5/2015
7/4/2016
7/4/2017

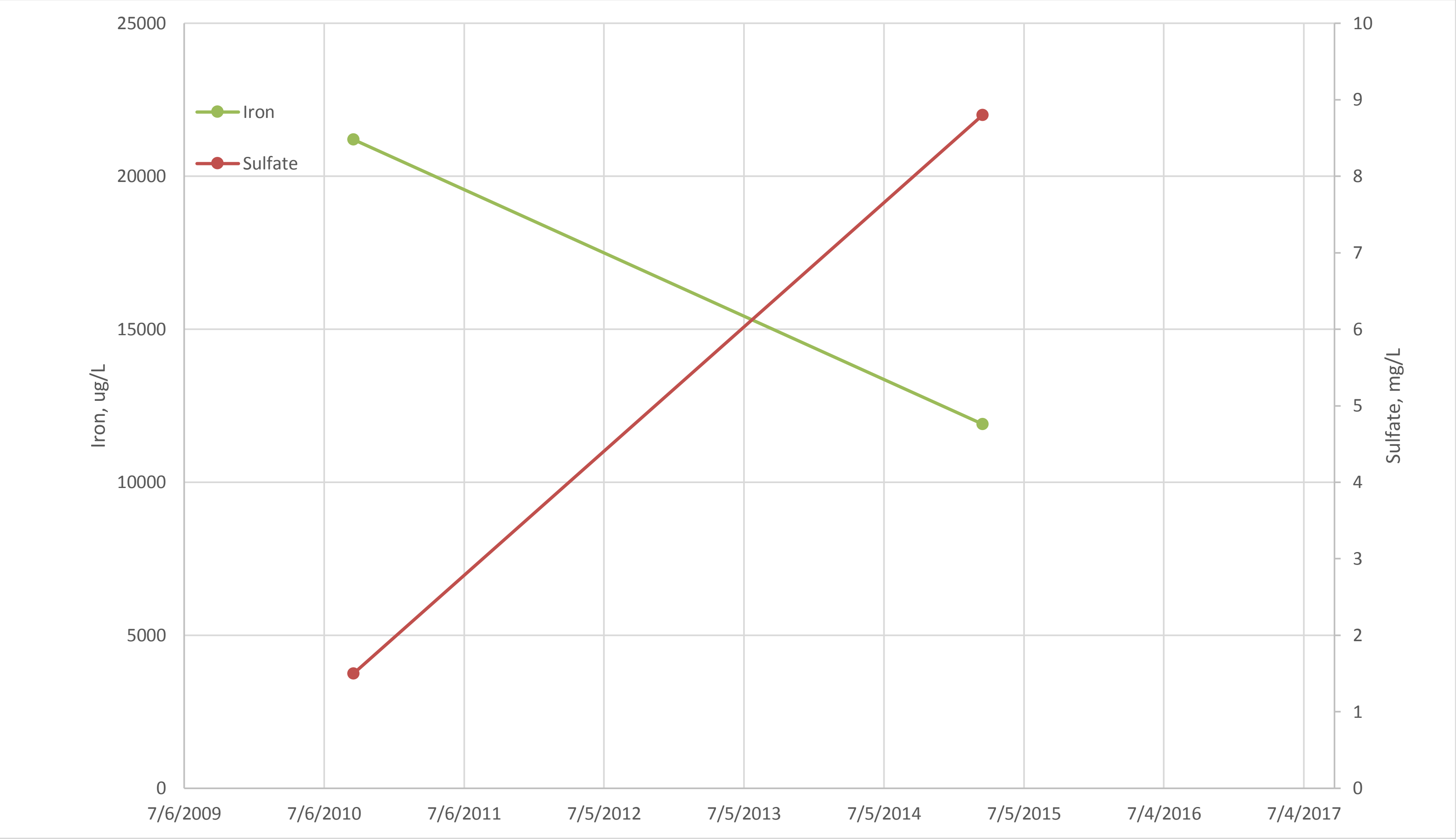


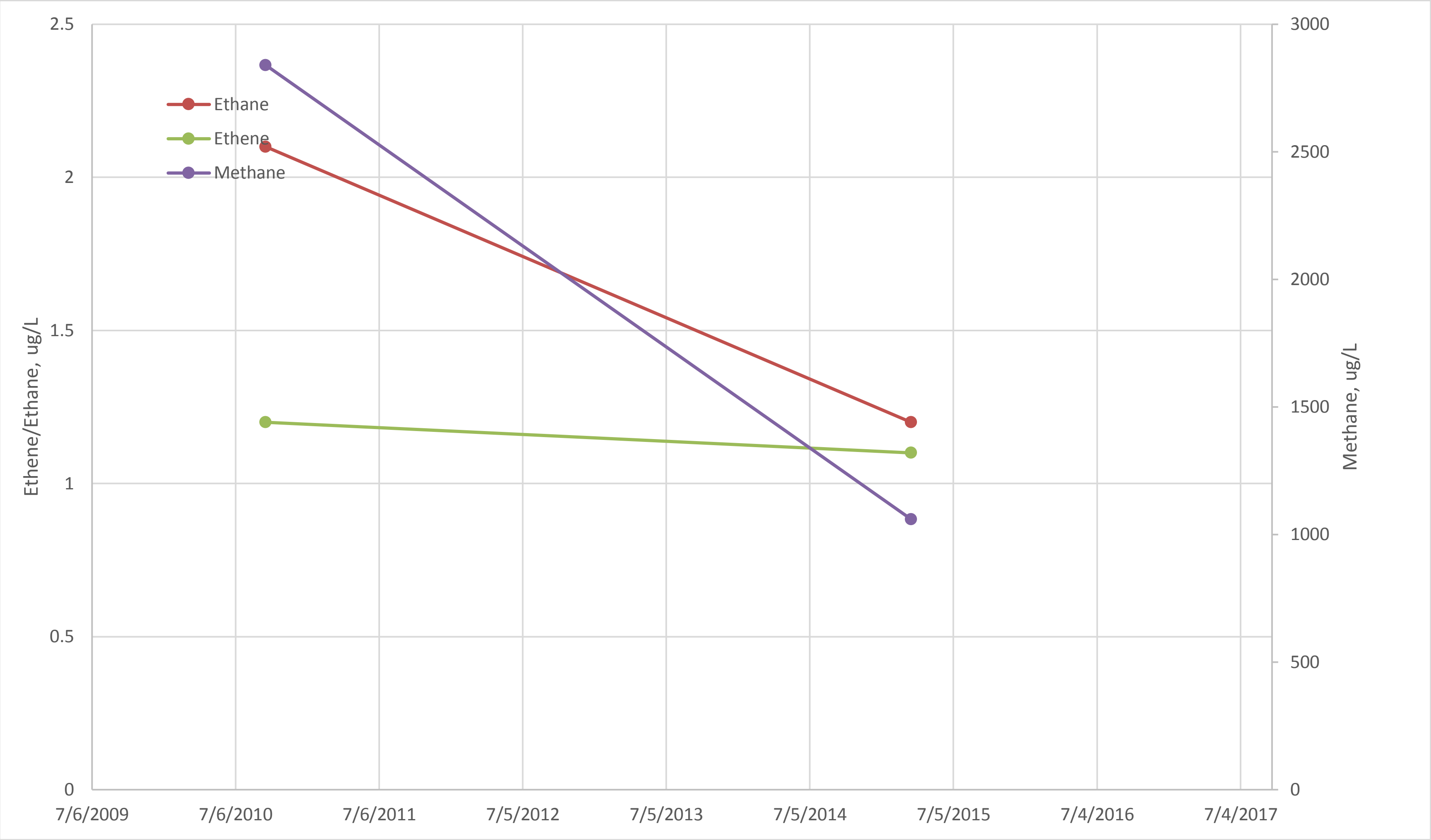
1.22
1.2
1.18
1.16
1.14
1.12
1.1
1.08
Ethene/Ethane, ug/L
12000
10000
8000
6000
4000
2000
0
Methane, ug/L
Ethane
Ethene
Methane
7/6/2009
7/6/2010
7/6/2011
7/5/2012
7/5/2013
7/5/2014
7/5/2015
7/4/2016
7/4/2017



4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
DO, mg/L
0
-50
-100
-150
-200
-250
-300
-350
-400
ORP, mV
Dissolved Oxygen
ORP
12/3/2009
12/3/2010
12/3/2011
12/2/2012
12/2/2013
12/2/2014
12/2/2015

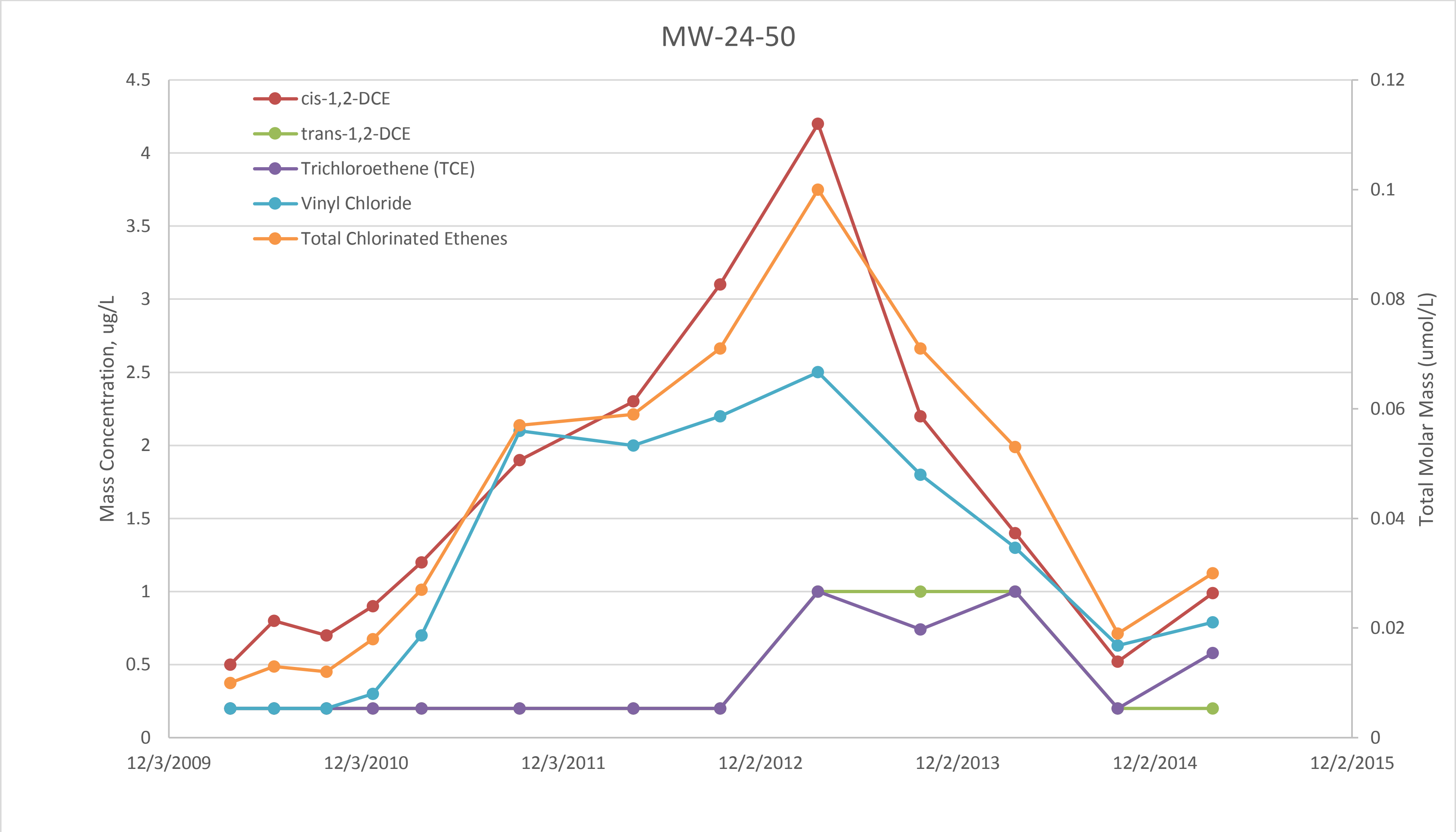

MW-24-30
200
180
160
140
120
100
80
60
40
20
0
Mass Concentration, ug/L
4
3.5
3
2.5
2
1.5
1
0.5
0
Total Molar Mass (umol/L)
12/3/2008
12/3/2009
12/3/2010
12/3/2011
12/2/2012
12/2/2013
12/2/2014
12/2/2015
12/1/2016
12/1/2017
cis-1,2-DCE
trans-1,2-DCE
Trichloroethene (TCE)
Vinyl Chloride
Total Chlorinated Ethenes

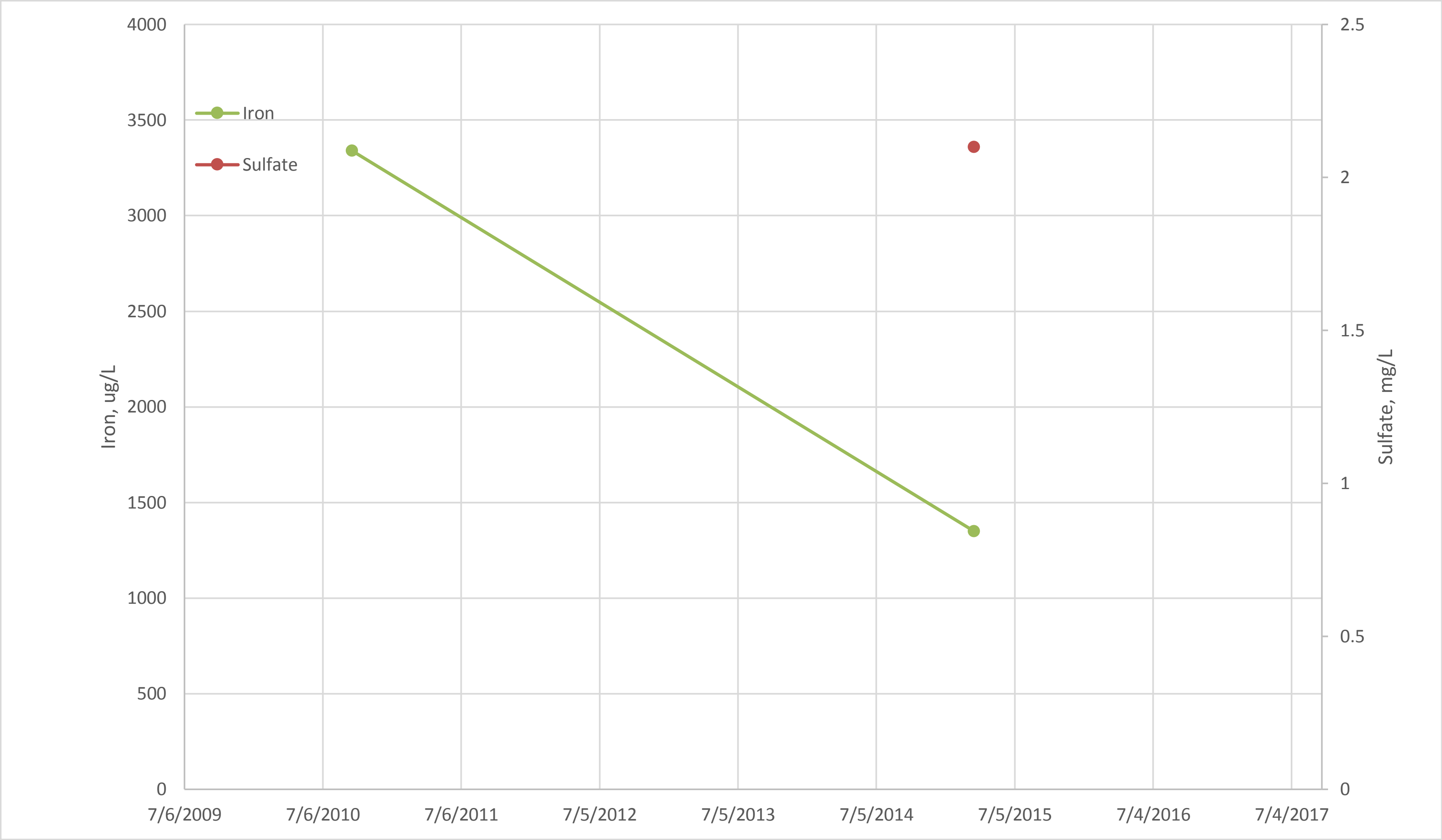

25000
20000
15000
10000
5000
0
Iron, ug/L
10
9
8
7
6
5
4
3
2
1
0
Sulfate, mg/L
7/6/2009
7/6/2010
7/6/2011
7/5/2012
7/5/2013
7/5/2014
7/5/2015
7/4/2016
7/4/2017
Iron
Sulfate

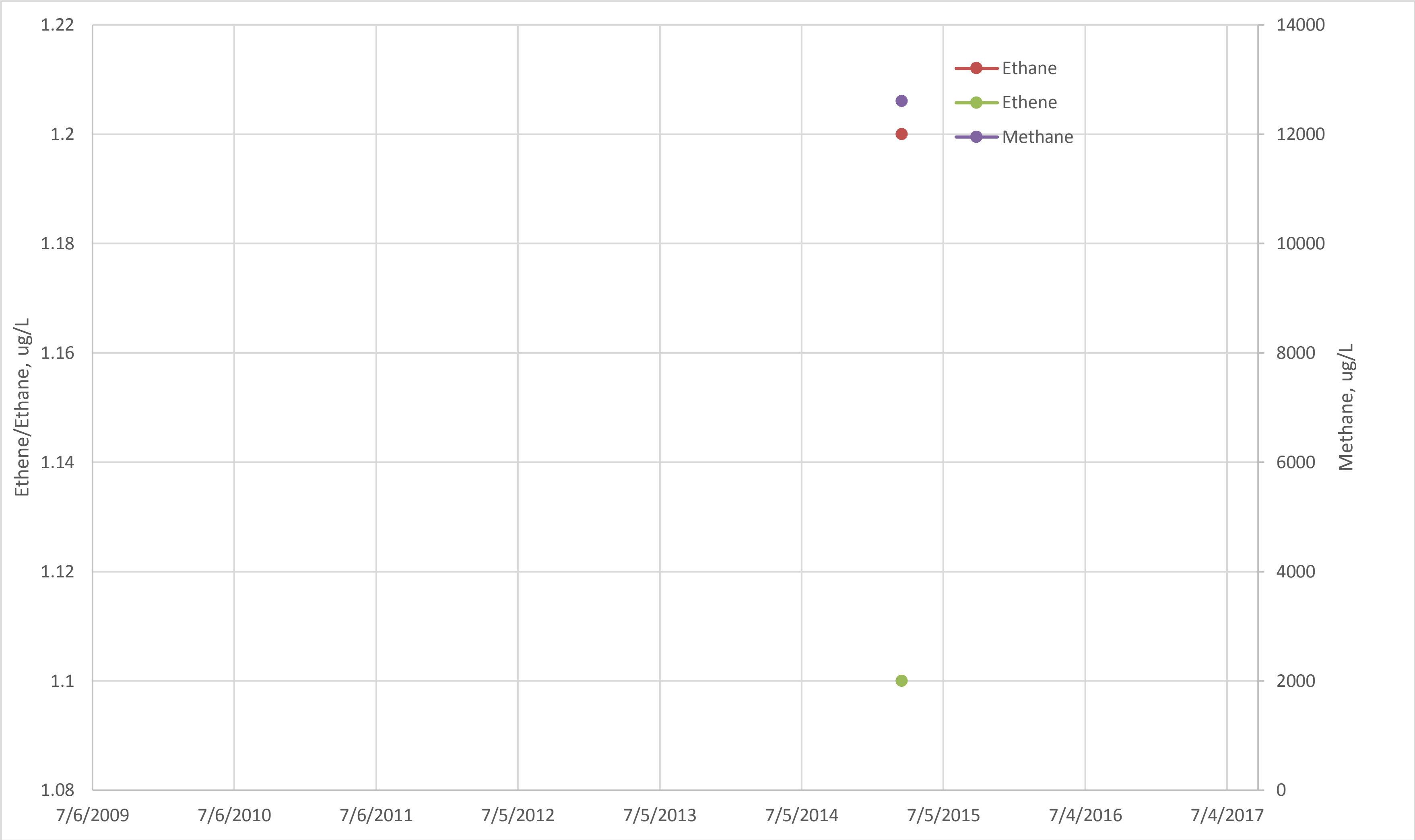


Ethane
Ethene
Methane
Ethene/Ethane, ug/L
Methane, ug/L
2.5
2
1.5
1
0.5
0
3000
2500
2000
1500
1000
500
0
7/6/2009
7/6/2010
7/6/2011
7/5/2012
7/5/2013
7/5/2014
7/5/2015
7/4/2016
7/4/2017

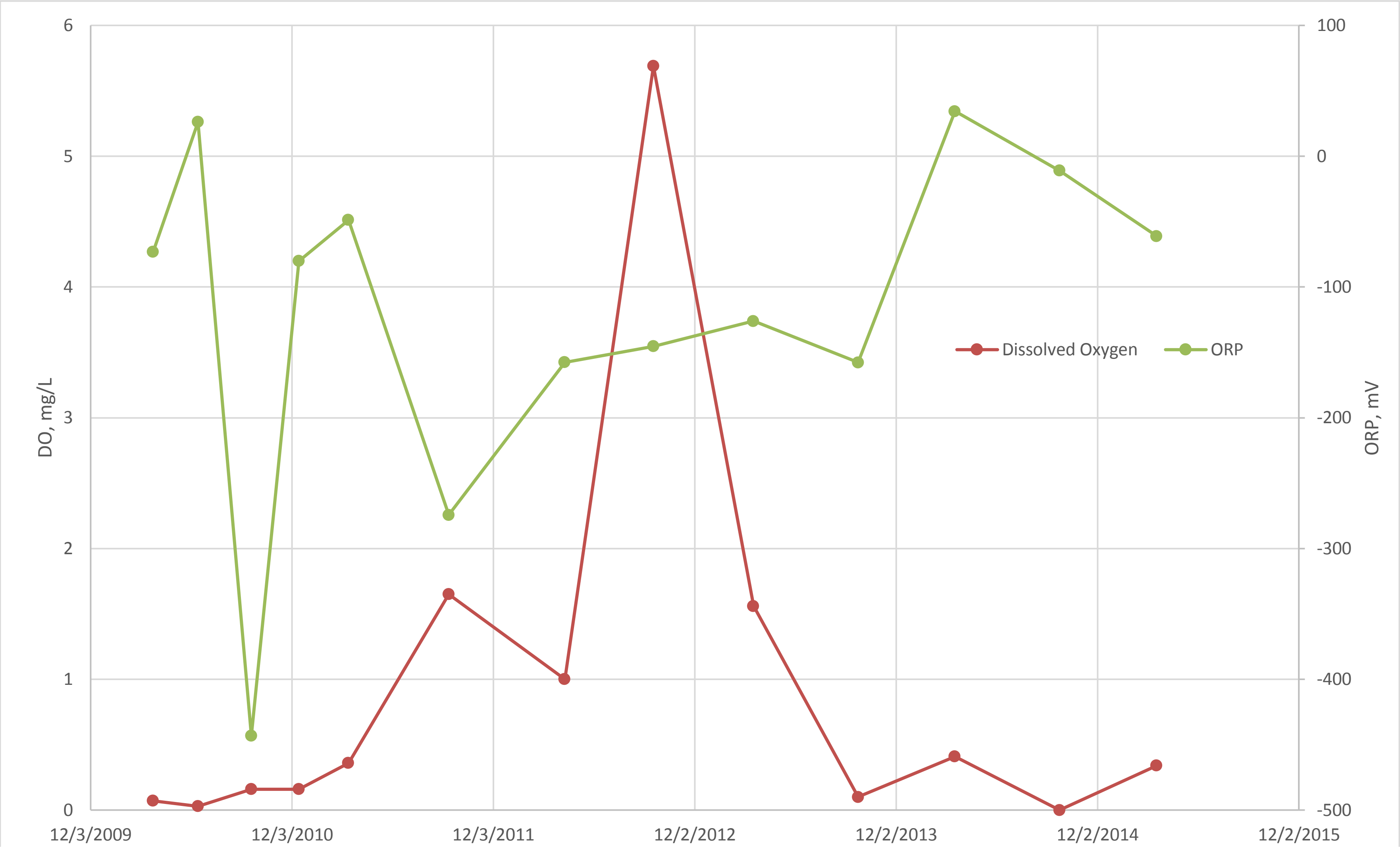
Dissolved Oxygen
ORP
DO, mg/L
ORP, mV
6
5
4
3
2
1
0
100
0
-100
-200
-300
-400
-500
-600
-700
12/3/2009
12/3/2010
12/3/2011
12/2/2012
12/2/2013
12/2/2014
12/2/2015
12/1/2016


MW-24-50
cis-1,2-DCE
trans-1,2-DCE
Trichloroethene (TCE)
Vinyl Chloride
Total Chlorinated Ethenes
Mass Concentration, ug/L
Total Molar Mass (umol/L)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0.12
0.1
0.08
0.06
0.04
0.02
0
12/3/2009
12/3/2010
12/3/2011
12/2/2012
12/2/2013
12/2/2014
12/2/2015

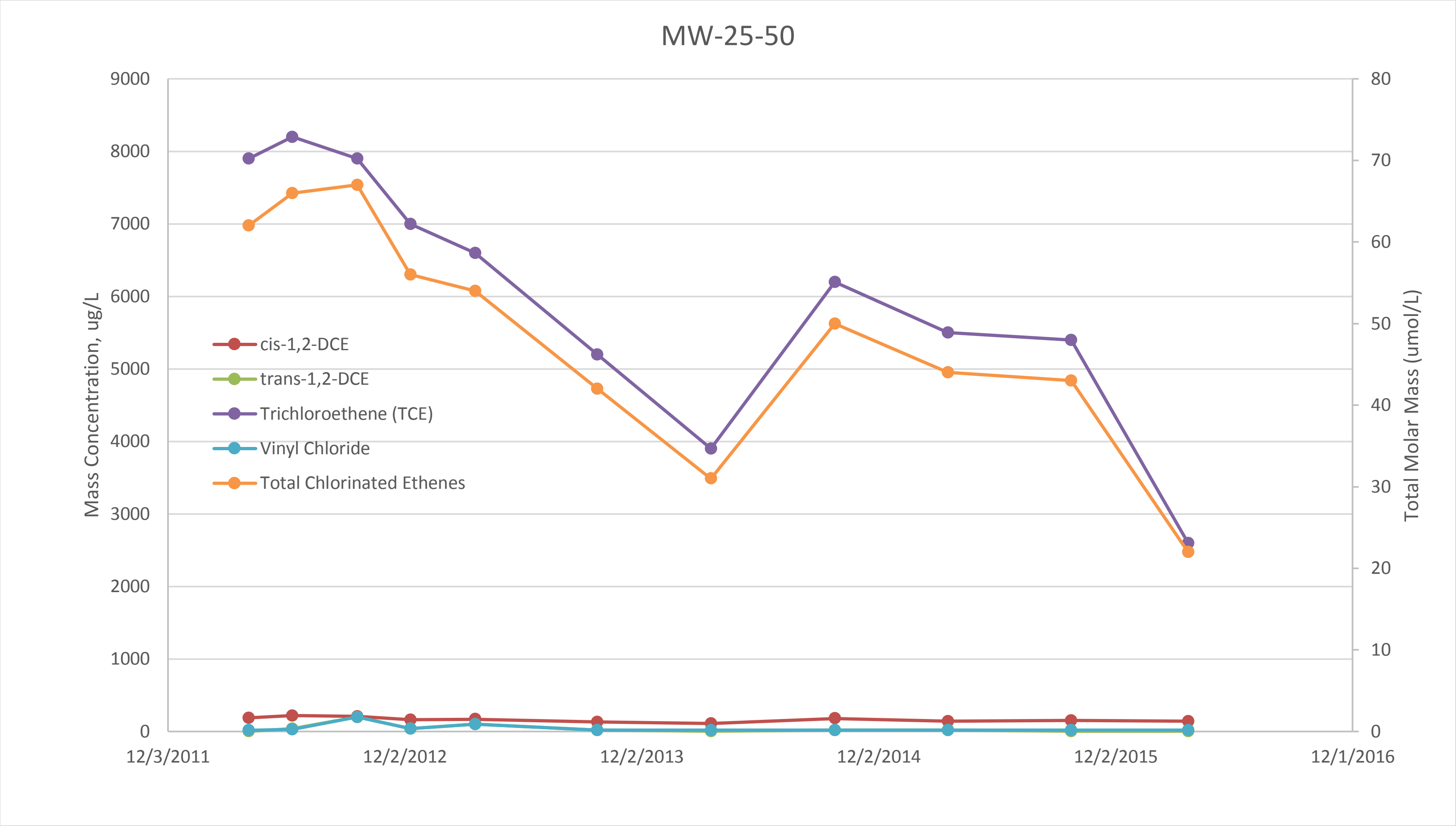

Iron
Sulfate
Iron, ug/L
Sulfate, mg/L
4000
3500
3000
2500
2000
1500
1000
500
0
2.5
2
1.5
1
0.5
0
7/6/2009
7/6/2010
7/6/2011
7/5/2012
7/5/2013
7/5/2014
7/5/2015
7/4/2016
7/4/2017

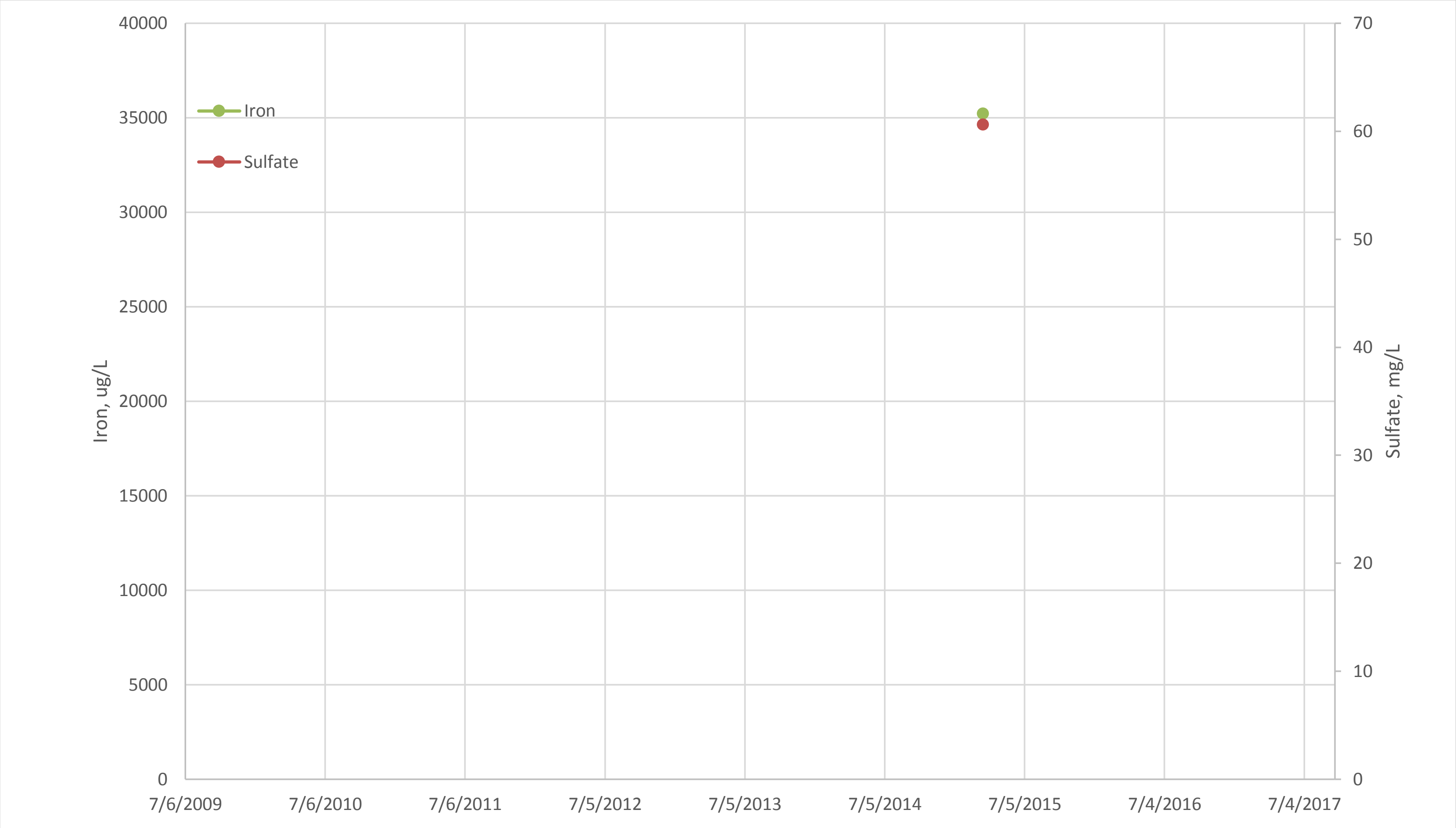


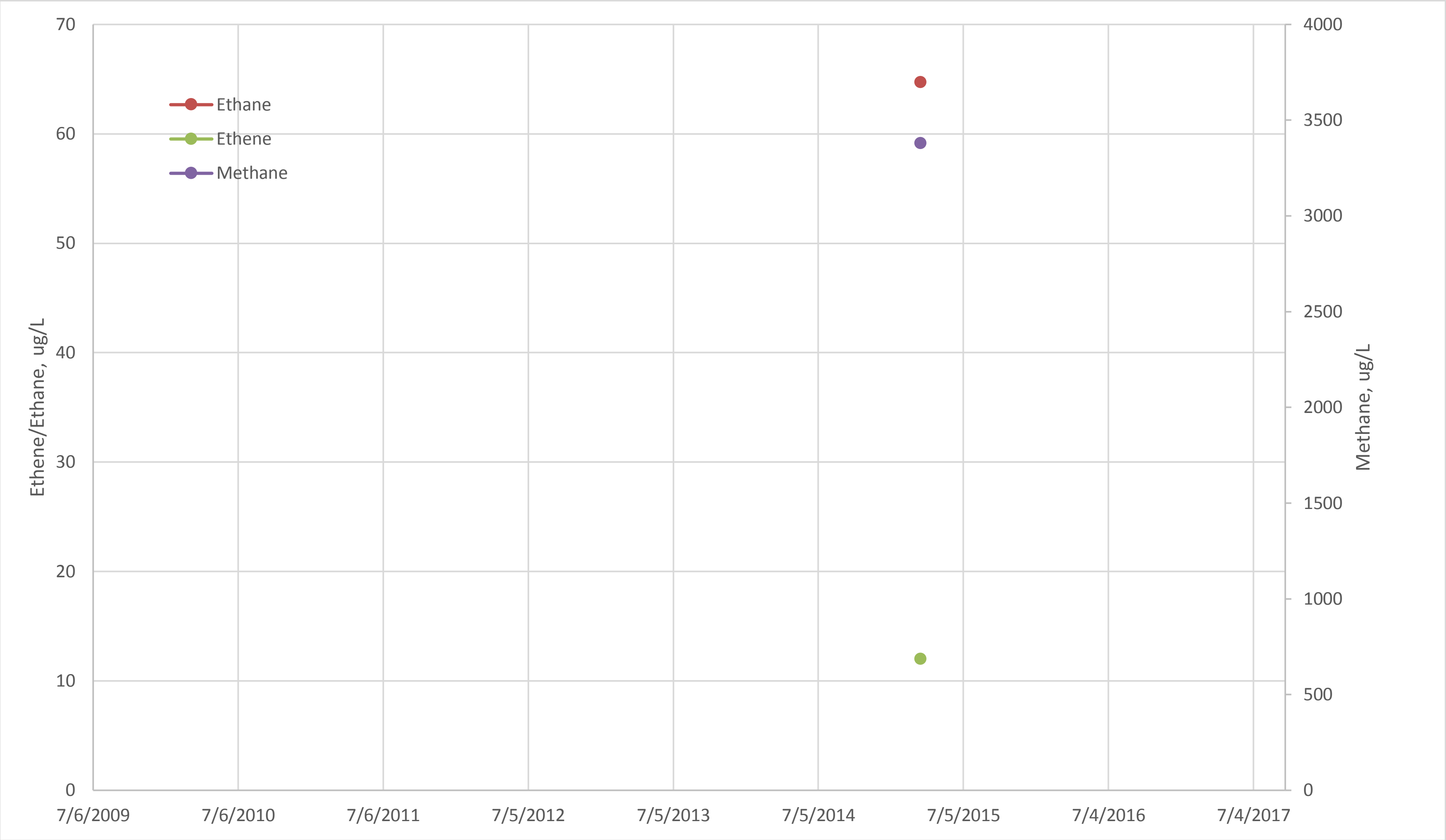
Ethene/Ethane, ug/L
1.22
1.2
1.18
1.16
1.14
1.12
1.1
1.08
Methane, ug/L
14000
12000
10000
8000
6000
4000
2000
0
7/6/2009
7/6/2010
7/6/2011
7/5/2012
7/5/2013
7/5/2014
7/5/2015
7/4/2016
7/4/2017
Ethane
Ethene
Methane

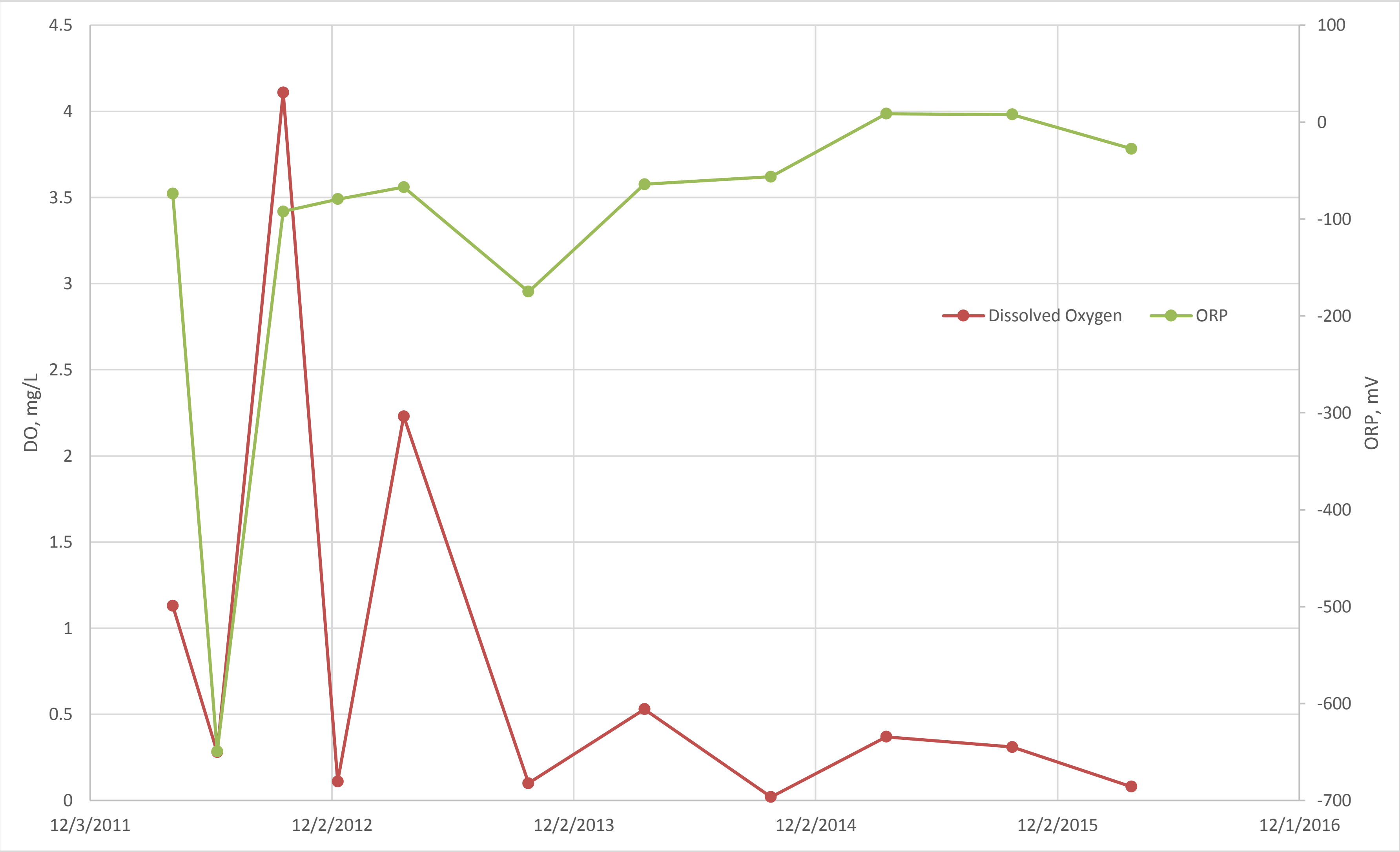


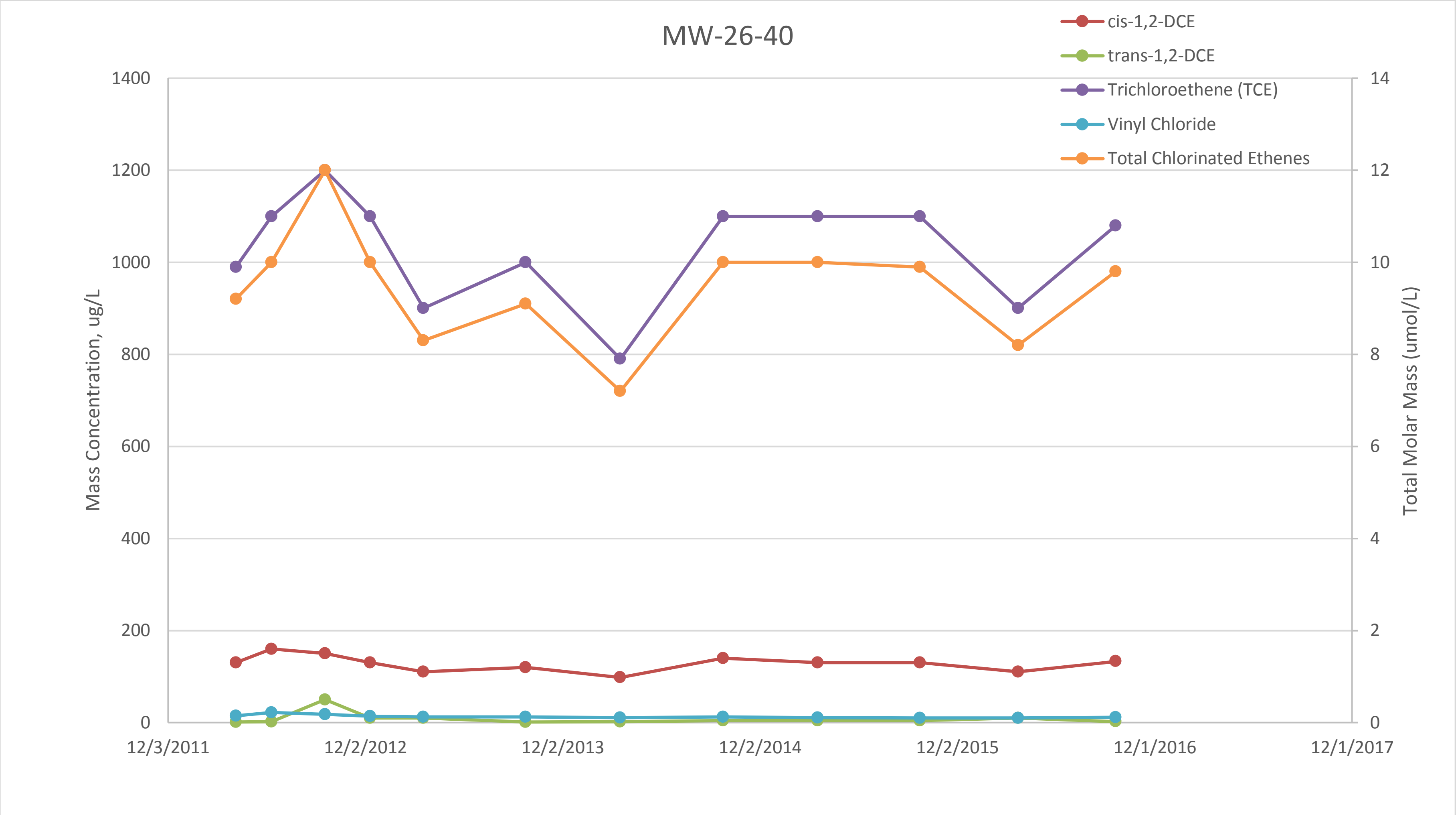
DO, mg/L
6
5
4
3
2
1
0
ORP, mV
100
0
-100
-200
-300
-400
-500
12/3/2009
12/3/2010
12/3/2011
12/2/2012
12/2/2013
12/2/2014
12/2/2015
Dissolved Oxygen
ORP

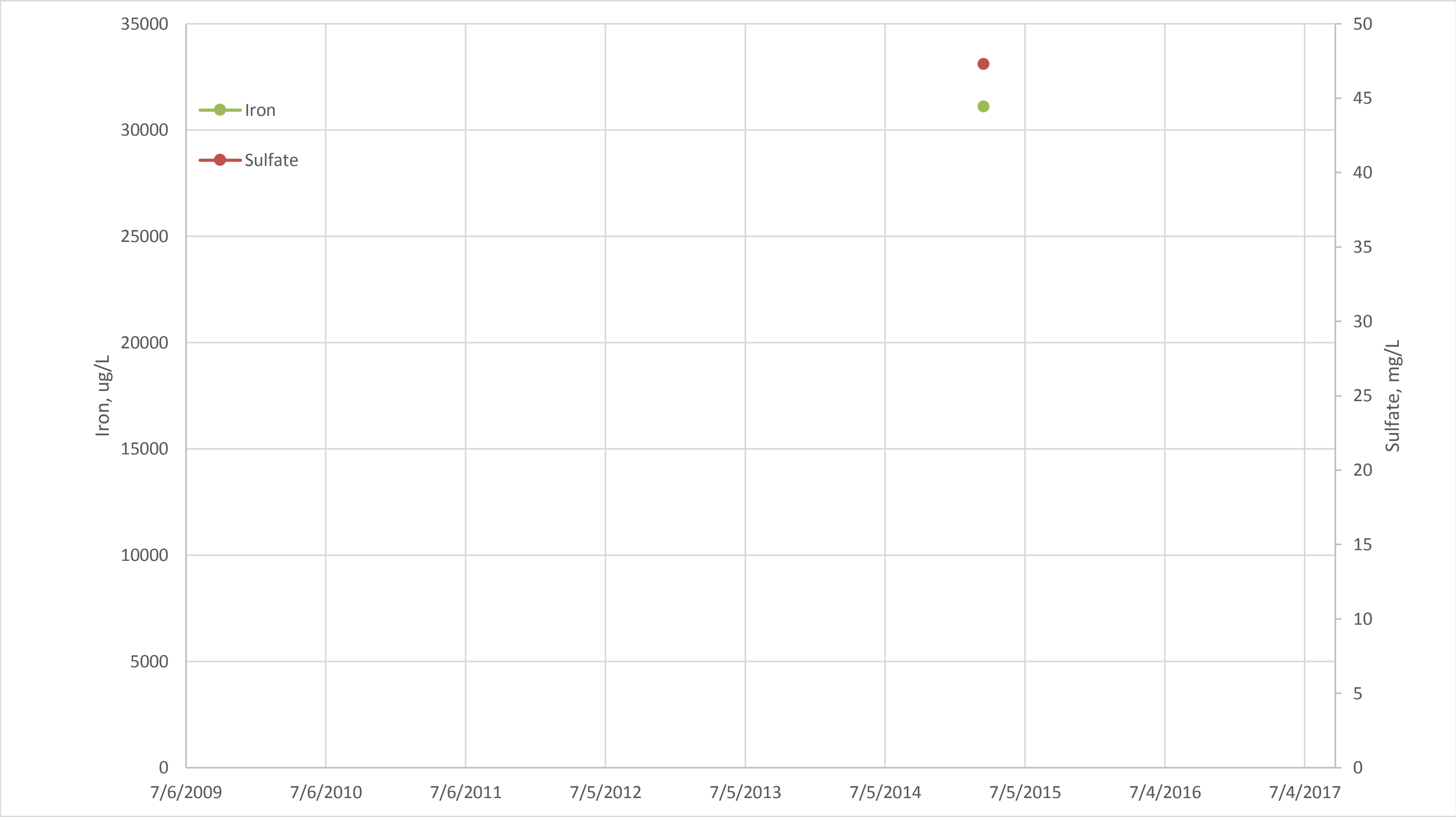

MW-25-50
Mass Concentration, ug/L
Total Molar Mass (umol/L)
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
80
70
60
50
40
30
20
10
0
12/3/2011
12/2/2012
12/2/2013
12/2/2014
12/2/2015
12/1/2016
cis-1,2-DCE
trans-1,2-DCE
Trichloroethene (TCE)
Vinyl Chloride
Total Chlorinated Ethenes

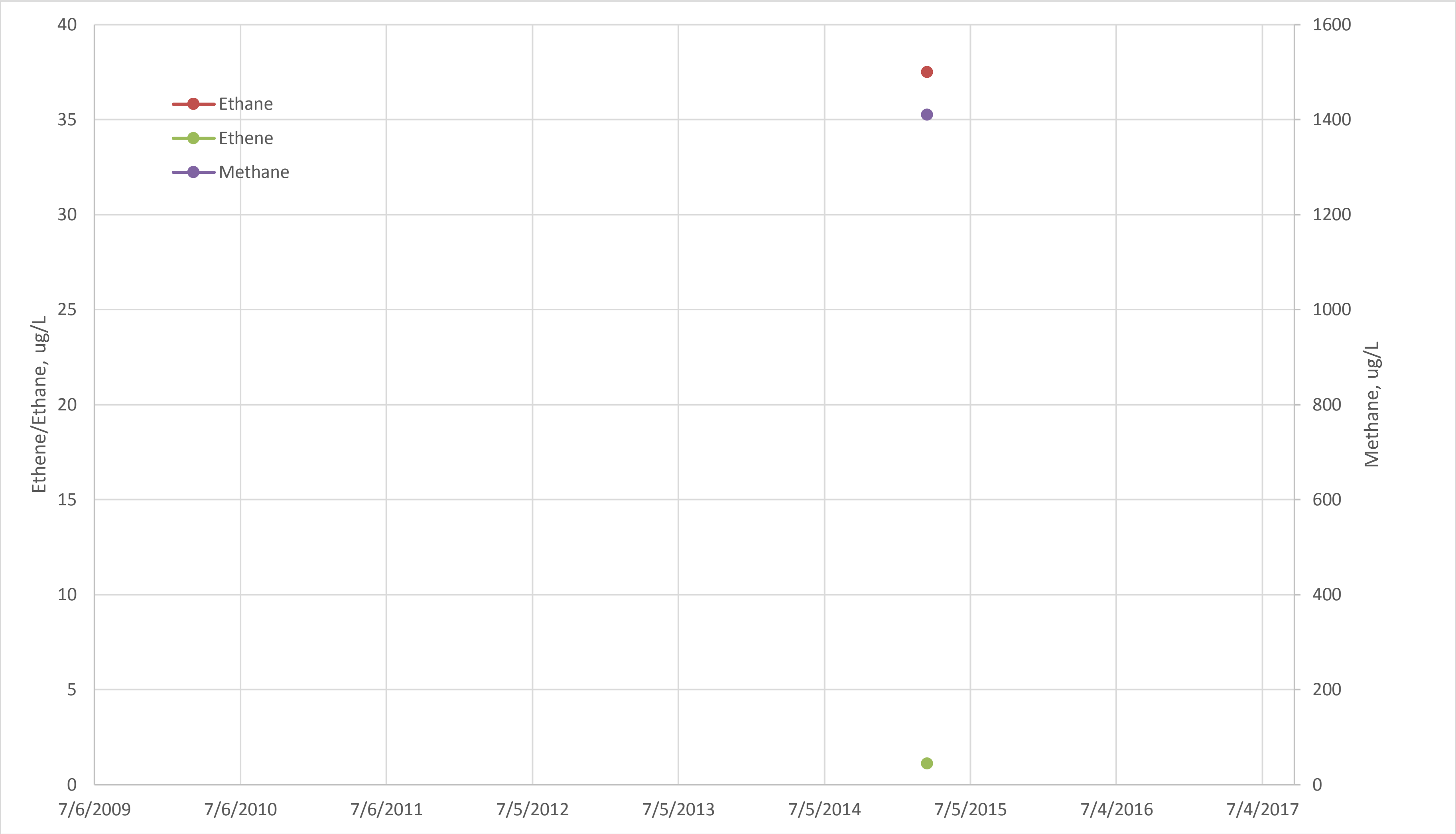

Iron, ug/L
Sulfate, mg/L
40000
35000
30000
25000
20000
15000
10000
5000
0
70
60
50
40
30
20
10
0
7/6/2009
7/6/2010
7/6/2011
7/5/2012
7/5/2013
7/5/2014
7/5/2015
7/4/2016
7/4/2017
Iron
Sulfate

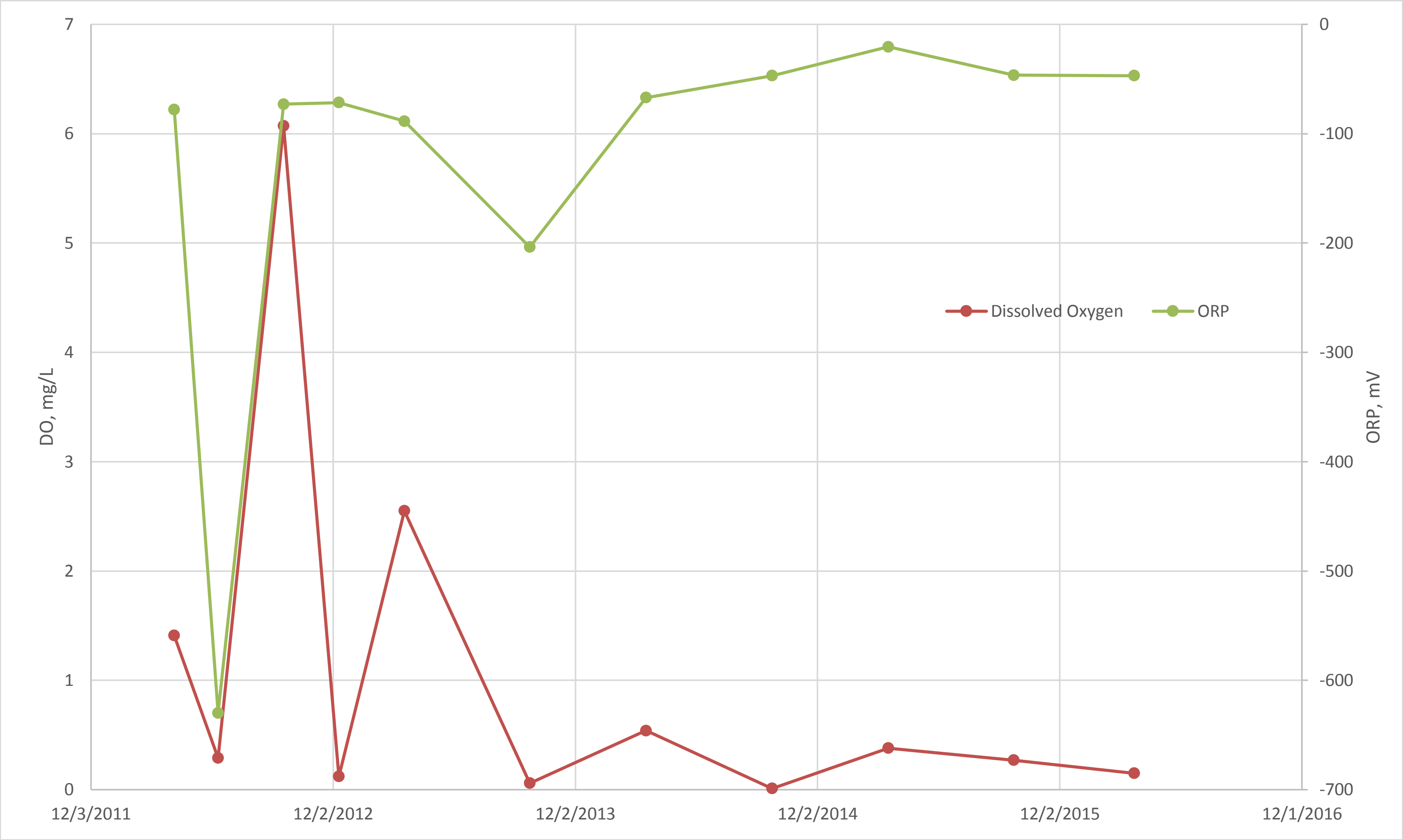

70
60
50
40
30
20
10
0
Ethene/Ethane, ug/L
4000
3500
3000
2500
2000
1500
1000
500
0
Methane, ug/L
Ethane
Ethene
Methane
7/6/2009
7/6/2010
7/6/2011
7/5/2012
7/5/2013
7/5/2014
7/5/2015
7/4/2016
7/4/2017

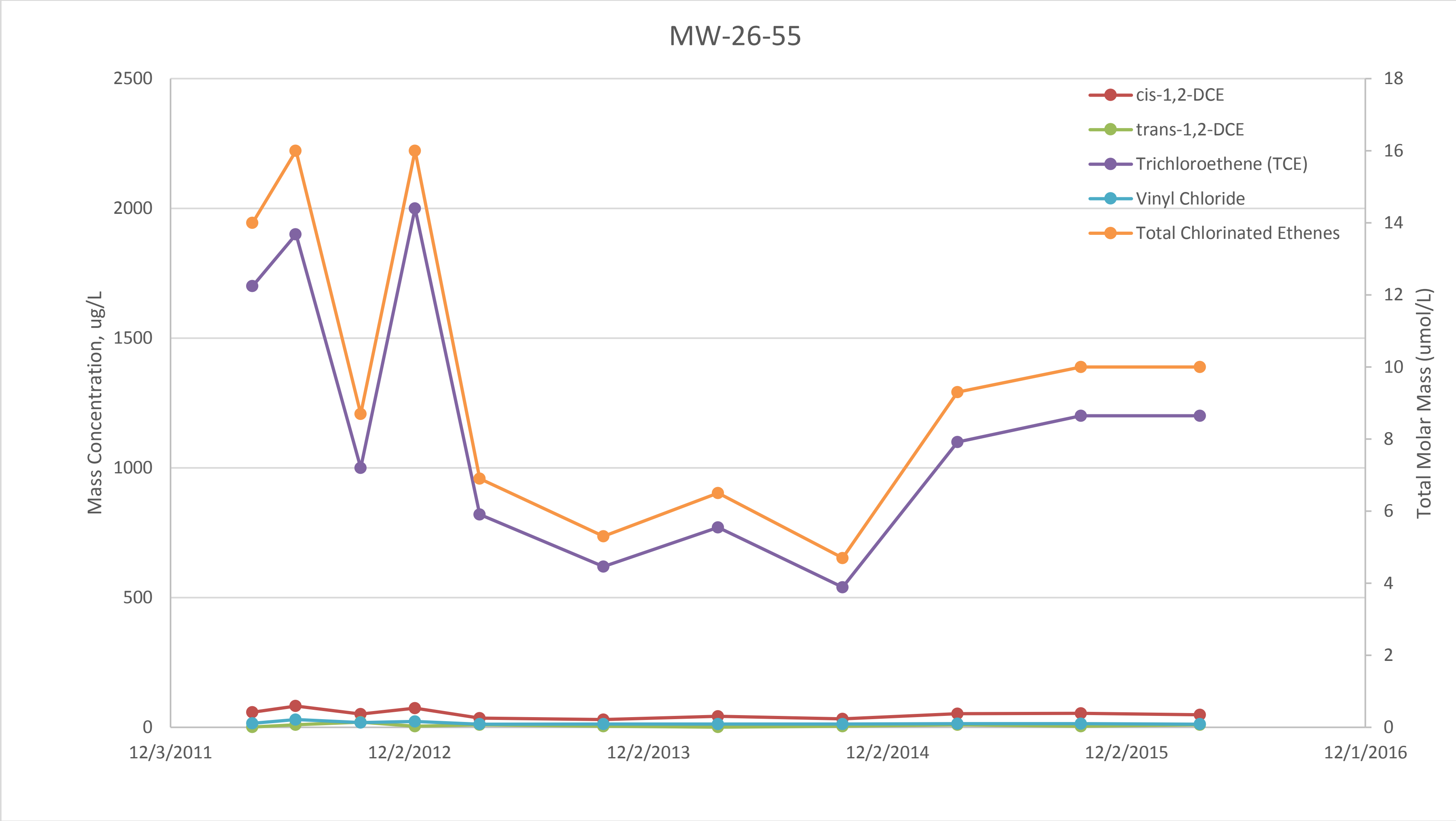

4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
DO, mg/L
100
0
-100
-200
-300
-400
-500
-600
-700
ORP, mV
Dissolved Oxygen
ORP
12/3/2011
12/2/2012
12/2/2013
12/2/2014
12/2/2015
12/1/2016

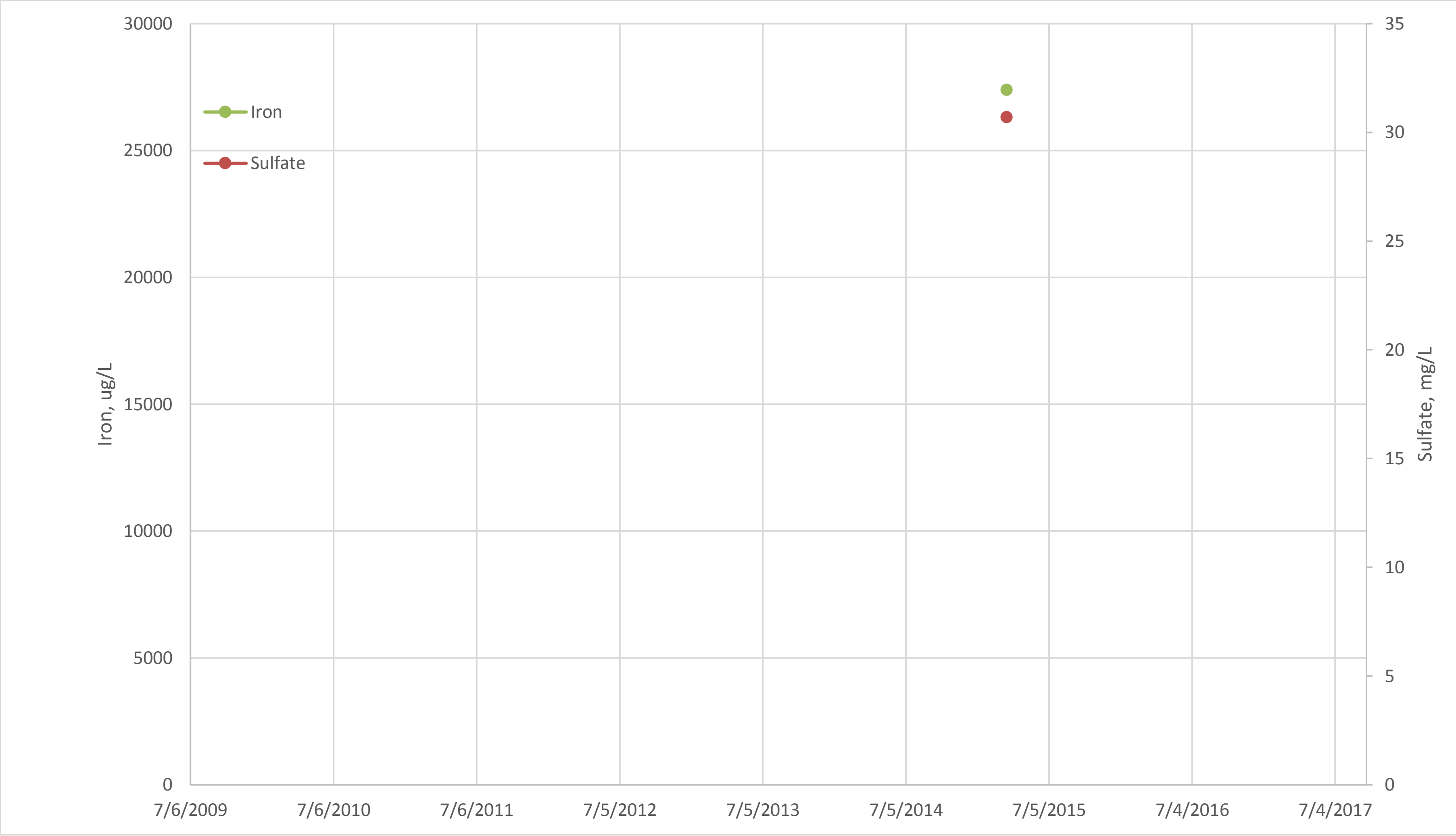

MW-26-40
cis-1,2-DCE
trans-1,2-DCE
Trichloroethene (TCE)
Vinyl Chloride
Total Chlorinated Ethenes
Mass Concentration, ug/L
Total Molar Mass (umol/L)
1400
1200
1000
800
600
400
200
0
14
12
10
8
6
4
2
0
12/3/2011
12/2/2012
12/2/2013
12/2/2014
12/2/2015
12/1/2016
12/1/2017

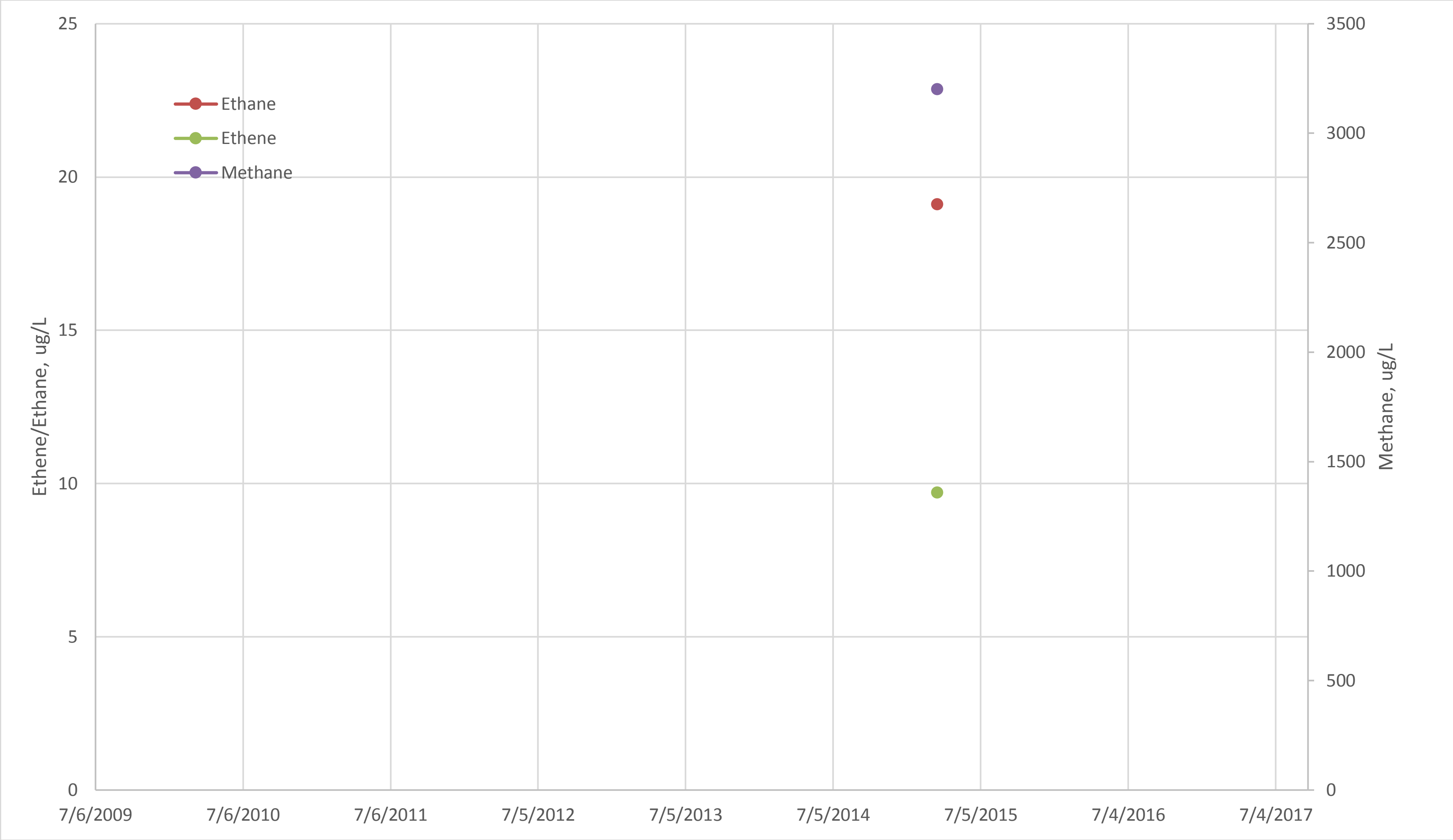

Iron
Sulfate
Iron, ug/L
Sulfate, mg/L
35000
30000
25000
20000
15000
10000
5000
0
50
45
40
35
30
25
20
15
10
5
0
7/6/2009
7/6/2010
7/6/2011
7/5/2012
7/5/2013
7/5/2014
7/5/2015
7/4/2016
7/4/2017


Ethane
Ethene
Methane
Ethene/Ethane, ug/L
Methane, ug/L
0
5
10
15
20
25
30
35
40
0
200
400
600
800
1000
1200
1400
1600
7/6/2009
7/6/2010
7/6/2011
7/5/2012
7/5/2013
7/5/2014
7/5/2015
7/4/2016
7/4/2017


Dissolved Oxygen
ORP
DO, mg/L
ORP, mV
0
1
2
3
4
5
6
7
0
-100
-200
-300
-400
-500
-600
-700
12/3/2011
12/2/2012
12/2/2013
12/2/2014
12/2/2015
12/1/2016

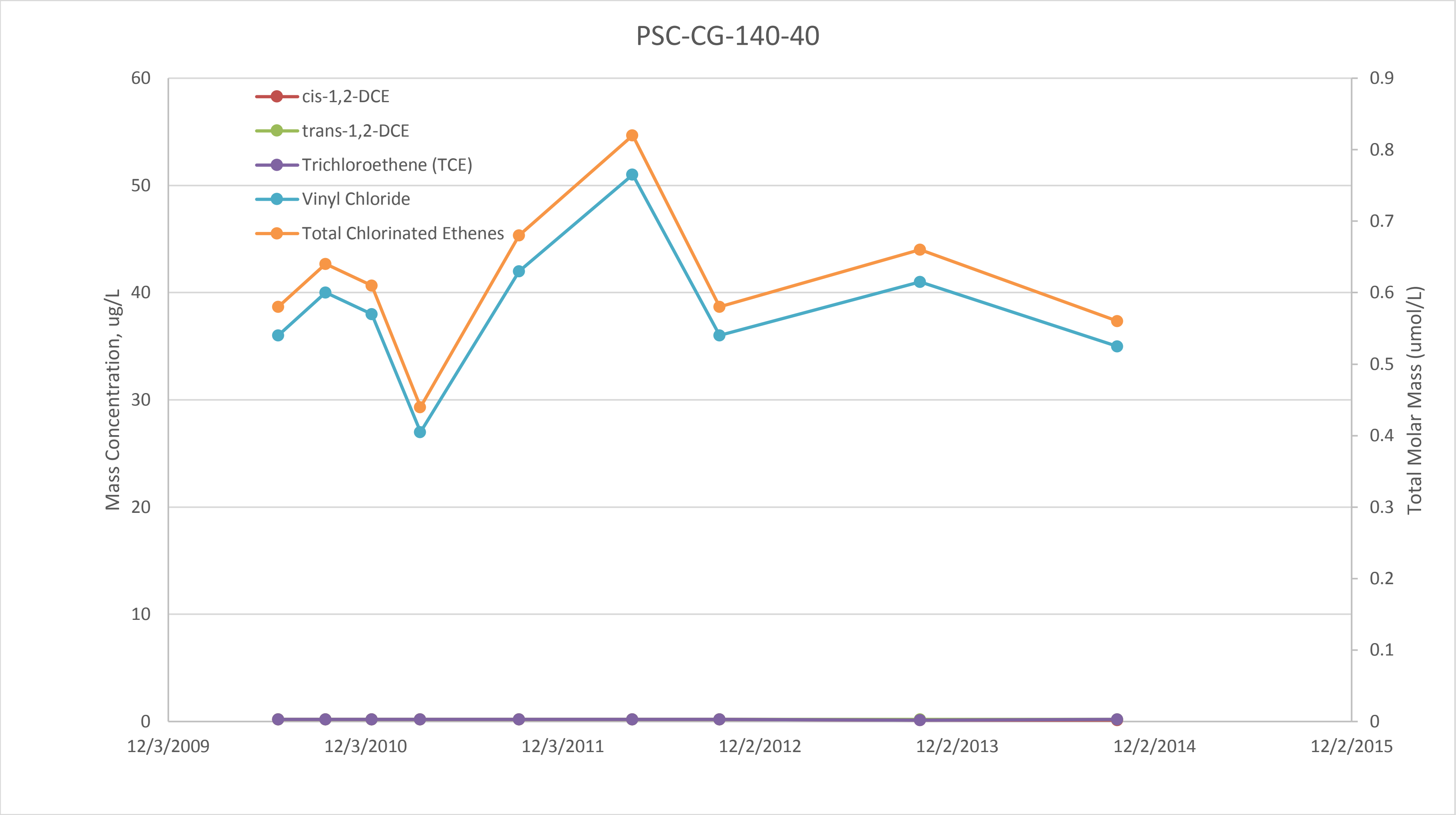

MW-26-55
Mass Concentration, ug/L
Total Molar Mass (umol/L)
2500
2000
1500
1000
500
0
18
16
14
12
10
8
6
4
2
0
12/3/2011
12/2/2012
12/2/2013
12/2/2014
12/2/2015
12/1/2016
cis-1,2-DCE
trans-1,2-DCE
Trichloroethene (TCE)
Vinyl Chloride
Total Chlorinated Ethenes

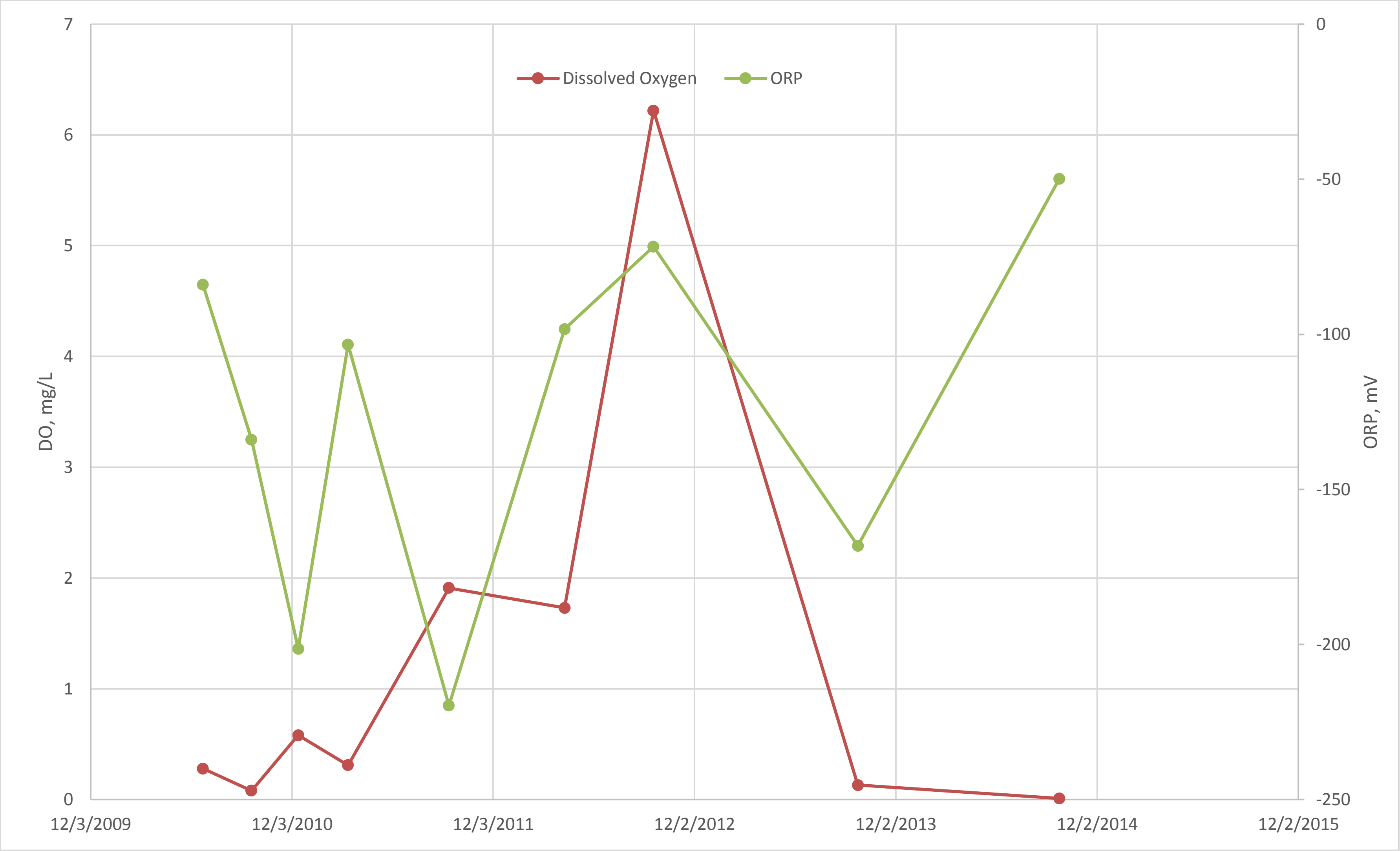

Iron, ug/L
Sulfate, mg/L
30000
25000
20000
15000
10000
5000
0
35
30
25
20
15
10
5
0
7/6/2009
7/6/2010
7/6/2011
7/5/2012
7/5/2013
7/5/2014
7/5/2015
7/4/2016
7/4/2017
Iron
Sulfate



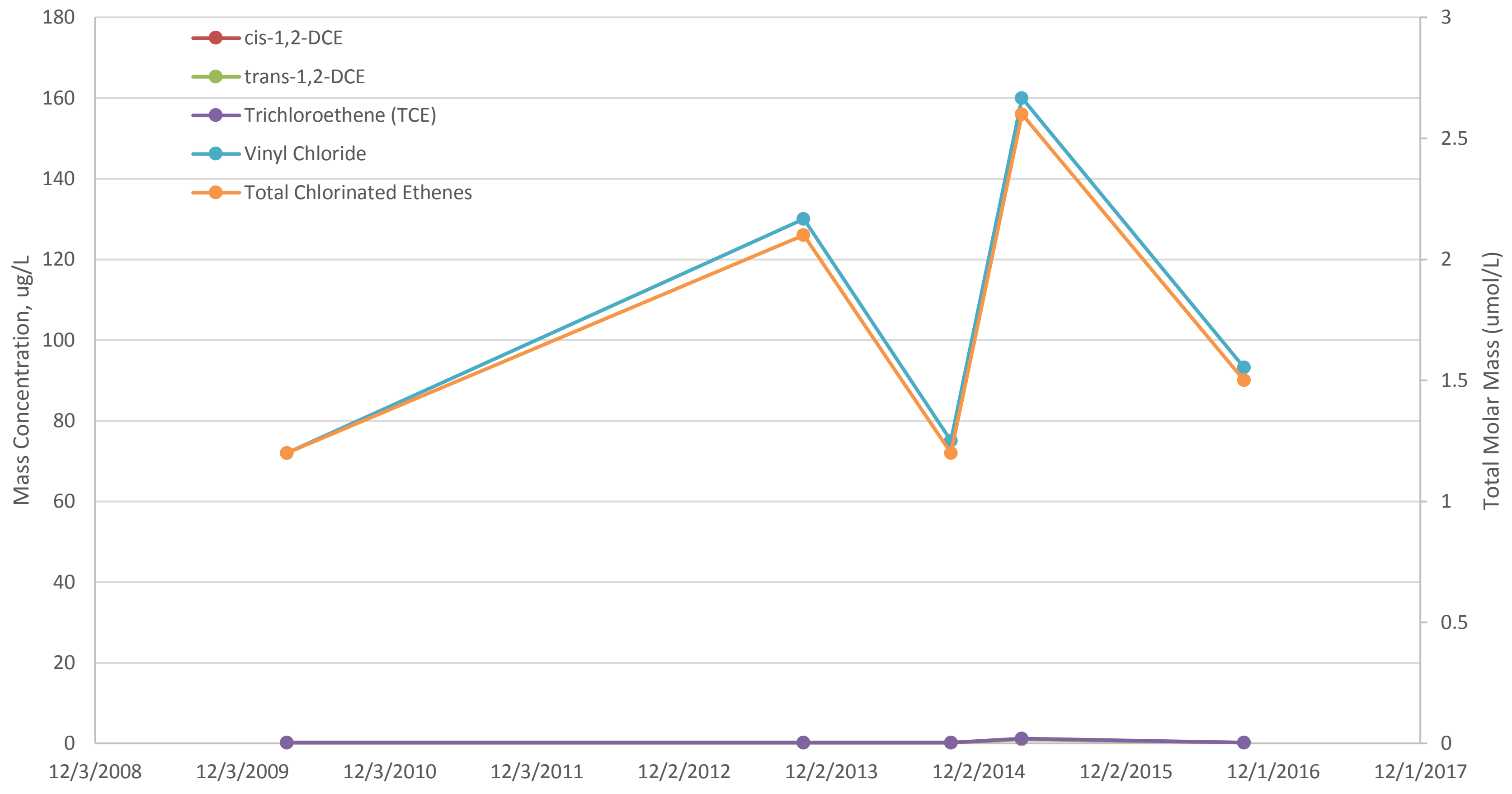
Ethane
Ethene
Methane
Ethene/Ethane, ug/L
Methane, ug/L
0
5
10
15
20
25
0
500
1000
1500
2000
2500
3000
3500
7/6/2009
7/6/2010
7/6/2011
7/5/2012
7/5/2013
7/5/2014
7/5/2015
7/4/2016
7/4/2017

Dissolved Oxygen
ORP
DO, mg/L
ORP, mV
0
1
2
3
4
5
6
0
-100
-200
-300
-400
-500
-600
-700
12/3/2011
12/2/2012
12/2/2013
12/2/2014
12/2/2015
12/1/2016

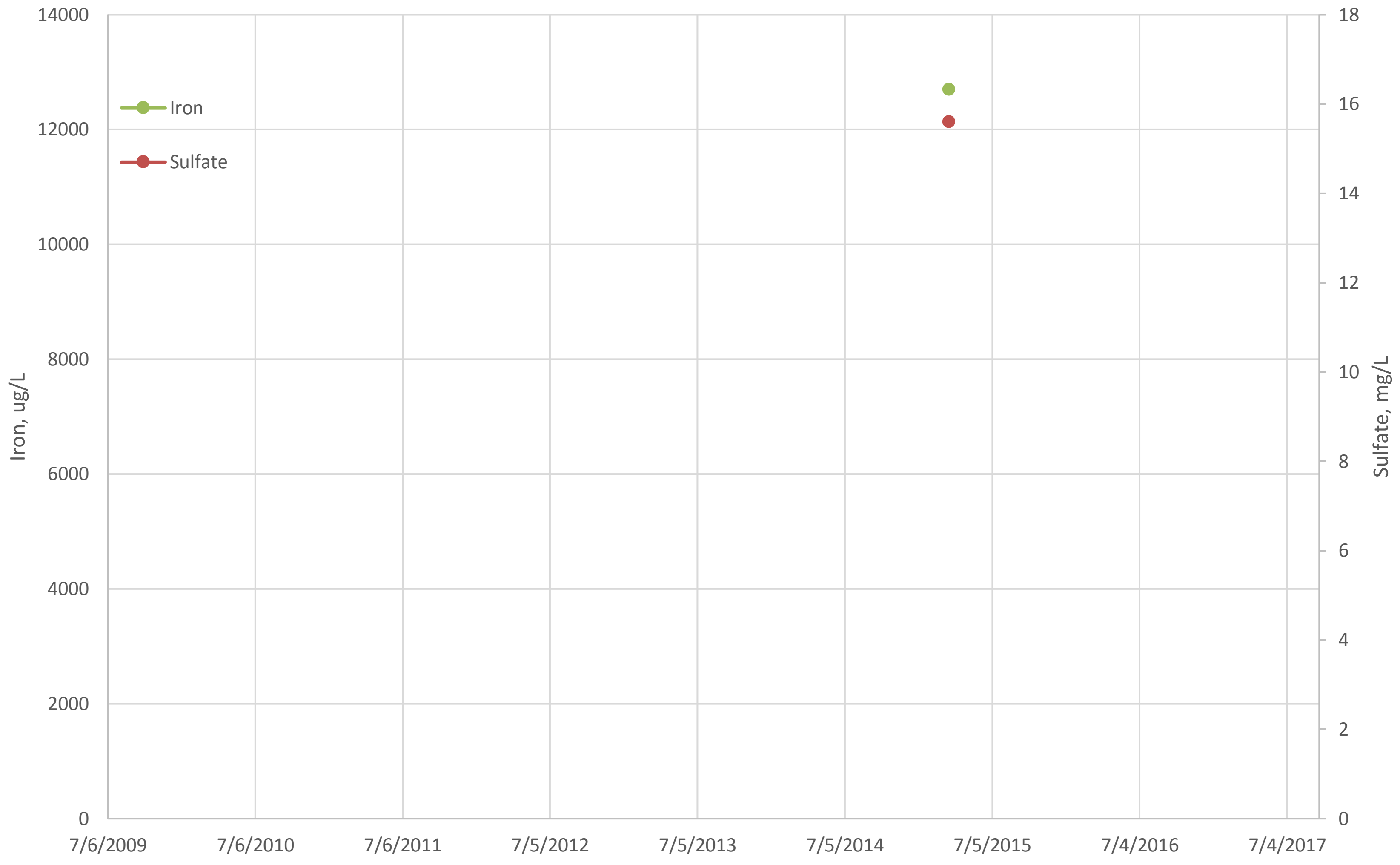

PSC-CG-140-40
cis-1,2-DCE
trans-1,2-DCE
Trichloroethene (TCE)
Vinyl Chloride
Total Chlorinated Ethenes
Mass Concentration, ug/L
Total Molar Mass (umol/L)
60
50
40
30
20
10
0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
12/3/2009
12/3/2010
12/3/2011
12/2/2012
12/2/2013
12/2/2014
12/2/2015


Dissolved Oxygen
ORP
DO, mg/L
ORP, mV
7
6
5
4
3
2
1
0
0
-50
-100
-150
-200
-250
12/3/2009
12/3/2010
12/3/2011
12/2/2012
12/2/2013
12/2/2014
12/2/2015

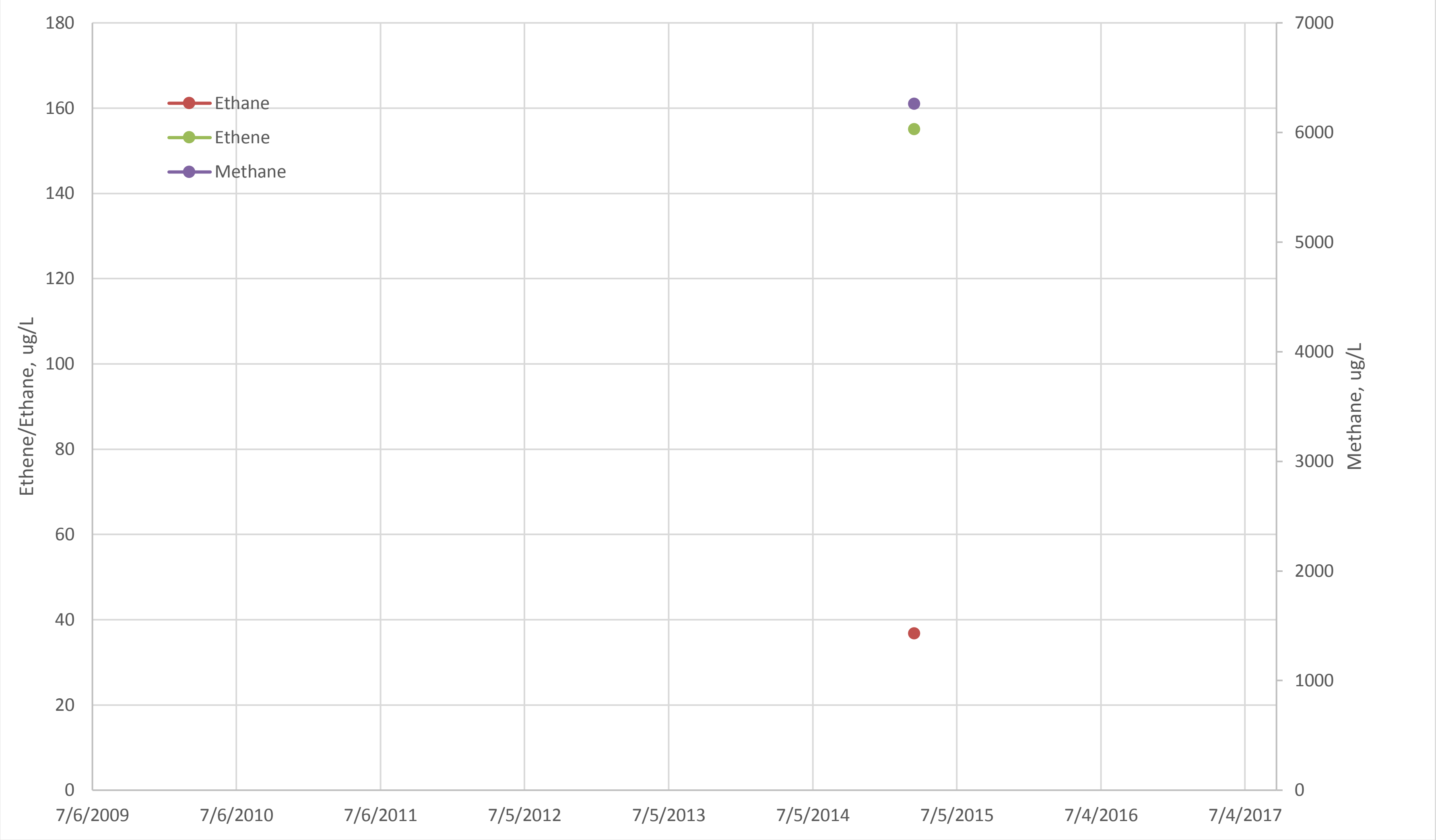
PSC-CG-140-40



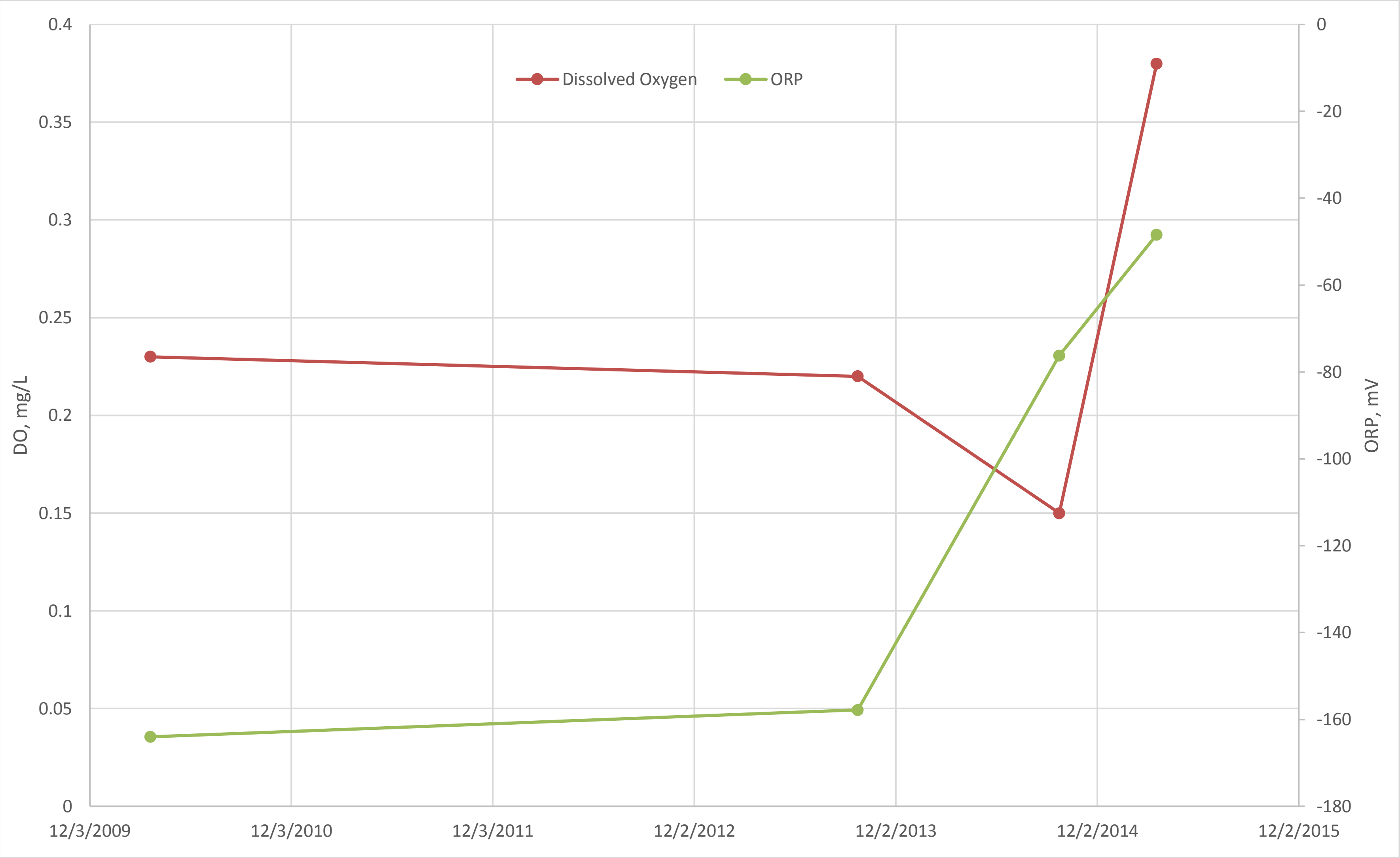
cis-1,2-DCE
trans-1,2-DCE
Trichloroethene (TCE)
Vinyl Chloride
Total Chlorinated Ethenes
Mass Concentration, ug/L
Total Molar Mass (umol/L)
180
160
140
120
100
80
60
40
20
0
3
2.5
2
1.5
1
0.5
0
12/3/2008
12/3/2009
12/3/2010
12/3/2011
12/2/2012
12/2/2013
12/2/2014
12/2/2015
12/1/2016
12/1/2017



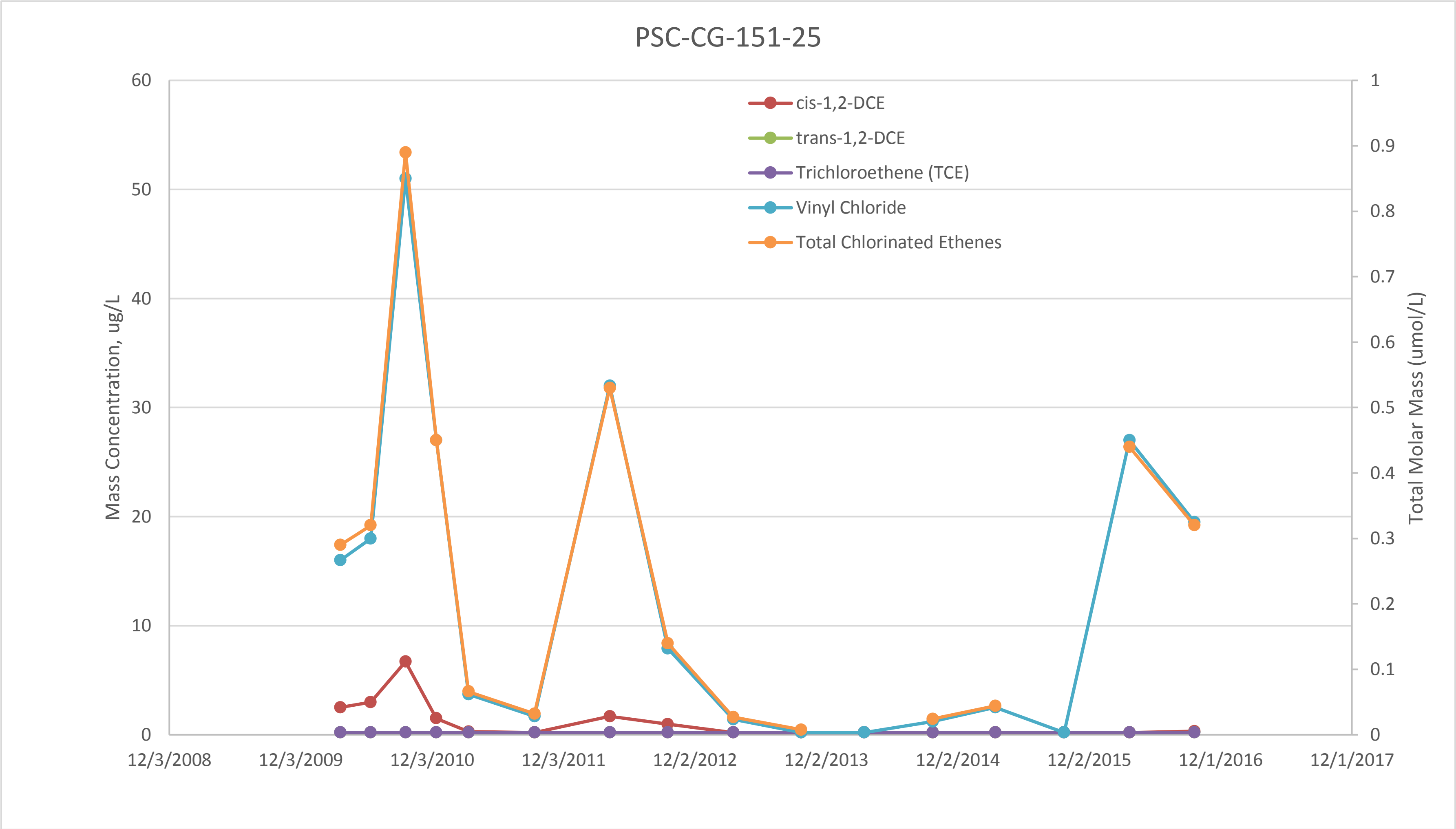
Iron
Sulfate
Iron, ug/L
Sulfate, mg/L
14000
12000
10000
8000
6000
4000
2000
0
18
16
14
12
10
8
6
4
2
0
7/6/2009
7/6/2010
7/6/2011
7/5/2012
7/5/2013
7/5/2014
7/5/2015
7/4/2016
7/4/2017



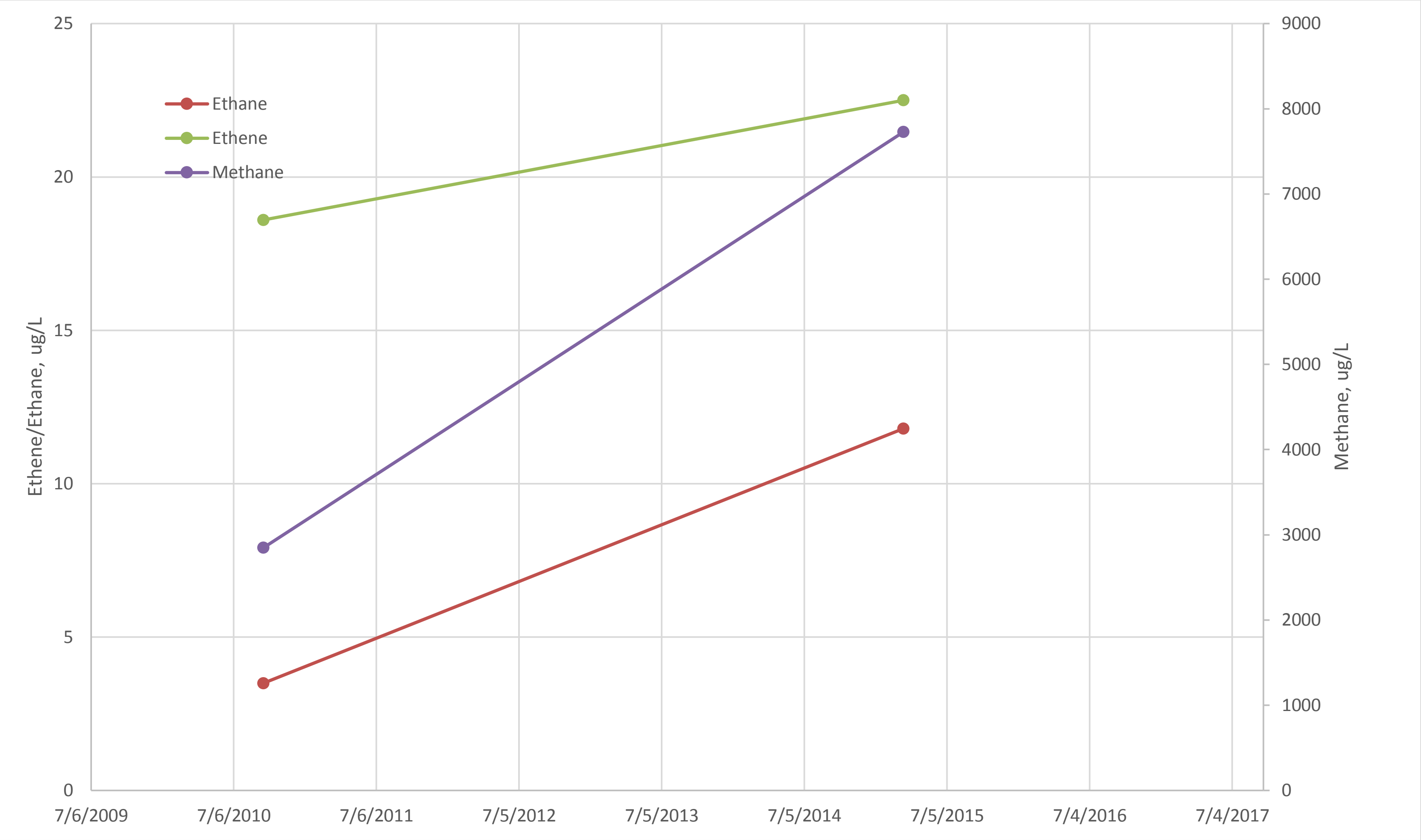
Ethane
Ethene
Methane
Ethene/Ethane, ug/L
Methane, ug/L
0
20
40
60
80
100
120
140
160
180
0
1000
2000
3000
4000
5000
6000
7000
7/6/2009
7/6/2010
7/6/2011
7/5/2012
7/5/2013
7/5/2014
7/5/2015
7/4/2016
7/4/2017



Dissolved Oxygen
ORP
DO, mg/L
ORP, mV
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
-180
-160
-140
-120
-100
-80
-60
-40
-20
0
12/3/2009
12/3/2010
12/3/2011
12/2/2012
12/2/2013
12/2/2014
12/2/2015


PSC-CG-151-25
cis-1,2-DCE
trans-1,2-DCE
Trichloroethene (TCE)
Vinyl Chloride
Total Chlorinated Ethenes
Mass Concentration, ug/L
Total Molar Mass (umol/L)
0
10
20
30
40
50
60
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
12/3/2008
12/3/2009
12/3/2010
12/3/2011
12/2/2012
12/2/2013
12/2/2014
12/2/2015
12/1/2016
12/1/2017

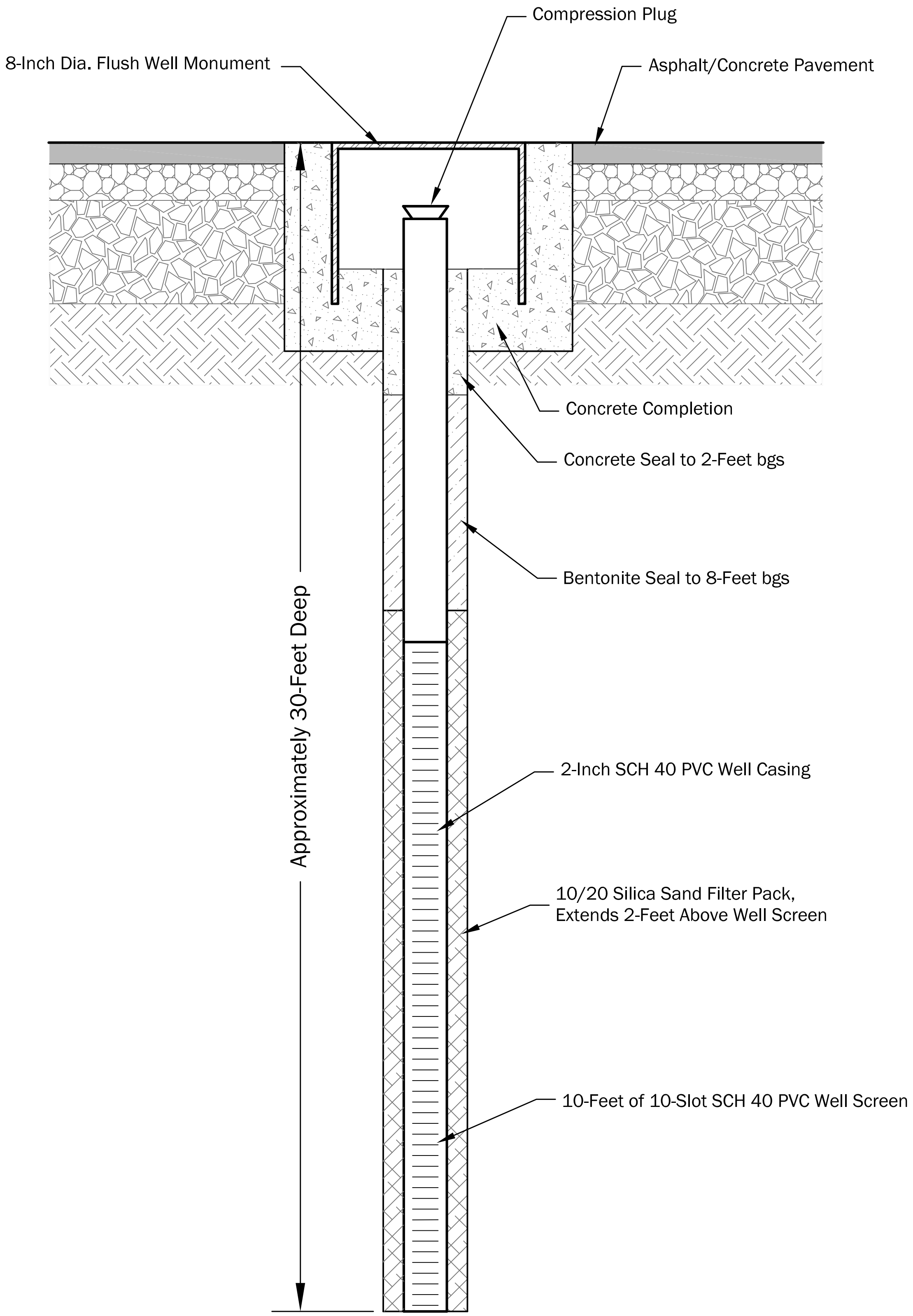

Iron
Sulfate
Iron, ug/L
Sulfate, mg/L
565
570
575
580
585
590
595
600
605
0
5
10
15
20
25
30
35
40
45
7/6/2009
7/6/2010
7/6/2011
7/5/2012
7/5/2013
7/5/2014
7/5/2015
7/4/2016
7/4/2017


25
20
15
10
5
0
Ethene/Ethane, ug/L
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Methane, ug/L
Ethane
Ethene
Methane
7/6/2009
7/6/2010
7/6/2011
7/5/2012
7/5/2013
7/5/2014
7/5/2015
7/4/2016
7/4/2017


6
5
4
3
2
1
0
DO, mg/L
0
-50
-100
-150
-200
-250
-300
-350
ORP, mV
Dissolved Oxygen
ORP
12/3/2009
12/3/2010
12/3/2011
12/2/2012
12/2/2013
12/2/2014
12/2/2015
12/1/2016

APPENDIX B

Well Construction Diagram



NOTE: NOT TO SCALE

Proposed Monitoring Well Construction Details

CVOC Pilot Study Work Plan
Art Brass Plating
Seattle, Washington

Aspect CONSULTING	Mar-2017	BY: ELG/SCC	*Appendix*
	PROJECT NO. 050067	REVISED BY: DIM/SCC	**B**

CAD Path: Q:\Art Brass Plating\050067 Art Brass\2017-03 Appendix B\050067-B WELL SCHEMATIC.dwg 8.5x11 Landscape || Date Saved: Mar 24, 2017 2:28pm || User: rpepin

APPENDIX C

Historical Groundwater Analytical Results

Appendix C - Historical Groundwater Analytical Results

Art Brass Plating 050067

Chemical Name	MW-21-50 3/25/10	MW-21-50 6/16/10	MW-21-50 9/22/10	MW-21-50 12/15/10	MW-21-50 3/15/11	MW-21-50 9/13/11	MW-21-50 4/6/12	MW-21-50 9/18/12	MW-21-50 3/19/13	MW-21-50 9/24/13	MW-21-50 3/18/14	MW-21-50 9/24/14	MW-21-50 3/18/15	MW-21-50 9/23/15	MW-21-50 3/23/16	MW-21-50 9/20/16	MW-21-75 3/25/10	MW-21-75 6/16/10	MW-21-75 9/22/10
COCs and Degradation Products																			
1,1,1-Trichloroethane in ug/L	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	1.0 U	0.2 U	0.2 U	0.20 U	0.2 U	0.20 U	0.20 U	0.2 U	0.20 U	0.2 U	0.2 UJ	0.2 U
1,1-Dichloroethane in ug/L	1.4	1.8 J	2.0	2.1	2.2	3.4	4.4	5.7	5.8	6.3	6.4	6.8	7.5	7.6	7.8	9.49	0.2 U	0.2 UJ	0.2 U
1,1-Dichloroethene in ug/L	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	1.0 U	0.2 U	0.2 U	0.20 U	0.2 U	0.20 U	0.20 U	0.2 U	0.20 U	0.2 U	0.2 UJ	0.2 U
1,2-Dichloroethane (EDC) in ug/L	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	1.0 U	0.2 U	0.2 U	0.20 U	0.2 U	0.20 U	0.20 U	0.2 U	0.20 U	0.2 U	0.2 UJ	0.2 U
Chloroethane in ug/L	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	1.0 U	0.2 U	0.2 U	0.20 U	0.2 U	0.20 U	0.20 U	0.2 U	0.20 U	0.2 U	0.2 UJ	0.2 U
cis-1,2-Dichloroethene (DCE) in ug/L	0.9	1.4 J	1.7	2.1	2.3	5.2	7.0	11	9.9	11	12	13	14	15	17	17.4	0.2 U	0.2 UJ	0.2 U
Tetrachloroethene (PCE) in ug/L	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	1.0 U	0.2 U	0.2 U	0.20 U	0.2 U	0.20 U	0.20 U	0.2 U	0.20 U	0.2 U	0.2 UJ	0.2 U
trans-1,2-Dichloroethene in ug/L	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	1.0 U	0.2 U	0.2 U	0.20 U	0.2 U	0.20 U	0.20 U	0.2 U	0.20 U	0.2 U	0.2 UJ	0.2 U
Trichloroethene (TCE) in ug/L	4.4	1.6 J	0.7	0.2 U	0.3	0.4	4.2	13	11	9.0	10	9.3	14	16	20	18.9	2.8	0.6 J	0.2
Vinyl chloride in ug/L	25	30 J	26	28	27	32	32	34	28	31	26	29	30	30	28	34.8	0.4	0.2 UJ	0.2
Total Chlorinated Ethenes in umol/L	0.45	0.51	0.44	0.47	0.46	0.57	0.62	0.77	0.64	0.68	0.62	0.67	0.74	0.76	0.78	0.88	0.031	0.0099	0.0085
Ethane in ug/L																			
Ethene in ug/L																			
Methane in ug/L																			
MNA Evaluation Parameters/ General Chemistry																			
Alkalinity (Total) in mg/L as CaCO3																			
Bicarbonate in mg/L as CaCO3																			
Carbonate in mg/L as CaCO3																			
Chloride in mg/L																			
Dissolved Calcium in ug/L																			
Dissolved Potassium in ug/L																			
Dissolved Sodium in ug/L																			
Hydroxide in mg/L as CaCO3																			
Nitrate as Nitrogen in mg-N/L																			
Nitrite as Nitrogen in mg-N/L																			
ortho-Phosphorus in mg/L																			
Sulfate in mg/L																			
Sulfide in mg/L																			
Total Organic Carbon in mg/L																			
Metals																			
Dissolved Aluminum in ug/L																			
Dissolved Cadmium in ug/L																			
Dissolved Calcium in ug/L																			
Dissolved Copper in ug/L																			
Dissolved Iron in ug/L																			
Dissolved Iron, Ferrous, Fe+2 in ug/L																			
Dissolved Magnesium in ug/L																			
Dissolved Manganese in ug/L																			
Dissolved Nickel in ug/L																			
Dissolved Potassium in ug/L																			
Dissolved Silicon in ug/L																			
Dissolved Sodium in ug/L																			
Dissolved Zinc in ug/L																			
Iron, Ferrous, Fe+2 in ug/L																			
Total Iron in ug/L			6,170																810
Total Manganese in ug/L			563																364
Field Parameters																			
Dissolved Oxygen in mg/L	0.09	0.08	0.22	0.10	0.18	1.49	1.34	6.32	2.31	0.08	0.43	0.00	0.28	0.20	0.05	0.19	0.14	0.04	0.12
ORP in mVolts	-41.6	-84.9	-415.5	-113.8	-35.9	-144.3	-107.2	-112.7	-96.7	-219.1	-75.1	-49.5	-10.2	-26.8	-55.7	-43.7	-58.7	-111.7	-417.8
pH in pH Units	6.81	6.82	6.04	8.93 R	6.87 R	6.76	6.70	7.34	6.70	6.55	6.76	6.79	6.48	6.49	6.64	6.73	7.24	7.47	6.70
Specific Conductance in us/cm	372	343	403	414	439	439.9	520.3	446.3	506.4	485.4	546.4	459.5	480.5	494.3	496.4	498.7	421	351	412
Temperature in deg C	13.73	13.9	14.0	13.57	13.38	14.4	13.6	14.4	13.3	14.4	13.4	14.5	13.9	14.8	14	16.6	13.4	14.02	14.19
Turbidity in NTU						2.03	2.0	2.35	1.84	2.43	1.12	1.01	2.93	2.65	4.61	15.0			

Notes

J - Analyte was positively identified. The reported result is an estimate.
R - Rejected.
U - Analyte was not detected at or above the reported result.
UJ - Analyte was not detected at or above the reported estimate

Appendix C - Historical Groundwater Analytical Results

Art Brass Plating 050067

Chemical Name	MW-21-75 12/15/10	MW-21-75 3/15/11	MW-21-75 9/13/11	MW-21-75 4/6/12	MW-21-75 9/18/12	MW-21-75 3/18/15	MW-22-30 3/25/10	MW-22-30 6/15/10	MW-22-30 6/15/10 FD	MW-22-30 9/20/10	MW-22-30 12/14/10	MW-22-30 12/14/10 FD	MW-22-30 3/15/11	MW-22-30 3/15/11 FD	MW-22-30 6/9/11	MW-22-30 9/12/11	MW-22-30 12/12/11	MW-22-30 12/12/11 FD	MW-22-30 4/9/12
COCs and Degradation Products																			
1,1,1-Trichloroethane in ug/L	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.20 U	0.2 U	2.0 UJ	2.0 UJ	2.0 U	2.0 U	2.0 U	2.0 U	2.0 U	0.2 U	3.0 U	2.0 U	2.0 U	2.0 U
1,1-Dichloroethane in ug/L	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.20 U	4.8	8.9 J	8.0 J	7.3	3.2	3.2	5.5	5.4	5.7	5.5	4.1	4.2	7.4
1,1-Dichloroethene in ug/L	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.20 U	2.8	2.4 J	2.6 J	2.4	3.5	3.2	2.2	2.2	1.9	3.0 U	2.4	2.7	2.9
1,2-Dichloroethane (EDC) in ug/L	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.20 U	0.2 U	2.0 UJ	2.0 UJ	2.0 U	2.0 U	2.0 U	2.0 U	2.0 U	0.2 U	3.0 U	2.0 U	2.0 U	2.0 U
Chloroethane in ug/L	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.20 U	0.2 U	2.0 UJ	2.0 UJ	2.0 U	2.0 U	2.0 U	2.0 U	2.0 U	0.2 U	3.0 U	2.0 U	2.0 U	2.0 U
cis-1,2-Dichloroethene (DCE) in ug/L	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.20 U	42	74 J	67 J	180	180	180	250 J	260	210	320	230	220	660
Tetrachloroethene (PCE) in ug/L	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.20 U	0.2 U	2.0 UJ	2.0 UJ	2.0 U	2.0 U	2.0 U	2.0 U	2.0 U	0.2 U	3.0 U	2.0 U	2.0 U	2.0 U
trans-1,2-Dichloroethene in ug/L	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.20 U	1.6	2.9 J	2.8 J	3.0	2.0 U	2.8	18	20	1.6	3.0 U	2.0 U	2.1	4.1
Trichloroethene (TCE) in ug/L	0.2 U	0.2 U	0.2 U	0.2 U	0.28	0.20 U	320	630	590 J	530	100	96	140	150	200	94	71	71	160
Vinyl chloride in ug/L	0.2 U	0.2 U	0.6	0.3	1.8	1.2	19	17 J	16 J	15	16	16	11	10	8.3	9.6	14	13	20
Total Chlorinated Ethenes in umol/L	ND	ND	0.014	0.0093	0.035	0.024	3.2	5.9	5.5	6.2	2.9	2.9	4.1	4.3	3.9	4.2	3.2	3.1	8.5
Ethane in ug/L										6.7									
Ethene in ug/L										2.9									
Methane in ug/L										3,430									
MNA Evaluation Parameters/ General Chemistry																			
Alkalinity (Total) in mg/L as CaCO3										290									
Bicarbonate in mg/L as CaCO3										290									
Carbonate in mg/L as CaCO3										1.0 U									
Chloride in mg/L										236									
Dissolved Calcium in ug/L																			
Dissolved Potassium in ug/L																			
Dissolved Sodium in ug/L																			
Hydroxide in mg/L as CaCO3										1.0 U									
Nitrate as Nitrogen in mg-N/L										0.1 U									
Nitrite as Nitrogen in mg-N/L										0.1 U									
ortho-Phosphorus in mg/L																			
Sulfate in mg/L										55.0									
Sulfide in mg/L																			
Total Organic Carbon in mg/L																			
Metals																			
Dissolved Aluminum in ug/L																			
Dissolved Cadmium in ug/L																			
Dissolved Calcium in ug/L																			
Dissolved Copper in ug/L																			
Dissolved Iron in ug/L																			
Dissolved Iron, Ferrous, Fe+2 in ug/L																			
Dissolved Magnesium in ug/L																			
Dissolved Manganese in ug/L																			
Dissolved Nickel in ug/L																			
Dissolved Potassium in ug/L																			
Dissolved Silicon in ug/L																			
Dissolved Sodium in ug/L																			
Dissolved Zinc in ug/L																			
Iron, Ferrous, Fe+2 in ug/L										2,320									
Total Iron in ug/L										28,500									
Total Manganese in ug/L										265									
Field Parameters																			
Dissolved Oxygen in mg/L	0.10	0.21	1.38	1.34	6.24	0.35	0.09	0.03		0.23	0.43		0.30			3.62	1.10		1.68
ORP in mVolts	-133	-51.7	-268.7	-148.6	-159	-038.0	-46.3	-132.2		-396.7	-39.8		-13.2			-75.3	-130.6		-122.6
pH in pH Units	9.41 R	7.10 R	7.41	7.34	7.76	7.13	6.72	7.06		5.89	6.37 R		6.92 R			6.80	6.62		6.66
Specific Conductance in us/cm	412	428	430.6	484.9	419.3	434.6	2,233	1,152		1,484	2,725		2,182			1,610	2,219		1,129
Temperature in deg C	13.26	13.13	14.6	13.4	14.7	14.1	15.33	16.08		17.05	13.14		14.74			16.0	15.1		15.4
Turbidity in NTU			5.98	13	9.17	7.26										5.35	34.7		8.76

Notes

J - Analyte was positively identified. The reported result is an estimate.
R - Rejected.
U - Analyte was not detected at or above the reported result.
UJ - Analyte was not detected at or above the reported estimate

Appendix C - Historical Groundwater Analytical Results

Art Brass Plating 050067

DRAFT

Chemical Name	MW-22-30 6/11/12	MW-22-30 6/11/12 FD	MW-22-30 9/17/12	MW-22-30 12/10/12	MW-22-30 3/18/13	MW-22-30 3/18/13 FD	MW-22-30 9/27/13	MW-22-30 9/27/13 FD	MW-22-30 3/17/14	MW-22-30 3/17/14 FD	MW-22-30 9/23/14	MW-22-30 9/23/14 FD	MW-22-30 3/16/15	MW-22-30 3/16/15 FD	MW-22-30 9/23/15	MW-22-30 9/23/15 FD	MW-22-30 3/23/16	MW-22-30 9/20/16	MW-22-30 9/20/16 FD
COCs and Degradation Products																			
1,1,1-Trichloroethane in ug/L	4.0 U	4.0 U	20 U	2.0 U	2.0 U	2.0 U	1.0 U	1.0 U	4.0 U	10 U	0.2 U	2 U	2.0 U	2.0 U	2.0 U	2.0 U	2 U	0.20 U	0.20 U
1,1-Dichloroethane in ug/L	5.2	5.6	5.8 J	3.9	4.0	3.8	5.0	4.6	4.0 U	10 U	3.6	3	3.6	3.6	5.5	5.4	5	4.57	4.77
1,1-Dichloroethene in ug/L	3.0 J	3.0 J	20 U	2.0 U	1.1 UJ	1.9 UJ	2.2	2.2	4.0 U	10 U	0.87	2 U	2.0 U	2.0 U	2.9	3.2	2 U	1.36	1.36
1,2-Dichloroethane (EDC) in ug/L	4.0 U	4.0 U	20 U	2.0 U	2.0 U	2.0 U	1.0 U	1.0 U	4.0 U	10 U	0.2 U	2 U	2.0 U	2.0 U	2.0 U	2.0 U	2 U	0.20 U	0.20 U
Chloroethane in ug/L	4.0 U	4.0 U	20 U	2.0 U	2.0 U	2.0 U	1.0 U	1.0 U	4.0 U	10 U	0.2 U	2 U	2.0 U	2.0 U	2.0 U	2.0 U	2 U	0.20 U	0.20 U
cis-1,2-Dichloroethene (DCE) in ug/L	520	550	640	280	220	210	640	620	790	680	400	370	360	350	1,100	1,200	510	554	576
Tetrachloroethene (PCE) in ug/L	4.0 U	4.0 U	20 U	2.0 U	2.0 U	2.0 U	1.0 U	1.0 U	4.0 U	10 U	0.2 U	2 U	2.0 U	2.0 U	2.0 U	2.0 U	2 U	0.20 U	0.20 U
trans-1,2-Dichloroethene in ug/L	3.0 J	3.4 J	3.0 J	2.0 U	2.0 U	1.2 UJ	5.2	4.4	7.2	10 U	2.2	2 U	3.1	2.8	7.8	8.1	4.2	3.50	3.50
Trichloroethene (TCE) in ug/L	110	120	78	26	28	29	15	15	21	22	5.4	6.1	5.6	5.1	14	15	14	12.2	12.1
Vinyl chloride in ug/L	19	19	16 J	15	12	12	30	23	31	27	44 J	35	100	91	57	57	66	58.4	59.6
Total Chlorinated Ethenes in umol/L	6.6	7.0	7.7	3.4	2.7	2.6	7.3	7.0	9.0	7.8	4.9	4.5	5.4	5.2	13	14	6.5	6.9	7.1
Ethane in ug/L													9.3	9.9					
Ethene in ug/L													6.3	6.9					
Methane in ug/L													4,090	4,450					
MNA Evaluation Parameters/ General Chemistry																			
Alkalinity (Total) in mg/L as CaCO3											308		323	321					
Bicarbonate in mg/L as CaCO3											308		323	321					
Carbonate in mg/L as CaCO3											1 U		1.0 U	1.0 U					
Chloride in mg/L											446								
Dissolved Calcium in ug/L											63,200								
Dissolved Potassium in ug/L											16,100								
Dissolved Sodium in ug/L											291,000								
Hydroxide in mg/L as CaCO3											1 U		1.0 U	1.0 U					
Nitrate as Nitrogen in mg-N/L											0.1 U		0.1 U	0.1 U					
Nitrite as Nitrogen in mg-N/L													0.5 U	1.0 U					
ortho-Phosphorus in mg/L											0.4								
Sulfate in mg/L											98.5		68.1	63.1					
Sulfide in mg/L											0.412								
Total Organic Carbon in mg/L											12.8								
Metals																			
Dissolved Aluminum in ug/L											50 U								
Dissolved Cadmium in ug/L											0.1 U								
Dissolved Calcium in ug/L											63,200								
Dissolved Copper in ug/L											0.5								
Dissolved Iron in ug/L											2,850								
Dissolved Iron, Ferrous, Fe+2 in ug/L													4,110	4,180					
Dissolved Magnesium in ug/L											43,500								
Dissolved Manganese in ug/L											256								
Dissolved Nickel in ug/L											1.8								
Dissolved Potassium in ug/L											16,100								
Dissolved Silicon in ug/L											28,200								
Dissolved Sodium in ug/L											291,000								
Dissolved Zinc in ug/L											4 U								
Iron, Ferrous, Fe+2 in ug/L																			
Total Iron in ug/L													4,030	3,860					
Total Manganese in ug/L													335	336					
Field Parameters																			
Dissolved Oxygen in mg/L	0.30		4.14	0.17	2.48		0.46		0.58		0.10		0.22		0.39		0.05	0.07	
ORP in mVolts	-651.7		-71	-44.7	-114.4		-116.2		-230.5		-49.6		-16.4		50.1		-48.7	36.4	
pH in pH Units	6.63		6.89	6.56	6.58		6.57		6.66		6.69		6.75		6.46		6.73	6.72	
Specific Conductance in us/cm	1,935		1,313	1,820	2,803		1,512		1,180		2,263		1,575		674		1,986	1,896	
Temperature in deg C	15.5		16.4	15.2	13.2		15.5		14.9		17.0		14.8		16.9		14	16.9	
Turbidity in NTU	6.5		14.2	3.64	8.11		5.97		10.3		6.44		2.39		9.02		37.1	9.66	

Notes

J - Analyte was positively identified. The reported result is an estimate.

R - Rejected.

U - Analyte was not detected at or above the reported result.

UJ - Analyte was not detected at or above the reported estimate

Appendix C - Historical Groundwater Analytical Results

Art Brass Plating 050067

Chemical Name	MW-22-50 3/25/10	MW-22-50 6/15/10	MW-22-50 9/20/10	MW-22-50 12/14/10	MW-22-50 3/15/11	MW-22-50 9/12/11	MW-22-50 4/9/12	MW-22-50 9/17/12	MW-22-50 3/18/13	MW-22-50 9/23/13	MW-22-50 3/17/14	MW-22-50 9/23/14	MW-22-50 3/16/15	MW-23-30 3/25/10	MW-23-30 6/15/10	MW-23-30 9/20/10	MW-23-30 12/14/10	MW-23-30 3/15/11	MW-23-30 9/12/11
COCs and Degradation Products																			
1,1,1-Trichloroethane in ug/L	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	1.0 U	1.0 U	1.0 U	1 U	0.20 U	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U
1,1-Dichloroethane in ug/L	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	1.0 U	1.0 U	1.0 U	1 U	0.20 U	0.4	0.6 J	0.6	0.7	0.7	1.6
1,1-Dichloroethene in ug/L	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	1.0 U	1.0 U	1.0 U	1 U	0.20 U	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U
1,2-Dichloroethane (EDC) in ug/L	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	1.0 U	1.0 U	1.0 U	1 U	0.20 U	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U
Chloroethane in ug/L	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	1.0 U	1.0 U	1.0 U	1 U	0.20 U	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U
cis-1,2-Dichloroethene (DCE) in ug/L	0.5	0.2 J	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.22	1.0 U	1.0 U	1.0 U	1 U	0.20 U	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U
Tetrachloroethene (PCE) in ug/L	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	1.0 U	1.0 U	1.0 U	1 U	0.20 U	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U
trans-1,2-Dichloroethene in ug/L	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	1.0 U	1.0 U	1.0 U	1 U	0.20 U	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U
Trichloroethene (TCE) in ug/L	1.2	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	1.0 U	1.0 U	1.0 U	1 U	0.20 U	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U
Vinyl chloride in ug/L	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	1.0 U	1.0 U	1.0 U	1 U	0.20 U	7.5	12 J	15	14	11	29
Total Chlorinated Ethenes in umol/L	0.019	0.0071	ND	ND	ND	ND	ND	0.0073	ND	ND	ND	ND	ND	0.12	0.2	0.24	0.23	0.18	0.47
Ethane in ug/L													1.2 U						
Ethene in ug/L													1.1 U						
Methane in ug/L													28,200						
MNA Evaluation Parameters/ General Chemistry																			
Alkalinity (Total) in mg/L as CaCO3													669						
Bicarbonate in mg/L as CaCO3													669						
Carbonate in mg/L as CaCO3													1.0 U						
Chloride in mg/L																			
Dissolved Calcium in ug/L																			
Dissolved Potassium in ug/L																			
Dissolved Sodium in ug/L																			
Hydroxide in mg/L as CaCO3													1.0 U						
Nitrate as Nitrogen in mg-N/L													0.1 U						
Nitrite as Nitrogen in mg-N/L													1.0 U						
ortho-Phosphorus in mg/L																			
Sulfate in mg/L													1.2						
Sulfide in mg/L																			
Total Organic Carbon in mg/L																			
Metals																			
Dissolved Aluminum in ug/L																			
Dissolved Cadmium in ug/L																			
Dissolved Calcium in ug/L																			
Dissolved Copper in ug/L																			
Dissolved Iron in ug/L																			
Dissolved Iron, Ferrous, Fe+2 in ug/L													4,940						
Dissolved Magnesium in ug/L																			
Dissolved Manganese in ug/L																			
Dissolved Nickel in ug/L																			
Dissolved Potassium in ug/L																			
Dissolved Silicon in ug/L																			
Dissolved Sodium in ug/L																			
Dissolved Zinc in ug/L																			
Iron, Ferrous, Fe+2 in ug/L																			
Total Iron in ug/L			14,300										5,200			5,880			
Total Manganese in ug/L			516										522			459			
Field Parameters																			
Dissolved Oxygen in mg/L	0.17	0.02	0.22	0.30	0.25	3.41	2.02	4.49	2.39	0.06	0.58	0.06	0.39	0.24	0.02	0.4	0.28	0.19	1.00
ORP in mVolts	-109.4	-156.2	-570.5	-92.3	-94.3	-156.7	-160.5	-158.4	-150.9	-61.6	-237	-120.1	-131.4	-28.6	-126	-375.9	-89.7	-26.5	-73.8
pH in pH Units	7.23	7.53	6.37	6.68 R	7.39 R	7.38	7.12	7.25	7.00	6.92	7.16	7.23	7.31	6.70	6.83	5.77	6.25 R	6.66 R	6.62
Specific Conductance in us/cm	2,615	2,432	2,876	2,812	3,019	2,440	3,307	2,873	3,300	2,944	3,209	3,271	3,185	399	372	460	423	452	435.4
Temperature in deg C	14.55	16.62	16.48	14.1	14.28	15.9	15.4	16.4	14.5	15.9	13.9	16.3	14.5	15.66	17.17	17.39	15.88	16.14	16.9
Turbidity in NTU						32.5	35.2	43.3	11.2	14.2	21.1	4.11	13.6						0.98

Notes

J - Analyte was positively identified. The reported result is an estimate.

R - Rejected.

U - Analyte was not detected at or above the reported result.

UJ - Analyte was not detected at or above the reported estimate

Appendix C - Historical Groundwater Analytical Results

Art Brass Plating 050067

Chemical Name	MW-23-30 4/9/12	MW-23-30 9/17/12	MW-23-30 3/18/13	MW-23-30 9/23/13	MW-23-30 3/17/14	MW-23-30 9/24/14	MW-23-30 3/16/15	MW-23-30 9/23/15	MW-23-30 3/23/16	MW-23-30 9/20/16	MW-23-50 3/25/10	MW-23-50 6/15/10	MW-23-50 9/20/10	MW-23-50 12/14/10	MW-23-50 3/17/11	MW-23-50 9/12/11	MW-23-50 4/9/12	MW-23-50 9/17/12	MW-23-50 3/18/13
COCs and Degradation Products																			
1,1,1-Trichloroethane in ug/L	0.2 U	0.2 U	0.2 U	0.2 U	0.20 U	0.2 U	0.20 U	0.20 U	0.2 U	0.20 U	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U
1,1-Dichloroethane in ug/L	2.1	2.3	1.8	1.6	1.6	1.6	1.5	1.4	1.4	1.79	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U
1,1-Dichloroethene in ug/L	0.2 U	0.2 U	0.2 U	0.2 U	0.20 U	0.2 U	0.20 U	0.20 U	0.2 U	0.20 U	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U
1,2-Dichloroethane (EDC) in ug/L	0.2 U	0.2 U	0.2 U	0.2 U	0.20 U	0.2 U	0.20 U	0.20 U	0.2 U	0.20 U	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U
Chloroethane in ug/L	0.2 U	0.2 U	0.2 U	0.22	0.20 U	0.2 U	0.20 U	0.20 U	0.2 U	0.20 U	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U
cis-1,2-Dichloroethene (DCE) in ug/L	0.2 U	0.2 U	0.2 U	0.14 J	0.20 U	0.2 U	0.20 U	0.20 U	0.2 U	0.20 U	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U
Tetrachloroethene (PCE) in ug/L	0.2 U	0.2 U	0.2 U	0.2 U	0.20 U	0.2 U	0.20 U	0.20 U	0.2 U	0.20 U	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U
trans-1,2-Dichloroethene in ug/L	0.2 U	0.2 U	0.2 U	0.2 U	0.20 U	0.2 U	0.20 U	0.20 U	0.2 U	0.20 U	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U
Trichloroethene (TCE) in ug/L	0.2 U	0.2 U	0.2 U	0.2 U	0.20 U	0.2 U	0.20 U	0.20 U	0.2 U	0.20 U	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U
Vinyl chloride in ug/L	22	12	5.9	6.4	5.5	5.6	5.2	4.8	5.4	6.23	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U
Total Chlorinated Ethenes in umol/L	0.36	0.2	0.099	0.11	0.092	0.094	0.088	0.081	0.091	0.1	ND	ND	ND	ND	ND	ND	ND	ND	ND
Ethane in ug/L							9.4												
Ethene in ug/L							1.1 U												
Methane in ug/L							1,210												
MNA Evaluation Parameters/ General Chemistry																			
Alkalinity (Total) in mg/L as CaCO3							234												
Bicarbonate in mg/L as CaCO3							234												
Carbonate in mg/L as CaCO3							1.0 U												
Chloride in mg/L																			
Dissolved Calcium in ug/L																			
Dissolved Potassium in ug/L																			
Dissolved Sodium in ug/L																			
Hydroxide in mg/L as CaCO3							1.0 U												
Nitrate as Nitrogen in mg-N/L							0.1												
Nitrite as Nitrogen in mg-N/L							0.1 U												
ortho-Phosphorus in mg/L																			
Sulfate in mg/L							6.3												
Sulfide in mg/L																			
Total Organic Carbon in mg/L																			
Metals																			
Dissolved Aluminum in ug/L																			
Dissolved Cadmium in ug/L																			
Dissolved Calcium in ug/L																			
Dissolved Copper in ug/L																			
Dissolved Iron in ug/L																			
Dissolved Iron, Ferrous, Fe+2 in ug/L							10,900												
Dissolved Magnesium in ug/L																			
Dissolved Manganese in ug/L																			
Dissolved Nickel in ug/L																			
Dissolved Potassium in ug/L																			
Dissolved Silicon in ug/L																			
Dissolved Sodium in ug/L																			
Dissolved Zinc in ug/L																			
Iron, Ferrous, Fe+2 in ug/L																			
Total Iron in ug/L							13,700						2,670						
Total Manganese in ug/L							653						392						
Field Parameters																			
Dissolved Oxygen in mg/L	2.52	2.16	2.06	0.07	0.59	0.08	0.20	0.23	0.08	0.08	0.15	0.04	0.74	0.28	0.56	2.58	1.79	2.10	2.30
ORP in mVolts	-66.2	-75.9	-71.6	-105.3	-190.1	-49.2	-8.1	4.3	-7.6	4.7	-49.7	-149.7	-440.9	-148.2	-9.3	-154.7	-177.6	-159	-137.9
pH in pH Units	6.27	6.73	6.37	6.37	6.58	6.55	6.51	6.28	6.57	6.48	7.30	7.53	6.49	6.90 R	7.74 R	7.46	7.00	7.34	7.08
Specific Conductance in us/cm	554.5	439.7	498.4	458.1	599.8	511.4	526.5	492.0	528.7	501.8	2,479	2,105	2,537	2,871	2,659	2,304	3,115	2,709	3,086
Temperature in deg C	16.4	17.6	16.0	17.1	15.6	17.2	16.5	17.7	16.4	17.5	15.1	16.74	16.55	15.57	14.66	16.3	16.0	17.0	14.5
Turbidity in NTU	1.53	3.08	5.00	2.46	22.6	202	137	120	5.43	25.6						12.4	19.5	22.9	11.5

Notes

J - Analyte was positively identified. The reported result is an estimate.

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U - Analyte was not detected at or above the reported result.

UJ - Analyte was not detected at or above the reported estimate

Appendix C - Historical Groundwater Analytical Results

Art Brass Plating 050067

Chemical Name	MW-23-50 9/23/13	MW-23-50 3/17/14	MW-23-50 9/24/14	MW-23-50 3/20/15	MW-24 3/26/10	MW-24 6/15/10	MW-24 9/20/10	MW-24 12/15/10	MW-24 3/15/11	MW-24 9/13/11	MW-24 4/9/12	MW-24 9/18/12	MW-24 9/23/14	MW-24 3/16/15	MW-24-30 3/26/10	MW-24-30 6/15/10	MW-24-30 9/20/10	MW-24-30 12/15/10	MW-24-30 3/15/11
COCs and Degradation Products																			
1,1,1-Trichloroethane in ug/L	0.2 U	2.0 U	0.2 U	1.0 U	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U		0.20 U	0.2 U	0.6 UJ	0.6 U	0.2 U	3.0 U
1,1-Dichloroethane in ug/L	0.2 U	2.0 U	0.2 U	1.0 U	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U		0.20 U	0.7	0.7 J	0.6 U	0.5	3.0 U
1,1-Dichloroethene in ug/L	0.2 U	2.0 U	0.2 U	1.0 U	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U		0.20 U	1.6	1.8 J	1.8	2.7	4.0
1,2-Dichloroethane (EDC) in ug/L	0.2 U	2.0 U	0.2 U	1.0 U	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U		0.20 U	0.2 U	0.6 UJ	0.6 U	0.2 U	3.0 U
Chloroethane in ug/L	0.2 U	2.0 U	0.2 U	1.0 U	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U		0.20 U	0.2 U	0.6 UJ	0.6 U	0.2 U	3.0 U
cis-1,2-Dichloroethene (DCE) in ug/L	0.2 U	2.0 U	0.2 U	1.0 U	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.11 J		0.20 U	72	86 J	88	120	79
Tetrachloroethene (PCE) in ug/L	0.2 U	2.0 U	0.2 U	1.0 U	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U		0.20 U	0.2 U	0.6 UJ	0.6 U	0.2 U	3.0 U
trans-1,2-Dichloroethene in ug/L	0.2 U	2.0 U	0.2 U	1.0 U	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U		0.20 U	6.4	7.8 J	7.4	10	5.9
Trichloroethene (TCE) in ug/L	0.2 U	2.0 U	0.2 U	1.2	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U		0.20 U	110	140 J	100	100	100
Vinyl chloride in ug/L	0.2 U	2.0 U	0.2 U	1.0 U	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U		0.20 U	14	13 J	17	34	31
Total Chlorinated Ethenes in umol/L	ND	ND	ND	0.036	ND	ND	ND	ND	ND	ND	ND	0.0062		ND	1.9	2.3	2.0	2.7	2.2
Ethane in ug/L							1.2 U							1.2 U			2.1		
Ethene in ug/L							1.1 U							1.1 U			1.2		
Methane in ug/L							5,800							9,560			2,840		
MNA Evaluation Parameters/ General Chemistry																			
Alkalinity (Total) in mg/L as CaCO3							279						300	368			145		
Bicarbonate in mg/L as CaCO3							279						300	368			145		
Carbonate in mg/L as CaCO3							1.0 U						1 U	1.0 U			1.0 U		
Chloride in mg/L							35.2						56.9				14.2		
Dissolved Calcium in ug/L													77,600						
Dissolved Potassium in ug/L													10,800						
Dissolved Sodium in ug/L													59,700						
Hydroxide in mg/L as CaCO3							1.0 U						1 U	1.0 U			1.0 U		
Nitrate as Nitrogen in mg-N/L							0.1 U						0.1 U	0.1			0.1 U		
Nitrite as Nitrogen in mg-N/L							0.1 U							0.1 U			0.1 U		
ortho-Phosphorus in mg/L													0.1 U						
Sulfate in mg/L							6.5						6.6	6.4			1.5		
Sulfide in mg/L													0.226						
Total Organic Carbon in mg/L													5.31						
Metals																			
Dissolved Aluminum in ug/L													50 U						
Dissolved Cadmium in ug/L													0.1 U						
Dissolved Calcium in ug/L													77,600						
Dissolved Copper in ug/L													4.8						
Dissolved Iron in ug/L													9,810						
Dissolved Iron, Ferrous, Fe+2 in ug/L														13,400					
Dissolved Magnesium in ug/L													9,940						
Dissolved Manganese in ug/L													398						
Dissolved Nickel in ug/L													2.2						
Dissolved Potassium in ug/L													10,800						
Dissolved Silicon in ug/L													26,400						
Dissolved Sodium in ug/L													59,700						
Dissolved Zinc in ug/L													4 U						
Iron, Ferrous, Fe+2 in ug/L							7,850										6,850		
Total Iron in ug/L							8,340							12,600			21,200		
Total Manganese in ug/L							276							490			483		
Field Parameters																			
Dissolved Oxygen in mg/L	0.04	0.55	0.02	0.22	0.18	0.07	0.17	0.16	0.40	1.50	2.49	4.02	0.01	0.44	0.11	0.07	0.13	0.13	0.78
ORP in mVolts	-86.5	-150.3	-126.1	-17.7	-38.6	-143.5	-342.3	-138.8	-33.3	-257	-145.1	-111.6	-33.1	-48.7	-34.9	-132	-294.6	-52.8	3.6
pH in pH Units	7.12	7.26	7.35	7.35	6.82	6.90	5.82	9.02 R	7.06 R	6.51	6.57	6.64	6.66	6.51	6.79	6.96	5.93	8.40 R	6.79 R
Specific Conductance in us/cm	2,926	2,839	3,067	2,840	630	545	649	629	605	654	876	581.0	799	872	396	353	321	326	433
Temperature in deg C	16.7	15.7	16.5	15.8	11.77	17.27	21.45	12.6	9.82	21.5	11.5	21.3	21.7	12.2	15.08	15.84	16.48	14.96	14.47
Turbidity in NTU	11.5	14.9	27.9	49.5						2.04	2.68	4.34	3.31	13.7					

Notes

J - Analyte was positively identified. The reported result is an estimate.

R - Rejected.

U - Analyte was not detected at or above the reported result.

UJ - Analyte was not detected at or above the reported estimate

Appendix C - Historical Groundwater Analytical Results

Art Brass Plating 050067

Chemical Name	MW-24-30 6/9/11	MW-24-30 9/13/11	MW-24-30 9/13/11 FD	MW-24-30 12/12/11	MW-24-30 4/10/12	MW-24-30 6/11/12	MW-24-30 9/18/12	MW-24-30 12/10/12	MW-24-30 3/18/13	MW-24-30 3/18/13 FD	MW-24-30 9/24/13	MW-24-30 9/24/13 FD	MW-24-30 3/18/14	MW-24-30 3/18/14 FD	MW-24-30 9/24/14	MW-24-30 9/24/14 FD	MW-24-30 3/19/15	MW-24-30 9/23/15	MW-24-30 3/23/16
COCs and Degradation Products																			
1,1,1-Trichloroethane in ug/L	0.2 U	0.6 U	0.6 U	0.6 U	0.6 U	0.4 U	2.0 U	0.4 U	1.2 U	1.2 U	1.0 U	1.0 U	1.0 U	1.0 U	2 U	2 U	1.0 U	1.0 U	0.2 U
1,1-Dichloroethane in ug/L	0.6	0.6 U	0.6 U	0.8	0.6	1.4	0.72 J	0.58	1.8	1.6	1.1	1.0 U	1.0 U	1.0 U	1.4 J	1.4 J	1.0 U	1.0 U	0.56
1,1-Dichloroethene in ug/L	4.1	3.4	3.1	4.1	2.1	3.9	2.4	1.6	5.0	4.9	8.3	8.4	4.7	4.4	1.7 J	1.6 J	2.0	1.0	1.9
1,2-Dichloroethane (EDC) in ug/L	0.2 U	0.6 U	0.6 U	0.6 U	0.6 U	0.4 U	2.0 U	0.4 U	1.2 U	1.2 U	1.0 U	1.0 U	1.0 U	1.0 U	2 U	2 U	1.0 U	1.0 U	0.2 U
Chloroethane in ug/L	0.2 U	0.6 U	0.6 U	0.6 U	0.6 U	0.4 U	2.0 U	0.4 U	1.2 U	1.2 U	1.0 U	1.0 U	1.0 U	1.0 U	2 U	2 U	1.0 U	1.0 U	0.2 U
cis-1,2-Dichloroethene (DCE) in ug/L	63	55	51	63	39	69	45	36	74	70	100	100	150	140	190	180	140	64	120
Tetrachloroethene (PCE) in ug/L	0.2 U	0.6 U	0.6 U	0.6 U	0.6 U	0.4 U	2.0 U	0.4 U	1.2 U	1.2 U	1.0 U	1.0 U	1.0 U	1.0 U	2 U	2 U	1.0 U	1.0 U	0.2 U
trans-1,2-Dichloroethene in ug/L	5.7	4.8	4.7	5.1	3.3	5.6	4.7	4.0	6.7	5.9	8.8	8.2	7.6	7.0	17	16	8.8	5.6	5.8
Trichloroethene (TCE) in ug/L	120	100	94	120	71	100	97	62	110	110	170	180	150	150	140	140	100	63	21
Vinyl chloride in ug/L	29	29	28	28	23	28	26	18	27	25	24	29	20 J	19	20	18	27	19	42
Total Chlorinated Ethenes in umol/L	2.1	1.9	1.8	2.1	1.4	2.0	1.7	1.2	2.2	2.1	2.9	3.1	3.2	3.0	3.6	3.4	2.8	1.5	2.2
Ethane in ug/L																	1.2 U		
Ethene in ug/L																	1.1 U		
Methane in ug/L																	1,060		
MNA Evaluation Parameters/ General Chemistry																			
Alkalinity (Total) in mg/L as CaCO3																	222		
Bicarbonate in mg/L as CaCO3																	222		
Carbonate in mg/L as CaCO3																	1.0 U		
Chloride in mg/L																			
Dissolved Calcium in ug/L																			
Dissolved Potassium in ug/L																			
Dissolved Sodium in ug/L																			
Hydroxide in mg/L as CaCO3																	1.0 U		
Nitrate as Nitrogen in mg-N/L																	0.1		
Nitrite as Nitrogen in mg-N/L																	0.1 U		
ortho-Phosphorus in mg/L																			
Sulfate in mg/L																	8.8		
Sulfide in mg/L																			
Total Organic Carbon in mg/L																			
Metals																			
Dissolved Aluminum in ug/L																			
Dissolved Cadmium in ug/L																			
Dissolved Calcium in ug/L																			
Dissolved Copper in ug/L																			
Dissolved Iron in ug/L																			
Dissolved Iron, Ferrous, Fe+2 in ug/L																	8,650		
Dissolved Magnesium in ug/L																			
Dissolved Manganese in ug/L																			
Dissolved Nickel in ug/L																			
Dissolved Potassium in ug/L																			
Dissolved Silicon in ug/L																			
Dissolved Sodium in ug/L																			
Dissolved Zinc in ug/L																			
Iron, Ferrous, Fe+2 in ug/L																			
Total Iron in ug/L																	11,900		
Total Manganese in ug/L																	496		
Field Parameters																			
Dissolved Oxygen in mg/L		1.70		0.67	1.41	0.23	5.62	0.14	1.77		0.19		0.47		0.02		0.31	0.22	0.06
ORP in mVolts		-0240		-126.1	-123.2	-602.3	-94.6	-95.6	-93.2		-175.5		-74		-40.1		-38.1	-78.8	-86.8
pH in pH Units		6.71		6.67	6.82	6.73	6.87	6.80	6.39		6.6		6.82		6.92		6.73	6.55	6.74
Specific Conductance in us/cm		399.4		389.8	457.4	478.9	343.9	420.7	548.7		477.6		516.7		499.9		475.4	590.7	538.6
Temperature in deg C		16.0		14.9	14.8	15.3	15.9	15.2	14.5		15.8		14.7		16.3		14.8	16.5	15.2
Turbidity in NTU		24.7		21.3	22.4	7.49	18.4	7.19	7.38		7.26		10.3		9.22		43.6	3.53	36.9

Notes

J - Analyte was positively identified. The reported result is an estimate.

R - Rejected.

U - Analyte was not detected at or above the reported result.

UJ - Analyte was not detected at or above the reported estimate

Appendix C - Historical Groundwater Analytical Results

Art Brass Plating 050067

Chemical Name	MW-24-30 9/20/16	MW-24-50 3/26/10	MW-24-50 6/15/10	MW-24-50 9/20/10	MW-24-50 12/15/10	MW-24-50 3/15/11	MW-24-50 9/13/11	MW-24-50 4/10/12	MW-24-50 9/18/12	MW-24-50 3/18/13	MW-24-50 9/24/13	MW-24-50 3/18/14	MW-24-50 9/24/14	MW-24-50 3/19/15	MW-25-50 4/5/12	MW-25-50 6/11/12	MW-25-50 9/19/12	MW-25-50 12/10/12	MW-25-50 3/20/13
COCs and Degradation Products																			
1,1,1-Trichloroethane in ug/L	0.20 U	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	1.0 U	1.0 U	1.0 U	0.2 U	0.20 U	0.2 U	40 U	200 U	40 U	100 U
1,1-Dichloroethane in ug/L	0.57	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	1.0 U	1.0 U	1.0 U	0.2 U	0.20 U	24	34 J	32 J	40 U	100 U
1,1-Dichloroethene in ug/L	1.16	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	1.0 U	1.0 U	1.0 U	0.2 U	0.20 U	2.3	40 U	200 U	40 U	100 U
1,2-Dichloroethane (EDC) in ug/L	0.20 U	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	1.0 U	1.0 U	1.0 U	0.2 U	0.20 U	4.4	40 U	200 U	40 U	100 U
Chloroethane in ug/L	0.20 U	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	1.0 U	1.0 U	1.0 U	0.2 U	0.20 U	0.2 U	40 U	200 U	40 U	100 U
cis-1,2-Dichloroethene (DCE) in ug/L	117	0.5	0.8 J	0.7	0.9	1.2	1.9	2.3	3.1	4.2	2.2	1.4	0.52	0.99	190	220	210	160	170
Tetrachloroethene (PCE) in ug/L	0.20 U	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	1.0 U	1.0 U	1.0 U	0.2 U	0.20 U	0.2 U	40 U	200 U	40 U	100 U
trans-1,2-Dichloroethene in ug/L	3.82	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	1.0 U	1.0 U	1.0 U	0.2 U	0.20 U	2.1	40 U	200 U	40 U	100 U
Trichloroethene (TCE) in ug/L	15.8	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	1.0 U	0.74 J	1.0 U	0.2 U	0.58	7,900	8,200	7,900	7,000	6,600
Vinyl chloride in ug/L	24.0	0.2 U	0.2 UJ	0.2 U	0.3	0.7	2.1	2.0	2.2	2.5	1.8	1.3	0.63	0.79 J	16	28 J	200 U	40 U	100 U
Total Chlorinated Ethenes in umol/L	1.8	0.01	0.013	0.012	0.018	0.027	0.057	0.059	0.071	0.1	0.071	0.053	0.019	0.03	62	66	67	56	54
Ethane in ug/L														1.2 U					
Ethene in ug/L														1.1 U					
Methane in ug/L														12,600					
MNA Evaluation Parameters/ General Chemistry																			
Alkalinity (Total) in mg/L as CaCO3														196					
Bicarbonate in mg/L as CaCO3														196					
Carbonate in mg/L as CaCO3														1.0 U					
Chloride in mg/L																			
Dissolved Calcium in ug/L																			
Dissolved Potassium in ug/L																			
Dissolved Sodium in ug/L																			
Hydroxide in mg/L as CaCO3														1.0 U					
Nitrate as Nitrogen in mg-N/L														0.1					
Nitrite as Nitrogen in mg-N/L														0.1 U					
ortho-Phosphorus in mg/L																			
Sulfate in mg/L														2.1 J					
Sulfide in mg/L																			
Total Organic Carbon in mg/L																			
Metals																			
Dissolved Aluminum in ug/L																			
Dissolved Cadmium in ug/L																			
Dissolved Calcium in ug/L																			
Dissolved Copper in ug/L																			
Dissolved Iron in ug/L																			
Dissolved Iron, Ferrous, Fe+2 in ug/L														1,030					
Dissolved Magnesium in ug/L																			
Dissolved Manganese in ug/L																			
Dissolved Nickel in ug/L																			
Dissolved Potassium in ug/L																			
Dissolved Silicon in ug/L																			
Dissolved Sodium in ug/L																			
Dissolved Zinc in ug/L																			
Iron, Ferrous, Fe+2 in ug/L																			
Total Iron in ug/L				3,340										1,350					
Total Manganese in ug/L				166										132					
Field Parameters																			
Dissolved Oxygen in mg/L	0.14	0.07	0.03	0.16	0.16	0.36	1.65	1.00	5.69	1.56	0.10	0.41	0.00	0.34	1.13	0.28	4.11	0.11	2.23
ORP in mVolts	-0245.0	-73.1	26.1	-443.3	-80.2	-48.8	-274.3	-157.6	-145.4	-126.1	-157.7	34.4	-11.1	-61.2	-73.7	-649.3	-92.2	-79.6	-67.1
pH in pH Units	6.79	7.50	7.69	6.77	8.40 R	7.33 R	7.46	7.46	7.55	7.00	7.38	7.54	7.62	7.60	6.25	6.45	6.41	6.22	6.47
Specific Conductance in us/cm	501.1	467	411	495	503	499	480.8	554.4	412.1	494.0	480.3	541.1	509.1	465.5	694	657	560.8	636.5	643.2
Temperature in deg C	16.8	14.58	15.35	16.75	14.25	14.33	16.1	14.5	15.5	14.1	15.5	14.3	16.2	14.7	13.3	14.2	14.2	13.8	13.3
Turbidity in NTU	9.76						6.56	0 ear	4.91	4.44	2.06	18.9	7.99	6.90	13.9	15.1	4.87	11.7	7.72

Notes

J - Analyte was positively identified. The reported result is an estimate.

R - Rejected.

U - Analyte was not detected at or above the reported result.

UJ - Analyte was not detected at or above the reported estimate

Appendix C - Historical Groundwater Analytical Results

Art Brass Plating 050067

DRAFT

Chemical Name	MW-25-50 9/24/13	MW-25-50 3/18/14	MW-25-50 9/25/14	MW-25-50 3/18/15	MW-25-50 9/24/15	MW-25-50 3/22/16	MW-25-75 4/5/12	MW-25-75 6/11/12	MW-25-75 9/19/12	MW-25-75 12/10/12	MW-25-75 3/20/13	MW-25-75 9/24/13	MW-25-75 3/18/14	MW-25-75 9/25/14	MW-25-75 3/18/15	MW-26-40 4/6/12	MW-26-40 6/11/12	MW-26-40 9/18/12	MW-26-40 12/10/12
COCs and Degradation Products																			
1,1,1-Trichloroethane in ug/L	20 U	0.20 U	20 U	20 U	0.20 U	0.2 U	0.2 U	0.2 U	1.0 U	0.2 U	0.2 U	0.2 U	0.20 U	0.2 U	0.20 U	0.2 U	4.0 U	50 U	10 U
1,1-Dichloroethane in ug/L	24	22	29	22	23	21	0.2 U	0.2 U	1.0 U	0.2 U	0.2 U	0.2 U	0.20 U	0.2 U	0.20 U	15	21	18 J	16
1,1-Dichloroethene in ug/L	20 U	2.0	20 U	20 U	2.1	1.8	0.2 U	0.2 U	1.0 U	0.2 U	0.2 U	0.2 U	0.20 U	0.2 U	0.20 U	1.4	2.4 J	50 U	10 U
1,2-Dichloroethane (EDC) in ug/L	20 U	0.20 U	20 U	20 U	0.20 U	0.2 UJ	0.2 U	0.2 U	1.0 U	0.2 U	0.2 U	0.2 U	0.20 U	0.2 U	0.20 U	0.6	4.0 U	50 U	10 U
Chloroethane in ug/L	20 U	0.20 U	20 U	20 U	0.20 U	0.2 U	0.2 U	0.2 U	1.0 U	0.2 U	0.2 U	0.2 U	0.20 U	0.2 U	0.20 U	0.2 U	4.0 U	50 U	10 U
cis-1,2-Dichloroethene (DCE) in ug/L	130	110	180	140	150	140	0.2 U	0.2 U	1.0 U	0.2 U	0.2 U	0.16 J	0.20 U	0.2 U	0.20 U	130	160	150	130
Tetrachloroethene (PCE) in ug/L	20 U	0.20 U	20 U	20 U	0.20 U	0.2 U	0.2 U	0.2 U	1.0 U	0.2 U	0.2 U	0.2 U	0.20 U	0.2 U	0.20 U	0.2 U	4.0 U	50 U	10 U
trans-1,2-Dichloroethene in ug/L	20 U	2.5	20 U	20 U	3.1	3.7	0.2 U	0.2 U	1.0 U	0.2 U	0.2 U	0.2 U	0.20 U	0.2 U	0.20 U	1.2	2.0 J	50 U	10 U
Trichloroethene (TCE) in ug/L	5,200	3,900	6,200	5,500	5,400	2,600	0.9	0.5	0.19 J	0.51	0.2 U	3.9	0.66	2	0.20 U	990	1,100	1,200	1,100
Vinyl chloride in ug/L	19 J	17	19 J	20 U	19	17	8.3	14	16	12	16	20	17	15	20	15	22	18 J	14
Total Chlorinated Ethenes in umol/L	42	31	50	44	43	22	0.14	0.23	0.28	0.2	0.26	0.35	0.28	0.26	0.32	9.2	10	12	10
Ethane in ug/L				64.7											24.1				
Ethene in ug/L				12.0											62.3				
Methane in ug/L				3,380											25,200				
MNA Evaluation Parameters/ General Chemistry																			
Alkalinity (Total) in mg/L as CaCO3				120											212				
Bicarbonate in mg/L as CaCO3				120											212				
Carbonate in mg/L as CaCO3				1.0 U											1.0 U				
Chloride in mg/L																			
Dissolved Calcium in ug/L																			
Dissolved Potassium in ug/L																			
Dissolved Sodium in ug/L																			
Hydroxide in mg/L as CaCO3				1.0 U											1.0 U				
Nitrate as Nitrogen in mg-N/L				0.1											0.1				
Nitrite as Nitrogen in mg-N/L				0.1 U											0.1 U				
ortho-Phosphorus in mg/L																			
Sulfate in mg/L				60.6 J											6.2 J				
Sulfide in mg/L																			
Total Organic Carbon in mg/L																			
Metals																			
Dissolved Aluminum in ug/L																			
Dissolved Cadmium in ug/L																			
Dissolved Calcium in ug/L																			
Dissolved Copper in ug/L																			
Dissolved Iron in ug/L																			
Dissolved Iron, Ferrous, Fe+2 in ug/L				37,000											1,850				
Dissolved Magnesium in ug/L																			
Dissolved Manganese in ug/L																			
Dissolved Nickel in ug/L																			
Dissolved Potassium in ug/L																			
Dissolved Silicon in ug/L																			
Dissolved Sodium in ug/L																			
Dissolved Zinc in ug/L																			
Iron, Ferrous, Fe+2 in ug/L																			
Total Iron in ug/L				35,200											2,400				
Total Manganese in ug/L				1,070											362				
Field Parameters																			
Dissolved Oxygen in mg/L	0.10	0.53	0.02	0.37	0.31	0.08	0.94	0.19	2.49	0.10	1.65	0.07	0.50	0.02	0.38	1.41	0.29	6.07	0.12
ORP in mVolts	-175	-64.1	-56.4	8.6	7.8	-27.5	-111.7	-716	-139.1	-107.3	-122.7	-279.1	-127.9	-0114.0	-33.3	-78	-0630	-73	-71.6
pH in pH Units	6.37	6.52	6.69	6.60	6.20	6.43	7.59	7.49	7.42	7.11	7.35	7.27	7.38	7.53	7.41	6.38	6.41	6.52	6.32
Specific Conductance in us/cm	611.3	744.0	612.2	610.5	573.3	549.7	592.8	534.3	454.2	502.5	517.7	502.4	571.0	503.6	505.3	614.5	562.9	519.4	557.3
Temperature in deg C	14.5	13.4	14.8	13.6	14.6	13.8	12.9	14.6	14.4	13.6	13.0	14.1	13.2	15.0	13.7	14.5	15.0	15.4	14.2
Turbidity in NTU	11.8	3.39	4.79	6.37	5.84	3.37	264	19.5	18.7	26.6	11.7	4.46	7.98	8.87	16.7	55.1	34.2	14.6	

Notes

J - Analyte was positively identified. The reported result is an estimate.

R - Rejected.

U - Analyte was not detected at or above the reported result.

UJ - Analyte was not detected at or above the reported estimate

Appendix C - Historical Groundwater Analytical Results

Art Brass Plating 050067

Chemical Name	MW-26-40 3/19/13	MW-26-40 9/24/13	MW-26-40 3/18/14	MW-26-40 9/24/14	MW-26-40 3/18/15	MW-26-40 9/23/15	MW-26-40 3/23/16	MW-26-40 9/20/16	MW-26-55 4/6/12	MW-26-55 6/11/12	MW-26-55 9/18/12	MW-26-55 12/10/12	MW-26-55 3/19/13	MW-26-55 9/24/13	MW-26-55 3/18/14	MW-26-55 9/24/14	MW-26-55 3/19/15	MW-26-55 9/23/15	MW-26-55 3/23/16
COCs and Degradation Products																			
1,1,1-Trichloroethane in ug/L	10 U	0.2 U	0.20 U	4 U	4.0 U	4.0 U	10 U	0.20 U	0.2 U	10 U	20 U	4.0 U	10 U	4.0 U	0.20 U	4 U	10 U	4.0 U	10 U
1,1-Dichloroethane in ug/L	12	13	14	14	12	13	10	13.3	14	21	12 J	18	7.5 UJ	6.4	10	8.2	12	11	10 U
1,1-Dichloroethene in ug/L	10 U	1.3	1.4	4 U	4.0 U	4.0 U	10 U	1.76	1.2	10 U	20 U	4.0 U	10 U	4.0 U	0.80	4 U	10 U	4.0 U	10 U
1,2-Dichloroethane (EDC) in ug/L	10 U	0.2 U	0.20 U	4 U	4.0 U	4.0 U	10 U	0.20 U	1.0	10 U	20 U	4.0 U	10 U	4.0 U	0.20 U	4 U	10 U	4.0 U	10 U
Chloroethane in ug/L	10 U	0.2 U	0.20 U	4 U	4.0 U	4.0 U	10 U	0.20 U	0.2 U	10 U	20 U	4.0 U	10 U	4.0 U	0.20 U	4 U	10 U	4.0 U	10 U
cis-1,2-Dichloroethene (DCE) in ug/L	110	120	98	140	130	130	110	133	58	82	51	74	36	30	42	33	52	54	48
Tetrachloroethene (PCE) in ug/L	10 U	0.2 U	0.20 U	4 U	4.0 U	4.0 U	10 U	0.20 U	0.2 U	10 U	20 U	4.0 U	10 U	4.0 U	0.20 U	4 U	10 U	4.0 U	10 U
trans-1,2-Dichloroethene in ug/L	10 U	1.4	1.6	4 U	4.0 U	4.0 U	10 U	2.29	0.7	10 U	20 U	4.0 U	10 U	4.0 U	0.67	4 U	10 U	4.0 U	10 U
Trichloroethene (TCE) in ug/L	900	1,000	790	1,100	1,100	1,100	900	1,080	1,700	1,900	1,000	2,000	820	620	770	540	1,100	1,200	1,200
Vinyl chloride in ug/L	12	12	11	12	11	10	10 U	11.7	16	30	18 J	23	12	13	13	13	14 J	14	12
Total Chlorinated Ethenes in umol/L	8.3	9.1	7.2	10	10	9.9	8.2	9.8	14	16	8.7	16	6.9	5.3	6.5	4.7	9.3	10	10
Ethane in ug/L					37.5												19.1		
Ethene in ug/L					1.1 U												9.7		
Methane in ug/L					1,410												3,200		
MNA Evaluation Parameters/ General Chemistry																			
Alkalinity (Total) in mg/L as CaCO3					125												118		
Bicarbonate in mg/L as CaCO3					125												118		
Carbonate in mg/L as CaCO3					1.0 U												1.0 U		
Chloride in mg/L																			
Dissolved Calcium in ug/L																			
Dissolved Potassium in ug/L																			
Dissolved Sodium in ug/L																			
Hydroxide in mg/L as CaCO3					1.0 U												1.0 U		
Nitrate as Nitrogen in mg-N/L					0.1												0.1		
Nitrite as Nitrogen in mg-N/L					0.1 U												0.1 U		
ortho-Phosphorus in mg/L																			
Sulfate in mg/L					47.3 J												30.7		
Sulfide in mg/L																			
Total Organic Carbon in mg/L																			
Metals																			
Dissolved Aluminum in ug/L																			
Dissolved Cadmium in ug/L																			
Dissolved Calcium in ug/L																			
Dissolved Copper in ug/L																			
Dissolved Iron in ug/L																			
Dissolved Iron, Ferrous, Fe+2 in ug/L					31,000												29,800		
Dissolved Magnesium in ug/L																			
Dissolved Manganese in ug/L																			
Dissolved Nickel in ug/L																			
Dissolved Potassium in ug/L																			
Dissolved Silicon in ug/L																			
Dissolved Sodium in ug/L																			
Dissolved Zinc in ug/L																			
Iron, Ferrous, Fe+2 in ug/L																			
Total Iron in ug/L					31,100												27,400		
Total Manganese in ug/L					896												972		
Field Parameters																			
Dissolved Oxygen in mg/L	2.55	0.06	0.54	0.01	0.38	0.27	0.15	0.19	1.27	0.24	5.55	0.12	1.91	0.60	0.51	0.02	0.15	0.28	0.31
ORP in mVolts	-88.5	-203.7	-67	-46.9	-20.5	-46.4	-47	-26.2	-101.5	-657.1	-102.1	-99.2	-115.2	-209.6	-101.8	-081.0	-53.5	-59.8	-79.3
pH in pH Units	6.38	6.22	6.48	6.45	6.26	6.19	6.3	6.45	6.61	6.64	6.74	6.58	6.72	6.58	6.73	6.74	6.57	6.38	6.51
Specific Conductance in us/cm	599.0	559.4	607.3	508.5	519.9	522.8	518.7	509.6	593.9	560.2	474.5	571.3	536.4	488.1	620.1	491.6	553.4	593.2	603.5
Temperature in deg C	14.3	14.8	14.4	15.8	15.6	16.1	14.8	16.4	13.5	14.5	16.0	14.0	14.0	15.4	13.9	15.8	14.6	14.8	14.7
Turbidity in NTU	35.6	10.6	12.6	25.3	27.8	8.30	132	23.2	16.4	11.8	9.90	3.6	6.96	9.45	5.62	7.34	2.96	13.0	11

Notes

J - Analyte was positively identified. The reported result is an estimate.
R - Rejected.
U - Analyte was not detected at or above the reported result.
UJ - Analyte was not detected at or above the reported estimate

Appendix C - Historical Groundwater Analytical Results

Art Brass Plating 050067

Chemical Name	PSC-CG-140-30 6/24/10	PSC-CG-140-30 9/20/10	PSC-CG-140-30 12/14/10	PSC-CG-140-30 3/14/11	PSC-CG-140-30 9/13/11	PSC-CG-140-30 4/10/12	PSC-CG-140-30 9/18/12	PSC-CG-140-30 9/24/13	PSC-CG-140-30 9/24/14	PSC-CG-140-40 3/23/10	PSC-CG-140-40 9/24/13	PSC-CG-140-40 9/24/14	PSC-CG-140-40 3/19/15	PSC-CG-140-40 9/20/16	AB-CG-140-70 3/24/10	AB-CG-140-70 6/15/10	AB-CG-140-70 9/20/10	AB-CG-140-70 12/14/10	AB-CG-140-70 4/10/12
COCs and Degradation Products																			
1,1,1-Trichloroethane in ug/L	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 UJ	1.0 U	0.20 U	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U
1,1-Dichloroethane in ug/L	5.2	5.1	3.4	6.6	2.6	4.0	3.7	2.6	2.8	0.2 U	0.2 U	0.2 UJ	1.0 U	0.21	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U
1,1-Dichloroethene in ug/L	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 UJ	1.0 U	0.20 U	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U
1,2-Dichloroethane (EDC) in ug/L	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 UJ	1.0 U	0.20 U	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U
Chloroethane in ug/L	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 UJ	1.0 U	0.20 U	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U
cis-1,2-Dichloroethene (DCE) in ug/L	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.13 J	0.13 J	0.2 U	0.2 U	0.2 UJ	1.0 U	0.20 U	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U
Tetrachloroethene (PCE) in ug/L	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 UJ	1.0 U	0.20 U	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U
trans-1,2-Dichloroethene in ug/L	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 UJ	1.0 U	0.20 U	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U
Trichloroethene (TCE) in ug/L	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.13 J	0.2 U	0.2 U	0.2 U	0.2 UJ	1.2	0.20 U	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U
Vinyl chloride in ug/L	36	40	38	27	42	51	36	41	35	72	130	75 J	160	93.2	0.2	0.2 UJ	0.2 U	0.2 U	0.2 U
Total Chlorinated Ethenes in umol/L	0.58	0.64	0.61	0.44	0.68	0.82	0.58	0.66	0.56	1.2	2.1	1.2	2.6	1.5	0.0077	ND	ND	ND	ND
Ethane in ug/L													36.8						
Ethene in ug/L													155						
Methane in ug/L													6,260						
MNA Evaluation Parameters/ General Chemistry																			
Alkalinity (Total) in mg/L as CaCO3													174						
Bicarbonate in mg/L as CaCO3													174						
Carbonate in mg/L as CaCO3													1.0 U						
Chloride in mg/L																			
Dissolved Calcium in ug/L																			
Dissolved Potassium in ug/L																			
Dissolved Sodium in ug/L																			
Hydroxide in mg/L as CaCO3													1.0 U						
Nitrate as Nitrogen in mg-N/L													0.1 U						
Nitrite as Nitrogen in mg-N/L													0.1 U						
ortho-Phosphorus in mg/L																			
Sulfate in mg/L													15.6						
Sulfide in mg/L																			
Total Organic Carbon in mg/L																			
Metals																			
Dissolved Aluminum in ug/L																			
Dissolved Cadmium in ug/L																			
Dissolved Calcium in ug/L																			
Dissolved Copper in ug/L																			
Dissolved Iron in ug/L																			
Dissolved Iron, Ferrous, Fe+2 in ug/L													13,100						
Dissolved Magnesium in ug/L																			
Dissolved Manganese in ug/L																			
Dissolved Nickel in ug/L																			
Dissolved Potassium in ug/L																			
Dissolved Silicon in ug/L																			
Dissolved Sodium in ug/L																			
Dissolved Zinc in ug/L																			
Iron, Ferrous, Fe+2 in ug/L																			
Total Iron in ug/L		14,700											12,700				3,600		
Total Manganese in ug/L		480											743				126		
Field Parameters																			
Dissolved Oxygen in mg/L	0.28	0.08	0.58	0.31	1.91	1.73	6.22	0.13	0.01	0.23	0.22	0.15	0.38	0.39	0.10	0.02	0.09	0.25	0.93
ORP in mVolts	-84	-134	-201.4	-103.3	-219.7	-98.3	-71.7	-168.2	-49.9	-164	-157.8	-76.2	-48.4	-45.1	-97.5	-163	-449.6	-230.7	-177.3
pH in pH Units	7.00	6.39	6.46 R	6.66 R	6.39	6.40	6.54	6.41	6.65	6.79	6.70	7.08	6.80	6.74	7.25	8.06	6.96	7.20 R	7.71
Specific Conductance in us/cm	343	407	293	434	478	516.3	386.5	382.3	498.6	373	454.5	496.8	448.9	490.6	391	354	412	405	473.4
Temperature in deg C	15.4	15.82	13.72	14.33	15.7	14.4	15.2	15.4	15.0	14.57	15.4	15.2	14.5	16.5	14.87	14.3	16.75	13.77	14.2
Turbidity in NTU					0.97	3.53	9.14	3.4	17.0		3.51	11.3	3.58	12.9					8.45

Notes

J - Analyte was positively identified. The reported result is an estimate.

R - Rejected.

U - Analyte was not detected at or above the reported result.

UJ - Analyte was not detected at or above the reported estimate

Appendix C - Historical Groundwater Analytical Results

Art Brass Plating 050067

Chemical Name	AB-CG-140-70 3/19/15	PSC-CG-151-25 3/23/10	PSC-CG-151-25 6/15/10	PSC-CG-151-25 9/20/10	PSC-CG-151-25 12/14/10	PSC-CG-151-25 3/14/11	PSC-CG-151-25 9/13/11	PSC-CG-151-25 4/9/12	PSC-CG-151-25 9/17/12	PSC-CG-151-25 3/18/13	PSC-CG-151-25 9/23/13	PSC-CG-151-25 3/17/14	PSC-CG-151-25 9/23/14	PSC-CG-151-25 3/16/15	PSC-CG-151-25 9/23/15	PSC-CG-151-25 3/23/16	PSC-CG-151-25 9/20/16
COCs and Degradation Products																	
1,1,1-Trichloroethane in ug/L	0.20 U	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.20 U	0.2 U	0.20 U	0.20 U	0.2 U	0.20 U
1,1-Dichloroethane in ug/L	0.20 U	1.0	1.0 J	0.9	1.0	0.7	0.6	0.6	0.59	0.45	0.29	0.27	0.44	0.23	0.63	0.55	0.32
1,1-Dichloroethene in ug/L	0.20 U	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.20 U	0.2 U	0.20 U	0.20 U	0.2 U	0.20 U
1,2-Dichloroethane (EDC) in ug/L	0.20 U	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.20 U	0.2 U	0.20 U	0.20 U	0.2 U	0.20 U
Chloroethane in ug/L	0.20 U	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2	0.6	0.2 U	0.42	0.59	0.20 U	0.47	0.20 U	0.20 UJ	0.41	0.20 U
cis-1,2-Dichloroethene (DCE) in ug/L	0.20 U	2.5	3.0 J	6.7	1.5	0.3	0.2 U	1.7	0.97	0.2 U	0.2 U	0.20 U	0.2 U	0.20 U	0.20 U	0.2 U	0.32
Tetrachloroethene (PCE) in ug/L	0.20 U	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.20 U	0.2 U	0.20 U	0.20 U	0.2 U	0.20 U
trans-1,2-Dichloroethene in ug/L	0.20 U	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.20 U	0.2 U	0.20 U	0.20 U	0.2 U	0.20 U
Trichloroethene (TCE) in ug/L	2.1	0.2 U	0.2 UJ	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.20 U	0.2 U	0.20 U	0.20 U	0.2 U	0.20 U
Vinyl chloride in ug/L	0.20 U	16	18 J	51	27	3.7	1.7	32	7.9	1.4	0.20	0.20 U	1.2	2.5	0.20 U	27	19.5
Total Chlorinated Ethenes in umol/L	0.021	0.29	0.32	0.89	0.45	0.066	0.032	0.53	0.14	0.027	0.0077	ND	0.024	0.044	ND	0.44	0.32
Ethane in ug/L				3.5										11.8			
Ethene in ug/L				18.6										22.5			
Methane in ug/L				2,850										7,730			
MNA Evaluation Parameters/ General Chemistry																	
Alkalinity (Total) in mg/L as CaCO3				237										235			
Bicarbonate in mg/L as CaCO3				237										235			
Carbonate in mg/L as CaCO3				1.0 U										1.0 U			
Chloride in mg/L				491													
Dissolved Calcium in ug/L																	
Dissolved Potassium in ug/L																	
Dissolved Sodium in ug/L																	
Hydroxide in mg/L as CaCO3				1.0 U										1.0 U			
Nitrate as Nitrogen in mg-N/L				0.1 U										0.1 U			
Nitrite as Nitrogen in mg-N/L				0.1 U										1.0 U			
ortho-Phosphorus in mg/L																	
Sulfate in mg/L				42.1										27.4			
Sulfide in mg/L																	
Total Organic Carbon in mg/L																	
Metals																	
Dissolved Aluminum in ug/L																	
Dissolved Cadmium in ug/L																	
Dissolved Calcium in ug/L																	
Dissolved Copper in ug/L																	
Dissolved Iron in ug/L																	
Dissolved Iron, Ferrous, Fe+2 in ug/L														905			
Dissolved Magnesium in ug/L																	
Dissolved Manganese in ug/L																	
Dissolved Nickel in ug/L																	
Dissolved Potassium in ug/L																	
Dissolved Silicon in ug/L																	
Dissolved Sodium in ug/L																	
Dissolved Zinc in ug/L																	
Iron, Ferrous, Fe+2 in ug/L				647													
Total Iron in ug/L				600										570			
Total Manganese in ug/L				157										231			
Field Parameters																	
Dissolved Oxygen in mg/L	0.36	0.06	0.56	0.09	0.18	0.27	1.96	1.87	5.33	2.12	0.04	0.70	0.01	0.34	0.20	0.1	0.13
ORP in mVolts	-63.5	-232	-184.6	-178	-273.5	-273.5	-291.2	-201.3	-119.4	-191.9	-294.9	-184.1	-76.1	-109.3	-145.9	-95.3	-325.3
pH in pH Units	7.81	6.70	6.93	6.51	6.57 R	7.30 R	6.51	6.55	7.36	6.57	6.55	6.87	6.99	6.64	6.74	6.87	6.94
Specific Conductance in us/cm	409.1	1,855	2,298	2,008	1,975	1,766	4,294	898	1,194	2,016	3,505	3,544	1,176	1,879	2,211	1,173	4,921
Temperature in deg C	14.3	14.7	14.65	16.01	15.05	14.04	15.6	13.9	15.3	14.1	15.8	14.1	15.7	14.5	16.1	14.8	17.1
Turbidity in NTU	9.46						5.53	1.42	5.54	1.90	1.21	3.94	1.28	2.21	1.55	4.71	6.05

Notes

J - Analyte was positively identified. The reported result is an estimate.

R - Rejected.

U - Analyte was not detected at or above the reported result.

UJ - Analyte was not detected at or above the reported estimate

APPENDIX D

Boring and Well Construction Logs

Coarse-Grained Soils - More than 50%(1) Retained on No. 200 Sieve	Gravels - More than 50%(1) of Coarse Fraction Retained on No. 4 Sieve	≤5% Fines(5)	**GW**	Well-graded gravel and gravel with sand, little to no fines
			GP	Poorly-graded gravel and gravel with sand, little to no fines
		≥15% Fines(5)	**GM**	Silty gravel and silty gravel with sand
			GC	Clayey gravel and clayey gravel with sand
	Sands - 50%(1) or More of Coarse Fraction Passes No. 4 Sieve	≤5% Fines(5)	**SW**	Well-graded sand and sand with gravel, little to no fines
			SP	Poorly-graded sand and sand with gravel, little to no fines
		≥15% Fines(5)	**SM**	Silty sand and silty sand with gravel
			SC	Clayey sand and clayey sand with gravel
Fine-Grained Soils - 50%(1) or More Passes No. 200 Sieve	Silts and Clays Liquid Limit Less than 50		**ML**	Silt, sandy silt, gravelly silt, silt with sand or gravel
			CL	Clay of low to medium plasticity; silty, sandy, or gravelly clay, lean clay
			OL	Organic clay or silt of low plasticity
	Silts and Clays Liquid Limit 50 or More		**MH**	Elastic silt, clayey silt, silt with micaceous or diatomaceous fine sand or silt
			CH	Clay of high plasticity, sandy or gravelly clay, fat clay with sand or gravel
			OH	Organic clay or silt of medium to high plasticity
Highly Organic Soils			**PT**	Peat, muck and other highly organic soils

Terms Describing Relative Density and Consistency

	Density	SPT(2) blows/foot
Coarse-Grained Soils	Very Loose	0 to 4
	Loose	4 to 10
	Medium Dense	10 to 30
	Dense	30 to 50
	Very Dense	>50

	Consistency	SPT(2) blows/foot
Fine-Grained Soils	Very Soft	0 to 2
	Soft	2 to 4
	Medium Stiff	4 to 8
	Stiff	8 to 15
	Very Stiff	15 to 30
	Hard	>30

Test Symbols

FC = Fines Content
GS = Grain Size
MC = Moisture Content
AL = Atterberg Limits
C = Consolidation
DD = Dry Density
K = Permeability
Str = Shear Strength
Env = Environmental
PiD = Photoionization Detector

Component Definitions

Descriptive Term	Size Range and Sieve Number
Boulders	Larger than 12"
Cobbles	3" to 12"
Gravel	3" to No. 4 (4.75 mm)
Coarse Gravel	3" to 3/4"
Fine Gravel	3/4" to No. 4 (4.75 mm)
Sand	No. 4 (4.75 mm) to No. 200 (0.075 mm)
Coarse Sand	No. 4 (4.75 mm) to No. 10 (2.00 mm)
Medium Sand	No. 10 (2.00 mm) to No. 40 (0.425 mm)
Fine Sand	No. 40 (0.425 mm) to No. 200 (0.075 mm)
Silt and Clay	Smaller than No. 200 (0.075 mm)

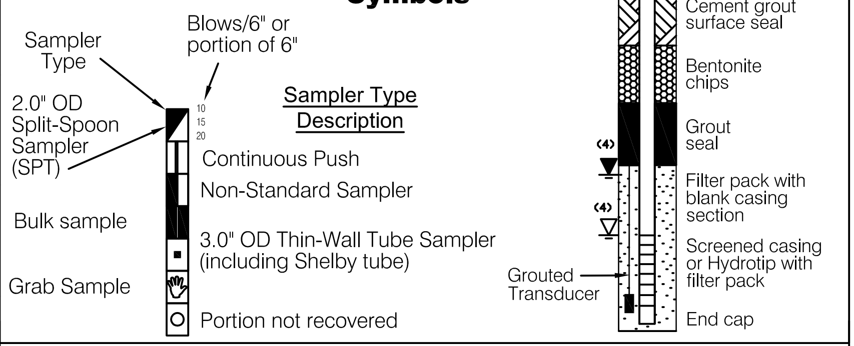
(3) Estimated Percentage

Percentage by Weight	Modifier
<5	Trace
5 to 15	Slightly (sandy, silty, clayey, gravelly)
15 to 30	Sandy, silty, clayey, gravelly)
30 to 49	Very (sandy, silty, clayey, gravelly)

Moisture Content

Dry - Absence of moisture, dusty, dry to the touch
Slightly Moist - Perceptible moisture
Moist - Damp but no visible water
Very Moist - Water visible but not free draining
Wet - Visible free water, usually from below water table

Symbols



(1) Percentage by dry weight
(2) (SPT) Standard Penetration Test (ASTM D-1586)
(3) In General Accordance with Standard Practice for Description and Identification of Soils (ASTM D-2488)
(4) Depth of groundwater
▽ ATD = At time of drilling
▼ Static water level (date)
(5) Combined USCS symbols used for fines between 5% and 15% as estimated in General Accordance with Standard Practice for Description and Identification of Soils (ASTM D-2488)

BGS = below ground surface

Classifications of soils in this report are based on visual field and/or laboratory observations, which include density/consistency, moisture condition, grain size, and plasticity estimates and should not be construed to imply field or laboratory testing unless presented herein. Visual-manual and/or laboratory classification methods of ASTM D-2487 and D-2488 were used as an identification guide for the Unified Soil Classification System.

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Exploration Log Key

DATE:
DESIGNED BY:
DRAWN BY:
REVISED BY:
PROJECT NO.
FIGURE NO.
A-1

Q:_ACAD Standards\Standard Details\Exploration Log Key A1.dwg

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Boring Log

Project Number	Boring Number	Sheet
050067	AB-CG-140-70	1 of 2

Project Name: Art Brass Plating
Ground Surface Elev
Location: Seattle, WA
Driller/Method: Cascade Drilling / Hollow Stem Auger
Depth to Water
Sampling Method: D&M / Hammer Weight: 140 lb Jars / Hammer Drop: 30"
Start/Finish Date 3/12/2010

Depth / Elevation (feet)	Borehole Completion	Sample Type/ID	Tests	PID (ppm)	Blows/ 6"	Material Type	Description	Depth (ft)
	8" flushmount monument, 2" thermos well cap, concrete seal, 0'-1'						Vacuumed to 5' to clear for utilities.	
5	2" diameter schedule 40 PVC casing, threaded connection, 0'-60'	S1		0.0	3 4 4		Loose, moist, brown, slightly silty to silty SAND (SP-SM); fine to medium sand; trace gravel.	5
10	Hydrated bentonite chips, 2'-58'	S2		0.0	4 9 16		Very stiff, moist, gray brown SILT (ML); occasional organics. Medium dense, moist, brown SAND (SP); trace silt; fine to medium sand.	10
15		S3		0.0	7 9 9		Medium dense, moist to wet, gray, slightly silty SAND (SP) with frequent, very thin SILT (ML) lenses; fine to medium sand, predominantly fine.	15
20		S4		0.0	10 11 12		Medium dense, wet, dark gray to black SAND (SP); fine to medium sand. Grades to medium dense, wet, dark gray, silty SAND (SM); fine sand.	20
25		S5		0.0	11 14 16		Hard.	25
30		S6		0.0	11 12 18		Medium dense, wet, dark gray SAND (SP); fine to medium sand; trace silt.	30
35		S7		0.0	16 20 21			35

Sampler Type:
○ No Recovery
◧ 3.25" OD D&M Split-Spoon Ring Sampler

PID - Photoionization Detector (Headspace Measurement)
▼ Static Water Level
▽ Water Level (ATD)

Logged by: AET
Approved by: DLC
Figure No.

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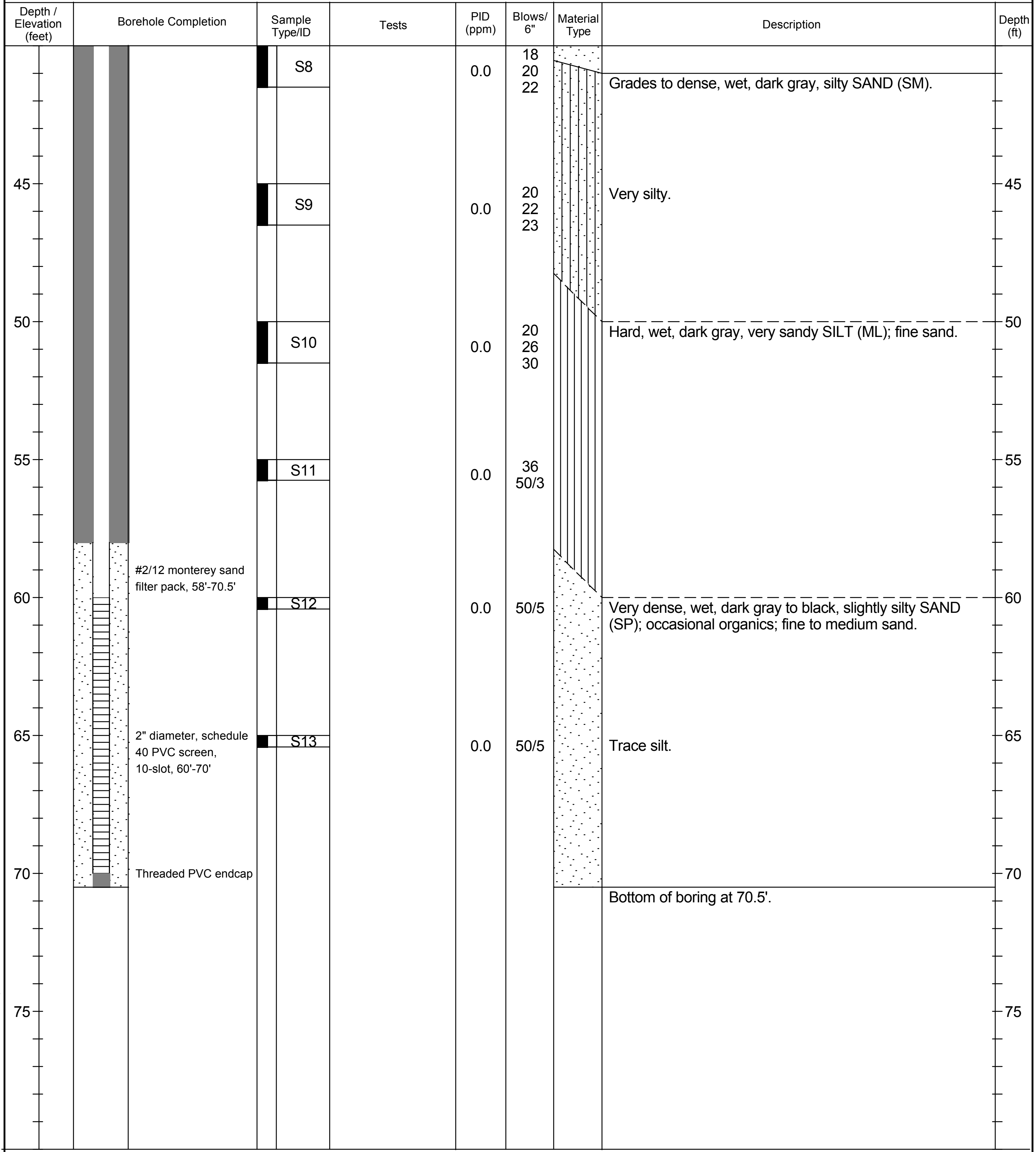
Boring Log

Project Number	Boring Number	Sheet
050067	AB-CG-140-70	2 of 2

Project Name: Art Brass Plating
Location: Seattle, WA
Driller/Method: Cascade Drilling / Hollow Stem Auger
Sampling Method: D&M / Hammer Weight: 140 lb Jars / Hammer Drop: 30"
Ground Surface Elev
Depth to Water
Start/Finish Date 3/12/2010



Depth (ft)	Sample Type/ID	PID (ppm)	Blows/ 6"	Description
40–41.5	S8	0.0	18 20 22	Grades to dense, wet, dark gray, silty SAND (SM).
45–46.5	S9	0.0	20 22 23	Very silty.
50–51.5	S10	0.0	20 26 30	Hard, wet, dark gray, very sandy SILT (ML); fine sand.
55	S11	0.0	36 50/3	
60	S12	0.0	50/5	Very dense, wet, dark gray to black, slightly silty SAND (SP); occasional organics; fine to medium sand.
65	S13	0.0	50/5	Trace silt.
70.5				Bottom of boring at 70.5'.

Sampler Type:
○ No Recovery
▮ 3.25" OD D&M Split-Spoon Ring Sampler

PID - Photoionization Detector (Headspace Measurement)
▼ Static Water Level
▽ Water Level (ATD)

Logged by: AET
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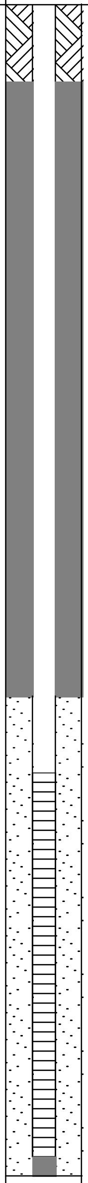
Boring Log

Project Number	Boring Number	Sheet
050067	MW-22-30	1 of 1

Project Name: Art Brass Plating
Location: Seattle, WA
Driller/Method: Cascade Drilling / Hollow Stem Auger
Sampling Method: D&M / Hammer Weight: 140 lb Jars / Hammer Drop: 30"
Ground Surface Elev
Depth to Water
Start/Finish Date 3/9/2010



Depth / Elevation (feet)	Borehole Completion	Sample Type/ID	Tests	PID (ppm)	Blows/ 6"	Material Type	Description	Depth (ft)
	8" flushmount monument, 2" thermos well cap, concrete seal, 0'-2'						Vacuumed to 5' to clear for utilities. No soil logging, see MW-22-50 boring log.	
5	2" diameter schedule 40 PVC casing, threaded connection, 0'-20'							5
10	Hydrated bentonite chips, 2'-18'							10
15								15
	#2/12 monterey sand filter pack, 18'-30'							
20								20
25	2" diameter, schedule 40 PVC screen, 10-slot, 20'-30'							25
30	Threaded PVC endcap							30
							Bottom of boring at 30.5'.	
35								35

Sampler Type:
○ No Recovery

PID - Photoionization Detector (Headspace Measurement)
▼ Static Water Level
▽ Water Level (ATD)

Logged by: AET
Approved by: DLC
Figure No.

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Boring Log

Project Number	Boring Number	Sheet
050067	MW-22-50	1 of 2

Project Name: Art Brass Plating

Location: Seattle, WA

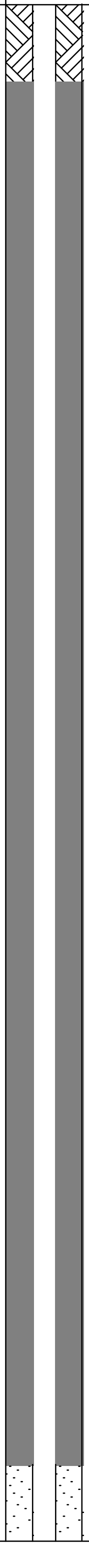
Driller/Method: Cascade Drilling / Hollow Stem Auger

Sampling Method: D&M / Hammer Weight: 140 lb Jars / Hammer Drop: 30"

Ground Surface Elev

Depth to Water

Start/Finish Date 3/9/2010



Depth / Elevation (feet)	Borehole Completion	Sample Type/ID	Tests	PID (ppm)	Blows/ 6"	Description	Depth (ft)
	8" flushmount monument, 2" thermos well cap, concrete seal, 0'-2'					Vacuumed to 5' to clear for utilities.	
5	2" diameter schedule 40 PVC casing, threaded connection, 0'-40'	○ S1		0.0	5 7 5	Stiff, very moist, brown SILT (ML); numerous organics, woody debris.	5
10	Hydrated bentonite chips, 2'-38'	○ S2		0.0	7 10 12	Medium dense, wet, gray brown, silty SAND (SM); numerous organics, woody debris.	10
15		○ S3		0.0	7 9 9	Medium dense, wet, dark gray SAND (SP); trace silt, occasional organics, fine to medium sand.	15
20		S4		0.0	10 10 11		20
25		S5		0.0	10 12 15		25
30		S6		0.0	7 20 21	Dense.	30
35		S7		0.0	50/5		35
	#2/12 monterey sand filter pack, 38'-50'						

Sampler Type:

○ No Recovery

▮ 3.25" OD D&M Split-Spoon Ring Sampler

PID - Photoionization Detector (Headspace Measurement)

▼ Static Water Level

▽ Water Level (ATD)

Logged by: AET

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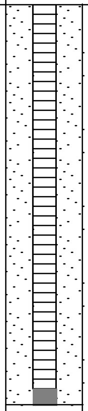
Boring Log

Project Number	Boring Number	Sheet
050067	MW-22-50	2 of 2

Project Name: Art Brass Plating
Location: Seattle, WA
Driller/Method: Cascade Drilling / Hollow Stem Auger
Sampling Method: D&M / Hammer Weight: 140 lb Jars / Hammer Drop: 30"
Ground Surface Elev
Depth to Water
Start/Finish Date 3/9/2010



Depth / Elevation (feet)	Borehole Completion	Sample Type/ID	Tests	PID (ppm)	Blows/ 6"	Material Type	Description	Depth (ft)
		■ S8		0.0	50/6	▥	Hard, wet, dark gray, very sandy SILT (ML); fine sand.	
45	2" diameter, schedule 40 PVC screen, 10-slot, 40'-50'	■ S9		0.0	32 50/3	▥		45
50	Threaded PVC endcap	■ S10		0.0	50/5	▥	Bottom of boring at approximately 50.5'.	50
55								55
60								60
65								65
70								70
75								75

Sampler Type:
○ No Recovery
■ 3.25" OD D&M Split-Spoon Ring Sampler

PID - Photoionization Detector (Headspace Measurement)
▼ Static Water Level
▽ Water Level (ATD)

Logged by: AET
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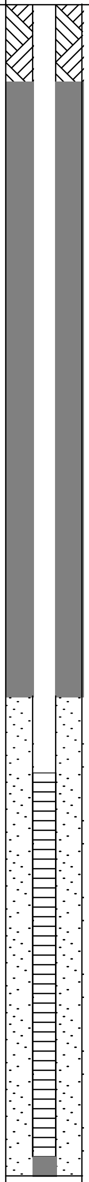
Boring Log

Project Number	Boring Number	Sheet
050067	MW-23-30	1 of 1

Project Name: Art Brass Plating
Location: Seattle, WA
Driller/Method: Cascade Drilling / Hollow Stem Auger
Sampling Method: D&M / Hammer Weight: 140 lb Jars / Hammer Drop: 30"
Ground Surface Elev
Depth to Water
Start/Finish Date 3/10/2010

Depth / Elevation (feet)	Borehole Completion	Sample Type/ID	Tests	PID (ppm)	Blows/ 6"	Material Type	Description	Depth (ft)
	 8" flushmount monument, 2" thermos well cap, concrete seal, 0'-2'						Vacuumed to 5' to clear for utilities. No soil logging, see MW-23-50 boring log.	
5	2" diameter schedule 40 PVC casing, threaded connection, 0'-20'							5
10	Hydrated bentonite chips, 2'-18'							10
15								15
	#2/12 monterey sand filter pack, 18'-30'							
20								20
25	2" diameter, schedule 40 PVC screen, 10-slot, 20'-30'							25
30	Threaded PVC endcap						Bottom of boring at 30.5'.	30
35								35

Sampler Type:
☐ No Recovery

PID - Photoionization Detector (Headspace Measurement)
▼ Static Water Level
▽ Water Level (ATD)

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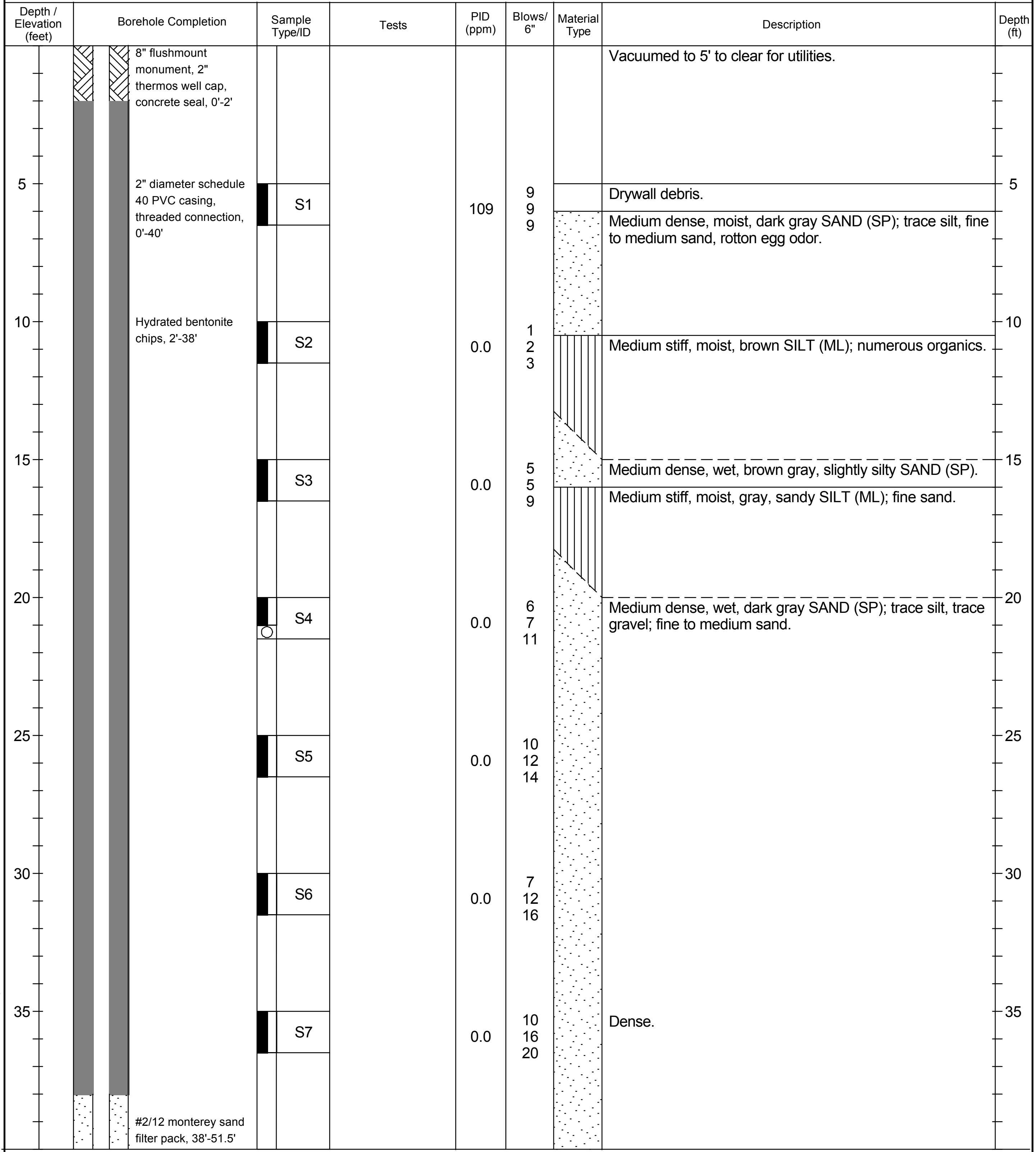
Boring Log

Project Number	Boring Number	Sheet
050067	MW-23-50	1 of 2

Project Name: Art Brass Plating
Location: Seattle, WA
Driller/Method: Cascade Drilling / Hollow Stem Auger
Sampling Method: D&M / Hammer Weight: 140 lb Jars / Hammer Drop: 30"
Ground Surface Elev
Depth to Water
Start/Finish Date 3/9/2010



Depth / Elevation (feet)	Borehole Completion	Sample Type/ID	Tests	PID (ppm)	Blows/ 6"	Material Type	Description	Depth (ft)
	8" flushmount monument, 2" thermos well cap, concrete seal, 0'-2'						Vacuumed to 5' to clear for utilities.	
5	2" diameter schedule 40 PVC casing, threaded connection, 0'-40'	S1		109	9 9 9		Drywall debris.	5
							Medium dense, moist, dark gray SAND (SP); trace silt, fine to medium sand, rotton egg odor.	
10	Hydrated bentonite chips, 2'-38'	S2		0.0	1 2 3		Medium stiff, moist, brown SILT (ML); numerous organics.	10
15		S3		0.0	5 5 9		Medium dense, wet, brown gray, slightly silty SAND (SP).	15
							Medium stiff, moist, gray, sandy SILT (ML); fine sand.	
20		S4 ○		0.0	6 7 11		Medium dense, wet, dark gray SAND (SP); trace silt, trace gravel; fine to medium sand.	20
25		S5		0.0	10 12 14			25
30		S6		0.0	7 12 16			30
35		S7		0.0	10 16 20		Dense.	35
	#2/12 monterey sand filter pack, 38'-51.5'							

Sampler Type:
○ No Recovery
▌ 3.25" OD D&M Split-Spoon Ring Sampler

PID - Photoionization Detector (Headspace Measurement)
▼ Static Water Level
▽ Water Level (ATD)

Logged by: AET
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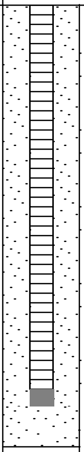
Boring Log

Project Number	Boring Number	Sheet
050067	MW-23-50	2 of 2

Project Name: Art Brass Plating
Location: Seattle, WA
Driller/Method: Cascade Drilling / Hollow Stem Auger
Sampling Method: D&M / Hammer Weight: 140 lb Jars / Hammer Drop: 30"
Ground Surface Elev
Depth to Water
Start/Finish Date 3/9/2010



Depth / Elevation (feet)	Borehole Completion	Sample Type/ID	Tests	PID (ppm)	Blows/ 6"	Material Type	Description	Depth (ft)
		▮ S8		0.0	19 21 26		Very stiff, wet, gray, sandy SILT (ML); fine sand.	
45	2" diameter, schedule 40 PVC screen, 10-slot, 40'-50'	▮ S9		0.0	20 26 29		Slightly sandy.	45
50	Threaded PVC endcap	▮ S10		0.0	17 23 30		Very sandy.	50
							Bottom of boring at 51.5'.	
55								55
60								60
65								65
70								70
75								75

Sampler Type:
○ No Recovery
▮ 3.25" OD D&M Split-Spoon Ring Sampler

PID - Photoionization Detector (Headspace Measurement)
▼ Static Water Level
▽ Water Level (ATD)

Logged by: AET
Approved by: DLC
Figure No.

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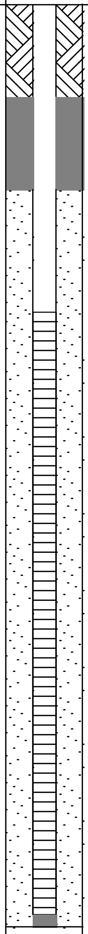
Boring Log

Project Number	Boring Number	Sheet
050067	MW-24	1 of 1

Project Name: Art Brass Plating
Location: Seattle, WA
Driller/Method: Cascade Drilling / Hollow Stem Auger
Sampling Method: D&M / Hammer Weight: 140 lb Jars / Hammer Drop: 30"
Ground Surface Elev
Depth to Water
Start/Finish Date 3/13/2010

Depth / Elevation (feet)	Borehole Completion	Sample Type/ID	Tests	PID (ppm)	Blows/ 6"	Material Type	Description	Depth (ft)
	 8" flushmount monument, 2" thermos well cap, concrete seal, 0'-1.5' 2" diameter schedule 40 PVC casing, threaded connection, 0'-5' Hydrated bentonite chips, 1.5'-3' #2/12 monterey sand filter pack, 3'-15'						Vacuumed to 5' to clear for utilities. No soil logging, see MW-24-50 boring log.	
5								5
10	2" diameter, schedule 40 PVC screen, 10-slot, 5'-15'							10
15	Threaded PVC endcap						Bottom of boring at 15'.	15
20								20

Sampler Type:
▢ No Recovery

PID - Photoionization Detector (Headspace Measurement)
▼ Static Water Level
▽ Water Level (ATD)

Logged by: RLR
Approved by: DLC
Figure No.

_ENV BORING LOG ART BRASS-MW70.GPJ May 5, 2010

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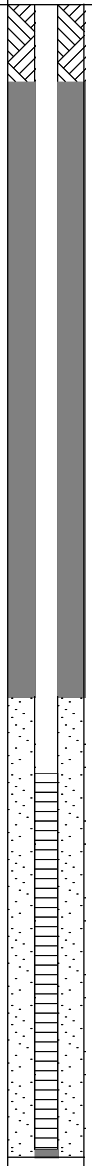
Boring Log

Project Number	Boring Number	Sheet
050067	MW-24-30	1 of 1

Project Name: Art Brass Plating
Location: Seattle, WA
Driller/Method: Cascade Drilling / Hollow Stem Auger
Sampling Method: D&M / Hammer Weight: 140 lb Jars / Hammer Drop: 30"
Ground Surface Elev
Depth to Water
Start/Finish Date 3/13/2010

Depth / Elevation (feet)	Borehole Completion	Sample Type/ID	Tests	PID (ppm)	Blows/ 6"	Material Type	Description	Depth (ft)
0	8" flushmount monument, 2" thermos well cap, concrete seal, 0'-2'						Vacuumed to 5' to clear for utilities. No soil logging, see MW-24-50 boring log.	
5	2" diameter schedule 40 PVC casing, threaded connection, 0'-20'							5
10	Hydrated bentonite chips, 2'-18'							10
15								15
20	#2/12 monterey sand filter pack, 18'-30'							20
25	2" diameter, schedule 40 PVC screen, 10-slot, 20'-30'							25
30	Threaded PVC endcap						Bottom of boring at 30'.	30
35								35



Sampler Type:
▢ No Recovery

PID - Photoionization Detector (Headspace Measurement)
▼ Static Water Level
▽ Water Level (ATD)

Logged by: RLR
Approved by: DLC
Figure No.

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Boring Log

Project Number	Boring Number	Sheet
050067	MW-24-50	1 of 2

Project Name: Art Brass Plating
Location: Seattle, WA
Driller/Method: Cascade Drilling / Hollow Stem Auger
Sampling Method: D&M / Hammer Weight: 140 lb Jars / Hammer Drop: 30"
Ground Surface Elev
Depth to Water
Start/Finish Date 3/13/2010

Depth / Elevation (feet)	Borehole Completion	Sample Type/ID	Tests	PID (ppm)	Blows/ 6"	Material Type	Description	Depth (ft)
0	8" flushmount monument, 2" thermos well cap, concrete seal, 0'-2'						Vacuumed to 5' to clear for utilities.	
5	2" diameter schedule 40 PVC casing, threaded connection, 0'-40'	S1		0.0	12 12 16	SP	Medium dense, moist, dark brown gray, slightly silty SAND (SP); fine to medium sand. Trace silt.	5
10	Hydrated bentonite chips, 2'-38'	S2		0.0	2 2 3	ML	Soft, moist, brown, slightly sandy SILT (ML); numerous organics.	10
15		S3		0.0	3 3 4	SP	Loose, wet, dark gray SAND (SP); trace silt; fine to medium sand.	15
20		S4		0.0	4 5 7		Medium dense.	20
25		S5		0.0	10 12 16		Occasional organics, woody debris.	25
30		S6		0.0	7 12 14		Slightly silty.	30
35		S7		0.0	8 10 13		Occasional organics, woody debris, trace silt.	35
38	#2/12 monterey sand filter pack, 38'-51.5'							

Sampler Type:
○ No Recovery
▮ 3.25" OD D&M Split-Spoon Ring Sampler

PID - Photoionization Detector (Headspace Measurement)
▼ Static Water Level
▽ Water Level (ATD)

Logged by: RLR
Approved by: DLC
Figure No.

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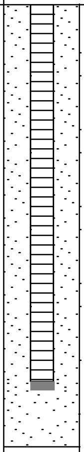
Boring Log

Project Number	Boring Number	Sheet
050067	MW-24-50	2 of 2

Project Name: Art Brass Plating
Location: Seattle, WA
Driller/Method: Cascade Drilling / Hollow Stem Auger
Sampling Method: D&M / Hammer Weight: 140 lb Jars / Hammer Drop: 30"
Ground Surface Elev
Depth to Water
Start/Finish Date 3/13/2010



Depth / Elevation (feet)	Borehole Completion	Sample Type/ID	Tests	PID (ppm)	Blows/ 6"	Material Type	Description	Depth (ft)
		S8		0.0	10 16 20		Dense, predominantly fine sand.	
45	2" diameter, schedule 40 PVC screen, 10-slot, 40'-50'	S9		0.0	16 19 19			45
50	Threaded PVC endcap	S10		0.0	19 20 24			50
							Bottom of boring at 51.5'.	
55								55
60								60
65								65
70								70
75								75

Sampler Type:
○ No Recovery
◧ 3.25" OD D&M Split-Spoon Ring Sampler

PID - Photoionization Detector (Headspace Measurement)
▼ Static Water Level
▽ Water Level (ATD)

Logged by: RLR
Approved by: DLC
Figure No.

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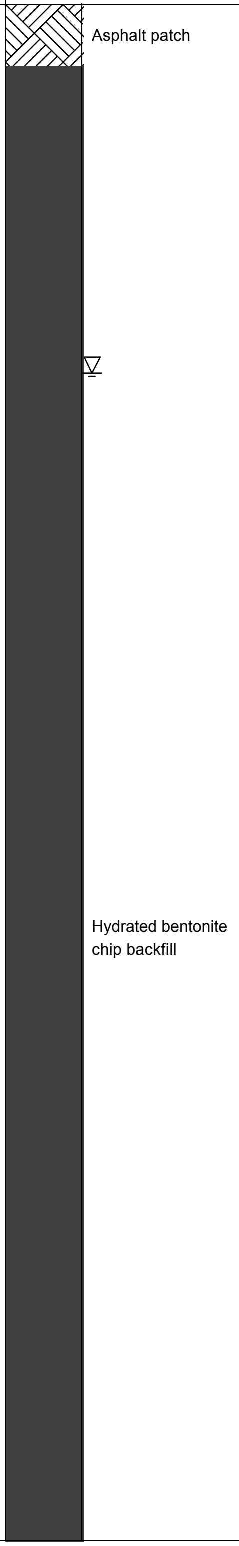
Boring Log

Project Number	Boring Number	Sheet
050067	SPO-42	1 of 3

Project Name: Art Brass Plating
Location: Seattle, Washington
Driller/Method: NW Probe / Geoprobe
Sampling Method: Direct Push
Ground Surface Elev
Depth to Water
Start/Finish Date 11/9/2009



Depth / Elevation (feet)	Borehole Completion	Sample Type/ID	Tests	PID (ppm)	Blows/ 6"	Material Type	Description	Depth (ft)
1							No soil samples taken.	1
2								2
3								3
4								4
5								5
6	▽							6
7								7
8								8
9								9
10								10
11								11
12								12
13								13
14								14
15								15
16								16
17								17
18								18
19								19
20								20
21								21
22								22
23								23
24								24

Sampler Type:
☐ No Recovery

PID - Photoionization Detector (Headspace Measurement)
▼ Static Water Level
▽ Water Level (ATD)

Logged by: AET
Approved by: EJM
Figure No. 6

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Boring Log

Project Number	Boring Number	Sheet
050067	SPO-42	2 of 3

Project Name: Art Brass Plating
Location: Seattle, Washington
Driller/Method: NW Probe / Geoprobe
Sampling Method: Direct Push
Ground Surface Elev
Depth to Water
Start/Finish Date 11/9/2009

Depth / Elevation (feet)	Borehole Completion	Sample Type/ID	Tests	PID (ppm)	Blows/ 6"	Material Type	Description	Depth (ft)
26								26
27								27
28								28
29								29
30								30
31								31
32								32
33								33
34								34
35								35
36								36
37								37
38								38
39								39
40								40
41								41
42							No water sample collected, not enough water produced.	42
43								43
44		SPO-42-(40-44)						44
45								45
46								46
47								47
48								48
49								49

Sampler Type:
○ No Recovery

PID - Photoionization Detector (Headspace Measurement)
▼ Static Water Level
▽ Water Level (ATD)

Logged by: AET
Approved by: EJM
Figure No. 6

Aspect consulting
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Boring Log

Project Number	Boring Number	Sheet
050067	SPO-42	3 of 3

Project Name: Art Brass Plating
Location: Seattle, Washington
Driller/Method: NW Probe / Geoprobe
Sampling Method: Direct Push
Ground Surface Elev
Depth to Water
Start/Finish Date 11/9/2009

Depth / Elevation (feet)	Borehole Completion	Sample Type/ID	Tests	PID (ppm)	Blows/ 6"	Material Type	Description	Depth (ft)
51							Water sample collected at approximately 53': Temperature: 11.8° C, Conductivity: 670 uS/cm	51
52		SPO-42-(51-53)						52
53								53
54								54
55							Water sample collected at approximately 58': Temperature: 11.9° C, Conductivity: 710 uS/cm	55
56		SPO-42-(55-58)						56
57								57
58								58
59								59
60								60
61								61
62								62
63		SPO-42-(63-64)					Water sample collected at approximately 64': Temperature: 12.6° C, Conductivity: 690 uS/cm	63
64								64
65								65
66								66
67								67
68								68
69								69
70								70
71								71
72							Water sample collected at approximately 74': Temperature: 12.5° C, Conductivity: 260 uS/cm	72
73		SPO-42-(72-74)						73
74							Bottom of boring at 74' bgs	74

Sampler Type:
☐ No Recovery

PID - Photoionization Detector (Headspace Measurement)
▼ Static Water Level
▽ Water Level (ATD)

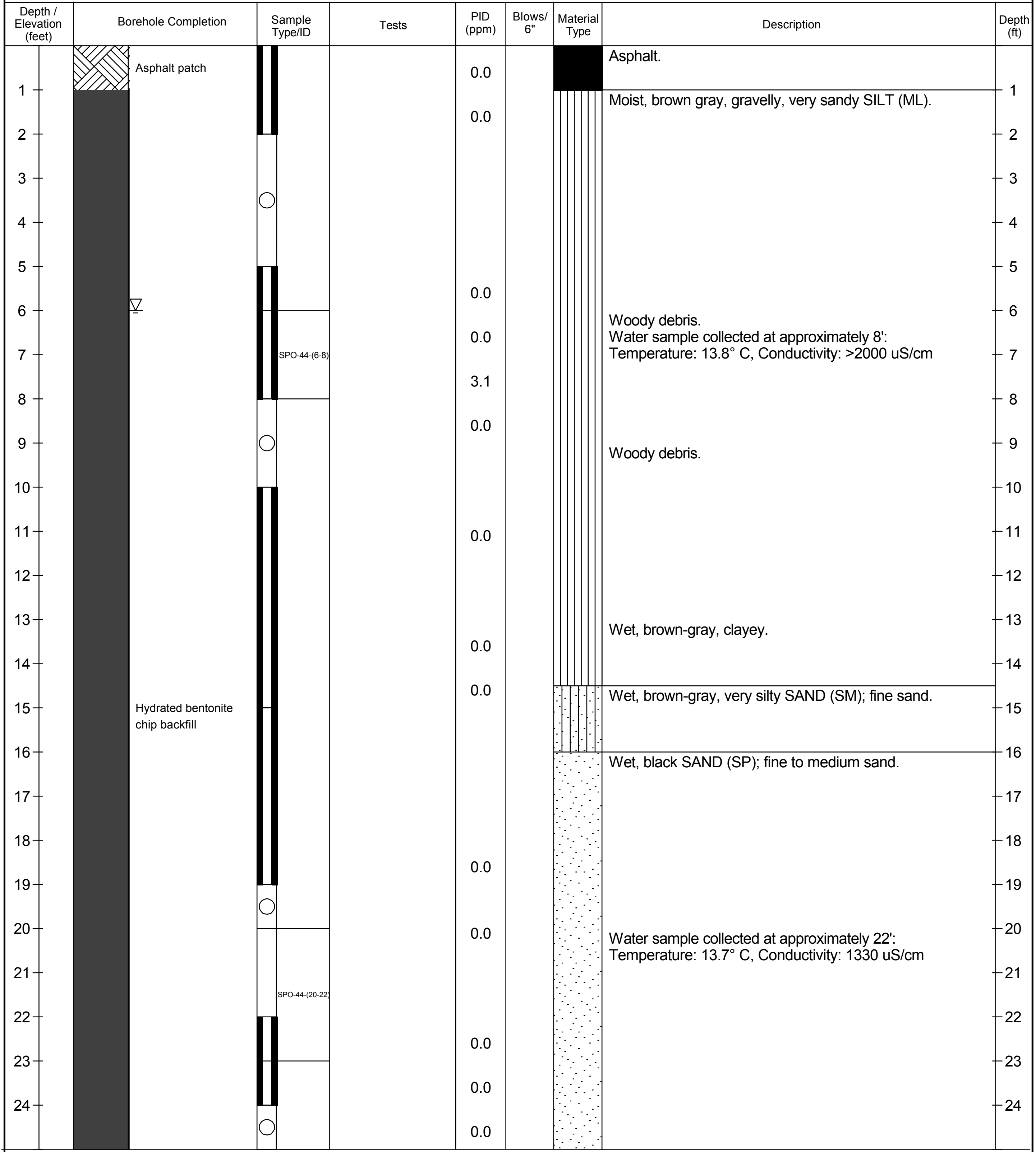
Logged by: AET
Approved by: EJM
Figure No. 6

Aspectconsulting
earth + water

Boring Log

Project Number	Boring Number	Sheet
050067	SPO-44	1 of 3

Project Name: Art Brass Plating
Location: Seattle, Washington
Driller/Method: NW Probe / Geoprobe
Sampling Method: Direct Push
Ground Surface Elev
Depth to Water
Start/Finish Date 11/11/2009



Depth / Elevation (feet)	Borehole Completion	Sample Type/ID	Tests	PID (ppm)	Blows/ 6"	Material Type	Description	Depth (ft)
	Asphalt patch	▮		0.0		■	Asphalt.	
1		▮		0.0			Moist, brown gray, gravelly, very sandy SILT (ML).	1
2								2
3		○						3
4								4
5		▮		0.0				5
6	▽	▮		0.0			Woody debris. Water sample collected at approximately 8': Temperature: 13.8° C, Conductivity: >2000 uS/cm	6
7		SPO-44-(6-8)		3.1				7
8				0.0				8
9		○					Woody debris.	9
10		▮						10
11		▮		0.0				11
12		▮						12
13		▮		0.0			Wet, brown-gray, clayey.	13
14		▮		0.0			Wet, brown-gray, very silty SAND (SM); fine sand.	14
15	Hydrated bentonite chip backfill	▮						15
16		▮					Wet, black SAND (SP); fine to medium sand.	16
17		▮						17
18		▮		0.0				18
19		○						19
20				0.0			Water sample collected at approximately 22': Temperature: 13.7° C, Conductivity: 1330 uS/cm	20
21		SPO-44-(20-22)						21
22		▮		0.0				22
23		▮		0.0				23
24		○		0.0				24

Sampler Type:
○ No Recovery
▮ Continuous Core

PID - Photoionization Detector (Headspace Measurement)
▼ Static Water Level
▽ Water Level (ATD)

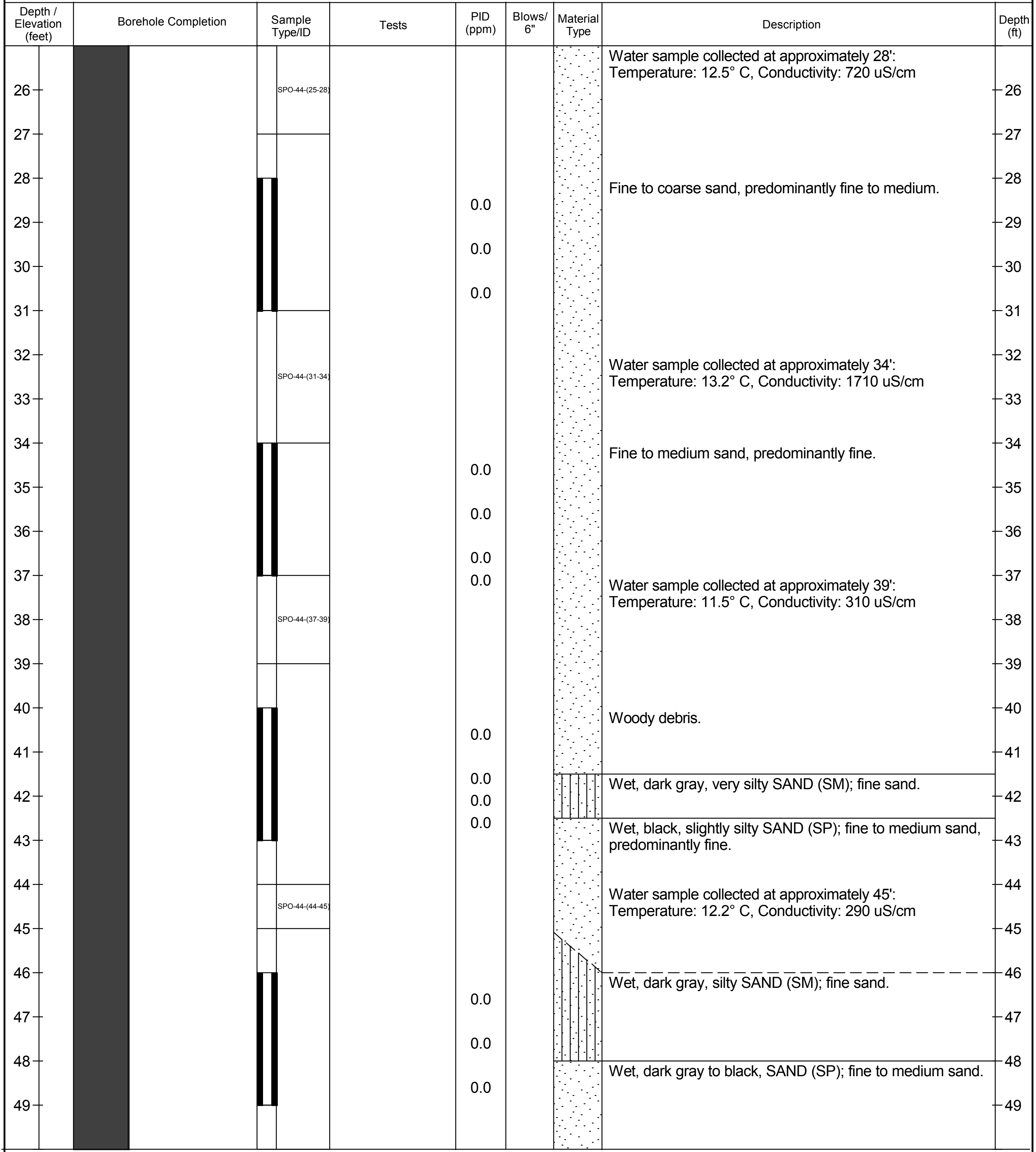
Logged by: AET
Approved by: EJM
Figure No. 7

Aspect consulting
earth + water

Boring Log

Project Number	Boring Number	Sheet
050067	SPO-44	2 of 3

Project Name: Art Brass Plating
Location: Seattle, Washington
Driller/Method: NW Probe / Geoprobe
Sampling Method: Direct Push
Ground Surface Elev
Depth to Water
Start/Finish Date 11/11/2009



Water sample collected at approximately 28': Temperature: 12.5° C, Conductivity: 720 uS/cm

Fine to coarse sand, predominantly fine to medium.

Water sample collected at approximately 34': Temperature: 13.2° C, Conductivity: 1710 uS/cm

Fine to medium sand, predominantly fine.

Water sample collected at approximately 39': Temperature: 11.5° C, Conductivity: 310 uS/cm

Woody debris.

Wet, dark gray, very silty SAND (SM); fine sand.

Wet, black, slightly silty SAND (SP); fine to medium sand, predominantly fine.

Water sample collected at approximately 45': Temperature: 12.2° C, Conductivity: 290 uS/cm

Wet, dark gray, silty SAND (SM); fine sand.

Wet, dark gray to black, SAND (SP); fine to medium sand.

Sampler Type:
○ No Recovery
▮ Continuous Core

PID - Photoionization Detector (Headspace Measurement)
▼ Static Water Level
▽ Water Level (ATD)

Logged by: AET
Approved by: EJM
Figure No. 7

Aspect consulting
earth + water

Boring Log

Project Number	Boring Number	Sheet
050067	SPO-44	3 of 3

Project Name: Art Brass Plating
Location: Seattle, Washington
Driller/Method: NW Probe / Geoprobe
Sampling Method: Direct Push
Ground Surface Elev
Depth to Water
Start/Finish Date 11/11/2009

Depth / Elevation (feet)	Sample Type/ID	Tests	PID (ppm)	Blows/ 6"	Description	Depth (ft)
50–51	SPO-44-(50-51)				Water sample collected at approximately 51': Temperature: 11.2° C, Conductivity: 280 uS/cm	51
52–53	Continuous Core		0.0		Wet, dark gray, very sandy SILT (ML); fine sand.	52
53–54	Continuous Core		0.0		Wet, dark gray, silty SAND (SM); fine sand.	53
54–55	Continuous Core		0.0		Wet, dark gray, slightly silty SAND (SP); fine sand.	54
56–57	SPO-44-(56-57)				Water sample collected at approximately 57': Temperature: 11.8° C, Conductivity: 590 uS/cm	56
58–61	No Recovery					59
64–65	SPO-44-(64-65)				Water sample collected at approximately 65': Temperature: 13.5° C, Conductivity: 690 uS/cm	64
66–68	Continuous Core		0.0 0.0		Wet, black, silty SAND (SM); fine sand.	66
68–69	No Recovery					68
70–72	SPO-44-(70-72)				Water sample collected at approximately 72': Temperature: 14.4° C, Conductivity: >2000 uS/cm	71
74					Bottom of boring at 74' bgs	74

Sampler Type:
○ No Recovery
▮ Continuous Core

PID - Photoionization Detector (Headspace Measurement)
▼ Static Water Level
▽ Water Level (ATD)

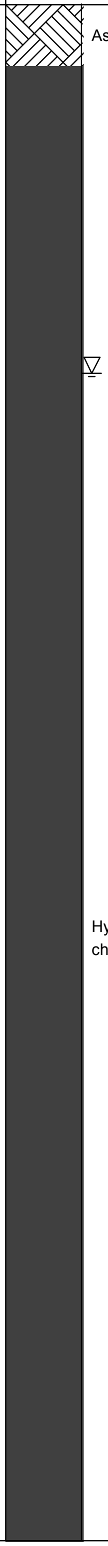
Logged by: AET
Approved by: EJM
Figure No. 7

Aspectconsulting
earth + water

Boring Log

Project Number	Boring Number	Sheet
050067	SPO-45	1 of 3

Project Name: Art Brass Plating
Location: Seattle, Washington
Driller/Method: NW Probe / Geoprobe
Sampling Method: Direct Push
Ground Surface Elev
Depth to Water
Start/Finish Date 11/10/2009



Depth / Elevation (feet)	Borehole Completion	Sample Type/ID	Tests	PID (ppm)	Blows/ 6"	Material Type	Description	Depth (ft)
0–1	Asphalt patch							
1							No soil samples taken.	1
6	▽						Water sample collected at approximately 8': Temperature: 13.8° C, Conductivity: >2000 uS/cm	6
7		SPO-45-(6-8)						7
15	Hydrated bentonite chip backfill							15
19							Water sample collected at approximately 22': Temperature: 13.7° C, Conductivity: 1330 uS/cm	19
20–21		SPO-45-(19-22)						21
24								24

Sampler Type:
☐ No Recovery

PID - Photoionization Detector (Headspace Measurement)
▼ Static Water Level
▽ Water Level (ATD)

Logged by: AET
Approved by: EJM
Figure No. 8

Aspectconsulting
earth + water

Boring Log

Project Number	Boring Number	Sheet
050067	SPO-45	2 of 3

Project Name: Art Brass Plating
Location: Seattle, Washington
Driller/Method: NW Probe / Geoprobe
Sampling Method: Direct Push
Ground Surface Elev
Depth to Water
Start/Finish Date 11/10/2009

Depth / Elevation (feet)	Borehole Completion	Sample Type/ID	Tests	PID (ppm)	Blows/ 6"	Material Type	Description	Depth (ft)
							Water sample collected at approximately 27': Temperature: 12.5° C, Conductivity: 720 uS/cm	
26		SPO-45-(25-27)						26
27								27
28								28
29								29
30								30
31								31
32		SPO-45-(32-33)					Water sample collected at approximately 33': Temperature: 13.2° C, Conductivity: 1710 uS/cm	32
33								33
34								34
35								35
36								36
37							Water sample collected at approximately 40': Temperature: 11.5° C, Conductivity: 310 uS/cm	37
38		SPO-45-(37-40)						38
39								39
40								40
41								41
42								42
43								43
44		SPO-45-(44-45)					Water sample collected at approximately 45': Temperature: 12.2° C, Conductivity: 290 uS/cm	44
45								45
46								46
47								47
48								48
49								49

Sampler Type:
○ No Recovery

PID - Photoionization Detector (Headspace Measurement)
▼ Static Water Level
▽ Water Level (ATD)

Logged by: AET
Approved by: EJM
Figure No. 8

_ENV BORING LOG ART_BRASS_SP.GPJ March 4, 2010

Aspect consulting
earth + water

Boring Log

Project Number	Boring Number	Sheet
050067	SPO-45	3 of 3

Project Name: Art Brass Plating
Location: Seattle, Washington
Driller/Method: NW Probe / Geoprobe
Sampling Method: Direct Push
Ground Surface Elev
Depth to Water
Start/Finish Date 11/10/2009

Depth / Elevation (feet)	Borehole Completion	Sample Type/ID	Tests	PID (ppm)	Blows/ 6"	Material Type	Description	Depth (ft)
	▇	SPO-45-(50-51)					Water sample collected at approximately 51': Temperature: 11.2° C, Conductivity: 280 uS/cm	
51	▇							51
52	▇							52
53	▇							53
54	▇							54
55	▇						Water sample collected at approximately 58': Temperature: 11.8° C, Conductivity: 590 uS/cm	55
56	▇	SPO-45-(55-58)						56
57	▇							57
58	▇							58
59	▇							59
60	▇							60
61	▇							61
62	▇							62
63	▇							63
64	▇	SPO-45-(64-65)					Water sample collected at approximately 65': Temperature: 13.5° C, Conductivity: 690 uS/cm	64
65	▇							65
66	▇							66
67	▇							67
68	▇							68
69	▇							69
70	▇							70
71	▇						Water sample collected at approximately 73': Temperature: 14.4° C, Conductivity: >2000 uS/cm	71
72	▇	SPO-45-(71-73)						72
73	▇							73
74							Bottom of boring at 74' bgs	74

Sampler Type:
○ No Recovery

PID - Photoionization Detector (Headspace Measurement)
▼ Static Water Level
▽ Water Level (ATD)

Logged by: AET
Approved by: EJM
Figure No. 8

APPENDIX E

Injection Reagents, Product Sheets, Safety Data Sheets, and Case Studies'

Vendor	Reagent Type	Reagent	% Iron	% Carbon	Formulation	Packaging	Spec Sheet
Peroxychem	ISCR	EHC ISCR Reagent	40	60	Dry powder	50-lb bags	http://www.peroxychem.com/media/191081/peroxychem-ehc-product-sheet.pdf
	ISCR	EHC Liquid Reagent (25% microemulsion)	-	25	Emulsion	420 lb drums	http://www.peroxychem.com/media/174892/peroxychem-ehc-liquid-product-sheet-06-02-esd-14fnl.pdf
	ISCR	EHC Liquid Reagent (100% concentrate)		100	Liquid	460 lb drum	http://www.peroxychem.com/media/174892/peroxychem-ehc-liquid-product-sheet-06-02-esd-14fnl.pdf
	ISCR	EHC Liquid Fe Reagent (add to ELS)	100	-	Liquid	524.6 lb bags	http://www.peroxychem.com/media/174892/peroxychem-ehc-liquid-product-sheet-06-02-esd-14fnl.pdf
	EAB	ELS Microemulsion	-	25	Emulsion	420 lb drums	http://www.peroxychem.com/media/165670/peroxychem-els-product-sheet.pdf
Provectus	ISCR	Provect-IR	15	-	Dry powder	50-lb bags	http://www.provectusenvironmental.com/marketing/tech_docs/Provect-IR_Tech_Sheet_FINAL.pdf
	ISCR	EZVI-CH4	14	-	Emulsion	330 USG IBC Totes	http://www.provectusenvironmental.com/marketing/tech_docs/EZVI-CH4_Tech_Sheet_FINAL.pdf
	EAB	ERD-CH4	-	60	Liquid	275 USG IBC Totes	http://www.provectusenvironmental.com/marketing/tech_docs/ERD-CH4_Tech_Sheet_Final.pdf
EOS Remediation	ISCR	EOS ZVI	50	48	Slurry	420 lb drums	http://www.eosremediation.com/download/product_information/eos-products/EOSZVI-Product-Sheet.pdf
	EAB	EOS Pro	-	74	Emulsion	420 lb drums	http://www.eosremediation.com/download/product_information/eos-products/EOSPro-Product-Sheet.pdf
	EAB	EOS 100	-	100	Concentrated oil	550 lb drums	http://www.eosremediation.com/download/product_information/eos-products/EOS100-Product-Sheet.pdf
Tersus	ISCR	MicroEVO ISCR	33	60		N/A	
	EAB	EDS-ER	-	100	Concentrated oil	275-gallon IBC containers	
	EAB	NanoEVO	-	100	Emulsion	N/A	
	EAB	MacroEVO	-	-	Emulsion	N/A	
Hepure	ISCR	Emulsified ZVI	14	39	Emulsion	N/A	
	EAB	Renewal-SD	0	45	Emulsion	N/A	
	EAB	Renewal-FRL	0	45	Emulsion	N/A	

Notes:

N/A: not available at this time

Anaerobic Bioremediation of Groundwater Using Edible Oil Substrate EOS® In an Unconfined Groundwater Aquifer

Matt Sedor, M.S., Yonathon Yoseph, P.G., C.H.G., msedor-rsi@sbcglobal.net,
(Remediation Sciences, Inc.), Jeff Baker (Vironex, Inc.), and
John Sankey, P.Eng. (True Blue Technologies Inc.).

ABSTRACT: To treat groundwater contaminants *in situ*, enhanced anaerobic bioremediation processes can be stimulated through addition of soluble substrates. At a dry cleaners site located in San Jose, California, the goal was to find a substrate that is long lasting and easily distributed into the saturated soils. After evaluating several alternatives, *in situ* bioremediation using an emulsified edible oil substrate (EOS®) was selected as the preferred alternative for groundwater remediation.

At this site, the impact of injecting substrate into the upper aquifer was observed in an unconfined groundwater aquifer. Tetrachloroethene (PCE) breakdown was monitored at three locations across the site. The highest PCE and trichloroethene (TCE) concentrations in the January 2005 pre-EOS injection-sampling event were detected in well MW-1A at concentrations of 8,500 µg/L and 200 g/L, respectively. The highest *cis*-1,2-dichloroethene (*cis*-DCE) was detected in well MW-1A at concentration of 160 µg/L. *Trans*-1,2-DCE (*trans*-DCE) was also detected and only small amounts of VC were detected in the groundwater prior to treatment.

After 2.5 months post-injection (July 2005), the PCE concentration in MW-1A was reduced to 18 µg/L and the TCE concentration was reported to be 100 µg/L. The concentration of *cis*-DCE had increased in MW-1A to 1,200 µg/L, suggesting the presence of enhanced bioremediation. No PCE, TCE, or 1,1-DCE was detected in the shallow wells during the October 2005 sampling event (6-months post-injection). Conversely, the concentration *cis*-DCE continued to increase and was detected in well MW-1A at 2,300 µg/L. By six months after treatment, VC was readily detected in each of the monitor wells at concentrations of 39, 200, and 35 µg/L in MW-1A, MW-2, and MW-3, respectively.

Sub-reportable levels of PCE, TCE, and 1,1-DCE were detected again in the shallow wells during the January 2006 sampling event (9-months post-injection) The concentration of *cis*-DCE also began to decrease and was detected in well MW-1A at 630 µg/L. By nine months after treatment, VC was readily detected in each of the monitor wells at concentrations of 300, 40, and 88 µg/L in MW-1A, MW-2, and MW-3, respectively.

The results of the pre- and post-injection sampling of three wells in the treatment zone showed the rapid conversion of the aquifer to anaerobic reducing conditions favorable for reductive dechlorination to occur. The enhanced conditions resulted in rapid disappearance of PCE from 8,500 µg/L to below the MDL, reductions in TCE, and a measurable increase of *cis*-DCE and VC at all the shallow zone wells. Some methane is being produced, but ethane or ethene production has yet to be detected. The emulsified oil substrate (EOS®) is expected to continue to sustain favorable conditions for an extended duration. Continued monitoring is expected to eventually document to complete remediation of the site.

INTRODUCTION: To treat groundwater contaminants *in situ*, enhanced anaerobic bioremediation is a cost-effective alternative. Contaminants amenable to *in situ* anaerobic bioremediation include certain heavy metals, nitrate, perchlorate, acid mine drainage and chlorinated organics, such as tetrachloroethene (PCE), trichloroethene (TCE), *cis*-1, 2-dichloroethene (*cis*-DCE), vinyl chloride (VC), 1,1,1-trichloroethane (1,1,1-TCA), 1,1,2-trichloroethane (1,1,2-TCA), 1,2-dichloroethane (1,2-DCA), carbon tetrachloride (CT), and chloroform (CF).

Anaerobic bioremediation processes can be stimulated through addition of soluble substrates (e.g., lactate, butyrate, propionate, acetate, molasses, and refined sugars), solid substrates (e.g., bark mulch, compost, chitin and peat), and slowly soluble substrates such as vegetable oil. For some sites, the goal is to find a substrate that is long lasting and easily distributed into the saturated soils. After evaluating several alternatives, *in situ* bioremediation using an emulsified edible oil substrate (EOS®) was selected as the preferred alternative for groundwater remediation.

EOS® TECHNOLOGY: Remediation Sciences, Inc. (RSI) purchased EOS® from EOS Remediation of Raleigh, NC. The concentrated emulsified soybean oil product is manufactured with uniform oil droplets approximately 1 micron in diameter. It is primarily composed of food-grade vegetable oil and emulsifiers with additional vitamins to support bacterial growth. The emulsion is injected into the saturated zone. The soybean oil ferments, provides hydrogen, and donates its electrons to the chlorinated contaminants resulting in a microbial-mediated sequential removal of chlorine atoms from the target chlorinated volatile organic compounds (CVOCs). Sequential anaerobic reductive dechlorination of TCE results in the formation of intermediate, less-chlorinated daughter products including *cis*-DCE and VC, and non-toxic metabolic non-chlorinated end products, ethane and/or ethane.

DIRECT PUSH INJECTION OF EOS®: Vironex, Inc., a national environmental field service company, was contracted to inject the EOS®. They utilized Geoprobe® direct push technology systems (truck, track, or limited access mounted) to advance a Vironex custom-designed bottom-up injection tool at each of the injection boreholes. This injection tooling promotes lateral distribution of reagents to enhance contact with contaminants throughout the target injection interval. To ensure that the site remains safe, clean and professional throughout the process, Vironex integrated a one-way check valve assembly to eliminate any backpressure that may occur while retracting the injection tooling out of the borehole.

While the injection tooling was advanced, Vironex utilized its custom built, self-contained remediation delivery systems to prepare the EOS® to the desired concentration. The injection system integrated a single motor control center to operate their mixing systems and pumps, which was integrated within a stainless steel secondary containment.

Vironex targeted 1 feet to 5 feet (0.3 to 1.5 m) injection intervals with their customized injection tooling to provide for uniform vertical and horizontal distribution of EOS® throughout the target injection zone.

During injection flow, total flow and pressure are continuously monitored to ensure adherence to injection design parameters. Over the duration of the project, Vironex injected 4,400 gallons of EOS mix and 22,700 gallons of flush water over a period of 6 days.

Once the injection tooling was retracted through the injection zone, it was removed from the borehole and sealed with an appropriate backfill material.

INJECTION DESIGN: Injecting the oil as an oil-in-water emulsion can enhance distribution of edible oils in the subsurface. The emulsion is prepared to: (1) be stable for extended time periods (e.g., non-coalescing); (2) have small, uniform droplets to allow transport in most aquifers; and (3) have a negative surface charge to optimize oil droplet sorption to soil. At other project sites, emulsified oils have been effectively distributed over 20 ft (6.1 m) away from the injection point and were demonstrated to provide a long-lasting carbon source to support reductive dechlorination (Borden et al., 2001) for over 3 years.

Oil emulsions have been used to treat contaminated groundwater in a permeable reactive barrier (PRB) configuration by injecting the emulsion through a series of injection points or permanent wells installed in a line perpendicular to groundwater flow. The oil breaks down to shorter-chain fatty acids and eventually to hydrogen, and donates its electrons to the chlorinated contaminants in the groundwater that pass through the emulsion treated zone. Typical injection well layouts for a permeable reactive barrier and source zone grid approach are shown in Diagram 1.

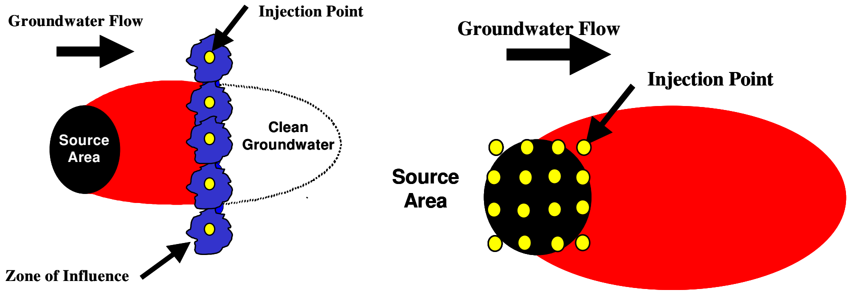


DIAGRAM 1. Typical Layouts for Injecting EOS®

RSI injected the emulsified oil substrate (EOS®), into the groundwater at a dry cleaners site in the proximity of San Jose area between April 20 and April 28, 2005. The injections were the initial steps in a bioremediation process to break down PCE in groundwater at the site, by applying the substrate in a 10-foot (3.1 m) center grid in three areas. Part of the application was in a small grid layout into the source area with PCE concentration of over 5,000 µg/L. Additional substrate was injected in barrier formations up gradient of the source area just north of the north wall of the dry cleaners, and also down gradient of the source area just south of the south wall.

RSI applied vegetable oil substrate in a barrier line parallel to the alley in the source area and a second barrier line just east of the cleaners by introducing the emulsified oil using six borings 10 feet (3.1 m) apart just west of the cleaners and also in a second line in front of the cleaners. Based on a model RSI ran using the substrate calculation spreadsheet furnished by EOS Remediation, approximately 1,100 gallons (4,164 liters) of EOS® concentrate were required for the shallow zone groundwater remediation. Following the vendor recommendations, the emulsified concentrate was diluted to a ratio of 3 portions of water to 1 portion of concentrate and then injected. Therefore, approximately 4,400 gallons (16,655 liters) of the diluted emulsion was injected into the groundwater zones.

Following the application of the vegetable oil, approximately 22,700 gallons (85,928 liters) of dechlorinated tap water were injected, and dispersed through the aquifer via the 12 injection points, to distribute the vegetable oil into zone of contamination beneath the cleaners. The water was mixed with vitamin B-12 to nourish and enhance the bacteria already present. Pre-injection samples collected from the contaminated aquifer indicated the presence of a viable population of Dehalococcoides ethenogenes, the microorganisms necessary for the complete biotransformation of the PCE to ethene to occur.

RESULTS: The impact of injecting substrate into the aquifer beneath the dry cleaners site on PCE breakdown was monitored at three locations across the site. MW-1A is located up gradient, just north of the plume, in close proximity to the source area of contamination. MW-2 is located northwest of the source toward the edge of the plume. MW-3 is located down gradient of the source, in the center of the original contamination plume. Of the three wells, MW-1A was the most heavily impacted at the beginning of the project. Well locations are indicated in the Figures 1 thru 4 (See Appendix 1).

The highest PCE and TCE concentrations in the January 2005, pre-EOS injection, sampling event were detected in well MW-1A at a concentrations of 8,500 µg/L and 200 g/L, respectively. The highest *cis*-DCE was detected in well MW-1A at concentration of 160 µg/L. *Trans*-DCE was also detected and only small amounts of VC were detected in the groundwater prior to treatment. Analytical data are summarized in Table 1 and plotted in charts 1 through 3 corresponding to each well. The extent of the plume of the major contaminants is given in Figure 1 (See Appendix 1).

After just 2.5 months post-injection (July 2005), the PCE concentration in MW-1A was reduced to 18 µg/L and the TCE concentration was reported to be 100 µg/L. The concentration of *cis*-DCE had increased in MW-1A to 1,200 µg/L, suggesting the presence of enhanced bioremediation. The analytical data are provided in Table 1 and plotted in charts 1 through 3 corresponding to each well. The extent of the plume of the major contaminants is given in Figure 2 (See Appendix 1).

No PCE, TCE, or 1, 1-DCE was detected in the shallow wells during the October 2005 sampling event (6-months post-injection). Conversely, the concentration *cis*-DCE continued to increase and was detected in well MW-1A at 2,300 µg/L. By six months after treatment, VC was readily detected in each of the monitor wells at concentrations of 39, 200, and 35 µg/L in MW-1A, MW-2, and MW-3, respectively. Tabulated data are provided in Table 1 and plotted in charts 1 through 3 corresponding to each well. The extent of the plume of the major contaminants is given in Figure 3 (See Appendix 1).

Sub-reportable levels of PCE, TCE, and 1, 1-DCE were detected again in the shallow wells during the January 2006 sampling event (9-months post-injection) The concentration of *cis*-DCE also began to decrease and was detected in well MW-1A at 630 µg/L. By nine months after treatment, VC was readily detected in each of the monitor wells at concentrations of 300, 40, and 88 µg/L in MW-1A, MW-2, and MW-3, respectively. The data in Table 1 are plotted in charts 1 through 3 corresponding to each well. The extent of the plume of the major contaminants is given in Figure 4 (See Appendix 1).

The results of the pre- and post-injection sampling of three wells in the treatment zone showed the rapid conversion of the aquifer to anaerobic reducing conditions favorable for reductive dechlorination to occur. The enhanced conditions resulted in rapid disappearance of PCE from 8,500 µg/L to below the MDL, reductions in TCE, and a measurable increase of *cis*-DCE and VC at all the shallow zone wells. Some methane is being produced, but ethane or ethene production has yet to be detected. The emulsified oil substrate (EOS$^{®}$) is expected to continue to sustain favorable conditions for an extended duration. Continued monitoring is expected to eventually document to complete remediation of the site.

REFERENCES

Robert C. Borden and Christie Zawtocki, Michael D. Lee, Erica S Becvar, Patrick E. Haas, Bruce M. Henry, AFCEE Protocol For Enhanced Anaerobic Bioremediation Using Edible Oils

APPENDIX 1

TABLE 1 ANALYTICAL AND FIELD MEASUREMENT PARAMETER DATA

Well ID	Analyte Units DATE SAMPLED	PCE[1] µg/L[2]	TCE[3] µg/L	Cis-1,2-DCE[4] µg/L	Trans-1,2-DCE[5] µg/L	Vinyl Chloride µg/L	Methane mg/L	Ethane mg/L	Ethene mg/L	TOC[6] mg/L[7]	DO[8] mg/L	ORP[9] mV[10]	pH --	SEC[11] mS/cm[12]	Sulfate mg/L	Chloride mg/L
Shallow Zone:																
MW-1A	5/21/2002	11,000	ND(250)/212(J)[7]	ND(250)/80(J)	ND(250)/36(J)	ND(250)	--	--	--	--	0.14	104	6.31	0.233	--	--
	1/27/2005	8,500	200	160	30J	79	--	--	--	2.4	--	--	--	--	--	--
	7/14/2005	18	100	1,200	26	23	0.80	ND(0.12)	ND(0.0050)	830	0.90	-114	5.77	0.247	24	37
	10/26/2005	ND(14)	ND(14)	2,300	32	39	3.60	ND(0.00030)	ND(0.00040)	326	0.00	-164	6.09	0.207	ND(2)[2]	46
	1/18/2006	ND(1.3)	ND(1.2)	630	19	300	3.50	ND(0.00030)	ND(0.00040)	202	0.00	-160	6.31	0.233	0.79J	57
MW-2	5/21/2002	470	30	34	ND(0.5)/3.5(J)	ND(0.5)	--	--	--	--	--	--	--	--	--	--
	1/27/2005	540	32	37	5.6	1.8J	--	--	--	1.9	--	--	--	--	--	--
	7/14/2005	4.4J[9]	5.6J	520	19	12	0.59	ND(0.12)	ND(0.0050)	87	0.00	-229	6.04	0.253	13	87
	10/26/2005	ND(1.7)	ND(1.8)	15	3.8	200	3.60	ND(0.00030)	ND(0.00040)	84	0.00	-114	6.01	0.265	ND(2)	84
	1/18/2006	ND(0.13)	0.16J	5.5	1.1	40	2.60	ND(0.00030)	ND(0.00040)	85.1	0.00	-155	6.22	0.265	3.4	84
MW-3	5/21/2002	860	44	23	ND(100)/3.4(J)	ND(100)	--	--	--	--	0.02	135	6.42	0.328	--	--
	1/27/2005	340	15	7.7	1.3J	ND(1.2)	--	--	--	1.9	--	--	--	--	--	--
	7/14/2005	1.7J	3.5J	270	8.6	4.6J	1.20	ND(0.12)	ND(0.0050)	88	0.00	-134	6.13	0.283	5.8	88
	10/26/2005	ND(1.4)	ND(1.4)	130	4.2	35	4.60	ND(0.00030)	ND(0.00040)	85	0.00	-98	6.09	0.261	ND(2)	85
	1/18/2006	0.2J	0.37J	2.2	5.8	88	4.60	ND(0.00030)	ND(0.00040)	114	0.00	-89	6.26	0.233	ND(0.33)	82
	MCLs[24]	5	5	6	10											

Notes:

1. PCE = tetrachloroethene
2. µg/L = microgram per liter
3. TCE = trichloroethene
4. Cis-1,2-DCE = cis-1,2-dichloroethene
5. Trans-1,2-DCE = trans dichloroethene
6. TOC = Total organic carbon
7. mg/L = milligram per liter
8. DO = Dissolved oxygen
9. ORP= Oxidation Reduction Potential
10. mV = millivolt
11. SEC = Specific Electric Conductance
12. mS/cm = milliSiemens per centimeter
13. Mn = Manganese
14. Fe = Ferrous iron
15. COD = Chemical oxygen demand
16. BOD = Biochemical oxygen demand

-- = Not Analyzed

J = Below the reporting limits, but above the minimum detection limits (MDL)

FIGURES 1 THRU 4 EXTENT OF THE PLUME OF THE MAJOR CONTAMINANTS

REMEDIATION SCIENCES, INC.
4500 CAMPUS DRIVE, SUITE 380
NEWPORT BEACH, CALIFORNIA
TEL. (949) 660-9292
FAX (949) 660-9295

OCTOBER 2005
VOLATILE ORGANIC COMPOUND CONCENTRATIONS
SAN JOSE, CALIFORNIA

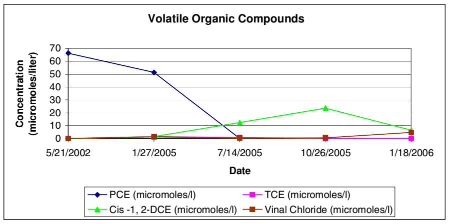
Figure
3

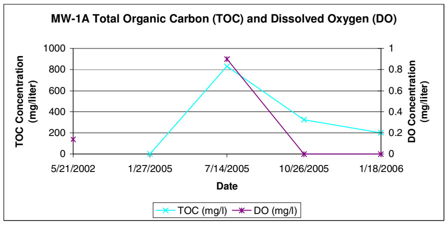
REMEDIATION SCIENCES, INC.
4500 CAMPUS DRIVE, SUITE 380
NEWPORT BEACH, CALIFORNIA
TEL. (949) 660-9292
FAX (949) 660-9295

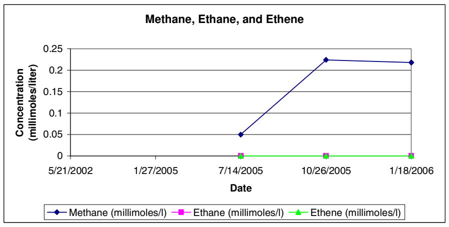
JANUARY 2006 INJECTION
VOLATILE ORGANIC COMPOUND CONCENTRATIONS
SAN JOSE, CALIFORNIA

Figure
4

CHART 1: MW-1A ANALYTICAL RESULTS VERSES TIME







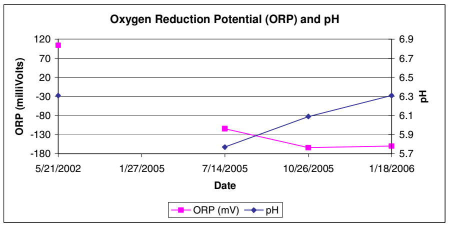
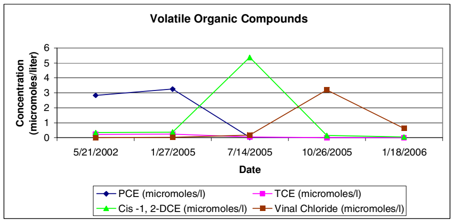
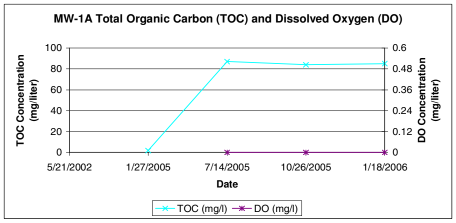
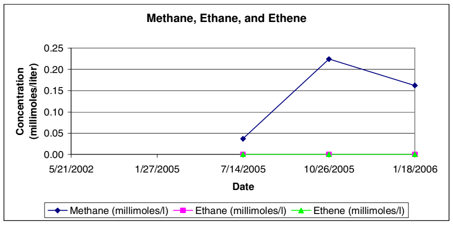


CHART 2: MW-2 ANALYTICAL RESULTS VERSES TIME







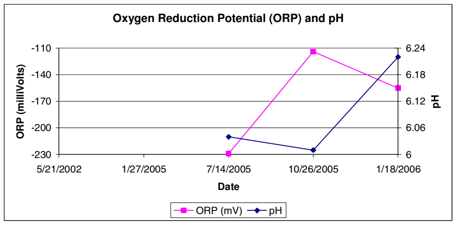
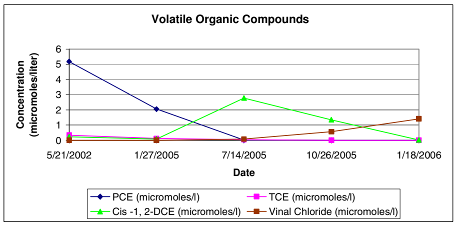
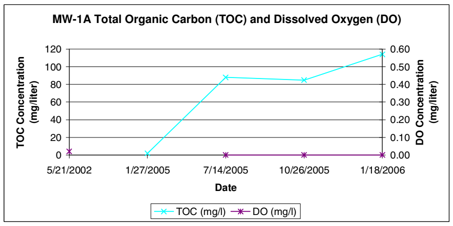
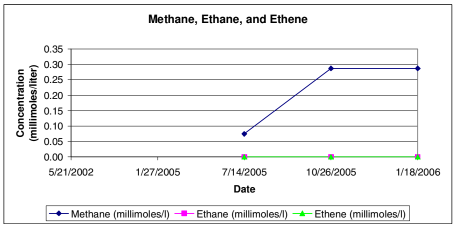
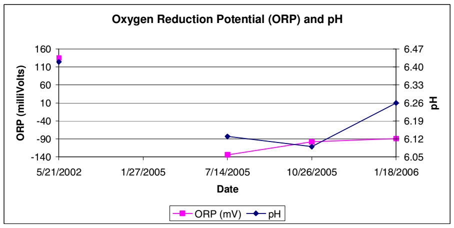


CHART 3: MW-3 ANALYTICAL RESULTS VERSES TIME









SAFETY DATA SHEET
EHC® Liquid Reagent Mix

SDS # : EHCLM-C
Revision date: 2016-02-03
Format: NA
Version 1.01

1. PRODUCT AND COMPANY IDENTIFICATION

Product Identifier

Product Name	EHC® Liquid Reagent Mix

Other means of identification

Alternate Commercial Name	EHC®-L Mix; EHC® Liquid - Solid Component

Recommended use of the chemical and restrictions on use

Recommended Use:	Bioremediation product for the remediation of contaminated soil and groundwater
Restrictions on Use:	Not for drinking water purification treatment.

Manufacturer/Supplier

PeroxyChem LLC
2005 Market Street
Suite 3200
Philadelphia, PA 19103
Phone: +1 267/ 422-2400 (General Information)
E-Mail: sdsinfo@peroxychem.com

Emergency telephone number

For leak, fire, spill or accident emergencies, call:
1 800 / 424 9300 (CHEMTREC - U.S.A.)
1 703 / 527 3887 (CHEMTREC - Collect - All Other Countries)
1 303/ 389-1409 (Medical - U.S. - Call Collect)

2. HAZARDS IDENTIFICATION

Classification

OSHA Regulatory Status

This chemical is considered hazardous by the 2012 OSHA Hazard Communication Standard (29 CFR 1910.1200).

Combustible dust

GHS Label elements, including precautionary statements

EMERGENCY OVERVIEW

Warning

Hazard Statements
May form combustible dust concentrations in air

Precautionary Statements - Prevention
Keep away from all ignition sources including heat,sparks and flame.
Keep container closed and grounded.
Prevent dust accumulations to minimize explosion hazard.

Hazards not otherwise classified (HNOC)
No hazards not otherwise classified were identified.

Other Information

CONTAINMENT HAZARD: Any vessel that contains wet EHC must be vented due to potential pressure build up from fermentation gases

3. COMPOSITION/INFORMATION ON INGREDIENTS

Chemical name	CAS-No	Weight %
Iron salt	Proprietary	92-97
amino acid	Proprietary	3-7

Occupational exposure limits, if available, are listed in section 8

4. FIRST AID MEASURES

Eye Contact	Rinse thoroughly with plenty of water for at least 15 minutes, lifting lower and upper eyelids intermittently. Consult a physician.
Skin Contact	Wash off with warm water and soap. Get medical attention if irritation develops and persists.
Inhalation	Remove from exposure, lie down. If symptoms persist, call a physician.
Ingestion	If swallowed, do not induce vomiting - seek medical advice.
Protection of first-aiders	No information available.
Most important symptoms and effects, both acute and delayed	Gastrointestinal effects. Inhalation of dust in high concentration may cause irritation of respiratory system.
Indication of immediate medical attention and special treatment needed, if necessary	Treat symptomatically

5. FIRE-FIGHTING MEASURES

Suitable Extinguishing Media	Use extinguishing measures that are appropriate to local circumstances and the surrounding environment.
Specific Hazards Arising from the Chemical	Avoid generating dust; fine dust dispersed in air in sufficient concentrations, and in the presence of an ignition source is a potential dust explosion hazard.
Hazardous Combustion Products	Carbon oxides (COx).

Explosion data

Sensitivity to Mechanical Impact	Not sensitive.
Sensitivity to Static Discharge	Not sensitive.

Protective equipment and precautions for firefighters	As in any fire, wear self-contained breathing apparatus pressure-demand, MSHA/NIOSH (approved or equivalent) and full protective gear.

6. ACCIDENTAL RELEASE MEASURES

Personal Precautions	For personal protection see Section 8. Avoid dispersal of dust in the air (i.e., cleaning dust surfaces with compressed air.).
Other	Eliminate all ignition sources (no smoking, flares, sparks or flames in immediate area). Use only non-sparking tools.
Environmental Precautions	No special environmental precautions required.
Methods for Containment	Sweep or vacuum up spillage and return to container. Avoid wetting dust and clean up as a dry powder with appropriate PPE for handling dry dusty materials; store in containers that keep material dry, segregated but allow to vent. Avoid dispersal of dust in the air (i.e., cleaning dust surfaces with compressed air.). Dust deposits should not be allowed to accumulate on surfaces, as these may form an explosive mixture if they are released into the atmosphere in sufficient concentration. Material may be recycled when contamination is not a problem.
Methods for cleaning up	Following product recovery, flush area with water.

7. HANDLING AND STORAGE

Handling	Avoid contact with skin, eyes and clothing. Do not ingest. Ensure adequate ventilation. Minimize dust generation and accumulation. Routine housekeeping should be instituted to ensure that dusts do not accumulate on surfaces. Dry powdered material can build static electricity when subjected to the friction of transfer and mixing operations. Provide adequate precautions, such as electrical grounding and bonding, or inert atmosphere.
Storage	Keep tightly closed in a dry and cool place. Keep away from open flames, hot surfaces and sources of ignition.
Incompatible products	. Strong oxidizing agents

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

Control parameters

Exposure Guidelines	Ingredients with workplace control parameters.

Chemical name	ACGIH TLV	OSHA PEL	NIOSH	Mexico
Iron salt	TWA: 1 mg/m^3	-	-	-
Chemical name	**British Columbia**	**Quebec**	**Ontario TWAEV**	**Alberta**
Iron salt	TWA: 1 mg/m^3	TWA: 1.0 mg/m^3	TWA: 1 mg/m^3	TWA: 1 mg/m^3

Appropriate engineering controls

Engineering measures	Ensure adequate ventilation, especially in confined areas. It is recommended that all dust control equipment such as local exhaust ventilation and material transport systems involved in the handling of this product contain explosion relief vents or an explosion suppression or an oxygen-deficient environment. Ensure that dust-handling systems (such as exhaust ducts, dust collectors, vessels, and processing equipment) are designed in a manner to prevent the escape of dust into the work area (i.e., there is no leakage from the equipment). Use only appropriately classified electrical equipment and powered industrial trucks.

Individual protection measures, such as personal protective equipment

Eye/Face Protection	Safety glasses with side-shields.
Skin and Body Protection	Wear suitable protective clothing.
Hand Protection	Protective gloves
Respiratory Protection	When workers are facing concentrations above the exposure limit they must use appropriate certified respirators.
Hygiene measures	Handle in accordance with good industrial hygiene and safety practice.

9. PHYSICAL AND CHEMICAL PROPERTIES

Information on basic physical and chemical properties

Appearance	Dry powder
Physical State	Solid
Color	light gray
Odor	Slight
Odor threshold	No information available
pH	4.5 (1% solution)
Melting point/freezing point	100 °C
Boiling Point/Range	No information available
Flash point	Not applicable
Evaporation Rate	No information available
Flammability (solid, gas)	May be combustible at high temperatures
Flammability Limit in Air	
Upper flammability limit:	No information available
Lower flammability limit:	No information available
Vapor pressure	No information available
Vapor density	No information available
Density	No information available
Specific gravity	No information available
Water solubility	Fairly soluble
Solubility in other solvents	
Partition coefficient	No information available
Autoignition temperature	
Decomposition temperature	No information available
Viscosity, kinematic	No information available
Viscosity, dynamic	No information available
Explosive properties	Low level dust explosion hazard
K_{st}	76 bar-m/sec: St1 Class dust
Oxidizing properties	No information available
Molecular weight	No information available
Bulk density	Not applicable

10. STABILITY AND REACTIVITY

None under normal use conditions

Chemical Stability	Stable under recommended storage conditions. Decomposes on heating.
Possibility of Hazardous Reactions	None under normal processing.
Hazardous polymerization	Hazardous polymerization does not occur.
Conditions to avoid	To avoid thermal decomposition, do not overheat.
Incompatible materials	Strong oxidizing agents.
Hazardous Decomposition Products	Carbon oxides (COx).

11. TOXICOLOGICAL INFORMATION

Product Information

LD50 Oral	Iron Salt: 2100 mg/kg (guinea pig) Cysteine: 1890 mg/kg (rat)
LD50 Dermal	No information available
LC50 Inhalation	No information available
Sensitization	Not expected to be sensitizing based on the components.

Information on toxicological effects

Symptoms	Dust is irritating eyes, nose, throat, and lungs.

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

Carcinogenicity	Contains no ingredient listed as a carcinogen.
Mutagenicity	This product is not recognized as mutagenic by Research Agencies
Reproductive toxicity	This product does not contain any known or suspected reproductive hazards.
STOT - single exposure	No information available.
STOT - repeated exposure	No information available.
Aspiration hazard	Not applicable.

12. ECOLOGICAL INFORMATION

Ecotoxicity

Ecotoxicity effects	Not expected to have significant environmental effects
Persistence and degradability	No information available.
Bioaccumulation	No information available.
Mobility	No information available.
Other Adverse Effects	None known.

13. DISPOSAL CONSIDERATIONS

Waste disposal methods	It must undergo special treatment, e.g. at suitable disposal site, to comply with local regulations.
Contaminated Packaging	Dispose of in accordance with local regulations.

14. TRANSPORT INFORMATION

DOT	NOT REGULATED

15. REGULATORY INFORMATION

U.S. Federal Regulations

SARA 313
Section 313 of Title III of the Superfund Amendments and Reauthorization Act of 1986 (SARA). This product does not contain any chemicals which are subject to the reporting requirements of the Act and Title 40 of the Code of Federal Regulations, Part 372

SARA 311/312 Hazard Categories

Acute health hazard	No
Chronic health hazard	No
Fire hazard	No
Sudden release of pressure hazard	No
Reactive Hazard	No

Clean Water Act
This product does not contain any substances regulated as pollutants pursuant to the Clean Water Act (40 CFR 122.21 and 40 CFR 122.42)

CERCLA/EPCRA
This material, as supplied, does not contain any substances regulated as hazardous substances under the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) (40 CFR 302) or the Superfund Amendments and Reauthorization Act (SARA) (40 CFR 355). There may be specific reporting requirements at the local, regional, or state level pertaining to releases of this material

International Inventories

Component	TSCA (United States)	DSL (Canada)	EINECS/ELINCS (Europe)	ENCS (Japan)	China (IECSC)	KECL (Korea)	PICCS (Philippines)	AICS (Australia)	NZIoC (New Zealand)
Iron salt (92-97)	X	X	X			X	X	X	X
amino acid (3-7)	X	X	X	X	X	X	X	X	X

CANADA

WHMIS Hazard Class Non-controlled

16. OTHER INFORMATION

NFPA	**Health Hazards** 1	**Flammability** 1	**Stability** 0	**Special Hazards** -
HMIS	**Health Hazards** 1	**Flammability** 1	**Physical hazard** 0	**Special precautions** -

NFPA/HMIS Ratings Legend Severe = 4; Serious = 3; Moderate = 2; Slight = 1; Minimal = 0

Uniform Fire Code COMBUSTIBLE DUST/POWDER
References Refer to NFPA 654, *Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids* , for safe handling.

Revision date: 2016-02-03
Revision note (M)SDS sections updated 9
Issuing Date: 2016-01-26

Disclaimer

PeroxyChem believes that the information and recommendations contained herein (including data and statements) are accurate as of the date hereof. NO WARRANTY OF FITNESS FOR ANY PARTICULAR PURPOSE, WARRANTY OF MERCHANTABILITY OR ANY OTHER WARRANTY, EXPRESSED OR IMPLIED, IS MADE CONCERNING THE INFORMATION PROVIDED HEREIN. The information provided herein relates only to the specified product designated and may not be applicable where such product is used in combination with any other materials or in any process. Further, since the conditions and methods of use are beyond the control of PeroxyChem, PeroxyChem expressly disclaims any and all liability as to any results obtained or arising from any use of the products or reliance on such information.

Prepared By:

PeroxyChem

End of Safety Data Sheet

SAFETY DATA SHEET
ELS™ Microemulsion

SDS # : ELS-C
Revision date: 2015-07-22
Format: NA
Version 1

1. PRODUCT AND COMPANY IDENTIFICATION

Product Identifier

Product Name	ELS™ Microemulsion

Other means of identification

Synonyms	Lecithin: L-α-Phosphatidylcholine, Azolectin; Sodium Benzoate: Benzoic acid sodium salt; Sorbitan monooleate, ethoxylated: Polyoxyethylenesorbitan monooleate

Recommended use of the chemical and restrictions on use

Recommended Use:	Bioremediation product for the remediation of contaminated soil and groundwater
Restrictions on Use:	Not for drinking water purification treatment.

Manufacturer/Supplier

PeroxyChem LLC
2005 Market Street
Suite 3200
Philadelphia, PA 19103
Phone: +1 267/ 422-2400 (General Information)
E-Mail: sdsinfo@peroxychem.com

Emergency telephone number

For leak, fire, spill or accident emergencies, call:
1 800 / 424 9300 (CHEMTREC - U.S.A.)
1 703 / 527 3887 (CHEMTREC - Collect - All Other Countries)
1 303/ 389-1409 (Medical - U.S. - Call Collect)

2. HAZARDS IDENTIFICATION

Classification

OSHA Regulatory Status

This material is not considered hazardous by the 2012 OSHA Hazard Communication Standard (29 CFR 1910.1200).

GHS Label elements, including precautionary statements

EMERGENCY OVERVIEW

Hazards not otherwise classified (HNOC)
No hazards not otherwise classified were identified.

Other Information

CONTAINMENT HAZARD: Any vessel that contains wet ELS must be vented due to potential pressure build up from fermentation gases

3. COMPOSITION/INFORMATION ON INGREDIENTS

Chemical name	CAS-No	Weight %
Sorbitan monooleate, ethoxylated	9005-65-6	2-4
Lecithin	8002-43-5	20-30
Water	7732-18-5	60-80
Sodium Benzoate	532-32-1	2-4

Synonyms are provided in Section 1.

4. FIRST AID MEASURES

Eye Contact	In case of contact, immediately flush eyes with plenty of water. Get medical attention if irritation develops and persists.
Skin Contact	Wash skin with soap and water. Get medical attention if irritation develops and persists.
Inhalation	Move to fresh air in case of accidental inhalation of vapors. Consult a physician if necessary.
Ingestion	Drink 1 or 2 glasses of water. Get medical attention if symptoms occur. If swallowed, do not induce vomiting - seek medical advice. Never give anything by mouth to an unconscious person.
Most important symptoms and effects, both acute and delayed	None known
Indication of immediate medical attention and special treatment needed, if necessary	Treat symptomatically

5. FIRE-FIGHTING MEASURES

Suitable Extinguishing Media	Carbon dioxide (CO_2). Dry chemical. Dry powder.
Specific Hazards Arising from the Chemical	. Combustible material: may burn but does not ignite readily

Explosion data

Sensitivity to Mechanical Impact	Not sensitive.
Sensitivity to Static Discharge	Not sensitive.
Protective equipment and precautions for firefighters	As in any fire, wear self-contained breathing apparatus pressure-demand, MSHA/NIOSH (approved or equivalent) and full protective gear.

6. ACCIDENTAL RELEASE MEASURES

Personal Precautions	For personal protection see Section 8.

Other	For further clean-up instructions, call PeroxyChem Emergency Hotline number listed in Section 1 "Product and Company Identification" above.
Environmental Precautions	No special environmental precautions required.
Methods for Containment	Absorb with earth, sand or other non-combustible material and transfer to containers for later disposal.
Methods for cleaning up	After cleaning, flush away traces with water.

7. HANDLING AND STORAGE

Handling	Handle in accordance with good industrial hygiene and safety practice.
Storage	Any vessel that contains wet ELS must be vented due to potential pressure build up from fermentation gases. Keep away from open flames, hot surfaces and sources of ignition.
Incompatible products	Water, Alkalis

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

Control parameters

Exposure Guidelines	This product, as supplied, does not contain any hazardous materials with occupational exposure limits established by the region specific regulatory bodies.

Appropriate engineering controls

Engineering measures	None under normal use conditions.

Individual protection measures, such as personal protective equipment

Eye/Face Protection	Safety glasses with side-shields.
Skin and Body Protection	Wear suitable protective clothing.
Hand Protection	Protective gloves
Respiratory Protection	Use only with adequate ventilation.
Hygiene measures	Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and immediately after handling the product.

9. PHYSICAL AND CHEMICAL PROPERTIES

Information on basic physical and chemical properties

Appearance	Light amber emulsion
Physical State	Liquid
Color	No information available
Odor	odorless
Odor threshold	No information available
pH	6.5 - 6.9
Melting point/freezing point	Not applicable No data available
Boiling Point/Range	No information available
Flash point	> 200 °F
Evaporation Rate	No information available
Flammability (solid, gas)	No information available
Flammability Limit in Air	
Upper flammability limit:	No information available
Lower flammability limit:	No information available
Vapor pressure	No information available

Vapor density	No information available
Density	No information available
Specific gravity	No information available
Water solubility	Dispersible in water
Solubility in other solvents	No information available
Partition coefficient	No information available
Autoignition temperature	No information available
Decomposition temperature	No information available
Viscosity, kinematic	No information available
Viscosity, dynamic	No information available
Explosive properties	Not explosive
Oxidizing properties	Non-oxidizing
Molecular weight	No information available
Bulk density	Not applicable

10. STABILITY AND REACTIVITY

Reactivity	None under normal use conditions
Chemical Stability	Stable under recommended storage conditions.
Possibility of Hazardous Reactions	None under normal processing.
Hazardous polymerization	Hazardous polymerization does not occur.
Conditions to avoid	Temperatures above 71°C
Incompatible materials	Water, Alkalis.
Hazardous Decomposition Products	None under normal use.

11. TOXICOLOGICAL INFORMATION

Product Information

Ingredients in this product have been designated as GRAS (Generally Recognized as Safe) by govenment agencies.

LD50 Oral	There are no data available for this product
LD50 Dermal	There are no data available for this product
LC50 Inhalation	No information available

Sensitization	Not expected to be sensitizing based on the components.

Information on toxicological effects

Symptoms	No information available.

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

Carcinogenicity	Contains no ingredient listed as a carcinogen.
Mutagenicity	No information available
Reproductive toxicity	No information available.
STOT - single exposure	No information available.
STOT - repeated exposure	No information available.

Aspiration hazard	No information available.

12. ECOLOGICAL INFORMATION

Ecotoxicity

Ecotoxicity effects	Contains no substances known to be hazardous to the environment or that are not degradable in waste water treatment plants
Persistence and degradability	Expected to biodegrade, based on component information.
Bioaccumulation	Bioaccumulation is unlikely.
Mobility	Will likely be mobile in the environment due to its water solubility but will likely degrade over time.
Other Adverse Effects	None known.

13. DISPOSAL CONSIDERATIONS

Waste disposal methods	Can be landfilled or incinerated, when in compliance with local regulations.
Contaminated Packaging	Dispose of in accordance with local regulations.

14. TRANSPORT INFORMATION

DOT	NOT REGULATED

15. REGULATORY INFORMATION

U.S. Federal Regulations

SARA 313
Section 313 of Title III of the Superfund Amendments and Reauthorization Act of 1986 (SARA). This product does not contain any chemicals which are subject to the reporting requirements of the Act and Title 40 of the Code of Federal Regulations, Part 372

SARA 311/312 Hazard Categories

Acute health hazard	No
Chronic health hazard	NO
Fire hazard	NO
Sudden release of pressure hazard	NO
Reactive Hazard	NO

Clean Water Act
This product does not contain any substances regulated as pollutants pursuant to the Clean Water Act (40 CFR 122.21 and 40 CFR 122.42)

CERCLA
This material, as supplied, does not contain any substances regulated as hazardous substances under the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) (40 CFR 302) or the Superfund Amendments and Reauthorization Act (SARA) (40 CFR 355). There may be specific reporting requirements at the local, regional, or state level pertaining to releases of this material

International Inventories

Component	TSCA (United States)	DSL (Canada)	EINECS/ELINCS (Europe)	ENCS (Japan)	China (IECSC)	KECL (Korea)	PICCS (Philippines)	AICS (Australia)	NZIoC (New Zealand)
Sorbitan monooleate, ethoxylated 9005-65-6 (2-4)	X	X	X	X	X	X	X	X	X
Lecithin 8002-43-5 (20-30)	X	X	X		X	X	X	X	X
Sodium Benzoate 532-32-1 (2-4)	X	X	X	X	X	X	X	X	X

Mexico - Grade Minimum risk, Grade 0

CANADA

WHMIS Hazard Class Non-controlled

16. OTHER INFORMATION

NFPA	**Health Hazards** 1	**Flammability** 0	**Stability** 0	**Special Hazards** -
HMIS	**Health Hazards** 1	**Flammability** 0	**Physical hazard** 0	**Special precautions** -

NFPA/HMIS Ratings Legend Severe = 4; Serious = 3; Moderate = 2; Slight = 1; Minimal = 0

Revision date: 2015-07-22
Revision note Initial Release
Issuing Date: 2015-07-14

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Prepared By:

PeroxyChem

End of Safety Data Sheet

Focused Bioremediation of Carbon Tetrachloride in Groundwater

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Brad Elkins (belkins@eosremediation.com) (EOS Remediation, Raleigh, NC, USA)

Background/Objectives. In 1998, a carbon tetrachloride source was identified in groundwater at a closed industrial landfill in the Shenandoah region of Virginia. This source was observed in the upgradient portion of the landfill, and based upon downgradient compliance monitoring, was understood to be limited in horizontal and vertical extent. Historical attempts to further delineate this source yielded mixed results, but indicated that carbon tetrachloride impacts were localized.

Approach/Activities. As part of a Corrective Action implementation and to further delineate the carbon tetrachloride source; five (5) nested injection wells were installed in 2010 and 2011 in the source area, which was characterized by historical carbon tetrachloride concentrations up to 82.4 ug/L. For each nested injection well; the upper well was screened within alluvial deposits, which sit atop shale and contain perched groundwater. The deeper well was screened within the underlying shale. Two (2) rounds of baseline groundwater samples were collected from the injection wells to refine the volumetric distribution of the carbon tetrachloride impacts, which was subsequently determined to be localized within the overlying alluvial deposits.

Enhanced Bioremediation was conducted in the Spring of 2011 to target carbon tetrachloride impacts. Three (3) targeted injection wells were utilized. Biostimulation was conducted by the MaxOx Group® via co-injection of approximately 5,000 gallons of emulsified, long-term, vegetable-oil based electron donor (i.e., EOS Pro) along with a patented nitrogen gas injection technology. The nitrogen was applied to increase the radius of influence and distribution of the electron donor. Also, a Primawave^{TM} Sidewinder (Wavefront Technology) was attached to each well (via a customized wellhead adaptor) and used to promote greater distribution. Based on soil/groundwater acidity testing, around 3,000 gallons of EOS® AquaBuph® (a vegetable-oil based emulsion containing a slow-release alkaline buffer) was injected into the alluvial deposits to increase the pH to a value near physiological pH.

Results/Lessons Learned. Through subsequent performance monitoring, Enhanced Bioremediation has proven effective at reducing concentrations of carbon tetrachloride to either non-detect or below the US EPA MCL of 5 ug/L, and limiting the migration thereof. As of October of 2012, reducing conditions are persistent in the treatment area, pH is within the optimal range between 6.0- and 8.0-standard units, and total organic carbon (TOC) and concentrations indicate that electron donor is still bioavailable. Increases in concentrations of intermediate products (i.e., chloroform and methylene chloride) were observed within the six (6) months following injection that indicated that the step-wise anaerobic reductive process was proceeding. Detection of chloromethane and increases in methane (the terminal reductive dechlorination product) by orders of magnitude have been observed in and/or directly downgradient of the source. Of particular note, increases in concentrations of select redox-sensitive metals have occurred as a result of reducing conditions and are expected to decrease to natural concentrations following successful completion of the Corrective Action.

EOSPRO

Engineered formula of emulsified vegetable oil, nutrients and vitamins optimizes distribution and contaminant degradation

Enriched emulsified vegetable oil used to stimulate anaerobic bioremediation of chlorinated solvents and other recalcitrant chemicals in contaminated groundwater

USDA CERTIFIED BIOBASED PRODUCT
PRODUCT 95%

Product Advantages

- Vitamin B12 and micronutrients
- Slow and fast release substrates
- Engineered for effective transport
- Third party validated
- Food-grade and USDA certified
- 74% fermentable carbon
- Regulatory acceptance

EOS

EOS Remediation

Experience you can rely on, Products you can trust™

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Brad Elkins
BElkins@eosremediation.com

EOSPRO

Technical Information

Emulsified Oils Family

Description

USDA CERTIFIED BIOBASED PRODUCT
PRODUCT 95%

EOSPRO is a nutrient-enriched, DoD-validated, emulsified vegetable oil (EVO). EOSPRO is engineered to quickly stimulate microbial activity while providing long-term nourishment to enhance anaerobic bioremediation of chlorinated solvents, nitrates, perchlorate, energetics, acid mine drainage, and other recalcitrant chemicals in contaminated groundwater. EOSPRO can also be used to reduce redox sensitive metals and radionuclides. The negative surface charges on the droplets combined with small droplet size promote effective transport in the subsurface.

EOSPRO benefits include:

- Vitamin B-12 and micro-nutrients
- Rapidly-biodegradable substrates to “jump start” bacterial growth
- Slow release biodegradable substrates to promote long-term biological activity
- Engineered for effective transport in the subsurface
    - Small oil droplet size
    - Negative surface charge
- Extensive third-party validation

EOSPRO incorporates the patented EOS® technologies that clients have trusted for more than a decade. Domestic supply made in the USA with US farmed soybeans.

Chemical & Physical Properties

Oil Emulsion Concentrate: EOSPRO	Typical
Refined and Bleached US Soybean Oil (% by wt.)	59.8
Rapidly Biodegradable Soluble Substrate (% by wt.)	4
Other Organics (emulsifiers, food additives, etc.) (% by wt.)	10
Specific Gravity	0.96 - 0.98
pH (Standard Units)	6 - 7
Median Oil Droplet Size (microns)	1.0
Organic Carbon (% by wt.)	74
Mass of Hydrogen Produced (lbs. H_2 per lbs. EOSPRO)	0.25

Packaging

Shipped in 55-gallon drums, 275-gallon IBC totes or bulk tankers (40,000 lbs.)

Handling & Storage

EOSPRO is shipped as a ready-to-use concentrated emulsion that can be diluted with water in the field to prepare a high quality suspension for easy injection. EOSPRO has a low viscosity and can be distributed with commonly available pumps or by continuous metering with a diluter (e.g., Dosatron™). Dilution ratios for EOSPRO typically range from 4:1 to 20:1 (water: EOSPRO) depending on site conditions. EOSPRO injections should be followed with additional chase water to maximize distribution of EOSPRO into the formation.

EOSPRO can be injected with EOSQR, CoBupHMg or BAC-9. Call us for more details.

For best performance, use EOSPRO as shipped, within 60 days of delivery and store at a temperature between 40°F (4°C) to 100°F (38°C).

Rev. 5.2016

EOS Remediation, LLC

Abiotic and Biotic Treatment Using ZVI and Organic Substrates

Ed Alperin, QEP; Brad Elkins, P.G. (EOS Remediation, LLC, Raleigh, NC) and
Bilgen Yuncu, Ph.D., P.E.; Robert Borden, Ph.D., P.E. (Solutions-IES, Inc., Raleigh, NC)

Solutions-IES
Industrial & Environmental Services

Introduction

EOS Remediation has developed a patent-pending, cost-effective, and reliable technology for *in situ* treatment of contaminated aquifers with ZVI by coating mZVI (micro-scale Zero Valent Iron) with vegetable oil (EOSZVI).

- The oil droplets have a negative surface charge which prevents agglomeration of the ZVI particles and also reduces attachment to sediment surfaces.
- The small particle size of the product allows effective transport through most aquifers.
- The oil droplets provide a low cost electron donor to consume competing electron acceptors, extending the ZVI life.

Theory

Background:

Laboratory studies have demonstrated that nano-scale ZVI (nZVI) and micro-scale ZVI (mZVI) can be very effective for *in situ* treatment of chlorinated solvents (CVOC) and other oxidized contaminants. However, there are some considerations in cost-effectively applying this technology in the field. Material costs for both nZVI and mZVI are significantly higher than other electron donors, so practioners often try to use the minimum amount of material required. This can be problematic since much of the ZVI is often consumed in side reactions with background electron acceptors (O2, NO3, SO4). If too little ZVI is injected, contaminant concentrations drop immediately after injection, then rebound after a few months when the ZVI has been depleted.

Effectively distributing nZVI and mZVI is also a major challenge. Multiple field studies and supporting laboratory experiments have shown that transporting these materials more than a few feet away from the injection point can be very difficult. Colloidal transport of iron particles is directly affected by it's diameter (Tratnyek and Johnson, 2006). In some cases, thin layers of ZVI are transported away from the injection well through high permeability zones or fractures, leaving much of the formation untreated. This can dramatically reduce treatment performance since CVOC reduction by ZVI is a surface mediated process where the contaminant must come into direct contact with the ZVI surface to be degraded. **Figure 1** below shows a mathematical model for iron transport as a function of particle size under different sticking coefficient (α) conditions.

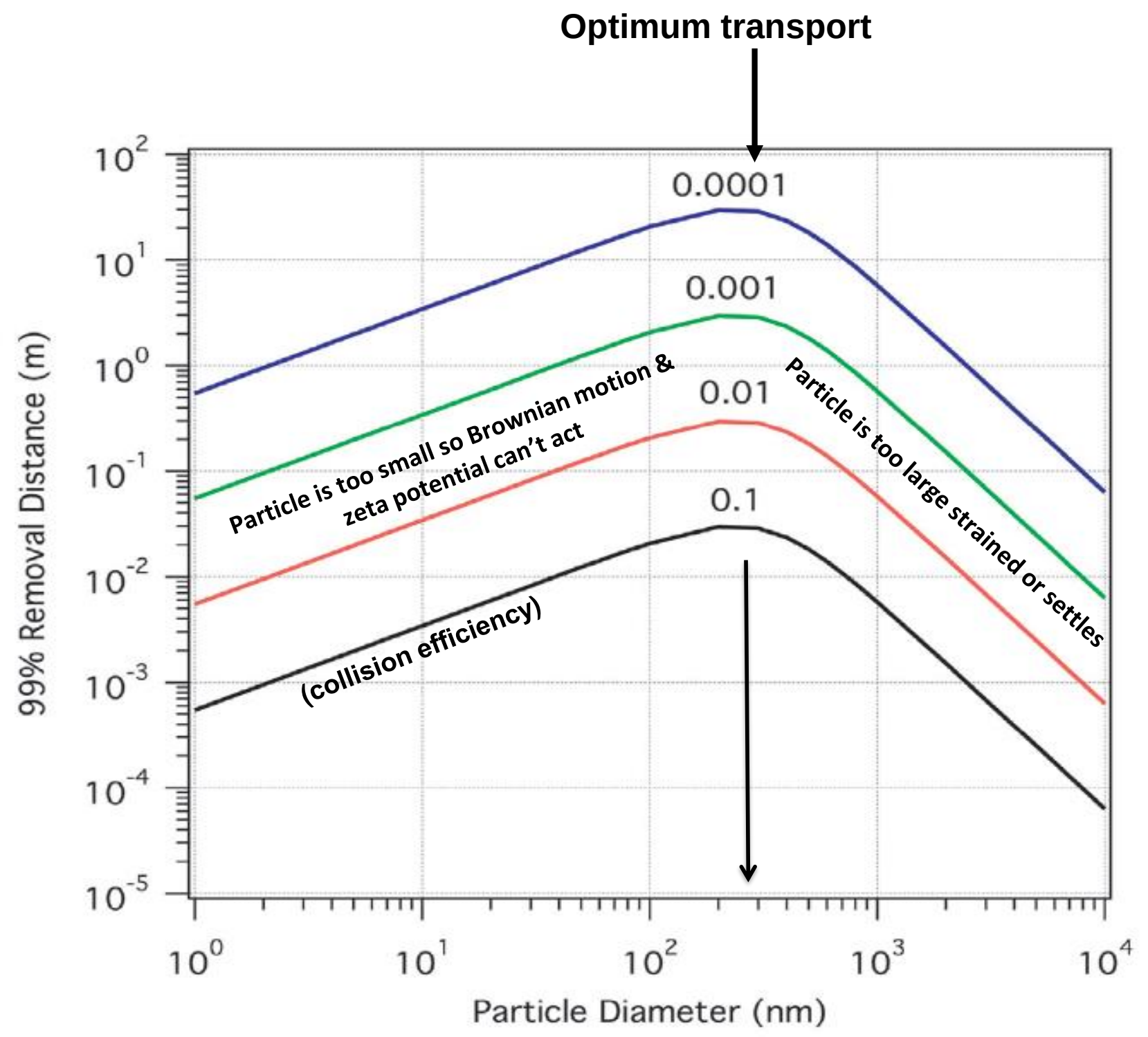


Figure 1. Tratnyek and Johnson, Nanotoday, 44-48, 2006

Concentrated EOS ZVI dispersion in water

Formulation

EOSZVI

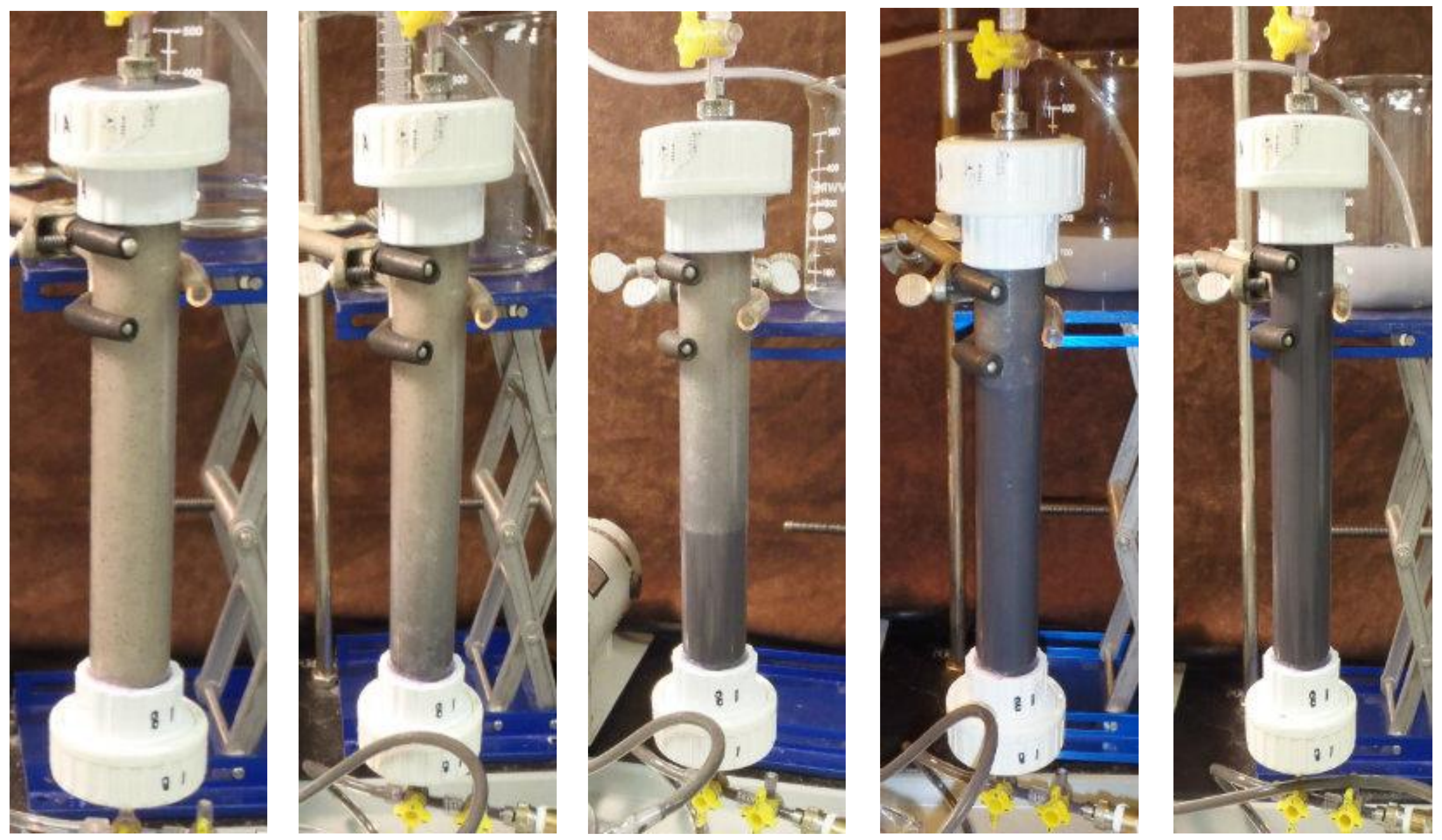
Oil Concentrate:	Typical
Micron-scale Carbonyl Iron (ZVI) (% by wt.)	50
Stabilizer (% by wt.)	2
Refined and Bleached US Soybean Oil (% by wt.)	41
Slow Release Organics (% by wt.)	7
Specific Gravity	~1.6
Viscosity (cP)	2,350
Organic Carbon (% by wt.)	48

EOSZVI is shipped as concentrated oil and iron slurry that is diluted with water in the field to prepare a solution for easy injection. EOSZVI can be distributed with commonly available pumps. Dilution ratios for EOSZVI typically range from 1:1 to 5:1 (water: EOSZVI) depending on site conditions. EOSZVI injections should be followed with additional chase water to maximize distribution of EOSZVI into the formation.

Laboratory Studies

The effective oil retention and colloidal transport of the iron particles:

- ➢ Column packed with clean medium sand 10 inches in length
- ➢ 5 pore volumes of simulated groundwater pumped to remove all entrained air
- ➢ 3 pore volumes of EOSZVI was injected
- ➢ No significant pressure build up in the column

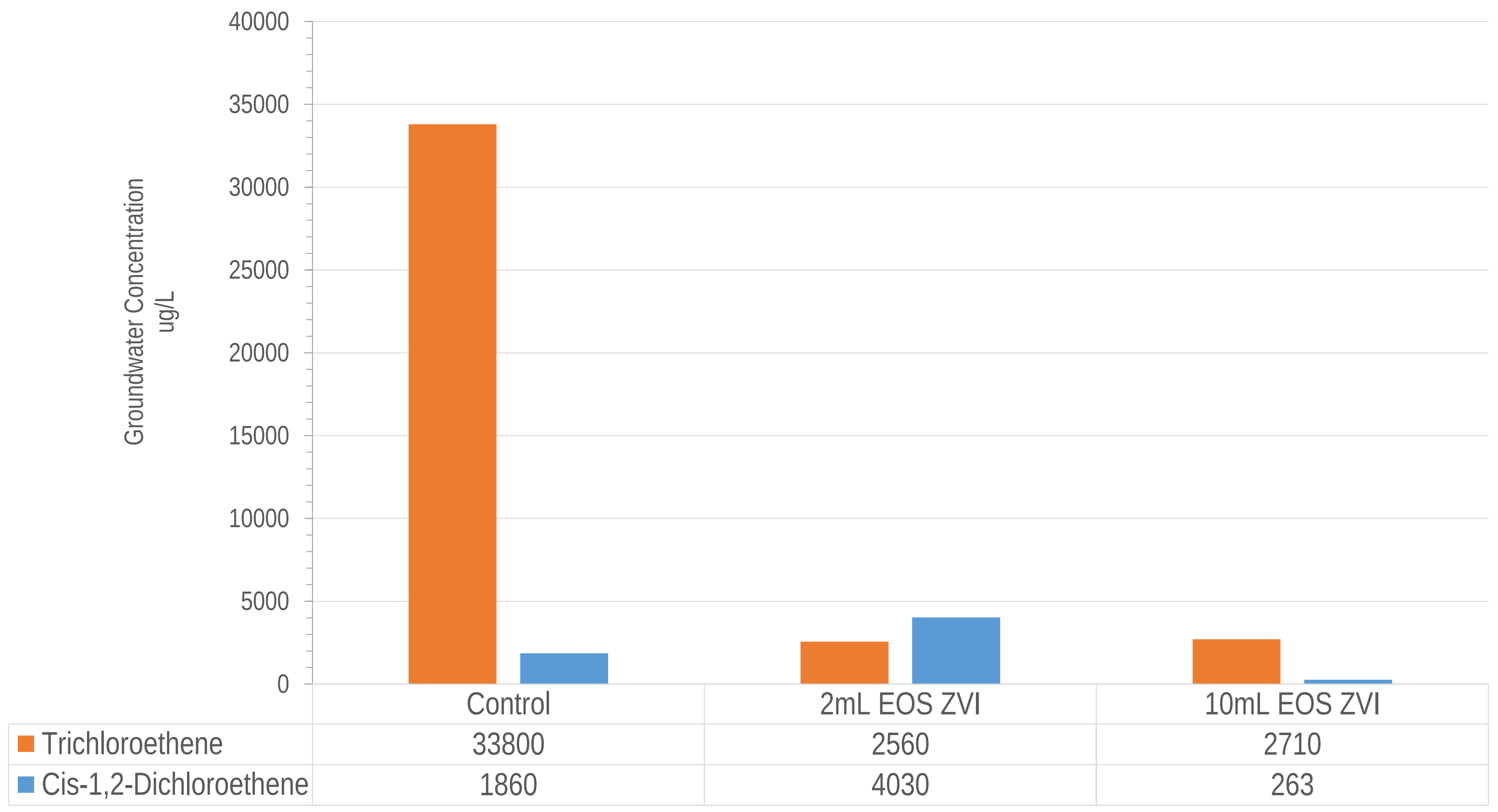


- ► Photos above show a time-laps (approximately 20 mins.) as EOSZVI transports from the bottom to the top of the column.

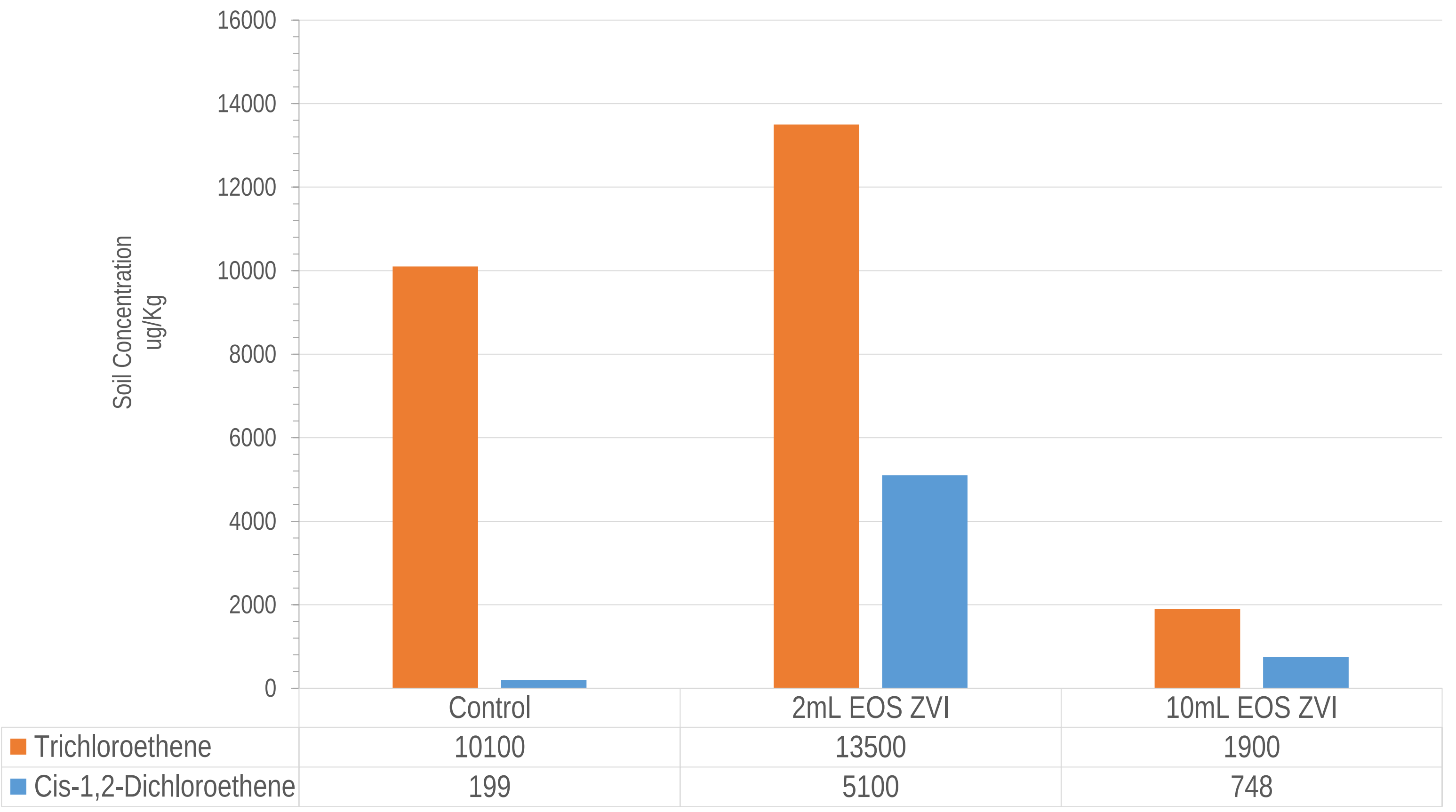
Treatability Study

Third party consultant performed a 1 week treatability study:

- ➢ Each microcosm contained 115 mL of groundwater and 30 g of soil
- ➢ Performed two doses; 2mL and 10mL of the EOSZVI
- ➢ Samples were collected and measured in duplicate



	Control	2mL EOS ZVI	10mL EOS ZVI
🟧 Trichloroethene	33800	2560	2710
🟦 Cis-1,2-Dichloroethene	1860	4030	263



	Control	2mL EOS ZVI	10mL EOS ZVI
🟧 Trichloroethene	10100	13500	1900
🟦 Cis-1,2-Dichloroethene	199	5100	748

Lessons Learned

- ► EOSZVI
  - ☐ 80% reduction in groundwater TCE concentration within 1 week.
  - ☐ Column study shows EOSZVI is capable of plug-flow transport.
  - ☐ Easily mixes with water to create an injection ready solution.
  - ☐ Project has moved to pilot scale.

EOSZVI

Water-mixable oil and zero valent iron (ZVI) slurry formulation to enhance anaerobic reductive dechlorination

Water-mixable vegetable oil based substrate containing 50% micro-scale carbonyl iron, soy bean oil, surfactant and stabilizer, providing a long-lasting source for anerobic remediation of DNAPL

Product Advantages

- Waterless concentrate, easy to use formulation
- Effective on DNAPL
- Abiotic and biotic pathways for recalcitrant contaminants
- Highest iron to carbon ratio on the market; greater than 1:1

EOS Remediation

Experience you can rely on, Products you can trust™

+1 919.873.2204
www.eosremediation.com

Brad Elkins
BElkins@eosremediation.com

EOSZVI

Technical Information

Emulsified Oils Family

Description

EOSZVI is a patent-pending water-mixable vegetable oil based organic substrate with the highest concentration of micron-scale zero valent iron (ZVI) available. This unique product combines the proven reactivity of ZVI with a long lasting source of electron donor for enhanced *in situ* anaerobic, abiotic, and biotic remediation. EOSZVI is shipped as a waterless concentrate; simply add water in the field to instantly create an injection-ready solution.

EOSZVI benefits:

- Ideal for DNAPL sites
- Quickly reduces ORP of aquifers
- Highest ratio of ZVI to carbon on the market; greater than 1:1
- Employs the proven EOS® technology
- Larger droplet size for greater oil retention
- Excellent for barrier and fractured rock applications
- Can be used with other EOS® products
- Carbonyl iron particle size average 3-4µm

Domestic supply made in the USA with US farmed soybeans.

Chemical & Physical Properties

Oil Concentrate: EOSZVI	Typical
Micron-scale Carbonyl Iron (ZVI) (% by wt.)	50
Stabilizer (% by wt.)	2
Refined and Bleached US Soybean Oil (% by wt.)	41
Slow Release Organics (% by wt.)	7
Specific Gravity	~1.6
Viscosity (cP)	2,350
Organic Carbon (% by wt.)	48

Packaging

Shipped in 5-gallon pails (net 50 lbs. each), 55-gallon drums or 275-gallon IBC totes.

Handling & Storage

EOSZVI is shipped as concentrated oil and iron slurry that is diluted with water in the field to prepare a solution for easy injection. EOSZVI can be distributed with commonly available pumps. Dilution ratios for EOSZVI typically range from 1:1 to 5:1 (water: EOSZVI) depending on site conditions. EOSZVI injections should be followed with additional chase water to maximize distribution of EOSZVI into the formation.

EOSZVI as shipped, has a shelf-life of ≥ 2 years depending on storage conditions.

Environmental
Solutions

In Situ Chemical Reduction vs. Enhanced Reductive Dechlorination
Case Study

PROJECT

Comparison of *In Situ* Chemical Reduction (ISCR) to enhanced reductive dechlorination to treat trichloroethene in an aerobic aquifer.

Site: Concord Naval Weapons Base in Concord, CA

SUMMARY

In Situ Chemical Reduction (ISCR) was compared to enhanced reductive dechlorination (ERD) to treat groundwater affected by trichloroethene (TCE). Two pilot tests were conducted that compared the rates of contaminant degradation as well as other biogeochemical processes of both processes. The ISCR process was demonstrated to degrade the TCE substantially faster than the ERD process while minimizing the generation of vinyl chloride. ISCR is currently being applied to treat the extended TCE plume.

CHALLENGE

The Concord Naval Weapons Station (CNWS) facility is located in Concord CA and is included in the Base Realignment and Closure (BRAC) program. Soil and groundwater at Installation Restoration (IR) Site 29 at the CNWS facility has been affected by a discharge TCE. The affected aquifer consists of unconsolidated silt, sands and clays. Groundwater, which is encountered approximately 50 feet below ground surface, is highly aerobic (dissolved oxygen (DO) ~7 mg/L) and mildly oxidizing (oxidation reduction potential (ORP) ~250 millivolts (mV). The source of TCE is a building previously used to refurbish munitions. TCE was discharged, likely through drain lines, in a source are east of the building. The TCE plume extends approximately 700 feet down hydraulic gradient from the source area and up to 100 feet below ground surface. The site is shown on Figure 1.

Figure 1: TCE plume at IR Site 29 at Concord Naval Weapons Station

Enhanced Reductive Dechlorination Pilot Test:

An Enhanced Reductive Dechlorination (ERD) pilot test was previously conducted in the TCE source area from 2011 to 2014. The ERD pilot test used buffered emulsified vegetable oil substrate which was augmented with dechlorinating microbial consortium (SDC-9™). Sodium lactate was added to the injection water to condition the water prior to bioaugmentation. Injections were conducted from 50 to 65 feet below ground surface (bgs) at 2.5 foot vertical intervals in locations 12 foot on center to achieve a 6.5 foot radius of influence. The degradation of CEs during the ERD pilot test was measured in wells S29MW10 and S29MW11. The ERD pilot test demonstrated that application of resulted in complete degradation the TCE and daughter products concentration from approximately 5,000 microgram per liter (µg/L) to less than 1 µg/L in approximately 550 days. However, arsenic concentrations were observed to increase during the test. The ERD pilot test area is shown on Figure 2.

The Navy intends divest the property under the Base Realignment and Closure (BRAC) program as rapidly as possible. To achieve this goal, the Navy requested an approach that would aggressively treat the TCE, reduce the potential for daughter products and maintain conditions conducive to continued reductive dechlorination for a longer duration.

SOLUTION

In Situ Chemical Reduction (ISCR) was selected for evaluation enhance the ERD process demonstrated to be applicable during the initial ERD pilot test. The ISCR process was selected because it combines benefits of biotic processes previously demonstrated to be applicable at the site, and abiotic processes which enhance the biological process. ELS™ Microemulsion, a lecithin-based substrate of food grade carbon, was selected for the biotic degradation of TCE. ELS was selected for the organic substrate because of its longevity as a substrate, high electron donor capacity, enhanced transport characteristics, and because essential nutrients nitrogen and phosphate are included in the molecular structure of the molecule. Zero valent iron was also incorporated to enhance abiotic degradation to reduce the potential for generation of toxic degradation products. The abiotic degradation process primarily bypasses the generation of these toxic degradation product by the β-elimination pathway which temporarily generates unstable chlorinated acetylenes which may be converted to ethene and ethane.

ISCR Pilot Study: A Design Optimization Test (DOT) was conducted to compare the ISCR approach to the previously evaluated ERD approach. The DOT was conducted in the TCE source area in wells (S29MW01 and S29MW03) not affected by the ERD pilot test. The ERD and ISCR test wells and injection locations are shown on Figure 2. The DOT was conducted by distribution of the ISCR substrate at 3 locations located at a distance of 10 feet from wells S29MW01 and 3 locations at a distance of 15 feet from S29MW03. At each vertical interval, the aquifer was first primed for substrate distribution by fracturing the aquifer using the ELS and bioaugmentation solution.

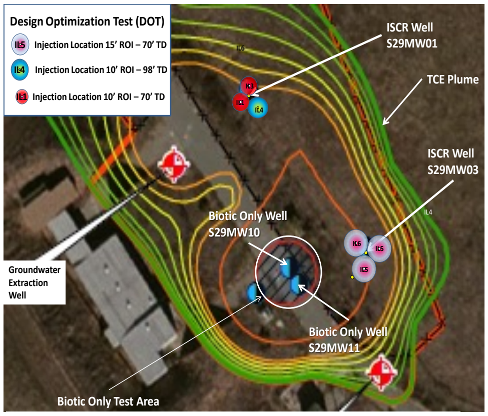


Figure 2: ISCR and ERD pilot test wells and injection locations

Following confirmation of fracture development, ZVI suspended in guar was injected into the interval followed immediately by the lactate, ELS solution and bioaugmentation culture. Monitoring was then conducted to verify the degradation of TCE.

Pilot Test Analytical Results: The following graphs compare the results of the ERD and ISCR pilot tests.

pH: The hydrogen ion activity (pH) substantially affect the biological reductive dechlorination has been demonstrated to be inhibited by low pH conditions Dehalococcoides (Dhc). Below pH of 6.0 Standard Units (SU), the degradation rate of CEs begins to decrease and at pH 5.0 SU Dhc stop degradation. Therefore maintaining pH in a range favorable to reductive dechlorination is critical for effective application of ERD.

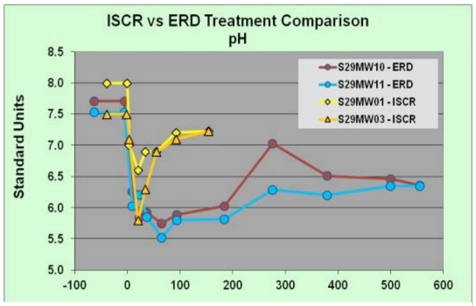


Figure 3: Change in pH during ISCR and ERD pilot tests

Following injection, the pH of the groundwater in the ERD test gradually decreased to 5.52 SU (Day 66) and required 200 days to return to favorable conditions (>6.0 SU). Whereas pH only fell below 6.5 in one well (pH 5.8 SU, well S29MW03) and had returned to favorable conditions the following sample event (Day 35) and maintained pH within the favorable range for the duration of the DOT.

Although excursions of pH outside the range favorable to biological degradation do not affect the abiotic degradation of the CEs by the zero valent iron (ZVI), the ZVI injected with the ELS act to maintain the pH within a range favorable to biological reductive dechlorination. The pH of the pilot tests is presented in Figure 3.

Arsenic: During the establishment of highly reducing condition necessary for reductive dechlorination, dissolved arsenic (As) concentration increases as insoluble As(V) is reduced to soluble As (III). The increase in As during establishment of reducing conditions can result in concentrations of this contaminant to regulatory levels. During the ERD pilot test, dissolved As concentrations increased to over 0.050 mg/L and maintained concentrations in excess of the primary drinking water standard (0.010 mg/L) for the duration of the pilot test. During the DOT however, only slight increases in As were observed and those concentrations never exceeded the primary drinking water standard. The change in As concentrations in the two tests are shown in Figure 4.

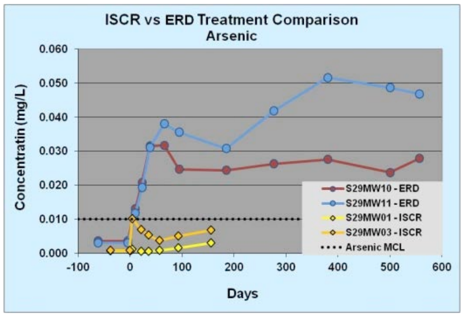


Figure 4: Change in arsenic concentration in ISCR and ERD pilot tests

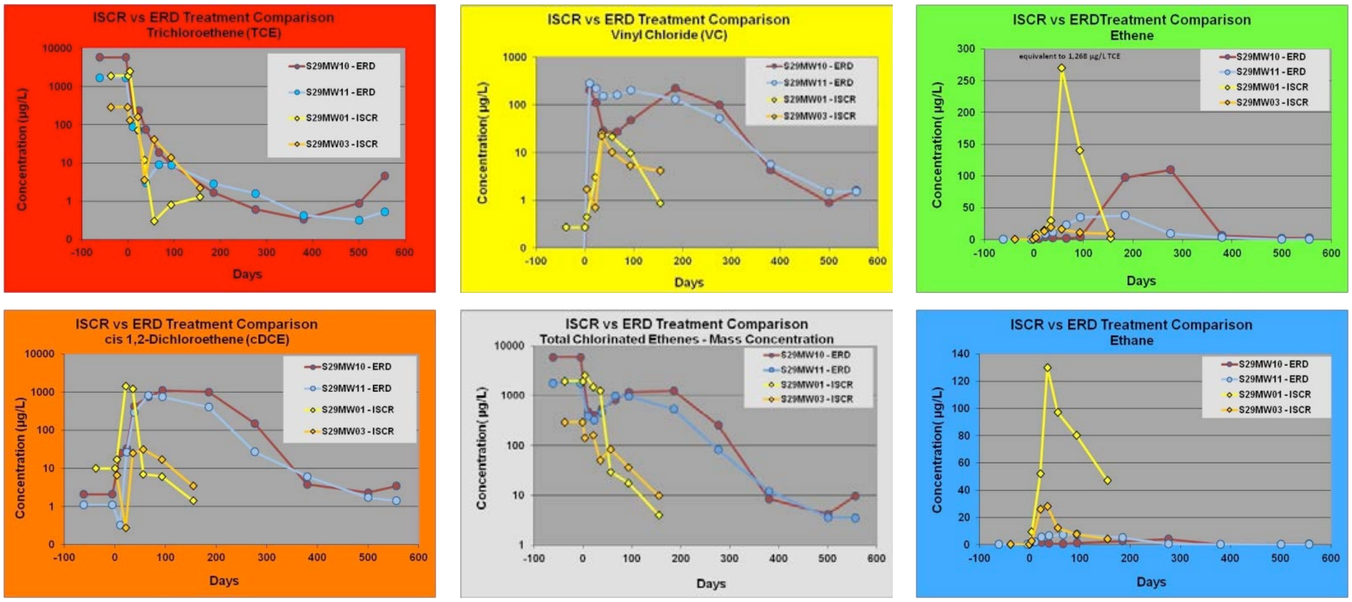


Figure 5: Change in ethenes, and ethane concentration during ISCR and ERD pilot tests

VOCs: As highly reducing conditions were established, rapid reductive dechlorination of the TCE was observed in both the ERD and ISCR tests. Notable differences were observed in the production and degradation of chlorinated daughter products dichloroethene (DCE) and vinyl chloride (VC) in the two tests. Cis 1,2-DCE concentrations increased substantially in both tests, however, DCE degradation occurred much more rapidly in the ISCR test. As DCE concentration decreased concentrations of VC increased in both tests, however at substantially lower concentrations in the ISCR test. The minor production of VC indicates that the β-elimination pathway is the primary DCE degradation pathway. The persistence of DCE, and resulting generation and degradation of VC, and the higher ratio of VC generated by DCE reduction by ERD processes appears to be the primary reason for the longer remedial time when applying ERD approach to this site.

Complete reductive dechlorination of the CEs was confirmed by the near stoichiometric conversion of the CEs to ethene and ethane (270 and 130 micrograms per liter; µg/L respectively well S29MW01) observed by Day 56 of the DOT. The results of the total CE concentration decreased at a much faster rate by ISCR in the DOT than in the ERD Test. This resulted in a reduction of total mass concentration of 99.8 % within 155 days. Whereas, 500 days was required in the ERD test to achieve the same amount of mass reduction.

The molar fraction of the chlorinated ethenes, and ethene, ethane and acetylene was plotted on pie charts to evaluate the extent of dechlorination. The sequential reduction of chlorinated ethenes TCE (red) to DCE (orange) VC (yellow) to non toxic degradation products ethene (green), ethane (blue), and acetylene (purple) are presented in Figure 6. The pie charts demonstrate that the process ISCR process (shown in the bottom two rows) more rapidly advanced the sequential dechlorination than the ERD process (shown in top two rows). The presence of ethane in the ISCR process also demonstrates that the reductive process continued after the generation of ethene indicating that more strongly reducing conditions and hydrogen

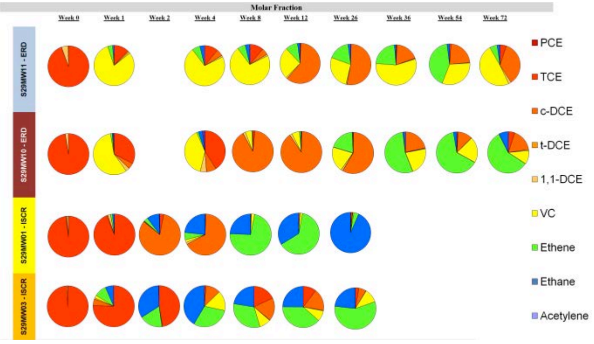


Figure 6: Change in total molar concentration during ISCR and ERD pilot tests

RESULTS

The data collected during the DOT and Biotic Only pilot allowed for a comparison of ISCR to standard enhanced reductive dechlorination. The data demonstrate that the ISCR process had substantial advantages over the Biotic Only approach to remediation. These benefits advantages include the following:

- The ISCR process can be effectively applied in highly aerobic aquifers.
- The ZVI in the ISCR approach buffered the aquifer and maintained the pH within the favorable range for biological reductive dechlorination, whereas pH remained below the optimal level for a substantially longer period of time thereby reducing the degradation rate.
- The ISCR process maintained the dissolved arsenic concentration below the MCL whereas arsenic has exceeded the MCL by a factor of 3 to 5 for more than 500 days and does not appear to be decreasing
- Degradation of each of the chlorinated ethenes was substantially faster in the ISCR pilot test than in the ERD pilot test. The longer time for dechlorination in the ERD pilot test is considered to be attributable to the slow biotic reductive dechlorination of cis 1,2-DCE and VC compared to the more rapid abiotic degradation of cis 1,2-DCE and the ERD of residual VC generated during the ISCR process.
- The pie charts indicate that the CEs are more rapidly converted to primarily non toxic degradation products by the ISCR process than by the ERD process.

CONCLUSION

In Situ Chemical Reduction, represents a significant improvement to standard enhanced biological reductive dechlorination for treatment of CEs. The symbiotic processes which constitute the ISCR approach more rapidly achieve the remedial goals than ERD processes alone. ELS was confirmed to be highly effective electron donor for biologically enhanced reductive dechlorination processes in the ISCR technology. Significantly, the primary degradation process of the cis 1,2-DCE was abiotic β-elimination resulting from contact with the incorporated ZVI.

This process was demonstrated to be much quicker than the degradation of cis 1,2-DCE by ERD and minimized the production of VC.

The ELS was demonstrated to rapidly established highly reducing conditions which were buffered by the incorporated ZVI. The combination of these biotic and abiotic processes established conditions whereby the supplied bioaugmentation culture efficiently dechlorinated the minor amount of residual VC. The remedial goals for this project were achieved within the DOT area within 155 days as compared to more than 500 days using the ERD approach. The application of this technology provides the contractor with a mechanism for rapidly achieving site remedial goals which is essential in performance based contracts. Ultimately, the reduced remedial time allows for the Navy to achieve its goal of divesting the base in a timely fashion.

EHC® Liquid Pilot Application to Treat CVOCs at a Former Industrial Site, Holmdel, NJ

Summary

Groundwater at a site in Holmdel, NJ is impacted with chlorinated solvents (primarily PCE, TCE and 1,2-DCE). A pilot test was first conducted in Nov 2011 by injecting EHC® Liquid reagent into the shallow aquifer. EHC Liquid is composed primarily of ELS™ Microemulsion, a controlled-release organic carbon substrate and EHC Liquid mix, an organo-ferrous compound. The injected amendments were successful at establishing long-lasting, highly-reducing conditions conducive to chemical and biological reduction of cVOCs.

Remedial Strategy

The geology is primarily silty sand in the top 30 ft of the aquifer, vertical impacts span from 7 ft to 21 ft bgs. The upgradient source area was formerly excavated where EHC reagent was applied at the bottom of the excavation to treat residual contamination in saturated soil. The downgradient portion of the area of interest was to be addressed with EHC Liquid, an *in situ* chemical substrate to promoting biotic and abiotic reduction of CVOCs with a possible addition of a buffer to raise the pH of the acidic aquifer.

Solution

Figure 1 shows the site map with the layout of pilot test injection and monitoring wells. A total of 5,110 gallons of solution was injected containing 10,920 pounds of ELS Microemulsion, 639 lbs of EHC Liquid Mix (organo-iron compound), 3,670 lbs of magnesium hydroxide buffering agent and 24 L of dehalococcoides (*Dhc*) containing solution. Nineteen injection points targeted a vertical zone from 7-21 ft bgs.

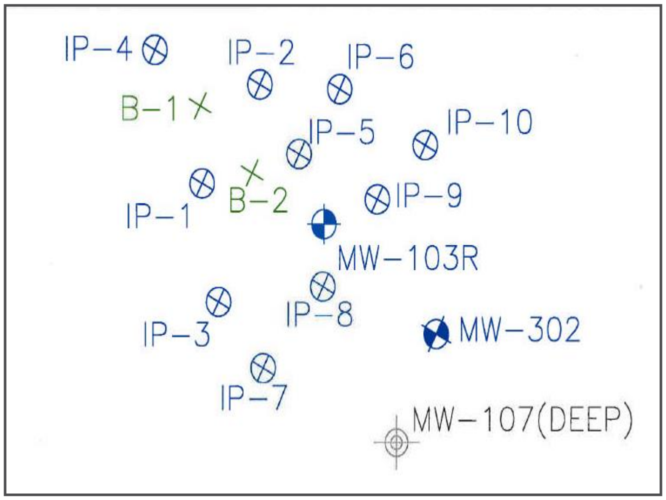
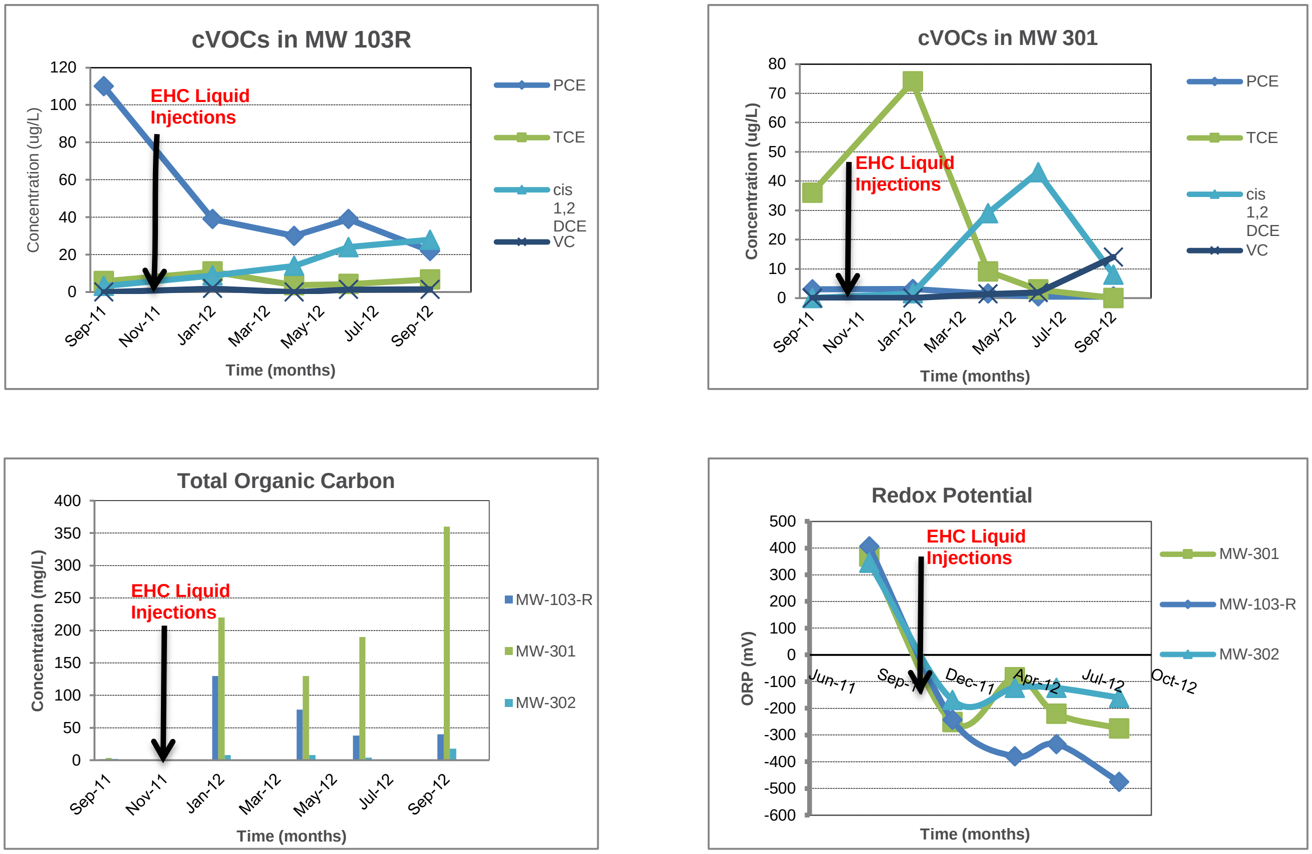


Figure 1 – Pilot test injection locations

Results

Figure 2 shows the concentrations of CVOCs, Total Organic Carbon and ORP in performance monitoring wells within the treatment area. PCE and TCE concentrations were reduced to concentrations below the GWQS within 9 months following the pilot-scale treatment.

Figure 2 – cVOCs, Total Organic Carbon, Redox Potential data baseline and post injection



Future Scope of Work

The quantity of magnesium hydroxide (alkaline buffer) injected during the pilot test was excessive, resulting in high pH conditions restricting the proliferation of microbial community. Full-scale remedy will be designed to address shortcomings identified during the pilot test, which included proper pH dosing and introduction of a sufficient population of bacteria capable of dechlorinating VC and 1,2-DCE.

Environmental Solutions

EHC® Liquid

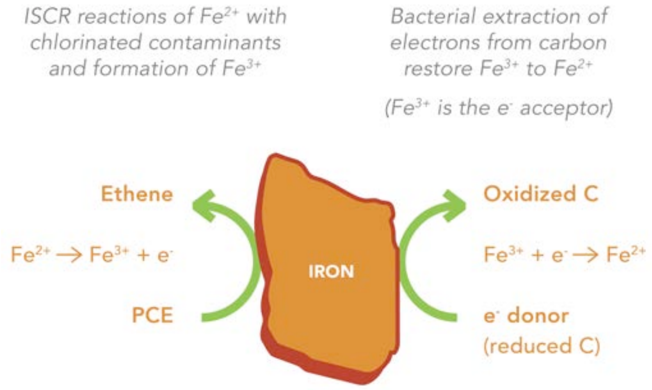
Product Sheet

A Dynamic Solution Promoting Abiotic and Biotic Processes

EHC® Liquid Reagent is an *in situ* chemical reduction (ISCR) product for the treatment of impacted groundwater. It is a cold-water soluble formulation that is specially designed for injection via existing wells or hydraulic injection networks for the treatment of a wide range of groundwater contaminants. EHC Liquid creates strong reducing conditions and promotes both biotic and abiotic dechlorination reactions. EHC Liquid is composed of two parts: EHC Liquid Reagent Mix, an organo-iron compound, and ELS™ Microemulsion, which are easily combined and diluted for injection.

The benefits of EHC Liquid

- Stimulation of biotic reductive dechlorination through the generation of strong reducing conditions
- Structurally bound nutrients phosphorous and nitrogen released to bacteria via the fermentation of the lecithin molecule
- Direct chemical reduction from redox reaction of organo-iron compound
- Surface dechlorination by magnetite and green rust precipitates from iron corrosion
- Replenished reactive iron surface provided by the cycling of iron from ferrous to ferric state in the presence of a carbon source - anticipated longevity of 2-3 yrs. depending on site conditions
- Easy to handle and cold water soluble

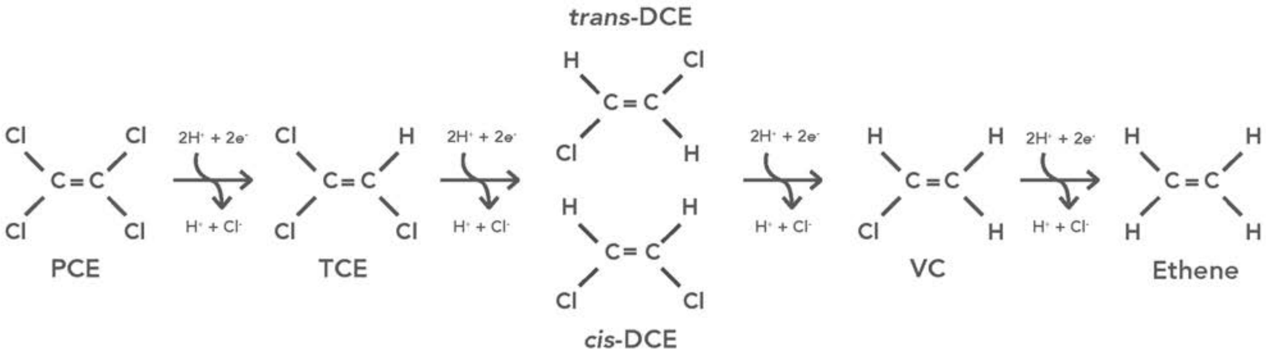


Contaminants treated

- Chlorinated solvents such as PCE, TCE, TCA, DCA, CCl_4, chloroform and methylene chloride
- Chlorobenzenes including di- and tri-chlorobenzene
- Energetic compounds such as TNT, DNT, HMX, RDX, nitroglycerine and perchlorate
- Most pesticides including DDT, DDE, dieldrin, 2,4-D and 2,4,5-T
- Chlorofluorocarbons
- Nitrate compounds
- Chromium

The sound science of EHC Liquid

Organic carbon addition in the saturated zone is well-known to promote conventional enzymatic reductive dechlorination reactions. This happens because the carbon in the subsurface will support the growth of indigenous microbes in the groundwater environment. As bacteria feed on the soluble carbon, they consume dissolved oxygen and other electron acceptors, thereby reducing the redox potential in groundwater. As bacteria ferment the ELS microemulsion, they release a variety of volatile fatty acids (VFAs) such as lactic, propionic and butyric, which diffuse from the site of fermentation into the groundwater plume and serve as electron donors for other bacteria, including dehalogenators. The biogenolysis/hydrogenolysis reaction for the reduction of PCE is shown below.



Lecithin itself is composed primarily of phospholipids, which have both hydrophilic and hydrophobic regions in their molecular structure. As a result, ELS emulsions tend to be stable emulsions, expectedly more stable than with only hydrophobic compounds. Further, phospholipids support remediation by providing essential nutrients (carbon, nitrogen, phosphorus) to bacteria.

The soluble organo-iron compound is comprised of a ferrous iron (Fe^{+2}) that can form a variety of iron minerals (e.g. magnetite, pyrite) that are capable of reducing contaminants as they oxidize further to the ferric (Fe^{+3}) state via one electron transfer. The ferric ion can be “recycled” back to ferrous as long as other electrons from supplied carbon and indigenous carbon are available.

EHC Liquid is primarily recommended for plume treatment. It can be used as a source treatment depending on site conditions.

Application methods

- Direct push injection
- Gravity feed through existing wells
- Low pressure injections
- Recirculation systems

For more information and detailed case studies, please visit our website.

EOS Remediation, LLC

EOS PRO

SAFETY DATA SHEET

Section 1: Identification

Product Name:	**EOS Pro**
Chemical Description:	Mixture; vegetable oil emulsion
Manufacturer:	EOS Remediation 1101 Nowell Road Raleigh, NC 27607 (P): 919-873-2204 www.eosremediation.com
Recommended Use:	Groundwater bioremediation (environmental applications)
Restricted Use:	Not for human consumption.
24-Hour Emergency Contact:	ChemTel: United States (P): 800-255-3924 ChemTel: International (P): 813-248-0585

Section 2: Hazard(s) Identification

Hazard Classification:	Irritant (skin and eye)
Signal Word:	Warning
Hazard Statement(s):	Potential eye and skin irritant.
Pictograms:	
Precautionary Statement(s):	Not for human consumption. Do not store near excessive heat or oxidizers. Avoid contact with eyes and skin. Wear protective gloves and eye protection.

Section 3: Composition/Information on Ingredients

Common Name(s)	**CAS NO.**	**% by Weight**
Soybean Oil	8001-22-7	59.8
Food Grade Emulsifiers Trade Secret[1,2]	Proprietary	10
Soluble Substrates Trade Secret[1,2]	Proprietary	4
Food Additives/Preservatives Trade Secret[1]	Proprietary	0.3
Nutrients/Extracts Trade Secret[1,2]	Proprietary	1
Water	7732-18-5	Balance

1 – The precise composition of this product is proprietary information. A more complete disclosure will be provided to a physician in the event of a medical emergency.

2 – The soluble substrates and emulsifiers are generally recognized as safe for food contact.

Section 4: First-Aid Measures	
Routes of Exposure	**Emergency First-Aid Procedures**
Inhalation	Remove to fresh air.
Eye Contact	Flush with water for 15 minutes; if irritation persists see a physician.
Skin Contact	Wash with mild soap and water.
Ingestion	Product is non-toxic. If nausea occurs, induce vomiting and seek medical attention.

Section 5: Fire-Fighting Measures	
Extinguishing Media:	CO_2, foam, dry chemical Note: Water, fog and foam may cause frothing and spattering.
Special Fire Fighting Procedures:	Wear self-contained breathing apparatus and chemical resistant clothing. Use water spray to cool fire exposed containers.
Fire Hazard(s):	Burning will cause oxides of carbon.

Section 6: Accidental Release Measures	
Personal Precautions:	Avoid contact with eyes and skin. Do not consume.
Emergency Procedures:	N/A
Methods & Materials used for Containment:	Compatible granular absorbent
Cleanup Procedures:	Spread compatible granular absorbent over spill area and sweep using broom and pan; dispose in appropriate receptacle. Clean area with water.

Section 7: Handling and Storage	
Safe Handling & Storage:	Do not store near excessive heat or oxidizers.
Other Precautions:	Consumption of food and beverages should be prevented in work area where product is being used. After handling product, always wash hands and face thoroughly with soap and water before eating, drinking, or smoking.

Section 8: Exposure Controls/Personal Protection		
Exposure Limits		
OSHA PEL:	NE	
ACGIH TLV:	NE	
NIOSH REL:	NE	
Personal Protective Measures		
Respiratory Protection:	Not normally required. P95 respirator if aerosols might be generated.	
Hand Protection:	Protective gloves are recommended	
Eye Protection:	Recommended	
Engineering Measures:	Local exhaust ventilation if aerosols are generated	
Hygiene Measures:	Wash promptly with soap & water if skin becomes irritated from contact.	
Other Protection:	Wear appropriate clothing to prevent skin contact.	

Section 9: Physical and Chemical Properties

Appearance:	White Liquid	Explosive Limits:	NE
Odor:	Vegetable Oil	Vapor Pressure:	NE
Odor Threshold:	NE	Vapor Density:	Heavier than air
pH:	Neutral	Relative Density:	0.96-0.98
Melting Point/Freezing Point:	Liquid at room temperature	Solubility:	Dispersible
Boiling Point:	212°F (100°C)	Partition coefficient:	NE
Flash Point:	>300°F (149°C)	Auto-ignition Temperature:	NE
Evaporation Rate:	NE	Decomposition Temperature:	N/A
Flammability (solid, gas):	NE	Viscosity:	500-1500 cP

NE – Not Established

Section 10: Stability and Reactivity

Stability:	Stable
Incompatibility:	Strong acids and oxidizers
Hazardous Decomposition Products:	Thermal decomposition may produce oxides of carbon
Hazardous Reactions/Polymerization:	Will not occur
Conditions to Avoid:	None known

Section 11: Toxicological Information

Likely Routes of Exposure:		Ingestion, dermal and eye contact
Signs and Symptoms of Exposure:		None known
Health Hazards		
	Acute:	Potential eye and skin irritant
	Chronic:	None known
Carcinogenicity		
	NTP:	No
	IARC:	No
	OSHA:	No

Section 12: Ecological Information (non-mandatory)

There is no data on the ecotoxicity of this product.

Section 13: Disposal Considerations (non-mandatory)

Waste Disposal Methods:	Dispose of according to Federal and local regulations for non-hazardous waste. Recycle, if practical.

Section 14: Transport Information (non-mandatory)

The product is not covered by international regulation on the transport of dangerous goods.

No transport warning required.

Section 15: Regulatory Information (non-mandatory)

N/A

Section 16: Other Information

Date of Preparation:	29 May 2014
Last Modified Date:	5 September 2014

The information contained herein is based on available data and is believed to be correct. However, EOS Remediation, LLC makes no warranty, expressed or implied, regarding the accuracy of this data or the results to be obtained thereof. This information and product are furnished on the condition that the person receiving them shall make his/her own determination as to the suitability of the product for his/her particular purpose.

EOS Remediation, LLC

EOSZVI

SAFETY DATA SHEET

Section 1: Identification

Product Name:	**EOS ZVI**
Chemical Description:	Mixture; carbonyl iron powder in vegetable oil
Manufacturer:	EOS Remediation 1101 Nowell Road Raleigh, NC 27607 (P): 919-873-2204
Recommended Use:	Groundwater Bioremediation (environmental applications)
Restricted Use:	Not for human consumption
24-Hour Emergency Contact:	ChemTel: United States (P): 800-255-3924 ChemTel: International (P): 813-248-0585

Section 2: Hazard(s) Identification

Hazard Classification:	Irritant (eye and skin)
Signal Word:	Warning
Hazard Statement(s):	Potential eye and skin irritant.
Pictograms:	
Precautionary Statement(s):	Not for human consumption. Protect from freezing. Do not store near excessive heat or oxidizers. Avoid contact with eyes and skin. Wear protective gloves and eye protection.

Section 3: Composition/Information on Ingredients

Common Name(s)	CAS NO.	% by Weight
Soybean Oil	8001-22-7	40 - 45
Emulsifiers Trade Secret[1,2]	Proprietary	5 - 10
Stabilizers Trade Secret[1,2]	Proprietary	1 - 5
Carbonyl Iron	7439-89-6	45 - 55

1 – The precise composition of this product is proprietary information. A more complete disclosure will be provided to a physician in the event of a medical emergency.

2 – The soluble substrates and emulsifiers are generally recognized as safe.

Section 4: First-Aid Measures

Routes of Exposure	**Emergency First-Aid Procedures**
Inhalation	Remove to fresh air.
Eye Contact	Flush with water for 15 minutes; if irritation persists see a physician.
Dermal	Wash with mild soap and water.
Ingestion	Product is non-toxic. If nausea occurs, induce vomiting and seek medical attention.

Section 5: Fire-Fighting Measures

Extinguishing Media:	CO_2, foam, dry chemical Note: Water, fog and foam may cause frothing and spattering.
Special Fire Fighting Procedures:	Wear self-contained breathing apparatus and chemical resistant clothing. Use water spray to cool fire exposed containers.
Fire Hazard(s):	Burning will cause oxides of carbon.

Section 6: Accidental Release Measures

Personal Precautions:	Avoid contact with eyes and skin. Do not consume.
Emergency Procedures:	N/A
Methods & Materials used for Containment:	Compatible granular absorbent
Cleanup Procedures:	Spread compatible granular absorbent over spill area and sweep using broom and pan; dispose in appropriate receptacle. Clean area with water.

Section 7: Handling and Storage

Safe Handing & Storage:	Do not store near excessive heat (> 150°C) or oxidizers.
Other Precautions:	Consumption of food and beverages should be prevented in work area where product is being used. After handling product, always wash hands and face thoroughly with soap and water before eating, drinking, or smoking.

Section 8: Exposure Controls/Personal Protection

Exposure Limits		
OSHA PEL:	Vegetable Oil Mist	15 mg/m^3 (total) 5 mg/m^3 (respirable)
ACGIH TLV:	NE	NE
NIOSH REL:	Vegetable Oil Mist	10 mg/m^3 (total) 5 mg/m^3 (respirable)
Personal Protective Measures		
Respiratory Protection:	Not normally required. P95 respirator if aerosols might be generated.	

Hand Protection:	Protective gloves are recommended
Eye Protection:	Recommended
Engineering Measures:	Local exhaust ventilation if aerosols are generated
Hygiene Measures:	Wash promptly with soap & water if skin becomes irritated from contact.
Other Protection:	Wear appropriate clothing to prevent skin contact.

NE – Not Established

Section 9: Physical and Chemical Properties

Appearance:	Black	Explosive Limits:	NE
Odor:	Vegetable Oil	Vapor Pressure:	NE
Odor Threshold:	NE	Vapor Density:	Heavier than air
pH:	NE	Relative Density:	1.5 – 1.7
Melting Point/Freezing Point:	Liquid at room temperature	Solubility:	Easily soluble & dispersible
Boiling Point:	N/A	Partition coefficient:	NE
Flash Point:	>600°F (316°C)	Auto-ignition Temperature:	NE
Evaporation Rate:	NE	Decomposition Temperature:	N/A
Flammability (solid, gas):	NE	Viscosity:	2350 cP

NE – Not Established

N/A – Non-Applicable

Section 10: Stability and Reactivity

Stability:	Stable
Incompatibility:	Strong acids and oxidizers
Hazardous Decomposition Products:	Thermal decomposition may produce oxides of carbon
Hazardous Reactions/Polymerization:	Will not occur
Conditions to Avoid:	Do not expose to temperatures above 150°C

Section 11: Toxicological Information

Likely Routes of Exposure:		Ingestion, dermal and eye contact
Signs and Symptoms of Exposure:		None known
Health Hazards		
	Acute:	Potential eye and skin irritant
	Chronic:	None known
Carcinogenicity		
	NTP:	No
	IARC:	No
	OSHA:	No

Section 12: Ecological Information (non-mandatory)

There is no data on the ecotoxicity of this product.

Section 13: Disposal Considerations (non-mandatory)

Waste Disposal Methods:	Dispose of according to Federal and local regulations for non-hazardous waste.

Section 14: Transport Information (non-mandatory)

The product is not covered by international regulation on the transport of dangerous goods.

No transport warning required.

Section 15: Regulatory Information (non-mandatory)

N/A

Section 16: Other Information

Date of Preparation:	2 June 2016
Last Modified Date:	2 June 2016

The information contained herein is based on available data and is believed to be correct. However, EOS Remediation, LLC makes no warranty, expressed or implied, regarding the accuracy of this data or the results to be obtained thereof. This information and product are furnished on the condition that the person receiving them shall make his/her own determination as to the suitability of the product for his/her particular purpose.

Anaerobic Bioremediation of a Piedmont Saprolite Source Area with EOS®

Walter J. Beckwith,P.G. wbeckwith@solutions-ies.com, Robert C. Borden, Ph.D, P.E., Christie Zawtocki, P.E., and M. Tony Lieberman, RSM (Solutions-IES, Raleigh, NC)
Donald Koch, P.E., C.C. Johnson & Malhotra, P.C., Columbia, MD
Ira May, P.G., US Army Environmental Center, Aberdeen, MD

ABSTRACT: Solutions-IES is presently using Emulsified Oil Substrate (EOS®) to remediate trichloroethene (TCE) in a source area at the Tarheel Army Missile Plant. Previous chlorinated solvent use at the facility resulted in both soil and groundwater impacts. Ten years of active remediation including pump-and-treat, *in situ* soil vacuum extraction, and air sparging (SVE/AS) were largely ineffective in reducing the TCE/PCE groundwater plume.

In 2002, the Army authorized preparation of an amended Remedial Action Plan (RAP) to evaluate *in situ* bioremediation methods to remediate remaining TCE in groundwater. The RAP prepared by CC Johnson & Malhotra evaluated eight groundwater remediation technologies and recommended EOS® as the preferred bioremediation alternative for the site. Unique site characteristics required careful planning of the injection process for effective substrate distribution while minimizing capital and operating costs. Groundwater flow at the site was simulated using MODFLOW. EOS® distribution was simulated using RT3D with a special module developed to describe the transport and retention of oil emulsions. With these tools, Solutions-IES evaluated a variety of different injection and distribution alternatives. This was critical because of the low formation permeability, extensive infrastructure at the site, and high drilling costs.

From June to September 2004, Solutions-IES injected 13,000 pounds of EOS® concentrate into the 100 x 100 ft zone believed to be the primary source area for the TCE plume. The EOS® treatment quickly stimulated anaerobic conditions as evidenced by decreased dissolved oxygen, oxidation-reduction potential, and sulfate concentrations and increasing ferrous iron, methane, and TCE degradation products. The regular monitoring program has confirmed the effectiveness of the selected treatment technology. TCE concentrations have decreased while *cis*-1,2-dichloroethene and vinyl chloride have increased in several wells indicating that suitable conditions have been established for the contaminants to be reduced to non-chlorinated end-products without bioaugmentation.

INTRODUCTION

The Tarheel Army Missile Plant (TAMP) has a 50-year history of use by government contractors, including Fairchild Aircraft Company, Firestone Tire and Rubber Company, Western Electric Company, AT&T and its successor Lucent Technologies Inc., for production of defense-related and private sector electronics. Groundwater and soil contamination were discovered at TAMP in 1993 when benzene, toluene, ethylbenzene, xylenes (BTEX), and chlorinated volatile organic compounds (CVOCs) including tetrachloroethene (PCE), trichloroethene (TCE), *cis*-1,2-dichloroethene (*cis*-1,2-DCE), and vinyl chloride

(VC) were identified in soil and groundwater. The BTEX compounds were attributed to leaking USTs and the CVOCs were attributed to a chlorinated solvent cleaning machine and a waste accumulation pad. Subsequent assessment showed partially commingled, dissolved phase plumes of both petroleum hydrocarbons and CVOCs in groundwater at the facility.

A Corrective Action Plan (CAP) to remediate soil and groundwater using soil vapor extraction/air sparge (SVE/AS) was implemented in 1995 and amended in 1998 to include a pump-and-treat system to provide hydraulic gradient control of the groundwater plume at the northwest corner of the property. The facility has been vacant since 1993 and, in order to transfer ownership of the facility, the Army signed a Consent Agreement with the State of North Carolina in early 2004 committing to an expedited groundwater cleanup program. The data indicated that the SVE system had effectively reduced VOC concentrations in soil and the AS system had reduced BTEX constituents in groundwater, but the systems in place had only achieved limited improvement to the CVOC concentrations in groundwater. The Army retained C.C. Johnson & Malhotra, P.C. (CCJM) to provide an alternate remediation approach that could more effectively and rapidly address the remaining CVOC contamination and make the site more desirable for sale.

REMEDIATION PLAN

In August 2003, the Army received approval of a Remedial Action Plan (RAP) prepared by CCJM that recommended ***in situ*** bioremediation of the CVOCs using an emulsified oil substrate (EOS®)[1]. The RAP included the provision to perform a field pilot test to evaluate the ability of EOS® to reduce the contaminants in the source area to interim groundwater goals that had been established in the Consent Agreement. The RAP recommended that after the interim goal for TCE had been met that monitored natural attenuation (MNA) be used to track further reduction of the remaining CVOCS to the North Carolina Groundwater Standards.

Site Conditions. TAMP occupies approximately 33 acres in an area that has seen previous commercial development in northeast Burlington, N.C. More than 95 percent of the land is covered with impervious surfaces, severely limiting aquifer recharge. Soils are weathered from underlying bedrock and tend to be very clayey near the ground surface (Unified Soil Classifications of CL, ML, and CH). Soils tend to become more silty and sandy (ML and SM) with increasing depth, transitioning to saprolite (decomposed rock) and sheared granite bedrock. The depth to bedrock varies across the property, ranging from 12 to 35 feet bgs. The water table occurs within the soil overburden at depths of 7 to 13 feet bgs depending on topographic position. Groundwater flow is toward the northwest toward an unnamed stream west of the property. Recovery wells installed at the site in 1998 yield little water, suggesting the granitic saprolite yields/accepts fluids with some difficulty.

Since 1995 when active remediation was initiated, soil and groundwater samples have been collected at the site periodically by other consultants to monitor effectiveness of the SVE/AS systems. In April 2003, the latest data collected prior to CCJM and Solutions-IES beginning work at the site showed the TCE plume extending approximately 900 feet west-northwest of the presumed source area in the vicinity of monitor well MW-108. Figure 1 shows the TCE plume in April 1992. The highest TCE concentrations were in MW-108 at 1,900 μg/L and MW-110 at 2,600 μg/L.

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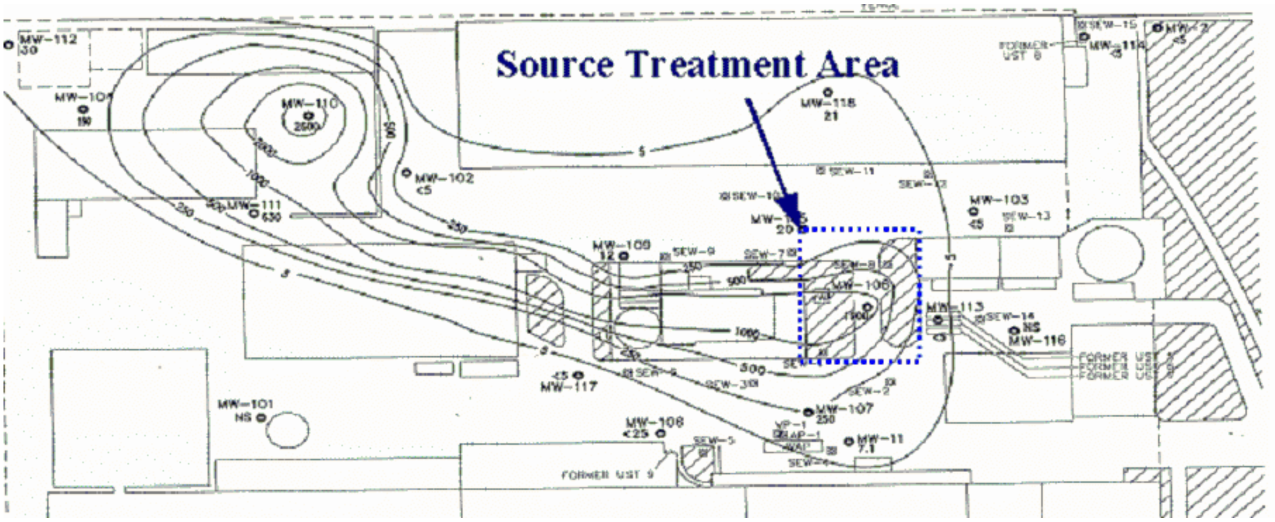
[1] Solutions-IES (U.S. Patent #6,398,960)

Figure 1. Extent of TCE in Groundwater in April 2002



EOS® Technology. Solutions-IES purchased EOS® from EOS Remediation of Raleigh, NC. The oil/water emulsion is manufactured with uniform oil droplets approximately 1 micron in diameter. The emulsion is injected into the subsurface where it serves as an electron donor. Under anaerobic conditions, hydrogen provided through fermentation of the oil donates its electrons to the chlorinated contaminants resulting in a microbially-mediated sequential removal of chlorine atoms from the target CVOCs. Sequential anaerobic reductive dechlorination of TCE results in the formation of intermediate, less-chlorinated daughter products including *cis*-1,2-DCE and vinyl chloride, and non-toxic metabolic non-chlorinated end products, ethene and/or ethane.

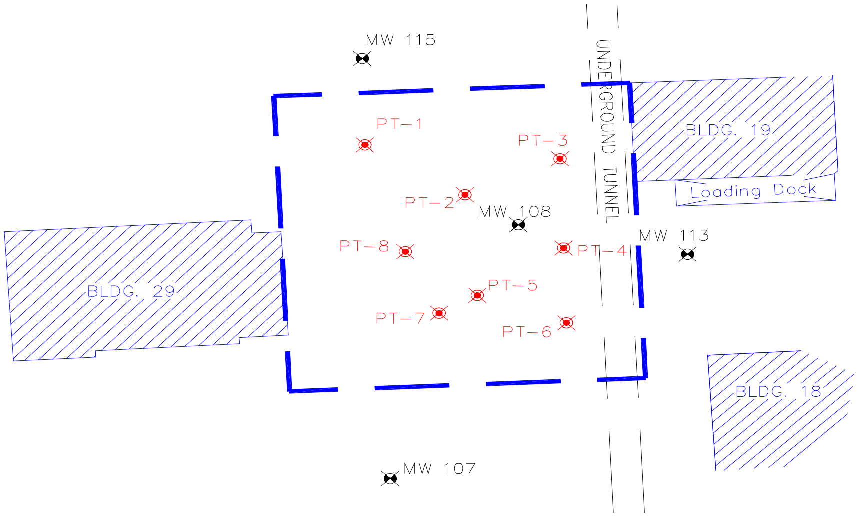
PILOT TEST

Solutions-IES and CCJM began implementation of the RAP in 2003. The project team coordinated the timely production of multiple deliverables including a site and project-specific work plan, health and safety plan, quality assurance plan, and a long-term monitoring plan that were submitted for State approval. Because the remediation plan required that EOS® would be introduced into the aquifer via a series of wells, an injection permit was also required by the North Carolina Underground Injection Control (UIC) Program. The UIC Permit and project plan approvals were granted in April 2004.

The Army specified that the effectiveness of EOS® would be first demonstrated within a 100-ft by 100-ft treatment zone within the presumed source area. Implementation of an *in situ* anaerobic bioremediation design in this area presented several significant engineering challenges including an underground pedestrian tunnel located along the east side of the test area, a relatively low-yielding saprolite aquifer, and presence of subsurface infrastructure. There were also regulatory hurdles including shutting down the active SVE/AS system in the treatment zone and addressing the possibility that bioaugmentation would be needed to replace existing dehalorespiring microorganisms likely adversely influence by the strongly oxidative conditions.

Engineering Design and Implementation. Since the treatment area was located within an area that had been actively sparged for nearly10 years, Solutions-IES received permission from the State to shut down the SVE/AS in early 2004. Concurrently, Solutions-IES designed a two-step approach to "smear" the EOS® emulsion throughout the subsurface. To implement the design, eight 4-inch diameter injection wells were installed approximately 30 to 35 feet apart using air rotary drilling methods. The locations were chosen to provide coverage of the treatment area, (Figure 2). The wells extended to the top of competent bedrock and were constructed with 10 feet of 0.020 inch slotted PVC screens, which intercepted the contaminated zone of the aquifer.

Figure 2. EOS® treatment area



During the first step, the EOS® concentrate was diluted and injected into the subsurface through four of the eight wells (PT-1, PT-4, PT-6, and PT-7). Each of the other four wells was paired with one of the injection wells and the four individual temporary re-circulation recovery-injection systems were operated for approximately three to four weeks. To comply with one of the requirements of the UIC permit that prohibited re-injection of any extracted contaminated groundwater that was brought aboveground but not treated, all piping between each well pair was run underground through a 3-inch PVC conduit. Approximately 6,500 lbs of emulsion and 83,000 gallons of groundwater were re-circulated during the first step. Consistent with the design, the extraction wells yielded less than 1 gpm; the double diaphragm pumps were able to maintain approximately 20 feet of drawdown in the recovery wells and mounding within the injection wells never reached the top of the well casing.

Approximately one month later, step two began by reversing the process using the original four recovery wells for injection of additional amendment (PT-2, PT-3, PT-5, and PT-8). Another 6,500 lbs of emulsion and 80,000 gallons of groundwater were re-circulated as before. The simultaneous injection and groundwater recovery process effectively increased the hydraulic gradients in the test area and improved the distribution (i.e., smearing) of the amendment throughout the target treatment zone.

RESULTS AND DISCUSSION

Monitoring. Three of the injection wells (PT-3, PT-6 and PT-8) and monitor well MW-108 were used to monitor the injection process and subsequent progress of the *in situ* bioremediation of TCE. Pre-injection groundwater samples were collected on June 22, 2005. Samples were again collected after injection steps one and two were completed and the aquifer was given a period to re-stabilize, August 18 and October 14, respectively. The samples were analyzed for CVOCs, total organic carbon (TOC), selected dissolved metals, light hydrocarbon gasses (methane, ethane, and ethene) and volatile fatty acids (VFAs). Field parameters, including pH, conductivity, dissolved oxygen (DO) and oxidation-reduction potential (ORP) were also measured. Additional performance monitoring samples have since been collected on December 1, 2004 (Day 154) and February 2, 2005 (Day 217).

Observations and Results. During the first injection, indications of the successful spread of EOS® as slight milkiness were observed in MW-108 located 20 feet from the PT-2. EOS® was also observed within the dewatering sump for the pedestrian tunnel, again confirming the spread of the emulsion. However, this was an undesirable outcome and injection into PT-3 and PT-4, located closest to the tunnel, was terminated early.

The pre-injection characterization showed nitrate to be absent in the aquifer. Sulfate was generally low, ranging from less than 5 mg/L to 61 mg/L. Total organic carbon was also low, ranging from less than 1 mg/L to 11 mg/L. Pre-injection groundwater conditions were generally oxidative as a result of the extended operation of the AS system prior to implementing the pilot test. DO ranged from approximately 5 mg/L to 8 mg/L and ORP was positive, ranging from +97 to +495 mV in the test area. Total CVOCS in MW-108 were approximately 2,000 µg/L prior to injection.

Table 1 summarizes CVOC concentrations for the test area wells. The Day 50 results were collected between injection steps one and two. The final injection and re-circulation activities ended on October 10, 103 days after beginning the first injection. Samples collected on October 14 were four days after completion of the second phase.

Samples collected on August 18 showed reduced PCE and TCE concentrations. At MW-108, TCE decreased from 1,690 µg/L (pre-injection) to 13.9 µg/L. Other PT wells showed similar reductions. *Cis*-1,2-DCE remained the same (MW-108) or increased in concentration (PT-8) post injection. Slightly increasing, then deceasing, concentrations of *trans*-1,2-DCE and 1,1-DCE were identified post-injection in MW-108 and PT-8. Vinyl chloride, identified in PT-8 prior to injection, initially decreased to below the detection limit after injection, but eventually was observed at substantially higher concentrations in both PT-8 and MW-108 in February 2005.

Methane, ethane, and ethene were also monitored along with field parameters (Table 2). Methane is an indicator of strong reducing conditions and ethene and ethane are the non-chlorinated non-toxic end products of dechlorination of PCE/TCE. As shown in Table 2, methane was almost nonexistent in the aquifer pre-injection, as would be expected with elevated DO and positive ORP.

Corresponding decreases in DO and ORP were noted quickly after the first injection. Post-injection bio-geochemical parameters confirmed that conditions for enhanced reductive dechlorination were quickly established. In MW-108, TOC (not shown) increased from 2.1 to 177 mg/L, DO decreased from 5.7 to 0.01 mg/L, ORP dropped from +97 to –178 mV, and sulfate (not shown) was reduced from 61 to 8 mg/L. Methane concentrations did not begin to increase until after the completion of the second injection, when concentrations rose to more than
7,200 µg/L in PT-8.

TABLE 1. CVOC concentrations in selected treatment area wells.

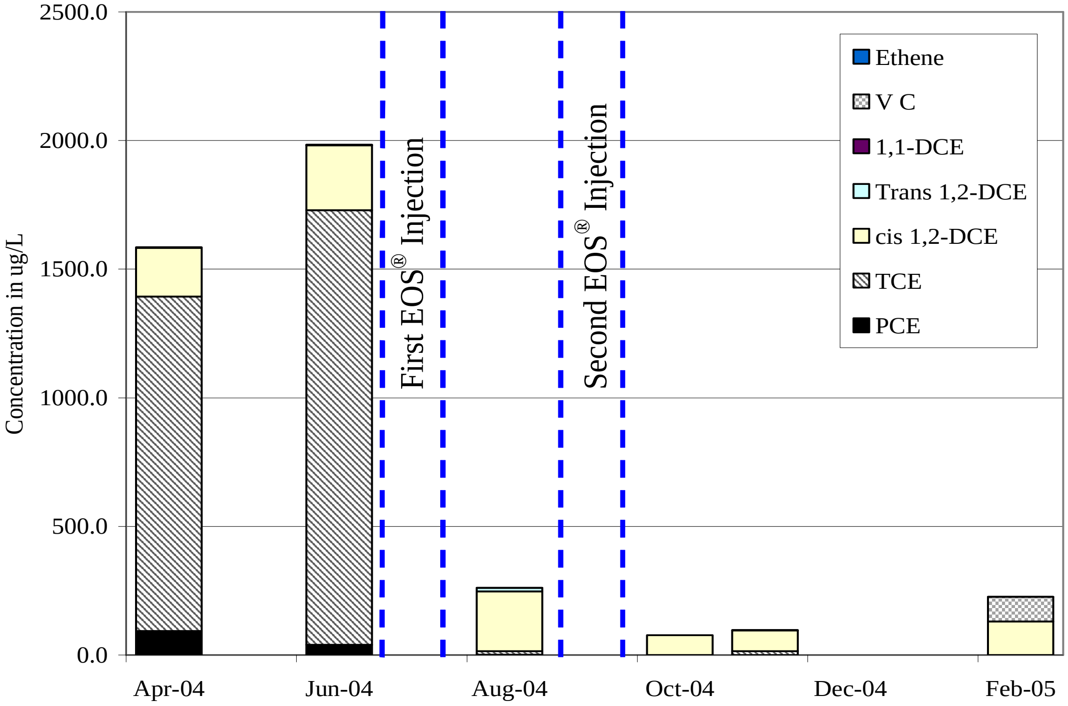
Sample Date	Days after Beginning EOS® Injection	Concentration (μg/L)					
		PCE	TCE	*Cis*-1,2-DCE	*Trans*-1,2-DCE	1,1-DCE	VC
Injection Well PT-3							
6/22/2004	-7	6.77	176	39.0	<1	<1	<1
8/18/2004	50	<1	3.76	6.90	<1	<1	<1
10/14/2004	107	<1	<1	12.0	<1	<1	<1
12/1/2004	154	<1	<1	2.3	<1	<1	<1
2/2/2005	217	N/S	N/S	N/S	N/S	N/S	N/S
Injection Well PT-6							
6/22/2004	-7	1.17	30.3	<1	<1	<1	<1
8/18/2004	50	1.26	94.60	9.49	<1	<1	<1
10/14/2004	107	<1	<1	5.8	<1	<1	<1
12/1/2004	154	<1	<1	2	<1	<1	<1
2/2&3/05	217	N/S	N/S	N/S	N/S	N/S	N/S
Injection Well PT-8							
6/22/2004	-7	49.8	240	161	2.61	<1	17.9
8/18/2004	50	<1	47.10	2102	88.20	4.98	<1
10/14/2004	107	<1	1.2	300	1.6	1.3	<1
12/1/2004	154	<5	<5	430	<5	<5	20
2/2/2005	217	<1	<1	190	3.4	<1	110
Monitor Well MW-108							
4/14/2004	-74	150	1,600	310	<10	<10	<10
6/22/2004	-7	39.4	1,690	252	1.21	1.67	<1
8/18/2004	50	1.32	13.9	232	13.20	<1	<1
10/14/2004	107	<10	<10	77	<10	<10	<10
11/30/2004	153	<1	12	82	<1	<1	<1
2/2/2005	217	<1	<1	130	<1	<1	96

Three months after initiating injection and re-circulation of EOS® throughout the treatment zone, TCE was below detection and *cis*-1,2-DCE was reduced to 77 μg/L. The data obtained immediately post-injection suggest that some of the TCE has been immobilized through sorption into the EOS®. Subsequent sampling events show the onset of biodegradation without rebound of the TCE.

TABLE 2. Light hydrocarbon gasses and field parameters for selected wells in the treatment area.

Sample Date	Days after Start of EOS® Injection	Light Hydrocarbon Gasses			Field Parameters		
		Methane (µg/L)	Ethane (µg/L)	Ethene (µg/L)	Dissolved Oxygen (mg/L)	ORP (mV)	pH (Standard Units)
Injection Well PT-3							
6/22/2004	-7	2.00	0.01	0.04	6.78	139	6.8
8/5/2004	37	N/S	N/S	N/S	1.48	-46.3	5.5
8/18/2004	50	103.70	0.03	0.15	0.14	-209	7.09
10/14/2004	107	3,180.4	0.02	0.23	0.39	-65	7.02
12/1/2004	154	3,214.6	<0.01	0.03	0.09	-2.0	6.84
2/2/2005	217	N/S	N/S	N/S	0.49	-45.2	6.3
Injection Well PT-6							
6/22/2004	-7	<200	<10	0.02	6.05	495	5.0
8/5/2004	37	N/S	N/S	N/S	0.37	-180	5.99
8/18/2004	50	4.10	<10	0.03	0.43	-181.5	6.79
10/14/2004	107	122.0	<0.01	0.01	5.61	56.3	7.66
12/1/2004	154	493.1	<0.01	<0.01	0.08	26.5	6.20
2/2&3/05	217	N/S	N/S	N/S	5.02	-112.2	7.23
Injection Well PT-8							
6/22/2004	-7	59.20	0.15	0.25	0.16	135	6.48
8/18/2004	37	5.10	0.16	0.56	0.14	-213	6.61
10/14/2004	50	1,874.6	0.17	0.50	0.51	-111.3	6.20
12/1/2004	107	7,268.9	0.04	0.58	0.02	-106.5	6.03
2/2/2005	154	5,150.2	<0.01	0.35	0.08	-109	6.29
Monitor Well MW-108							
4/14/2004	-7	N/S	N/S	N/S	5.71	96.9	6.77
6/22/2004	37	0.50	0.02	<10	2.67	171.0	6.10
8/18/2004	50	121.00	0.14	0.32	0.13	-178.5	6.31
10/14/2004	107	4,583.0	0.16	0.32	0.46	-80.4	5.61
11/30/2004	153	3,751.6	0.01	0.15	0.01	-91.4	6.1
2/2/2005	217	1,259.5	<0.01	0.07	0.11	-88.0	6.2

FIGURE 3. CVOC Concentrations in MW-108.



CONCLUSIONS

The project demonstrated that EOS® could be effectively injected into saprolite using relatively inexpensive pneumatic pumps and that following the emulsion with additional groundwater effectively moved the emulsion throughout the 10,000-ft^2 treatment area. Visual observation of water samples collected from MW-108 and from the pedestrian tunnel showed that it was possible to move the EOS® more than 20 feet from the injection points.

While the low yield of the site wells extended the time required to complete both steps of the injection to 100 days, using in-well instrumentation and performing most of the water re-circulation process unattended kept labor and equipment costs low. During the second application of EOS®, the emulsion was successfully gravity drained into the injection wells, further reducing labor costs.

Four months of post-injection groundwater data for MW-108 and the pilot test wells shows that EOS® quickly facilitated anaerobic reducing conditions, as noted by increased methanogenesis. TCE was reduced in MW-108 from approximately 1,600 µg/L to <10 µg/L. *Cis*-1,2 DCE concentrations after injection have remained similar to pre-injection levels, but increasing concentrations of vinyl chloride in several wells four months post-injection suggest that reductive dechlorination is proceeding beyond *cis*-1,2 DCE. Although Solutions-IES had secured approval from the State toxicologist to inject a commercially-prepared culture of dehalorespiring bacteria (KB-1 from SiREM, Guelph, Ontario), the results have shown that bioaugmentation will not be necessary at this site. Site-wide treatment is now in the planning stages.

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