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November 19, 2014

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Subject: **Final Work Plan for In Situ Chemical Oxidation Pilot Study**  
401 National Avenue, Former Fairchild Building 9  
Middlefield-Ellis-Whisman Area  
Mountain View, California

Dear Ms. Ma:

Enclosed with this letter is the Final Work Plan for *In Situ* Chemical Oxidation (ISCO) Pilot Study at the former Fairchild Building 9, located at 401 National Avenue, Mountain View, California. A previous version of this work plan was submitted to the U.S. Environmental Protection Agency (EPA) on 3 July 2014 and EPA provided comments in a letter dated 23 September 2014. This Final Work Plan has been revised based on the EPA comments. A response to comments table is provided in Appendix A and a contingency plan for mitigating potential ISCO-related secondary water quality impacts at the 401/405 National Shared Treatment Plant is provided in Appendix D.

As indicated in the Final Work Plan, the ISCO pilot study is scheduled to take place following the demolition of Building 9. Based on a general schedule provided verbally by the developer, it is anticipated that building demolition will be completed and the site open for pilot study implementation in January 2015. We are therefore requesting approval of this Work Plan by 31 December 2014.

In addition, in its letter dated 23 September 2014, EPA requested that Schlumberger "reassess and evaluate implementation of a treatability study of a funnel-and-gate system in the downgradient (northern) slurry wall in conjunction with and consideration of the ISCO pilot study work and the redevelopment of the 401 National Avenue property." Schlumberger intends to complete this evaluation and submit a work plan for a funnel-and-gate treatability study to EPA by 30 January 2015.

If you have any questions about the enclosed work plan, please feel free to contact me.

Very truly yours,

A handwritten signature in blue ink that reads "V. COCIANNI". The signature is stylized and includes a large, sweeping flourish above the name.

Virgilio Cocianni  
Remediation Manager

Enclosure

CC: MEW Distribution List  
Victor R. Fracaro, National Avenue Partners, LLC

*Prepared for*

**Schlumberger Technology Corporation**

105 Industrial Boulevard

Sugar Land, Texas 77478

**FINAL WORK PLAN  
FOR IN SITU CHEMICAL OXIDATION  
PILOT STUDY**

**401 NATIONAL AVENUE  
FORMER FAIRCHILD BUILDING 9  
MIDDLEFIELD-ELLIS-WHISMAN AREA  
MOUNTAIN VIEW, CALIFORNIA**

*Prepared by*

**Geosyntec**   
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engineers | scientists | innovators

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Project Number: WR1133B

19 November 2014

# Final Work Plan for In Situ Chemical Oxidation Pilot Study

401 National Avenue  
Former Fairchild Building 9  
Middlefield-Ellis-Whisman Area  
Mountain View, California

*Prepared by*

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19 November 2014

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## LIST OF ACRONYMS AND ABBREVIATIONS

|           |   |
|-----------|---|
| AMEC      | AMEC Environment and Infrastructure, Inc.     |
| bgs       | below ground surface                          |
| cDCE      | cis-1,2-dichloroethene                        |
| cVOCs     | chlorinated volatile organic compounds        |
| DO        | dissolved oxygen                              |
| ECD       | electron capture detector                     |
| EPA       | United States Environmental Protection Agency |
| ESD       | Explanation of Significant Differences        |
| Fairchild | Fairchild Semiconductor Corporation           |
| FS        | Feasibility Study                             |
| Ft        | Feet  |
| Geosyntec | Geosyntec Consultants, Inc.                   |
| gpm       | gallons per minute                            |
| HASP      | health and safety plan                        |
| HLA       | Harding Lawson Associates                     |
| ISCO      | in situ chemical oxidation                    |
| lbs       | pounds  |
| Locus     | Locus Technologies                            |
| µg/L      | micrograms per liter                          |
| MIP       | membrane interface probe                      |
| MEW       | Middlefield-Ellis-Whisman                     |
| MIP       | membrane interface probe                      |
| MSL       | mean sea level                                |
| ORP       | oxidation-reduction potential                 |

|           |   |
|-----------|---|
| PID       | photoionization detector  |
| PPE       | personal protective equipment                                     |
| psi       | pounds per square inch  |
| PSOD      | permanganate soil oxidant demand                                  |
| PVC       | polyvinyl chloride  |
| QA/QC     | quality assurance/quality control                                 |
| QAPP      | quality assurance project plan                                    |
| RI        | Remedial Investigation  |
| ROD       | Record of Decision  |
| ROI       | radius of influence   |
| SCRW      | Source Control Recovery Well                                      |
| SCVWD     | Santa Clara Valley Water District                                 |
| Site      | former Building 9, 401 National Avenue, Mountain View, California |
| STC       | Schlumberger Technology Corporation                               |
| SUMCO     | SUMCO Phoenix Corporation   |
| SVE       | soil vapor extraction   |
| TCE       | trichloroethene   |
| TDS       | Total dissolved solids  |
| USA       | Underground Service Alert   |
| VC        | vinyl chloride  |
| Vishay    | Vishay GSI Inc.   |
| Work Plan | Work Plan for In Situ Chemical Oxidation Pilot Study              |

## 1. INTRODUCTION

This Final Work Plan for In Situ Chemical Oxidation (ISCO) Pilot Study (Work Plan) presents a scope of work for an ISCO pilot study to address chlorinated volatile organic compounds (cVOCs) in groundwater at the former Fairchild Semiconductor Corporation (Fairchild) Building 9 facility located at 401 National Avenue<sup>1</sup> in Mountain View, California (Site, Figure 1 and Figure 2). Geosyntec Consultants, Inc. (Geosyntec) has developed this Work Plan on behalf of Schlumberger Technology Corporation (STC) based on data available from previous characterization and remediation activities conducted at the Site since the mid-1980s and a supplemental data collection field program conducted in September 2013 (Geosyntec, 2014b).

A previous version of this Work Plan was submitted to the U.S. Environmental Protection Agency (EPA) on 3 July 2014 (Geosyntec, 2014d), and EPA provided comments in a letter dated 23 September 2014 (EPA, 2014). This Final Work Plan has been revised based on the EPA comments and a response to comments table is provided in Appendix A.

### 1.1 Purpose and Scope

In March 2013, EPA directed the Middlefield-Ellis-Whisman (MEW) Study Area Parties to perform pilot studies at their sites to evaluate alternative technologies or approaches for increasing the rate of cVOC mass removal.<sup>2</sup> On behalf of STC, Geosyntec is planning this ISCO pilot study as a means of increasing the rate of cVOC mass removal at 401 National Avenue. The scope of work for the ISCO pilot study includes:

- Supplemental data collection to (1) assess site-specific oxidant demand and the efficacy of selected oxidant formulations, and (2) determine the injection

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<sup>1</sup> As part of a planned redevelopment, 401 National Avenue and the properties located to the immediate north (620 through 640 National Avenue) have been consolidated into a single address: 600 National Avenue (Figure 3). For consistency with historical project documents, the project site for the ISCO pilot study will be referred to as the Site, former Building 9, or 401 National Avenue throughout this Work Plan.

<sup>2</sup> P.W. Reddy, EPA, Email Communication, 11 March 2013.

footprint beneath the former Building 9 following planned demolition of the building;<sup>3</sup>

- Targeted ISCO injections in areas containing relatively high cVOC concentrations, to be implemented following building demolition;
- Pilot study monitoring during the ISCO field injection activities and performance monitoring following the ISCO injection program;
- Operation of one or more of the existing on-Site source control recovery wells (SCRWs) during the injection event to manage groundwater hydraulics during the active injection period; and
- A contingency plan to mitigate potential discharge exceedances at the 401/405 National Shared Treatment Plant if ISCO-related secondary groundwater impacts are detected outside the slurry wall.

The proposed pilot study is not associated with, or part of, the planned redevelopment activities at 401 National Avenue. However, the planned redevelopment provides access to portions of 401 National presently occupied by buildings (Section 2.1).

## **1.2 Report Organization**

The remainder of this Work Plan is organized as follows:

- Section 2, *Background*, presents a description of the local hydrogeology and cVOC distribution at the Site, a description of previous remedial actions, and summary of remedy performance;
- Section 3, *Design Basis for Pilot Study*, summarizes the specific project objectives for the pilot study; evaluates current remedy performance, summarizes pilot study treatment area and depth interval selection based on recent data collected; and presents the proposed approach, layout, and performance monitoring approach for the pilot study;
- Section 4, *Implementation Work Plan*, provides a work plan for implementing the pilot study scope of work;

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<sup>3</sup> A work plan for the supplemental data collection activities has been submitted to the EPA under separate cover (Geosyntec, 2014c).

- Section 5, *Criteria for Restarting Recovery Wells*, describes the evaluation that will be periodically conducted to assess whether groundwater extraction should resume from some or all of the on-Site SCRWs;
- Section 6, *Reporting and Schedule*, summarizes the reports that will be submitted to document the pilot study results and presents a schedule for implementing the pilot study; and
- Section 7, *References*, provides the references cited in this Work Plan.

Tables, figures, and appendices are provided at the end of this Work Plan.

## 2. BACKGROUND

The Site is located within the MEW Study Area in Mountain View, California. STC has been performing soil and groundwater remedies for cVOCs, primarily trichloroethene (TCE) and its breakdown products (cis-1,2-dichloroethene [cDCE] and vinyl chloride [VC]), at the former Building 9 facility since 1986. In conformance with the 1989 Record of Decision (ROD) and two subsequent Explanations of Significant Differences (ESDs) issued by the EPA for the MEW Study Area (EPA, 1989; 1990; 1996), the Building 9 groundwater remedy consists of groundwater extraction and treatment (pump-and-treat) by means of four recovery wells within an area bounded by a slurry wall constructed to a depth of approximately 40 feet below ground surface.

In March 2013, EPA directed the MEW Parties to perform pilot studies at their sites to evaluate alternative technologies or approaches for increasing the rate of cVOC mass removal. On behalf of STC, Geosyntec is planning this ISCO pilot study as a means of increasing the rate of cVOC mass removal at 401 National Avenue.

### 2.1 Site Description and History

Building 9 operated as a facility for receiving, mixing, and delivering chemicals for Fairchild from 1966 to 1987. During the Remedial Investigation/Feasibility Study (RI/FS) completed in 1988 for the MEW Study Area (HLA, 1987; Canonie, 1988a), two potential source areas (LS28 and LS29) were identified at the Site. LS28 was located on the north side of Building 9 and consisted of four solvent storage tanks and a spill collection sump. LS29 was a pH neutralization system located inside Building 9 that consisted of three treatment sumps.

A number of remedial actions have been conducted as part of the facility-specific remedy for the Site, including (in chronological order):

- 1986: installation of a soil-bentonite slurry wall in the A-zone to a depth of approximately 40 feet below ground surface (bgs) (Figure 2). The slurry wall is an approximately 34 inches thick<sup>4</sup>, with an average permeability coefficient

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<sup>4</sup> Test pits across the uppermost 5 feet of the slurry wall were excavated in September 2013 and the maximum thickness of soil-bentonite backfill was observed to be approximately 35 inches (Geosyntec, 2014b) and post construction drawings indicate that the slurry wall is a minimum of 30 inches thick (Canonie, 1988b).

(hydraulic conductivity) of  $3.8 \times 10^{-8}$  centimeters per second (cm/sec,  $1.1 \times 10^{-4}$  feet per day) based on post-construction quality control testing (Canonie, 1988b);

- Ongoing since 1986: groundwater extraction at SCRWs AE/RW-9-1, AE/RW-9-2, RW-20A, and RW-21A located within the Site slurry wall (Figure 2);
- Ongoing since 1996: groundwater extraction at SCRWs GSF-1A, GSF-1B1, and GSF-1B2 operated jointly for both 401 National Avenue and the adjacent 405 National Avenue site (AMEC, 2013) (Figure 2);
- 1995: 3,000 cubic yards of soil were excavated to a depth of 6 feet bgs and aerated at the Site (Smith, 1995; EPA, 2004); and
- 1996 through 1997: soil vapor extraction (SVE) in shallow soil at depths from 6 feet bgs to 18 inches above the water table (Locus, 1997; Smith, 1997a; and Smith, 1997b).

Between 28 August and 27 September 2013, field work was performed to collect data to support the pilot study design (Geosyntec, 2014b). A Data Collection Summary Report detailing the results of this field work was submitted to EPA on 3 July 2014 (Geosyntec, 2014b).

Also in 2013, the 401 National Avenue property was purchased by National Avenue Partners, LLC and in May 2014 redevelopment of 401 National was approved by the City of Mountain View in conjunction with three properties to the north. The approved redevelopment activities include the demolition of the former Building 9 and the construction of a two-story aboveground parking garage over most of the current 401 National Avenue property, as shown on Figure 3.

## **2.2 Local Hydrogeology**

The MEW Study Area is located within the northern portion of the Santa Clara Valley Groundwater Sub-basin, the northernmost of three interconnected groundwater basins within Santa Clara County (Santa Clara Valley Water District [SCVWD], 2001). The groundwater flow direction is northerly, toward the San Francisco Bay, and generally sub-parallel to the ground slope. The hydrostratigraphy in this part of the sub-basin is

divided into upper and lower water-bearing zones, separated by an extensive regional aquitard (SCVWD, 1989).

The upper water-bearing zone underlying the MEW Study Area is subdivided into two water-bearing zones: the A-zone (roughly between 14 and 40 feet bgs) and the B-zone (roughly between 45 and 160 feet bgs), which are separated by the A/B Aquitard. The B-zone is further subdivided into three zones (B1-, B2-, and B3-zones). The lower water-bearing zone occurs below a depth of about 200 feet bgs. The lower water bearing zone is subdivided into the C-zone (which extends to about 240 feet bgs) and the Deep zone. The aquitard separating the upper and lower water-bearing zones is represented as the B/C Aquitard and is the major confining layer beneath the Site.

Groundwater flow beneath the MEW Study Area is generally towards the north in the A- and B-zones under both non-pumping and pumping conditions. Groundwater hydraulic gradients are locally modified by the operation of groundwater recovery wells (both source control and regional recovery wells) and slurry walls, resulting in steeper gradients in the vicinity of pumping wells.

The A-zone is the primary groundwater unit monitored at the Site. Under pumping conditions, the potentiometric surface of the A-zone at the Site generally occurs under confined conditions. During the September 2013 semi-annual gauging event, groundwater at the Site was encountered at a depth of approximately 17 feet bgs, corresponding to groundwater elevations of approximately 26 feet above mean sea level (MSL) (Geosyntec, 2014a). An upward vertical gradient is observed within the slurry wall footprint from the deeper B1-zone into the A-zone during pumping conditions (Geosyntec, 2014a). Inward horizontal gradients are observed along most of the slurry wall during pumping, with the periodic exception of some locations along the northern, downgradient sections (Geosyntec, et al., 2008).

### **2.3 Nature and Extent of cVOCs**

The primary cVOCs in Site groundwater are TCE and its reductive dechlorination daughter products cDCE and VC. TCE concentrations in groundwater from Site monitoring wells sampled in 2012/2013 and grab groundwater samples collected in 2013 are shown in Figure 4. Plots of TCE, cDCE, and VC concentration versus time for select A-zone monitoring wells are included as Appendix B. Over the last 5 years (2008 to 2013), the maximum concentration of TCE detected in Site groundwater

monitoring wells or SCRWs was 13,000 micrograms per liter ( $\mu\text{g/L}$ ) in AE/RW-9-2 in 2013 (Geosyntec, 2014a). TCE concentrations in grab groundwater samples collected during the September 2013 data collection effort ranged from 100 to 560,000  $\mu\text{g/L}$  (Figure 4, Table 1). Total cVOC concentrations detected in September 2013 ranged from approximately 2,500 to 630,000  $\mu\text{g/L}$  and predominantly consisted of TCE and cDCE, with other cVOCs detected at concentrations one to two orders of magnitude lower in value (Table 1). The TCE concentration measured in 2013 for Site well 123A, located upgradient (south) of the slurry wall, was 510  $\mu\text{g/L}$ . TCE concentrations at Site wells 41A and 42A, located downgradient (north) of the slurry wall, were 580 and 470  $\mu\text{g/L}$ , respectively (Figure 4).

## **2.4 Current Groundwater Remedy**

As specified in the ROD for the MEW Study Area, the current, facility-specific groundwater remedy at the Site consists of slurry wall containment (A-zone) and groundwater extraction and treatment.

There are four A-zone SCRWs on Site within the area bounded by the slurry wall (referred to as the 401 National SCRWs) that are primarily used to recover cVOC mass and maintain inward and upward groundwater gradients within the slurry wall, as stipulated by the ROD (Figure 2). The efficiency of mass recovery by the slurry wall SCRWs has declined over time (Geosyntec, et al., 2008), although mass recovery from the on-Site wells over the past 3 years has averaged 166 pounds of cVOCs per year. On-Site SCRWs are connected to the Fairchild System 1 treatment facility (Geosyntec, 2014a).

Outside of the slurry wall, there are currently three SCRWs (one in each of the A-, B1-, and B2-zones) and one additional planned A-zone SCRW associated with the Site. The existing off-Site SCRWs are located approximately 200 feet downgradient (north) of the Site and primarily provide Site containment. The location of the A-zone SCRW outside the slurry wall (well GSF-1A) is shown in Figure 5. The SCRWs in the B1 and B2-zones outside of the slurry wall (Wells GSF-1B1 and GSF-1B2) are immediately adjacent to GSF-1A. In addition, a new SCRW is planned to comply with EPA's directive for increased mass removal in the vicinity of monitoring well 116A, located approximately 70 feet downgradient of the 401 National slurry wall. STC and Vishay GSI Inc. (Vishay)/SUMCO Phoenix Corporation (SUMCO) jointly operate wells GSF-1A, GSF-1B1 and GSF-1B2 by agreement as part of the source control measures for

both 401 National Avenue and the adjacent 405 National Avenue site. These wells (referred to as the Shared SCRWs) are connected to the 401/405 National Shared Treatment Plant (also referred to as the Vishay/SUMCO treatment facility) that is currently located on the Site.<sup>5</sup> This off-Site remedy is referred to as the Shared Remedy. The anticipated extraction well in the vicinity of monitoring well 116A will also be operated as part of the Shared Remedy. As shown in Figure 5, the Shared Remedy provides containment of groundwater for Site areas outside of, and below, the slurry wall.

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<sup>5</sup> The 401/405 National Shared Treatment Plant will be relocated on Site to accommodate the planned redevelopment activities. The off-Site SCRWs would continue to be connected to the plant in the event it is relocated.

### 3. DESIGN BASIS FOR PILOT STUDY

The design basis for the ISCO pilot study was developed based on recent investigations of the hydrogeology and extent of cVOCs within the Site slurry wall, a review of previous pilot studies conducted at other sites within the MEW Study Area, and the professional experience of the design engineers.

#### 3.1 Pilot Study Objective

The pilot study described in this Work Plan has been designed to: (1) increase the short-term rate of mass removal at the Site to comply with EPA’s directive for accelerating cVOC mass removal at each facility, and (2) to generate performance metrics for alternative technologies for use in a future groundwater feasibility study planned by EPA.

#### 3.2 Mass Removal Rate of Current Remedy

As shown in the table below, annual mass removal rates for the 401 National SCRWs ranged from 157 to 173 pounds per year between 2011 and 2013 (average of 166 pounds per year).

| SCRW/Treatment System   | cVOC Mass Removal (Pounds) |            |            |
|---|----------------------------|------------|------------|
|   | 2011                       | 2012       | 2013       |
| AE/RW-9-1   | 26                         | 37         | 38         |
| AE/RW-9-2   | 101                        | 69         | 66         |
| RW-20A  | 29                         | 25         | 40         |
| RW-21A  | 17                         | 26         | 25         |
| <b>Total Mass Removal for Site SCRWs Located Inside the Slurry Wall</b> | <b>173</b>                 | <b>157</b> | <b>169</b> |

**Note:** Individual well mass removal was calculated based on the estimated average annual groundwater extraction rate and the SCRW annual sampling results (sum of the cVOC concentrations) for the associated year from Table 1 and Table 17b<sup>6</sup>, respectively, of the Annual Progress Report Former Fairchild Buildings 1-4, 9 and 18 (Geosyntec 2012, 2013a, 2014a).

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<sup>6</sup> Table 10 in the 2011 Annual Report for Former Fairchild Building 9 (Geosyntec, 2012a).

If the current average cVOC mass removal rate of 166 pounds per year is extrapolated over the next 30 years, the mass removal for the current remedy would be approximately 5,000 pounds of cVOCs. Based on the historical mass removal rates by the current remedy, some decline in extracted cVOC concentrations over time is expected (see e.g., Geosyntec, 2008; Geosyntec, 2012b), resulting in an expected 30-year mass removal of less than 5,000 pounds.

For areas outside of, and below, the slurry wall, mass is currently being removed by Shared SCRWs GSF-1A, GSF-1B1, and GSF-1B2, which are operated as part of the Shared Remedy. The mass removal of the Shared Remedy is expected to increase with the initiation of groundwater extraction at well 116A.

### **3.3 Treatment Area and Depth Interval**

The results of the September 2013 data collection effort were used to assess the Site hydrogeology and distribution of cVOCs prior to selecting pilot study treatment areas within the slurry wall (Geosyntec, 2014b). Relevant results from the supplemental data collection field work and treatment areas selected based on these results are discussed below.

#### ***A-zone Hydrostratigraphy***

Cross-sections depicting the hydrogeology at the Site (Figure 6 and Figure 7) were developed using historical information and information generated during the September 2013 supplemental data collection field program. These cross-sections show that two relatively continuous layers of coarse-grained material are present in the A-zone within the planned pilot study area: the shallow coarse-grained layer is generally encountered between 17 and 23 feet bgs and the deep coarse-grained layer is generally encountered between 32 and 37 feet bgs. While there are multiple thin, discontinuous fine-grained layers between the shallow and deep coarse-grained layers, there is no aquitard present within the A-zone.

#### ***Distribution of cVOCs***

During the 2013 supplemental data collection activities, membrane interface probe (MIP) borings were advanced at several locations across the Site to provide qualitative information on the distribution of cVOCs (MIP-01 through MIP-12, Figure 4). The MIP results are discussed in detail in the Data Collection Summary Report (Geosyntec,

2014b). Electron capture detector (ECD) and photoionization detector (PID) profiles for the MIP borings are shown in cross-sectional view on Figures 6 and 7.

During the advancement of the MIP borings, the highest detector responses were observed at MIP-02 and MIP-09/MIP-12. At most locations, the highest detector responses were generally observed between 17 and 26 feet bgs.<sup>7</sup> High ECD responses were also observed between 32 and 36 feet bgs, with limited or no response for the other detectors. These zones of higher response generally correspond with the two coarse-grained layers identified in cross-sections A-A' and B-B' (Figure 6 and Figure 7). For the shallow coarse-grained layer (17 to 23 feet bgs), the highest detector response was observed just above and continuing, to a limited extent, into the underlying zone of fine-grained materials.

At selected MIP borings, grab groundwater samples were collected for comparison to the qualitative results from the MIP detectors. TCE concentrations in grab groundwater samples collected from temporary points set in the shallow and deep coarse-grained layers ranged from 100 to 560,000 µg/L (Figure 4, Table 1). Total cVOC concentrations detected in September 2013 ranged from approximately 2,500 to 630,000 µg/L and predominantly consisted of TCE and cDCE, with other detected cVOC concentrations one to two orders of magnitude lower in value (Table 1). TCE and total cVOC concentrations increased with depth in the shallow coarse-grained layer, with TCE concentrations measured at 16 to 22 feet bgs two orders of magnitude lower than TCE concentrations measured at 22 to 26 feet bgs at boring MIP-12 (Table 1 and Figure 6). TCE and total cVOC concentrations in groundwater collected from the deep coarse-grained layer were significantly lower than cVOC concentrations in the shallow coarse-grained layer, ranging from 100 to 1,200 µg/L and 3,200 to 5,600 µg/L, respectively.

### **Target Injection Zones**

Target injection zones for the ISCO pilot study developed based on the September 2013 data collection activities are provided in plan view in Figure 8. ISCO pilot study

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<sup>7</sup> The ECD, which detects cVOCs, was the most responsive detector and reached its maximum value of  $1.4 \times 10^7$  microvolts (µV) at most borings. In general, the PID, which detects chlorinated and non-chlorinated VOCs, and halogen-specific detector (XSD, detects cVOCs) responses were similar to each other but less responsive than the ECD, tending to respond only when the ECD response was sustained at the maximum value over a given depth interval.

injections will include three upper zones (U-1, U-2a, and U-2b) in the shallow coarse-grained layer totaling approximately 13,000 square feet (ft<sup>2</sup>), and a single smaller lower zone (L-1) in the deep coarse-grained layer totaling approximately 8,000 ft<sup>2</sup>. Injection zones in both the shallow and deep coarse-grained layers were selected to address the boring/well locations with the highest cVOC concentrations detected in groundwater or the largest PID response observed during the September 2013 MIP field program (e.g., MIP-2, MIP-9, and MIP-12).

Based on groundwater cVOC concentrations and vertical profiles of PID response measured in the MIP borings, the target upper vertical injection zones in the shallow coarse-grained layer are approximately 17 to 23 feet bgs (Figure 9 and Figure 10).

Based on groundwater cVOC concentrations and vertical profiles of PID and ECD response measured in the MIP borings, the concentrations of cVOCs in the deep coarse-grained layer are generally lower than those observed in the shallow coarse-grained layer. The target vertical injection zone in the deep coarse-grained layer is approximately 33 to 36 feet bgs (Figure 9 and Figure 10).

Limited groundwater data are available within the footprint of the former Building 9. As a result, a supplemental data collection field program will be performed following the demolition of Building 9 to evaluate the distribution of cVOC concentrations in the saturated zone beneath the building, and to further refine the injection zone boundaries (Geosyntec, 2014c). If required, modifications to the target injection zones and suggestions for additional monitoring points, as needed, would be provided to EPA as an addendum to this Work Plan prior to implementation of the ISCO pilot study.

### **3.4 Oxidant Selection**

Sodium permanganate (NaMnO<sub>4</sub>) was selected as the chemical oxidant to determine the initial design parameters for the injection approach. However, the oxidant selection may be revised based on the outcome of the ISCO bench-scale testing, as presented in the Work Plan for ISCO Pilot Study Data Collection (Geosyntec, 2014c, Appendix I). Any modifications to the oxidant based on review of the treatability study data will be provided to EPA in an addendum to this Work Plan prior to the implementation of the ISCO pilot study.

The selection of sodium permanganate is based on the following:

- Sodium permanganate is a well-studied chemical oxidant that has been demonstrated to effectively degrade TCE and other chlorinated ethenes (e.g., ITRC, 2005).
- It has been demonstrated that sodium permanganate can be successfully injected during pilot testing at two high concentration cVOC areas located along Evandale Avenue, west of the MEW Study Area. Natural soil oxidant demand testing with soils collected on Evandale Avenue provided the design basis for dosing at the Site.
- Sodium permanganate has a higher aqueous solubility than potassium permanganate, making it a better choice for treatment of high cVOC concentrations.
- Sodium permanganate will be shipped to the Site as a liquid compound from which diluted solutions can be prepared onsite by mixing with groundwater or tap water. Other permanganate formulations (e.g., potassium permanganate) are solid, which can make mixing and handling more difficult.

Bench-scale testing will be performed by Prima Laboratory of Sacramento, California to confirm the oxidant selection criteria described above. The bench-scale testing will consist of two tasks:

- Sodium permanganate soil oxidant demand (PSOD) bench-scale testing will be performed to provide information regarding the rate and extent of oxidant consumption by Site soil and groundwater when dosed with sodium permanganate.
- A comparative oxidant performance test will be performed to compare the treatment of Site soil and groundwater when dosed with sodium permanganate, iron activated sodium persulfate, and a mixture of sodium permanganate and sodium persulfate.

Details on the bench-scale testing scope of work are provided in the Work Plan for ISCO Pilot Study Data Collection (Geosyntec, 2014c).

### 3.5 Oxidant Demand

The oxidant dosing is designed to account for the natural soil demand (i.e., oxidant use by naturally occurring organic matter) and cVOC demand (i.e., oxidant use by cVOCs) in the target treatment areas within the slurry wall. Site-specific bench-scale permanganate soil oxidant demand (PSOD) testing will be performed prior to implementation of the ISCO pilot study at 401 National; details of this bench-scale testing are presented in the Work Plan for ISCO Pilot Study Data Collection (Geosyntec, 2014c, Appendix I).

For the purpose of developing this preliminary ISCO design basis, results of PSOD testing conducted as part of the ongoing ISCO pilot study along Evandale Avenue<sup>8</sup> have been used for guidance (Geosyntec, 2013b). The Evandale Avenue bench-scale PSOD testing was performed in April and May 2013 to evaluate the rate and extent of oxidant consumption by soil and groundwater<sup>9</sup> when treated with permanganate. The PSOD testing results report from the treatability laboratory is provided in the Final Pilot Study Design and Implementation Work Plan for Evandale Avenue Sources (Geosyntec, 2013b).

The cumulative soil oxidant demand measured during PSOD testing can be presented on a grams (g) of  $\text{MnO}_4^-$  per kilogram (kg) of soil basis. This provides an estimate of the soil oxidant demand (i.e., oxidant use by naturally occurring organic matter along with any cVOCs present in the tested soil and groundwater) and can be used to develop an oxidant dosing design basis. Both coarse-grained soil (i.e., sand and silty sand) and fine-grained soil (i.e., silt and clay) from along Evandale Avenue (consistent with the predominant soil types present at the 401 National area), were used for the PSOD testing. Bench-scale 10-day PSOD testing results for the Evandale Avenue soil ranged from 1.3 to 5.5 g  $\text{MnO}_4^-$ /kg soil, with a mean 10-day PSOD of 3.4 g  $\text{MnO}_4^-$ /kg soil (n=5;  $\sigma=1.2$  g/kg). A mean 10-day PSOD of 3.4 g/kg is relatively low, with long-term permanganate natural oxidant demand values ranging from 0.8 to over 35 g  $\text{MnO}_4^-$ /kg soil reported in the literature (e.g., Strategic Environmental Research and Development Program [SERDP], 2007).

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<sup>8</sup> The location of the Evandale Avenue ISCO pilot study is approximately 0.25 miles from 401 National Avenue and has similar hydrogeologic conditions and cVOC concentrations.

<sup>9</sup> Soil and groundwater for PSOD testing were collected from borings located near the CPT-15 and CPT-21 Areas along Evandale Avenue (Geosyntec, 2013b).

### 3.6 Oxidant Dosing

The oxidant dosing for the ISCO pilot study is dependent on two key design criteria: (1) the volume of the target treatment zone, and (2) the Site-specific PSOD value determined during bench-scale testing.

As described in Section 3.3, existing data were used to identify the lateral and vertical extent of several conceptual ISCO treatment zones. The table below lists design criteria for each conceptual treatment zone and provides the target permanganate dosing required for each area to satisfy a PSOD of 3.4 g MnO<sub>4</sub><sup>-</sup>/kg soil. For the ISCO pilot study, the design concentration of the sodium permanganate solution will be 35 grams as MnO<sub>4</sub><sup>-</sup> per liter (g MnO<sub>4</sub><sup>-</sup>/L) (Section 4.4.2).

| Treatment Zone                           | Lithology                  | Area (ft <sup>2</sup> ) | Depth Interval (feet bgs) | Thickness (feet) | Volume Soil (ft <sup>3</sup> ) | Mass Soil (lbs) | Mass Permanganate lbs as MnO <sub>4</sub> <sup>-</sup> |
|--|----------------------------|-------------------------|---------------------------|------------------|--------------------------------|-----------------|--|
| U-1                                      | upper coarse-grained layer | 8,900                   | 18 to 23                  | 5                | 44,500                         | 4,450,000       | 18,000   |
| U-2a                                     |                            | 2,200                   | 17 to 23                  | 5                | 11,000                         | 1,095,000       | 5,050  |
| U-2b                                     |                            | 1,900                   | 16.5 to 23                | 5                | 9,500                          | 945,000         | 4,350  |
| L-1                                      | lower coarse-grained layer | 8,000                   | 33 to 36                  | 3                | 24,000                         | 2,400,000       | 9,700  |
| Total Mass MnO <sub>4</sub> <sup>-</sup> |                            |                         |                           |                  |                                |                 | 37,100   |
| Total Mass NaMnO <sub>4</sub>            |                            |                         |                           |                  |                                |                 | 44,260   |

**Note:** Depth intervals may be adjusted based on conditions encountered in the field and interpreted lithology within each zone.

After completion of the scope of work described in the Work Plan for ISCO Pilot Study Data Collection (Geosyntec, 2014c), the extent of the proposed target treatment zones will be reviewed based on the results of sample collection from beneath the former Building 9 footprint, and the PSOD design assumption will be reviewed based on the results of the site-specific bench-scale testing. If required based on this review, modifications to the pilot study oxidant dosing would be provided to EPA as an addendum to this Work Plan prior to implementation of the ISCO pilot study.

### **3.7 Injection Methods, Rates, and Radius of Influence**

Injection solution will be delivered to the subsurface using a combination of temporary direct push points and temporary injection wells. The temporary injection wells will be installed in shallow zones U-2a and U-2b as discussed in Section 4.3 (Figure 8). The temporary direct push points will be used to deliver injection solution to the shallow zone U-1 and the deeper zone L-1 (Figure 8).

An injection test was performed during the September 2013 data collection field work to facilitate the development of depth-specific estimates for achievable injection rates and pressures within the pilot study area. The results of the injection test showed that flow rates of approximately 2 gallons per minute (gpm) can be achieved at low pressures (15 to 25 pounds per square inch [psi] above hydrostatic pressure) for most depth intervals.

Based on the above results, a nominal injection rate of 3 gpm was selected for each injection depth interval in the shallow and deep coarse-grained layers. While achieving this injection rate may require injecting at pressures in excess of 25 psi, engineering controls will be employed to limit injection pressures to less than 50 psi during implementation to reduce the potential for development of preferential flow pathways in the formation. This approach will be reviewed based on initial testing conducted during the pilot study.

The design injection spacing in both the upper and lower zones is approximately 15 feet on center; the target radius of influence (ROI) for these injections is approximately 10 feet, allowing for some potential overlap between adjacent injection locations. A 10-foot ROI is considered reasonable based on experience with ISCO injections in similar geologic formations to those present at the Site.

During injection activities, one or more of the 401 National SCRWs will be operated to limit increases in hydraulic head within the coarse-grained layers that could result from the injection of large volumes of oxidant solution within the slurry wall. Both during and following injection activities, SCRWs may also be utilized to enhance the distribution of oxidant by pumping until residual oxidant breakthrough is observed. Procedures for managing extracted groundwater during injection activities are presented in Section 4.4.1.

If design injection rates and volumes cannot be reasonably achieved in the field during initial injections, the actual injection rates and/or oxidant solution concentration will be modified. Modifications to the design injection rates or concentration, if necessary, would be determined in consultation with EPA. If injection rates and pressures observed during the beginning of the injection program are consistent with the design basis, the ISCO injection program would proceed as designed.

### **3.8 Evaluation of Potential Secondary Water Quality Impacts**

As part of the ISCO pilot study design, an assessment of potential post-injection impacts to secondary water quality downgradient of the 401 National slurry wall was conducted. The assessment considered the following:

- The potential flow of groundwater from within the slurry wall to areas downgradient of the Site;
- The potential transport of  $\text{MnO}_4^-$  from within the pilot study area to downgradient receptor wells (the proposed SCRW at 116A, located north of the Site, and SCRW wells EX-1 through EX-4, located east of the Site); and
- The potential generation and transport of hexavalent chromium [Cr(VI)] from within the pilot study area to downgradient receptor wells.

#### ***Groundwater Flow***

Groundwater flow was evaluated under the conservative assumption that on-Site SCRWs would be temporarily shut down following the ISCO pilot study injections. Two A-zone SCRWs (one currently installed and one planned for future installation) immediately downgradient of the former 401 National slurry wall were assumed to remain operational for the duration of the pilot study (Section 2.4). These wells would continue to provide vertical and lateral containment of cVOCs from the Site for the duration of the pilot study, which is consistent with the criterion for installing and operating SCRWs as described in the Revised Final Design, Regional Groundwater Remediation Program (Smith, 1996).

Based on data collected in September 2013, post-injection groundwater elevations within the slurry wall when the on-Site SCRWs are not operating may be approximately 4 to 5 feet higher than elevations under pumping conditions (Geosyntec, 2014b). However, long-term data under non-pumping conditions inside the slurry wall are not

available. Therefore, numerical modeling methods were used to assess hydraulic conditions that would occur following injection and shutdown of the on-Site SCRWs. The groundwater modeling is not intended to simulate groundwater flow conditions during the pilot study injection program.

The numerical model used to evaluate hydraulic conditions at the Site is based on the MEW Study Area regional groundwater flow model, with a refined model domain in order to obtain a higher resolution characterization of the subsurface and groundwater flow field around the slurry wall. Details regarding the modeling approach are included in Appendix C.

The results of the groundwater flow modeling indicate that a small amount of groundwater, on the order of approximately 0.7 gpm flows upwards and into the area surrounded by the slurry wall along the southern (upgradient) wall. The groundwater travels north through the aquifer material isolated by the slurry wall until it reaches the northern (downgradient) wall. Upon reaching the downgradient wall, a similarly small amount of groundwater (0.7 gpm) flows downward and out of the area surrounded by the slurry wall. The low rate of groundwater flux from within the slurry wall suggests that groundwater originating from within the slurry wall is not expected to be a significant component of groundwater extracted by nearby wells located outside of the slurry wall, even in the absence of on-site groundwater extraction.

### ***Permanganate Fate and Transport***

A version of the MEW Study Area regional groundwater model with the capability of modeling solute transport was used to assess the fate of residual permanganate following ISCO injection (Appendix C). The Evandale Avenue bench-scale PSOD testing results (Geosyntec, 2013b) were used to develop a kinetic model for reactive transport of permanganate. The model assumed a residual permanganate concentration in groundwater of 30 g MnO<sub>4</sub><sup>-</sup>/L throughout the target treatment zones at the conclusion of the ISCO injection program, resulting in a residual permanganate mass loading that is approximately 50% greater than what is proposed for the pilot study.

Under these conservative conditions, the model results indicate that residual permanganate is expected to be consumed by natural organic matter present in the aquifer material prior to reaching the nearest SCRWs to the north (planned SCRW at 116A) and to the east (EX-1 through EX-4, operated as part of the groundwater remedy at 405 National Avenue, Figure 2).

### ***Hexavalent Chromium Fate and Transport***

Cr(VI) can be generated or introduced during ISCO implementation using oxidant solutions. However, the body of scientific literature on ISCO and Cr(VI) fate and transport (e.g., Siegrist et al., 2011; EPA, 2007) indicates the following:

- Generation of Cr(VI) is a transient process that occurs while residual oxidant is present in the system and once the oxidant is depleted, additional Cr(VI) generation is not expected;
- Cr(VI) is expected to sorb to mineral surfaces, retarding its potential transport through the subsurface; and
- Due to the naturally occurring reduced subsurface environment, Cr(VI) generated during ISCO will be reduced to trivalent chromium [Cr(III)] over distance and time following implementation.

Data collected during previous ISCO injections conducted at the MEW Study Area indicate that the above attenuation processes can be expected at the Site. For example, concentrations of Cr(VI) were reportedly below the analytical method detection limit (0.010 milligrams per liter [mg/L]) within 4.5 months following the ISCO injections at the SMI Holding, Inc. site located at 501/505 East Middlefield Road (PES Environmental, 2001). In addition, Cr(VI) has not been observed above background levels in samples collected from performance monitoring wells located downgradient of the ISCO injections ongoing along Evandale Avenue.

Overall, the results of the evaluation of potential secondary water quality impacts suggest that potential impacts to monitoring wells located outside of the slurry wall are limited. However, a monitoring program has been developed to assess potential secondary water quality impacts and is presented in Section 4.5 of this Work Plan.

### **3.9 Pilot Study Monitoring**

Monitoring will be conducted inside the treatment area during and after injections for the following purposes:

- To assess water levels and the degree of mounding during injection so that on-Site SCRWs can be effectively used to minimize mounding;

- To assess the progress of the ISCO injection program by evaluating the distribution and consumption of oxidant and verifying that the oxidant injection is controlled; and
- To limit the potential for extraction of residual oxidant during operation of on-site SCRWs while injections are ongoing.

Pilot study effectiveness will be indicated if cVOC degradation is observed inside the slurry wall following implementation of the pilot study ISCO injections, with cVOCs considered to be degrading if concentrations of TCE are reduced from the baseline sample concentrations. Chloride production will be used as a second line of evidence of cVOC destruction. However, the observed cVOC concentrations may be low while oxidant is present in the subsurface with a “rebound” in the cVOC concentrations as residual oxidant is depleted and geochemical conditions return to near baseline (ITRC, 2005). Therefore, evaluation of overall cVOC concentration reduction at the Site will be based on observed cVOC and chloride concentrations once the oxidant has been depleted from the system. The on-Site monitoring program is discussed in detail in Section 4.5.

Monitoring will also be conducted at wells located outside the slurry wall and in close proximity to the off-Site shared SCRWs and 405 National SCRWs (referred to as sentry wells throughout the remainder of this document) during and following completion of the injection program. The objective of the sentry well monitoring is to identify potential impacts to groundwater quality outside of the slurry wall due to the oxidant injection program that could result in discharges from the 401/405 National treatment system exceeding limits specified in the NPDES permit. The off-Site monitoring program is discussed in detail in Section 4.5.

### **3.10 Contingency Plan**

If ISCO-related secondary groundwater impacts are detected outside the slurry wall above action levels (Section 4.5) the contingency plan provided in Appendix D to mitigate potential discharge exceedances at the 401/405 National Shared Treatment Plant will be implemented.

### **3.11 Estimated ISCO cVOC Mass Removal**

As described in Section 3.6, at minimum of 37,100 pounds of permanganate ion ( $MnO_4^-$ ) will be injected during the pilot study, corresponding to an oxidant dosing of 3.4 grams of  $MnO_4^-$  per kilogram of soil (g  $MnO_4^-$ /kg soil). The stoichiometric equation for oxidation of TCE ( $C_2HCl_3$ ) by  $MnO_4^-$  is:



Based on the above equation and the molar mass of TCE and  $MnO_4^-$ , one pound of  $MnO_4^-$  is expected to degrade 0.55 pound of TCE. If 37,100 pounds of  $MnO_4^-$  are potentially available for degradation of target cVOCs, the resulting TCE mass removal could be as high as 20,400 pounds. As described in Section 3.2, the average cVOC mass removal via the on-Site SCRWs was 166 pounds per year over the last three years. The ISCO process could therefore accelerate mass removal at the Site by as much as 105 years compared to the current remedy.

However, between 50% and 90% of the applied oxidant may be consumed by non-target reactions with organic matter or other reduced species under field applications. Therefore, the ISCO pilot study injections will more likely remove between 2,040 and 10,200 pounds of TCE. As a result, the ISCO process will likely accelerate mass removal over ten times as compared to the current remedy and be equivalent to between 10 and 50 years of groundwater extraction and treatment.

## **4. IMPLEMENTATION WORK PLAN**

Details regarding the methods and procedures that will be used for implementation of the ISCO injection program and associated monitoring are provided in this section.

### **4.1 Pre-Field Activities**

#### **4.1.1 Health and Safety Planning**

The existing site-specific health and safety plan (HASP) will be updated to include all field activities associated with the ISCO pilot study implementation. The HASP will contain procedures for hazard identification and mitigation, emergency response including a map of the nearest hospital and emergency contact information, incident reporting, use of appropriate personal protective equipment (PPE), and air monitoring procedures.

Prior to the start of field activities each day, a safety tailgate meeting will be conducted that will include a discussion of the field activities to be performed, safe work practices, identification of potential hazards, use of PPE, decontamination procedures, and emergency response protocols. Health and safety protocols related to oxidant handling are discussed in Section 4.4.7.

#### **4.1.2 Notifications, Access, and Permitting**

Prior to the start of field activities, the following will be performed:

- Coordinate with National Avenue Partners for access to the Site;
- Coordinate and subcontract with the drilling contractor, oxidant vendor, and analytical laboratory; and,
- Obtain drilling permits from the SCVWD.

The EPA, SCVWD, City of Mountain View, and National Avenue Partners will be notified of the planned work schedule prior to the start of field activities.

#### **4.1.3 Utility Clearance**

Boring locations will be marked with white paint and Underground Service Alert (USA) North will be contacted a minimum of 48 hours prior to commencement of intrusive

subsurface activities. Additionally, Site reconnaissance will be conducted to locate utilities using available as-built drawings and a private utility locator will perform a geophysical survey in the vicinity of each proposed boring location area to identify potential utilities, pipelines, or other subsurface obstructions prior to drilling.

#### **4.2 Performance Monitoring Well Network Installation**

Three temporary pilot study monitoring wells will be installed within the pilot study treatment zones (Figure 11). Anticipated construction details for these wells are provided in Table 2, along with information on existing wells that will be included in the performance monitoring network (Section 4.5). Actual total depths and screen intervals for the individual temporary performance monitoring wells may be adjusted in the field based on the subsurface conditions encountered. The wells will be named B9-1A, B9-2A, and B9-3A.

The monitoring wells will be installed by a C-57 licensed drilling subcontractor using hollow stem auger drilling methods. Geologic logging of the hollow stem auger soil cuttings will be conducted by Geosyntec field staff under the direction of a California Professional Geologist using the Unified Soil Classification System. The soil will be field-screened for volatile organic compounds using a PID and the readings recorded on the boring logs. All downhole equipment will be decontaminated prior to use and between boring locations.

Once the target depth is reached at each boring, the monitoring well will be constructed through the hollow stem auger casing. The monitoring wells will be constructed of 2-inch diameter, flush-threaded, Schedule 40 polyvinyl chloride (PVC) casing, with 0.020-inch factory-slotted well screen, and a flush-threaded bottom cap. A graded silica sand pack will be tremie filled into the annular space across the screened interval of each monitoring well, extending approximately 1 foot above the top of the screen. Approximately 2 feet of bentonite pellets or chips will be placed on top of the sand pack and hydrated to provide a seal above the filter pack. The remainder of the borehole will be tremie filled with neat cement grout (maximum 6 gallons of water per 94 pound bag of cement) to one foot below the ground surface. A waterproof locking cap will be installed over each monitoring well within an appropriately-sized flush-mounted well box.

Once installed, the grout seal will be allowed to set for at least 48 hours prior to development. Well development will be performed by a subcontractor under

supervision of Geosyntec field staff. Development will consist of a combination of bailing, surging, and pumping as described in the MEW quality assurance project plan (QAPP) (Canonie, 1991) and will serve to stabilize the filter pack and remove fines from the filter pack and well screen. Groundwater quality parameters (temperature, pH, specific conductance, and turbidity) will be measured during well development. Groundwater generated during development will be temporarily stored onsite prior to disposal at one of the MEW Study Area groundwater treatment systems.

The north side of each well box and PVC well casing will be surveyed for elevation and location by a California-licensed surveyor.

### **4.3 Injection Well Network Installation for Shallow Zones U-2a and U-b**

Seven temporary injection wells will be installed within each of the pilot study treatment zones U-2a and U-2b (total of 14 injection wells). Actual total depths and screen intervals for the individual temporary injection wells may be adjusted in the field based on the subsurface conditions encountered. The wells will be named U-2a-inj1 through U-2a-inj7 and U-2b-inj1 through U-2b-inj7. The injection wells will be screened within the target injection interval of 16.5 to 23 feet bgs, which defines the upper and lower bounds of the coarse sand horizon within the U-1, U-2a and U-2b treatment zones. Within this horizon, the thickness of the coarse sand layer is typically about 5 feet. The screen interval of the injection wells will therefore be 5 feet. The final placement of the 5-foot well screens for each temporary injection well will be determined by analyzing the previous MIP investigation and may be adjusted in the field based on the subsurface conditions encountered.

The temporary injection wells will be installed by a C-57 licensed drilling subcontractor using hollow stem auger drilling methods. Once the target depth is reached at each boring, the injection well will be constructed through the hollow stem auger casing. The injection wells will be constructed of 2-inch diameter, flush-threaded, Schedule 40 polyvinyl chloride (PVC) casing, with 0.020-inch factory-slotted well screen, and a flush-threaded bottom cap. A graded silica sand pack will be tremie filled into the annular space across the screened interval of each injection well, extending approximately 1 foot above the top of the screen. The remainder of the borehole will be tremie filled with neat cement grout (maximum 6 gallons of water per 94 pound bag of cement) to approximately ground surface. A waterproof locking cap will be installed over each injection well.

Once installed, the grout seal will be allowed to set for at least 48 hours prior to development. Well development will be performed by a subcontractor under supervision of Geosyntec field staff. Development will consist of a combination of bailing, surging, and pumping as described in the MEW quality assurance project plan (QAPP) (Canonie, 1991) and will serve to stabilize the filter pack and remove fines from the filter pack and well screen. Groundwater generated during development will be temporarily stored on Site prior to disposal at one of the MEW Study Area groundwater treatment systems.

Upon completion of the injection program, all temporary injection wells will be decommissioned in accordance with County, State, and Federal requirements.

#### **4.4 ISCO Injections**

##### **4.4.1 Operation of Groundwater Recovery System**

One or more of the 401 National SCRWs (e.g. AE/RW-9-1 and RW-21A) will be pumped continuously during injections to promote oxidant distribution, reduce hydraulic mounding, and capture groundwater that is displaced by the injected solution. The extraction wells will be operated at flow rates to create a net zero injection, where the amount of injected fluid is equal to the amount of extracted groundwater on a given day. For example, if the oxidant is injected at a flow rate of 24 gpm (3 gpm per point at 8 points) over an 8-hour day, then approximately 11,500 gallons of fluid would be injected into the A-zone on a given day. To create a net zero injection, the extraction wells will be operated at a minimum of 8 gpm over 24 hours to remove 11,500 gallons from the slurry wall enclosure.

Groundwater extracted from the on-Site SCRWs will be pumped to a temporary on-Site holding tank and used as mixing water for the ISCO injections. The oxidant concentration in the groundwater entering the tank will be measured at least once per day using a field spectrophotometer.

##### **4.4.2 Materials Handling and Mixing**

Oxidant handling will be in compliance with City of Mountain View Fire Department requirements and the *National Fire Protection Association (NFPA) 430: Code for the Storage of Liquid and Solid Oxidizers* (NFPA, 2004). The project HASP will include a list of emergency response materials that will be present onsite such as containment

materials, adsorbent, neutralizing solution (e.g., ascorbic acid,  $C_6H_8O_6$ , or equivalent), and personal protective equipment.

The project team will receive on-Site training in oxidant handling and emergency response prior to beginning injections. Emergency response supplies and equipment will be staged near the work area in the event of a release and verified daily.

The following activities will be conducted as part of the mixing equipment set up:

- Establishment of Site control areas (i.e., exclusion zone, decontamination zone, etc.); and
- Receipt of oxidant and staging in a temporary secondary containment system.

The oxidant will be mixed with extracted groundwater to achieve the target injection solution concentration. The oxidant batch mixing will be performed numerous times during the injection activities and will include the following:

- Checking safety supplies and donning personal protective equipment;
- Connecting the mix tanks to the water supply and begin filling of the mix tanks. Mix tanks will be staged within temporary secondary containment with a capacity of at least 110% of the working volume of the largest individual tank. Mix tanks will be equipped with electric mechanical mixer(s), a recirculation pump, and lines to the distribution system [filter, pump(s) and manifold(s)].
  - Groundwater extracted from one or more of the on-Site SCRWs (e.g., AE/RW-9-1 and RW-21A) will be used for mixing the injection solution. Extraction of groundwater from these wells will be conducted to enhance distribution of oxidant and create a net zero injection program to reduce mounding associated with the ISCO injections.
  - Potable water will be used to supplement the ISCO injection volume, if needed.
- Transfer of oxidant to the mix tanks. Oxidant will be stored in a chemical storage area with secondary containment and a controlled work zone. The storage configuration will be consistent with the California Code of Regulations and approved by the City of Mountain View Fire Department prior to delivery of oxidant to the jobsite.

- Mixing the mix tank contents; and
- Periodically sampling the solution to confirm the oxidant concentration. Oxidant content will be measured using a field test kit.

Potential modification of the oxidant formulation would be determined on the basis of the bench-scale testing proposed in the Work Plan for ISCO Pilot Study Data Collection (Geosyntec, 2014c). As discussed in Section 6.1, an addendum to this Work Plan would be submitted to EPA if bench-scale testing supports modification of the proposed oxidant formulation.

#### **4.4.3 Injection Program Sequencing**

Up to three rounds of injections are anticipated. For each round, injection solution will be delivered to the subsurface using a combination of temporary direct push points and injection wells. The temporary injection wells will be installed in shallow zones U-2a and U-2b as described in Section 4.3 (Figure 8). Temporary direct push points will be used to deliver injection solution to the shallow zone U-1 and deeper zone L-1 (Figure 8). The direct push approach will use a ‘top down’ methodology to deliver oxidant solution.

The temporary direct push points will be advanced by a C-57 licensed drilling contractor using direct-push drilling. All down-hole equipment will be decontaminated prior to use. At each location, hollow direct-push rods will be advanced to the target injection interval and injection solution will be emplaced. Injections will occur at up to eight locations concurrently. Cross-sections showing target vertical injection intervals for each zone are shown in Figure 9 and Figure 10. The sequencing of injection events in each target injection zone will follow the steps outlined below.

##### ***4.4.3.1 First Round of Injections – Deep Zone L-1 and Shallow Zones U-1, U-2a and U-2b***

The first round of injections will be performed in the L-1 (lower) injection zone and the U-1, U-2a, and U-2b (upper) injection zones.

##### **Deep Injection Zone L-1**

The first round of injections will be performed by direct-push method in the L-1 (lower) injection zone to provide targeted treatment of cVOC concentrations in this zone and

establish an oxidizing zone below the elevation of subsequent injections in the shallow coarse-grained layer. Creating a reactive zone in L-1, in conjunction with pumping of one or more SCRWs (e.g., AE/RW-9-1 and RW-21A) to limit mounding during ISCO injections is intended to limit the potential for downward migration of residual cVOC contamination during the injection program. Each injection point within the L-1 zone will consist of one depth interval (3 ft thick) between 31 and 36 ft bgs. The exact depth of treatment will be dependent on interpreted lithology within each portion of the L-1 zone (Figure 9 and Figure 10).

The volume of permanganate solution that will be injected in L-1 has been developed based on the estimated target dosing described in Section 3.6 and the proposed injection location spacing and target vertical depth interval described above. However, the final oxidant selection may be revised based on the results of the bench-scale testing (Geosyntec, 2014c). At each of the 25 planned direct push injection locations, the injections will be performed as follows:

- The target volume of permanganate solution for a single injection event will be approximately 900 gallons applied in a single 3 foot interval at each direct push injection location;
- The concentration of permanganate in the injection solution will be approximately 35 g  $\text{MnO}_4^-/\text{L}$ ;
- The total nominal injection volume for L-1 will be 35,300 gallons, corresponding to the injection of approximately 9,300 pounds (lbs)  $\text{MnO}_4^-$ ; and
- The target permanganate dose applied in the L-1 injection zone based on the design oxidant demand is approximately 3.4 g  $\text{MnO}_4^-/\text{kg}$  soil for a single injection event.

The number of injection locations, injection volume, and permanganate dosing will be re-evaluated based on the monitoring conducted during the injection activities within the L-1 injection zone.

If oxidant surfacing, preferential pathways, or other potentially negative impacts are observed during L-1 injections and cannot be remedied by altering the ISCO pilot study design or implementing engineering controls at the Site, EPA will be notified and additional ISCO pilot study injections will not be implemented in L-1.

Shallow Injection Zones U-2a and U-2b

Following injection in the L-1 zone, injections will be performed in the U-2a and U-2b injection zones utilizing temporary injection wells. Each injection well within the U-2 zones will consist of a screened interval of 5 feet located between 16 and 24 feet bgs.<sup>10</sup> The exact depth of treatment will be dependent on interpreted lithology within each portion of the U-2 zones (Figure 9 and Figure 10).

The volume of permanganate solution that will be injected in U-2a has been developed based on the estimated target dosing described in Section 3.6, the lateral extent of the injection zone, and a target vertical depth interval of 5 feet. However, the final oxidant selection may be revised based on the results of the bench-scale testing (Geosyntec, 2014c). At each of the planned 7 temporary injection well locations, the injections will be performed as follows:

- The target volume of permanganate solution for the first injection event will be a total of approximately 2,300 gallons distributed across a 5-foot interval at each injection well;
- Concentration of permanganate in the injection solution will be approximately 35 g  $\text{MnO}_4^-/\text{L}$ ;
- Total nominal injection volume for U-2a will be 16,188 gallons per injection event, corresponding to the injection of approximately 5,050 lbs  $\text{MnO}_4^-$ ; and
- The target permanganate dose applied in the U-2a injection zone is approximately 3.4 g  $\text{MnO}_4^-/\text{kg}$  soil.

The volume of permanganate solution that will be injected in U-2b has been developed based on the estimated target dosing described in Section 3.6, the lateral extent of the injection zone, and a target vertical depth interval of 5 feet. However, the final oxidant selection may be revised based on the results of the bench-scale testing (Geosyntec, 2014c). At each of the planned 7 temporary injection well locations, the injections will be performed as follows:

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<sup>10</sup> The injection depth intervals may be extended slightly into the fine-grained layer underlying the shallow coarse-grained layer to promote oxidant injection into relatively lower permeability materials containing high cVOC concentrations.

- The target volume of permanganate solution for the first injection event will be a total of approximately 2,000 gallons distributed across a 5 foot interval at each injection well;
- Concentration of permanganate in the injection solution will be approximately 35 g MnO<sub>4</sub><sup>-</sup>/L;
- Total nominal injection volume for U-2b will be 13,980 gallons per injection event, corresponding to the injection of approximately 4,350 lbs MnO<sub>4</sub><sup>-</sup>; and
- The target permanganate dose applied in the U-2b injection zones is approximately 3.4 g MnO<sub>4</sub><sup>-</sup>/kg soil.

The number of injection locations, injection volume, and permanganate dosing will be re-evaluated based on the monitoring conducted during the injection activities within the U-2 injection zone.

If oxidant surfacing, preferential pathways, or other potentially negative impacts are observed during the U-2a or U-2b zone injections and cannot be remedied by altering the injection process or implementing engineering controls at the Site, EPA will be notified and additional ISCO pilot study injections will not be implemented in the U-2a or U-2b zones.

#### Shallow Injection Zone U-1

Following injection in the U-2 zones, injections will be performed in the U-1 injection zone using the direct-push method. The volume of permanganate solution that will be injected in U-1 has been developed based on the estimated target dosing described in Section 3.6, the lateral extent of the injection zone, and a target vertical depth interval of 5 feet. However, the final oxidant selection may be revised based on the results of the bench-scale testing (Geosyntec, 2014c). At each of the 50 planned direct push injection locations, the injections will be performed as follows:

- The target volume of permanganate solution for a single injection event will be a total of approximately 1,330 gallons distributed to a 5-foot injection interval at each direct push injection location;
- Concentration of permanganate in the injection solution will be approximately 35 g MnO<sub>4</sub><sup>-</sup>/L;

- Total nominal injection volume for U-1 will be 65,486 gallons, corresponding to the injection of approximately 18,000 lbs  $\text{MnO}_4^-$ ; and
- Target permanganate dose applied in the U-1 injection zone is approximately 3.4 g  $\text{MnO}_4^-/\text{kg}$  soil.

The planned injection locations, injection volume, and permanganate dosing will be re-evaluated based on the monitoring conducted during the injection activities within the U-1 injection zone.

If oxidant surfacing, preferential pathways, or other potentially negative impacts are observed during U-1 injections and cannot be remedied by altering the injection process or implementing engineering controls at the Site, EPA will be notified and additional ISCO pilot study injections will not be implemented in the U-1 zone.

#### ***4.4.3.2 Second Round of Injections – Shallow Zones U-1, U-2a and U-2b***

A second round of injections will be conducted in shallow zones U-1, U-2a and U-2b. The second round of injections will be conducted based on the monitoring observations from the initial round of injections in these zones. The monitoring data will be used to determine the final volumes and masses of oxidant to be delivered to the subsurface during the second event.

##### *Shallow Injection Zones U-2a and U-2b*

During the second round, injections within the U-2 zones will consist of a depth interval of 5 feet between 16 and 24 feet bgs. The exact depth of treatment will be dependent on interpreted lithology within each portion of the U-2 zones (Figure 9 and Figure 10).

The volume of permanganate solution that will be injected in U-2a during the second event will be 80% to 100% of the volume injected during the first round of injections and will be applied over a target vertical depth interval of 5 feet. At each of the planned 7 temporary injection well locations, the injections will be performed as follows:

- The target volume of permanganate solution for the second injection event will be a total of approximately 1,800 to 2,300 gallons distributed over a 5-foot screened interval at each temporary injection well location;

- Concentration of permanganate in the injection solution will be approximately 35 g MnO<sub>4</sub><sup>-</sup>/L;
- Total nominal injection volume for U-2a will be 12,950 to 16,188 gallons per injection event, corresponding to the injection of approximately 4,040 to 5,050 lbs MnO<sub>4</sub><sup>-</sup>; and
- The target permanganate dose applied in the U-2a injection zones is approximately 3.4 g MnO<sub>4</sub><sup>-</sup>/kg soil.

The final volume of permanganate solution that will be injected in U-2b during the second injection event will be 80% to 100% of the volume injected during the first round of injections and will be applied over a target vertical depth interval of 5 feet. At each of the 7 temporary injection well locations, the injections will be performed as follows:

- The target volume of permanganate solution for the second injection event will be a total of approximately 1,600 to 2,000 gallons distributed over a 5-foot screened interval at each temporary injection well location;
- Concentration of permanganate in the injection solution will be approximately 35 g MnO<sub>4</sub><sup>-</sup>/L;
- Total nominal injection volume for U-2b will be 1,180 to 13,980 gallons per injection event, corresponding to the injection of approximately 3,480 to 4,350 lbs MnO<sub>4</sub><sup>-</sup>; and
- The target permanganate dose applied in the U-2b injection zones is approximately 3.4 g MnO<sub>4</sub><sup>-</sup>/kg soil.

The planned injection locations, injection volume, and permanganate dosing will be re-evaluated based on the monitoring data collected during the first injection event in the U-2 injection zones.

If oxidant surfacing, preferential pathways, or other potentially negative impacts are observed during the U-2a or U-2b zone injections and cannot be remedied by altering the injection process or implementing engineering controls at the Site, EPA will be notified and additional ISCO pilot study injections will not be implemented in the U-2a or U-2b zones.

### *Shallow Injection Zone U-1*

A targeted second round of injections will be conducted in shallow zone U-1 using the direct-push method.

The scope for a second round of injections will be developed based on the results of the Site-specific PSOD testing and monitoring observations from the initial round of injections in this zone. This will likely entail a lesser volume and concentration than the first injection event in the U-1 zone (65,486 gallons at a concentration of 35 g/l  $\text{MnO}_4^-$  concentration based on an approximate oxidant demand of 3.4 g  $\text{MnO}_4^-/\text{kg}$  soil). Geosyntec will provide EPA with an addendum to this Work Plan prior to implementation of the ISCO pilot study detailing the scope of work for undertaking a limited targeted injection to the shallow zone U-1 before the second event commences.

#### ***4.4.3.3 Third Round of Injection Events – Shallow Zones U-1, U2a and U2-b***

A third round of injection events will be considered as part of the pilot study to target the shallow zones U-1, U-2a and U-2b. However, conducting a third injection will depend on several factors such as:

- Potential Site access limitations due to ongoing redevelopment activities; and,
- An assessment of the effectiveness of the first two injection events with respect to distributing oxidant within the desired treatment zones.

If a third round of injections is implemented, an injection scope will be provided to EPA for concurrence prior to injections.

#### **4.4.4 Oxidant Injection Approach**

The oxidant solution will be injected from the aboveground storage tank through an injection line connected to the temporary direct push rods/injection wells. Prior to starting injections, the injection line will be inspected for signs of damage or leaks, and connections will be checked. The injection line will be equipped with a mechanical flow totalizer, flow meter, pressure gauge, and flow control valve to monitor the injection volume, rate, and pressure.

Within each of the injection zones defined in Section 3.3 (L-1, U-1, U-2a, U-2b), injections will begin at the edges of the target injection zone and proceed toward the

center of the injection zone, to mitigate potential displacement of contaminated groundwater outside of the injection zone. The active injection points will be staggered (i.e., adjacent points will not be injected into simultaneously) to reduce potential groundwater mounding.

Design injection volumes and rates are described above and in Section 3.7. If possible based on achievable injection rates and pressures, the design volume of oxidant solution will be injected during each injection event. At the start of each injection, the rate and pressure will be slowly increased from conservatively low values to the design injection rate. The oxidant delivery rate and target injection volume may be adjusted during implementation based on observed field conditions.<sup>11</sup> If the oxidant cannot be delivered under pressures less than the maximum allowable injection pressure at a given injection interval, the oxidant volume that cannot be injected will be re-allocated to adjacent boreholes.

The total duration of the injection program will depend on the selected number of injection locations and achievable injection rates. The primary injection line will be equipped with a mechanical flow totalizer, flow meter, pressure gauge, and flow control valve to monitor the injection volume, rate, and pressure. Each injection point will be monitored with a flow meter, flow regulator, and pressure gauge.

Once injections at a given direct push point/temporary injection well location are complete, the point or well will be decommissioned in accordance with County, State and Federal requirements.

#### **4.4.5 Water Level Monitoring During Injection**

Pressure transducers will be temporarily installed in up to three A-zone wells located inside the slurry wall prior to the start of injection. Pressure transducers will be downloaded daily during the injection program to collect real-time data on groundwater elevation changes inside the slurry wall. Groundwater level measurements will be collected from Site wells located inside the slurry wall and adjacent to the injection areas before injections begin and periodically each day during the injection program. In

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<sup>11</sup> EPA will be notified if there is a need to revise the oxidant delivery rate or target injection volume.

addition, groundwater levels will be monitored daily at wells 31A, 39A, 41A, 43A, 69B1, 116A, and 138A, located outside the slurry wall, to monitor for potential hydraulic response outside the slurry wall.

As described in Section 4.4.1, one or more of the 401 National SCRWs (e.g. AE/RW-9-1 and RW-21A) will be pumped continuously during injections to promote oxidant distribution, reduce hydraulic mounding, and capture groundwater that is displaced by the injected solution. The extraction wells will be operated at flow rates to create a net zero injection, where the amount of injected fluid is equal to the amount of extracted groundwater on a given day.

#### **4.4.6 Surfacing and Preferential Pathway Monitoring**

As oxidant solution is injected into the subsurface, it will move away from the injection point and can be influenced by natural heterogeneities in the subsurface, bedding and backfill materials associated with buried utilities, and compromised buried utility conduits (i.e., leaking storm sewers). Prior to the start of injections, features where oxidant solution could surface (i.e., manholes, storm drains, etc.) will be identified and then monitored prior to and during injections. In addition, available as-built drawings will be reviewed and Site reconnaissance will be conducted to locate subsurface features that may potentially cross the 401 National slurry wall in the vicinity of the treatment areas.

During injection activities, potential preferential pathways in close proximity to the injection points will be visually monitored for the presence of the oxidant. Locations of storm sewer manholes and catch basins that could be preferential pathways and are present following building demolition will be marked as part of pilot study data collection activities. These Site features will be monitored during injection activities. If oxidant indicators (e.g., purple liquid if a permanganate-containing oxidant formulation is injected) are observed in a potential preferential pathway, the injections will be temporarily stopped while an approach for mitigating the preferential pathway is investigated. In the event that the presence of excess oxidant solution requires neutralization emergency response, procedures will be implemented as discussed in the following section.

#### 4.4.7 Emergency Response Procedures

In the event that the presence of excess oxidant solution requires neutralization or process chemical are spilled during Site operations and require neutralization, emergency response procedures will be implemented. Activities involved include the following:

- Stopping the oxidant injections;
- Notifying the Project Manager and Site Safety Officer in accordance with the HASP;
- Notifying the EPA and City of Mountain View if the spill exceeds the reportable quantity (100 pounds in the case of permanganate);
- Containment of oxidant solutions;
- Managing any surface seepage of oxidant solutions; and
- Neutralize spilled oxidant using ascorbic acid or similar neutralizing solution.

Prior to injection activities, STC will work with EPA and the City of Mountain View to develop a list of contacts that will be notified in the event of an oxidant spill or release. The contact list will be included in the HASP that will be onsite while field work is underway.

#### 4.5 Sampling and Analysis Plan

The pilot study monitoring program consists of the following components:

- **Baseline:** Baseline samples will be collected to establish cVOC and geochemical conditions prior to the oxidant injections.
- **Injection Program Monitoring:** Samples will be collected while injections are ongoing to assess the progress of the ISCO injection program and make adjustments to the program as needed.
- **Performance Monitoring Following Injections:** Once the injection program has been completed, performance monitoring samples will be collected within the slurry wall to assess the progress of the pilot study with respect to achieving

the pilot study objectives and monitoring for potential secondary water quality impacts.

- **Sentry Well Monitoring:** Sentry wells will be monitored during and after the injection program to assess changes in groundwater conditions outside the slurry wall due to the oxidant injection program that have the potential to impact the 401/405 National Shared Treatment Plant. The sentry well monitoring program includes contingencies for mitigating potential discharge exceedances at the 401/405 National Shared Treatment Plant due to the presence of groundwater with ISCO-related secondary groundwater impacts outside the slurry wall.

Performance and sentry monitoring points are shown on Figures 11 and 12, respectively, and listed on Table 2. A monitoring schedule is provided in Table 3. Contingencies for mitigating potential treated groundwater discharge exceedances at the 401/405 National Shared Treatment Plant resulting from the ISCO pilot study are provided in Appendix D. The follow sections describe monitoring that will be conducted to evaluate the progress of the pilot study.

#### 4.5.1 Baseline Sampling

A minimum of 72 hours after the completion of well development, baseline groundwater samples will be collected from the six wells in the performance monitoring well network (36A, 137A, AE/RW-9-2, BLDG9-MW-1, BLDG9-MW-2, and BLDG9-MW-3, Figure 11) to establish baseline cVOC and geochemical conditions prior to the implementation of oxidant injections. Additionally, baseline samples will be collected from the seven sentry monitoring wells that will be included in the off-Site monitoring program (31A, 39A, 41A, 43A, 69B1, 116A, and 138A), from the shared SCRWs and 405 National SCRWs (EX-1, EX-2, EX-3, EX-4, 116A<sup>12</sup>, GSF-1A, GSF-1B1), and from the 401/405 National treatment system (influent and effluent ports).

During baseline sampling, the performance monitoring wells will be purged three to five casing volumes prior to collection of groundwater samples. The wells will be purged using a submersible pump equipped with new disposable tubing. Water will be pumped through a closed flow-through cell fitted with a multi-parameter groundwater

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<sup>12</sup> 116A will be converted into an SCRW as part of optimization of the STC/Vishay shared remedy.

meter. Temperature, pH, electrical conductivity, turbidity, dissolved oxygen (DO), and oxidation reduction potential (ORP) will be measured during purging. Groundwater will be purged until the temperature, pH, and electrical conductivity values stabilize. Groundwater levels will be monitored during purging to confirm that drawdown stabilizes prior to sampling.

Baseline samples will be collected from the 401/405 National Shared Treatment Plant directly from the influent and effluent ports. Following stabilization of field parameters, groundwater samples will be collected. Samples will be analyzed for the following compounds:

- cVOCs by EPA Method 8260B (8010 analyte list);
- Total dissolved solids (TDS) by Method SM 2540C;
- Chloride by EPA Method 300.0;
- Dissolved manganese, iron, and chromium by EPA Method 6010B; and
- Dissolved hexavalent chromium by EPA Method 7196.

#### **4.5.2 Injection Program Monitoring**

Daily monitoring during injections will include sampling for the presence of oxidant and periodically checking groundwater elevations in the six performance monitoring wells (Table 3). If oxidant is observed, a sample will be collected and analyzed for oxidant using a field spectrophotometer. Water levels will also be monitored during injections as described in Section 4.4.5.

#### **4.5.3 Performance Monitoring After Injection**

Pilot Study performance monitoring will be conducted in accordance with the schedule provided in Table 3. Wells not included in the ISCO pilot study monitoring program will be monitored during the 2015 annual sampling event for the MEW Study Area and would continue to be monitored on the schedule specified in the Fairchild O&M plans and previous annual reports.

Beginning one month after completion of the oxidant injection program, monthly sampling for the presence of oxidant will be conducted at the six performance monitoring wells located inside the slurry wall (Table 3) until the oxidant is exhausted.

All other analytes will be monitored quarterly for the first year following pilot study implementation. A quarterly monitoring frequency has been selected for the pilot study because it will provide sufficient temporal and spatial monitoring information to evaluate the progress of the pilot study with respect to meeting the objectives described in Section 3.1. After the first year, the scope and frequency of the monitoring will be evaluated and modified in consultation with EPA, as appropriate.

During each performance monitoring event, the performance monitoring wells will be purged three to five casing volumes prior to collection of groundwater samples. The wells will be purged using a submersible pump equipped with new disposable tubing. Water will be pumped through an enclosed flow-through cell fitted with a multi-parameter groundwater meter. Temperature, pH, electrical conductivity, turbidity, DO, and ORP will be measured during purging. Groundwater will be purged until the field parameter values stabilize. Groundwater levels will be monitored during purging to confirm that drawdown stabilizes prior to sampling. Following stabilization of field parameters, groundwater samples will be collected and analyzed for the following compounds:

- Quenched cVOCs by EPA Method 8260B (8010 analyte list);
- Oxidant using a field spectrophotometer or a commercially available field test kit if other oxidants are used;
- TDS by Method SM 2540C;
- Chloride by EPA Method 300.0;
- Dissolved total manganese, iron, and chromium by EPA Method 6010B; and
- Dissolved hexavalent chromium by EPA Method 7196. This analysis is subject to interference in the presence of permanganate. If permanganate is used in the oxidant formulation and groundwater is pink or purple during sampling, samples will not be analyzed for this compound.

#### **4.5.4 Monitoring Outside Slurry Wall**

Although groundwater quality impacts related to the ISCO injection program are not anticipated outside of the slurry wall (Section 3.8), a monitoring program has been developed to assess potential secondary water quality impacts at extraction wells located in close proximity to the Site.

In consultation with Vishay and their technical representatives, the following approach for monitoring potential impacts to the 405 National and Shared SCRWs and 401/405 National Shared Treatment System was developed:

- Periodic monitoring of sentry wells for ISCO-related groundwater impacts;
- Periodic monitoring of the shared SCRWs and 405 National SCRWs for impacts exceeding the action levels described below; and
- If necessary based on sentry well and extraction well data, implement the contingency plan described in Appendix D.

While injections are ongoing, the sentry wells (Table 3) will be monitored daily for the presence of oxidant outside of the slurry wall. A field meter will be deployed once per day into the sentry wells to monitor specific conductance and ORP, which can be early indicators of changes to geochemical conditions outside the slurry wall due to injections. Following the collection of field meter readings, a bailer will be deployed into each sentry well to look for visible signs of oxidant (e.g., purple color). If visible oxidant is observed, a sample will be collected by bailer to measure the oxidant concentrations using a field spectrophotometer. If oxidant is detected in one or more of the sentry wells injection operations will be temporarily stopped and groundwater samples will be collected from selected monitoring and extraction wells to evaluate potential impacts to the 401/405 National Shared Treatment System.

Beginning one month after completion of the oxidant injection program, monthly sampling will be conducted at the sentry wells, shared SCRWs, and 405 National SCRWs for the first year following pilot study implementation. After the first year, the scope and frequency of sentry well monitoring will be evaluated and modified, as appropriate. EPA and other stakeholders would be notified of any proposed changes in the monitoring program scope or frequency.

During each post-injection monitoring event (or if sentry wells are sampled during injections due to the presence of oxidant as described above), the sentry wells, shared SCRWs, and 405 National SCRWs will be sampled. The sentry wells will be purged to remove three to five casing volumes prior to collection of groundwater samples. Samples collected from the extraction wells will be collected directly from the pump discharge line at the wellhead during normal operation.

The sentry wells will be purged using a submersible pump equipped with new disposable tubing. Water will be pumped through an enclosed flow-through cell fitted with a multi-parameter groundwater meter. Temperature, pH, electrical conductivity, turbidity, DO, and ORP will be measured during purging. Groundwater will be purged until the field parameter values stabilize. Groundwater levels will be monitored during purging to confirm that drawdown stabilizes prior to sampling. Following stabilization of field parameters, groundwater samples will be collected. Extraction wells will not be purged, however groundwater from the wells will be pumped through an enclosed flow-through cell fitted with a multi-parameter groundwater meter for collection of field parameters.

Groundwater samples from the sentry wells will be analyzed for the following compounds:

- Quenched cVOCs by EPA Method 8260B (8010 analyte list);
- Oxidant using a field spectrophotometer or a commercially available field test kit if other oxidants are used;
- TDS by Method SM 2540C;
- Chloride by EPA Method 300.0;
- Dissolved total manganese, iron, and chromium by EPA Method 6010B; and
- Dissolved hexavalent chromium by EPA Method 7196.

Groundwater samples from the shared SCRWs and 405 National SCRWs will be analyzed for the following compounds:

- Oxidant using a field spectrophotometer or a commercially available field test kit if other oxidants are used; and
- Dissolved hexavalent chromium by EPA Method 7196.

Concentrations of oxidant and hexavalent chromium in the samples collected from the shared SCRWs and 405 National SCRWs will be compared to the following action levels:

- Oxidant ion exceeding 1 mg/L, or approximately one-half of the lethal concentration at a 50% mortality rate (LC-50) for rainbow trout of 1.8 mg/L for permanganate; and
- Hexavalent chromium exceeding 5 ug/L, or one half of the California MCL of 10 µg/L.

If the sample results at the sentry wells or extraction wells do not exceed the above action levels, no further action (other than continued monitoring) would be required. If the sample results at the sentry wells or extraction wells exceed the action level, Geosyntec will work with Vishay to implement mitigation measures for the analytes exceeding the action levels. A contingency plan for mitigating potential discharge exceedances at the 401/405 National Shared Treatment System is provided in Appendix D.

#### **4.5.5 Sample Packaging, Shipping, and Quality Control**

In order to ensure that residual oxidant in the groundwater (if present) does not further oxidize the cVOCs between sample collection and laboratory analysis, cVOC samples will be quenched in the field immediately following sample collection. Preservation of groundwater samples will be conducting based on the EPA guidance document *Groundwater Sample Preservation at In-Situ Chemical Oxidation Sites* (EPA, 2012). This process involves adding ascorbic acid to the groundwater sample as the preservative before the groundwater sample is packed and shipped to the analytical laboratory for analysis (see Appendix E for procedure guidelines).

Performance monitoring samples will be collected in laboratory-supplied sample containers and labeled with project identification, sample location, analytical method, time and date of sampling, and any preservative added to the sample. Samples will be stored in an ice-cooled chest, maintained at approximately 4° C, for transport under chain-of-custody procedures to a State of California-certified laboratory for analysis.

QA/QC samples will be collected for cVOC samples. In accordance with the MEW QAPP (Canonie, 1991), one duplicate, one field blank and one equipment blank will be collected for every 20 groundwater samples collected for cVOC analysis. In addition a laboratory provided trip blank will be included with each cooler containing groundwater samples for cVOC analysis that is sent to the laboratory.

#### **4.6 Temporary Performance Monitoring Well Destruction Plan**

At the conclusion of the pilot study, STC will request EPA approval to destroy the temporary performance monitoring wells. If EPA approves the request for one or more of the wells, the wells would be destroyed. The temporary performance monitoring wells will be decommissioned in accordance with County, State and Federal requirements.

#### **4.7 Investigation Derived Waste Management**

Water generated during the pilot study implementation activities will be neutralized if residual oxidant is present, and then treated and discharged through one of the MEW Study Area groundwater treatment systems. Soil cuttings will be temporarily stored on-Site in 55-gallon drums or roll off bins pending analysis. Following waste profiling, soil cuttings will be disposed of in accordance with Federal and State requirements at an appropriate off-Site facility.

## **5. CRITERIA FOR RESTARTING RECOVERY WELLS**

At the conclusion of the pilot study, groundwater extraction and treatment within the slurry wall will be resumed to satisfy the conditions of the MEW ROD. STC will work with EPA to review the findings of the post-injection performance monitoring program to determine when to conclude the ISCO pilot study and resume extraction for the slurry wall SCRWs.

## 6. REPORTING AND SCHEDULE

This section summarizes the pilot study reporting and presents a schedule for implementing the pilot study.

### 6.1 Pilot Study Reporting

#### *Work Plan Addendum, If Necessary*

As described in the ISCO Pilot Study Data Collection Work Plan (Geosyntec, 2014c), the results of the proposed data collection activities will be reviewed to assess the need for modifications to the pilot study design basis (Section 3) or implementation work plan (Section 4). If necessary based on the data review, Geosyntec will submit an addendum to this Work Plan to EPA summarizing the findings of the ISCO pilot study data collection program and proposing adjustments to the ISCO pilot study scope of work (e.g., modifications to the treatment area dimensions, oxidant selection, or design oxidant dosing). If modifications to this Work Plan are not required, Geosyntec will notify EPA of STC's intent to proceed with the proposed pilot study scope of work.

#### *Implementation Report*

A Pilot Study Implementation Report will be prepared and submitted to EPA following implementation of the ISCO injection program. The Pilot Study Implementation Report will include the following:

- A description of the pilot study data collection activities (Geosyntec, 2014c);
- A description of activities related to temporary performance monitoring well installation and development, including boring logs and well construction diagrams;
- A summary of the results of the baseline sampling, including data tabulation;
- A summary of the oxidant injection program, including the volume and concentration of oxidant injected, the observed injection rates and pressures, and the results of surfacing and preferential pathways monitoring; and
- The results of process monitoring sampling, including data tabulation and creation of data summary figures.

### ***Progress Reporting***

The progress of the pilot study will be documented in Annual Progress Reports submitted to EPA as part of the Annual Monitoring Reports for former Fairchild Buildings 1-4, 9, and 18. The Annual Progress Reports will include the following:

- A summary of the performance monitoring sampling, including data tabulation and the creation of data summary figures;
- A discussion of the performance monitoring results; and
- Recommendations for follow-on work. Follow-on work could potentially include continued annual performance monitoring of the pilot study area to assess long-term oxidant depletion and cVOC concentration trends or resumption of groundwater extraction from within the 401 National.

### **6.2 Schedule**

A summary of the proposed schedule is presented below. The proposed schedule was developed in consideration of the planned redevelopment activities at 401 National Avenue and may be adjusted to accommodate changes to the development schedule. In addition, the schedule may be adjusted as needed following EPA review and approval of the work plan due to delays in obtaining required access or permits or due to conditions encountered during field implementation. EPA will be notified if there is a need to adjust the pilot study implementation schedule.

- 23 September 2014 – EPA approval of ISCO Pilot Study Data Collection Work Plan (Geosyntec, 2014c).<sup>13</sup>
- 20 November 2014 – Submittal of Final ISCO Pilot Study Work Plan.
- 31 December 2014 - EPA Approval of Final ISCO Pilot Study Work Plan.
- October through November 2014 – Data collection activities.
- 31 December 2014 – Submittal of Work Plan Addendum (if necessary) for EPA concurrence.

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<sup>13</sup> EPA has approved the Data Collection Work Plan and STC is proceeding with implementation of the proposed scope of work.

- January 2015 – Permitting, installation, development, and baseline sampling of temporary performance monitoring wells.
- January through March 2015 – ISCO injection program and associated process monitoring.
- April 2015 – Beginning of pilot study performance monitoring events.
- May 2015 – Submittal of Pilot Study Implementation Report.
- April 2016 – Submittal of first pilot study Annual Progress Report as part of the Annual Monitoring Reports for former Fairchild Buildings 1-4, 9, and 18.

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# TABLES

**Table 1**  
**Groundwater Analytical Results: Detected cVOCs**

401 National Avenue  
Mountain View, California

| Sample Location                           | Sample Date | Sample Depth (ft bgs) <sup>1</sup> | Concentration in µg/L by EPA method 8260B |             |             |                |                |             |         |         |           |                         |
|---|-------------|------------------------------------|---|-------------|-------------|----------------|----------------|-------------|---------|---------|-----------|-------------------------|
|   |             |                                    | PCE                                       | TCE         | cis-1,2-DCE | trans-1,2- DCE | Vinyl Chloride | 1,1,1-TCA   | 1,1-DCA | 1,1-DCE | Freon 113 | Total VOCs <sup>2</sup> |
| <b>Wells Inside Slurry Wall</b>           |             |                                    |   |             |             |                |                |             |         |         |           |                         |
| 35A                                       | 9/25/2012   | 12-37                              | <0.50                                     | 220         | 130         | 1.7            | 1.1            | <0.50       | 3.6     | 2.5     | 2.1       | 400                     |
| 36A                                       | 9/18/2012   | 35-40                              | <0.50                                     | 110         | 270         | 2.1            | 0.7            | <0.50       | 3.3     | 2.7     | 0.64      | 400                     |
| 37A                                       | 10/23/2013  | 15-30                              | <0.50                                     | 72          | 370         | 3.7            | 49             | 7.6         | 36      | 8.6     | 1.1       | 500                     |
| 122A                                      | 9/26/2012   | 28-38                              | <0.50/<0.50                               | 210/230     | 100/100     | 1.6/1.6        | <0.50/<0.50    | <0.50/<0.50 | 3.0/3.0 | 2.1/2.1 | 1.0/0.97  | 300                     |
| 137A                                      | 10/23/2013  | 34-36                              | <5.0                                      | 6,400       | 4,300       | 41             | <5.0           | <5.0        | <5.0    | 11      | 16        | 10,800                  |
| AE/RW-9-1                                 | 10/17/2013  | 8-33                               | 1.5                                       | 810         | 710         | 7.7            | 13             | 45          | 53      | 12      | 3.9       | 1,700                   |
| AE/RW-9-2                                 | 10/17/2013  | 8-37                               | 4.6                                       | 13,000      | 8,800       | 78             | 260            | 49          | 84      | 38      | 190       | 22,500                  |
| RW-20A                                    | 10/17/2013  | 26.5-36.5                          | 1.7                                       | 1,100       | 940         | 7.0            | 4.1            | 9.1         | 12      | 9.3     | 7.2       | 2,100                   |
| RW-21A                                    | 10/17/2013  | 21-36                              | 4.6                                       | 410         | 350         | 5.8            | 1.8            | 1.6         | 5.0     | 5.0     | 9.0       | 800                     |
| <b>Grab Samples Inside Slurry Wall</b>    |             |                                    |   |             |             |                |                |             |         |         |           |                         |
| MIP-02                                    | 9/9/2013    | 21-25                              | <1,000                                    | 560,000     | 59,000      | <1,000         | 3,000          | <1,000      | <1,000  | <1,000  | 7,100     | 630,000                 |
| MIP-02                                    | 9/9/2013    | 33-36                              | <25                                       | 100         | 5,300       | 71             | 86             | <25         | <25     | <25     | <25       | 5,600                   |
| MIP-03                                    | 9/10/2013   | 18-22                              | <50                                       | 6,600       | 15,000      | 200            | 56             | <50         | <50     | <50     | <50       | 21,900                  |
| MIP-04                                    | 9/9/2013    | 16-20                              | <50                                       | 360         | 11,000      | 79             | 180            | <50         | <50     | <50     | <50       | 11,600                  |
| MIP-04                                    | 9/9/2013    | 33-36                              | <25/<25                                   | 1,200/1,200 | 2,700/2,700 | <25/<25        | 25/25          | <25/<25     | <25/<25 | <25/<25 | <25/<25   | 3,900                   |
| MIP-08                                    | 9/10/2013   | 18-22                              | <50                                       | 2,100       | 1,200       | <50            | <50            | <50         | <50     | <50     | 64        | 3,400                   |
| MIP-09                                    | 9/10/2013   | 20-23                              | <50                                       | 76,000      | 45,000      | 480            | 570            | 50          | 210     | 140     | 410       | 120,000                 |
| MIP-12                                    | 9/10/2013   | 18-22                              | <25                                       | 2,300       | 180         | <25            | <25            | <25         | <25     | <25     | 36        | 2,500                   |
| MIP-12                                    | 9/10/2013   | 22-26                              | 59  | 120,000     | 55,000      | 280            | 520            | <50         | 310     | 160     | 1,200     | 180,000                 |
| MIP-12                                    | 9/10/2013   | 33-35                              | <50                                       | 770         | 2,400       | <50            | <50            | <50         | <50     | <50     | <50       | 3,200                   |
| <b>Well Upgradient of Slurry Wall</b>     |             |                                    |   |             |             |                |                |             |         |         |           |                         |
| 123A                                      | 10/23/2013  | 28-38                              | <5.0                                      | 510         | 260         | <5.0           | <5.0           | <5.0        | <5.0    | <5.0    | 6.2       | 800                     |
| <b>Wells Downgradient of Slurry Wall</b>  |             |                                    |   |             |             |                |                |             |         |         |           |                         |
| 41A                                       | 10/23/2013  | 13-25                              | <5.0                                      | 580         | 220         | <5.0           | <5.0           | <5.0        | <5.0    | <5.0    | 7.0       | 800                     |
| 42A                                       | 10/23/2013  | 10-35                              | 1.9/1.7                                   | 480/470     | 87/85       | 1.4/1.3        | 1.1/1.0        | 1.8/1.7     | 1.4/1.4 | 2.2/2.1 | 6.8/6.5   | 600                     |
| <b>Wells Transgradient of Slurry Wall</b> |             |                                    |   |             |             |                |                |             |         |         |           |                         |
| 40A                                       | 10/23/2013  | 11.5-27                            | 1.2                                       | 560         | 180         | 2.0            | 1.6            | 3.8         | 3.6     | 4.8     | 10        | 800                     |
| 43A                                       | 10/23/2013  | 15-27                              | 1.5                                       | 420         | 96          | 1.2            | 1.5            | 1.4         | 1.3     | 1.8     | 3.5       | 500                     |
| 44A                                       | 10/23/2013  | 13.5-28                            | 1.8                                       | 330         | 51          | 0.79           | <0.50          | 1.0         | 0.7     | 1.2     | 2.4       | 400                     |
| 126A                                      | 9/25/2012   | 23-38                              | <0.50                                     | 130         | 110         | 1.0            | 0.59           | <0.50       | 4.0     | 2.8     | 1.7       | 300                     |
| 138A                                      | 10/23/2013  | 34-37                              | <0.50                                     | 340         | 920         | 6.4            | 16             | <0.50       | 3.2     | 3.6     | <50       | 1,300                   |

**Notes:**

- 1. Sample depth represents screen intervals for monitoring wells or grab sample depths
  - 2. The Total VOCs values were rounded
- ft bgs = feet below ground surface  
µg/L = micrograms per liter  
EPA = Environmental Protection Agency  
1,200/1,200 indicates primary and duplicate sample results  
< indicates analyte not detected above the reported detection limit

- PCE = Tetrachloroethene
- TCE = Trichloroethene
- cis-1,2-DCE = cis-1,2-Dichloroethene
- trans-1,2-DCE = trans-1,2-Dichloroethene
- 1,1,1-TCA = 1,1,1-Trichloroethane
- 1,1-DCA = 1,1-Dichloroethane
- 1,1-DCE = 1,1-Dichloroethene

- Freon 113 = Trichlorotrifluoroethane
- VOC = volatile organic compounds
- cVOCs = chlorinated volatile organic compounds

**Table 2**  
**Extraction and Monitoring Well Construction Summary**  
 401 National Avenue ISCO Pilot Study  
 Mountain View, California

| Well ID  | Reference Elevation <sup>1</sup> (ft msl) | Diameter (inches) | Total Well Depth (ft bgs) | Top of Screened Interval (ft bgs) | Bottom of Screened Interval (ft bgs) | Top of Sand Pack (ft bgs) | Bottom of Sand Pack (ft bgs) | Well Type        | Included in Monitoring program | Rationale for Inclusion/Exclusion in Pilot Study Monitoring Program     |
|--|---|-------------------|---------------------------|-----------------------------------|--------------------------------------|---------------------------|------------------------------|------------------|--------------------------------|---|
| <b>Current A Zone Well Located Inside Slurry Wall</b>                        |   |                   |                           |                                   |                                      |                           |                              |                  |                                |   |
| 35A  | 42.67                                     | 2                 | 37                        | 12                                | 37                                   | 12                        | 37                           | Mon              |                                | Located outside of pilot study area                                     |
| 36A  | 42.32                                     | 2                 | 40                        | 35                                | 40                                   | 15                        | 40                           | Mon              | X                              | Located adjacent to pilot study area treatment area                     |
| 37A  | 43.21                                     | 2                 | 30                        | 15                                | 30                                   | 12                        | 30                           | Mon              |                                | Proximity to 36A, 36A will be monitored instead of 37A                  |
| 122A   | 44.23                                     | 4                 | 38                        | 28                                | 38                                   | 18                        | 39                           | Mon              |                                | Located outside of pilot study area                                     |
| 137A   | 43.68                                     | 4                 | 36                        | 34                                | 36                                   | 32                        | 38                           | Mon              | X                              | Located within pilot study area treatment area                          |
| AE/RW-9-1  | 43.15                                     | 6                 | 33                        | 8                                 | 33                                   | 6                         | 36                           | Ext              |                                | Located outside of pilot study area                                     |
| AE/RW-9-2  | 43.85                                     | 6                 | 37                        | 8                                 | 37                                   | 6                         | 38                           | Ext              | X                              | Located within pilot study treatment area                               |
| RW-20A   | 43.57                                     | 8                 | 37.5                      | 26.5                              | 36.5                                 | 11                        | 38                           | Ext              |                                | Located outside of pilot study area                                     |
| RW-21A   | 43.16                                     | 6                 | 37                        | 21                                | 36                                   | 11                        | 38                           | Ext              |                                | Located outside of pilot study area                                     |
| <b>Proposed Temporary A Zone Well Located Inside Slurry Wall<sup>2</sup></b> |   |                   |                           |                                   |                                      |                           |                              |                  |                                |   |
| B9-1A  | --  | 2                 | 23                        | 16                                | 23                                   | 15                        | 23                           | Mon              | X                              | New well to be installed within pilot study area treatment area         |
| B9-2A  | --  | 2                 | 23                        | 16                                | 23                                   | 15                        | 23                           | Mon              | X                              | New well to be installed within pilot study area treatment area         |
| B9-3A  | --  | 2                 | 37                        | 32                                | 37                                   | 31                        | 37                           | Mon              | X                              | New well to be installed within pilot study area treatment area         |
| <b>Nearby A Zone Well Located Outside Slurry Wall</b>                        |   |                   |                           |                                   |                                      |                           |                              |                  |                                |   |
| 31A  | 43.87                                     | 2                 | 27                        | 14.5                              | 27                                   | 10                        | 27                           | Mon              | X                              | Located upgradient of EX-1  |
| 39A  | 42.77                                     | 2                 | 35                        | 15                                | 35                                   | 12                        | 35                           | Mon              | X                              | Located upgradient of EX-3 and EX-4                                     |
| 40A  | 43.44                                     | 2                 | 27                        | 11.5                              | 27                                   | 12                        | 27                           | Mon              |                                | Proximity to 39A, 39A will be monitored instead of 40A                  |
| 41A  | 42.40                                     | 2                 | 25                        | 13                                | 25                                   | 13                        | 25                           | Mon              | X                              | Located upgradient of 116A and GSF wells                                |
| 42A  | 42.97                                     | 2                 | 35                        | 10                                | 35                                   | 12                        | 35                           | Mon              |                                | Conditions up-gradient of 116A and the GSF wells to be monitored by 41A |
| 43A  | 43.38                                     | 2                 | 27                        | 15                                | 27                                   | 15                        | 27                           | Mon              | X                              | Located upgradient of EX-4  |
| 44A  | 43.13                                     | 2                 | 28                        | 13.5                              | 28                                   | 13.5                      | 28                           | Mon              |                                | Downgradient of EX-1 through EX-4                                       |
| 69A  | 42.48                                     | 2                 | 31                        | 21                                | 31                                   | 10                        | 31                           | Mon              |                                | GSF wells to be monitored by 41A and 116A                               |
| 116A   | 40.97                                     | 4                 | 41                        | 19                                | 39                                   | 17                        | 41                           | Mon <sup>3</sup> | X                              | Located upgradient of GSF wells   |
| 123A   | 44.37                                     | 4                 | 38                        | 28                                | 38                                   | 18                        | 39                           | Mon              |                                | Located upgradient of pilot study area                                  |
| 126A   | 42.85                                     | 4                 | 38                        | 23                                | 38                                   | 18                        | 40                           | Mon              |                                | Located crossgradient of pilot study area                               |
| 138A   | 43.60                                     | 4                 | 37                        | 34                                | 37                                   | 32                        | 38                           | Mon              | X                              | Located upgradient of EX-2, EX-3, and EX-4                              |
| EX-1 <sup>4</sup>  | 44.20                                     | NA                | 29.7                      | 9.9                               | 28.5                                 | 8.5                       | 29.7                         | Ext              | X                              | 405 National SCRW   |
| EX-2 <sup>4</sup>  | 44.10                                     | NA                | 29.0                      | 9.4                               | 27.9                                 | 8.1                       | 29.0                         | Ext              | X                              | 405 National SCRW   |
| EX-3 <sup>4</sup>  | 43.80                                     | NA                | 30.1                      | 9.9                               | 29.3                                 | 8.5                       | 30.1                         | Ext              | X                              | 405 National SCRW   |
| EX-4 <sup>4</sup>  | 43.70                                     | NA                | 31.1                      | 10.4                              | 28.6                                 | 8.5                       | 31.1                         | Ext              | X                              | 405 National SCRW   |
| GSF-1A   | 39.46                                     | NA                | 35                        | 19                                | 34                                   | 17.0                      | 35.0                         | Ext              | X                              | Shared SCRW   |
| <b>B1 Zone Wells</b>   |   |                   |                           |                                   |                                      |                           |                              |                  |                                |   |
| 69B1   | 42.62                                     | 4                 | 59                        | 54                                | 59                                   | 50                        | 61                           | Mon              | X                              | Monitoring conditions below the slurry wall                             |
| GSF-1B1  | 39.43                                     | NA                | 71                        | 63.6                              | 70.5                                 | 61                        | 71                           | Ext              | X                              | Shared SCRW   |

## Notes:

- Reference Elevations are in National Geodetic Vertical Datum from 1929 (NGVD 29).
- Actual total depths and screen intervals for the individual monitoring wells may be adjusted in the field based on the subsurface conditions encountered.
- 116A is planned to be converted into an SCRW to support the STC/Vishay shared remedy.
- Wells drilled at a 45 degree angle to the east. Construction depths provided are approximate depths below ground surface. See Section 4.4 of work plan for monitoring program details.

## Abbreviations:

ft msl = feet mean sea level  
 ft bgs = feet below ground surface  
 Ext = extraction well  
 Mon = monitoring well

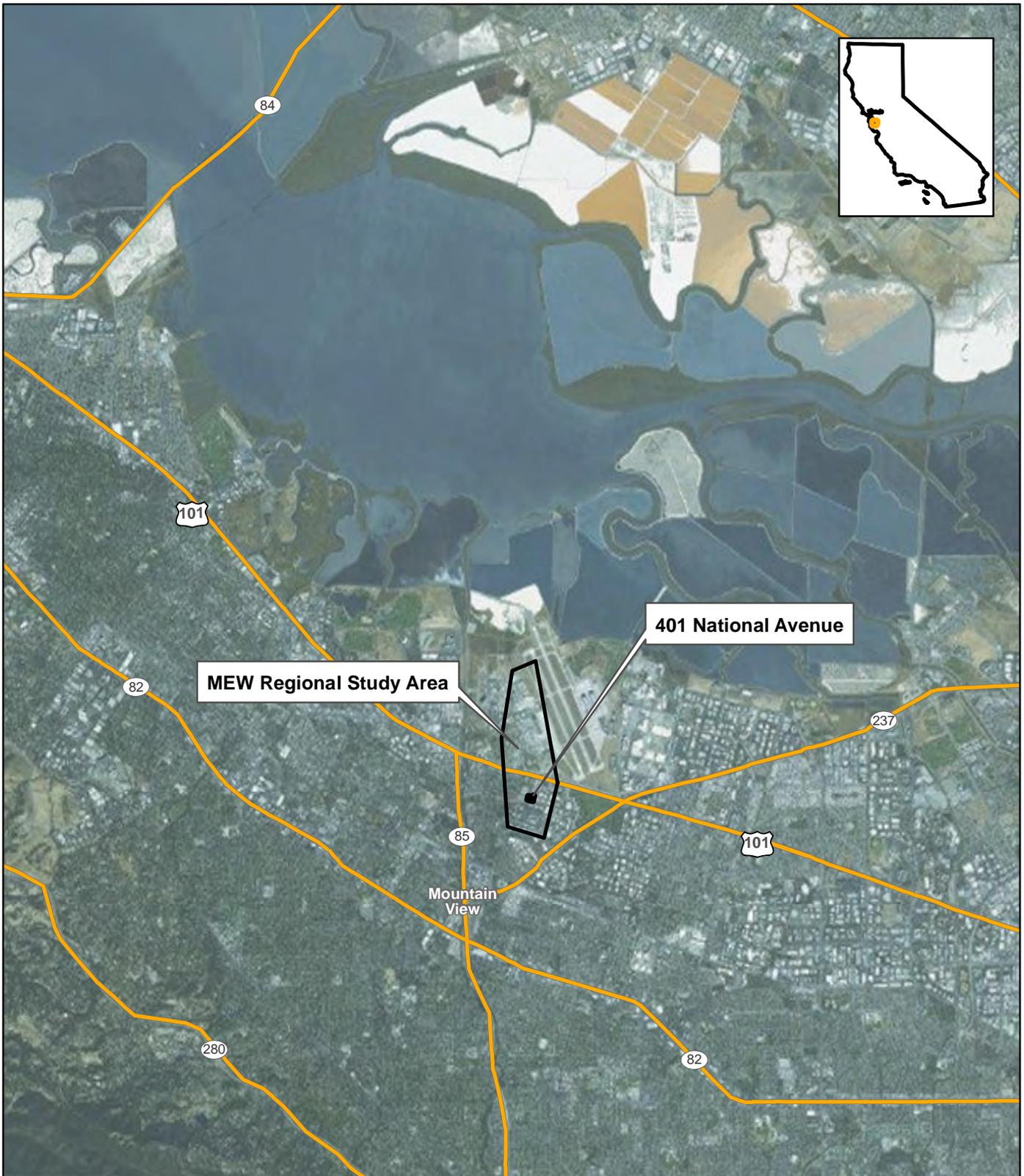
**Table 3**  
**Monitoring Schedule**  
 401 National Avenue ISCO Pilot Study  
 Mountain View, California

| Component   | Pilot Study Performance Monitoring Wells  | Sentry Wells  | Shared SCRWs and 405 National SCRWs               | Vishay Treatment System                 |   |
|---|---|---|---|---|---|
| Monitoring Point(s)   | AE/RW-9-2, 36A, 137A, B9-1A, B9-2A, B9-3A   | 31A, 39A, 41A, 43A, 116A, 138A, and 69B1                | EX-1, EX-2, EX-3, EX-4, 116A, GSF-1A, and GSF-1B1 | Influent                                | Effluent                                |
| <b>Baseline Sampling</b>                                    |   |   |   |   |   |
| cVOCs by EPA Method 8260B                                   | Prior to the start of injections. A minimum of 72 hours after the completion of well development. | Prior to the start of injections                        | Prior to the start of injections                  | Prior to the start of injections        | Prior to the start of injections        |
| Total dissolved solids (TDS) by Method SM 2540C             |   |   |   |   |   |
| Chloride by EPA Method 300.0                                |   |   |   |   |   |
| Dissolved manganese, iron, and chromium by EPA Method 6010B |   |   |   |   |   |
| Dissolved hexavalent chromium by EPA Method 7196            |   |   |   |   |   |
| <b>Monitoring During Injection Program</b>                  |   |   |   |   |   |
| Gauging   | Daily during injections   | Daily during injections                                 | --  | --                                      | --                                      |
| Visual presence of oxidant                                  | Daily during injections   | Daily during injections                                 | --  | --                                      | --                                      |
| Oxidant using a commercially available field test kit       | If MnO <sub>4</sub> is observed during daily monitoring   | If MnO <sub>4</sub> is observed during daily monitoring | Note 2  | --                                      | --                                      |
| ORP and SC  | --  | Daily during injections                                 | --  | --                                      | --                                      |
| Dissolved hexavalent chromium by EPA Method 7196            | --  | Note 2  | Note 2  | --                                      | --                                      |
| <b>Monitoring Following Injection Program<sup>3</sup></b>   |   |   |   |   |   |
| cVOCs by EPA Method 8260B                                   | Quarterly for first year  | Monthly for first year                                  | Sampled in accordance with NPDES Permit           | Sampled in accordance with NPDES Permit | Sampled in accordance with NPDES Permit |
| Oxidant using a commercially available field test kit       | Monthly for first year  | Monthly for first year                                  | Monthly for first year                            | --                                      | --                                      |
| Dissolved hexavalent chromium by EPA Method 7196            | Quarterly for first year  | Monthly for first year                                  | Monthly for first year                            | Sampled in accordance with NPDES Permit | Sampled in accordance with NPDES Permit |
| TDS by Method SM 2540C                                      | Quarterly for first year  | Monthly for first year                                  | Monthly for first year                            | --                                      | --                                      |
| Chloride by EPA Method 300.0                                | Quarterly for first year  | Monthly for first year                                  | Monthly for first year                            | --                                      | --                                      |
| Dissolved total iron and manganese by EPA Method 6010B      | Quarterly for first year  | Monthly for first year                                  | Monthly for first year                            | --                                      | --                                      |
| Dissolved total chromium by EPA Method 6010B                | Quarterly for first year  | Monthly for first year                                  | Monthly for first year                            | Sampled in accordance with NPDES Permit | Sampled in accordance with NPDES Permit |

**Notes:**

- 1) 116A is planned to be converted into an SCRW to support the STC/Vishay shared remedy.
  - 2) If oxidant is observed in the sentry wells, then the sentry wells, the shared SCRWs, and 405 National SCRWs will be sampled for oxidant and hexavalent chromium.
  - 3) After the first year, the scope and frequency of monitoring will be evaluated and modified, as appropriate.
- cVOCs - chlorinated volatile organic compounds  
 EPA - United States Environmental Protection Agency  
 ORP - oxidation-reduction potential  
 SC - specific conductance

# FIGURES



**MEW Regional Study Area**

**401 National Avenue**

Mountain View

**Site Location Map**

**401 National Avenue  
Mountain View, California**

**Geosyntec**  
consultants

Figure

**1**



Basemap Sources: USGS, ESRI, TANA, AND, DeLorme, NPS

Oakland

November 2014



**Legend**

- Recovery Well
- ☒ Recovery Well (Inactive)
- Monitoring Well
- ▭ 401 National Avenue
- ==== Slurry Wall †

Notes:  
 † The slurry wall location in the north eastern portion of the site was revised based on information collected during 2013 utility location activities.  
 Aerial Source: USGS April 2011

50 25 0 50 Feet

**Site Plan Under Current Configuration**  
 401 National Avenue  
 Mountain View, California

**Geosyntec**  
 consultants

Figure  
**2**

Oakland      November 2014



Location of office building and parking structure provided by National Avenue Partners, LLC.

**Legend**

- Recovery Well
- ⊠ Recovery Well (Inactive)
- Monitoring Well
- ▨ Proposed Four Story Office Building
- ▨ Proposed One Level Aboveground Parking Structure
- ==== Slurry Wall †
- ▭ 401 National Avenue

**Notes:**

† The slurry wall location in the north eastern portion of the site was revised based on information collected during 2013 utility location activities.  
 Aerial Source: USGS April 2011



**Proposed Redevelopment Plans**

401 National Avenue  
 Mountain View, California

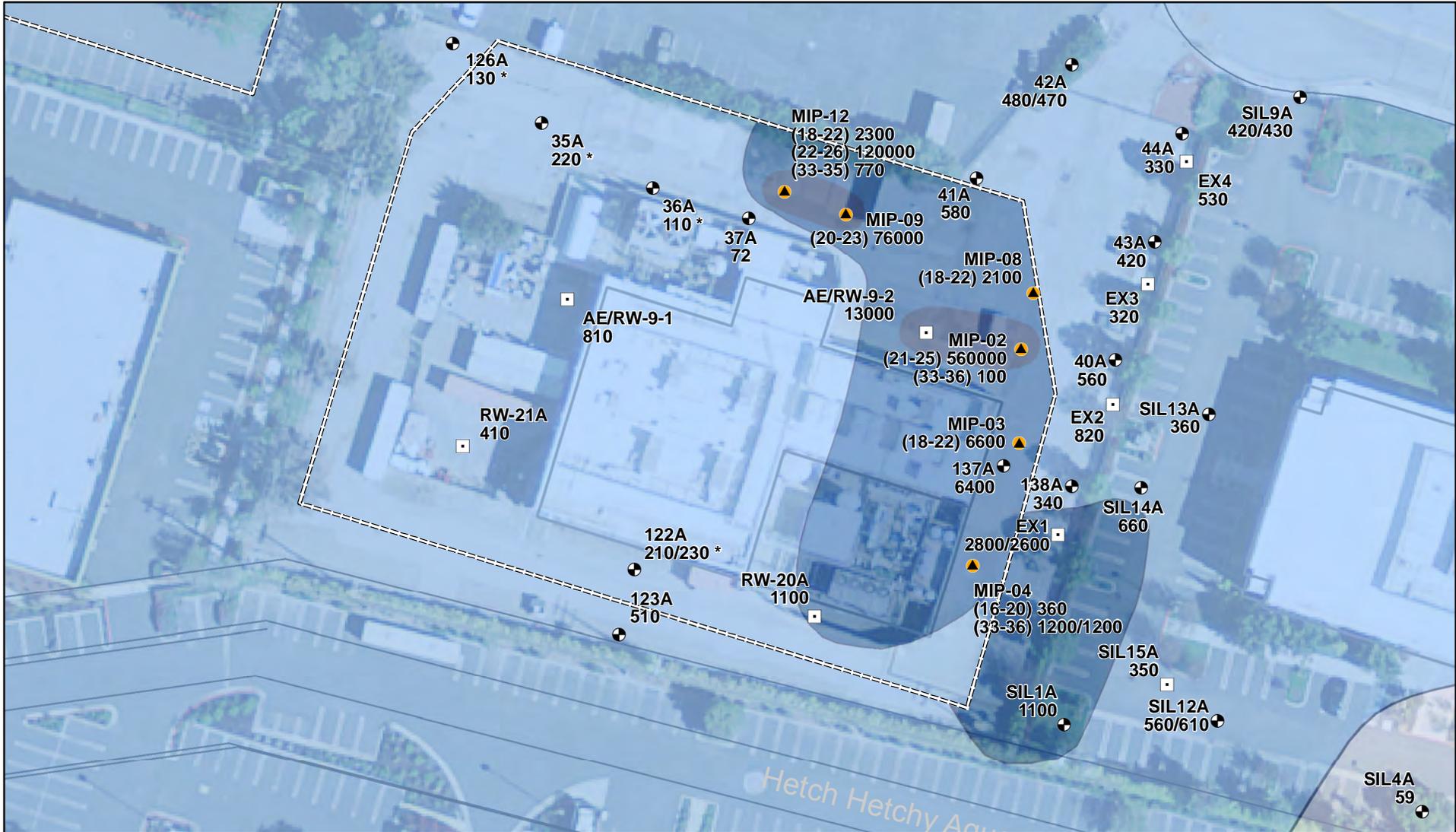


Figure

**3**

Oakland

November 2014



**Legend**

- MIP/SCP Boring Location
- Recovery Well
- Monitoring Well

MIP-12 (18-22) 2300  
 MIP ID (Sample Depth in ft bgs) TCE Concentration

Notes:  
 TCE = Trichloroethene ft bgs = Feet below ground surface  
 ug/L = micrograms per liter SCP = Soil Conductivity Probe  
 MIP = Membrane Interface Probe

\* Only wells sampled in 2012 or 2013 shown in Figure. Star indicates well last sampled in 2012.

† The slurry wall location in the northeastern portion of the site was revised based on information collected during 2013 utility location activities.

**TCE Concentration**

- 5 - 100 ug/L
- 100 - 1,000 ug/L
- 1,000 - 10,000 ug/L
- Greater than 10,000 ug/L

==== Slurry Wall †



30 15 0 30 Feet



**A-Zone TCE Concentrations**  
 401 National Avenue  
 Mountain View, California

**Geosyntec**  
 consultants

Figure

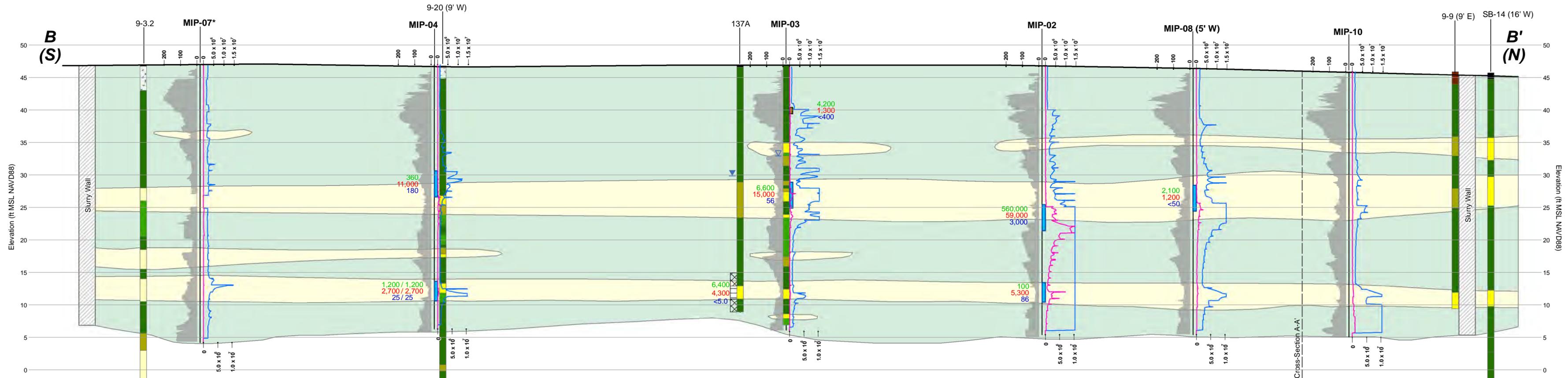
4

Oakland

November 2014







**LEGEND**

MIP Location with Distance and Direction Projected to Cross-Section

SCP response range in mS/M

September 2013 Sample Results

Trichloroethene Concentration [ug/Kg] 770

cis-1,2-Dichloroethene Concentration [ug/Kg] 2,400

Vinyl Chloride Concentration [ug/Kg] <50

Soil Sample

Filter Pack

Well Screen

September 2013 Sample Results

Trichloroethene Concentration [ug/L] 190

cis-1,2 Dichloroethene Concentration [ug/L] 120

<0.50 Vinyl Chloride Concentration [ug/L]

Groundwater Elevation (September 2013)

Groundwater Elevation During Drilling (September 2013)

September 2013 Sample Results

Trichloroethene Concentration [ug/L] 770

cis-1,2 Dichloroethene Concentration [ug/L] 2,400

Vinyl Chloride Concentration [ug/L] <50

Grab Groundwater Sample

PID response range in uV

Abbreviations:

- \* Indicates duplicate sample
- ft MSL = Feet above Mean Sea Level
- MIP = Membrane Interface Probe
- PID = Photoionization Detector
- ECD = Electron Capture Detector
- SCP = Soil Conductivity Probe
- mS/M = milliSiemens per meter
- uV = microvolts
- ug/Kg = micrograms per kilogram
- ug/L = micrograms per liter

**Notes:**

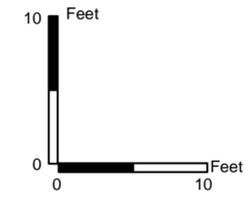
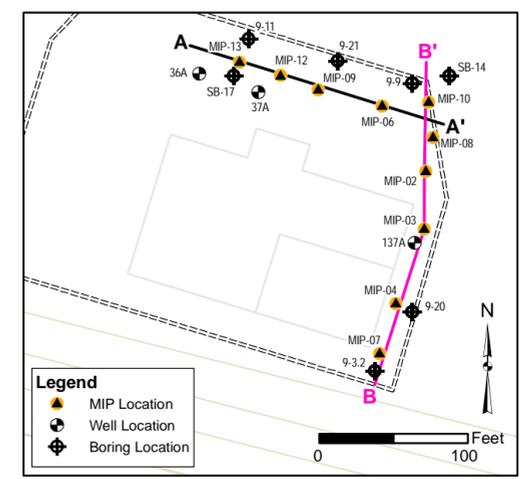
- Groundwater elevation for MIP-3 was measured on 3 September 2013, monitoring well groundwater measurements are from September 2013.
- Boring logs for Site monitoring wells and "9-#" borings were logged using ~12-inch soil samples collected approximately every 5 feet. Lithology interpretations between these samples were estimated on historical boring logs. "MIP" soil borings and SCP borings advanced in 2013 were logged continuously and are expected to be more representative of subsurface conditions.
- Slurry wall depth is approximate.
- Ground surface from topographic survey found in construction drawings provided by Kenneth Rodrigues and Partners, Inc., December, 2013.
- Slurry wall location adjusted 5 feet east on cross-section to include log for MIP-8 inside slurry wall.
- Data for MIP-07 is approximate due to a computer failure at 20 feet bgs. It is likely that no data was collected between 20 and 22 feet bgs.

**Soil Class**

- No Recovery
- Asphalt; Fill
- Sand and Gravel Fill Material
- Topsoil
- CL Clay
- ML Silt
- SC-SM Clayey Sand to Silty Sand
- SP-SW Poorly Graded Sand to Well Graded Sand
- SW-GW Well Graded Gravelly Sand to Well Graded Gravel

**Lithology**

- Generalized Fine-Grained Layer
- Generalized Coarse-Grained Layer



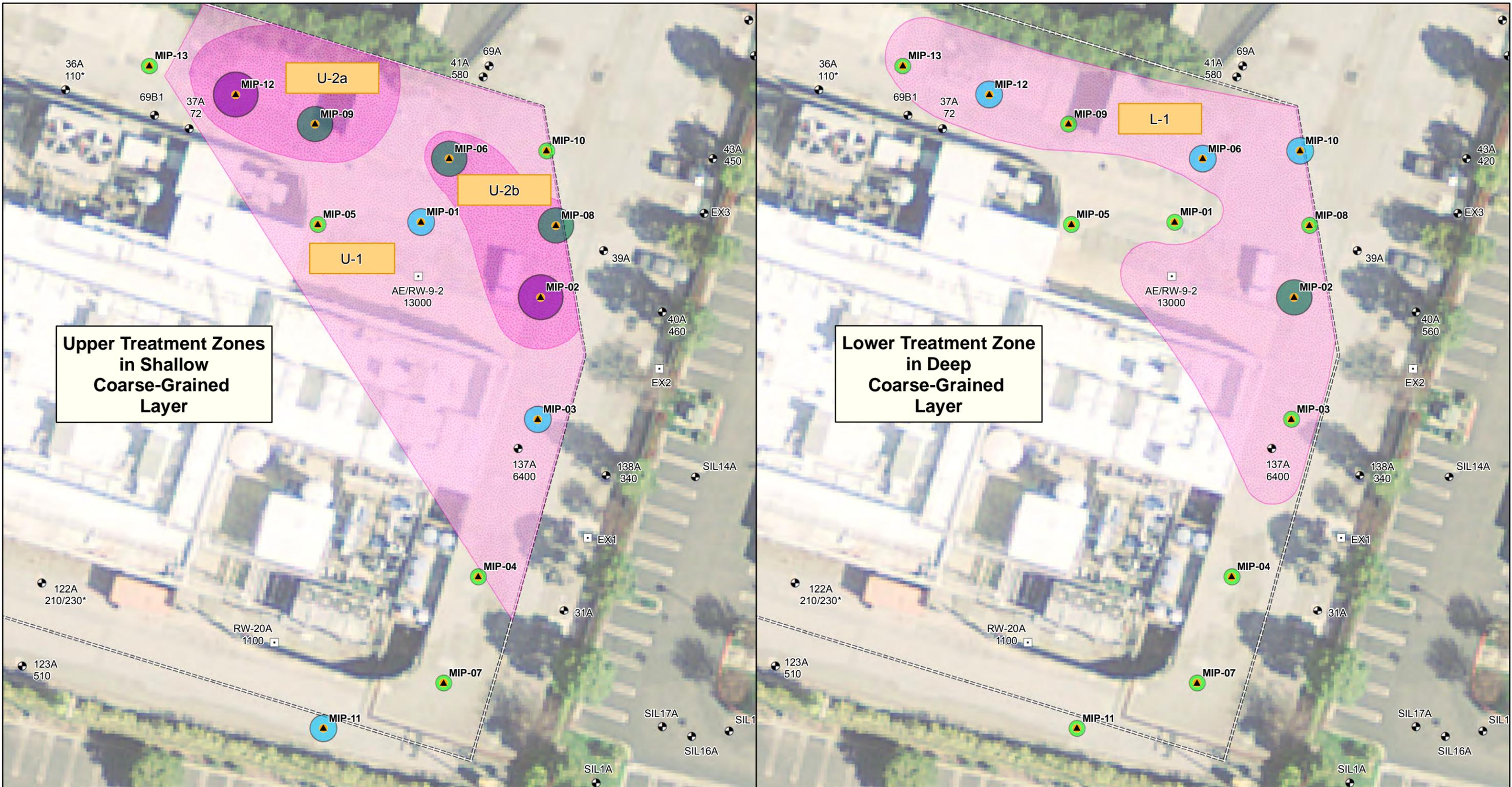
**Cross-Section B-B'**

401 National Avenue  
Mountain View, California

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consultants

Oakland November 2014

**Figure 7**



**Upper Treatment Zones in Shallow Coarse-Grained Layer**

**Lower Treatment Zone in Deep Coarse-Grained Layer**

**Legend**

- Recovery Well
- Monitoring Well
- 36A 110\* Well ID
- 36A 110\* TCE Concentration
- ▲ MIP Location (September 2013)
- Slurry Wall†
- Conceptual Treatment Zones

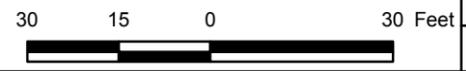
**Sum of PID Responses**

- 0.0 - 0.5E+08 μV
- 0.5E+08 - 1.0E+08 μV
- 1.0E+08 - 3.0E+08 μV
- >3E+08 μV

**Notes:**

- Colored halos represent the sum of PID response measurements from 14-31 ft bgs (left panel) and 31-40 ft bgs (right panel). PID responses are measured every 0.05 ft bgs during MIP advancement.
- \* Figure shows results for only those wells sampled in 2012 and 2013 for 401 National Avenue. Star indicates wells that were last sampled in 2012.
- † The slurry wall location in the north eastern portion of the site was revised based on information collected during 2013 utility location activities.
- Data for MIP-07 is approximate due to a computer failure at 20 ft bgs. It is likely that no data was collected between 20 and 22 ft bgs.

μV - microvolts  
 ug/L - micrograms per liter  
 ft bgs - feet below ground surface  
 MIP - membrane interface probe  
 PID - photoionization detector



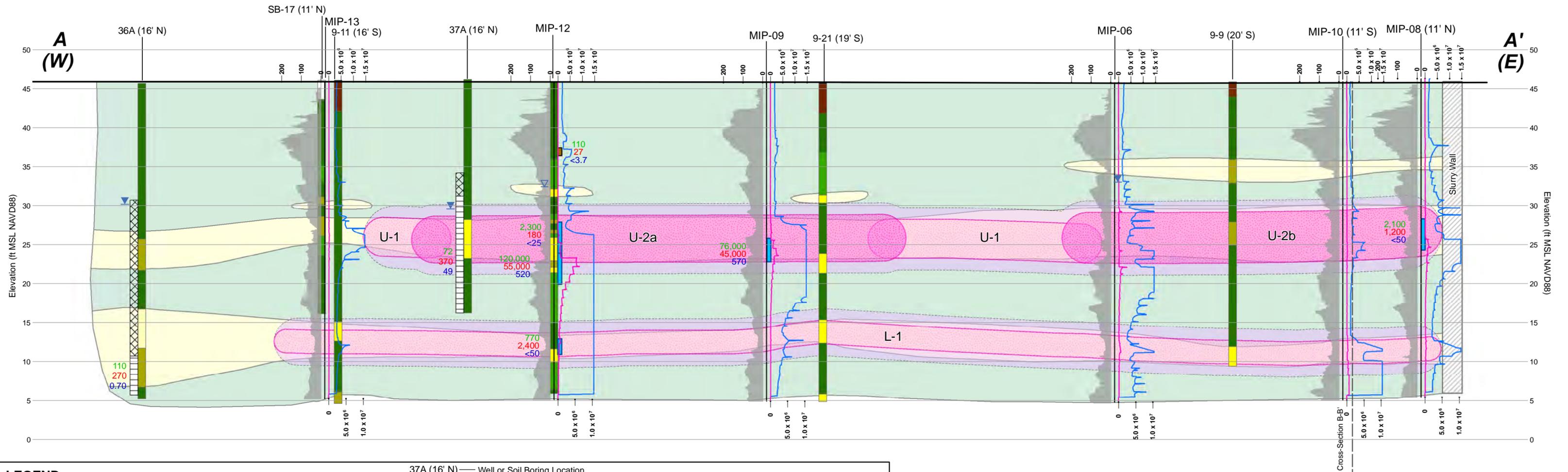
**Conceptual Treatment Zones  
Plan View**

401 National Avenue  
Mountain View, California

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**Figure  
8**



**LEGEND**

MIP Location with Distance and Direction Projected to Cross-Section

**MIP-01 (20' N)**

SCP response range in mS/M

September 2013 Sample Results

Trichloroethene Concentration [ug/Kg] 770

cis-1,2-Dichloroethene Concentration [ug/Kg] 2,400

Vinyl Chloride Concentration [ug/Kg] <50

Soil Sample

September 2013 Sample Results

Trichloroethene Concentration [ug/L] 770

cis-1,2-Dichloroethene Concentration [ug/L] 2,400

Vinyl Chloride Concentration [ug/L] <50

Grab Groundwater Sample

PID response range in uV

ECD response range in uV

Filter Pack

Well Screen

Groundwater Elevation (September 2013)

Groundwater Elevation During Drilling (September 2013)

Target Injection Zone

Potential Zone of Oxidant Influence

**37A (16' N)** — Well or Soil Boring Location with Distance and Direction Projected to Cross-Section

September 2012 and October 2013 Sample Results (see Note)

Trichloroethene Concentration [ug/L] 190

cis-1,2-Dichloroethene Concentration [ug/L] 120

Vinyl Chloride Concentration [ug/L] <0.50

**Soil Class**

- No Recovery
- Asphalt; Fill
- Sand and Gravel Fill Material
- Topsoil
- CL Clay
- ML Silt
- SC-SM Clayey Sand to Silty Sand
- SP-SW Poorly Graded Sand to Well Graded Sand
- SW-GW Well Graded Gravelly Sand to Well Graded Gravel

**Lithology**

- Generalized Fine-Grained Layer
- Generalized Coarse-Grained Layer

**Abbreviations:**

ft MSL = Feet above Mean Sea Level

MIP = Membrane Interface Probe

PID = Photoionization Detector

ECD = Electron Capture Detector

SCP = Soil Conductivity Probe

mS/M = milliSiemens per meter

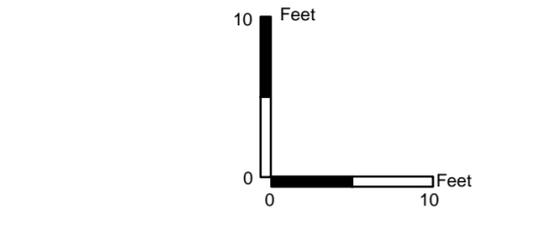
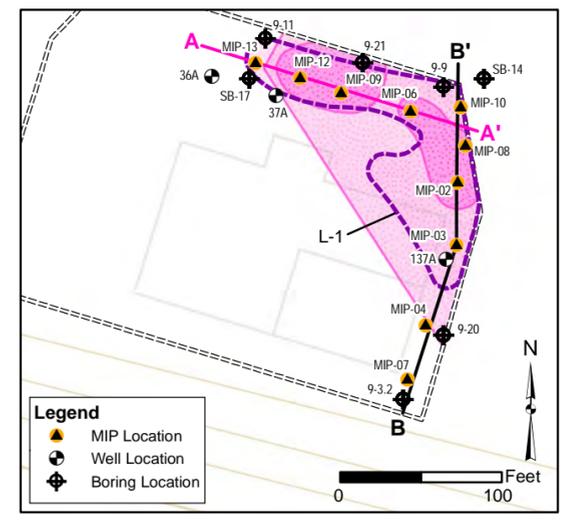
uV = microvolts

ug/Kg = micrograms per kilogram

ug/L = micrograms per liter

**Notes:**

- Groundwater elevation for MIP-12 was measured on 6 September 2013, monitoring well groundwater measurements are from September 2013.
- Monitoring wells 37A and 41A were sampled in October 2013. Monitoring well 36A was sampled in September 2013.
- Boring logs for Site monitoring wells and "9-#" borings were logged using ~12-inch soil samples collected approximately every 5 feet. Lithology interpretations between these samples were estimated on historical boring logs. "MIP" soil borings and SCP borings advanced in 2013 were logged continuously and are expected to be more representative of subsurface conditions.
- Slurry wall location adjusted 5 feet east on cross-section to include log for MIP-8 inside slurry wall.
- Ground surface from topographic survey found in construction drawings provided by Kenneth Rodrigues and Partners, Inc., December, 2013.



**Conceptual Treatment Zones - Cross-Section A-A'**

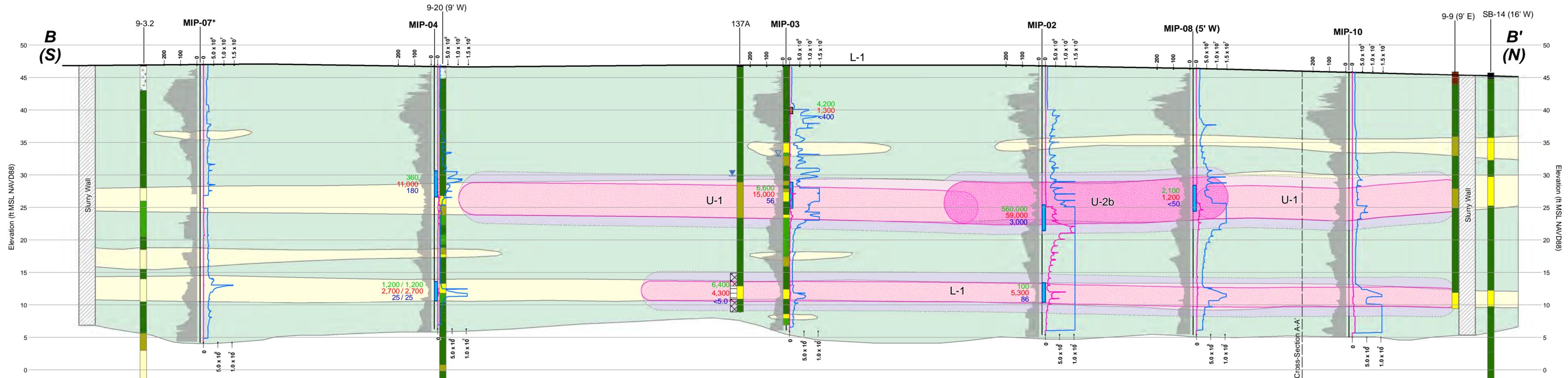
401 National Avenue  
Mountain View, California

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November 2014

**Figure 9**



**LEGEND**

MIP Location with Distance and Direction Projected to Cross-Section

SCP response range in mS/M

September 2013 Sample Results

- Trichloroethene Concentration [ug/Kg]: 770
- cis-1,2-Dichloroethene Concentration [ug/Kg]: 2,400
- Vinyl Chloride Concentration [ug/Kg]: <50

Soil Sample

September 2013 Sample Results

- Trichloroethene Concentration [ug/L]: 770
- cis-1,2-Dichloroethene Concentration [ug/L]: 2,400
- Vinyl Chloride Concentration [ug/L]: <50

Grab Groundwater Sample

September 2013 Sample Results

- Trichloroethene Concentration [ug/L]: 770
- cis-1,2-Dichloroethene Concentration [ug/L]: 2,400
- Vinyl Chloride Concentration [ug/L]: <50

Filter Pack

Well Screen

September 2013 Sample Results

- Trichloroethene Concentration [ug/L]: 190
- cis-1,2-Dichloroethene Concentration [ug/L]: 120
- Vinyl Chloride Concentration [ug/L]: <0.50

Groundwater Elevation (September 2013)

Groundwater Elevation During Drilling (September 2013)

Target Injection Zone

Potential Zone of Oxidant Influence

**Soil Class**

- No Recovery
- Asphalt; Fill
- Sand and Gravel Fill Material
- Topsoil
- CL Clay
- ML Silt
- SC-SM Clayey Sand to Silty Sand
- SP-SW Poorly Graded Sand to Well Graded Sand
- SW-GW Well Graded Gravelly Sand to Well Graded Gravel

**Lithology**

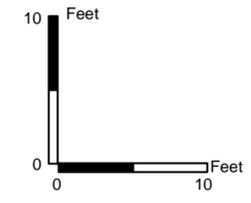
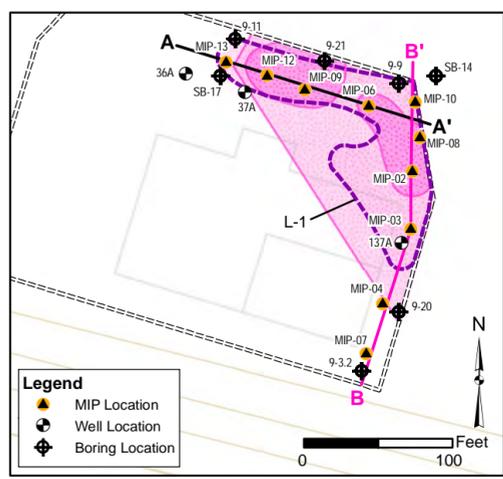
- Generalized Fine-Grained Layer
- Generalized Coarse-Grained Layer

**Abbreviations:**

- \* Indicates duplicate sample
- ft MSL = Feet above Mean Sea Level
- MIP = Membrane Interface Probe
- PID = Photoionization Detector
- ECD = Electron Capture Detector
- SCP = Soil Conductivity Probe
- mS/M = milliSiemens per meter
- uV = microvolts
- ug/Kg = micrograms per kilogram
- ug/L = micrograms per liter

**Notes:**

- Groundwater elevation for MIP-3 was measured on 3 September 2013, monitoring well groundwater measurements are from September 2013.
- Boring logs for Site monitoring wells and "9-#" borings were logged using ~12-inch soil samples collected approximately every 5 feet. Lithology interpretations between these samples were estimated on historical boring logs. "MIP" soil borings and SCP borings advanced in 2013 were logged continuously and are expected to be more representative of subsurface conditions.
- Slurry wall depth is approximate.
- Ground surface from topographic survey found in construction drawings provided by Kenneth Rodrigues and Partners, Inc., December, 2013.
- Slurry wall location adjusted 5 feet east on cross-section to include log for MIP-8 inside slurry wall.
- Data for MIP-07 is approximate due to a computer failure at 20 feet bgs. It is likely that no data was collected between 20 and 22 feet bgs.



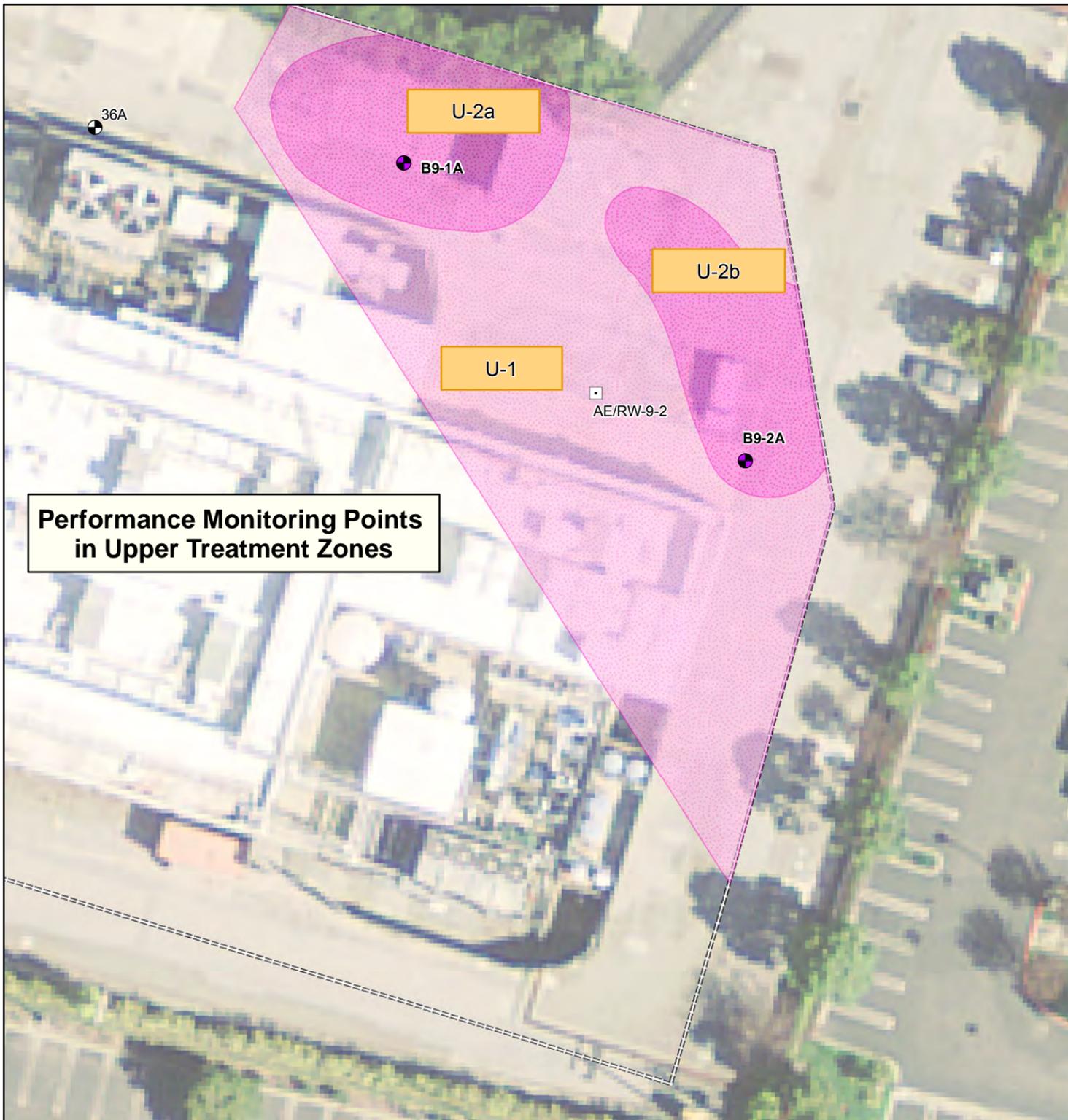
**Conceptual Treatment Zones - Cross-Section B-B'**

401 National Avenue  
Mountain View, California

**Geosyntec**  
consultants

Oakland      November 2014

**Figure 10**



**Performance Monitoring Points  
in Upper Treatment Zones**



**Performance Monitoring Points  
in Lower Treatment Zones**

**Legend**

- Proposed Temporary Pilot Study Monitoring Well
- Recovery Well
- Monitoring Well
- Slurry Wall†
- Conceptual Treatment Zones

**Notes:**  
 † The slurry wall location in the northeastern portion of the site was revised based on information collected during 2013 utility location activities.

**ISCO Pilot Study Performance Monitoring Points**  
 401 National Avenue  
 Mountain View, California

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**Figure  
11**



**Legend**

- Shared Remedy Recovery Well
- ◻● Vishay Recovery Well (Angled Recovery Well)
- Monitoring Well
- ==== Slurry Wall
- ▭ 401 National Avenue
- Approximate Location of Angled Well Screen
- Well Head Location

Notes:  
 \* Installation of an additional shared SCRW has been proposed at 116A.  
 Aerial Source: USGS April 2011

30 15 0 30 Feet

**Offsite Groundwater Quality Monitoring  
Sentry Wells**  
 401 National Avenue  
 Mountain View, California

**Geosyntec**  
 consultants

Figure  
**12**

Oakland      November 2014

APPENDIX A  
Response to EPA Comments on ISCO Pilot  
Study Work Plan

**Appendix A - Response to Comments**  
**Review of ISCO Pilot Study Implementation Work Plan**  
**401 National Avenue**  
**Mountain View, CA**

| Comment No.                  | Section Number, Section Title, Page Number      | Comment  | Response  |
|------------------------------|---|--|---|
| <b>EPA General Comments</b>  |   |  |   |
| 1                            | NA  | This work plan proposes to use in-situ chemical oxidation (ISCO) treatment at select areas and depths at the Site contaminated with high concentrations of chlorinated volatile organic compounds (CVOCs). The proposed approach is to use single high volume injections of sodium permanganate. EPA's recent experience at the MEW Site using ISCO, and also standard industry practice for this situation, at each location and depth multiple injection rounds of oxidant are typically needed to be effective, rather than a single large injection. The work plan needs to be revised to include additional follow-on ISCO injections prior to construction of the overlying building or a proposed method to deliver follow on injections after building construction, such as permanent injection wells completed below grade or via directional drilling   | The work plan has been revised to incorporate multiple ISCO events that will be implemented during the program. The scope of the revised injection program includes two injection events with the possibility of a third event compared to the original scope, which included one injection event with the possibility of a second event. The scope does not include post-construction injections as this is not feasible at this site.   |
| 2                            | NA  | EPA does not agree with the proposal in the work plan for keeping the groundwater extraction walls off within the slurry wall at the conclusion of the pilot study. At the conclusion of the pilot study, groundwater extraction and treatment within the slurry wall must be resumed.   | The work plan has been revised to reflect that at the conclusion of the pilot study, groundwater extraction and treatment from some or all of the wells located within the pilot study area will be resumed. The pilot study duration has been defined to include both the active oxidant injection phase of work, as well as the post-injection performance monitoring program. STC will work with EPA to review the monitoring results to identify the conclusion of the post-injection performance monitoring program.   |
| 3                            | NA  | Some extraction wells are proposed to be shut down during the ISCO pilot study, and others will continue operating. An assessment was provided in the work plan regarding the potential for the extraction wells on the exterior of the slurry wall to capture the injected oxidant. EPA acknowledges the significant effort put forth in the modeling work and the results are useful as a first cut analysis of potential contaminant transport outside the slurry wall. One conclusion in the assessment was that MnO <sub>4</sub> <sup>-</sup> (the dissociated permanganate ion) would be completely consumed inside the slurry wall by contaminants and naturally occurring organic matter and therefore would not reach extraction wells downgradient of the slurry wall. As the oxidant capture was not projected as part of the modeling work, the work plan needs to include monitoring of wells to confirm that the oxidant does not reach the extraction wells, as well as a contingency plan in the event that oxidant does in fact reach extraction wells. | The work plan has been revised to include the monitoring and contingency plans requested by EPA. The text in Sections 3.9, 4.4.5, and 4.5 has been updated with a proposed plan to monitor conditions outside the slurry wall and in close proximity to the off-site extraction wells during the pilot study. The objective of the monitoring plan is to identify potential impacts to groundwater quality from the oxidant injection program and assess whether the impacts could result in discharges from the 401/405 National treatment system exceeding limits specified in their NPDES permit. The work plan has been revised to include the contingency plan requested by EPA.   |
| 4                            | NA  | The work plan needs to include a contingency plan with steps to be implemented in the event permanganate is detected in the influent of the groundwater treatment system. The work plan states that a groundwater flow model was used to examine permanganate transport from the pilot study area. The results indicate that the permanganate would be consumed prior to reaching nearby extraction wells. However, the modeling effort could not take into consideration unknown preferential pathways associated with natural and man-made preferential pathways in the groundwater flow systems.  | The work plan has been revised to include the contingency plan requested by EPA. The contingency plan outlines actions to be taken if permanganate or hexavalent chromium are detected in the 401/405 National treatment system extraction wells at concentrations that indicate that NPDES discharge requirements could be exceeded. Details of the contingency plan are provided as Appendix D.   |
| 5                            | NA  | It is unclear to what extent the wells at the 401 National Ave property are screened across confining and/or semi-confining hydrogeological layers. Two wells 36A, 37A, and perhaps others, appear to be in this situation. Under ambient conditions, and especially under groundwater pumping conditions, groundwater can be transported from one unit to another through such well screens. This is especially true given the vertical groundwater flow such that high concentrations of CVOCs may be unintentionally dispersed from higher CVOC concentration zones into lower CVOC concentration zones. The work plan needs to include a technical assessment of this potential condition and potential impacts and include contingencies.   | The work plan has been revised to include a discussion of vertical connectivity within the A-Zone. Wells 36A and 37A are both screened in the A aquifer, which extends to approximately 40 feet below ground surface (bgs). It is important to note that fine grained layers within the A-Zone are thin, variable, and discontinuous across the site and are not considered to be aquitards. Therefore, it is not practical to consider preventing CVOC dispersion within the A-zone. The first encountered aquitard at the site is the fine grained unit that is encountered from approximately 36 to 45 feet below ground surface and separates the A-zone from the B1-zone. No wells at the site are screened into or through this aquitard. |
| <b>EPA Specific Comments</b> |   |  |   |
| 1                            | Section 2.3, Nature and Extent of CVOCs, page 5 | Include a summary of the recent CVOC data obtained from the membrane interface probe (MIP) investigation.  | Section 2.3 of the work plan has been revised to include a summary of CVOC data collected during the September 2013 data collection activities.   |

**Appendix A - Response to Comments**  
**Review of ISCO Pilot Study Implementation Work Plan**  
**401 National Avenue**  
**Mountain View, CA**

| Comment No. | Section Number, Section Title, Page Number                         | Comment   | Response   |
|-------------|--|---|--|
| 2           | Section 3.6, Oxidant Dosing, page 14                               | The pilot study phase proposes to inject 38,180 pounds of sodium permanganate applied over four zones and at various depths below ground surface (bgs); zone U-1, over the entire base of the study area (8,900 ft <sup>2</sup> ) at approximately 18-23 feet bgs; zone U-2a, over an approximately 2200 ft <sup>2</sup> area and at approximately 17-23 ft bgs; and, zone U-2b, over an approximately 1,900 ft <sup>2</sup> area at approximately 16.5-23 ft bgs. Vertically, the oxidant delivered into U-1 covers most of U-2a except for the 17-18 ft bgs interval, and most of U-2b except for the 16.5-18 ft bgs interval. The mass of soil and oxidant estimated and reported appears to be a double application of oxidant over areas U-2a and U-2b at the 18-23 ft bgs interval. Please clarify. | Zone U-1 is not inclusive of the entire base of the study area. As shown in Figure 8, the extent of the study area base in the upper zone is 13,000 square feet (ft <sup>2</sup> ) and includes the following: <ul style="list-style-type: none"> <li>• U-1: 8,900 ft<sup>2</sup></li> <li>• U-2a: 2,200 ft<sup>2</sup></li> <li>• U-2b: 1,900 ft<sup>2</sup></li> <li>• <b>Total: 13,000 ft<sup>2</sup></b></li> </ul> Because zone U-1 is not inclusive of the entire base of the pilot study, the ISCO application presented in Section 3.6 does not represent a double application of oxidant over areas U-2a and U-2b at the 18-23 ft bgs interval.   |
| 3a          | Section 3.7, Injection Rates and Radius of Influence, pages 14-15. | The work plan states that oxidant may be injected at up to 80 psi to achieve an oxidant injection rate of 3.5 gpm. This injection pressure is relatively high and may lead to hydraulic short-circuiting if preferential pathways are present. This elevated pressure may also cause preferential pathways to develop relative to using lower injection pressures. The work plan needs to incorporate an alternative approach to inject oxidant at more locations and at lower application pressures and rates.   | The work plan has been revised to include adjusted design parameters based on the following points that clarify our selection of design flow and pressure: <ol style="list-style-type: none"> <li>1) The anticipated flow rate per well has been reduced from 3.5 gpm to 3 gpm. The maximum pressure not to exceed has been reduced from 80 psi to 50 psi. Site-specific flow rates and pressures will be discussed with EPA during the initial stages of the pilot test utilizing potable water.</li> <li>2) The injection approach has been revised to use a combination of direct push point and injection wells to deliver oxidant to the subsurface, thereby improving the potential to achieve higher flow rates at lower pressures.</li> <li>3) The injection will be conducted over multiple events and over a longer timeframe than originally scoped (the original design was based on an available period to inject of one month, which has been extended to 3 months).</li> </ol> A site-specific injection test will be conducted before injection of reagent commences to determine appropriate and safe injection pressures per injection area and depth horizon to prevent hydraulic fracturing. |
| 3b          | Section 3.7, Injection Rates and Radius of Influence, pages 14-15  | The work plan proposes that the oxidant loading may need to be adjusted (i.e., injection rate and/or oxidant concentration) based on observed effects, such as daylighting, during actual field application. Higher concentrations of oxidant (>35 g/L) may result in long-term oxidant persistence in some areas. The maximum MnO <sub>4</sub> <sup>-</sup> concentration needs to be based on site-specific conditions. Since the long-term persistence of MnO <sub>4</sub> <sup>-</sup> impacts the timeframe in which the extraction wells are re-started (if needed), elevated [MnO <sub>4</sub> <sup>-</sup> ] needs to be scrutinized.   | As discussed in Section 3.6 of the work plan, site-specific loading and choice of oxidant will be based on the outcome of a bench-scale study before entering the field implementation stage. If any changes are made to the scope of work based on the bench-scale study results, EPA will be provided with an addendum to the work plan before site work is commenced. <p>In addition, the work plan has been revised to reflect that at the conclusion of the pilot study, groundwater extraction and treatment from some or all of the wells located within the pilot study area will be resumed.</p>  |
| 3c          | Section 3.7, Injection Rates and Radius of Influence, pages 14-15  | The work plan states that one or more of the source control recovery wells (SCRWs) located inside the slurry wall may need to be operated to limit increases in hydraulic head within the coarse grained layers. It is recommended that RW-21A be considered for this purpose due to the transport distance between this well location and the proposed ISCO pilot study area. Operation of wells inside the slurry wall is of significant importance considering that without pumping the water table may rise 4 to 5 feet within the slurry wall as described in the second paragraph on page 16.   | The work plan has been revised to include more information about how SCRWs will be used to manage groundwater levels during injections.  |
| 4           | Section 3.8, Permanganate Fate and Transport, page 17              | The work plan states that a groundwater flow model was used to examine MnO <sub>4</sub> <sup>-</sup> transport from the pilot study area. The results indicate that the MnO <sub>4</sub> <sup>-</sup> would be consumed prior to reaching nearby extraction wells. However, the modeling effort could not take into consideration unknown preferential pathways associated with natural and man-made preferential pathways in the groundwater flow systems. It is these preferential pathways that govern rapid oxidant fate and transport anomalies and unexpected oxidant breakthroughs are often reported  | As discussed in the response to General Comment 4, the work plan has been revised to include a contingency plan that would be implemented in the event that the oxidant is detected in the 401/405 National treatment system extraction wells.   |

**Appendix A - Response to Comments**  
**Review of ISCO Pilot Study Implementation Work Plan**  
**401 National Avenue**  
**Mountain View, CA**

| Comment No. | Section Number, Section Title, Page Number  | Comment   | Response   |
|-------------|---|---|--|
|             |   | with sodium permanganate ISCO. This is especially true given that the oxidant will be injected at multiple locations and depths, at elevated concentrations, under a broad range of pressurized conditions, and that extraction wells will be used to enhance transport direction. In recognition of these complexities, the work plan needs to include a contingency plan that outlines steps to be implemented in the event permanganate is detected in the influent of the groundwater treatment system.   |  |
| 5           | Section 3.9, Evaluation of Potential Secondary Water Quality Impacts, Groundwater Flow, page 18 | The work plan needs to include monitoring groundwater monitor wells adjacent to and outside of the slurry wall for the occurrence of oxidant. As stated in Specific Comment 4, the work plan needs to develop a contingency plan in the event that oxidant is discovered in downgradient extraction wells.  | As discussed in the response to General Comment 3, the work plan has been revised to include a plan for monitoring potential impacts to the off-site extraction wells.   |
| 6           | Section 3.9, Pilot Study Process and Performance Monitoring, page 18                            | The work plan needs to include a schedule for monitoring and groundwater sample collection.   | The work plan has been revised to include a groundwater monitoring schedule (Table 3). A reference to the schedule is provided in Section 4.5 of the text.   |
| 7           | Section 3.10, Estimated ISCO CVOC Mass Removal, page 19   | The work plan indicates that it was estimated that 50-90% of the oxidant mass could be consumed by non-target reactants (e.g., naturally occurring organic matter). However, the oxidant demand associated with non-target reactants diminishes with subsequent oxidant injection events. Reductions in the role of background oxidant demand and improvement in oxidation efficiency favors multiple oxidant injections especially in areas where CVOCs persist. This information should be reflected in the work plan.  | The work plan has been revised to include this information. In addition, data gathered during site injection events will also provide real-time direction on oxidation efficiency.   |
| 8           | Section 4.2, Performance Monitoring Network Installation, page 21                               | <p>Clarify the number of performance monitoring wells that would be installed. The five performance monitoring wells (three in the upper A aquifer zone; two in the lower B1 aquifer zone) in the work plan provide a limited number of monitoring points. However, there appears to be only four wells in this system since AE/RW-9-2 will be used in the upper A and the lower B1 Aquifer zones. It is unclear why 31A, 69B1, 36A, and 35A are not included in the monitoring network. Other wells located outside of the slurry wall (31A, 39A, 41A, 138A, etc.) should be monitored to provide insight to the areal influence of the injected oxidant. One additional monitoring well near existing wells 41A and 69A inside the slurry wall is needed to serve as a well pair to measure water levels and the extent of oxidant injections. In addition, the work plan needs to include additional monitoring at wells EX-1, EX-2, EX-3, EX-4, and well SIL15A at the adjacent 425 National Avenue property.</p> <p>All monitoring wells must remain unless and until EPA approves well decommissioning. The work plan needs to include construction details of these wells and modification to existing wells on the 401 National Avenue property including below grade completion in a vault for access after the parking garage is constructed. Access to all the monitoring and extraction well network and slurry wall infrastructure is needed post-development of the 401 National Avenue property.</p> | <p>The work plan has been revised to include this information. Text and a table (Table 2) have been added to Section 4.5 of the work plan to clarify which wells will be monitored as part of the performance monitoring program. Well 36A will be added to the performance monitoring program due to its proximity to the pilot study treatment area. Sentry wells have been added to the performance monitoring network to monitor conditions in the vicinity of nearby off-site extraction wells (see response to General Comment 3). Well construction details have been included in Table 2.</p> <p>It is important to note that the lower B1 aquifer zone is not present within the 40-foot deep slurry wall enclosure. The monitoring wells proposed in the work plan are (or will be) screened within the A-Zone, with the exception of monitoring well 69B1. Proposed performance monitoring wells are screened at different depths to monitor portions of the A-Zone with proportionally higher sand content. There is no documented continuous aquitard at the Site shallower than 40 feet bgs, although relatively continuous fine-grained lenses have been documented within the treatment area. Well 69B1 will be used to monitor the B1-Zone at the Site, which is separated from the A-Zone by a fine grained aquitard that is encountered from approximately 36 to 45 feet below ground surface.</p> <p>Wells not included in the ISCO pilot study performance monitoring program will be monitored during the 2015 annual sampling event for the MEW Study Area and would continue to be monitored on the schedule specified in the Fairchild O&amp;M plans and previous annual reports.</p> <p>During pilot study design, Geosyntec reviewed the possibility of installing an additional monitoring well inside the slurry wall, adjacent to 41A and 69A. Installation of a well in this area is infeasible due to the large number of closely spaced underground utilities in this portion of the site that will remain in place during redevelopment.</p> <p>STC will obtain EPA approval before decommissioning site monitoring wells. All wells will have flush mount well lids and will be protected during redevelopment activities. Ongoing site access is provided by an existing access agreement with the property owner.</p> |

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| 9           | Section 4.3.1, Ground Water Recovery System, page 22            | The work plan proposes that the SCRWs will be turned off prior to ISCO injections but may be pumped periodically to promote oxidant dispersal and to prevent hydraulic mounding. The pumped water would be stored in an on-site holding tank and used to supplement potable water used for ISCO injections. Turning off the extraction wells while injecting approximately 130,000 gallons (i.e., 38,180 pounds permanganate, 35 g/L) of permanganate solution within and adjacent to the slurry wall will likely have a significant impact on the water level inside the slurry wall. The work plan needs to use SCRWs within the treatment zone to proactively address concerns regarding potential groundwater mounding. RW-21A is a good candidate since it is located the furthest from the injection areas and contains the lowest CVOC concentration relative to other extraction wells.   | The work plan has been revised to include more information about how SCRWs will be used to manage groundwater levels during injections.   |
| 10          | Section 4.3.2, Materials Handling and Mixing, page 23.          | The work plan should consider the use of food grade ascorbic acid as a neutralizer of MnO <sub>4</sub> <sup>-</sup> . Ascorbic acid can be used to neutralize MnO <sub>4</sub> <sup>-</sup> present in groundwater samples given that significant background work has been performed indicating no negative impact to either the quality of the analytical sample being used to detect the presence or absence of MnO <sub>4</sub> <sup>-</sup> or the analytical instruments (Ko et al., 2012). Ascorbic acid can also be used to neutralize MnO <sub>4</sub> <sup>-</sup> resulting from oxidant daylighting or spills.   | The work plan has been revised to include the use of ascorbic acid as a preservative for sampling of cVOCs during the post injection performance monitoring phase and for cleanup of spilled liquid containing oxidant.   |
| 11          | Section 4.3.3, Injection Zone Sequencing, page 24.              | <p>The work plan proposes to inject into the deeper L-1 injection zone, followed by the shallower U-1, U-2a, and U-2b zones and this would limit mounding and the potential for downward migration. As per Figures 9 and 10, a 5-10 ft hydrogeological aquitard exists between the upper and lower zones to limit vertical transport. Alternatively, EPA recommends that a “top-down” injection method be used rather than the “bottom-up” injection method approach described in this section of the work plan. A top-down approach has less risk of oxidant short-circuiting and increased certainty that the oxidant is delivered to the targeted interval.</p> <p>There are two oxidant injection approaches used with direct push oxidant injection technology, (1) the top-down, and (2) the bottom-up. The top-down approach involves advancing the injection tip to the first depth interval, delivering the oxidant, driving to the next depth, and delivering the oxidant, etc. This sequence of events continues until the final targeted depth is achieved. Subsequently, the direct push rod and injection tip string is removed and the hole is sealed with an appropriate mixture of bentonite and cement. The bottom-up approach starts at the lowest injection interval elevation where oxidant injection is initiated. The drill string is moved upward to a shallower injection interval, and oxidant injection continues. This sequence of events continues until the final targeted depth is achieved. The main disadvantage of the bottom-up oxidant injection approach is there is significant potential for hydraulic short circuiting of the oxidant into the underlying collapsed geologic strata or open injection hole. Short circuiting is likely to occur downward since there is only a 3-4” segment of the injection tip separating the open hole below the injection tip from the injection interval on the injection tip. During injection, there is potential for porous media to collapse near the injection tip due to the injection of oxidant under injection pressure. Erosion of the porous media adjacent to the injection tip would allow short circuiting of oxidant between the injection interval and the open/collapsed hole below. During the top-down injection method, soil erosion due to injected fluids will not occur near the top end of the injection string (i.e., in the upward direction) since the direct-push hole is tightly sealed by the direct push assembly between the injection interval and the surface. This configuration results in less risk of oxidant short-circuiting and greater certainty that the oxidant is delivered to the targeted interval.</p> | The work plan has been revised to include a top-down methodology when using direct push to inject oxidant into the deep zone, L-1 and shallow zone, U-1.  |
| 12          | Section 4.3.3, 2 <sup>nd</sup> U-2 Injection Zones, page 25     | Clarify how 6-6.5 ft intervals will be targeted with 2 ft and 5 ft direct push injection tips.  | The work plan has been revised to include temporary injection wells and not direct push points for injection zones U-2a and U-2b. The target screen intervals for the installation of the temporary injection wells in zones U-2a and U-2b will be 5 feet and will be selected based on conditions observed during installation.  |
| 13          | Section 4.3.4, Water Level Monitoring During Injection, page 31 | The work plan estimates that if water levels are less than 5 feet from the ground surface, injection rates would be reduced and/or injections may be temporarily suspended. After long term injection, mounding may become an issue. If mounding is an issue and injection is suspended, in addition to the groundwater extraction discussed above, the work plans needs to include oxidant injection at other locations farther away from the injection point  | The work plan has been revised to include more information about how SCRWs will be used to manage groundwater levels during injections. Injection spacing is designed to limit mounding at the site. As discussed in the response to General Comment 3, the work plan has been revised to include a plan for monitoring potential impacts to the off-site extraction wells. Rather than |

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|                                     |  | where mounding may be limited. In addition to the three proposed pressure transducers, the work plan needs to include a pressure transducer in wells 138A, 39A, and 41A to monitor whether there is a hydraulic response outside the slurry walls.  | installing transducers, groundwater elevation data will be collected regularly as part of process monitoring.  |
| <b>14</b>                           | Section 4.3.6, Emergency Response Procedures, page 32                        | It was reported that specific reagents would be used to neutralize permanganate solution if it is spilled or released. The work plan needs food grade ascorbic acid for this purpose.   | The work plan has been revised to include the use of ascorbic acid as a preservative for sampling of CVOCs during the post injection performance monitoring phase and for cleanup of spilled liquid containing oxidant.  |
| <b>15</b>                           | Section 4.4.1, Baseline Sampling, page 32                                    | Include the performance monitoring well proposed by EPA (see Specific Comment 8, Section 4.2).  | As discussed in the response to Specific Comment 8, the installation of the proposed monitoring well is infeasible due to the large number of closely spaced underground utilities in this portion of the site that will remain in place during redevelopment.   |
| <b>16</b>                           | Section 4.4.2, Process Monitoring, page 32                                   | See Comment 8, Section 4.2. The work plan proposes to monitor electrical conductance in wells 31A, 39A, 41A, 138A, as an increase in conductance may indicate changes to geochemical conditions outside the slurry wall due to injection. The work plan also needs to include that these wells be monitored for MnO <sub>4</sub> <sup>-</sup> concentrations and oxidation- reduction potential (ORP). The presence of small concentrations of MnO <sub>4</sub> <sup>-</sup> can be visually determined (i.e., <10 mg/L) and could provide immediate early warning feedback regarding discharge from the containment system and MnO <sub>4</sub> <sup>-</sup> fate and transport within the slurry wall. In addition, these parameters must be included in the process monitoring network.<br><br>The work plan needs to consider using ascorbic acid as the permanganate neutralizing reagent given that significant background work indicates it has no negative impact to the quality of the sample or analytical instruments (Ko et al., 2012). | As discussed in the response to General Comment 3, the work plan has been revised to include a plan for monitoring potential impacts to the off-site extraction wells. As discussed in the response to Specific Comment 10, the work plan has been revised to include the use of ascorbic acid as a preservative for sampling of CVOCs during the post injection performance monitoring phase and for cleanup of spilled liquid containing oxidant.  |
| <b>17</b>                           | Section 4.4.2, Process Monitoring, page 33                                   | Identify the selected monitoring wells outside of the slurry walls. Daily monitoring may satisfy concern raised in Specific Comment 13, Section 4.3.4.  | As discussed in the response to General Comment 3, the work plan has been revised to include a plan for monitoring potential impacts to the off-site extraction wells  |
| <b>18</b>                           | Section 4.4.3, Performance Monitoring, page 35                               | Based on the frequency of monitoring, EPA interprets that the persistence of the oxidant is about two months. The work plan needs to specify monthly sampling until oxidant is exhausted and to provide additional plans for subsequent injections along with process and performance monitoring. Once EPA has determined that oxidant injections are no longer warranted and the oxidant has been exhausted, then the performance monitoring frequency can be reduced, as appropriate.   | The work plan has been revised to include monthly sampling for oxidant. The scope has been revised to include multiple injections within the ISCO pilot study treatment area that would be completed prior to construction of the parking structure. Additional injections following construction of the parking structure are infeasible and are not planned. Monthly sampling for the presence of oxidant will be conducted at the performance monitoring wells and sentry wells on a monthly basis. |
| <b>19</b>                           | Section 4.5, Temporary Performance Monitoring Well Destruction Plan, page 36 | The statement must be revised to state, "At the conclusion of the pilot study, Schlumberger will seek EPA approval to destroy the four temporary performance monitoring wells. EPA may approve well destruction or may require these wells to become part of the permanent monitoring network." No wells may be destroyed without EPA approval.   | The work plan has been revised to state "At the conclusion of the pilot study, STC will request EPA approval to destroy the temporary performance monitoring wells. If EPA approves the request for one or more of the wells, the wells would be destroyed by pressure grouting by a C-57 licensed drilling contractor in accordance with County, State and Federal requirements."   |
| <b>20</b>                           | Section 5, Criteria for Restarting Recovery Wells, page 38                   | EPA does not agree with the criteria proposed in this section for restarting source control recovery wells after completion of the pilot study. Revise this section to state that: "At the conclusion of the pilot study, groundwater extraction and treatment within the slurry walls will be resumed. Based on ongoing periodic performance monitoring results and with EPA approval of criteria for turning off SCRWs, individual SCRWs may be turned off, replaced or designated as regional groundwater recovery wells." The remaining text in Section 5 should be deleted.  | As discussed in the response to General Comment 2, the work plan has been revised to reflect that at the conclusion of the pilot study, groundwater extraction and treatment from some or all of the wells located within the pilot study area will be resumed.  |
| <b>EKI Technical Comments (2-5)</b> |  |   |  |
| <b>2</b>                            | NA   | Section 5 of the ISCO Work Plan provides criteria for restarting of the SCRWs after shutdown for the ISCO injections and treatment. Several of these restart criteria are unreasonably stringent, resulting in a low probability of resumption of the ROD-selected groundwater extraction remedy. Without ongoing groundwater extraction within the slurry wall, the adjacent and nearby properties are being put at risk of being adversely impacted by cVOCs. The restart criteria that EKI considers to be unreasonably  | As discussed in response to General Comment 2, the work plan has been revised to reflect that at the conclusion of the pilot study, groundwater extraction and treatment from some or all of the wells located within the pilot study area will be resumed.  |

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|             |  | <p>stringent, paraphrased in italics below, include:</p> <ul style="list-style-type: none"> <li>• <i>All listed conditions must be met at <u>all</u> wells.</i> This requirement provides no opportunity for resumption of the ROD-selected remedy in a situation where some or most restart conditions are met at some wells. There is no explanation offered in the ISCO Work Plan as to why less stringent conditions are not more appropriate or why they are not proposed.</li> <li>• <i>No residual oxidant can be detected at the analytical method's limit of detection.</i> The presence of oxidant after injection may indicate that the ISCO reaction is not complete; however, if the ISCO reaction is still ongoing when a performance monitoring sample is collected, the efficacy of that ongoing reaction should be evident through decreased concentrations of the target cVOCs. Because the underlying purpose of the ISCO treatment is a reduction in the mass (or concentration) of the target cVOCs, that should be the true measure of the treatment's ongoing efficacy. For this reason, requiring that no oxidant be present at the method detection limit is too stringent a criterion for restarting the SCRWs. If any criterion based on oxidant concentration is set, we suggest that it be based on a reasonable percent consumption metric (e.g., 99 percent consumption) rather than on analytical method detection limits. Given that the residual mass of oxidant in the treatment zone is generally proportional to the further cvoe mass treatment possible, setting the criteria on a reasonable percent consumption metric would ensure that (a) the majority of possible cVOC treatment for the ISCO injection event was achieved, and (b) resumption of the SCRWs per the ROD-selected remedy is not unduly delayed.</li> <li>• <i>TCE concentrations must be "higher than observed concentrations in upgradient monitoring wells (approximately 500 [micrograms per liter] µg/L)".</i> Although this criterion is consistent with the third condition in the Draft Supplemental FS under which USEPA once contemplated that inward and upward gradients might be waived (see Comment No. 1 above), that criterion was never adopted. Further, this criterion in the ISCO Work Plan does not specify which well(s) would be used to establish the reference "upgradient" concentration. The ISCO Work Plan should more clearly define "upgradient," specify which well(s) would be used for comparison with Site conditions, and provide a basis for the selection of those well(s). EKI's review of the existing well network in the vicinity of the Site (i.e., Figure 2 of the ISCO Work Plan) indicates that only a single well (i.e., well 123A) exists outside of the slurry wall to the south (upgradient). This single well is not sufficient to characterize "upgradient" groundwater conditions. Additional wells would therefore need to be installed upgradient of the Site to establish upgradient groundwater conditions and to provide a basis for comparison with the Site conditions. Furthermore, the approximate TCE concentration of 500 µg/L in groundwater mentioned in the criterion is 100 times greater than the cleanup standard established under the ROD (as amended by the ESD) of 5 µg/L (see Section 13.0 of the ROD). The TCE criterion proposed in the ISCO Work Plan (i.e., "approximately 500 µg/L") would effectively allow for permanent suspension of the ROD-selected remedy at concentrations 100 times greater than the cleanup standard. As such, the criterion poses a risk and potential cleanup burden to adjacent and off-Site properties where that de facto standard would not apply.</li> <li>• <i>Hexavalent chromium (Cr{VI}), a potential byproduct of the oxidizing conditions established during ISCO treatment, and total dissolved solids ("TDS") may not be present at levels that pose secondary water quality concerns for discharge from the groundwater treatment system (6 µg/L, and 1,000 milligrams per liter ("mg/L") for Cr{VI} and TDS, respectively).</i> Essentially, the ISCO Work Plan proposes that the presence of an adverse condition in groundwater (i.e.,</li> </ul> |          |

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|             |  | <p>Cr[VI] or excessive TDS), which may be created or exacerbated by the proposed ISCO treatment and which may make resumption of the ROD-selected groundwater extraction and treatment remedy more difficult, would justify delaying the resumption of that remedy. EKI disagrees with the logic behind this criterion, and suggests that USEPA require that appropriate mitigation measures for these secondary water quality impacts be incorporated into the ISCO Work Plan (e.g., treatment for Cr[VI] and TDS prior to discharge) and that extraction at the SCRWs be resumed.</p> <p>The proposed suspension of the ROD-selected remedy inherently puts neighboring properties at risk of additional groundwater impacts by allowing for outward and downward hydraulic gradients which could allow flow of contaminated groundwater out of the slurry-walled area to off-Site properties. Given that the groundwater extraction and treatment and associated groundwater cleanup standards established in the ROD will still apply to the Site during and after this ISCO "pilot study," the criteria for SCRW resumption should be framed in a manner such that the SCRWs will be restarted unless certain performance criteria that are protective of both on-Site and off-Site conditions are continuously met, to be demonstrated by post-treatment monitoring. Chief among the suggested performance criteria that we recommend be continuously met is that TCE concentrations inside the slurry wall are similar to or less than upgradient TCE concentrations as determined by a more extensive upgradient monitoring well network. Additionally, if performance monitoring data, data from groundwater monitoring wells in the vicinity of 401 and 405 National Avenue properties (both on-Site and off-Site), and off-Site treatment system influent data show that on-Site TCE concentrations are greater than off-Site downgradient TCE concentrations or greater than influent TCE concentrations in off-Site extraction well(s) whose capture zone(s) include the Site, the SCRWs should be restarted to avoid migration of cVOCs towards those off-Site properties or extraction wells.</p> |  |
| 3           | NA   | <p>Even if initial post-treatment monitoring suggests the ISCO treatment has temporarily lowered TCE concentrations in the relatively permeable zones into which injection occurs, high concentrations of TCE (e.g., MIP-02, which had 560,000 µg/L TCE as of 2013) will likely persist in the low permeability zones above and below the injected zones. Results from the MIP study and grab groundwater sampling presented on Figures 6 and 7 of the ISCO Work Plan show that some of the highest responses from the photo ionization detector ("PID"), indicating the highest cVOC concentrations, exist in the fine-grained material below the upper coarse-grained interval (see, for example, the PID traces in MIP boreholes MIP-02 and MIP-12). After ISCO treatment has removed mass from the coarse-grained injection intervals, residual mass in these fine-grained layers could back diffuse into the coarser intervals, resulting in post-treatment cVOC concentration rebound. USEPA recognized this in Section 3.1.1.1 of the Draft Supplemental FS which describes results from three ISCO pilot studies performed in the vicinity of the MEW Study Area. In summarizing these pilot studies, the Draft Supplemental FS concludes:</p> <p>Each of the oxidation pilot tests utilized a single oxidant injection event, with a general return to pre-injection concentrations several weeks following injection. This return to original concentrations (rebound) was likely due to a combination of matrix diffusion effects and/or migration of untreated upgradient groundwater into the treatments area. (Emphasis added.)</p> <p>Rebound of TCE concentrations following the ISCO treatment at the Site is therefore likely. For this reason, vigilant post-injection monitoring is necessary to identify TCE concentration rebounding if and when it occurs. The schedule for post-injection performance monitoring proposed in the ISCO Work</p>   | <p>The work plan has been revised to include a contingency plan to address the potential for oxidant to reach off-site extraction wells. The text in Sections 3.9, 4.4.5, and 4.5 has been updated with a proposed plan to monitor conditions outside the slurry wall and in close proximity to the off-site extraction wells during the pilot study. The objective of the monitoring plan is to identify potential impacts to groundwater quality from the oxidant injection program and assess whether the impacts could result in discharges from the 401/405 National treatment system exceeding limits specified in their NPDES permit. The contingency plan outlines actions to be taken if permanganate or hexavalent chromium are detected in the 401/405 National treatment system extraction wells at concentrations that indicate that NPDES discharge requirements could be exceeded. The work plan has been revised to include more information about how SCRWs will be used to manage groundwater levels during injections. Sentry wells have been added to the monitoring program to monitor conditions outside of the slurry wall and in the vicinity of the neighboring groundwater extraction wells. See responses to General Comment 3, Specific Comments 8, and Specific Comment 18.</p> |

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|             |  | <p>Plan is initially two months following injection and then annually thereafter (see Section 4.4.3 of the ISCO Work Plan). The proposed performance monitoring is too infrequent to adequately identify and protect against any rebound or adverse impacts from the ISCO injections, on-Site and off-Site, particularly if the SCRWs are shut down as proposed in the ISCO Work Plan. For example, TCE concentrations could rebound just after 2 months, but before 14 months. During that time, the SCRWs would not be operating, potentially allowing for groundwater outside of the slurry wall to be impacted with chemicals migrating off-Site due to the likely outward and downward gradients created by the ISCO treatment and shutdown of the SCRWs, as discussed above.</p> <p>EKI therefore recommends that performance monitoring be performed on a more frequent schedule that will provide sufficient data to ensure that any rebound in cVOC concentrations are promptly addressed. In addition, off-Site conditions, particularly in EX-1, EX-2, EX-3, EX-4 and SIL15A at the former 405 National Avenue Property, should be evaluated to identify potential adverse impacts from shutdown of the SCRWs at the Site. Such monitoring is especially critical once ISCO process monitoring indicates nearly full depletion of the injected oxidant, as that is when rebound in TCE concentrations would be expected to begin.</p> <p>Furthermore, the ISCO Work Plan is not clear as to the future scope and schedule of groundwater monitoring activities in the existing monitoring wells; it only mentions the proposed monitoring of the five "performance monitoring wells". The locations of those five wells (shown on Figure 11 of the ISCO Work Plan) are not conducive to detecting potential impacts to off-site areas, including the nearby extraction wells (EX-1 through EX-4 and SIL15A) that extract groundwater under the former 405 National Avenue property. It is therefore important that monitoring of the existing monitoring well network continue during and after the ISCO pilot test. In addition, if monitoring data from the performance monitoring wells indicates that Cr[VI] has been generated at the Site, then analyses for Cr[VI] should also be included for sampling performed in the wells located outside and adjacent to the slurry wall, in particular, in the extraction wells EX-1 through EX-4 and SIL15A.</p> |   |
| 4           | NA   | <p>As discussed above, the ROD-selected remedy is groundwater extraction and treatment, with a requirement to protect off-Site areas by the maintenance of inward and upward hydraulic gradients into the slurry-walled area. The proposed ISCO "pilot study" includes the suspension of groundwater extraction that will diminish, and likely reverse, those gradients (see further discussion of potential hydraulic impacts of ISCO treatment in Comment No. 5 below). The ISCO "pilot study" therefore poses an inherent risk to adjacent and other off-Site properties due to, at a minimum, temporary creation of outward and downward gradients that could result in TCE and ISCO by-products (e.g., Cr[VI]) migrating into groundwater off-Site. Appropriate mitigation measures should be identified, evaluated and included in the ISCO Work Plan. This will allow for prompt implementation of the mitigation measure(s) at such time as on-Site and/or off-Site performance monitoring indicates the development of adverse groundwater quality conditions that could detrimentally impact off-Site areas. At a minimum, mitigation measures should include prompt resumption of pumping from the SCRWs (see Comments No. 1 and 2 above).</p>  | <p>As discussed above, the work plan has been revised to include a contingency plan to address the potential for oxidant to reach off-site extraction wells. The text in Sections 3.9, 4.4.5, and 4.5 has been updated with a proposed plan to monitor conditions outside the slurry wall and in close proximity to the off-site extraction wells during the pilot study. The objective of the monitoring plan is to identify potential impacts to groundwater quality from the oxidant injection program and assess whether the impacts could result in discharges from the 401/405 National treatment system exceeding limits specified in their NPDES permit. The contingency plan outlines actions to be taken if permanganate or hexavalent chromium are detected in the 401/405 National treatment system extraction wells at concentrations that indicate that NPDES discharge requirements could be exceeded. The work plan has been revised to include more information about how SCRWs will be used to manage groundwater levels during injections.</p> |
| 5           | NA   | <p>The numerical groundwater flow and permanganate fate and transport modeling study described in Appendix B of the ISCO Work Plan is based on several non-conservative and, in some cases, inappropriate, assumptions. As a consequence, the reported results cannot be relied upon to demonstrate a low risk of impact to off-Site properties. The non-conservative and/or inappropriate assumptions used in the modeling study include the following:</p>   | <p>The model was used as a tool during development of the Work Plan to assess the order-of-magnitude of the expected groundwater flow with the slurry wall SCRWs shut down and to assess potential permanganate transport outside of the slurry wall. The model results are informative and were used to support the design approach. However the limitations and uncertainties related to the model results are acknowledged and the monitoring program was developed accordingly. See</p>   |

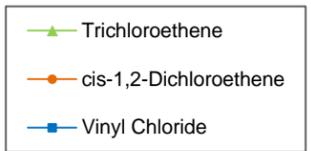
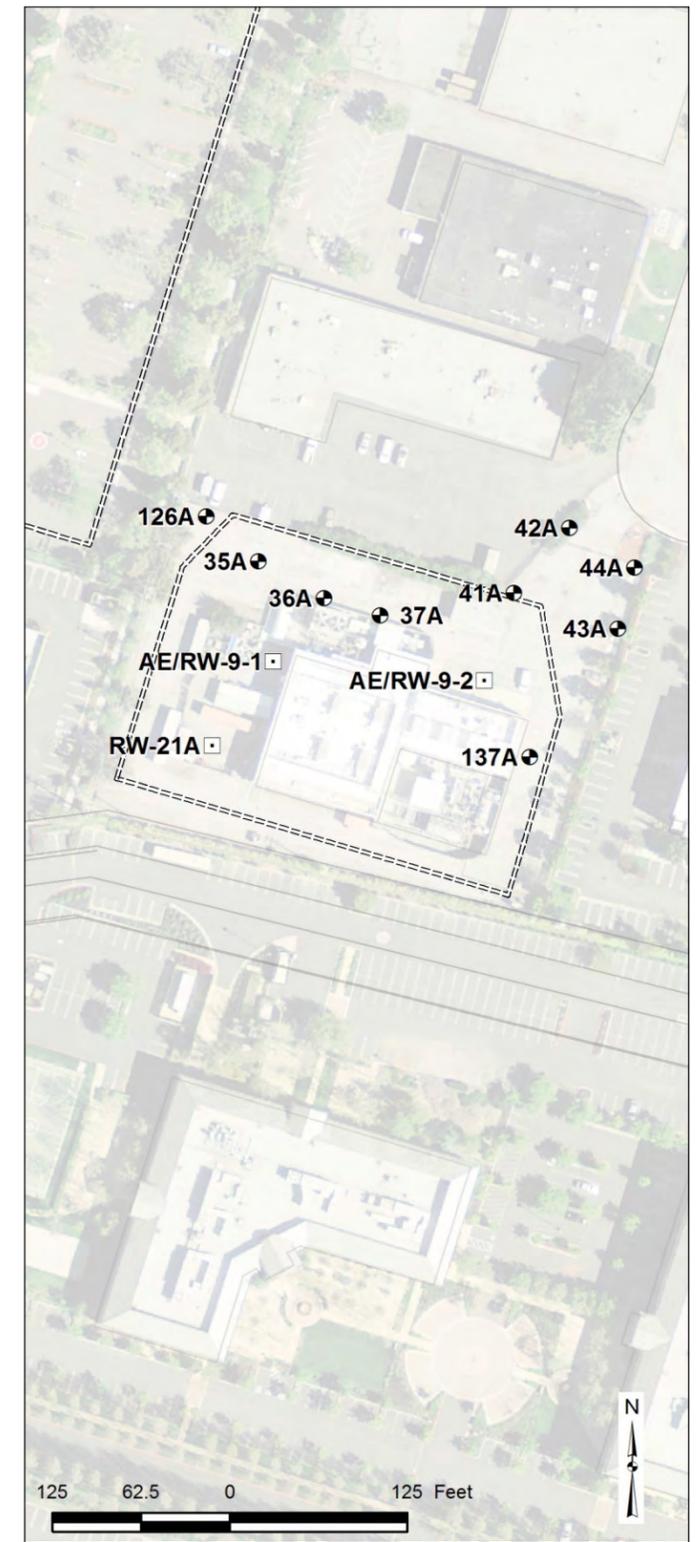
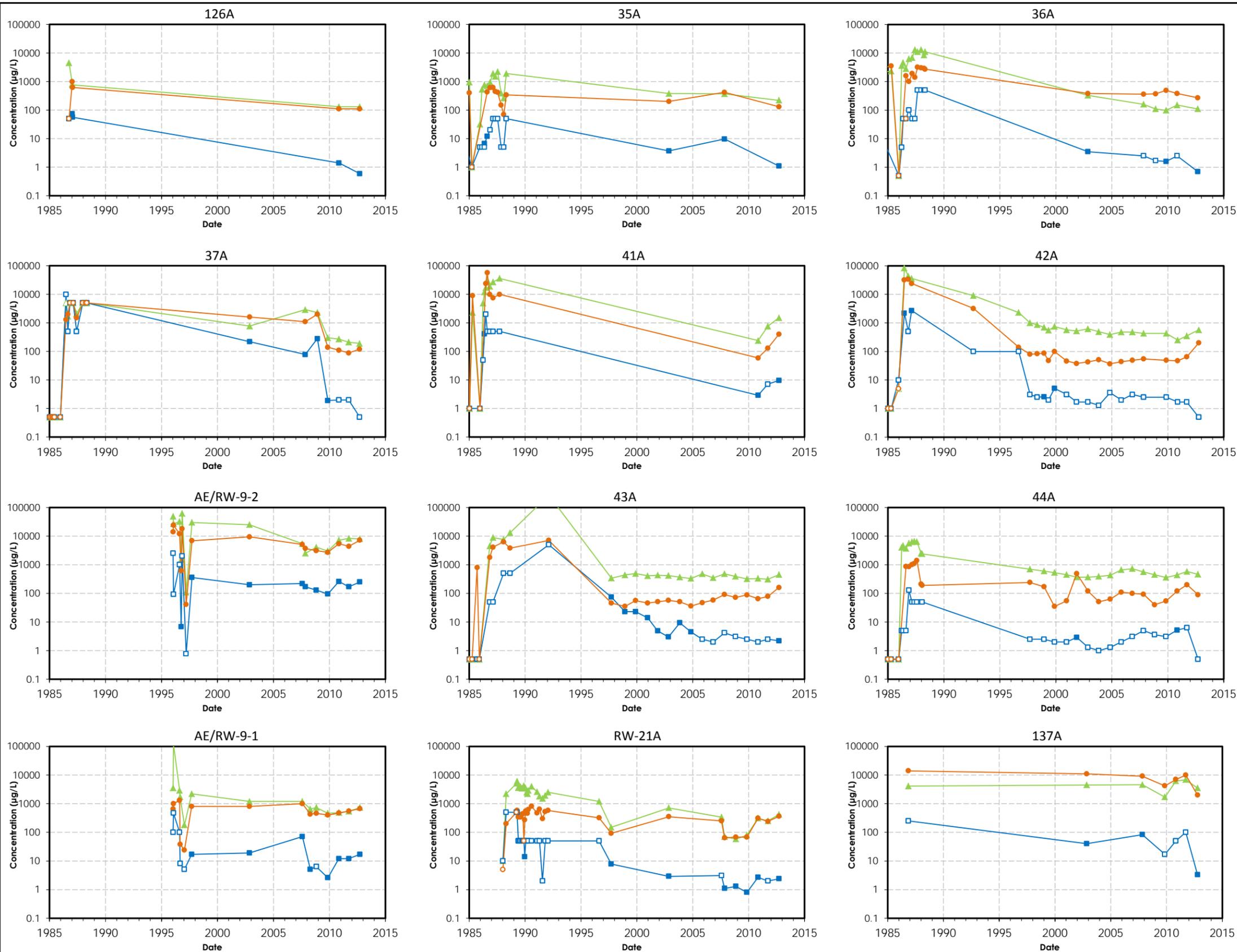
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|             |  | <ul style="list-style-type: none"> <li>• The model simulation assumes steady state conditions with SCRWs turned off, but does not account for the potentially significant temporary increase in hydraulic head (i.e., mounding) due to injection of the oxidant solution itself. As discussed above, a total volume of approximately 110,000 gallons of oxidant solution will be injected per the ISCO Work Plan. The injection intervals are described in the ISCO Work Plan as being generally confined (see Section 2.2 of the ISCO Work Plan). As such, the storage coefficient of these intervals is likely much lower than if the intervals were unconfined (e.g., Freeze and Cherry, 1979, page 61).<sup>13</sup> The low storage coefficients associated with confined aquifers could result in substantial increase in head within the slurry wall during injection. The Appendix B modeling study indicates an inflow and outflow rate through the basal fine-grained unit of 0.7 gpm. Based on the area within the slurry wall (approximately 58,000 square feet) and the estimated vertical hydraulic conductivity of the basal unit (0.1 feet per day; see Section 1.3.3 of Appendix B), and assuming half of the total basal area is inflow and half is outflow, the implied vertical gradient driving the outflow is approximately 0.046 feet per foot. Potentiometric head contour lines shown on Figure B-3 of the Appendix indicate a total head difference of approximately 0.3 ft over the basal unit in the outflow area.</li> <li>• Given the potential for several feet or more of injection-induced mounding, the vertical gradients over the basal unit could be much greater than the simulation suggests, and therefore outflow of oxidant and/or contaminants could be much greater. If the outflow rate is 0.7 gpm as stated in Appendix B, the oxidant volume added within the slurry wall would take approximately 109 days to dissipate, suggesting that elevated heads could persist within the slurry wall for an extended period of time. Because the model is steady-state and does not consider the hydraulic effects of mounding, it is therefore non-conservative in its estimate of potential off-site migration of oxidant or Site contaminants which could cause detrimental impacts to adjacent and nearby properties.</li> <li>• Section 1.5 of Appendix B of the ISCO Work Plan describes the results of the steady-state model calibration, and includes a table of simulated versus observed heads. The table shows that the model generally under-predicts the hydraulic head within the slurry wall (i.e., the average residual [observed head minus simulated head] is approximately 0.7 ft). In other words, even after calibration, the model predicts lower heads within the slurry wall than are actually observed. This calibration issue suggests that when the model is used in a predictive mode to simulate oxidant transport, the simulated outflow is less than what would actually be expected to occur. The calibrated model therefore is non-conservative in its estimate of potential off-site migration of oxidant or Site contaminants. Furthermore, it is unclear how the model was calibrated (i.e., which parameters were adjusted), as the Appendix B describes a method to estimate the hydraulic conductivity of each cell based on interpolated sand fraction (see Section 1.3.3 of Appendix B) and does not indicate whether these estimated values are pre-or post-calibration.</li> <li>• As described in Section 1.3.2 of Appendix B of the ISCO Work Plan, the slurry wall is represented in the model with the HFB package and extends down to a depth of 50 ft bgs. This is also shown on Figure B-3 of the Appendix. However, the slurry wall at the Site extends only to 40 ft bgs (see Section 2.1 of the ISCO Work Plan). By simulating a deeper slurry wall, the model is over-estimating the amount of containment provided by the slurry wall, and is therefore again non-conservative in its estimate of potential off-site migration of oxidant or Site</li> </ul> | <p>responses to General Comment 3, and the related Specific Comments which summarize the revised monitoring program. Responses to specific concerns raised related to the modeling are summarized below.</p> <ul style="list-style-type: none"> <li>• <b>Response to bullets 1 and 2:</b> The model was developed to assess groundwater flow under steady-state conditions with SCRWs turned off, and was not developed nor used to assess groundwater flow during injections inside the slurry wall. This assessment was not part of the modeling scope developed for this work plan and we agree that the modeling results do not apply to injection periods and potential mounding conditions. Mitigation measures to limit mounding at the site during injections are in place (i.e., operation of selected slurry wall SCRWs during injections) and are described in Section 4.4.5 of the Work Plan and further addressed in response to Specific Comment 8. The hydraulic conductivity of the basal unit varies between 0.8 and 0.02 ft/d and is based on the sand fraction vs. hydraulic conductivity relationship (see Section 1.3.3 of Appendix C). The simulated vertical hydraulic gradient across the basal unit varies accordingly, and the value of 0.3 ft shown on Figure B-3 is only representative of a small area of the site.</li> <li>• <b>Response to bullet 3:</b> The calibration at the regional scale was performed by adjusting the sand fraction vs. hydraulic conductivity relationship (see Section 1.3.3 of Appendix C) until a satisfying fit was obtained between simulated and observed heads. The same relationship was applied for the site model without further calibration. As a result, the heads inside the slurry wall are both higher and lower than observed heads. The average simulated head in the A-zone inside the slurry wall is 28.23 feet above mean sea level, which is higher than the average observed head inside the slurry wall (28.06 ft msl). Further, the simulated head in B1-zone below the slurry wall (at 69B1) is lower than the observed head; therefore the vertical gradient is not under-predicted on average with the model.</li> <li>• <b>Response to bullet 4:</b> The depth of the slurry wall was defined to be consistent with the MEW Study Area regional groundwater flow model. The regional model has a coarser vertical discretization, resulting in the slurry wall being defined deeper than the actual depth. This difference does not affect the results significantly.</li> <li>• <b>Response to bullet 5:</b> The numerical model was developed based on the MEW Study Area regional groundwater flow model. The hydraulic conductivity value used for the slurry wall (0.001 ft/d) was based on previously used value for the MEW Study Area regional groundwater flow model (Geosyntec, 2008). This value already results in no flow across the slurry wall, therefore using a lower value of 0.0001 ft/d would provide the same results.</li> </ul> |

**Appendix A - Response to Comments**  
**Review of ISCO Pilot Study Implementation Work Plan**  
**401 National Avenue**  
**Mountain View, CA**

| Comment No. | Section Number, Section Title, Page Number | Comment  | Response |
|-------------|--|--|----------|
|             |  | <p>contaminants. We note that this deeper simulated slurry wall may also have affected the model calibration, rendering the conclusions of the modeling study unreliable.</p> <ul style="list-style-type: none"> <li>• As described in Section 1.3.2 of Appendix B of the ISCO Work Plan, the hydraulic conductivity value used for the slurry wall is 0.001 feet per day. This value is an order of magnitude higher than the value (i.e., <math>1.1 \times 10^{-4}</math> feet per day) presented in Section 2.1 of the ISCO Work Plan which the ISCO Work Plan states was based on post-construction quality control testing. Although this discrepancy may not significant affect the simulated flow field, we suggest it be corrected (if a typographical error) or otherwise addressed.</li> </ul> |          |

**APPENDIX B**  
**VOC Concentrations vs. Time Graphs**



**Note:**  
Open symbols are non-detects,  
presented at limit of quantification

35A ● Monitoring Well  
RW-21A ◻ Extraction Well (On)

**VOCs vs. Time Graphs**

401 National Avenue  
Mountain View, California

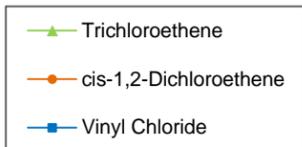
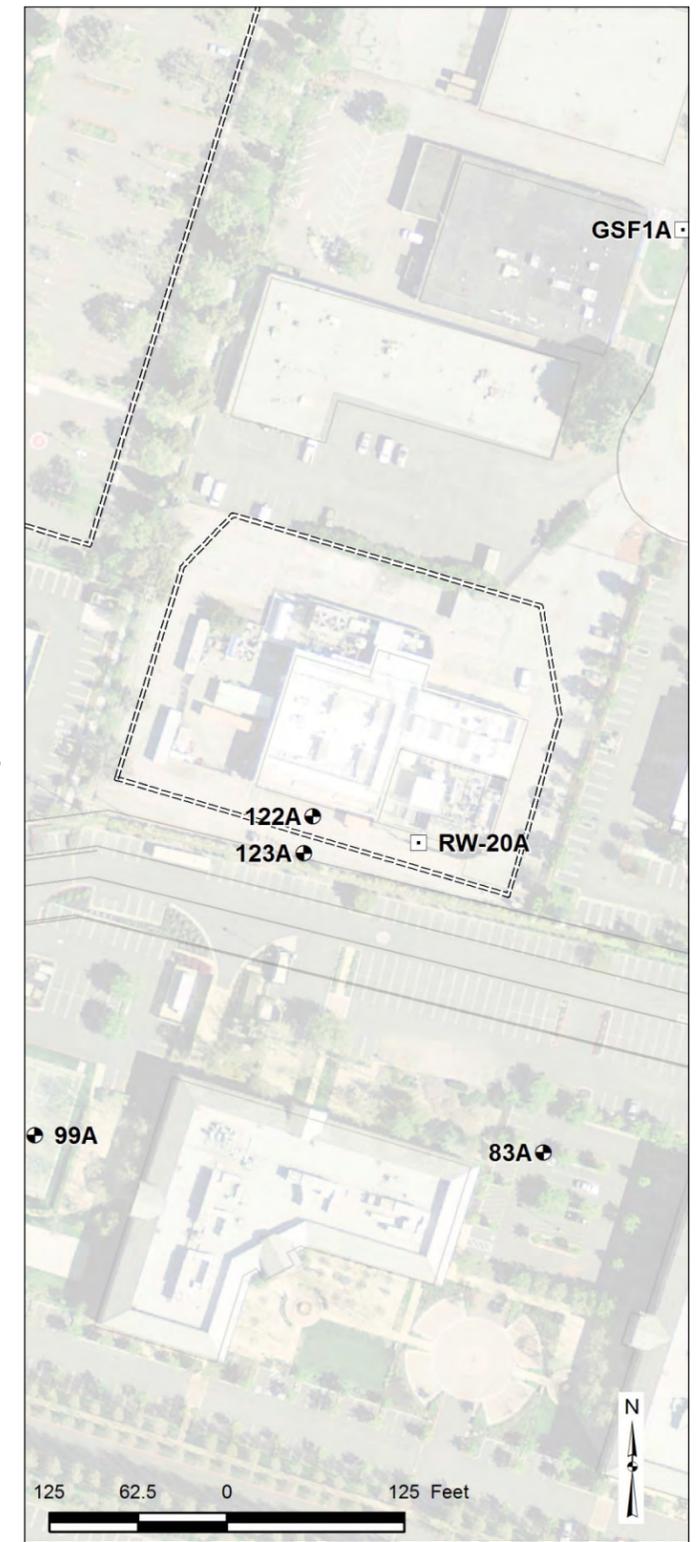
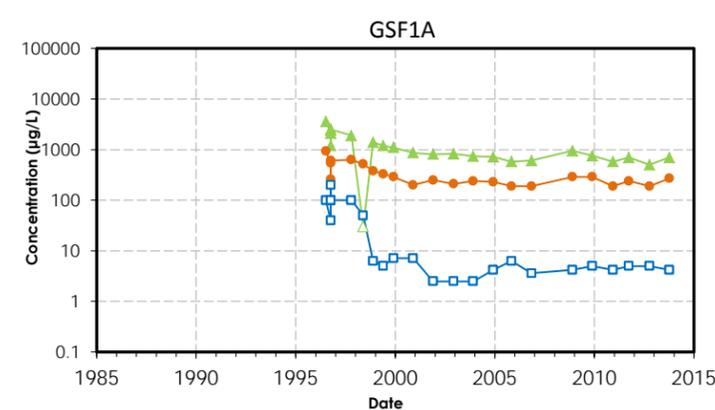
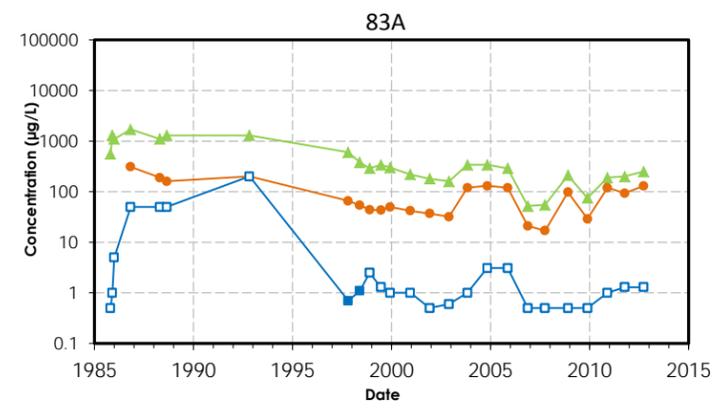
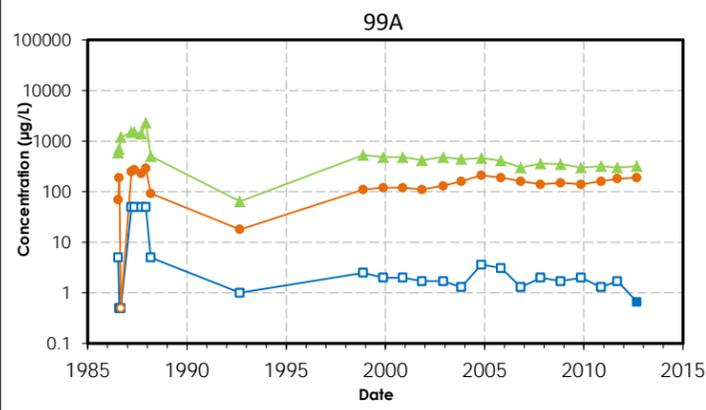
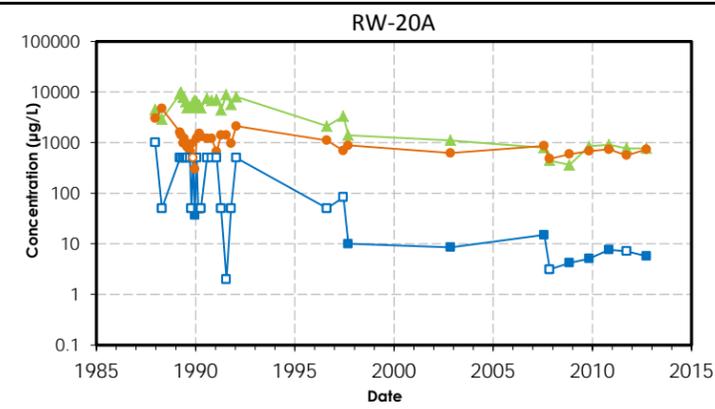
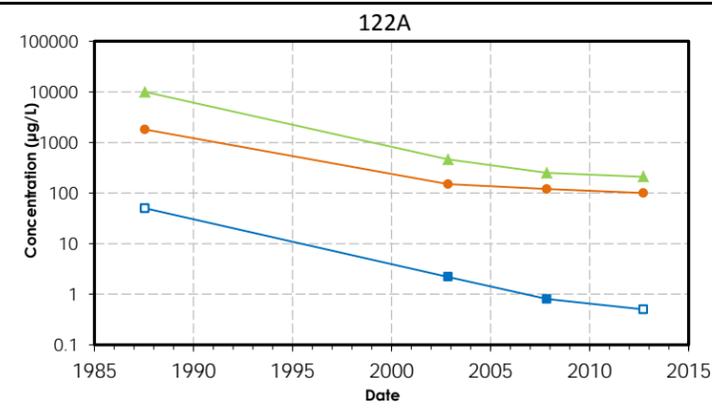
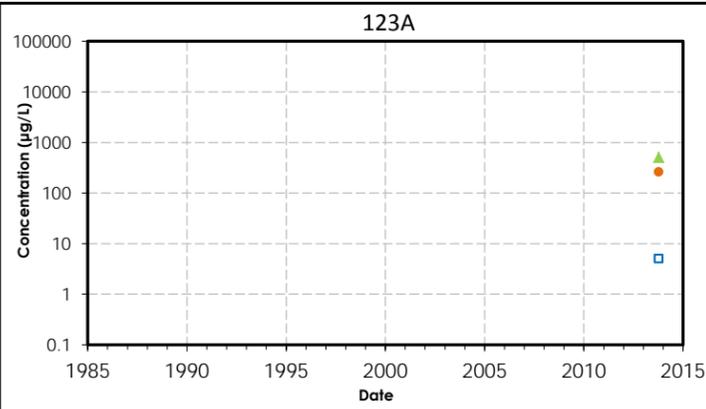


Oakland

November 2014

Figure

**B-1**



**Note:**  
Open symbols are non-detects,  
presented at limit of quantification

35A ● Monitoring Well  
RW-21A □ Extraction Well (On)

**VOCs vs. Time Graphs**

401 National Avenue  
Mountain View, California



Oakland

November 2014

Figure  
**B-2**

**APPENDIX C**  
**Numerical Model Supporting Information**

## **APPENDIX C – Numerical Flow and Transport Model**

The scope of work described in the Work Plan for In Situ Chemical Oxidation (ISCO) Pilot Study (Work Plan) includes injection of permanganate and shutdown of the on-site recovery wells located within the former Building 9 slurry wall (the Site). Because there are recovery wells operating adjacent to the Site, numerical modeling was performed to assess the potential for permanganate to reach the off-site recovery wells following implementation of the Pilot Study.

This assessment was performed by: (i) developing a numerical groundwater flow model of the Site; (ii) assessing the groundwater flow field after shutdown of the on-site recovery wells within the former Building 9 slurry wall; and (iii) assessing potential fate and transport of residual permanganate following injections.

### **1. NUMERICAL GROUNDWATER FLOW MODEL**

#### **1.1 Numerical Model Domain, Grid, and Layers**

The three-dimensional model for flow and transport was developed using MODFLOW and RT3D (for chemical transport analysis), industry standard finite-difference codes. Groundwater flow in the model was assumed to be steady-state.

The domain of the numerical model used at the Site is based on the Middlefield-Ellis-Whisman (MEW) regional groundwater flow model (Geosyntec, 2008). The model domain and the Site location are shown in Figure C-1.

The numerical model is similar to the revised regional groundwater flow model for MEW (Geosyntec, 2014). The details of the model development are given below.

The layering is not based on the A-, B1-, and B2-zone stratigraphy at MEW. Rather, each model layer is of uniform thickness and the distribution of soil types from site borings are used to interpolate the variation in material properties within each layer.

The model domain was divided into 13 layers as follows. The top seven layers were defined to match the stratigraphy observed at the Site. The layers below were chosen to best group materials of similar soil type, and remained the same as for the regional model.

- Layer 1 = 0 – 15 feet below ground surface (bgs); the top layer (Layer 1) is mostly dry and was therefore not active in the model simulations.

- Layer 2 = 15 – 20 feet bgs
- Layer 3 = 20 – 25 feet bgs
- Layer 4 = 25 – 32 feet bgs
- Layer 5 = 32 – 37 feet bgs
- Layer 6 = 37 – 45 feet bgs
- Layer 7 = 45 – 50 feet bgs
- Layer 8 = 50 – 60 feet bgs
- Layer 9 = 60 – 70 feet bgs
- Layer 10 = 70 – 80 feet bgs
- Layer 11 = 80 – 100 feet bgs
- Layer 12 = 100 feet bgs – top of the B3 aquifer (determined based on the top of the sandy layer observed in boring logs below 100 feet bgs)
- Layer 13 = B3 aquifer.

The top of the model domain was interpolated from a Digital Elevation Model (DEM) file obtained from USGS database.

The grid cells are 50 feet x 50 feet in most of the model domain and are refined to 2.5 feet x 2.5 feet in the vicinity of the Site.

## **1.2 Model Stratigraphy**

The model stratigraphy was defined following the same approach as for the revised regional groundwater flow model, with interpolated sand fraction maps created for the Layers 2 through 7 based on available boring and membrane interface probe (MIP) logs for the Site. The model stratigraphy below 50 feet bgs was not changed from the revised regional model.

## **1.3 Groundwater Flow Model**

### **1.3.1 Observation Data – Head**

The groundwater flow model has been calibrated to water level measurements collected between 2010 and 2012 from monitoring wells located inside the model domain.

### 1.3.2 Model Boundaries and Stresses

The model boundaries are unchanged from the regional flow model. Constant head boundaries were applied to the northern and southern edges of the model and no-flow boundaries were applied to the eastern and western sides of the model domain.

Recharge from direct precipitation was defined over the entire domain with a rate of 1 inch per year. Evapotranspiration was defined in the northern part of the domain, corresponding to the non-residential area of the model domain.

In the vicinity of the Site, the main stresses are the extraction wells and the presence of the slurry wall. The slurry wall was modeled with the horizontal flow barrier (HFB) package in MODFLOW. The HFB representing the slurry wall was defined down to 50 feet bgs (Layer 7). The HFB hydraulic parameter was defined assuming a constant slurry wall thickness of 3 feet and a hydraulic conductivity of 0.001 foot/day, which are consistent with information presented in the Slurry Cutoff Walls Record of Construction (Canonie, 1988).

The extraction wells were defined based on the screen interval. Average pumping rates from 2010-2012 were applied in all extraction wells for model calibration. Well construction and groundwater pumping rate information are included in the Annual Progress Report for the Site (Geosyntec, 2013a).

The locations of the Building 9 slurry wall and extraction and monitoring wells in the vicinity of the Site are shown in Figure C-2.

### 1.3.3 Material Properties

Aquifer hydraulic conductivity was defined using the same approach as for the regional model. A relationship between hydraulic conductivity and sand fraction was used to calculate hydraulic conductivity field in the refined model layers. The relationship between horizontal hydraulic conductivity ( $K_H$  in feet/day) and sand fraction (SF in %) is:

$$K_H = \begin{cases} 300 \cdot SF^3 & \text{if } SF \leq 50\% \\ 75 \cdot SF & \text{if } SF \geq 50\% \end{cases}$$

The ratio between horizontal and vertical hydraulic conductivity was set equal to 10.

The vertical hydraulic conductivity value of the low conductivity layer present at the bottom of the slurry wall was estimated to be 0.1 to 0.2 foot/day based on observed drawdown inside the slurry wall under pumping conditions. The median vertical hydraulic conductivity value of layer 6 (located from 37 to 45 feet bgs) in the slurry wall footprint is 0.14 foot/day based on the hydraulic conductivity relationship described above.

## **1.4 Solute Transport Model**

### **1.4.1 Model Boundaries and Stresses**

A uniform initial sodium permanganate concentration is assumed to be present throughout the target treatment zones for the ISCO pilot study (Figure 8 in Work Plan). The target treatment zones correspond to layer 3 (upper treatment zone) and layer 5 (lower treatment zone) in the model. The initial permanganate concentration is assumed to be 30 grams per liter (g/L), which is comparable to the oxidant solution concentration proposed for the pilot study, and results in a residual permanganate mass loading in the model that is approximately 50% greater than what is proposed for the pilot study.

### **1.4.2 Geochemical Model**

#### *Oxidant – Sodium Permanganate*

In order to model permanganate fate and transport, several additional model input parameters were incorporated using the Reactive Multi-Species Transport in 3-Dimensional Groundwater model (RT3D, Clement, 1997). The RT3D model allows consideration of parameters and reaction kinetics relevant to ISCO, including permanganate consumption by naturally-occurring organic compounds in aquifer material (i.e., natural oxidant demand [NOD]).

After injections, permanganate is consumed by at least three processes:

- Fast-reacting NOD (NOD-fast);
- Slow-reacting NOD (NOD-slow); and,
- Reaction with the target chlorinated solvents.

For this analysis the permanganate consumption by chlorinated solvents was not included, which is a conservative assumption when assessing the potential fate and transport of the oxidant after injections.

The kinetic model for permanganate consumption by NOD is based on the results of bench-scale testing to evaluate NOD that was conducted on soil and groundwater collected along Evandale Avenue (Geosyntec, 2013b).

- Based on these bench-scale testing data, a first-order rate constant was calculated for NOD-fast ( $0.2 \text{ day}^{-1}$ ). The calculated first-order rate constant yields an initial permanganate consumption by fast-reacting NOD of 6,000 milligrams per liter per day (mg/L-day) for an initial permanganate concentration of 30 g/L.
- The average zero-order NOD-slow oxidation rate was estimated to be 37 mg/L-day based on the bench-scale testing data.

The amount of fast-reacting NOD depends on the concentration of the injected oxidant and the duration of the fast reaction. Based on the bench-scale testing results, the amount of NOD-fast was estimated to be approximately 4,700 mg/L for an initial permanganate concentration of 30 g/L.

The bench testing results also indicated that the amount of slow-reacting NOD consumed was similar for different starting concentrations of permanganate. The model assumed that the amount of NOD-slow is approximately twice the amount of NOD-fast. Recent studies have reported that the fast-reacting NOD represents between 16 and 60 % of the total NOD (Thomson et al., 2009). In this analysis the fast-reacting NOD represents 33% of the total NOD, which is consistent with recent studies.

Based on the above conditions, the initial NOD-fast and NOD-slow concentrations were assumed to be 4,700 and 10,000 mg/L, respectively. As a simplifying assumption, the initial values of NOD-fast and NOD-slow were applied to the entire model domain. The final kinetic expressions for the reactive transport of NOD-fast, NOD-slow and permanganate are presented in Equations 1 through 3.

The kinetic expressions developed for decay of NOD-fast, in the presence of permanganate:

$$\text{Equation (1)} \quad \frac{d[NOD-fast]}{dt} = -0.2 * [MnO_4^-]$$

The kinetic expression developed for decay of NOD-slow, in the presence of permanganate:

$$\text{Equation (2)} \quad \frac{d[NOD-slow]}{dt} = -37$$

The kinetic expression developed for consumption of permanganate by NOD-fast and NOD-slow:

$$\text{Equation (3)} \quad \frac{d[MnO_4^-]}{dt} = -0.2 * [MnO_4^-] - 37$$

Where:

$[MnO_4^-]$  = concentration of permanganate (mg/L)

$[NOD-fast]$  = concentration of fast-reacting NOD in subsurface (mg/L)

$[NOD-slow]$  = concentration of slow-reacting NOD in subsurface (mg/L)

The above equations were incorporated into the reactive transport model and used to simulate the fate of injected permanganate.

### 1.4.3 Other Fate and Transport Properties

The longitudinal dispersivity was estimated based on a recent review article prepared by Schulze-Makush (2005), where longitudinal dispersivity from 156 sites with unconsolidated media was compiled. From this study, the longitudinal dispersivity ( $\alpha_L$ ) can be estimated by:

$$\alpha_L \text{ (feet)} = 0.106 \times L^{0.81}$$

where L is the scale of interest (feet). The objective of the fate and transport modeling at the Site is to assess solute transport from the injection interval within the slurry wall to closest extraction wells, with the nearest downgradient extraction well located approximately 400 feet away. The corresponding longitudinal dispersivity is 14 feet. The transverse horizontal and vertical dispersivities are assumed to be equal to 1/10 of the longitudinal dispersivity or 1.4 feet.

In the model, the effective porosity is assumed to be 0.25, which is within the range reported in literature for sand/silty sand (e.g., Morris and Johnson, 1967; McWhorter and Sunata, 1977).

### 1.5 Model Calibration

The flow model was calibrated to fit the average observed head at the monitoring wells between 2010 and 2012. At the regional scale (including all observation data), the root mean square error (RMSE) was 3.8 feet, corresponding to 5.3% of the range of the observed water levels.

The observed and simulated heads at the monitoring wells in the vicinity of the Site are summarized below. The locations of the monitoring wells are shown in Figure C-2.

| Monitoring Wells | Observed Head (feet msl) <sup>1</sup> | Simulated Head (feet msl) | Residual (feet) <sup>2</sup> |
|------------------|---------------------------------------|---------------------------|------------------------------|
| 116A             | 29.97                                 | 28.28                     | 1.69                         |
| 122A             | 28.31                                 | 28.38                     | -0.07                        |
| 123A             | 32.22                                 | 32.40                     | -0.18                        |
| 126A             | 30.08                                 | 29.72                     | 0.36                         |
| 137A             | 28.03                                 | 27.46                     | 0.57                         |
| 138A             | 31.48                                 | 30.36                     | 1.12                         |
| 36A              | 28.07                                 | 29.44                     | -1.37                        |
| 39A              | 30.84                                 | 28.46                     | 2.38                         |
| 69A              | 30.19                                 | 28.54                     | 1.65                         |
| 108A             | 30.14                                 | 28.40                     | 1.74                         |
| 31A              | 31.39                                 | 30.81                     | 0.58                         |
| 35A              | 28.07                                 | 28.22                     | -0.15                        |
| 37A              | 27.8                                  | 27.64                     | 0.16                         |
| 40A              | 31.03                                 | 28.63                     | 2.40                         |

| Monitoring Wells        | Observed Head (feet msl) <sup>1</sup> | Simulated Head (feet msl) | Residual (feet) <sup>2</sup> |
|-------------------------|---------------------------------------|---------------------------|------------------------------|
| 41A                     | 30.22                                 | 28.49                     | 1.73                         |
| 42A                     | 30.37                                 | 28.43                     | 1.94                         |
| 43A                     | 30.84                                 | 28.20                     | 2.64                         |
| 44A                     | 30.76                                 | 28.22                     | 2.54                         |
| SIL12A                  | 31.80                                 | 31.97                     | -0.17                        |
| SIL2A                   | 31.92                                 | 31.84                     | 0.08                         |
| SIL13A                  | 31.22                                 | 29.66                     | 1.56                         |
| SIL14A                  | 31.26                                 | 29.97                     | 1.29                         |
| SIL1A                   | 32.15                                 | 32.09                     | 0.06                         |
| SIL4A                   | 32.39                                 | 32.82                     | -0.43                        |
| SIL9A                   | 30.67                                 | 28.78                     | 1.89                         |
| 104B1                   | 28.58                                 | 29.69                     | -1.11                        |
| 109B1                   | 28.62                                 | 29.52                     | -0.90                        |
| 69B1                    | 30.98                                 | 30.30                     | 0.68                         |
| <b>RMSE<sup>3</sup></b> |                                       |                           | <b>1.40</b>                  |

1. Average observed head between 2010 and 2012
2. Residual = Observed Head – Simulated Head
3. RMSE = Root Mean Square Error

## 2. SIMULATED FLOW FIELD UPON SHUTDOWN OF EXTRACTION WELLS

Pumping rates were set to 0 at the four on-site extraction wells to simulate groundwater flow conditions in the absence of pumping. Pumping rates at the off-site recovery wells were set to the average 2013 pumping rates. Pumping rate at the planned extraction well near monitoring well 116A was set equal to the average 2013 pumping rate at GSF-1A (2.1 gallons per minute). The other boundary conditions remained unchanged.

### 2.1 Simulated Flow Field

The simulated hydraulic heads inside and in the vicinity of the slurry wall are shown in Figure C-3. Upward flow is simulated in the upgradient (southern) portion of the slurry wall, while downward flow is simulated in the downgradient (northern) portion of the wall. The rate of downward flow from the injection depth intervals (located above 37 feet bgs) is estimated to be 0.7 gallons per minute (gpm).

## 3. SIMULATED OXIDANT CONCENTRATION

For the oxidant fate and transport modeling, the points of compliance considered were the groundwater extraction wells located closest to Site (planned extraction well near monitoring well 116A to the north, and extraction wells EX-1 to EX-4 to the east). Simulated permanganate

concentration contours are shown in Figure C-4. The upper panels illustrate the simulated permanganate concentrations in the upper treatment zone described in the Work Plan. The lower panels illustrate the simulated permanganate concentrations in the lower treatment zone described in the Work Plan. The shown concentration contours of 300 milligrams per liter (mg/L), 30 mg/L, and 3 mg/L are equivalent to attenuation of 99%, 99.9%, and 99.99% of the residual permanganate concentration of 30 g/L, respectively. The simulated permanganate front does not reach the deeper zone (50 to 60 feet bgs) outside of the slurry wall. Based on the model simulations as shown in Figure C-4, even at a conservatively high residual value of 30 g/L and higher permanganate mass than proposed in the pilot study, sodium permanganate is expected to be consumed by natural organic matter present in the aquifer material prior to being transported outside of the slurry wall and reaching the extraction wells located in the vicinity of the site.

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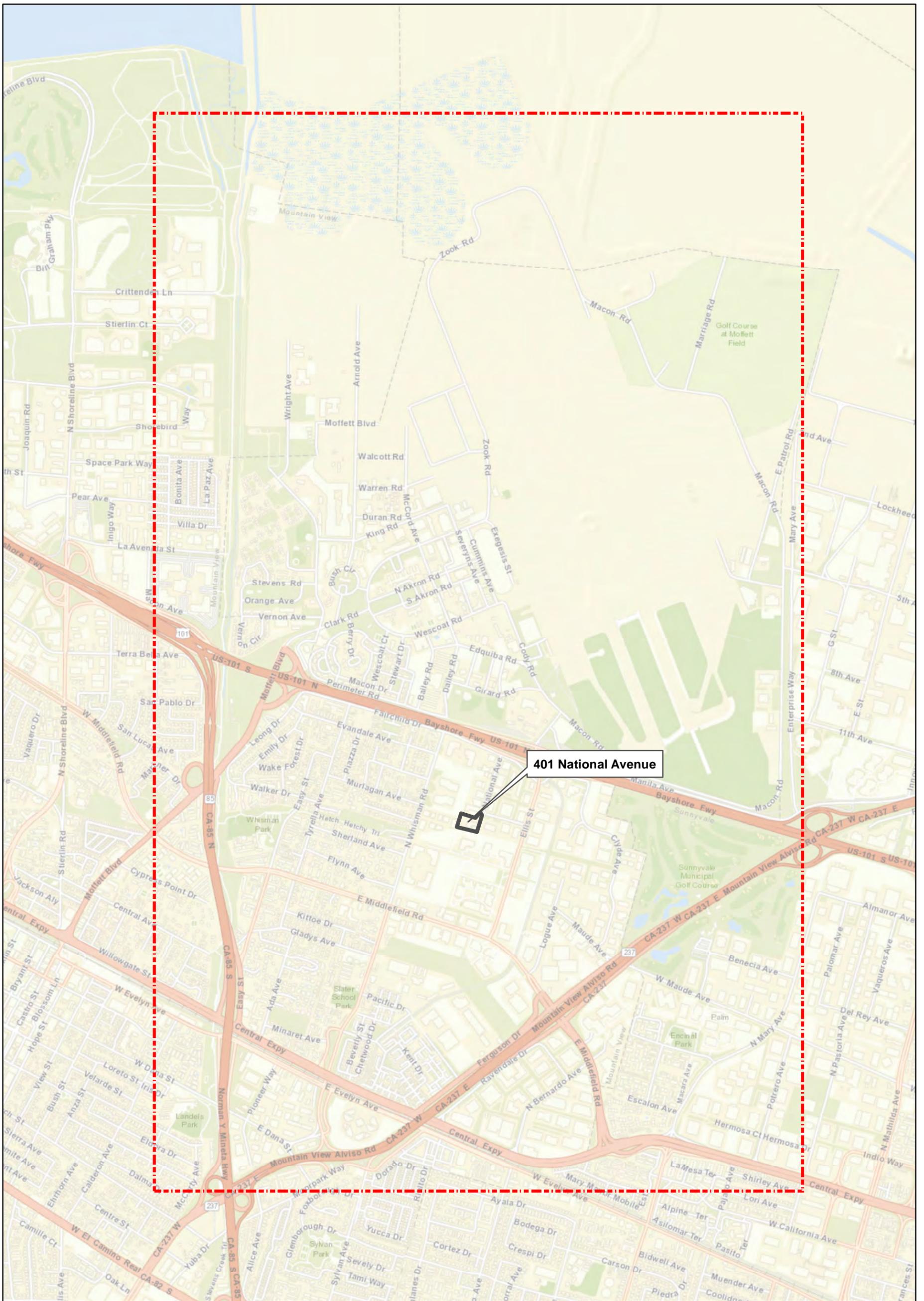
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\* \* \* \* \*



401 National Avenue

**Legend**

-  401 National Avenue
-  Model Domain

**Notes:**  
 Basemap Source: OpenStreetMap, October 2014



**Model Domain**

**401 National Avenue  
 Mountain View, California**

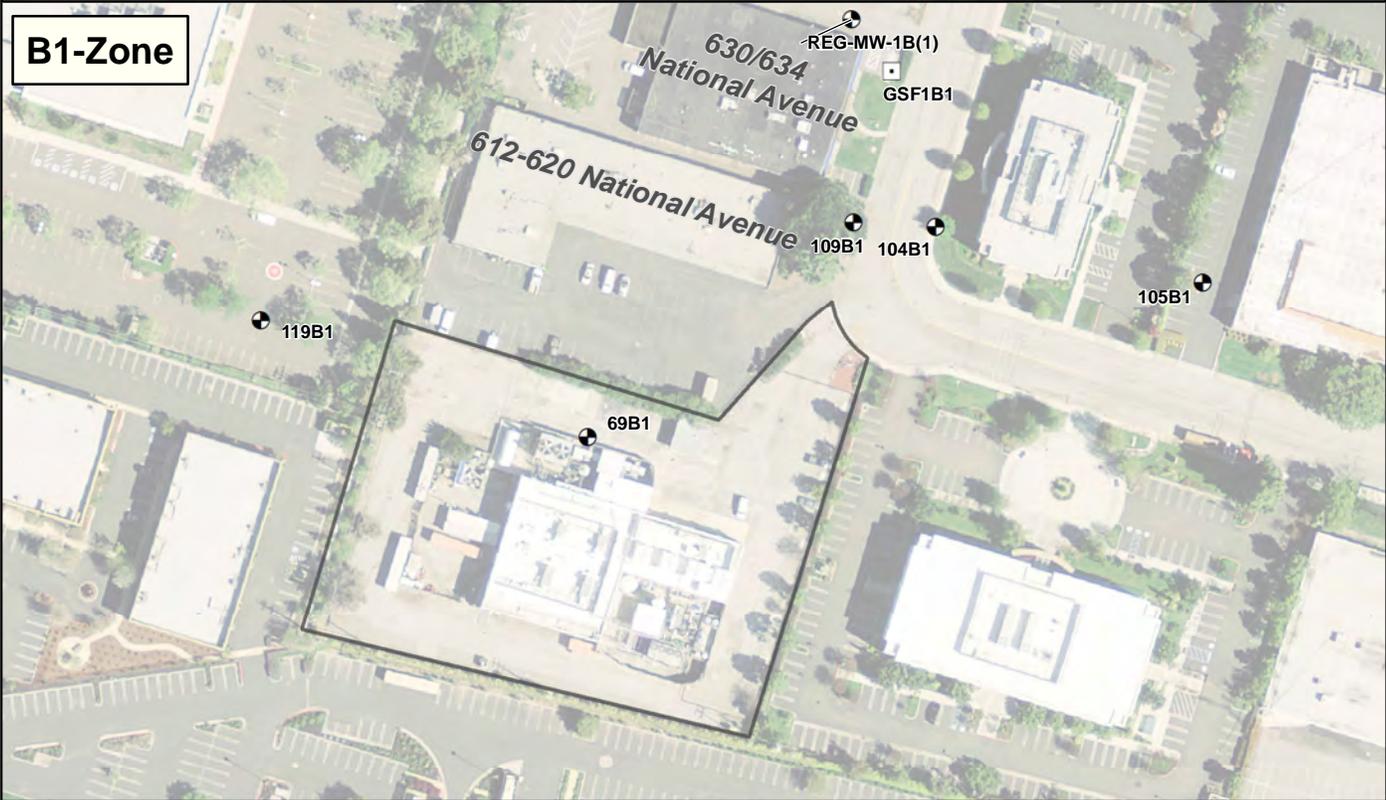
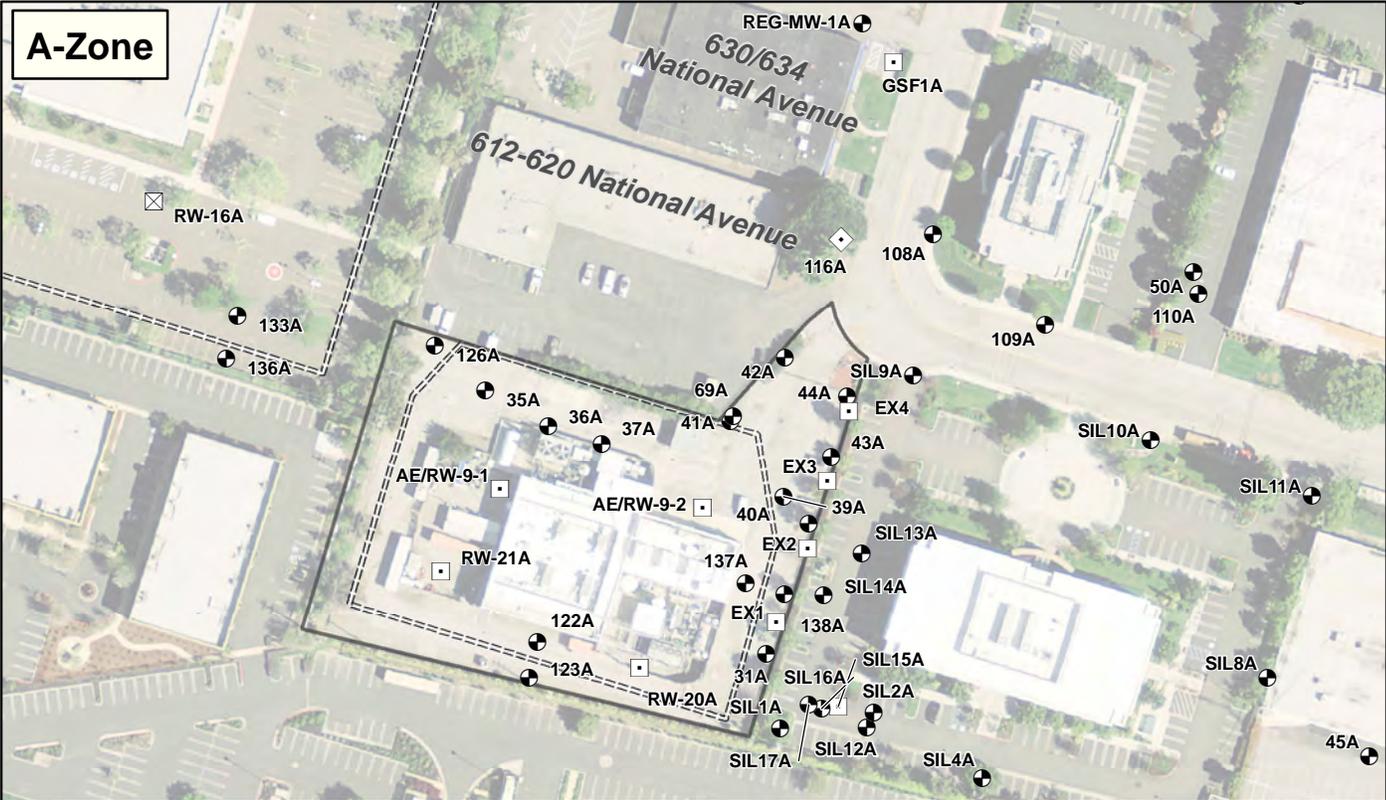
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 consultants

Oakland

October 2014

Figure

**C-1**



**Legend**

- Recovery Well
- ◇ Proposed Recovery Well
- Monitoring Well
- ▭ 401 National Avenue
- === Slurry Wall



Notes:  
 SCRW - Source Control Recovery Well  
 Aerial Source: USGS April 2011

70 35 0 70 Feet



**Local A- and B1-Zone Groundwater SCRWs and Monitoring Wells**

401 National Avenue  
 Mountain View, California

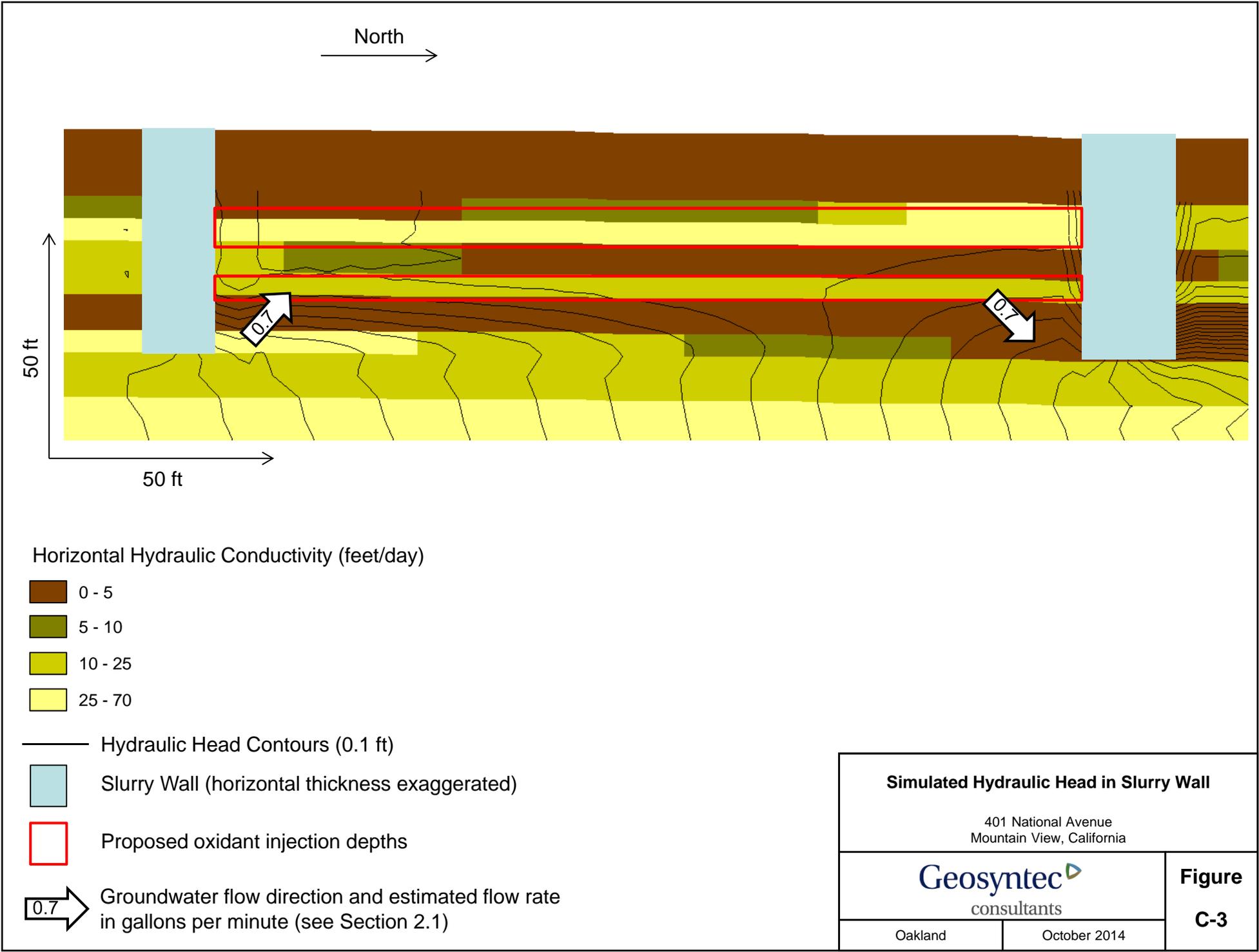
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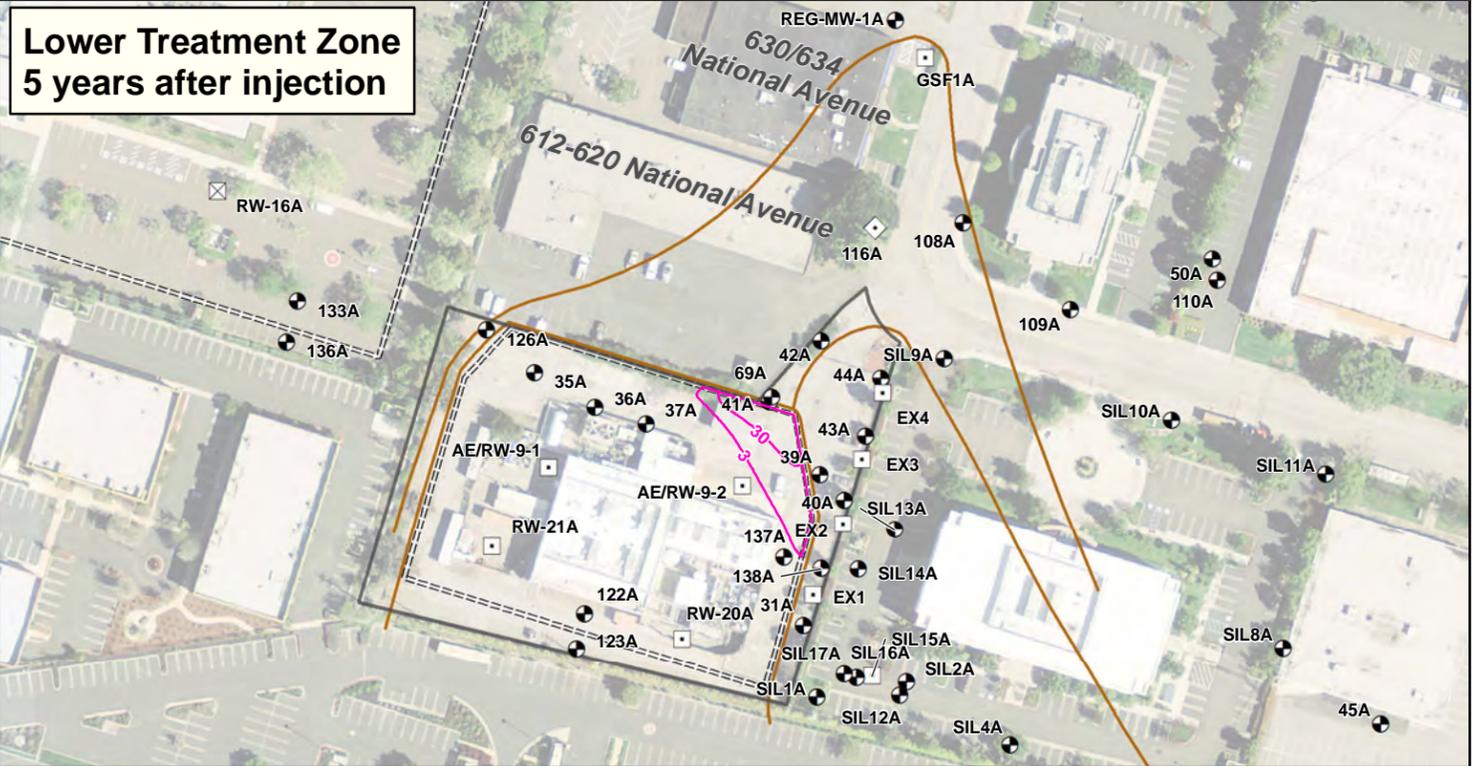
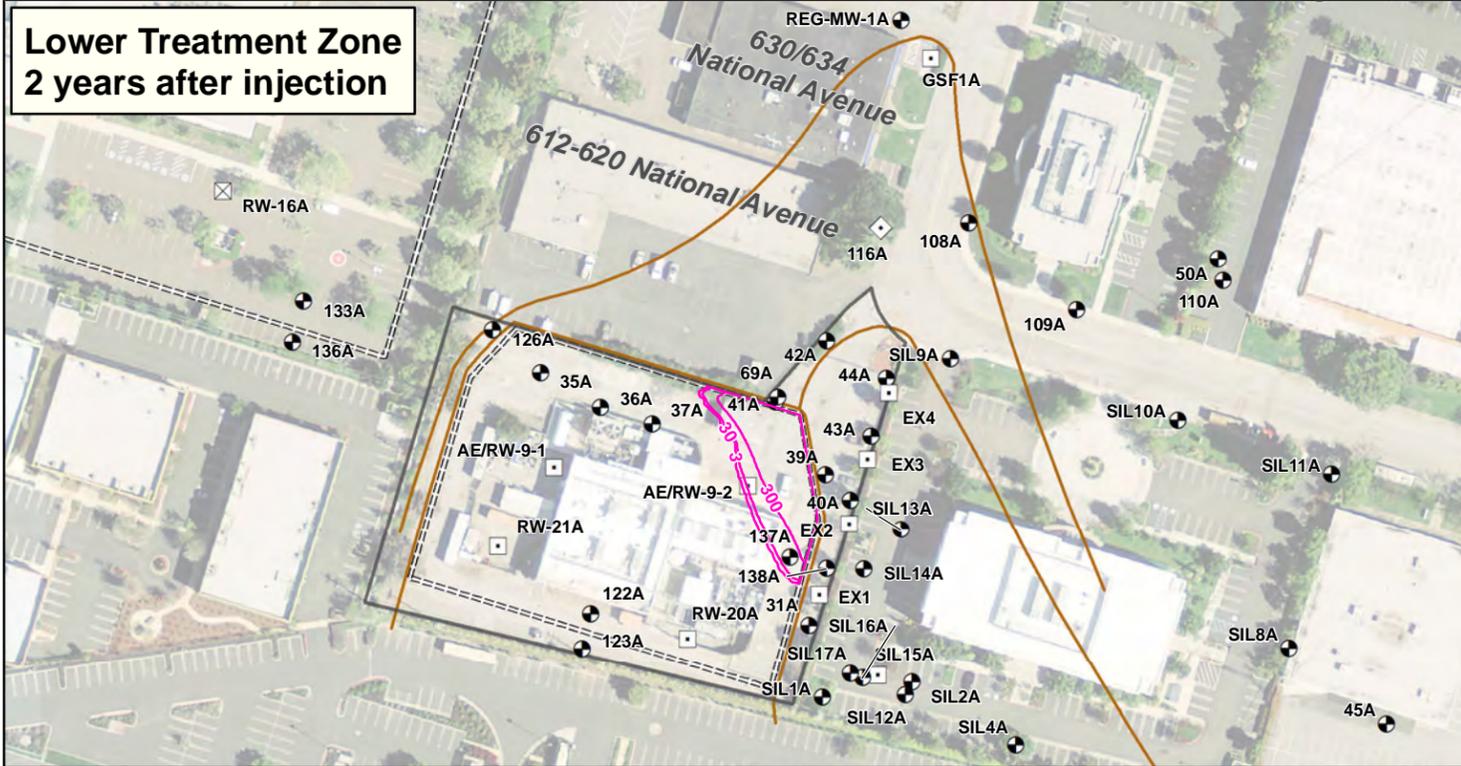
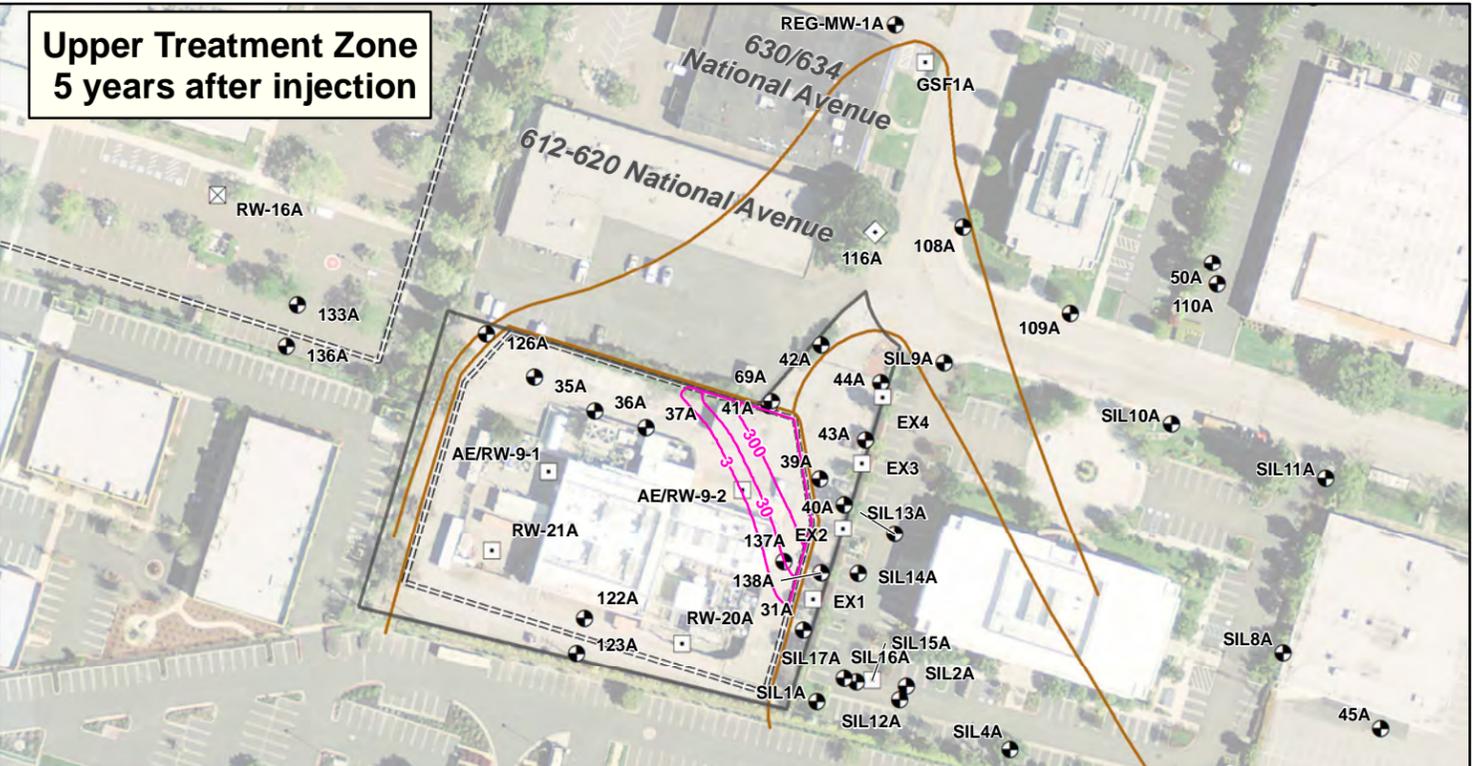
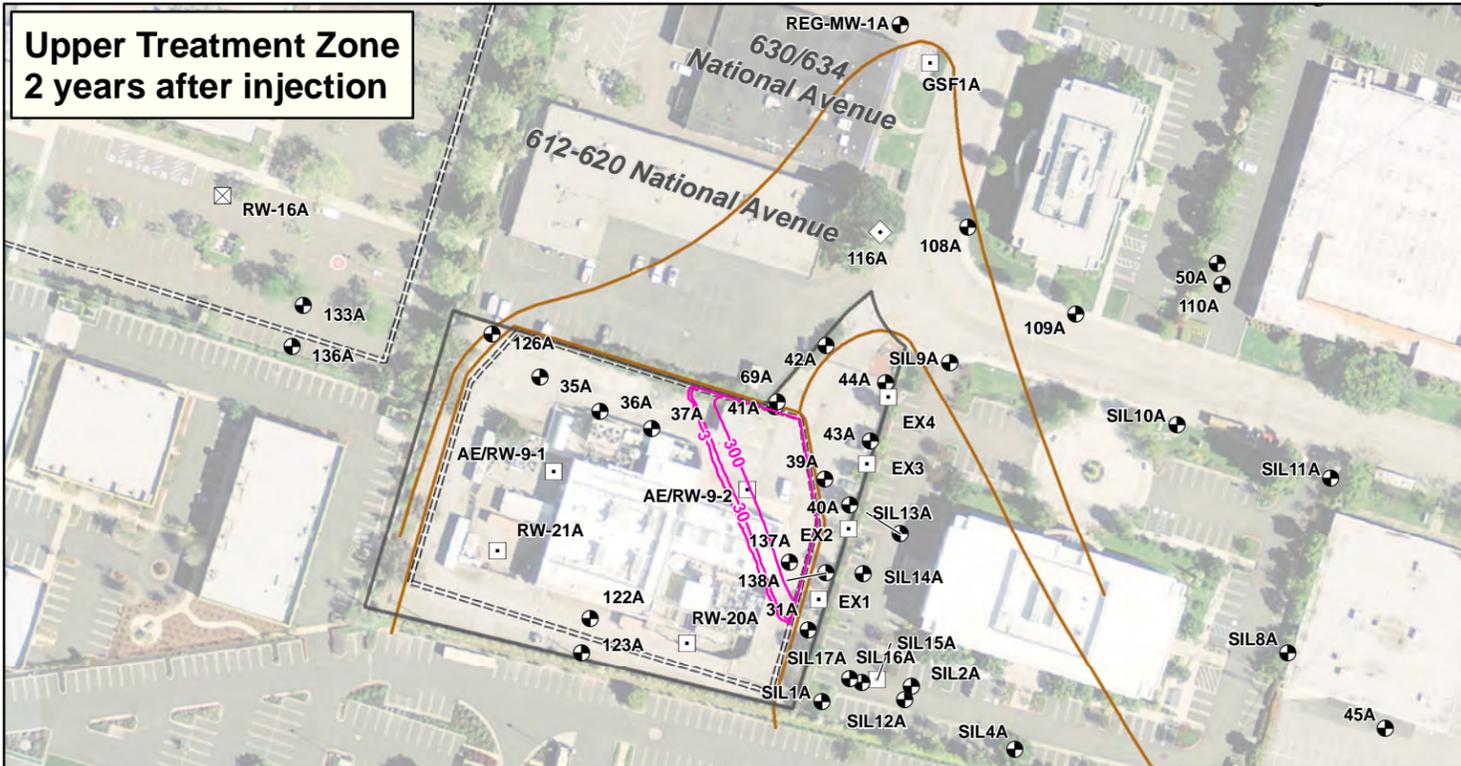
Figure

**C-2**

Oakland

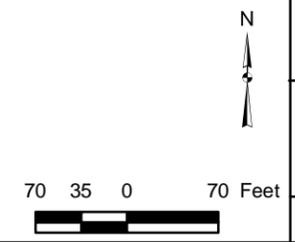
October 2014





- Legend**
- Recovery Well
  - ◇ Proposed Recovery Well
  - Monitoring Well
  - ▭ 401 National Avenue
  - Simulated Permanganate Concentration (mg/L)
  - Estimated Capture Zone
  - Slurry Wall

Notes:  
 mg/L = Milligrams per Liter  
 Estimated Capture Zone Source: Geosyntec, 2014. Annual Progress Report for Regional Groundwater Remediation Program, April 15.  
 Modeled Results Assume A-Zone Extraction Wells Located Inside 401 National Avenue Slurry Wall Will Not Operate Following Oxidant Injections.  
 Aerial Source: USGS April 2011



**Simulated Permanganate Concentrations**  
 401 National Avenue  
 Mountain View, California

**Geosyntec**  
 consultants

Oakland      October 2014

**Figure**  
**C-4**

## APPENDIX D

# Contingency Plan for Treatment of Secondary Water Quality Impacts

## **APPENDIX D – Contingency Plan for Treatment of Secondary Water Quality Impacts 401/405 National Shared Treatment System**

This contingency plan has been developed to describe procedures that will be followed to implement treatment for hexavalent chromium and/or residual oxidant at the 401/405 National Shared Treatment System if these compounds are detected at concentrations exceeding action levels in the treatment system extraction wells. The monitoring program and action levels that will be used to assess whether the contingency plan will be implemented are described in Section 4.5.4 of the in situ chemical oxidation (ISCO) work plan and are briefly summarized below.

### **1. MONITORING PROGRAM AND ACTION LEVELS**

The sentry wells, shared SCRWs and 405 National SCRWs will be sampled monthly following implementation of the ISCO injection program and analyzed for hexavalent chromium (EPA Method 7196), and residual oxidant (using a field spectrophotometer or a commercially available field test kit). As described in Section 4.5.4, the action levels are:

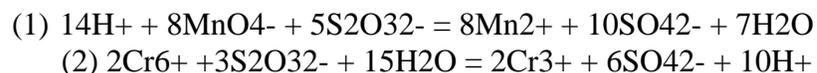
- Hexavalent chromium – 5 µg/L; and
- Oxidant – 1 mg/L.

If the action level for hexavalent chromium or oxidant is exceeded at one or more of the sentry wells or extraction wells, the contingency plan will be implemented.

### **2. CONTINGENCY TREATMENT DESIGN**

The contingency treatment plan is to install within the existing 401/405 National Shared Treatment System a skid-mounted treatment unit for reducing the chemical oxidant (likely permanganate) and the hexavalent chromium. The contingency treatment unit will add the strong reductant sodium thiosulfate to the groundwater after it has been treated by the existing ultraviolet light-hydrogen peroxide (UV-H2O2) oxidation unit, filter the water to remove precipitates that form, and return the water to the existing treatment train for final treatment and discharge.

The chemistry involves a rapid rate reaction whereby permanganate is reduced to divalent manganese and hexavalent chromium is reduced to trivalent chromium as follows:



Once the reactions are complete, divalent manganese will precipitate to form solid manganese dioxide and trivalent chromium will precipitate to form solid chromium (oxy)hydroxides.

The estimated thiosulfate concentration range for the contingency treatment unit was determined using a conservative range of potential breakthrough concentrations in the influent of the extraction system for oxidant (1 mg/L to 50 mg/L) and hexavalent chromium (5 µg/L to 50 µg/L). Based on the assumed ranges of breakthrough concentrations for oxidant and hexavalent chromium and reaction stoichiometry, the range of thiosulfate concentrations required to reduce the compounds ranges from 0.0021 mg/L to 59 mg/L.

### 3. CONTINGENCY IMPLEMENTATION STEPS

The steps described below are designed to reduce the timeframe for implementation of the contingency treatment to the extent practicable.

Step 1 - The contingency treatment skid will be assembled as shown on Figure D-1 prior to injection activities and will be staged at the 401/405 National Shared Treatment System, ready for use. The contingency skid will include the following items:

- Secondary containment;
- 55-gallon drum of 20% sodium thiosulfate solution;
- Chemical dosing pump;
- Booster pump;
- A length of piping with sufficient residence time for the reaction between the thiosulfate and permanganate and/or hexavalent chromium to occur; and,
- A filter system for removal of the solid byproducts from the flow stream.

Step 2 - If hexavalent chromium or oxidant are detected in the sentry wells, shared SCRWs or 405 National SCRWs at concentrations exceeding action levels, the existing 401/405 National Shared Treatment System will be shut down to prevent either of these compounds being discharged and exceeding the NPDES permit requirements. It is anticipated that the contingency system would be installed and operating within 48 hours of the system being shut down.

Step 3 - While the 401/405 National Shared Treatment System is shut down, 2-inch gate valves will be installed immediately downstream of the UV treatment system and immediately upstream of the descaling process.

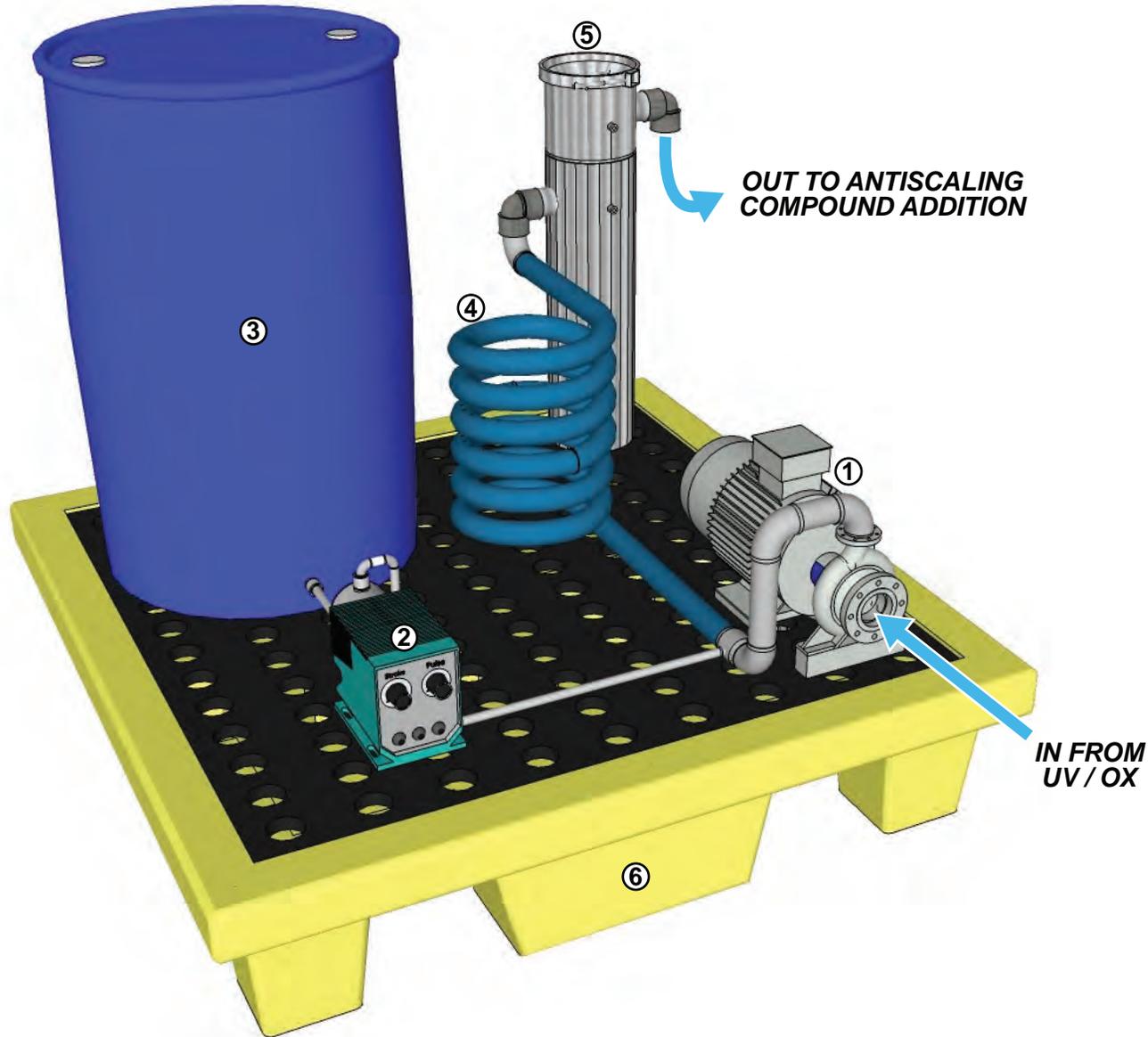
Step 4 - The contingency treatment unit skid will then be inserted into the treatment train of the 401/405 National Shared Treatment System using the installed 2-inch gate valves.

Step 5 - Once installed, the 401/405 National Shared Treatment System will be restarted.

Geosyntec will work with Vishay's consultant to coordinate activities associated with system start-up and shakedown will be performed in accordance with the 401/405 National Treatment System Operations and Maintenance Manual. System effluent will be tested for oxidant and hexavalent chromium as part of start-up and shakedown activities.

#### **4. CONTINGENCY TERMINATION**

It is anticipated that the presence of oxidant or hexavalent chromium will be temporary and that concentrations will subside with time. Termination of the contingency treatment will occur if concentrations of these compounds in the sentry wells, shared SCRWs and 405 National SCRWs return to levels below the action levels and remain below the action levels for three consecutive months. Monthly monitoring of the sentry wells, shared SCRWs and 405 National SCRWs will be continued for an additional three months following termination.



**Legend**

- ① Booster Pump
- ② Chemical Dosing Pump
- ③ 55 Gallon Drum of 20% Sodium Thiosulfate ( $\text{Na}_2\text{S}_2\text{O}_3$ )
- ④ 2"/4" Pipe
- ⑤ Filter
- ⑥ Spill Containment

*Note:  
Not to Scale*

**Contingency System Schematic**

401 National Avenue  
Mountain View, California

**Geosyntec**  
consultants

Figure

**1**

Oakland

October 2014

APPENDIX E  
Ground Water Sample Preservation at In-  
Situ Chemical Oxidation Sites

## Ground Water Sample Preservation at In-Situ Chemical Oxidation Sites – Recommended Guidelines

Saebom Ko<sup>1</sup>, Scott G. Huling<sup>2,\*</sup>, Bruce Pivetz<sup>3</sup>

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## 1. INTRODUCTION

In-situ chemical oxidation (ISCO) involves the introduction of a chemical oxidant into the subsurface for the purpose of transforming ground water and/or soil contaminants into less harmful chemical by-products (Huling and Pivetz, 2006; Rivas, 2006; Ferrarese *et al.*, 2008; Kao *et al.*, 2008). Often, ground water samples collected specifically to analyze organic contaminants may contain the oxidant and the organic contaminants in a “binary mixture” (Huling *et al.*, 2011a; Johnson *et al.*, 2012). When organic contaminants and oxidants are commingled in the ground water sample, there is significant potential for oxidative transformation of contaminants to occur after the sample is collected and the results of the sample analysis to become non-representative of in-situ conditions at the time of sampling. Consequently, the quality of the ground water sample may be compromised and a false negative result may occur.

An integral component of ISCO is the collection and analysis of ground water samples to assess ISCO treatment performance. A technical issue faced by Remedial Project Managers is the collection and analysis of representative, high quality ground water samples that can be used to support a site assessment and remedial performance monitoring at sites where ISCO is being deployed. The purpose of this *Issue Paper* is to provide background information and general guidelines involving methods and procedures that can be used to detect whether an oxidant (i.e., permanganate or persulfate) is present in ground water, to approximate the oxidant concentration, and to estimate and deliver the volume or mass of preservative, specifically ascorbic acid, required to preserve the binary mixture ground water sample. The focus of this *Issue Paper* is on permanganate and persulfate, two oxidants that can persist for long periods of time in the subsurface and therefore represent the greatest potential for binary mixture ground water samples. An Appendix to this *Issue Paper* (Recommended Operating Procedures - Preservation of Ground Water Samples at ISCO Sites Using Ascorbic Acid) provides specific details regarding the preservation procedures for use by EPA Regional personnel, contractors, and other environmental professionals engaged in ground water sample collection and analysis.

The guidelines are also applicable to bench-scale studies where oxidants are used to investigate the feasibility of ISCO treatment. For

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example, aqueous samples collected from bench-scale soil reactors are analyzed for organic contaminants, but may also contain the oxidant amended to the reactor to destroy the contaminant. Consequently, the guidelines described below also extend to bench-scale studies where the potential for binary mixture aqueous samples may occur, and are analyzed for organic contaminants.

### **1.1. Reasons to Sample and Analyze Binary Mixtures**

It is often desirable for oxidants in ground water to fully react prior to collecting and analyzing ground water samples for organic contaminants. However, there are circumstances where the collection and analysis of binary mixture ground water samples may not be avoided. These reasons vary widely and some examples include the need to:

- (1) conduct an immediate preliminary assessment of ISCO to validate in-progress treatment performance,
- (2) establish design parameters from interim ISCO pilot-scale studies needed to design full-scale ISCO deployment,
- (3) assess the potential redistribution of the ground water contaminant plume as affected by ISCO activities, and
- (4) evaluate reaction kinetics during oxidative treatment.

Rapid turnaround of field data and information may be needed to meet specified milestones and deadlines for full-scale remedy selection, design, construction, and implementation. In addition, regulatory-driven goals and associated timelines may require rapid completion of pilot-scale testing and full-scale deployment of ISCO. Therefore, a significant emphasis may be placed on the collection of ground water samples at ISCO sites prior to complete reaction of the oxidant (Huling *et al.*, 2011a).

### **1.2. Binary Mixtures of Oxidant and Organic Contaminants in Ground Water Samples**

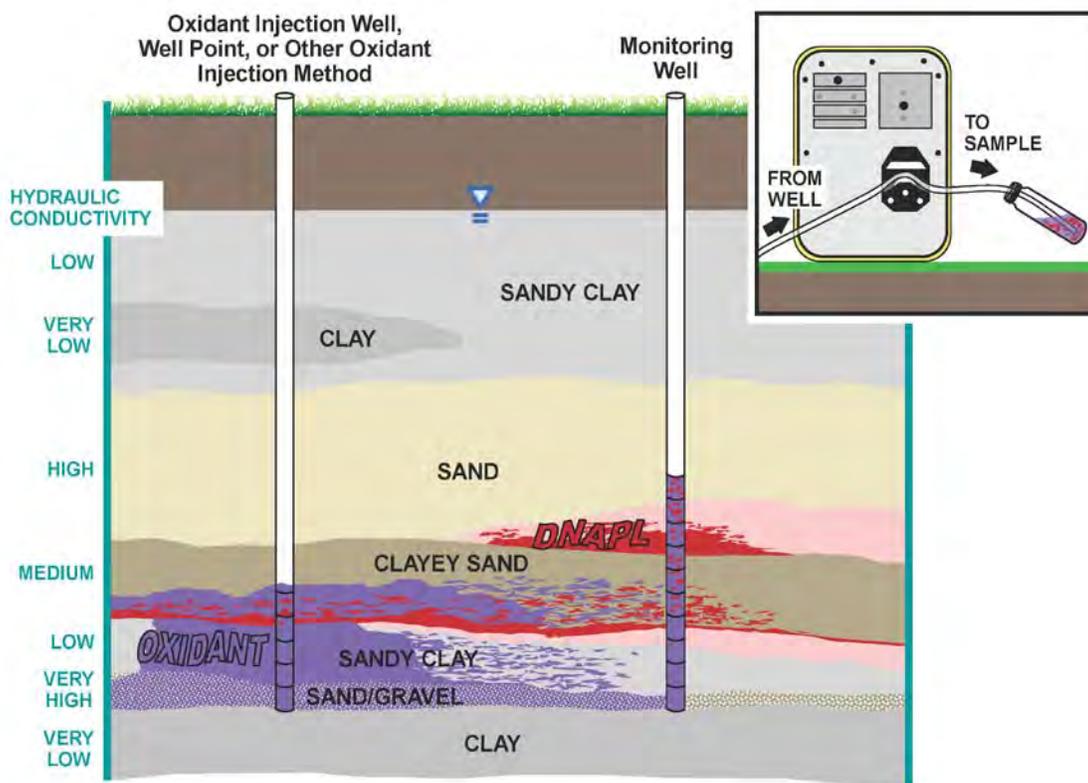
Heterogeneous distribution of oxidant and contaminants, and hydraulic conductivity variations in heterogeneous aquifers are two main causes of binary mixtures (Figure 1) (Huling *et al.*, 2011a). For example, oxidants and contaminants can enter a monitoring well screen from different lithologic zones. These solutes may be captured as separate solutes from different lithologic zones, or as separate or commingled solutes from the

same lithologic zone. Insufficient contact time (i.e., reaction time) between the oxidant and contaminants prior to, or after, entering the well leads to binary mixtures in the ground water sample.

Commingling of organic contaminants and oxidants in the ground water sample impacts the quality of the ground water sample, but may also impact the analytical instruments used to measure the concentration of analyte(s) in the ground water sample (Johnson *et al.*, 2012). Although rarely reported and documented, the impact of oxidants on analytical instruments is exclusively reported for permanganate and predominantly involves instrument malfunction resulting from MnO<sub>2</sub>(s)-clogged lines and ports. No information was found that documented the impact of hydrogen peroxide or persulfate on analytical instruments despite numerous studies where binary mixtures were analyzed.

### **1.3. Impact of Binary Mixtures – Previous Studies**

A detailed study involving the impact of residual persulfate on the quality of ground water samples was performed (Huling *et al.*, 2011a). A significant decline (49 to 100 percent (%)) in volatile organic compound (VOC) concentrations was measured in unpreserved binary mixture samples using gas chromatography (GC) purge and trap, and GC mass spectroscopy (MS) headspace analytical methods. In that study, preservation of the binary mixture samples was achieved through the addition of ascorbic acid and resulted in 99 to 100% VOC average recovery relative to oxidant-free control samples. Adding high concentrations of ascorbic acid (42 to 420 millimolar (mM)) to the samples did not interfere in the measurement of the VOCs and did not negatively impact the analytical instruments. These results indicated that if persulfate is present in the sample, and the binary sample is not appropriately preserved, the quality of the sample will be compromised. A companion study involving the impact of permanganate on the quality of ground water samples and analytical instruments, and the use of ascorbic acid yielded similar results (Johnson *et al.*, 2012). The results of these studies (Huling *et al.*, 2011a; Johnson *et al.*, 2012) serve as the basis for the guidelines provided in this *Issue Paper*.



**Figure 1.** Conceptual model of hydrogeologic, and oxidant and contaminant fate and transport conditions that contribute to binary mixture ground water samples. The oxidant illustrated in purple, conceptually represents any oxidant (permanganate, persulfate) used for in-situ chemical oxidation (Huling *et al.*, 2011a).

The analytical methods used in these studies are commonly used in commercial analytical laboratories. The analytes, including benzene, toluene, xylene (BTX), perchloroethylene (PCE), and trichloroethylene (TCE), are representative of contaminants commonly found at hazardous waste sites. Similarly, empirical results were obtained in the analysis of binary mixtures comprised of persulfate and pentachlorophenol (PCP) by high performance liquid chromatography (HPLC) where significant loss of PCP was measured in unpreserved samples relative to persulfate-free control samples and ascorbic acid-preserved samples (data not included). Currently, we do not have a firm explanation for a viable mechanism responsible for persulfate activation and PCP oxidation in these samples.

Overall, results are applicable to a broad set of analytical methods, analytes, and site conditions. It is unclear to what extent these results extend to analytical methods and contaminants that were not tested in these studies, however. Additional specific studies are needed in cases

where different analytical methods and ground water contaminants are involved.

Specifically, analysis involved the measurement of (1) BTX, PCE, and TCE using the GC/MS headspace method, and (2) BTX using the GC purge and trap method (Huling *et al.*, 2011a). The GC/MS headspace method is involved in EPA Method Nos. 8260C and 5021A. The automated headspace GC/MS method is used to confirm the identity and quantity of purgeable VOCs in water samples in 40 mL volatile organic analysis (VOA) vials. This method is used to quantify over sixty VOCs in drinking water, including aromatics, haloalkenes, haloalkanes, haloaromatics, and fuel oxygenates. This automated method involves the transfer of an aqueous sub-sample (10 mL) to a sealed headspace vial which is heated from room temperature to 80 degrees Celsius (°C) in 30 minutes. A sample of the headspace gas is then transferred to the capillary column in the GC. After separation on the GC column and introduction into the MS, the VOCs are identified and

quantified using the MS. We propose that contaminant loss occurs during the heating step of the sub-sample where residual persulfate is thermally activated resulting in VOC oxidation.

The automated purge and trap GC (Agilent, Model 6890, Wilmington, DE) method was used to quantify BTX in water samples (40 mL VOA vials). This method is most similar to EPA Methods 602 and 8020, but shares similarities with several other EPA methods that involve purge and trap, including: EPA 501, 502.2, 503.1, 524.2, 601, 602, 624, 8010, 8020, 8021, 8240, and 8260. In this method, a sub-sample (10 mL) is transferred to a sparge chamber and purged with helium (6 minutes). The VOCs are transferred to a K VOCARB 3000 Encon trap and dry purged with helium to remove water vapor. The VOCs are thermally desorbed and transferred to the GC column for separation and measurement. Sample transfer is through a heated 1.9 mm×1.0 m Silcosteel (Restek, Bellefonte, PA) transfer line coupled directly to the analytical column. Following separation on the column, the presence of VOCs is determined and quantified with photoionization and flame ionization detectors. It was proposed that the contaminant loss was due to the helium sparging step where aerosols are formed containing persulfate and are transferred to the VOC granular activated carbon trap (Huling *et al.*, 2011a). Subsequently, during the VOC thermal desorption step where the trap is heated from room temperature to 260 °C (25 min), the persulfate residing in the trap is thermally activated resulting in the oxidation of the VOCs immobilized and concentrated on the trap. Similarly, highly efficient oxidation of organics immobilized in solid media (i.e., granular activated carbon) by thermally activated persulfate has been demonstrated (Huling *et al.*, 2011b).

The impact of residual permanganate was evaluated in water samples prepared in the lab using a multi-component standard, and in ground water samples collected at ISCO sites (Johnson *et al.*, 2012). Binary mixture aqueous samples were prepared that contained a 52-component standard of organic compounds and permanganate. Ascorbic acid was added to the binary mixture which reacted rapidly with the  $\text{MnO}_4^-$ , preserved the sample, and limited the reaction between  $\text{MnO}_4^-$  and the organic compounds. Consequently, the concentrations of the majority of the compounds in

the multi-component standard were within the control limits established for quality assurance. However, despite timely efforts to preserve the laboratory-prepared binary mixture samples, the quality of the sample was impacted; concentrations were generally lower than oxidant-free controls, and the concentration of several compounds (*cis*-1,3-dichloropropene, styrene, *trans*-1,2-dichloroethene, *trans*-1,3-dichloropropene, vinyl chloride) fell below the applicable lower control limit.

Concentrations of VOCs measured in field-preserved binary mixture ground water samples were greater than in replicate samples refrigerated in the field and preserved with ascorbic acid upon arrival at the lab (Johnson *et al.*, 2012). These results indicate that the VOCs reacted in transit despite refrigeration. Excess ascorbic acid did not negatively impact the quality of the simulated ground water samples containing a 52-component stock standard, or actual ground water samples collected from two field sites, and did not negatively impact the GC/MS instruments used in the analysis.

## 2. GROUND WATER SAMPLE COLLECTION, OXIDANT MEASUREMENT, AND OXIDANT NEUTRALIZATION/SAMPLE PRESERVATION

Specific details regarding the procedures used in amending ground water samples with ascorbic acid are provided in the Appendix entitled, “Recommended Operating Procedures - Preservation of Ground Water Samples at ISCO Sites Using Ascorbic Acid”.

It is recommended that a representative ground water sample be collected at the well head in a test vial for the specific purpose of measuring the oxidant concentration. Ground water sample collection for this purpose should follow the normal ground water sampling protocol established at the site. This initial screening ground water sample is not collected for the purpose of measuring organic contaminant concentrations. If contaminant analysis of the ground water sample is desired, additional samples must be subsequently collected and preserved, if necessary. Normal sampling procedures appropriate for site conditions and regulatory acceptance are recommended. Sample preservation and handling requirements are based on the type of analyses being performed and should be specified in project-specific documents such as the quality assurance project plan, field sampling

plan, or in general EPA documents such as the Resource Conservation and Recovery Act (RCRA) guidance document (U.S. EPA, 1992) or EPA SW-846 (U.S. EPA, 1982). Additional direction on ground water sampling techniques can be found in Yeskis and Zavala (2002).

## 2.1. Permanganate (MnO<sub>4</sub><sup>-</sup>)

Data and information presented below are reported in terms of the permanganate anion (MnO<sub>4</sub><sup>-</sup>; 118.9 grams per mole (g/mol)). Permanganate is purchased either as sodium permanganate (NaMnO<sub>4</sub>; 141.9 g/mol) or potassium permanganate (KMnO<sub>4</sub>; 158.0 g/mol) and as a result conversion to the permanganate anion concentration is needed to determine sample preservation needs as per the *Issue Paper*. Specifically, the ratios 118.9/141.9 (g-mole/g-mole) and 118.9/158.0 (g-mole/g-mole) are used to convert NaMnO<sub>4</sub> and KMnO<sub>4</sub>, respectively to MnO<sub>4</sub><sup>-</sup>.

### 2.1.1. Analysis by Visual Observation

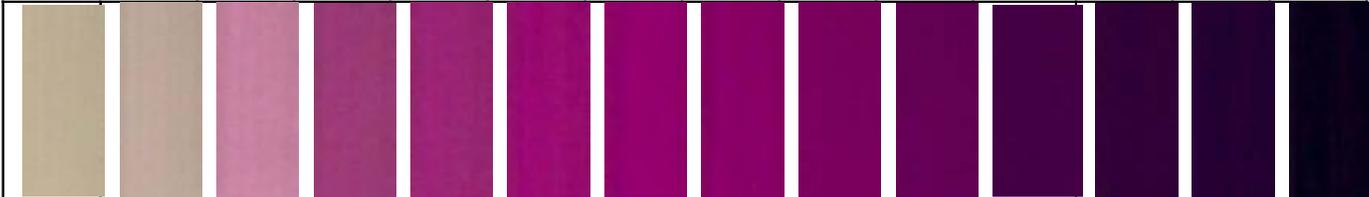
The characteristic pink or purple color of MnO<sub>4</sub><sup>-</sup> in a 40 mL VOA vial can be used as a general guideline to

estimate the concentration by using the MnO<sub>4</sub><sup>-</sup> colorimetric scale (Table 1). This method should be used with caution because ground water turbidity and colloidal manganese dioxide solids (MnO<sub>2</sub>(s)) can affect sample color and result in deviations from the tabulated color scale. Field filtration can help minimize these interferences, but may not fully remove all color if sub-micron colloidal and/or dissolved constituents are present.

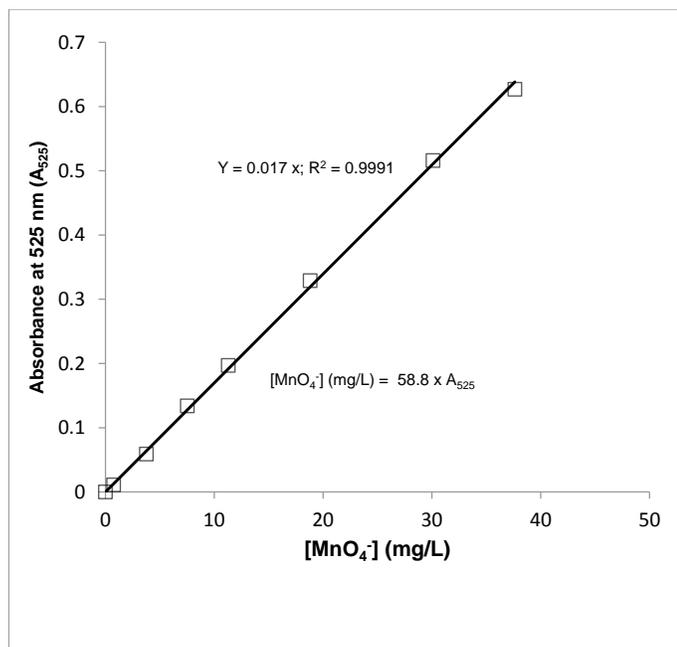
### 2.1.2. Spectrophotometric Analysis

The permanganate concentration can be determined using commercially available field test kits (SenSafe™, 2011; CHEMetrics, 2011). Additionally, an accurate measurement of the permanganate concentrations can be determined using a field spectrophotometer (maximum absorbance wavelength (λ) = 525 nanometers (nm) (A<sub>525</sub>)) and a calibration curve involving a linear correlation between MnO<sub>4</sub><sup>-</sup> concentration and A<sub>525</sub> (Figure 2, Table 1). Filtered samples (0.2-0.45 micron) may be required to eliminate background colloidal or suspended solid materials that can absorb light at 525 nm and interfere with permanganate measurement. Volatilization of

**Table 1.** Permanganate concentration, spectrophotometric absorbance at 525 nm, and required amount of ascorbic acid required to neutralize the oxidant in a 40 mL vial. The color scale represents actual photos of MnO<sub>4</sub><sup>-</sup> vials and is included for conceptual guidance. Actual colors vary based on background lighting, and color printers. Additionally, photographs of low concentrations (i.e., clear solutions) do not accurately capture transparency.

|  |        |        |        |        |        |        |        |        |        |        |        |        |        |
|--|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
|    |        |        |        |        |        |        |        |        |        |        |        |        |        |
| <b>[MnO<sub>4</sub><sup>-</sup>] (mg/L) (millimolar in parentheses)</b>  |        |        |        |        |        |        |        |        |        |        |        |        |        |
| 0  | 0.75   | 3.8    | 7.5    | 11.3   | 18.8   | 30.1   | 37.6   | 56.4   | 75.3   | 113    | 151    | 188    | 376    |
| (0)  | (0.01) | (0.03) | (0.06) | (0.09) | (0.16) | (0.25) | (0.32) | (0.47) | (0.63) | (0.95) | (1.27) | (1.58) | (3.16) |
| <b>Absorbance<sup>(1)</sup>, wavelength (λ) = 525 nm</b>   |        |        |        |        |        |        |        |        |        |        |        |        |        |
| 0  | 0.011  | 0.059  | 0.134  | 0.197  | 0.329  | 0.516  | 0.627  | NL     | NL     | NL     | NL     | NL     | NL     |
| <b>Ascorbic Acid Stock Solution (M)<sup>(2)</sup></b>  |        |        |        |        |        |        |        |        |        |        |        |        |        |
| -  | 0.015  | 0.015  | 0.15   | 0.15   | 0.15   | 0.15   | 0.15   | 1.5    | 1.5    | 1.5    | 1.5    | 1.5    | 1.5    |
| <b>Volume of Ascorbic Acid solution (μL)</b>   |        |        |        |        |        |        |        |        |        |        |        |        |        |
| 0  | 30     | 150    | 30     | 46     | 76     | 121    | 152    | 23     | 30     | 46     | 61     | 76     | 152    |
| <b>Mass of Ascorbic Acid (mg)</b>  |        |        |        |        |        |        |        |        |        |        |        |        |        |
| 0  | 0.08   | 0.4    | 0.79   | 1.21   | 2.1    | 3.32   | 4.17   | 6.1    | 7.9    | 12.2   | 16.1   | 20.1   | 40.2   |
| (1) [MnO <sub>4</sub> <sup>-</sup> ] (mg/L) = 58.8 × A <sub>525</sub> ; A <sub>525</sub> is the absorbance at 525 nm; non-linear above 38 mg/L MnO <sub>4</sub> <sup>-</sup> . |        |        |        |        |        |        |        |        |        |        |        |        |        |
| (2) To minimize sample dilution, the ascorbic acid stock solution used was 0.015, 0.15, and 1.5 M.   |        |        |        |        |        |        |        |        |        |        |        |        |        |

contaminants is not a concern since the initial screening ground water sample is used specifically to determine the concentration of permanganate.



**Figure 2.** Calibration curve of  $\text{MnO}_4^-$  concentration versus absorbance at wavelength ( $\lambda$ ) of 525 nm.

### 2.1.3. Results

If  $\text{MnO}_4^-$  is not detected in the ground water sample, it is recommended that normal ground water sampling and analysis procedures be used. If  $\text{MnO}_4^-$  is detected, there are two general options to consider. The first option is to delay the collection and analysis of the ground water sample for a sufficient time allowing the  $\text{MnO}_4^-$  concentration to fully diminish in the subsurface, if desired. In some cases,  $\text{MnO}_4^-$  persistence is lengthy and this option is not possible (as discussed above in Section 1.1). Due to the site-specific time-dependency of contaminant mass transfer and transport, the time required to approach chemical equilibrium in ground water will likely require additional time after the oxidant is fully consumed. Subsequently, ground water sampling would follow routine guidelines and requirements. The second option is to collect and preserve the ground water sample (i.e., neutralize the oxidant) prior to analysis to minimize the impact of the commingled oxidant. The second option may be desirable for a number of reasons described in Section 1.1.

### 2.1.4. Oxidant Neutralization and Sample Preservation

Given the  $\text{MnO}_4^-$  concentration, the volume of ascorbic acid stock solution (0.015, 0.15, or 1.5 mol/L), or weight of crystalline ascorbic acid (176.12 g/mol) required to preserve the binary mixture is determined (Table 1). Sample preservation involves the addition of the appropriate amount of ascorbic acid to preserve a binary mixture in a 40 mL VOA vial. In a lab study (Johnson *et al.*, 2012), the mass of ascorbic acid required to neutralize  $\text{MnO}_4^-$  ranging in concentration from 1-750 milligrams per liter (mg/L) was determined empirically. The average molar ratio ( $n=14$ ) was 1.64 mol ascorbic acid/mol  $\text{MnO}_4^-$  and values ranged from 1.45 to 1.75 mol/mol. Therefore, the weight of ascorbic acid that corresponded with the  $\text{MnO}_4^-$  colorimetric scale was conservatively based on a stoichiometric ratio of 1.8 mol ascorbic acid/mol  $\text{MnO}_4^-$ , since, as noted below, no negative side-effects were noted with over-dosing. Detailed recommended operating procedures are provided in the Appendix to estimate the volume of crystalline ascorbic acid or ascorbic acid stock solution required to neutralize the  $\text{MnO}_4^-$ . Once the oxidant is neutralized, it is recommended that normal ground water sample handling and procedures be followed.

The recommended volume and mass of ascorbic acid included in Table 1 is a guideline. The addition of ascorbic acid will rapidly reduce the  $\text{MnO}_4^-$  concentration and eliminate the pink/purple color. The formation of colloidal or particulate  $\text{MnO}_2(\text{s})$  (i.e.,  $\text{Mn}^{+4}$ ) may occur causing a brown tinge appearance of the solution. Incremental amendment of ascorbic acid is required to further reduce the  $\text{Mn}^{+4}$  to  $\text{Mn}^{+2}$ , and eliminate the brownish tinge color.  $\text{Mn}^{+2}$  is highly soluble and the most desirable form of Mn to minimize the impact of colloidal or particulate matter on the laboratory analytical instruments. Overall, Table 1 is used as a guideline but the actual amount of ascorbic acid to be added should be based on the amount required to fully eliminate the  $\text{MnO}_4^-$  and  $\text{MnO}_2(\text{s})$ , and to achieve a clear solution.

Excess ascorbic acid did not have a negative impact on the quality of the ground water sample involving GC and GC/MS analysis of a broad range of organic chemicals (Johnson *et al.*, 2012). The volume of ascorbic acid solution added to the sample vial should be recorded so

appropriate dilution calculations can be performed to obtain an accurate estimate of the contaminant concentrations. Pre-amending sample vials with ascorbic acid is also an option and is discussed further in Section 7.F of the Appendix. Other sample preservation requirements are based on the analyses being performed and are specified in the quality assurance project plan, field sampling plan, RCRA guidance document (U.S. EPA, 1992) or EPA SW-846 (U.S. EPA, 1982). Additional direction on ground water sampling techniques can be found in Yeskis and Zavala (2002)

## 2.2. Persulfate ( $S_2O_8^{2-}$ )

The data and information below are presented in terms of the persulfate anion ( $S_2O_8^{2-}$ ; 192.0 g/mol). However, persulfate is predominantly purchased as sodium persulfate ( $Na_2S_2O_8$ ; 238.1 g/mol). As a result, conversion of sodium persulfate to persulfate anion concentrations is necessary to determine sample preservation needs as per the *Issue Paper*. Specifically, the ratio of 192.0/238.1 (g-mol/g-mol) is used to convert  $Na_2S_2O_8$  to  $S_2O_8^{2-}$ . Persulfate is colorless and requires field measurement at the well head to determine its presence and concentration in the ground water sample.

### 2.2.1. Analysis by Field Test Kit Colorimetry

Field test kits are commercially available to measure persulfate concentration in aqueous samples (CHEMetrics, 2011; FMC, 2012). CHEMetrics persulfate test kits are available for two sodium persulfate concentration ranges (0-7, 7-70 mg/L). Given the high concentrations of persulfate injected into the subsurface at ISCO sites, significant dilution may be required in the use of these test kits. FMC commercial test kits are dependent on whether the persulfate activator is base or thermal (test kit "K"), or whether persulfate is activated by iron chelates or  $H_2O_2$  (test kit "C") (FMC, 2012). The lower detection limit of persulfate using the current FMC test kits is 500 mg/L, a sufficient quantity of oxidant to significantly impact the concentrations of VOCs and the quality of the sample. Based on the current detection limit using the FMC test kit, it is recommended that the minimum amount of ascorbic acid added to the sample vessel should conservatively account for 500 mg/L persulfate.

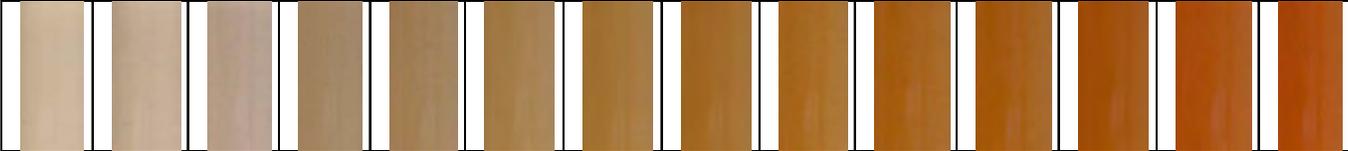
### 2.2.2. Analysis by Spectrophotometric Analysis (Ferrous Ammonium Sulfate (FAS) Method)

A spectrophotometric method can be used to analyze the persulfate concentration in aqueous samples. The ground water sample should be filtered (0.2-0.45 micron) to eliminate background material (i.e., turbidity) that may interfere with  $S_2O_8^{2-}$  analysis. A small volume of de-ionized (DI) water (0.9 mL) and sulfuric acid ( $H_2SO_4$ ) (10 mL, 2.5 normal (N)) (or, add 10.9 mL of 2.3 N  $H_2SO_4$ ) is placed in a 20 mL glass or plastic test vessel. These can be prepared prior to transport to the field. A blank is prepared by mixing 1 mL DI water with  $H_2SO_4$  (10 mL, 2.5 N). The filtered sample (0.1 mL) is placed in the test vessel, followed by the addition of ferrous ammonium sulfate (FAS) ( $Fe(SO_4)_2(NH_4)_2 \cdot 6H_2O$ ) (0.1 mL, 0.4 N) (prepared immediately before use). Adding a couple drops of  $H_2SO_4$  (conc.) to the FAS reagent increases the stability of the ferrous iron for several more hours (5 to 10 hours). The mixture is swirled/mixed and allowed to react for 30 to 40 minutes. Subsequently, the mixture is amended with ammonium thiocyanate ( $NH_4SCN$ ) (0.2 mL, 0.6 N) and the absorbance of the solution is analyzed immediately with a spectrophotometer at a wavelength of  $\lambda = 450$  nm ( $A_{450}$ ) (Huang *et al.*, 2002; Huling *et al.*, 2011a; b). The general colorimetric scale provided below can be used to estimate the persulfate concentration in a ground water sample (Table 2) analyzed by the FAS method. Alternatively, a calibration curve involving a linear correlation between  $S_2O_8^{2-}$  concentration and  $A_{450}$  can be used to determine a more precise estimate of the persulfate concentration (Figure 3).

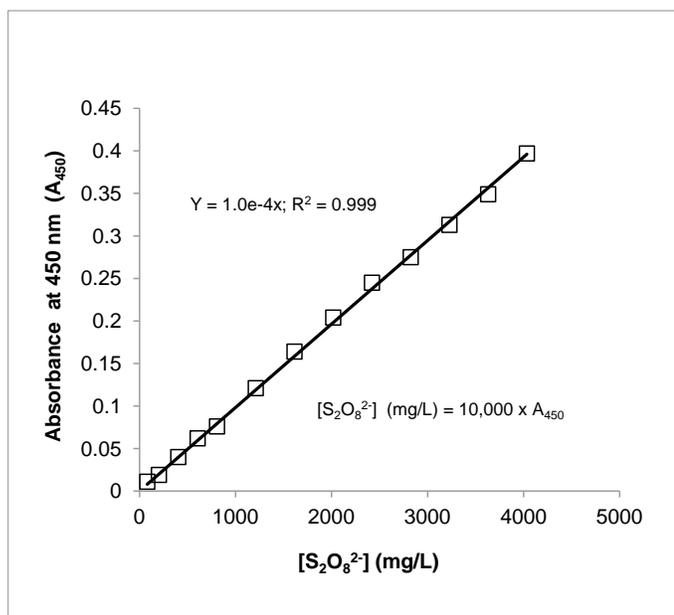
### 2.2.3. Results

If  $S_2O_8^{2-}$  is not detected in the ground water sample, it is recommended to proceed using normal ground water sampling and analysis procedures. If  $S_2O_8^{2-}$  is detected, there are two general options to consider. The first is to delay collection and analysis of the ground water sample for sufficient time which allows the persulfate concentration to fully diminish in the subsurface, if desired. Due to the site-specific time-dependency of contaminant mass transfer and transport, the time required to approach chemical equilibrium in ground water will likely require additional time after the oxidant is fully consumed. Subsequently, ground water sampling would follow routine guidelines. The second option is to collect and

**Table 2.** Persulfate concentrations resulting from the ferrous ammonium sulfate analytical method involving the spectrophotometric measurement ( $\lambda = 450$  nm) of the solution, and the required amount of ascorbic acid required to neutralize the oxidant in a 40 mL vial. The color scale represents actual photos of  $S_2O_8^{2-}$  vials and is included for conceptual guidance. Actual colors vary based on background lighting, and color printers. Additionally, photographs of low concentrations (i.e., clear solutions) do not accurately capture transparency.

|   |        |       |       |       |       |       |       |        |        |        |        |        |        |
|---|--------|-------|-------|-------|-------|-------|-------|--------|--------|--------|--------|--------|--------|
|   |        |       |       |       |       |       |       |        |        |        |        |        |        |
| <b>[S<sub>2</sub>O<sub>8</sub><sup>2-</sup>] (mg/L) (millimolar in parentheses)</b>   |        |       |       |       |       |       |       |        |        |        |        |        |        |
| 0   | 80     | 200   | 400   | 610   | 810   | 1210  | 1610  | 2020   | 2420   | 2820   | 3230   | 3630   | 4030   |
| 0   | (0.42) | (1.1) | (2.1) | (3.2) | (4.2) | (6.3) | (8.4) | (10.5) | (12.6) | (14.7) | (16.8) | (18.9) | (21.0) |
| <b>Absorbance<sup>(1)</sup>, wavelength (<math>\lambda</math>) = 450 nm</b>   |        |       |       |       |       |       |       |        |        |        |        |        |        |
| 0   | 0.011  | 0.019 | 0.04  | 0.062 | 0.076 | 0.121 | 0.164 | 0.204  | 0.245  | 0.275  | 0.313  | 0.349  | 0.397  |
| <b>Volume of Ascorbic Acid solution (mL)</b>  |        |       |       |       |       |       |       |        |        |        |        |        |        |
| 0   | 0.04   | 0.11  | 0.22  | 0.34  | 0.45  | 0.67  | 0.89  | 1.12   | 1.34   | 1.57   | 1.79   | 2.02   | 2.24   |
| <b>Mass of Ascorbic Acid (176.12 g/mol) (g)</b>   |        |       |       |       |       |       |       |        |        |        |        |        |        |
| 0   | 0.01   | 0.03  | 0.06  | 0.09  | 0.12  | 0.18  | 0.24  | 0.3    | 0.35   | 0.41   | 0.47   | 0.53   | 0.59   |
| (1) Solubility of ascorbic acid in water = 330 g/L (1.87 mol/L); 80% solubility (1.5 mol/L) used as stock solution; [S <sub>2</sub> O <sub>8</sub> <sup>2-</sup> ] (mg/L) = 10,000 × A <sub>450</sub> ; where A <sub>450</sub> is the absorbance at 450 nm. |        |       |       |       |       |       |       |        |        |        |        |        |        |

preserve the ground water sample prior to analysis to minimize the impact of persulfate on the ground water sample. The second option may be desirable for a number of reasons described in Section 1.1.



**Figure 3.** Calibration curve for  $S_2O_8^{2-}$  concentration versus absorbance at wavelength 450 nm using the ferrous ammonium sulfate method.

#### 2.2.4. Oxidant Neutralization and Sample Preservation

Guidelines for the volume of ascorbic acid stock solution (1.5 mol/L) or the weight of crystalline ascorbic acid (176.1 g/mol) required to preserve the binary mixture in a 40 mL sample vial are provided (Table 2). The mass of ascorbic acid that corresponds with the persulfate colorimetric scale is based on a stoichiometric ratio of 4 mol ascorbic acid/mol persulfate and was determined empirically in a laboratory study (Huling *et al.*, 2011a). Detailed recommended operating procedures are provided in the Appendix to estimate the volume of crystalline ascorbic acid or ascorbic acid stock solution required to neutralize the  $S_2O_8^{2-}$ . This stoichiometric ratio is in excess of the ideal stoichiometry for mineralization of persulfate by ascorbic acid. Excess ascorbic acid (4 – 40 mol ascorbic acid/mol persulfate) did not have a negative impact on the quality of the ground water sample involving GC and GC/MS analysis of BTX, TCE, and PCE (Huling *et al.*, 2011a). The basis for this quantity of ascorbic acid is to achieve favorable reaction kinetics between  $\cdot SO_4^-$  and ascorbic acid, relative to the reaction between the sulfate radical ( $\cdot SO_4^-$ ) and the VOCs. Following oxidant neutralization, it is recommended that other approved sample preservation and handling methods

in ground water sample handling be performed. For example, acidification of the sample is normally carried out to minimize biochemical and reduction reactions. Other sample preservation requirements are based on the analyses being performed and are specified in the quality assurance project plan, field sampling plan, RCRA guidance document (U.S. EPA, 1992) or EPA SW-846 (U.S. EPA, 1982). Additional direction on ground water sampling techniques can be found in Yeskis and Zavala (2002).

### 3. ADDITIONAL INFORMATION

It is recommended that the analytical laboratory be notified that the aqueous samples contain residual persulfate or permanganate and were preserved with ascorbic acid. The volume of ascorbic acid solution added to the sample should be recorded so the appropriate calculations can be used to correct for dilutions. If  $\text{MnO}_2(\text{s})$  has settled on the bottom of the VOA vial, it is important that the sample not be disturbed prior to analysis. This precaution in sample handling prevents the suspension of the  $\text{MnO}_2(\text{s})$  particles and the potential for accidental injection into the analytical instruments.

Other preservatives have been used to successfully neutralize these oxidants, but may negatively impact the quality of the sample (Huling *et al.*, 2011a). Despite efforts used to neutralize the oxidant and to preserve the quality of the ground water sample, the presence of oxidant in ground water samples introduces uncertainty in the precise measurement of contaminant concentrations in the subsurface. This is attributed to the potential impact of the oxidant on contaminant concentrations in the ground water sample prior to neutralization, the transient nature of contaminant fate and transport in the subsurface where ISCO activities were deployed, and the site-specific oxidant injection and hydrogeologic conditions contributing to binary mixtures. Consequently, additional ground water sample collection and analysis will likely be required to achieve an accurate evaluation of post-ISCO performance, and regulatory adherence with US EPA ground water compliance monitoring requirements.

Numerous examples exist where elevated permanganate and VOC concentrations have been measured in ground water samples collected over extended periods of time at

hazardous waste sites. It can be concluded from a simple kinetic analysis that long term VOC persistence can primarily be explained by spatial separation between the ground water containing the oxidant and contaminant (Figure 1) (Johnson *et al.*, 2012). Ground water samples derived from wells screened over spatially separate vertical intervals indicate an in-well mixture of ground water containing either oxidants or contaminants. Limited contact between the oxidant and contaminant within the same lithologic unit can be due to specific mass transfer or mass transport conditions including the dissolution of non-aqueous phase liquids (NAPLs) or slow diffusion of contaminants from low permeability materials. These fate and transport conditions indicate the oxidant has not been uniformly delivered to the contaminated zone(s). A critical analysis of screened intervals, injection intervals, contaminated intervals, oxidant and contaminant transport characteristics, and ground water sample results from analyzing preserved binary mixtures, could provide valuable insight for the development of a more accurate site conceptual model that could be used to design and deploy a more effective oxidant delivery system.

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- International) for graphics preparation and Ms. Martha Williams (SRA International) for desktop publishing. A portable document format (PDF) version of this document is available for viewing or downloading from <http://www.epa.gov/nrmrl/gwerd/publications.html> (please refer to “In Situ Chemical Oxidation; “Issue Paper”; or “2012”).

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# Appendix Recommended Operating Procedures - Preservation of Ground Water Samples at ISCO Sites Using Ascorbic Acid

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## 1. PURPOSE (SCOPE AND APPLICATION)

The commingling of organic contaminants and oxidants in ground water or aqueous samples represents a condition in which there is significant potential for oxidative transformation of the contaminants after the sample is collected. Consequently, the quality of the ground water or aqueous sample may be compromised and a false negative result may occur. These recommended operating procedures describe the steps used to preserve ground water samples containing the oxidants permanganate ( $\text{MnO}_4^-$ ), or persulfate ( $\text{S}_2\text{O}_8^{2-}$ ) and organic contaminants of concern (COCs) prior to analysis. It is applicable for ground water samples containing volatile and non-volatile organic contaminants to be analyzed by

gas chromatography (GC), or gas chromatography-mass spectroscopy (GC-MS), using either the purge and trap or headspace sample introduction methods, and high performance liquid chromatography (HPLC).

These procedures are also applicable to bench-scale studies where oxidants are used to investigate the feasibility of ISCO treatment. For example, aqueous samples collected from bench-scale soil reactors are analyzed for organic contaminants, but may also contain the oxidant amended to the reactor to destroy the contaminant. Consequently, the guidelines and general procedures described below also extend to bench-scale studies where the potential for binary mixture aqueous samples may occur, and are analyzed for organic contaminants.

## 2. METHOD SUMMARY

Based on the measured or estimated oxidant concentration in a ground water or aqueous sample, a specific quantity of the preservative, ascorbic acid, is added to the ground water or aqueous sample to either neutralize or to limit the impact of the residual oxidant on the quality of the sample. Tables 1 and 2 in the *Issue Paper* are used as guidelines to estimate the amount of ascorbic acid to add to a 40 mL VOA vial to preserve binary mixture ground water and/or aqueous samples.

## 3. REAGENTS

Ascorbic Acid ( $\text{C}_6\text{H}_8\text{O}_6$ ;  $176.1 \text{ g mol}^{-1}$ )

De-ionized (DI) water

Ferrous ammonium sulfate (FAS) reagents – sulfuric acid ( $\text{H}_2\text{SO}_4$ ), ferrous ammonium sulfate ( $\text{Fe}(\text{SO}_4)_2(\text{NH}_4)_2 \cdot 6\text{H}_2\text{O}$ ), ammonium thiocyanate ( $\text{NH}_4\text{SCN}$ ).

## 4. EQUIPMENT/APPARATUS

Pipette, volumetric flasks, spectrophotometer (or field test kits)

SenSafe™ or CHEMetrics field test kits for permanganate measurement (if used), or direct measurement.

CHEMetrics or FMC field test kits for persulfate measurement (if used), or measurement using FAS method.

## 5. HEALTH AND SAFETY PRECAUTIONS

The Materials Safety Data Sheet for ascorbic acid indicates potentially acute health effects: slightly hazardous in case of skin contact (irritant), of eye contact (irritant), of ingestion, of inhalation. In case of skin contact: wash

with soap and water. Cover the irritated skin with an emollient. Get medical attention if irritation develops. Cold water may be used. Other guidelines are available based on exposure (<http://www.sciencelab.com/msds.php?msdsId=9922972>). It is recommended to wear gloves and safety glasses during all of the procedures described herein due to the potential for exposure to oxidants, impacted ground water sample, and other chemicals involved in these procedures. Always consult site-specific health and safety plans prior to sampling.

## 6. INTERFERENCES

Colloidal and/or suspended solids in ground water samples may adsorb light and interfere with the measurement of oxidant concentration. For this reason, the ground water sample may require filtration (0.2-0.45  $\mu\text{m}$ ) to eliminate background material (i.e., turbidity).

## 7. PROCEDURES

### A. Ascorbic Acid

Prepare ascorbic acid stock solution either in the lab prior to ground water sampling, or in the field. The appropriate use of these stock solutions is dependent on concentrations of the oxidant measured in the ground water samples. The stock solution should be stored in a refrigerator or cooler until used, and discarded after 150 days.

High Concentration Stock Solution: 1.5 M ascorbic acid (e.g., add 264 g of ascorbic acid (MW=176.1 g/mol) to 1L volumetric flask and fill with DI water). This stock solution can be diluted in the preparation of 0.015 and 0.15 M ascorbic acid stock solutions.

Medium Concentration Stock Solution: 0.15 M ascorbic acid: Dilute 1.5 M ascorbic acid stock solution 1:10 (e.g., dilute 100 mL of 1.5 M stock solution to 1L with DI water).

Low Concentration Stock Solution: 0.015 M ascorbic acid: Dilute 1.5 M ascorbic acid stock solution 1:100 (e.g., dilute 10 mL of 1.5 M stock solution to 1L with DI water).

### B. Sample Filtration

Filter the ground water or aqueous sample using 0.2–0.45  $\mu\text{m}$  filter (as needed in accordance with the

site QAPP or Sampling and Analysis Plan) to eliminate background material (i.e., turbidity) that may interfere with oxidant analysis.

### C. Concentration Measurement

Determine the oxidant concentrations (permanganate or persulfate) through one of three methods below.

- 1) Commercially available test kits
  - a. Permanganate: SenSafe™ or CHEMetrics
  - b. Persulfate: CHEMetrics or FMC
- 2) UV-VIS absorbance
  - a. Permanganate (direct measurement): wavelength = 525 nm
  - b. Persulfate (Ferrous Ammonium Sulfate method): wavelength = 450 nm (Huang *et al.*, 2002; Huling *et al.*, 2011)
- 3) Colorimetric scales presented in Tables 1 and 2.

Based on the oxidant concentration determined, ascorbic acid stock solution is added to an empty sample vial according to Tables 1 and 2.

### D. Quality Assurance and Quality Control (QA/QC)

Quality control includes regularly scheduled analysis of method blanks and sample replicates, and the verification of stock solutions of known concentration via the analysis for concentrations of secondary solutions prepared from the stocks. Results of the analyses of method blanks, replicate analyses, and the verification of stock solution concentrations are logged and maintained in record books specific to the research being conducted. The frequency, control limits, and corrective actions should be appropriately developed for specific applications.

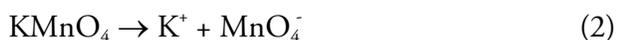
### E. Calculations

- 1) Concentration conversion
  - a. Permanganate.

The concentrations of permanganate ( $\text{MnO}_4^-$ ) have been presented in terms of the permanganate anion (118.9 g/mol) (Table 1). However, permanganate is purchased either as sodium permanganate ( $\text{NaMnO}_4$ ; 141.9 g/mol) or potassium permanganate ( $\text{KMnO}_4$ ; 158.0 g/mol) and as a result conversion to permanganate anion concentrations may be desired to determine

adequate sample preservation needs. Specifically, the ratios 118.9/141.9 (0.84) and 118.9/158.0 (0.75) are used to convert NaMnO<sub>4</sub> and KMnO<sub>4</sub> respectively, to MnO<sub>4</sub><sup>-</sup> (Table A1).

Because 1 mmole of either sodium or potassium permanganate produces 1 mmole of permanganate (Eqs 1 and 2), the molar concentrations of sodium and potassium permanganate are the same as permanganate (Table 3).



Converting sodium and potassium permanganate concentrations from mg/L to millimolar, and calculating their permanganate equivalence,

$$\begin{aligned} X \text{ mg/L NaMnO}_4 &= \\ (X \text{ mg/L}) \times (1 \text{ mmol}/141.9 \text{ mg}) &= \\ X/141.9 \text{ mM NaMnO}_4 &= \\ X/141.9 \text{ mM MnO}_4^- &= \\ ((X/141.9) \text{ mmol/L}) \times (118.9 \text{ mg}/\text{mmol}) &= \\ 0.84X \text{ mg/L MnO}_4^- & \end{aligned}$$

NOTE: 1 mmol = 0.001 mol; mM= mmol/L

$$\begin{aligned} Y \text{ mg/L KMnO}_4 &= \\ (Y \text{ mg/L}) \times (1 \text{ mmol}/158.0 \text{ mg}) &= \\ Y/158.0 \text{ mM KMnO}_4 &= \\ Y/158.0 \text{ mM MnO}_4^- &= \\ ((Y/158.0) \text{ mmol/L}) \times (118.9 \text{ mg}/\text{mmol}) &= \\ 0.75Y \text{ mg/L MnO}_4^- & \end{aligned}$$

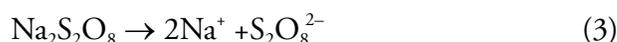
NOTE: 1 mmol = 0.001 mol; mM= mmol/L

b. Persulfate.

The concentration of persulfate is presented in terms of

the persulfate anion (S<sub>2</sub>O<sub>8</sub><sup>2-</sup>; 192.0 g/mol) (Table A2). However, persulfate is purchased as sodium persulfate (Na<sub>2</sub>S<sub>2</sub>O<sub>8</sub>; 238.1 g/mol) and as a result a conversion may be desired to correct for the anionic form of the oxidant and to determine adequate sample preservation needs. Specifically, the ratio of 192.0/238.1 (0.81) is used to convert Na<sub>2</sub>S<sub>2</sub>O<sub>8</sub> to S<sub>2</sub>O<sub>8</sub><sup>2-</sup>. Persulfate is colorless and requires field measurement at the well head to determine its presence and concentration in the ground water sample.

Converting sodium persulfate concentrations from mg/L to millimolar, and calculating the persulfate equivalence,



$$\begin{aligned} Z \text{ mg/L Na}_2\text{S}_2\text{O}_8 &= \\ (Z \text{ mg/L}) \times (1 \text{ mmole}/238.1 \text{ mg}) &= \\ Z/238.1 \text{ mM Na}_2\text{S}_2\text{O}_8 &= \\ Z/238.1 \text{ mM S}_2\text{O}_8^{2-} &= \\ (Z/238.1 \text{ mM S}_2\text{O}_8^{2-}) &= \\ ((Z/238.1) \text{ mmole/L}) \times (192 \text{ mg}/\text{mmole}) &= \\ 0.81Z \text{ mg/L S}_2\text{O}_8^{2-} & \end{aligned}$$

2) Required volume and mass of ascorbic acid to neutralize oxidants.

a. Permanganate.

1.8 mole ascorbic acid per mole of permanganate was empirically determined to effectively neutralize permanganate in an aqueous sample containing VOCs (Johnson *et al.*, 2012). Therefore, the mass balance equation (Eq 4) can be set up as follows,

$$1.8C_{\text{MnO}_4^-} V_{\text{MnO}_4^-} = C_{\text{H}_2\text{A}} V_{\text{H}_2\text{A}} \quad (4)$$

Where,

C<sub>MnO<sub>4</sub><sup>-</sup></sub> = permanganate concentration determined in step 7.C,

**Table A1.** Corresponding concentration of sodium permanganate and potassium permanganate to permanganate.

|                               |      |       |       |       |       |      |      |      |      |      |      |      |      |      |
|-------------------------------|------|-------|-------|-------|-------|------|------|------|------|------|------|------|------|------|
| NaMnO <sub>4</sub>            | mg/L | 0.90  | 4.5   | 9.0   | 13.5  | 22.4 | 35.9 | 44.9 | 67.3 | 89.9 | 135  | 180  | 224  | 449  |
|                               | mM   | 0.006 | 0.032 | 0.063 | 0.095 | 0.16 | 0.25 | 0.32 | 0.47 | 0.63 | 0.95 | 1.27 | 1.58 | 3.16 |
| KMnO <sub>4</sub>             | mg/L | 1.00  | 5.0   | 10.0  | 15.0  | 25.0 | 40.0 | 50.0 | 74.9 | 100  | 150  | 201  | 250  | 500  |
|                               | mM   | 0.006 | 0.032 | 0.063 | 0.095 | 0.16 | 0.25 | 0.32 | 0.47 | 0.63 | 0.95 | 1.27 | 1.58 | 3.16 |
| MnO <sub>4</sub> <sup>-</sup> | mg/L | 0.75  | 3.8   | 7.5   | 11.3  | 18.8 | 30.1 | 37.9 | 56.4 | 75.3 | 113  | 151  | 188  | 376  |
|                               | mM   | 0.006 | 0.032 | 0.063 | 0.095 | 0.16 | 0.25 | 0.32 | 0.47 | 0.63 | 0.95 | 1.27 | 1.58 | 3.16 |

**Table A2.** Corresponding concentration of sodium persulfate to persulfate ( $S_2O_8^{2-}$ ).

|   |      |      |     |     |     |      |      |      |      |      |      |      |      |      |
|---|------|------|-----|-----|-----|------|------|------|------|------|------|------|------|------|
| Na <sub>2</sub> S <sub>2</sub> O <sub>8</sub> | mg/L | 99   | 248 | 496 | 756 | 1004 | 1500 | 1996 | 2504 | 3000 | 3496 | 4004 | 4500 | 4996 |
|   | mM   | 0.42 | 1.0 | 2.1 | 3.2 | 4.2  | 6.3  | 8.4  | 10.5 | 12.6 | 14.7 | 16.8 | 18.9 | 21.0 |
| S <sub>2</sub> O <sub>8</sub> <sup>2-</sup>   | mg/L | 80   | 200 | 400 | 610 | 810  | 1210 | 1610 | 2020 | 2420 | 2820 | 3230 | 3630 | 4030 |
|   | mM   | 0.42 | 1.0 | 2.1 | 3.2 | 4.2  | 6.3  | 8.4  | 10.5 | 12.6 | 14.7 | 16.8 | 18.9 | 21.0 |

$V_{MnO_4^-}$  = volume of permanganate solution in the VOA vial (0.04 L),

$C_{H_2A}$  = ascorbic acid concentration (0.015, 0.15 or 1.5 M), and

$V_{H_2A}$  = volume of ascorbic acid required to neutralize permanganate.

$V_{H_2A}$  can be calculated (Eq 5) through rearranging Eq. (4)

$$V_{H_2A} = (1.8 \times C_{MnO_4^-} \times V_{MnO_4^-}) / C_{H_2A} \quad (5)$$

For example, a 40 mL permanganate concentration of 1.27mM (151 mg/L) is neutralized using 1.5 M ascorbic acid. The volume of stock solution and mass of ascorbic acid can be calculated as follows.

$$V_{H_2A} = (1.8 \times 1.27 \text{ mmol/L} \times 0.04\text{L} / 1.5 \text{ mol/L}) \times (1 \text{ mol} / 1000 \text{ mmol}) \times (10^6 \text{ } \mu\text{L} / 1\text{L}) = 61 \text{ } \mu\text{L}$$

$$M_{H_2A} = 1.5 \text{ mol/L} \times 61 \text{ } \mu\text{L} \times (1\text{L} / 10^6 \text{ } \mu\text{L}) \times (176.12 \text{ g/mol}) \times (1000 \text{ mg/g}) = 16.1 \text{ mg}$$

Where,

$M_{H_2A}$  = mass of ascorbic acid

The formation of colloidal or particulate  $MnO_2(s)$  (i.e.,  $Mn^{+4}$ ) may occur causing a brown tinge appearance of the solution. Incremental amendment of ascorbic acid may be required to further reduce the  $Mn^{+4}$  to  $Mn^{+2}$ , and eliminate the brownish tinge color.  $Mn^{+2}$  is highly soluble and the most desirable form of Mn to minimize the impact of colloidal or particulate matter on the laboratory analytical instruments. Overall, Table 1 is used as a guideline but the actual amount should be based on the amount required to fully eliminate the  $MnO_4^-$  and  $MnO_2(s)$ , and to achieve a clear solution. The volume of ascorbic acid solution added to the sample vial should be recorded so appropriate dilution calculations can be performed to obtain an accurate estimate of the contaminant concentrations.

b. Persulfate.

4 mole of ascorbic acid per mole of persulfate was

empirically determined to effectively limit the impact of the oxidant on VOCs in aqueous samples (Huling *et al.*, 2011). Therefore, the mass balance equation (Eq 6) can be set up as follows,

$$4C_{S_2O_8^{2-}} \cdot V_{S_2O_8^{2-}} = C_{H_2A} V_{H_2A} \quad (6)$$

Where,

$C_{S_2O_8^{2-}}$  = persulfate concentration determined in step 7.  $C_{S_2O_8^{2-}}$  = volume of persulfate solution in the VOA vial 0.04 L,

$C_{H_2A}$  = ascorbic acid concentration (1.5 M),

$V_{H_2A}$  = volume of ascorbic acid required to neutralize persulfate

$V_{H_2A}$  can be calculated (Eq 7) through rearranging Eq. (6)

$$V_{H_2A} = (4 \times C_{S_2O_8^{2-}} \times V_{S_2O_8^{2-}}) / C_{H_2A} \quad (7)$$

For example, persulfate concentration is 10.5 mM (2020 mg/L) and neutralized using 1.5 M ascorbic acid. The volume of stock solution and mass of ascorbic acid can be calculated as follows.

$$V_{H_2A} = (4 \times 10.5 \text{ mmol/L} \times 0.04\text{L} / 1.5 \text{ mol/L}) \times (1 \text{ mol} / 1000 \text{ mmol}) \times (1000 \text{ mL} / 1\text{L}) = 1.12 \text{ mL}$$

$$M_{H_2A} = 1.5 \text{ mol/L} \times 1.12 \text{ mL} \times (1 \text{ L} / 1000 \text{ mL}) \times (176.12 \text{ g/mol}) = 0.3 \text{ g}$$

Where,

$M_{H_2A}$  = mass of ascorbic acid

The volume of ascorbic acid solution added to the sample vial should be recorded so appropriate dilution calculations can be performed to obtain an accurate estimate of the contaminant concentrations.

### F. Pre-amending Sample Vials With Preservative

Pre-amending the 40 mL sample vials prior to performing ground water sample collection in the field is one step that may help simplify sample preservation procedures. The advantage is that all sample vials are

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amended with the preservative in a uniform manner, and this reduces the number of steps and time required during ground water sampling activities in the field. Specifically, this would involve amending the sample vial with an appropriate quantity of ascorbic acid using the procedures recommended above. Successful sample preservation would be immediately obvious in the case with permanganate binary mixtures as the pink/purple color would disappear and the sample would become clear. A persistent pink/purple or brown tinge color would indicate the need for additional preservative. The immediate visual feedback would not occur in the preservation of persulfate binary mixtures due to the absence of oxidant coloration. Success of the preservation method will most likely require prior knowledge of oxidant concentrations in ground water samples to support the selection of an appropriate quantity of preservative. A quality assurance step could include the collection of duplicate samples, and subsequent analysis for persulfate, when time permits, to confirm that a sufficient quantity of preservative was amended. Other appropriate quality assurance steps could be developed.

## 8. REFERENCES

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## 9. DISCLAIMER

This recommended operating procedure has been prepared for general use. This is not an official approved U.S. Environmental Protection Agency method and has not undergone the Agency's peer review process.



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