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MATRIXNEWORLD
Engineering Progress

November 9, 2015

Ms. Catherine Brown
EPA - Region IX
75 Hawthorne Street
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DELIVER TO 9TH FLOOR
San Francisco, CA 94105

Re: FINAL TECHNICAL MEMORANDUM #1: LABORATORY TREATABILITY STUDY DETAILS PHASE I SOURCE AREA REMEDIATION PHOENIX-GOODYEAR AIRPORT-NORTH SUPERFUND SITE GOODYEAR, ARIZONA

Dear Ms. Brown:

On behalf of Crane Co., Matrix New World Engineering, Inc. (Matrix) is pleased to present this Final Technical Memorandum #1 for the Phase I Source Area Remediation, Phoenix-Goodyear Airport-North (PGA-North) Superfund Site (Site) in Goodyear, Arizona. This Final Technical Memorandum was developed with assistance from Dr. Laurie LaPat-Polasko, Ph.D. of Ramboll, Dr. Dan Elliott, Ph.D. of Geosyntec, and Dr. Rosa Krajmalnik-Brown and Dr. Anca Delgado of Arizona State University (ASU). It provides details of the laboratory treatability study; specifies the types of zero valent iron (ZVI), bioamendments, and microbial cultures that will be used; and outlines the proposed methodologies that will be employed for both the batch microcosms and subsequent column studies. This Final Technical Memorandum has been modified in accordance with the Responsiveness Summary to the Draft Technical Memorandum #1: Laboratory Treatability Study Details dated September 10, 2015. It also addresses the questions and comments in the October 9, 2015 letter from Arizona Department of Environmental Quality (ADEQ) and the memo dated October 9, 2015 from Gilbane to Ms. Catherine Brown of the United States Environmental Protection Agency (EPA). This Final Technical Memorandum is being submitted in accordance with the EPA approved Final Remedial Design/Remedial Action (RDRA) Work Plan Phase I Source Area Remediation, dated April 16, 2015 and the October 9, 2015 EPA and Gilbane letter that found the PGA-North Teams responses to the Agency comments acceptable and a Final Technical Memorandum can be prepared.

After a thorough review and evaluation of proposals from multiple pre-qualified laboratories throughout North America, we anticipate that the treatability study will be conducted at the Swette Center for Environmental Biotechnology, Biodesign Institute at ASU in Tempe, Arizona, pending approval of this Final Technical Memorandum by EPA. Matrix believes that performing the studies locally provides great advantages in terms for logistics (e.g., close proximity and rapid transport of site material to lab) and communication between Matrix and the ASU project team Additionally Dr. Krajmalnik-Brown is an expert in reductive dechlorination and her lab has state of the art facilities to conduct this study. Recently Dr. Krajmalnik-Brown has been involved in various field-scale treatability projects in the area of

bioremediation of chlorinated solvents and perchlorate for the Roosevelt Irrigation District-92 Wellhead treatment system, West Van Buren Water Quality Assurance Revolving Fund (WQARF) Registry Site.

Objectives

The proposed laboratory treatability study will be conducted as part of the initial implementation of the Phase I remedial activities. Given the relative size of the Source Area, the Site's complex hydrostratigraphy, the naturally aerobic aquifer, and the principal contaminants (e.g., trichloroethene [TCE] and perchlorate), the main purpose of the treatability study is to develop needed design-related insights for the combined remedy of nanoscale zero valent iron (nZVI), micro scale zero valent iron (mZVI), and anaerobic reductive dechlorination (ARD), approved by the EPA and contained in the Record of Decision (ROD) Amendment dated September 2014 (EPA 2014). Considering that prior bench testing and Phase III Pilot study (H&A 2011) only evaluated nZVI, these studies are essential to develop the appropriate design and implementation considerations for the combination of nZVI, mZVI, and bioamendments.

The objectives of the laboratory treatability study will be to evaluate the potential for using in situ bioremediation, enhanced by ZVI abiotic reactions, as a feasible strategy for reduction of TCE concentrations greater than or equal to (≥) 1,000 micrograms per liter (µg/L) and perchlorate concentrations ≥ 100 µg/L in Source Area groundwater to meet the objectives outlined below:

1) Using microcosm batch reactors, establish a combination of ZVI and microbiological amendments that promotes the highest level of TCE and perchlorate reduction in Source Area sediment and groundwater. Evaluate the extent of TCE and perchlorate reduction in batch test microcosms using PGA-North Source Area sediment and groundwater; and

2) Design and operate a series of aquifer sediment columns for the reduction of TCE and perchlorate in PGA-North sediment and groundwater. The chemical and microbiological data obtained in Objective 1 will be used to enhance the design of the test column conditions for Objective 2. The findings from Objective 2 will serve as a proof of concept for designing the Phase I Source Area treatment.

As part of the treatability study scope, different types and combinations of nZVI and mZVI will be used in concert with various biostimulation and bioaugmentation options. At this juncture, the microcosm study is expected to include either or both BASF's OM grade carbonyl iron powder or Rio Tinto's Atomet 86™ as the mZVI component of the combined remedy. The microcosm study is also expected to include the assessment of one or more nZVI types as well. Candidate nZVI varieties could include NanoFer Star (NANO IRON s.r.o., Czech Republic), or Z-Loy™ (OnMaterials, LLC), a very fine mZVI with a size distribution very similar to that of commercially available nZVI products. While there are a wide variety of nZVI materials available in the research and development realm, few are truly commercially available. The PGA-North Technical Team is currently investigating the feasibility of utilizing an additional nZVI material for inclusion in the treatability study. If this effort proves successful, characterization details for this new nZVI will be developed in parallel with the treatability study. Table 1 below provides an overview of the candidate mZVI and nZVI products being considered for the PGA-North Site at this time. If other nZVI formulations become available, these will also be discussed with the EPA and considered in the treatability study. This bench-scale study will also include an evaluation of the chemical and microbial interactions of the various amendments.

Table 1. Comparative Overview of Candidate ZVI Products for PGA-North Treatability Study

ZVI Product	Type	Particle Size* (µm)	Composition	SSA** (m^2/g)	Comments
BASF OM	mZVI	4.5 µm.	Fe – 98.2% C – 0.78% O – 0.25%	0.17	ZVI fine powder. Increasing use in environmental remediation.
Atomet 86	mZVI	75 µm	Fe – 98% C – 0.15% O – 0.7%	0.011	ZVI fine powder. Increasing use in environmental remediation.
NanoFer Star	nZVI	0.05 µm	80-90% Fe 10-20% Fe-oxides	20-25	Air stable nZVI with a fine oxide coating. Requires aqueous activation. Significant usage of other NanoFer products in the Czech Republic and elsewhere in the EU.
Z-Loy	nZVI***	2-3 µm	Fe^0/Al^0	~0.3	Suspended in ethylene glycol. No additional composition data was available. Has been used extensively in remediation.

* The average (d_{50}) particle size is presented here, not the distribution of particle sizes.
**SSA – Specific Surface Area
***The Z-Loy™ iron is technically in the very fine microscale range but was historically marketed as nZVI although current product literature shows this to not be the case.

The specific bench-scale questions to be addressed include:

- What are the rates of TCE and perchlorate reduction post ZVI amendment and when bioaugmentation is applied in combination with biostimulation?
- What are the main electron-accepting microbial processes that compete with and limit TCE dechlorination and perchlorate reduction? What strategies can be implemented to minimize competing processes and maximize TCE and perchlorate reductions?
- What is the effect of the ZVI, varieties individually (as microscale and nanoscale irons) and collectively, on the biogeochemistry of the PGA-North sediments within the Source Area? Will microscale ZVI facilitate the effective abiotic reduction of TCE and perchlorate in Site Source Area groundwater? Will mZVI promote the rapid deoxygenation of Source Area groundwater and help to establish appropriate geochemical conditions for ARD? What doses of mZVI and nZVI are optimal for the abiotic degradation of TCE and, as applicable, perchlorate?
- Will fast-release electron donor/carbon source(s) sustain the ARD of TCE and perchlorate in order to achieve the desired transformation/removal rates for these contaminants or, will a slow-release electron donor/carbon source(s) accomplish this more effectively? Might a combination of both fast- and slow-release electron donors, either sequenced or delivered together provide better overall biostimulation performance?
- What is the most effective deployment strategy for the ZVI and electron donor amendments?
- What rates of TCE and perchlorate reduction, post ZVI addition, are achieved? What rates are achieved when bioaugmentation is combined with biostimulation?

- What are the major microbial terminal electron-accepting processes (TEAPs) that compete with and can limit TCE dechlorination and perchlorate reduction? Will any of these TEAPs affect the abiotic transformation of the primary contaminants? What strategies can be implemented to minimize these competing processes and maximize TCE and perchlorate reduction?
- How does bioaugmentation impact the rate of TCE and perchlorate biodegradation in comparison to non-bioaugmented systems?
- How do the fast- or slow-release electron donors and bioaugmentation amendments impact metal conversion or metal precipitation?
- What impact do the amendments have on potential clogging of the sediment columns?
- Which priority pollutant metals, if any, are released as a result of microbial processes in the sediment columns?

Background

Chlorinated ethenes reductive dechlorination

In situ bioremediation is a common and cost-effective avenue for treatment of sites contaminated with chlorinated solvents. Of particular importance for bioremediation are *Dehalococcoides mccartyi* strains that reduce the widespread soil and groundwater contaminant, TCE, and the daughter chlorinated products, *cis*-1,2-dichloroethene (*cis*-DCE) and vinyl chloride (VC) to the non-toxic, non-chlorinated end product, ethene (He et al. 2003; Loffler et al. 2013; Maymo-Gatell et al. 1997). These strains couple the sequential reductive dechlorination (shown in Figure 1) of these chlorinated ethenes to growth using hydrogen (H_2) as electron donor and acetate as carbon source (Loffler et al. 2013). The potential for partial reduction of TCE to *cis*-DCE exists in multiple bacterial taxa: *Chloroflexi, Firmicutes* and *Proteobacteria* (class *δ*- and *ε-Proteobacteria*) (Hug et al. 2013). On the other hand, the capacity to dechlorinate chlorinated ethenes to ethene is, to date, unique to *Dehalococcoides mccartyi*. *Dehalococcoides* have been identified at all contaminated sites where ethene was formed from TCE as a result of reductive dechlorination (Ellis et al. 2000; Hendrickson et al. 2002; Lendvay et al. 2003; Loffler et al. 2013; Major et al. 2002)

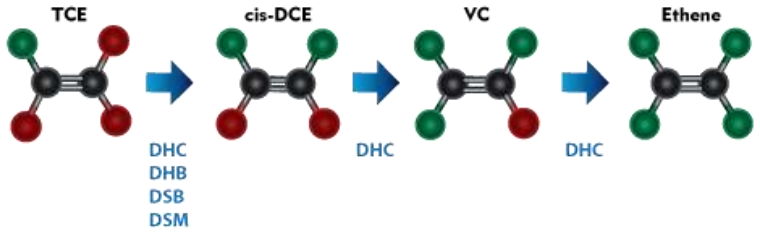

Figure 1. Microbial strains responsible for reductive dechlorination of PCE and byproducts: Dehalococcoides (DHC), Dehalobacter (DHB), Desulfitobacterium (DSB) and Desulfuromonas (DSM).

Biological perchlorate reduction

Similar to TCE, perchlorate can also be microbially transformed to an innocuous product, chloride (Cl^-) (Nerenberg et al. 2002). Perchlorate respiration is performed by microbes known as perchlorate-reducing bacteria (PRB). These are phylogenetically diverse, mostly found in α-, β-, γ-, and ε- *Proteobacteria* (Coates and Achenbach 2004). The majority of PRB can use other electron acceptors besides

perchlorate, i.e., oxygen (O_2), nitrate (NO_3^-), and chlorate (ClO_3^-) in preference to perchlorate (Bardiya and Bae 2011). As shown in Figure 2, PRB reduce perchlorate to Cl^- through ClO_3^-, then chlorite (ClO_2^-). PRB can grow heterotrophically or can use H_2 as electron donor for the reduction process (Bardiya and Bae 2011; Ontiveros-Valencia et al. 2013b; Zhao et al. 2013).

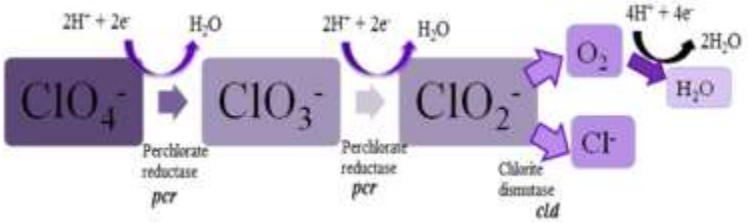

Figure 2. Perchlorate anaerobic biodegradation pathway.

Zero Valent Iron

mZVI and nZVI have been used for *in situ* degradation of chlorinated solvents and immobilization of heavy metals since 1991 and 2000, respectively. With respect to mZVI, the first ZVI permeable reactive barrier filled with micron-sized particles was installed to intercept a hexavalent chromium plume in Sunnyvale, CA (Tratnyek et al. 2014). The use of nZVI (nano-sized particles) in dechlorination was more recently developed, first demonstrated to provide *in situ* reduction of chlorinated solvents in 2000 at a site in Trenton, NJ (Elliott and Zhang 2001; Li et al. 2006). Both iron types leverage the reducing power of Fe^0 in the particles to reduce contaminants such as the chloroethenes to non-toxic or immobile forms. The resulting iron oxides are believed to represent little environmental concern, given that iron oxides are common constituents in the earth's crust. The iron oxidizes from Fe^0 to magnetite and maghemite (Fe_3O_4 and Fe_2O_3, respectively), thereby, providing 2-3 moles of e^- per mole of Fe for reducing the contaminants of interest (Liu et al. 2005). The higher surface area to volume ratio of nZVI compared to mZVI provides higher overall reaction rates with contaminants. Both mZVI and nZVI have been shown to effectively reduce TCE to ethene, as well as ethane (Arnold and Roberts 2000; Liu et al. 2007). In most cases, this abiotic reduction results in limited formation of chlorinated daughter products, *cis*- and *trans*-DCE or VC (Liu et al. 2005). Both mZVI and nZVI has also been shown to reduce perchlorate to chloride, albeit at slow to moderate rates, respectively (Cao et al. 2005). The use of ZVI to promote biodegradation of perchlorate appears more promising (Schaefer et al. 2007).

Injection of ZVI provides a secondary benefit in addition to the direct abiotic degradation of contaminants afforded by the iron. The strong reduction potential of ZVI and its relatively high reactivity with water leads to a rapid decrease in the standard reduction potential in the area of injection and in the groundwater in the pore spaces of the aquifer material for some distance downgradient of the injection (Johnson et al. 2013). The dissolved Fe^{2+} and other species including H_2 in the pore spaces are the primary reason for the ability to transmit reducing conditions downgradient from the injected iron. These conditions lead to a change in the biogeochemisty of the aquifer medium and promote sulfate reducing- and methanogenic-redox conditions (Kirschling et al. 2010). The presence of nZVI appears to inhibit *Dehalococcoides* populations containing the *tceA* gene in mixed cultures (Xiu et al. 2010a; Xiu et al. 2010b), but it is unclear if this is the case in the reduced zone of influence or downgradient from the injection source.

One consequence of the higher reactivity of nZVI and its relatively poor selectivity for reduction of contaminants is the rapid scavenging of dissolved O_2 (from water) (Li et al. 2010), and the reduction of

water (forming H_2) and NO_3^- (forming ammonia) (Liu et al. 2012; Liu et al. 2007). These side reactions consume Fe^0, and if they occur rapidly enough, can significantly impact the reducing power of the iron.

Dechlorination of TCE and perchlorate occurs at different oxidation-reduction potentials. *Dehalococcoides* are strict anaerobes (Loffler et al. 2005), while most PRB are facultative anaerobes (Bardiya and Bae 2011). Furthermore, perchlorate reduction produces O_2, as seen in Figure 2, although O_2 typically does not accumulate in the system (Bardiya and Bae 2011). *Dehalococcoides* are sensitive to O_2 (Amos et al. 2008). Therefore, in order for TCE dechlorination to proceed to ethene, O_2 from groundwater and sediment and any trace O_2 from perchlorate reduction must be removed for successful biodegradation of TCE and perchlorate to occur. This O_2 reduction will be initiated and maintained by the addition of ZVI, reducing agents and fermentable substrates. The reactivity of nZVI (and to some degree, mZVI) will be an important consideration in the design of the treatability study to assess the efficacy of the proposed combined remedy in light of the influent dissolved O_2 and nitrate, and will have to ultimately be considered in the full-scale deployment of the Source Area remediation.

Groundwater and sediment characterization

Our laboratory testing will begin with a through characterization of the site material (groundwater and sediment). A comprehensive list of the parameters to be measured are included in Attachment 1. Examples of parameters to be measured are VOCs, perchlorate, DO, pH, organic carbon, etc. Site groundwater and soil will also be tested for the following priority pollutant metals, which have been observed in site groundwater and/or soil: arsenic, barium, boron, cadmium, chromium, lead and zinc.

Microcosm Testing

The fill-and-draw microcosm testing will establish the combination of ZVI and microbiological amendments that will promote the highest degree of TCE and perchlorate reduction in Source Area sediment and groundwater. Material for the microcosm testing will be collected from soil and groundwater samples obtained during the installation of a monitor well in the Phase I Source Area as part of the Preliminary Characterization in the RD/RA Work Plan. The microcosms will be prepared as follows:

- 160-milliliters (mL) glass serum bottles will be filled with 25 grams (g) of PGA-North sediment and with Source Area Subunit A groundwater, the latter added to a total volume of 100 mL. Therefore, the mass ratio of soil to water will be 1:4, which is in the middle of the range of typical microcosm batch studies.

- The liquid contents will consist of Source Area Subunit A groundwater supplemented with a carbon source (5 mM lactate or 166 mg/L emulsified vegetable oil) and 200 mg/L yeast extract.

- The composition of the groundwater medium is described in the Methodologies section below.

- The bottles will be sealed with black butyl rubber stoppers and aluminum crimps. The microcosms will be stored in the dark at room temperature (22-25°Celsius [C]). They will be shaken by hand when amendments are added and will be incubated statically.

- The headspace and liquid of the microcosms will be sampled at discrete time points (as outlined in Attachment 1) to determine the concentrations of the contaminants, their by-products, and other relevant parameters.

- The microcosms will be monitored for up to 90 days. The sampling frequency and analyses will completed done according to Attachment 1.

The experimental conditions to be tested in the fill-and-draw microcosm experiments are shown in Table 2. With the exception of Set 2, ZVI will not be added directly to the microcosms. Instead, groundwater will be augmented with 15-50 grams per liter (g/L) mZVI and 1.5-15 g/L nZVI. This groundwater will be added to Microcosm Sets 2-9 from Table 2. Two mZVI iron varieties are being considered for inclusion in the treatability study – BASF's OM carbonyl iron powder and Rio Tinto's Atomet 86. Candidate nZVI products under consideration in the microcosm study include NanoFer STAR™ (Nano Iron, s.r.o., Czech Republic) and Z-Loy™ (OnMaterials, Escondido, CA). The PGA-North technical team is also assessing the merits of other nZVI materials which are not yet commercially available. If these efforts identify another candidate nZVI material, it will also be considered for inclusion in the microcosm study. The concentration of nZVI was chosen based on the results that were obtained during the ZVI pilot-scale study that was conducted in 2009 at the Site, past remediation experience with nZVI, and the work of Kirschling et al. (2010), who showed that addition of 1.5 g/L nZVI was sufficient to drop groundwater oxidation reduction potential (ORP) by 400 millivolts (mV) and promote sulfate-reducing and reductive dechlorinating conditions. A working concentration range from 1.5-15 g/L should be sufficient to ensure selection of an appropriate target injectate concentration. We anticipate that the primary goal of the mZVI is to scavenge oxidants from the groundwater entering the bioremediation zone, thereby, providing a continued reducing environment devoid of oxygen and nitrate, and potentially to supply hydrogen and/or ferrous iron (Fe^{2+}) as an electron donor. A secondary benefit of the ZVI will be the abiotic reduction of TCE. The properties of the candidate ZVI products are summarized in Table 2.

Table 2. Experimental conditions to be tested in Fill-and-Draw microcosms.

Microcosm Set	Remediation method	Description
1	None	Sediment and groundwater only
2	ZVI	ZVI-exposed groundwater and sediment
3	ZVI-exposed groundwater + Biostimulation A: buffer, nutrients, and lactate	10 millimolar (mM) phosphate buffer, 200 mg/L yeast extract, 5 mM lactate,166 mg/L EVO*
4	ZVI-exposed groundwater + Biostimulation A + bioaugmentation 1	10 mM phosphate buffer, yeast extract 200 mg/L, 5 mM lactate, 4 mL ZARA-10 bioaugmentation culture
5	ZVI-exposed groundwater + Biostimulation A + bioaugmentation 2	10 mM phosphate buffer, 200 mg/L yeast extract, 5 mM lactate, 4 mL SDC-9 bioaugmentation culture
6	ZVI-exposed groundwater + Biostimulation B: buffer, nutrients, and EVO	10 mM phosphate buffer, 200 mg/L yeast extract, 166 mg/L EVO, 4 mL ZARA-10 bioaugmentation culture
7	ZVI-exposed groundwater + Biostimulation B + bioaugmentation 1	10 mM phosphate buffer, 200 mg/L yeast extract, 166 mg/L EVO, 4 mL ZARA-10 bioaugmentation culture
8	ZVI-exposed groundwater + biostimulation B + bioaugmentation 2 (no buffer)	200 mg/L yeast extract, 166 mg/L EVO, 4 mL SDC-9 bioaugmentation culture
9	ZVI-exposed groundwater + biostimulation B + bioaugmentation 2	10 mM phosphate buffer, 200 mg/L yeast extract, 166 mg/L EVO, 4 mL SDC-9 bioaugmentation culture

*the concentrations of lactate and EVO proposed account for an equal number of me- equiv. The concentration of EVO was estimated assuming EVO was 100% oleic acid (MW 282.46, 102 electron equivalents/mole oleic acid). EVO concentration may have to be adjusted based the composition of the oil and the emulsified agent used. All microcosm conditions will be tested in triplicates. Sets 1 and 2 will be sampled only at time zero and at the end of the study.

- Microcosm Set 1 will provide background reactions based on the biogeochemistry of the Source Area sediment and groundwater (also a negative control).
- Microcosm Set 2 (ZVI only) will provide an indication of the effect of ZVI on ORP, abiotic reduction of chlorinated compounds, and the production of H_2 from ZVI.
- Microcosm Sets 3-9 (various biostimulation and bioaugmentation amendments), will provide data on the contributions of the indigenous and bioaugmented microbial populations to both TCE and perchlorate reduction.
- Microcosm Sets 4, 7 and 8 will be inoculated with ZARA-10, a culture developed and grown in Krajmalnik-Brown Laboratory (Delgado et al. 2014b; Ziv-El et al. 2011). Microcosm Sets 5 and 9 will be bioaugmented with culture SDC-9, which will be provided by CB&I of Lawrenceville, New Jersey.
- The treatability study will test both a quick-release electron donor and carbon source such as lactate (biostimulation A) and a slow-release electron donor and carbon source such as an emulsified vegetable oil (biostimulation B).

- Microcosm Set 8 will not contain added buffer. This microcosm set will evaluate pH changes and the need to buffer addition in the column studies and pilot project.

The dose for the slow release carbon donor, which will be used during the column testing will be adjusted depending on the results of the initial fill-and-draw microcosm testing. Typical concentrations of EVO used in the field range from 100 to 5,000 mg/L EVO. Therefore, the concentration currently planned for the column studies is within the range used for field studies. Likewise, the quick release and slow release carbon sources to be utilized during field implementation will depend on the results of the microcosm and soil column test results. At similar sites where lactate was amended as a quick release carbon substrate and EOS was used as the slow release carbon substrate, the injected concentrations were greater than 1,000 milligrams per liter (mg/L) total organic carbon (TOC) equivalents after both injections. Based on information presented in the ESTCP protocol, Enhanced In Situ Bioremediation Using Emulsified Edible Oil, immediately after oil injection, dissolved organic carbon (DOC) concentrations released from edible oil barriers may exceed 500 mg/L and the DOC concentrations decline over time. Subsequently, DOC levels ranging from 60 to 100 mg/L is typical for the long-term average concentration released from an EOS injection and barrier system. (ESTCP Protocol for Enhanced In Situ Bioremediation Using Emulsified Edible Oil, 2006).

The DHC concentration that is generally provided by CB&I to be used in the field is at 10^{11} gene copies per liter, which corresponds to approximately 10^8 cells per milliliter. Therefore, using 10^6 DHC cells per ml in the microcosms is an appropriate amount to use in the bench-scale study. Numerous bioaugmentation projects have been performed in the field and the results of these projects have shown DHC concentrations at 10^6 cells per bead or higher in site groundwater after bioaugmentation. Therefore, the amount of DHC selected for the bench-scale testing is appropriate to evaluate the potential for bioaugmentation in groundwater at the PGA-North site.

The PGA-North team anticipates that the microbial communities developed in these microcosms will be complex based on the abundance and variety of electron acceptors in the Source Area sediment and groundwater. Figure 3 depicts representative microbial processes that could occur in the fill-and-draw microcosms. As shown in Figure 3, H_2 is at the center of these processes as a universal electron donor; therefore, we anticipate competition for H2 and other resources among the various microbial groups. Sulfate (SO_4^{2-}) (up to 1,200 mg/L) and NO_3^- (10-16 mg/L) are also present in Subunit A groundwater. As such, the expectation is that a potentially elevated concentration of sulfide may be produced from the reduction of sulfate. Nitrate and sulfate will be monitored to evaluate the levels of nitrate- and sulfate-reductions and other microbiological processes that may be affecting or competing with the chlorinated compound-reductions such as methanogenesis and homoacetogenesis (Figure 3). This will be achieved by measuring the initial chemicals and changes in their concentrations. If these reductions are significant, these microbes could be tracked through their respective reductases (see perchlorate reductase as examples in Figure 2).

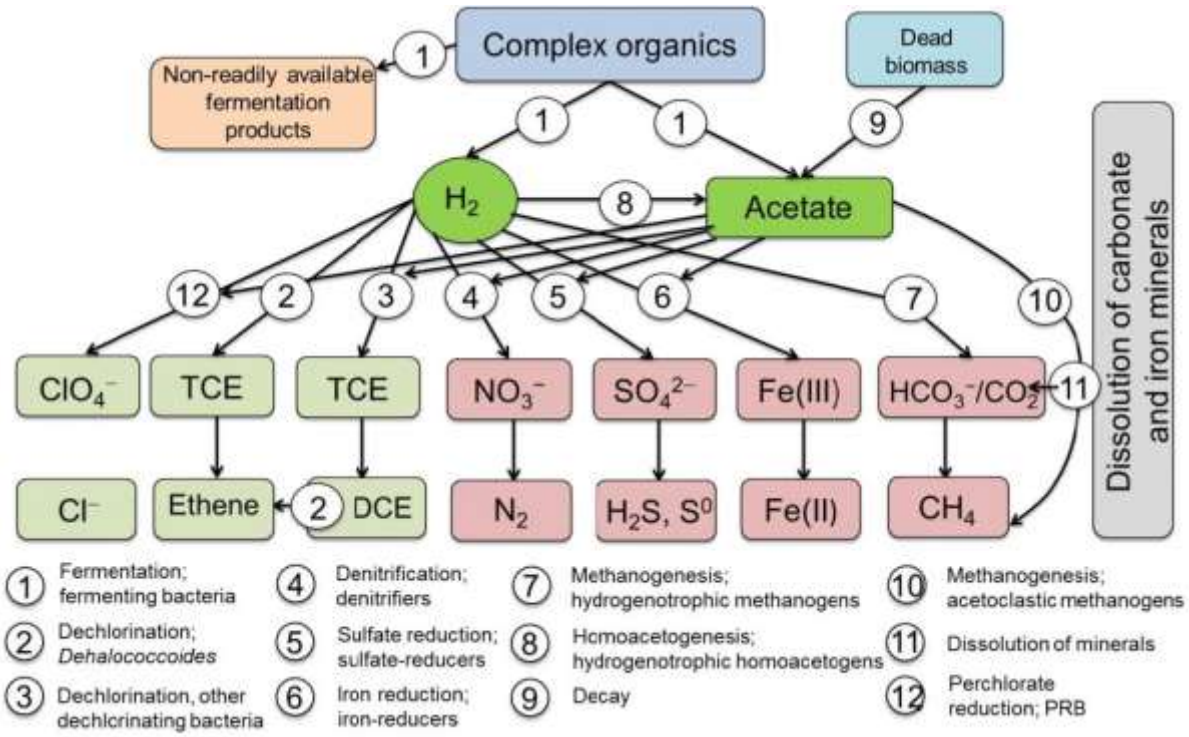

Figure 3. Select microbial processes and interactions centered on the electron donors H_2 and acetate in complex microbial communities at contaminated sites.

Fill-and-draw microcosms will be set-up using 25 g of sediment and 100groundwater, added to a total volume of 100mL, representing a sediment to water ratio of 1;4. Each week, 25% of liquid will be replaced (groundwater plus amendments) in an anaerobic glove box, by drawing out the liquid with a syringe at the same time that new liquid is injected into the bottle. The new liquid is Site groundwater that has been amended with 1,000 µg/L TCE and 100 µg/L perchlorate and will include other appropriate amendments as described in Table 1. This fill-and-draw process is depicted in Figure 4. The main advantages of the fill-and-draw microcosms (which are semi-batch) over standard microcosms is that they provide a recharge of the contaminants of interest and offer a way to obtain more comprehensive data than from typical batch microcosm bottles. ASU has previously used the fill-and-draw technique in a comprehensive study to 1) evaluate the distribution of electrons from lactate and methanol to TCE dechlorination, methanogenesis and homoacetogenesis and 2) to correlate the microbial communities developed at different TCE concentrations with the chemical data obtained from the fill-and-draw reactors (Ziv-El et al. 2012b).

Figure 4. Schematic depiction of the fill-and-draw microcosm process. The photograph shows a glass serum bottle containing sediment and groundwater.

Sediment Columns

The treatability study will also consist of a series of aquifer sediment columns to evaluate reduction of TCE and perchlorate in Source Area soil and groundwater. An important decision point will take place at the conclusion of the microcosm study (60-90 days). Consistent with the EPA/United States Army Corps of Engineers (USACE) Triad Approach, the data from the microcosm study is expected to provide key insight concerning which amendments and combinations are worth pursuing further and those that are not; thus, allowing the PGA-North team, ASU, and EPA and Stakeholders the opportunity to optimize the proposed design of the column studies relevant to the Site. This phased approach (Triad Approach) will allow us to gain valuable information related to the implementation of the 2014 ROD Amendment chosen remedy of nZVI + mZVI + ARD. Table 3 summarizes conditions to be tested in sediment columns.

Table 3. Experimental conditions to be tested in sediment columns.

Sediment column	Remediation method description
1a-b	ZVI
2a-b	ZVI + Guar Gum
3a-b	Effluent of Column Set 1a + Simultaneous Biostimulation A/B and Bioaugmentation culture
4a-b	Effluent of Column Set 1b + Sequential Biostimulation A/B and Bioaugmentation culture
5a-b	Effluent of Column Set 2a + Simultaneous Biostimulation A/B and Bioaugmentation culture
6a-b	Effluent of Column Set 2b + Sequential Biostimulation A/B and Bioaugmentation culture

Biostimulation A: 5 mM lactate, 200 mg/L yeast extract, and buffer, or

Biostimulation B: 166 mg/L EVO, 200 mg/L yeast extract, and buffer

The column experiments will reflect, to the best extent possible in the laboratory, conditions pertinent to the Source Area contamination at PGA-North: 1) continuous flow of groundwater, 2) immobile sediment matrix with its mineralogy, and 3) compound and microbial gradient profiles. For this objective, the lab

will construct 12 glass columns. The columns for Sets 3-6 will consist of 10-centimeter (cm) diameter glass cylinders with a length of ~0.5 meter (m). The columns for Sets 1-2 will have the same inner diameter; however, they will be 2% of the length of Sets 4-6. A schematic depiction of the columns is shown in Figure 5. The shorter length for the ZVI-only columns is designed to simulate the localization of ZVI at a target treatment zone. ZVI materials selection for the column study will be based on the performance and outcomes of the candidate mZVI products in the microcosms. All columns will be packed and oriented vertically with flow from the bottom to the top to prevent the potential for preferential flow paths.

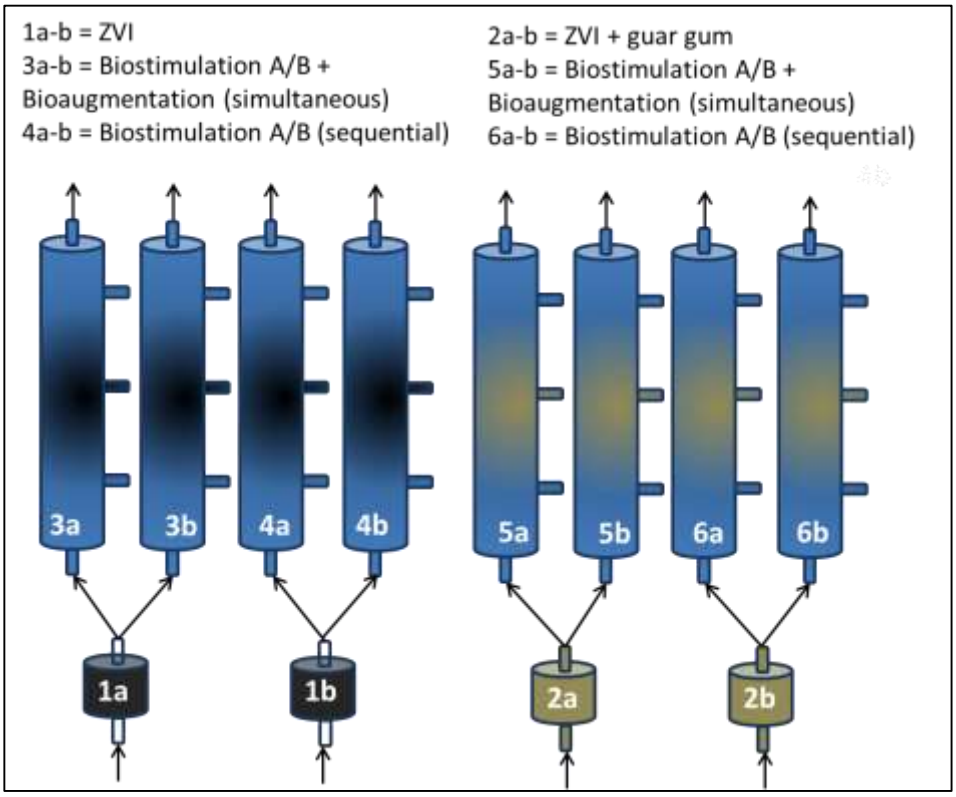

Figure 5. Schematic of sediment columns showing a shorter column for ZVI-only condition and longer columns with sampling ports along the length for biostimulation and bioaugmentation conditions. The arrows denote the flow of groundwater.

For reproducibility, duplicate columns will be prepared for each condition (denoted a and b). Because of poor mobility of ZVI, for columns 1 and 2, the sediments from the Source Area will first be homogenously mixed with ZVI and then packed into the columns. The column arrangement is shown in Figure 5. The influent of Column Sets 1 and 2 will be Site groundwater containing TCE and perchlorate. Flow rates will be representative of Subunit A groundwater velocities of 0.75 feet per day (ft/d). This flow will be achieved in the columns (assuming 50% porosity) by pumping groundwater at an initial hydraulic retention time (HRT) of approximately five days to help establish the indigenous microbial population and then reducing the HRT to approximately two to three days, which is more representative of in situ flow conditions. This rate may be adjusted based on new aquifer sediment information (e.g. hydraulic conductivity) that is obtained during the collection of the aquifer sediments.

Column Sets 1 and 2 will yield information on the effect of ZVI (without or with Guar Gum) on sediment and groundwater biogeochemical parameters, such as losses of TCE and perchlorate, as well as hydrogen, dissolved oxygen (DO), nitrate, etc. leaving the columns. Column Sets 3-6 will receive groundwater effluent from Sets 1 and 2 amended with a fast-release fermentable substrate (e.g., lactate) and/or slow-release (e.g. EVO). Once reducing conditions have been established in these columns, we will inoculate them with a pre-grown bioaugmentation culture, ZARA-10 (Delgado et al. 2014b) or SDC-9, depending on the results of the microcosm testing. The operation time for these columns will be approximately 4 to 6 months. Throughout this time, the columns will be frequently sampled as described in Attachment 2. The various electron acceptors and their reduction products will be monitored as described in the Methodologies section below. Select microbial groups such as the dechlorinators (Ritalahti et al. 2006; Ziv-El et al. 2011) and perchlorate reducers (Ontiveros-Valencia et al. 2013a) will be measured using quantitative polymerase chain reaction (qPCR) at discrete time points in the influent and effluent of the columns. qPCR on the sediment will be performed at time 0 and at the end of the experiments. Deep sequencing techniques will also be used on the sediment at time 0 and end of experiments to analyze the microbial communities. These analyses both will provide important information concerning how the microbial communities adapt and change over time as a function of treatment technology.

Methodologies

The chemical and microbial analyses will be performed in the ASU lab using state-of-the-art instruments and well-established, published protocols. The description of the methodologies from this section pertains to both microcosm and column studies. The frequency of sampling and types of analyses for microcosms and column study will be according to Attachments 1 and 2, respectively.

Medium preparation

For the microcosms study, the groundwater for all microcosms except Set 2 will be first exposed to 15-50 grams per liter (g/L) mZVI and 1.5-15 g/L nZVI. Then, it will be added to each microcosm bottle. TCE and perchlorate will be supplemented to achieve a final concentration of 1,000 µg/L and 100 µg/L, respectively. 200 mg/L will be used as a source of nutrients. Each set of fill-and-draw microcosms will be prepared in triplicate.

Chemical analyses

Volatile organic compounds (VOC) including chlorinated ethenes, chlorinated ethanes, ethene and ethane will be measured from 1 mL liquid samples and analyzed in general accordance with 8015B. Using 2-mL screw top vials with magnetic caps (MicroSolv, Eatontown, NJ), the laboratory will draw 1 mL of gas from the vials immediately before adding 1 mL of liquid. The vials will then be vortexed upside down for one minute to promote rapid partitioning of the chlorinated ethenes into the vial headspace. Analyses will be done using a solid-phase micro-extraction (SPME) fiber (85 mm Carboxen/PDMS StableFlex, Supelco, Bellefonte, PA) followed by GC with an Rt-QSPLOT column (30 m x 0.32 mm x 10 mm, Restek, Bellefonte, PA) equipped with a flame ionization detector (FID) (GC-2010, Shimadzu, Columbia, MD). The GC will be operated with an AOC 5000 Auto Injector. The samples will be shaken for one minute at 30˚C, after which the SPME fiber will be held in the headspace for 5 minutes to allow time for adsorption and then 5 minutes in the 240˚C injection port for desorption. The temperature program upon inserting the fiber will be 110˚C for 1 minute, followed by a 50˚C/min gradient to 200˚C, a 15˚C/min gradient to 220˚C, and then held at 220˚C for 3 minutes (Ziv-El et al. 2014; Ziv-El et al. 2012a).

200 µL gas samples will be taken to obtain methane measurements. Methane will be analyzed in general accordance with RSK 175 and will be quantified using a GC-FID (GC-2010, Shimadzu, Columbia, MD) as previously described (Delgado et al. 2012; Ziv-El et al. 2011). Ethene and ethane in groundwater are measured using automated headspace solid phase microextraction (Ziv-El et al 2014). In addition to using the GC-FID procedure described above, ASU will evaluate the groundwater samples for VOCs using the GC/ Mass spectrometry (MS) procedure, which is similar to EPA Method 8260. Also at the end of the experiment, 10 percent of the groundwater samples will be analyzed for VOCs at ASU's laboratory and an Arizona Department of Health Services (ADHS) certified laboratory.

Perchlorate will be analyzed in accordance with EPA method 314.0 using ion chromatography (IC) with an IC instrument (Dionex ICS 2000) with an AS16 column and AG16 pre-column, an eluent concentration of 35 mM potassium hydroxide (KOH), and an eluent flow rate of 1.5 mL/min. Nitrate, nitrite, chlorite, chlorate, and sulfate will be analyzed using an IC (Dionex ICS 3000) with an AG18 pre-column and an AS18 column, an eluent of 22 mM KOH, and an eluent flow rate of 1 ml/min (Ontiveros-Valencia et al. 2013b; Ontiveros-Valencia et al. 2014).

The pH will be analyzed with a pH meter calibrated with the standard solutions recommended by the manufacturer (Thermo Scientific Orion, Lake Champlain, VT). Sulfide will be measured through spectrophotometric analysis using Varian Cary Eclipse Fluorescence Spectrophotometer. O_2 influent and effluent concentrations will be measured with a PRO BOD YSI DO probe (YIS Inc., OH, USA). For total organic carbon (TOC) and inorganic carbon, the laboratory will use a Shimadzu TOC-5000 analyzer (Shimadzu Corp., MD, USA) with infrared detection of CO_2 produced from oxidizing the organic carbon at 680°C with a platinum catalyst

Short chain fatty acids, sugars and alcohols will be analyzed using High-Performance Liquid Chromatography (HPLC; Model LC-20AT, Shimadzu, Columbia, MD). The oven temperature will be kept constant at 50° C and the elution time will be 60 minutes. Separation will be performed with an Aminex HPX-86H column (Bio-Rad Laboratories, Hercules, CA) (Parameswaran et al. 2011). H_2 and CO_2 will be quantified by sampling the headspace gas and analyzing it using a GC with a thermal conductivity detector (TCD) and a packed column (ShinCarbon ST 100/120 mesh, Restek, Bellefonte, PA) (Lee et al. 2009).

Microbial analyses

Groundwater and sediment samples will be collected periodically as shown on Attachment 1 for microbial analyses. Genomic deoxyribonucleic acid (DNA) will be extracted using a MoBio PowerSoil DNA extraction kit using the protocol previously published (Ziv-El et al. 2011).

Two methods will be applied for assessing microbial growth and identifying the microorganisms of interest involved in bioremediation of the chlorinated contaminants from PGA-North Source Area groundwater and sediment. The first technique is high-throughput sequencing (Illumina MiSeq) and the second is quantitative polymerase chain reaction for identification of key microbes. Deep sequencing targeting combined conserved regions of the 16S rRNA gene of bacteria will provide us a comprehensive view of the microbial communities and their relative abundances. DNA sequencing will be performed at the beginning and at the end of each experimental condition to assess important microbial community changes under the different experimental conditions. Deep sequencing will enable us to identify key

microbial strains for further investigations using qPCR. qPCR will be used to quantify the dominant bacterial and archaeal members in the communities by either targeting the 16S rRNA gene or reductase genes. qPCR assays of interest for this proposal include the 16S rRNA gene of *Dehalococcoides mccartyi*, and their reductive dehalogenases, *tceA*, vcrA, bvcA, the *pcrA* gene of perchlorate-reducing bacteria, the 16S rRNA of *Archaea* for methanogens, the formyltetrahydrofolate synthetase (FTHFS) gene, which encodes a key enzyme in reductive acetogenesis, the *dsrA* gene of sulfate-reducers, and *nirK* and *nirS* of nitrate-reducers.

Dehalococcoides bioaugmentation cultures ZARA-10 and SDC-9

The treatability study laboratory has developed several chlorinated ethene bioaugmentation cultures from contaminated (Delgado et al. 2014b; Ziv-El et al. 2011) and pristine soils and sediments (Delgado et al. 2014b). These *Dehalococcoides*-containing bioaugmentation cultures were shown to be able to dechlorinate TCE to ethene at some of the fastest rates reported in the literature while achieving high concentrations of *Dehalococcoides* (10^{12} *Dehalococcoides* cells/L) (Delgado et al. 2014a; Delgado et al. 2014b; Fajardo-Williams et al. 2014; Ziv-El et al. 2011). In the past year, ASU has been growing one of our *Dehalococcoides* cultures, ZARA-10, in continuously-fed stirred tanks reactors (CSTRs) at large scale. ZARA-10 has been grown on TCE and the following fermentable substrates: lactate, methanol, molasses, emulsified vegetable oil (fresh) and recycled (from cooking) emulsified vegetable oil. All these substrates were able to support complete dechlorination of TCE to ethene and robust growth of *Dehalococcoides*. Culture ZARA-10 from ASU is currently undergoing field testing at a site in New Jersey. Culture SDC-9 was developed by the Shaw Environmental group. SDC-9 has been well characterized in terms of kinetic rates of dechlorination and has been used at multiple field sites.

Laboratory and Project Team

The chemical analytical facility located at ASU supports all analyses in Attachment 1. Key equipment include: Trace Analytical (now Ametek) Reduction Gas Analyzer, Shimadzu Prominence High-Performance Liquid Chromatograph with diode array and refractive index detectors, Waters Ultra High Pressure Liquid Chromatograph (UPLC) with diode array and ELSD detectors, Ionex ICS 3000 Ion Chromatograph with amperometric and conductivity detectors, Shimadzu Gas Chromatograph GC 2010 equipped with FID, ECD, and TCD detectors and a CombiPal robotic autosampler, Shimadzu QP2010 quadrupole GCMS, Thermo Electron Atomic Absorption Spectrophotometer with Dual flame/Furnace capability, Shimadzu TOC Analyzer with solids module, and Varian Fluorescence and UV/Vis Spectrophotometers. The ASU laboratory is also well-equipped for standard wet-chemistry analyses as well as high-purity water.

The microbiology and molecular biology facility at ASU also supports the analyses summarized in Attachment 1. Of particular importance are the following pieces of equipment and specialized facilities: Coy Anaerobic Glove Box, Anaerobic Gassing Station, standard and DGGE electrophoresis systems, Eppendorf epgradient Polymerase Chain Reaction Thermocyclers, BioRad iQ5 Quantitative Real-Time PCR Detection system, Biorad Experion Automated Electrophoresis System, Biorad Molecular Imager Gel Doc system, incubators, freezers, refrigerators, and ultracentrifuge.

Dr. Krajmalnik-Brown of ASU will lead the study. She is an Associate Professor at ASU in Environmental Engineering and the Swette Center for Environmental Biotechnology; she is an international leader in reductive dechlorination, anaerobic microbial interactions and molecular microbial ecology research. She

has over 60 peer-reviewed publications and four patents related to this topic. Her effort will include overall research organization, leading the experimental design and implementation of the research objectives, and communicating with the PGA-North team on the findings and direction of the project. She will advise the postdoctoral researcher and the undergraduate researcher.

Dr. Anca Delgado is a Postdoctoral Research Associate in the Krajmalnik-Brown laboratory at ASU. Dr. Delgado is a recognized expert in reductive dechlorination, microbial ecology of contaminated environments, and microbial kinetics. She also has expertise in designing and implementing bioreactors. Her effort will include conducting the microcosm and column studies and performing all analyses related to these studies. Dr. Delgado will work alongside undergraduate students who will help with sampling and some of the chemical and microbiological analyses

Dr. Greg Lowry from Carnegie Mellon University will serve as a consultant to ASU throughout the treatability study. Dr. Lowry is the Walter J. Blenko, Senior Professor of Civil & Environmental Engineering at Carnegie Mellon University. Dr. Lowry has been at the forefront of the development of nZVI technology since 2003. He presently serves as a key member of the Project Advisory Group (PAG) for NanoRem, the largest and most comprehensive international collaborations of industry, academia, and consultancies focusing on the development and application of nanotechnology-based remedial solutions for Brownfield sites throughout the European Union. He has published 30 peer-reviewed papers on the key attributes of nZVI reactivity and mobility in porous medium, how natural constituents in groundwater affects nZVI reactivity and performance, how nZVI addition affects the biogeochemical conditions of the subsurface, and the impacts of nZVI on the expression of the tceA gene and observed microbial dechlorination of TCE. He has performed similar nZVI treatability studies. Dr. Lowry will serve as consultant and advisor, bringing strong expertise in ZVI and nZVI technologies.

Project Schedule

The project schedule (Attachment 3) has been revised to present the anticipated timeline to complete the treatability study. Since the start of the treatability study is predicated on EPA approval of this Final Technical Memorandum, specific dates are not presented. However, upon approval, specific dates will be added to the schedule and an updated schedule will be provided to EPA via email twice per month in accordance with the RD/RA Work Plan. Based on the project schedule, within 30 days of EPA approval of this Final Technical Memorandum, a preconstruction meeting/conference call will be conducted with the EPA and stakeholders to discuss the treatability study activities. Within 30 days of completing the preconstruction meeting, the drilling of one soil boring and the installation of a monitor well within the Phase I Source Area (Attachment 4) will begin. Samples collected will be used in the treatability study. Once the sediment and groundwater samples are received by the ASU laboratory, the Microcosm Study will begin and is expected to take approximately four months to complete. Upon completion of the Microcosm study, a conference call will be conducted with the EPA and stakeholders to discuss the results and discuss the path forward for the sediment columns. Once the sediment column study begins, it is expected to take approximately five months to complete. It is anticipated that the total time to conduct the treatability study is approximately nine months. Sixty days after the completion of the treatability study, Technical Memorandum #2 will be submitted to EPA that will present the results of the treatability study and will include a summary of the experimental set up, a description of the bioaugmentation cultures and ZVI types used during the bench-scale testing, methodologies used to conduct the tests, conclusions, and recommendations for implementing the Phase I Source Area remedial effort. During the time the

treatability study is being conducted the PGA-North Team will complete the remainder of the Preliminary Characterization borings and the High Resolution Characterization borings as specified in the EPA approved Work Plan.

Please call any of the undersigned at 623-322-7003 if you have any questions or need additional information.

Sincerely,

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Attachments: Attachment 1 – Summary of Proposed Microcosm Testing
Attachment 2 – Summary of Proposed Sediment Column Testing
Attachment 3 – Draft Proposed RD/RA Work Plan Implementation Schedule through the end of the Treatability Study
Attachment 4 – Site Plan Showing Proposed Preliminary Characterization Borings and Monitor wells

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Attachments

Analysis type	Parameter	Methodology	EPA or Standard Methods	Frequency of sampling	Number of samples	Total samples to be analyzed during study
Chemical	VOCs (including chlorinated ethenes, chlorinated ethanes, and ethene)	Gas chromatography with flame ionization detector	EPA 8015B	biweekly	4/time point/experimental condition and influent groundwater	132
	VOCs (including chlorinated ethenes, chlorinated ethanes, and ethene)	Gas chromatography with mass spectrometry detector	EPA 8260B	three times (beginning, middle, end point)	4/time point/experimental condition and influent groundwater	9
	Methane	Gas chromatography with flame ionization detector	RSK175	biweekly	4/time point/experimental condition and influent groundwater	132
	Various cations	Ion chromatography	EPA 200.7	three times (beginning, middle, end point)	3/time point/influent groundwater	9
	Perchlorate	Ion chromatography	EPA 314.0	biweekly	4/time point/experimental condition and influent groundwater	132
	Chlorate	Ion chromatography	EPA 300.1	biweekly	4/time point/experimental condition and influent groundwater	132
	Chlorite, sulfate, nitrate, and other various anions	Ion chromatography	EPA 300.0	biweekly	4/time point/experimental condition and influent groundwater	132
	H_2S and sulfide	Fluorescence spectrophotometry	not applicable (NA)	biweekly	4/time point/experimental condition and influent groundwater	132
	H_2 and CO_2	Gas chromatography with thermal conductivity detector	NA	biweekly	4/time point/experimental condition and influent groundwater	132
	Lactate, emulsified vegetable oil, acetate, propionate, formate and various volatile fatty acids, sugars and alcohols	High-performance liquid chromatography	NA	biweekly	4/time point/experimental condition and influent groundwater	132
	pH	pH probe	NA (field parameter)	biweekly	3/time point/experimental condition and influent groundwater	132
	Dissolved oxygen	DO probe	NA (field parameter)	biweekly	3/time point/experimental condition and influent groundwater	132
	Oxidation reduction potential (ORP)	ORP	NA (field parameter)	biweekly	3/time point/influent groundwater	132
	Total organic and inorganic carbon	TOC analyzer	EPA 9060A	three times (beginning, middle, end point)	3/time point/influent groundwater	9
	TDS (Total dissolved solids)	TDS, salinity, conductivity probe	SM 2540C	three times (beginning, middle, end point)	3/time point/influent groundwater	9
	Salinity	TDS, salinity, conductivity probe	SM2520B	three times (beginning, middle, end point)	3/time point/influent groundwater	9
	Conductivity	TDS, salinity, conductivity probe	NA (field parameter)	three times (beginning, middle, end point)	3/time point/influent groundwater	9
Molecular microbial	*Dehalococcoides*	quantitative polymerase chain reaction (qPCR)	NA	three times (beginning, middle, end point)	2/time point/experimental condition and influent groundwater	36
	Dehalococcoides reductases	qPCR	NA	three times (beginning, middle, end point)	2/time point/experimental condition and influent groundwater	36
	Perchlorate-reducing bacteria	qPCR	NA	three times (beginning, middle, end point)	2/time point/experimental condition and influent groundwater	36
	Methanogens, acetogens, sulfate-reducing bacteria, nitrate-reducing bacteria	qPCR	NA	two times (beginning and end point)	2/time point/experimental condition and influent groundwater	96
	Bacterial community composition	MiSeq illumina sequencing	NA	two times (beginning and end point)	1/time point/experimental condition and influent groundwater	10

Analysis type	Parameter	Methodology	EPA or Standard Methods	Frequency of sampling	Number of samples	Total samples to be analyzed during study
Chemical	VOCs (including chlorinated ethenes, chlorinated ethanes, and ethene)	Gas chromatography with flame ionization detector	EPA 8015B	biweekly	2/time point/experimental condition and influent groundwater	144
	VOCs (including chlorinated ethenes, chlorinated ethanes, and ethene)	Gas chromatography with mass spectrometry detector	EPA 8260B	three times (beginning, middle, end point)	4/time point/experimental condition and influent groundwater	9
	Methane	Gas chromatography with flame ionization detector	RSK175	biweekly	2/time point/experimental condition and influent groundwater	144
	Various cations	Ion chromatography	EPA 200.7	three times (beginning, middle, end point)	3/time point/influent groundwater	9
	Perchlorate	Ion chromatography	EPA 314.0	three times (beginning, middle, end point)	3/time point/influent groundwater	9
	Chlorate	Ion chromatography	EPA 300.1	biweekly	2/time point/experimental condition and influent groundwater	144
	Chlorite, sulfate, nitrate, and other various anions	Ion chromatography	EPA 300.0	biweekly	2/time point/experimental condition and influent groundwater	144
	H_2S and sulfide	Fluorescence spectrophotometry	Not Applicable (NA)	biweekly	2/time point/experimental condition and influent groundwater	144
	H_2 and CO_2	Gas chromatography with thermal conductivity detector	NA	weekly	2/time point/experimental condition	134
	Lactate, emulsified vegetable oil, acetate, propionate, formate and various volatile fatty acids, sugars and alcohols	High-performance liquid chromatography	NA	biweekly	2/time point/experimental condition and influent groundwater	144
	pH	pH probe	NA (field parameter)	biweekly	2/time point/experimental condition and influent groundwater	144
	Dissolved oxygen/ ORP	DO probe	NA (field parameter)	biweekly	2/time point/experimental condition and influent groundwater	144
	ORP	ORP	NA (field parameter)	biweekly	2/time point/experimental condition and influent groundwater	144
	Total organic and inorganic carbon	TOC analyzer	EPA 9060A	three times (beginning, middle, end point)	3/time point/influent groundwater	9
	Total dissolved solids	TDS, salinity, conductivity probe	SM 2540C	three times (beginning, middle, end point)	3/time point/influent groundwater	9
	Salinity	TDS, salinity, conductivity probe	SM 2520B	three times (beginning, middle, end point)	3/time point/influent groundwater	9
	Conductivity	TDS, salinity, conductivity probe	NA (field parameter)	three times (beginning, middle, end point)	3/time point/influent groundwater	9
Molecular microbial	*Dehalococcoides*	quantitative polymerase chain reaction (qPCR)	NA	three times (beginning, middle, end point)	1/time point/experimental condition and influent groundwater	36
	Dehalococcoides reductases	qPCR	NA	three times (beginning, middle, end point)	1/time point/experimental condition and influent groundwater	36
	Perchlorate-reducing bacteria	qPCR	NA	three times (beginning, middle, end point)	1/time point/experimental condition and influent groundwater	36
	Methanogens, acetogens, sulfate-reducing bacteria, nitrate-reducing bacteria	qPCR	NA	two times (beginning and end point)	1/time point/experimental condition and influent groundwater	88
	Bacterial community composition	MiSeq illumina sequencing	NA	two times (beginning and end point)	1/time point/experimental condition and influent groundwater	20

Attachment 3 - Final Proposed RD/RA Work Plan Implementation Schedule through the end of the Treability Study
Phase I Source Area Remediation
Phoenix-Goodyear Airport - North Superfund Site
Goodyear, Arizona

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Engineering Progress

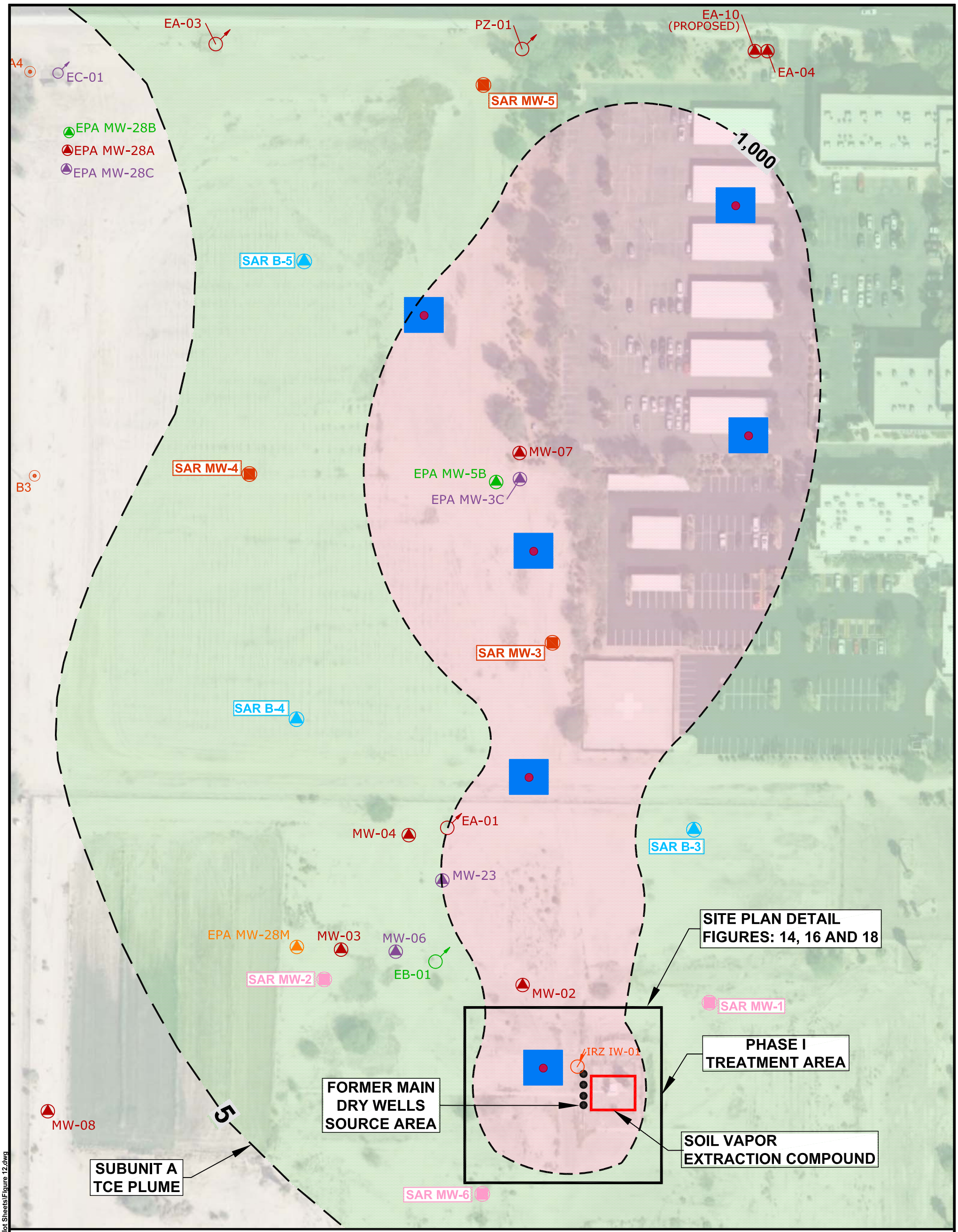
Task	Date		Month													
	05/08/15	11/09/15	0	1	2	3	4	5	6	7	8	9	10	11	12	13
Approval of Final RD/RA Work Plan																
Submit Final Technical Memorandum #1 - Treatability Study Design																
EPA Approval of Technical Memorandum #1																
Pre Construction Meeting/Conference Call																
Drill Boring and install monitor well in Phase I Source Area (Samples for Treatability Study)																
Laboratory Treatability Study - (Microcosom Testing)					Microcosom Testing											
Conference Call with EPA and Stakeholders																
Laboratory Treatability Study - (Sediment Column Testing)										Sediment Column Testing						
Preliminary Characterization Borings																
High Resolution Characterization Borings																
Technical Memorandum #2- Results of Treatability Study																

= Completed

= Conference Call

= Field Task

= Reporting



Explanation

- EPA MW-55A — Subunit A monitor well
- EA-01 — Subunit A extraction well
- IRZ IW-01 — Injection well (IRZ)
- EPA MW-5B — Subunit B monitor well
- EPA MW-5C — Subunit C monitor well
- EB-01 — Subunit B extraction well
- EC-01 — Subunit C extraction well
- EPA MW-1M — Middle Aluvial Unit monitor well

— 5 — Isocontour showing TCE concentration in µg/L. Dashed where inferred

—1,000— Note: Based on current data, Isocontours may change based on additional investigation.

Source Area Soil Boring and Monitor Wells

- SAR B-3 — SAR Soil Boring
- SAR MW-4 — SAR Subunit A Monitor Well
- SAR MW-7 — SAR Subunit A Monitor Well with Geophysical Sensors

Conceptual Design Phase I Infrastructure

- Preliminary Characterization Boring and Monitor Wells (Phase I)

N

Approximate scale in feet
0 75 150

Note: Aerial image taken by Landiscor in November 2012.

PHOENIX - GOODYEAR AIRPORT
NORTH SUPERFUND SITE
404 S. LITCHFIELD ROAD
GOODYEAR
MARICOPA COUNTY, ARIZONA

MATRIXNEWORLD
Engineering Progress

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SITE PLAN SHOWING PROPOSED PRELIMINARY CHARACTERIZATION BORINGS AND MONITOR WELLS

DRAWN BY:	DESIGNED BY:	APPROVED BY:	PROJECT NUMBER:
AR	PH	HB	15-100
DATE: 4-08-2015	DATE: 4-17-2015	DATE: 4-17-2015	SCALE: 1" = 100'

Attachment
4

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