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01 November 2013
File No. 37639-012

United States Environmental Protection Agency, Region 9
Superfund Program
Arizona and Navajo Site Section SFD-6-2
75 Hawthorne Street
San Francisco, California 94105

Attention: Ms. Catherine Brown

Subject: Source Area Remediation Focused Feasibility Study
Phoenix-Goodyear Airport-North Superfund Site
Former Unidynamics Facility
Goodyear, Arizona

Ms. Brown:

Haley & Aldrich, Inc. (Haley & Aldrich) is pleased to submit the third revision of the Final Source Area Remediation Focused Feasibility Study (SARFFS) report on behalf of Crane Co., for your review. The SARFFS was completed as a collaborative effort from the Crane Co. Team: Matrix New World Engineering, Inc., AMEC Environment & Infrastructure, Inc., and Haley & Aldrich. The third revision of the Final SARFFS attached to this letter addresses comments received from the United States Environmental Protection Agency (USEPA) and other stakeholders on 11 June, 22 August, and 5 September 2013, and is anticipated to be the final revision of the SARFFS report.

The SARFFS provides a comprehensive evaluation of remediation alternatives for the Main Dry Wells Source Area (source area) at the Phoenix-Goodyear Airport-North (PGA-North) Superfund Site, located at the Former Unidynamics Facility in Goodyear, Arizona. The SARFFS was conducted in accordance with the 1988 USEPA Region 9 Remedial Investigation/Feasibility Study Guidance, a USEPA-approved Work Plan, conceptual site model (CSM), and remedial action objectives (RAOs).

The following events have contributed to the development of the revised Final SARFFS:

- The first technical meeting between the Crane Co. Team, the USEPA, and other stakeholders to discuss the SARFFS was held on 15 September 2011. The RAOs and CSM for remediation of groundwater in the PGA-North source area presented in the SARFFS resulted from the joint agreement reached between parties during this meeting.

- The Remedial Technology Screening and Formulation of Remediation Alternatives Tables for the SARFFS were submitted for USEPA review on 14 October 2011 and approved with modifications in an email from Ms. Catherine Brown, the USEPA Remedial Project Manager for PGA-North, on 21 October 2011. Comments received from the USEPA and other stakeholders regarding the Remedial Technology Screening and Formulation of Remediation Alternatives Tables were incorporated into the draft SARFFS.

- The draft SARFFS was submitted to the USEPA and other stakeholders on the due date of 19 January 2012.

- Comments on the draft document were received on 27 February 2012 and were the focus of a second SARFFS technical meeting held on 9 March 2012.

- In accordance with the USEPA's request, additional groundwater samples were collected and analyzed from wells located in the source area on 30 April 2012, and the results were submitted to the USEPA on 29 June 2012.

- A third technical meeting was conducted on 11 July 2012, during which the groundwater analytical results were discussed in addition to revisions to Table 3 – Detailed Comparative Analysis Table of the draft SARFFS. Specific revisions to the table were agreed to by the parties in attendance. A revised table was submitted to the USEPA on 20 July 2012 and approval of the table with modifications was received from the USEPA on 29 July 2012. The Final SARFFS contains the updated Detailed Comparative Analysis Table together with revisions which arose from USEPA and stakeholder comments.

- The Final SARFFS was submitted to the USEPA and other stakeholders on the due date of 10 September 2012.

- Comments from the USEPA and other stakeholders on the Final SARFFS were received on 14 December 2012, and a response to those comments was submitted to the USEPA on 14 January 2013. Subsequent communications include USEPA's comments on the Crane team's response letter, a fourth technical meeting held on 6 February 2013, and USEPA's review of the Applicable or Relevant and Appropriate Requirements (ARARs) table and subsequent issuance of a revised comments table on 22 March 2013.

- Comments from the USEPA on the Revised Final SARFFS were received on 11 June 2013, which included embedded comments and red-lines in the text, and a separate list of comments on Table 4 – Applicable or Relevant and Appropriate Requirements (ARARs). A conference call was also conducted on 27 June 2013 to review and discuss the Agency comments. Our tracked changes in response to these comments were submitted to the Agency and stakeholders on 2 August 2013.

- Final comments on the changes to the SARFFS and Table 4 ARARs were received separately from the USEPA. An e-mail was received from Ms. Catherine Brown on 5 September 2013 with final comments on the text of the SARFFS, and on 22 August 2013, Ms. Bethany Dreyfus sent an e-mail containing a final comment on Table 4. A letter attached to the e-mail from Ms. Brown indicated approval of the changed SARFFS text. The e-mail from Ms. Dreyfus also indicated that the ARARs table was approved upon addressing her final comment. Both e-mails and the letter are enclosed with this cover letter together with the final SARFFS report.

- Two final edits to page 60, Section 2.10.11 were made at the request of the USEPA on 24 October 2013. An e-mail was received from Ms. Catherine Brown approving the production of the final SARFFS on 25 October 2013.

Should you have any questions regarding the contents of this submittal, please feel free to contact Ms. Paula R. Chang at 602.760.2418.

Sincerely yours,
HALEY & ALDRICH, INC.

Paula R. Chang
Remediation Program Manager

Timothy D. Schumacher, P.E.
Senior Engineer

Registered Professional Engineer (Civil)
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Date Signed 11/1/13
ARIZONA U.S.A.
Expires 6/30/15

Enclosures

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REPORT ON
SOURCE AREA REMEDIATION FOCUSED
FEASIBILITY STUDY
PHOENIX-GOODYEAR AIRPORT-NORTH SUPERFUND SITE
FORMER UNIDYNAMICS FACILITY
GOODYEAR, ARIZONA

by

Haley & Aldrich, Inc.
Phoenix, Arizona

Registered Professional Engineer (Civil)
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TIMOTHY D. SCHUMACHER
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for

Crane Co.
Stamford, Connecticut

File No. 37639-012
01 November 2013

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LIST OF ACRONYMS

μg/L	micrograms per liter
ADEQ	Arizona Department of Environmental Quality
ADHS	Arizona Department of Health Services
ADWR	Arizona Department of Water Resources
AMEC	AMEC Environment & Infrastructure, Inc.
ARARs	Applicable or Relevant and Appropriate Requirements
ARD	anaerobic reductive dechlorination
bgs	below ground surface
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
cis-1,2-DCE	cis-1,2-dichloroethene
COC	contaminant of concern
COG	City of Goodyear
CSM	Conceptual Site Model
1,1-DCE	1,1-dichloroethylene
DHC	dehalococcoides ethenogenes
DNAPL	dense non-aqueous phase liquid
DO	dissolved oxygen
DOE	United States Department of Energy
ERH	electric resistive heating with steam injection
ESD	Explanation of Significant Differences
FS	Feasibility Study
ft/day	feet per day
ft^2/day	square feet per day
FYR	Five year review
g/L	grams per liter
GAC	granular activated carbon
Geomatrix	Geomatrix Consultants, Inc.
gpm	gallons per minute
GHG	greenhouse gas
GCW	groundwater circulation well
GTS	groundwater treatment system
Haley & Aldrich	Haley & Aldrich, Inc.
HBGL	Health-based Guidance Level
HDPE	high density polyethylene
HHRA	Human Health Risk Assessment
I-10	Interstate 10
IRZ	in-situ reactive zone
ISCO	in-situ chemical oxidation
ISCR	in-situ chemical reduction
ITRC	Interstate Technology and Regulatory Council

LIST OF ACRONYMS (continued)

IWAS	in-well air stripping
LAU	Lower Alluvial Unit
LGAC	liquid-phase granular activated carbon
Matrix New World	Matrix New World Engineering, Inc.
MAU	Middle Alluvial Unit
MCL	Maximum Contaminant Level
MDL	Method Detection Limit
mg/L	milligrams per liter
MEK	methyl ethyl ketone
MTS	Main Treatment System
nZVI	nano-scale zero valent iron
O&M	operations and maintenance
ORP	oxidation reduction potential
Pacific Scientific	Pacific Scientific Energy Dynamics
PCE	tetrachloroethene (also known as perchloroethene)
psi	pounds per square inch
PSIW	Park Shadows Irrigation Well
PGA-North Site	the Phoenix-Goodyear Airport-North Superfund Site
PRB	permeable reactive barrier
PVC	polyvinyl chloride
RAM	Removal Action Memorandum
RAO	remedial action objective
RI	Remedial Investigation
RID	Roosevelt Irrigation District
ROD	Record of Decision
SARFFS	Source Area Remediation Focused Feasibility Study
SHMP	sodium hexametaphosphate
SVE	soil vapor extraction
TBC	to be considered
TCE	trichloroethene
TOC	total organic carbon
UAU	Upper Alluvial Unit
UPI	Unidynamics
USEPA	United States Environmental Protection Agency
VC	vinyl chloride
VE	vapor extraction
VOC	volatile organic compound
WSRV	West Salt River Valley
WTF	White Tanks Facility
WWTP	wastewater treatment plant
ZVI	macro-scale zero-valent iron

1. INTRODUCTION

This Source Area Remediation Focused Feasibility Study (SARFFS) was prepared by Haley & Aldrich, Inc. (Haley & Aldrich), on behalf of Crane Co., to provide detailed documentation of the process used to evaluate prospective remediation technologies and alternatives for source area groundwater in the vicinity of the Main Dry Wells Source Area (source area) at the Phoenix-Goodyear Airport-North Superfund Site (PGA-North Site). The PGA-North Site is located at 102 South Litchfield Road in Goodyear, Arizona (Figure 1). The SARFFS was prepared in accordance with the *Guidance for Conducting Remedial Investigations and Feasibility Studies Under the Comprehensive Environmental Recovery and Liability Act* published by the United Stated Environmental Protection Agency (USEPA) in October 1988.

1.1 Purpose and Organization

The purpose of this SARFFS is to document the nature and extent of the source area as currently understood, and to identify and evaluate potential remedial options. This SARFFS was completed as planned in the SARFFS Work Plan (Haley & Aldrich, 2011c) with modifying comments by the USEPA dated 27 June 2011. As stated in the above-referenced 1988 USEPA guidance document, the choices inherent to completing the SARFFS involve balancing a wide variety of factors and the exercise of best professional judgment by the PGA-North technical team, including the Crane Co. Team, USEPA, Arizona Department of Environmental Quality (ADEQ), and other key stakeholders (City of Goodyear [COG], City of Avondale, and City of Litchfield Park). Section 1 provides an introduction to the SARFFS and background information for the PGA-North Site. Section 2 discusses remedial action objectives (RAOs), general response actions, and identification and screening of technology types and process options. Section 3 describes the rationale for combining the technologies into remedial alternatives and provides a detailed analysis of the alternatives using a green remediation evaluation tool together with the nine USEPA-mandated criteria.

1.2 Background Information

This section provides background information important in defining the boundaries of the PGA-North Site source area for the purpose of evaluating potential remediation alternatives as part of this SARFFS process. The subsections include a PGA-North Site description and location, general PGA-North Site history, and a description and definition of the conceptual site model (CSM).

1.2.1 Site Description/Location

The PGA-North Site is located in Goodyear, Maricopa County, Arizona, approximately 17 miles west of downtown Phoenix. The PGA-North Site includes the former Unidynamics (UPI) facility which is located on approximately 58 acres. The physical boundaries of the PGA-North Site are Van Buren Street to the north, Litchfield Road to the east, a vacant field to the south, and the abandoned Union Pacific Railroad right-of-way to the west. Land use in the area surrounding the PGA-North Site source area is varied. Agricultural land is found to the west, vacant land zoned industrial lies to the south, residential and commercial properties lie to the east, and commercial properties are located north of the PGA-North Site.

1.2.2 Site History

1.2.2.1 Operations History

UPI operated the PGA-North Site as a research, design, development, testing, assembly, and manufacturing plant of ordnance components and related electromechanical devices from 1963 through 1993. Crane Co. purchased UPI, including the PGA-North Site, in 1985. Prior to acquisition by Crane Co., UPI was a division of UMC Industries, Inc. (ARCADIS, 2007a).

In April 1993, Crane Co. sold UPI (excluding buildings and land) to Pacific Scientific Energy Dynamics (Pacific Scientific). Pacific Scientific managed the business at this location for approximately 18 months before operations ceased in 1994. It is not known which buildings Pacific Scientific continued to use during its tenure. In October 1994, Pacific Scientific relocated operations to Chandler, Arizona.

Crane Co. is currently conducting groundwater and soil vapor remediation activities at the PGA-North Site under two USEPA Unilateral Orders (USEPA, 1990; USEPA, 2003). Following those Unilateral Orders, Crane Co. entered into a Consent Decree with the United States in 2006. The current remedy is being implemented under that Consent Decree (Federal Register, 2006).

1.2.2.2 Infrastructure History

The buildings were generally single story, with the exception of the Office and Administration Building (Building 1) and the Mechanical Equipment Building (Building 2), and constructed of masonry block or concrete on concrete pads. In addition to the buildings, the site infrastructure included a perimeter fence and fencing associated with some structures located in the interior of the complex. It also included parking lots, roadways, walkways, loading docks, and appropriate exterior lighting fixtures. In the exterior, only the walkways and loading docks were paved (ARCADIS, 2007a).

Earthen berms were constructed for buffer areas at select locations on site and ponds for storm water retention or oxidation of certain process waters. Sedimentation tanks and drywells were constructed for solvent collection or process water disposal. UPI had approximately 150 to 200 programs ongoing at any one time. The products could be worked on in several different buildings and locations at the PGA-North Site. These products ranged from small-scale research to the manufacturing of specialized products. The products were typically very small in size, shipped off site, and installed (by others) as a small component of a large system (typically missile systems on nuclear warheads). UPI did not manufacture system items or ordnance.

Buildings 1, 2, and 3 were constructed in 1963 when the site was first developed. These buildings were used for offices, powder processing, ordnance assembly and testing, research labs, and shipping and receiving. Building 1 included a leach field that handled the drainage from the laboratory sink in the southeast corner of the building. All other operations in Building 1 drained into the COG sewer system. The leach field was probably installed in 1963 when Building 1 was constructed. The sink in Building 1 associated with the leach field was last used for disposal in March 1979. Building 2 contained mechanical equipment for heating and cooling and was in service between 1967 and 1970; Building 2 also housed a plating laboratory. Building 3 was used for powder processing (ARCADIS, 2007a). Buildings 4 through 12, 14, 15, 17, and 18 were constructed between 1965 and 1967. This construction was the result of a large expansion of business and was related to the Vietnam War. Buildings 4, 5, and 6 were constructed for the purpose of handling smoke grenade chemicals and

assembling of smoke grenades. Building 7 was used for storage of inert materials and equipment, and was in operation between 1966 and 1970. Between 1966 and 1970, Building 8 was used to mix smoke grenade chemicals and as storage after 1971. The Building 9 complex included two buildings, Building 9 and 9a; Building 9 housed equipment and stored powder, and Building 9a was used for heat powder mixing. Building 10 was used to store records and equipment (ARCADIS, 2007a).

Powder processing was moved from Building 3 to Building 11 in 1971 and remained there until termination of UPI's plant operations. Building 12 was primarily used for the blending and processing of propellants, principally consisting of 5-cyanotetracola-tetraamine cobalt (III) perchlorate.

Building 13, constructed in 1971, housed the maintenance, welding and electrical shops. Building 14, constructed in 1966, was used as a lunch room, rest area, and dressing facility. Building 15, constructed in 1969, was used for storage of ordnance devices. Building 16 was used for storage of grenades and 81 mm candles from 1966 to 1970, and was then used as a packing area and for inert storage. Buildings 17 and 18 were used for the testing of ordnance (ARCADIS, 2007a).

Buildings 19 through 21 and 23 were constructed between 1966 and 1968. Building 19 was used to store solvents, both spent and virgin. Spent solvents were not stored in Building 19 until a solvent recycling program was started in 1974. Building 20 was used initially (1966 through 1983) for offices and the electronics laboratory. In 1980, its use was expanded to provide for tool storage, a paint shop, maintenance shops, and storage. Building 23 was used for non-chemical storage from 1968 through 1993.

Building 22 was constructed in 1982 and was referred to as the engineering building. Small-scale ordnance loading and testing were among the operations performed in this building. Building 24 was constructed in 1984 and used for smoke generator testing. The site was closed in 1994.

From February through September 2009, Matrix initiated the demolition of the former UPI facility. The project included the demolition of all on-site structures (including 26 Buildings, Bunkers, Magazines, concrete slabs, etc.). The objectives of the facility demolition were to remove the buildings and concrete slabs remaining on site in an effort to facilitate future phases of investigation and remediation. The demolition of the buildings and slabs was followed by the proper disposal and/or recycling of the debris generated by the demolition. A summary of the facility demolition is presented in the Final Building Demolition Report submitted in April 2010.

1.2.2.3 Chemical Usage

The manufacturing operations were primarily limited to machining and assembly, together with the production of 5-cyanotetracola-tetraamine cobalt (III) perchlorate, a pyrotechnic material produced by the U.S. Department of Energy. Other operations included propellant and powder preparation, explosive powder blending, and testing of ordnance components and electrochemical devices. UPI also stored reactive chemicals and products, engaged in ordnance component assembly and testing, assembling of smoke grenades, and blending and processing of propellants. A variety of chemicals such as acids, tear gas, explosives, propellants, paints, glues, oils, solvents, and radioactive materials were used, stored, and tested at the site. Of these chemicals, trichloroethylene (TCE) and perchlorate were known to have been disposed of at the former UPI facility (ARCADIS, 2007a).

The UPI facility used approximately 180 different chemicals and/or chemical mixtures during its years of operation. Typically, only a few grams of explosive or reactive chemicals were used in the units that were manufactured.

1.2.2.4 Disposal Practices

Prior to 1978, nearly all non-explosive wastes at the former UPI facility were disposed of on site. Explosive wastes were sent to the White Tanks Facility (WTF). Most of the wastes were sent to one of the thirteen on-site locations. Combined, these areas consisted of twelve dry wells, ten 750-gallon sedimentation tanks, and two shallow oxidation ponds. Some of the materials disposed of at these sites were solvents, floor wash water containing chemicals, propellants, process chemicals, metals, and pesticides. Small amounts of TCE were also sprayed sporadically in certain areas of the site as a weed killer. Past disposal practices regarding the spent solvent recycling program and perchlorate handling are not well documented (ARCADIS, 2007a).

All of the buildings that were sending wash water wastes to the sedimentation tanks and dry wells were subsequently connected to the COG sewer system. When the UPI facility was opened in 1963, only a few buildings were connected to the COG sewer system. As buildings were renovated and expanded, they were then connected to the sewer system. By March 1987, all remaining buildings were connected to the sewer system to prevent further contamination from the dry wells and other potential sources.

As mentioned above, Building 1 included a leach field that handled the drainage from the laboratory sink and was probably installed in 1963 when Building 1 was constructed. It was reported that the last date the sink was used for disposal was March 1979 (ARCADIS, 2007a). The sink was removed during remodeling in 1982 or 1983 and the sewer line to the tank was disconnected. The sludge in the tank was removed and the tank was rinsed. Long-time employees reported that small amounts of TCE, acetone, Freon, methyl ethyl ketone (MEK), isopropyl alcohol, and toluene may have been disposed of in the sink.

The drywells were allowed to dry up before they were covered with locking metal covers or concrete slabs in 1978. Lab pack systems were added to dispose of small quantities of chemical wastes.

Remaining wastes, depending on the type of wastes, were stored in 55-gallon drums and moved to a storage facility centrally located between Buildings 9 and 4, the waste solvent collection area at Building 19, and/or satellite waste solvent collection areas at Building 1, 6, and 20. From these storage locations, the wastes were sent to the UPI WTF (explosive only) where the solvents were shipped for recycling and the drums were dried and incinerated (ARCADIS, 2007a). The WTF (USEPA ID No. ADZ008398620) was closed in accordance with the ADEQ approved Closure Plan. The closure was completed on 25 October 1994.

1.2.2.5 Superfund Chronology

UPI was under contract almost exclusively to the federal government (directly or indirectly) for the production, testing, and development of components for tactical and strategic weapon and defense systems. The Agency for Toxic Substances and Disease Registry reported that site operations included metal machining, welding, electrical assembly in relation to making items such as grenades, missile warhead components, initiators, detonators, tear vapor, smoke generators, and other defense products (ARCADIS, 2007a).

A variety of chemicals such as acids, explosives, tear gas, propellants, paints, glue, oils, solvents, and limited quantities of radioactive materials were used and/or tested at the site. Additionally, UPI facility stored reactive chemicals and products, processed powder, and blended and processed propellants.

More than 180 different chemicals and chemical mixtures were used over the course of the site's operation. Several different chemicals, principally including solvents, were reportedly disposed in drywells on the property. In particular, TCE and perchlorate were known to have been disposed at the former UPI facility.

In 1981, the Arizona Department of Health Services (ADHS) found that groundwater in the area of the Litchfield Airport (later known as the Phoenix-Goodyear Airport) was affected by volatile organic compounds (VOCs), most notably TCE (ARCADIS, 2007a). In September 1983, the USEPA added the Phoenix-Goodyear Airport site to the National Priorities List (Federal Register, Vol. 48, No. 175, p. 40671).

In April 1984, the USEPA issued a Unilateral Administrative Order under the Resource Conservation and Recovery Act (Docket No. 84-03) to UPI "to conduct a comprehensive sampling and analysis program to support subsequent remedial actions." The work required by the Administrative Order was to be conducted in accordance with the "Final Workplan for the Litchfield Airport Area Remedial Investigation and Feasibility Study" prepared by Ecology & Environment in 1984. In May and June of 1984, UPI began subsurface investigations on the property.

In October 1984, UPI began Phase I of its Remedial Investigation (RI). In 1985, UPI continued RI activities, conducting a soil gas survey and installing five additional monitor wells. Phase II of the RI activities was conducted in two stages during 1986 and 1987, and it was found that the groundwater plume extended more than 1 mile north of the UPI property. During early 1988 additional soil sampling was undertaken at the site to ascertain sources of chemicals in groundwater. The four dry wells near the Office and Administration Building (Building 1) were identified as the primary source of TCE in groundwater (ARCADIS, 2007a).

Concurrent with the initial subsurface investigation, the USEPA began an RI of the PGA area. The RI activities identified "two major areas of non-contiguous contamination" (USEPA, 1988). Therefore, the PGA Superfund Site was divided into a north and a south area. The southern area consists of the Loral Defense Systems Arizona property and the Phoenix-Goodyear Airport property. The northern area consists of the UPI property, and is subsequently referred to as PGA-North. The principal contaminants at PGA-North are TCE and perchlorate, whereas TCE and chromium are the contaminants of concern at PGA-South.

A Record of Decision (ROD) for the entire PGA Superfund Site, including both PGA-North (UPI identified as source) and PGA-South (with various facilities at the Goodyear Airport identified as sources), was signed in September 1989 (USEPA, 1989). In October 1990, USEPA issued an Amended Administrative Order, Docket No. 90-20 (USEPA, 1990) to UPI to implement the ROD remedy. Crane Co. is currently conducting remediation activities at the PGA-North Site under the two Unilateral Administrative Orders.

Since 1991, groundwater monitoring of selected monitor wells has been conducted on a quarterly basis at PGA-North Site. Over time, the monitor well network has expanded from the initial 18 monitor wells (MW-01 through MW-18) which were installed during the RI in the 1980s. These wells were used to help track the extent of contamination and remediation of groundwater.

Monitor wells MW-19, MW-20, MW-21, and MW-22 were installed in 1992; monitor well MW-23 was installed in 1994; monitor well MW-24 was installed in 1997; monitor wells MW-2S and MW-26 were installed in 2000; monitor well MW-27, located east of the site and north of Park Shadows

Country Homes, was installed in 2001; and monitor wells MW-28 and MW-29 were installed in 2002. In 1998, SunCor irrigation well 33C was sealed to reduce its potential as a vertical conduit for migration of chemicals from Subunit A to Subunit C. Monitor well MW-26 was installed to assess conditions in Subunit C near the former well 33C (ARCADIS, 2007a).

A soil vapor extraction (SVE) system using thermal oxidation treatment was operated from June 1994 to October 1998, at which time the USEPA approved shutting down the system to evaluate progress of the SVE program. The program remained closed in response to community concern over air emissions.

Also in 1994, Crane Co. installed and began operating a groundwater treatment system for VOCs, as directed by the ROD. Response activities during this time included installing extraction well EA-01 in 1994 at the identified source area at the Site, and installing extraction well EA-02 in 1996 about one-half mile north of the PGA-North Site. Monitor well MW-05 was converted to extraction well EB-01. Extraction wells EA-03 and EA-04 were installed in 1997 and 1998, respectively, on the northern limits of the UPI property to create a hydraulic barrier (referred to as "the Van Buren Barrier" for its proximity to West Van Buren Street) to contain the further migration of chemicals from the Site. Extraction well EA-04 was used only for a short period in 1998 due to casing failure. During this time, subsequent hydraulic analyses concluded that extraction well EA-03 was providing sufficient capture and extraction EA-04 was not needed (ARCADIS, 2007a).

The Main Treatment System (MTS) extracted contaminated groundwater from Subunits A and B to remove VOCs by air stripping. In 2002, Crane Co. began a perchlorate treatability study; the treated groundwater was injected back into Subunit A via injection wells located at the southern end of the UPI site. The VOC groundwater system was not designed to treat perchlorate in the early 1990s because perchlorate had not been tested for at the PGA-North site. In 1997, advances in analytical technology led to the ability to detect perchlorate to 4 micrograms per liter (μg/L), whereas the prior detection limit was on the order of 400 (μg/L) (USEPA, 2002). Analysis of groundwater from the PGA-North Site in 1998 led to the detection of perchlorate at levels up to approximately 94 μg/L. Perchlorate was identified in monitor wells at the Site in 1998, and select monitor wells were included in the groundwater monitoring program in 1999. Section 1.3.1 provides a more detailed description of the nature and extent of perchlorate at the Site.

In addition, wellhead aeration systems were installed in 1994 at existing SunCor irrigation wells 33A and 33C, as interim emergency remedial measures in response to the discovery of TCE in the irrigation wells. Irrigation wells 33A and 33C are located approximately two miles and one and one-half miles, respectively, north-northwest of the former UPI property. In December 1997, SunCor irrigation well 33A was rehabilitated to extract a majority of its groundwater from Subunit A. The rehabilitation consisted of retrofitting the well and installation of a liquid-phase granular activated carbon (LGAC) system. This system functions as a groundwater extraction system for the treatment of VOCs. On 4 November 1998 a Notice to Abandon a Well was filed with the Arizona Department of Water Resources (ADWR) by SunCor; shortly thereafter, irrigation well 33C was abandoned.

The 33A Groundwater Treatment System (GTS) consists of four 20,000-pound LGAC vessels. Groundwater is extracted from PGA-North Subunit A TCE plume and conveyed to two parallel trains of LGAC vessels, which include the 100 series vessels (Vessels 101 and 102) and the 200 series vessels (Vessels 201 and 202). Each series is capable of operating in lead or lag vessel configurations. A bag filter vessel is installed at the 33A GTS discharge piping, on a 6-inch polyvinyl chloride (PVC) bypass pipe network. During backwashing activities following each LGAC vessel carbon change, backwash

water is discharged through the bag filter vessel for removal of carbon fines. This occurs prior to conveyance to an off-site pond at the Palm Valley Golf Course (ARCADIS, 2007a). Extraction well 33A was developed and a pump test was completed in January 1998. The pump resumed operation in late January 1998 and was incorporated into the final groundwater remedy to capture the PGA-North Subunit A TCE plume north of the Van Buren Barrier.

In April 1998, concentrations of TCE began to increase in monitoring well MW-01, which was the upgradient monitoring location for the TCE plume in Subunit A. Concentrations rose relatively steadily over the next year and a half, at which time concentrations stabilized around 200 μg/L beginning in January 2000. Additionally, TCE was detected in the nearby Park Shadows Irrigation Well (PSIW), with concentrations of 23 μg/L, 7.9 μg/L, and 41 μg/L measured in March 1999, April 2000, and May 2001 respectively. Due to the relatively close proximity of MW-01 and PSIW to the injection wells used to discharge treated water from the treatment plant, it is believed that the increase in TCE concentrations in the two wells is related to the inadvertent discharge of untreated and partially treated water to the injection wells.

USEPA directed Crane Co. to conduct a Phase I groundwater investigation, including installation of monitor well MW-27. The initial focus of the investigation was to evaluate the potential for impacts in the Upper Alluvial Unit (UAU), including the upper aquifer in this unit (Subunit A), to migrate via conduit wells into the deeper aquifers (Subunit C and the Middle Alluvial Unit [MAU]). In November 2001, as a result of increasing concentrations of TCE and perchlorate in Subunit C in monitor well MW-20, the scope of the Phase I investigation was expanded to encompass the entire source area in the northern part of the PGA-North Site. Prior to 2001, impacts at the PGA-North Site were generally interpreted to be confined within Subunit A, with underlying Subunit B acting as an aquitard.

In 2002, the scope of Phase I was further expanded to include investigation of areas located southeast, northeast, and north of the PGA-North Site. Specific activities included the installation of two sentinel monitor wells (MW-28 and MW-29), aquifer testing, hydrogeological data collection, identification of potential conduit wells, completion of an updated well inventory, and a series of aquifer tests on monitor well MW-20. MW-20 became an extraction well and started pumping on 10 July 2002.

In May 2002, the USEPA developed and implemented a Phase II Work Plan to further investigate the source and extent of impacts within Subunit C (CH2M Hill, 2004). This work included a transects-based investigation which characterized the spatial distribution of groundwater impacts within Subunit A, Subunit B, and Subunit C in 15 boreholes at the PGA-North Site. The investigation was focused on the extent of contamination in the Subunit C aquifer near West Van Buren Road, located north of the Site in the down-gradient direction. The goals of the investigation were (1) to identify the source of Subunit C contamination in the vicinity of monitor well MW-20; (2) determine the vertical and lateral extent of Subunit C contamination in the vicinity of MW-20 to develop plume definition; (3) collect sufficient hydrogeological data to fill in data gaps needed for the development of the PGA-North groundwater model and to model Subunit C contamination fate and transport; and (4) to collect data to begin to characterize the vertical and lateral extent of Dense Non-Aqueous Phase Liquids (DNAPLs) in Subunit A in the source area, as well as to monitor remedial effectiveness.

USEPA's Phase II yielded depth-specific groundwater quality information, lithologic logs, and limited geotechnical information and concluded that (1) the historical geological data confirms the existence of a highly heterogeneous subsurface geology; (2) groundwater in Subunits A, B, and C are contaminated; and (3) the highest perchlorate concentration (200 μg/L) occurs in the central section of the Site in Subunit A and in the upper portion of Subunit B (ARCADIS, 2007a).

During 2001-2003, subsequent studies and quarterly groundwater sampling events helped begin defining the extent of perchlorate contamination at the Site. In July 2002, Crane Co. began a perchlorate treatability study to evaluate the feasibility of biodegradation to remove the perchlorate at the COG's wastewater treatment plant (WWTP). When the perchlorate treatability study was initiated in 2002, the injection of VOC-treated water into the aquifer ceased entirely. This treatability study progressed to pilot stage testing in 2003, and a Phase IV operations and maintenance study was scheduled for 2004 (ARCADIS, 2007a). The treatability study continued to discharge VOC-treated water containing perchlorate from the MTS into the COG sanitary sewer system for further perchlorate treatment until April 2005.

Following USEPA issuance of an Order in 2003, Crane Co. conducted a pilot test, restarting the SVE system with granular activated carbon (GAC) to address potential vapor emissions. The pilot test evaluated flow and contaminant concentrations in the subsurface. The system has continued to operate continuously since the pilot test (May 2004).

In October 2004, Crane Co. implemented a work plan to further investigate and characterize the primary source of TCE and possible source of perchlorate at the Site. The work plan focused on the area west of Building 1 and contiguous areas which continue to demonstrate elevated concentrations of TCE and perchlorate. The objectives of the source area investigation program were to 1) further characterize the source area of TCE and potential source of perchlorate; 2) characterize the equilibrium between TCE in soil vapor and TCE in groundwater; 3) retrofit the SVE system; and 4) install an In-situ Reactive Zone (IRZ) injection well to facilitate IRZ pilot studies and evaluate in-situ remedies for both TCE and perchlorate.

In April of 2005, Crane Co. installed an ion exchange system which was added to the MTS to remove perchlorate in the extracted groundwater and allow on-site treatment. The resulting treated waters have been injected into the subsurface. There was success in treating perchlorate during the study of the COG WWTP, but there has also been success in the implementation of the ion exchange treatment and injection of groundwater at the Site itself.

The presence of DNAPL was investigated as part of the source area investigation conducted from May through July 2006. The absence of TCE contamination in the vadose zone identified by analytical results, in addition to the negative DNAPL field test, suggest no significant TCE source is present in the vadose zone beneath the source area. Although high TCE concentrations were identified in groundwater beneath the source area, no DNAPL was identified. Depth-specific groundwater samples indicated detectable TCE above the site-specific cleanup levels and the federal maximum contaminant levels (MCLs) in all groundwater samples collected except some regions near the source area that exceed 200 feet below ground surface (bgs). Although TCE concentrations were as high as 41,200 μg/L, which occurred in source area boring SA-03 at a depth of 110 feet bgs, no DNAPL was indicated in the samples collected (Figure 3).

The results of this investigation contributed significantly to understanding the fate and transport of TCE from the drywells to groundwater, and showed that TCE is not detected in vadose zone soil. Additionally, data gaps identified as a result of the investigation included that additional sampling would be required to define the potential presence of DNAPL in the source area.

Pursuant to Task 2.0 of the Scope of Work included in the Consent Decree between the United States Department of Justice, the USEPA, and Crane Co. that was recorded by the District Court on 26 April 2006, the Year 1, Year 2, and Year 3 Groundwater Investigations were conducted. These

investigations have played an integral role in: 1) defining the contaminants of concern (COCs) in groundwater; 2) defining the vertical and lateral extent of impacts to groundwater in Subunits A, B, and C; 3) characterizing the aquifer properties of Subunits A, B, and C; 4) defining the hydraulic connection between Subunits A, B, and C; and 5) providing hydraulic parameters for the development and refinement of the numerical groundwater flow model.

From March 2006 through September 2007, ARCADIS G&M, on behalf of Crane Co., installed a total of 15 monitor wells (EPA MW-1M, EPA MW-28M, EPA MW-9C, EPA MW-10A, EPA MW-16A, EPA MW-18A, EPA MW-20A, EPA MW-6C, EPA MW-17A, EPA MW-25A, EPA MW-10C, EPA MW-1C, EPA MW-30A, EPA MW-31A, and EPA MW-24C), one groundwater extraction well (EC-01), and one groundwater injection well (IA-06) as part of the Year 1 Groundwater Investigation. A summary of these activities and the analytical results were presented in monthly "Operation and Maintenance Reports and the Final Year 1 Well Installation Report," dated 14 August 2008 (ARCADIS G&M, 2008c).

In August 2007 through March 2008, ARCADIS G&M, on behalf of Crane Co., installed two extraction wells, GTSs (EA-05 and EA-06), and one injection well (IA-10). The wells and GTSs were installed in accordance with the USEPA-approved Work Plan, "Final Work Plan Implementation of Additional Plume Control Measures in the Northeast Area," dated 4 May 2007 (ARCADIS G&M, 2007b) to help control the expansion of the Subunit A plume in the northeastern area, north of Interstate 10 (I-10).

From September 2007 through December 2008, ARCADIS G&M, on behalf of Crane Co., installed a total of 13 monitor wells as part of the Year 2 Groundwater Investigation. Monitor wells EPA MW-6A, EPA MW-7A, EPA MW-11A, EPA MW-32A, EPA MW-34A, EPA MW-35A, EPA MW-36A, EPA MW-37A, EPA MW-43A, EPA MW-14C, EPA MW-15C, EPA MW-16C, and EPA MW-17C were installed as part of this investigation. The project was then transitioned to AMEC Environment & Infrastructure, Inc. (AMEC) in January 2009, and the final Year 2 monitor well, EPA MW-45A, was installed. A summary of these activities and the analytical results were presented in the "Final Year 2 Groundwater Investigation Report," dated 21 December 2009 (AMEC, 2009).

From May 2009 through December 2010, AMEC, on behalf of Crane Co., installed a total of nine monitor wells and two piezometers as part of the Year 3 Groundwater Investigation (EPA MW-1A, EPA MW-23A, EPA MW-26A, EPA MW-39A, EPA MW-40A, EPA MW-41A, EPA MW-8C, EPA MW-39C, EPA MW-40C, and piezometers PZ-09 and PZ-10). A summary of these activities and the analytical results were presented in the "Final Year 3 Groundwater Investigation Report," dated 17 October 2011 (AMEC, 2011e).

From January 2010 through April 2013, AMEC, on behalf of Crane Co., installed a total of 41 monitor wells as part of the "Final Remaining Wells Groundwater Investigation Work Plan (Work Plan)", dated 11 April 2011 (AMEC, 2011c). The current groundwater investigation being conducted under this Work Plan includes the installation of EPA MW-12A, EPA MW-13A, EPA MW-21A, EPA MW-27A, EPA MW-28A, EPA MW-38A, EPA MW-42A, EPA MW-44A, EPA MW-46A, EPA MW-47A, EPA MW-48A, EPA MW-50A, EPA MW-51A, EPA MW-52A, EPA MW-53A, EPA MW-54A, EPA MW-55A, EPA MW-56A, EPA MW-57A, EPA MW-58A, EPA MW-59A, EPA MW-60A, EPA MW-61A, EPA MW-62A, EPA MW-63A, EPA MW-4B, EPA MW-2C, EPA MW-3C, EPA MW-4C, EPA MW-5C, EPA MW-7C, EPA MW-12C, EPA MW-13C, EPA MW-19C, EPA MW-22C, EPA MW-26C, EPA MW-27C, EPA MW-28C, EPA MW-47C, EPA MW-48C, and EPA MW-63C. Although a comprehensive summary of these activities and analytical results have not been presented, the data collected were used in the preparation of this SARFFS.

From March 2010 through May 2011, AMEC, on behalf of Crane Co., completed Phase 1 of the USEPA-approved "Final Comprehensive Regional Approach for Northeast Subunit A Plume Capture Augmentation and Treatment Work Plan", dated 11 April 2011 (AMEC, 2011b). Crane Co. installed extraction well EA-07 interior to the Subunit A TCE plume boundary to allow for additional plume containment. Groundwater extracted from this well is conveyed by underground piping to the EA-06 GTS. Monitor well MW-29 became operational as an extraction well on 7 June 2010. In addition, Crane Co. installed injection wells IA-11 through IA-15 along with six miles of associated piping from the EA-06 GTS to develop and maintain an effective hydraulic barrier between public supply wells and the eastern/northeastern PGA-North Subunit A TCE plume boundary.

From April through December 2011, Matrix New World Engineering, Inc. (Matrix), on behalf of Crane Co., completed installation of extraction well EA-08. This well was installed in accordance with the USEPA approved "Work Plan for Augmentation of Subunit A Plume Containment in the North Central Area", dated 28 February 2011 (Matrix, 2011a) to help contain the Subunit A TCE plume in the northwestern area. Installation of extraction well EA-08 was completed on 21 June 2011 and the GTS became operational in December 2011. Currently, groundwater extracted from extraction well EA-08 is discharged to the Roosevelt Irrigation District (RID) canal.

In May and June 2011, Matrix, on behalf of Crane Co., installed four new 4-inch high density polyethylene (HDPE) pipes for conveying groundwater to the MTS. Three of the installed HDPE pipes are used to segregate extracted water from wells that had shared a common pipeline and subsequently increased the pumping capacity of extraction wells EA-02 and MW-29. The fourth 4-inch HDPE pipe was installed for future expansion and is currently not in-use. The pairs of extraction wells that shared a common pipeline and have been separated with the installation of these new pipelines are EA-01/ EB-01, EA-03/PZ-01, and MW-29/EA-02. Currently, extraction wells EA-01, EB-01, EA-03, and PZ-01 have been connected to individual pipelines to convey water to the MTS. In addition to the new pipelines, Matrix also completed rehabilitation of extraction well EA-01, increasing its yield from 50 gallons per minute (gpm) to 90 gpm, and completed the rehabilitation of EA-02 increasing its yield from 19 gpm to 80 gpm. Matrix has also upgraded all above-ground piping at the MTS extraction wells and MTS influent manifold to reduce pressure losses and increase the efficiency of all submersible extraction pumps.

1.2.2.6 Regulatory Framework

The 1989 ROD and subsequent Explanation of Significant Differences (ESDs) outlined the regulatory setting for the project. The following information is excerpted from those documents and Table 1 provides a summary of the selected remedy, and subsequent changes to that remedy as ESDs were added to the ROD. Table 2 provides a listing of the Original Legally Applicable State & Federal Requirements and Other Criteria for Groundwater that was last amended in the ESD dated March 1998. The Cleanup Levels provided in this table are discussed further in the Section 2.1, Contaminants of Concern, of this report.

> "Arizona law establishes a comprehensive scheme for classifying and protecting aquifers. Portions of this scheme are relevant and appropriate in defining the cleanup levels for PGS-North, Subunit A. Under Arizona law, Subunit A is classified for drinking water protected use, and is subject to aquifer water quality standards. These standards include MCLs) established pursuant to the Safe Drinking Water Act. Arizona law also establishes statutory and regulatory requirements governing the selection of cleanup remedies for contaminated aquifers.

> EPA believes that the Arizona groundwater classification scheme, as applied through the Arizona statutory and regulatory criteria for selection of cleanup remedies, is relevant and appropriate to the setting of cleanup levels. As applied here, Subunit A is protected for drinking water uses because it is part of a definable aquifer and has not received an aquifer exemption. Therefore, Safe Drinking Water Act MCLs are water quality standards for Subunit A. Pursuant to Arizona law, cleanups must achieve the maximum protection of drinking water (i.e., compliance with aquifer water quality standards) consistent with the other requirements for selection of remedial actions.
>
> EPA interprets this requirement here to require the cleanup of Subunit A to achieve MCLs unless that is not cost effective; not reasonable and necessary to prevent, minimize, or mitigate danger to public health or welfare or to the environment; or inconsistent with other relevant aspects of Arizona water law. In this case, EPA determines that complying with MCLs is cost-effective, is reasonable and necessary to prevent, minimize, or mitigate danger to public health, welfare, and the environment, and can be achieved consistent with relevant Arizona water law. Therefore, MCLs are ARARs for Subunit A throughout the subunit, unless Subunit A qualifies for an aquifer exemption, or EPA has reason to alter its determination as to whether achieving such levels is cost-effective, reasonable and necessary, or achievable consistent with Arizona law."

Since 1998, perchlorate has been analyzed for and detected over levels of concern in site groundwater. No national drinking water standard currently exists for perchlorate; however, USEPA anticipates publication of a proposed rule pertaining to perchlorate for public review and comment by 2015. In the interim, the State of Arizona published a Health-Based Guidance Level (HBGL) for perchlorate of 14 μg/L in 2000 (ADHS, 2000). The HBGL is calculated to limit excess lifetime cancer risk to one-in-one million for known human carcinogens and one-to-one-hundred-thousand for possible and probable human carcinogens. The HBGL is designed to protect human health over a lifetime, but might not necessarily represent a health hazard when exceeded.

Perchlorate was not addressed in the 1989 ROD and, therefore, no treatment for perchlorate was initially implemented at the Site. Once the presence of perchlorate was discovered in 1998, an investigation was begun to determine the extent of the perchlorate impacts and establish a viable treatment plan. From October 2003 to June 2005, reinjection at the MTS well field stopped and the TCE treated water was conveyed to the COG WWTP for perchlorate treatment. In June 2005, perchlorate treatment using ion exchange resin for site groundwater commenced at PGA-North and injection into the MTS injection wells resumed. On behalf of the USEPA, an "Engineering Evaluation/Cost Analysis Report for Perchlorate Treatment" was prepared by CH2M Hill in August 2007. To be protective in this action, account for the uncertainty of non-water sources of perchlorate, and remain consistent with other Arizona sites, USEPA selected the HBGL of 14 μg/L of perchlorate as the site-specific cleanup level for the PGA-North Site (CH2M Hill, 2007). The selection process for this site-specific cleanup level is documented in the USEPA's Removal Action Memorandum (RAM) dated 22 May 2008 (USEPA, 2008a).

1.3 Conceptual Site Model

The CSM presented below is based on results of the Year 1, Year 2, Year 3, and Remaining Wells Groundwater Investigations, as well as other prior investigations conducted for the PGA-North Site. These data have been submitted to the USEPA in various reports and are available in the public record, with the exception of the Remaining Wells Groundwater Investigation, which is the current groundwater investigation being conducted.

1.3.1 Nature and Extent of Contamination

The environmental impacts associated with the PGA-North Site are the result of past disposal practices of waste materials from site operations into a series of dry wells located in the central portion of the former UPI facility (Figure 2), referred to as the source area. These drywells were approximately 13 feet deep and were installed exclusively within the vadose zone (ARCADIS G&M, 2006). When the drywells were in use, the waste materials disposed in them migrated downward by gravity, over time, through the vadose zone to the water table. Following migration through the vadose zone, the waste materials entered the groundwater and have since migrated horizontally and vertically into the local aquifer system through the processes of advection and dispersion.

Although the dry wells were identified as the main source area, and TCE and perchlorate identified as COCs, it is important to note from a historical perspective that the main dry wells were not the only location where wastes were disposed and investigated. Approximately 180 different chemicals and/or chemical mixtures were used at the UPI facility during its operation from 1963 until the site was closed in 1994 (ARCADIS, 2007a). In the Revised Final Site Evaluation Report (ARCADIS, 2007a), a total of 13 locations were identified as waste disposal and spillage areas, and an additional 18 Potential Source Areas were designated. As noted in the 1989 ROD, no sludges were known to have been disposed of on the UPI property. Below is the waste disposal narrative from the 1989 ROD to further explain waste disposal practices. It should be clarified that all UPI buildings and structures noted in the excerpted text below were removed from the Site in 2009 (USEPA, 1989):

> "Prior to 1974, the majority of waste solvents generated at the Unidynamics facility were collected in cans in each operational area and disposed of in five dry wells. Disposal of TCE in the dry wells was terminated in 1974. The solvents primarily consisted of trichloroethylene (TCE), methyl ethyl ketone (MEK), acetone, and alcohols. The largest amount of solvents was (sic) disposed of in four dry wells located west of Building 1 (Waste Facility 1 in Figure 2.1). Much smaller amounts of solvents were placed in the dry well adjacent to Building 3 (Waste Facility 4 in Figure 2.1). Most solvent wastes are now accumulated in satellite collection areas 2-5 and then stored at Building 19 (Figure 2.1) for less than 90 days prior to being removed from the facility for reclamation. When the facility was constructed, several sedimentation tanks were installed outside the various buildings to collect wash water, cooling water, and spent coolant or machine oils from different processes. Most of these waste streams reportedly contained only trace amounts of process chemicals from these operations. Some of the sedimentation tanks, such as those outside Buildings 4 and 5, were connected to the City of Goodyear sewer system. However, in most cases the sedimentation tanks were connected dry wells. Two of the sedimentation tanks were also connected to ponds. All sedimentation tanks are now connected directly to the City of Goodyear sewer system."

Numerous investigations have been performed at the UPI facility including the "Phase I Soil Gas Investigation Report" (AMEC, 2011a), and the "Final Source Areas, Soils, and Facility Structures Investigations" (AMEC, 2011d). Results of these investigations did not identify any additional sources of groundwater contamination other than the source area and are depicted in cross section in Figure 3. This is also confirmed by the ongoing groundwater monitoring that shows that the greatest mass of TCE resides in Subunit A near and down gradient from the source area.

A number of hazardous materials and wastes were used and handled at the UPI facility during historical operations. However, following completion of extensive soil and groundwater remedial investigations on the PGA-North area, it has been determined that the COCs, from a remediation perspective, are limited to the chlorinated VOC TCE and the inorganic compound perchlorate.

The most recent quarterly groundwater monitoring data (February 2013), as it relates to the current distribution of TCE and perchlorate in Subunit A groundwater, is summarized below. For purposes of this discussion, the PGA-North Site has been divided into four areas: 1) the area south of Van Buren Street; 2) the area between I-10 and Van Buren Street; 3) the northeast area north of I-10; and 4) the northwest area north of I-10.

1.3.1.1 Area South of Van Buren Street

TCE

Recent groundwater analytical results from on-site Subunit A monitor wells (MW-01 through MW-04, MW-07, MW-08, MW-09, and EPA MW-1A) continue to exhibit TCE concentrations ranging from non-detect (<0.20 µg/L) in MW-01 to 140 µg/L in MW-09. East of Litchfield Road, monitor wells MW-27, EPA MW-10A, and EPA MW-7A continue to exhibit concentrations above the MCL, with current concentrations of TCE at 5.6 µg/L, 120 µg/L, and 13 µg/L, respectively. The highest historical TCE concentration in this area was reported at monitor well MW-02 in August 1986, at a concentration of 350,000 µg/L.

Monitor wells EPA MW-6A, MW-11, MW-13, APS MW-03, EPA MW-11A, and EPA MW-58A continue to exhibit concentrations less than the MCL of 5 µg/L for TCE, and continue to define the western, eastern, and southern boundary of the Subunit A TCE plume in this area of the Site.

Perchlorate

Recent groundwater analytical results indicate that this area contains the highest concentrations of perchlorate in Subunit A groundwater, as identified by monitor wells MW-04 (27.1 µg/L); MW-08 (40 µg/L); MW-09 (14 µg/L); and EPA MW-10A (25 µg/L). The perchlorate concentrations in these wells are well above the site-specific cleanup level established in the RAM (EPA 2008a) of 14 µg/L. The highest historical perchlorate concentration in this area was reported in monitor well MW-07 in February 2010, at a concentration of 94 µg/L. Sentinel wells (APS MW-3, MW-11, MW-03, EPA MW-6A, EPA MW-7A, MW-27, EPA MW-58A, and EPA MW-11A) continue to demonstrate detectable concentrations of perchlorate less than the site-specific cleanup level and continue to define the western and eastern boundaries of the Subunit A perchlorate plume.

1.3.1.2 Area Between I-10 and Van Buren Street

TCE

Recent groundwater analytical results indicate that monitor wells MW-12, EPA MW-48A, and EPA MW-47A, located north of the Site, exhibit TCE concentrations ranging from 150 µg/L in EPA MW-48A to 720 µg/L in MW-12. Monitor wells EPA MW-46A, EPA MW-57A, and EPA MW-12A continue to exhibit TCE concentrations less than the MCL and define the eastern and western extent of the Subunit A TCE plume in this area. The highest historical TCE concentration in this area was reported at monitor well MW-12 in February 2005 at a concentration of 6,190 µg/L.

Perchlorate

Recent groundwater analytical results indicate that perchlorate in Subunit A groundwater in this area ranges in concentration from 1.7 μg/L in monitor well EPA MW-12A to 16 μg/L in monitor well MW-12, which is above the site-specific cleanup level of 14 μg/L. The highest historical perchlorate concentration in this area was measured at monitor well EPA MW-47A in April 2012 at a concentration of 30 μg/L. Sentinel wells (EPA MW-12A, EPA MW-47A, MW-13, EPA MW-56A, EPA MW-57A, EPA MW-46A) continue to demonstrate detectable concentrations less than the cleanup level and continue to define the western, eastern, and northern boundaries of the Subunit A perchlorate plume.

1.3.1.3 Northeast Area

TCE

Recent groundwater analytical results indicate that sentinel monitor wells EPA MW-18A, EPA MW-31A, EPA MW-34A, EPA MW-60A, EPA MW-54A, EPA MW-43A, EPA MW-39A, EPA MW-55A, EPA MW-45A, and EPA MW-40A continue to exhibit concentrations less than the MCL of 5 μg/L for TCE and continue to define the eastern/northeastern boundary of the Subunit A TCE plume.

Interior plume monitor wells MW-18, MW-25, EPA MW-30A, and EPA MW-16A continue to exhibit concentrations above the MCL with current concentrations of TCE at 28 μg/L, 44 μg/L, 6.3 μg/L, and 130 μg/L, respectively. Historically, concentrations of TCE in monitor well EPA MW-35A have fluctuated seasonally in response to the seasonal operation of irrigation well IR-3B, which is utilized for golf course irrigation. However, since the onset of injection of treated groundwater into injection wells IA-11 and IA-12 in August 2010, TCE concentrations have remained below the MCL of 5 μg/L. The highest historical TCE concentration in this area was measured at monitor well MW-25 in December 2005 at a concentration of 1,200 μg/L.

Perchlorate

Recent groundwater analytical results indicate that the detectable perchlorate in Subunit A groundwater in this area ranges from 1.1 μg/L in monitor well EPA MW-39A to 3.0 μg/L in monitor well MW-25. Only two monitor wells, EPA MW-18A and EPA MW-31A, indicated a perchlorate concentration less than the laboratory method detection limit (MDL). The highest historical perchlorate concentration in this area was detected at monitor well MW-25 in January 2005, at a concentration of 27.9 μg/L. Currently, all monitor wells in the area continue to define the perchlorate plume in this area.

1.3.1.4 Northwest Area

TCE

Recent groundwater analytical results indicate that sentinel monitor wells EPA MW-17A, EPA MW-32A, EPA MW-37A, EPA MW-44A, EPA MW-51A, and MW-17 continue to exhibit concentrations less than the MCL of 5 μg/L for TCE and continue to define the northern and western boundary of the Subunit A TCE plume. The highest historical TCE concentration in this area was measured at monitor well MW-15 in December 1991 at a concentration of 6,600 μg/L.

Interior plume monitor wells MW-15, MW-18, EPA MW-26A, MW-19, EPA MW-25A, MW-16, EPA MW-42A, EPA MW-38A, and EPA MW-50A continue to exhibit concentrations of TCE ranging from 6.5 μg/L in EPA MW-50A to 190 μg/L in MW-16. TCE concentrations in monitor well EPA MW-20A fluctuate based on the operational schedule of extraction well 33A. Specifically, monitor well EPA MW-20A exhibits concentrations of TCE less than the MCL when extraction well 33A is operational; however, when extraction well 33A is inactive during shutdown of the RID canal in November of each year, concentrations of TCE increase to levels slightly above the MCL.

Perchlorate

Recent groundwater analytical results indicate that the detectable perchlorate in Subunit A groundwater in this area ranges from 1.1 μg/L in EPA MW-44A to 3.4 μg/L in extraction well 33A. Only one monitor well (EPA MW-20A) indicated a perchlorate concentration less than the laboratory MDL. All monitor wells in the area continue to define the perchlorate plume in this area. The highest historical perchlorate concentration in this area was reported at monitor well MW-16 in November 2001 at a concentration of 10 µg/L.

1.3.2 Regional Geologic and Hydrogeologic Conditions

The PGA-North Site lies within the Basin and Range physiographic providence, which consists of alluvial basins or plains separated by north to northwest trending mountain ranges (ADWR, 1993). Specifically, the PGA-North Site is located within the West Salt River Valley (WSRV) sub-basin of the Salt River Valley located in central Arizona. The regional geology of the WSRV consists of a deep alluvial basin bounded by bedrock mountain ranges consisting primarily of granitic, metamorphic, and volcanic rocks of Precambrian to Tertiary age (Brown and Pool, 1989). Mountain ranges surrounding the WSRV sub-basin include the Hieroglyphic Mountains, the Phoenix Mountains, South Mountain, the Sierra Estrella Mountains, the Buckeye Hills, and the White Tank Mountains. These surrounding mountain ranges are nearly impermeable barriers to groundwater flow. The WSRV alluvial sub-basin consists of thick basin-fill deposits (alluvial fan, playa, and fluvial deposits) of unconsolidated to semi-consolidated clastic sediments of Late Tertiary to Quaternary age.

The alluvial deposits generally increase in thickness and grain size toward the central areas of the sub-basin. The basin-wide, alluvial deposits have been subdivided into three hydrogeologic units (ADWR, 1993). The three hydrogeologic units are designated in descending order as: (1) the UAU, (2) the MAU, and (3) the Lower Alluvial Unit (LAU). The lithology of each alluvial unit is summarized below:

- UAU: Gravel, sand, and silt. Mostly unconsolidated with locally strong cementation near mountain fronts and major stream courses.

- MAU: Silt, siltstone, silty sand, and gravel. Mostly weakly consolidated, but moderately to well-cemented. Siltstone occurs locally; most commonly present in the center of the basin, typically pinches out toward basin boundaries.

- LAU: Clays, silts, mudstone, evaporites, sandstone, gravel, conglomerate, and andesitic basalt. The lower and older part of this unit is moderately to well-cemented. The upper part of this unit is weakly to well-cemented and contains inter-bedded sand, gravel, and conglomerate.

The basin-fill deposits range in thickness from a couple of feet near the basin margins to over 10,000 feet in the central area of the sub-basin. The thickest basin-fill deposits in the WSRV occur near Luke Air Force Base, where the structure and lithology of basin-fill deposits have been influenced by a massive evaporite diapir referred to as the Luke Salt Body (Easton et al., 1972). The principal aquifers of the WSRV sub-basin are the alluvial units described above. The UAU aquifer is generally hydraulically unconfined, while the MAU ranges from an unconfined to a semi-confined aquifer. The LAU aquifer ranges from semi-confined to confined conditions, but may be unconfined in areas where the MAU is not present. Natural recharge to the basin occurs as mountain front recharge, along perennial and ephemeral streams, and as agricultural and urban irrigation (ADWR, 1994).

1.3.3 Local Geologic and Hydrogeologic Conditions

In the vicinity of the PGA-North Site, the UAU is approximately 350 feet thick, and the local stratigraphic sequence includes three subunits that represent divisions of the UAU: Subunit A, Subunit B, and Subunit C. The depositional environments associated with each Subunit at the PGA-North Site are suggested to be derived from a combination of regressive sequences of alluvial fan deposits (proximal facies, midfan facies, and distal facies) eroded from the White Tank Mountains and from ephemeral fluvial deposits associated with the ancestral Bullard Wash and Agua Fria River. Typically, the longitudinal axis of deposition of the alluvial fan deposits trend northwest to southeast. Conversely, the longitudinal axis of deposition of the fluvial deposits associated with the ancestral Bullard Wash and Agua Fria River trend north to south and northeast to southwest, respectively (Figure 4). Each Subunit of the UAU is described as follows.

1.3.3.1 Subunit A

Subunit A is generally composed of interbedded sands, silty sands, and clayey sands that can locally contain sequences of gravel and cobbles. The predominance of sand and the presence of the coarse-grained material suggest a medium to high energy depositional environment related to the braided stream deposits of the ancestral Aqua Fria River and, to a limited extent, the ancestral braided drainage of Bullard Wash. Generally, these deposits are heterogeneous, anisotropic, and unconsolidated, although some cemented zones and well developed caliche have been locally identified in both the vadose and saturated zones (Figure 4). Subunit A typically extends from ground surface to approximately 160 to 200 feet bgs in the vicinity of the PGA-North Site, and generally deepens to the north to depths of approximately 190 to 240 feet bgs. Approximately one-third to one-half of the lower portion of Subunit A is saturated and is considered an unconfined aquifer.

South of I-10 and in the vicinity of the source area, groundwater flow directions in Subunit A are primarily toward the north, with variable hydraulic gradients that are locally influenced by groundwater extraction from extraction wells EA-01, EA-03, and PZ-01 and the injection of treated water into injection wells IA-01 through IA-06.

The heterogeneous and anisotropic nature of the deposits results in variable aquifer properties across the PGA-North Site. Previously, Geomatrix Consultants, Inc. (Geomatrix) estimated the average horizontal hydraulic conductivity of Subunit A in the vicinity of the PGA-North Site to be approximately 60 feet per day (ft/day) (Geomatrix, 2002). Because Subunit A is unconfined, the storativity value for Subunit A is equivalent to the specific yield for this unit. Geomatrix reported that the average specific yield of Subunit A is approximately 0.05, which suggests that the deposits of Subunit A are stratified, vertically anisotropic, and locally semi-confined by laterally discontinuous fine-grained lenses (Geomatrix, 2002). Results of a 2005 tracer test performed by ARCADIS G&M in Subunit A at the source area indicated that the effective porosity of Subunit A is approximately 7 percent. Total porosity values are estimated to range between 25 and 30 percent. These values correspond well to the lithologic descriptions of the material comprising this subunit and published data regarding the total and effective porosity of aquifer materials.

Since mid-2006, most Subunit A monitor wells that have been installed have had aquifer tests performed as part of the Year 1, Year 2, and Year 3 Groundwater Investigations. The results of these tests suggest that hydraulic conductivity of Subunit A is variable across the PGA-North Site.

- Aquifer tests performed on Year 1 Subunit A monitor wells (EPA MW-10A, EPA MW-16A, EPA MW-17A, EPA MW-18A, and EPA MW-20A [Figure 5]) indicated a range in hydraulic conductivity from 4 to 245 ft/day.

- Aquifer tests performed on Year 2 Subunit A monitor wells (EPA MW-6A, EPA MW-7A, EPA MW-11A, EPA MW-32A, EPA MW-35A, EPA MW-36A, EPA MW-37A, EPA MW-43A, and EPA MW-45A) also indicated a range in hydraulic conductivity from 8 to 244 ft/day.

- Aquifer testing performed on Year 3 Subunit A monitor wells (EPA MW-1A, EPA MW-23A, EPA MW-26A, EPA MW-39A, EPA MW-40A, and EPA MW-41A) indicated a range in hydraulic conductivity from 2 to 729 ft/day.

In general, based on the spatial relationship of the hydraulic conductivity values, Subunit A north of I-10 is highly transmissive with hydraulic conductivity values estimated to be as high as 729 ft/day. Results of aquifer tests south of I-10 indicate that Subunit A is moderately transmissive with hydraulic conductivity values up to 133 ft/day. Additionally, the vertical hydraulic conductivity values identified from laboratory analysis are more than an order of magnitude less than the horizontal hydraulic conductivity values. This is expected due to the stratified nature of the deposits in Subunit A.

1.3.3.2 Subunit B

Subunit B is generally unconsolidated silt and clay dominant deposits composed of interbedded silts and clays with lenses of fine to coarse sand. The ubiquitous nature of the Subunit and predominance of fine-grained material suggest low energy deposits, possible distal facies of an alluvial fan depositional environment eroded from the White Tank Mountains during heavy precipitation events or may represent a succession of overbank flood deposits, or a combination (Figure 4). Subunit B generally has variable thickness (20 to 70 feet thick near the PGA-North Site) with depths extending from approximately 160 to 230 feet bgs and is fully saturated.

Based on data collected during drilling, Subunit B is suggested to deepen and is locally thin north of I-10 and may not be laterally continuous due to washouts from the braided deposits of the paleo Agua Fria River channel to the east. North and northeast of the PGA-North Site, lithologic data obtained during the installation of PGA-North monitor wells MW-29, EPA MW-47C, and EPA MW-48C indicate that Subunit B in the north and northeast of the Site may thin, or become more coarse-grained, and in monitor wells MW-28 and EPA MW-40C, Subunit B may be absent. However, in other areas in the northeast, in the vicinity of EPA MW-14C and EPA MW-39C, Subunit B is thick and fine-grained dominant with little to no interbedded sand lenses. The absence of Subunit B at monitor well MW-28 and EPA MW-40C may be due to a washout of the Subunit from the ancestral Agua Fria River or it may not have been recognized during soil logging conducted during drilling and well installation activities.

The vertical anisotropy and the predominance of fine-grained deposits impede the connectivity and vertical movement of groundwater and contamination from Subunit A into Subunit C. This is strongly supported by several lines of evidence, including the lack of TCE impacts in Subunit C north of the PGA-North Site, the hydraulic head differences between Subunit A and Subunit C well pairs, and by the differences in geochemical signatures between groundwater in Subunit A and Subunit C.

As previously noted, Subunit B acts as a partial hydraulic barrier and impedes groundwater flow and hydraulic communication between Subunit A and Subunit C. Lithologic logs from the Subunit C Investigation south of I-10 indicate that the silt/clay dominant deposits which comprise Subunit B can contain local interbedded, more permeable zones consisting of sand dominant lenses which can contribute to groundwater flow.

Aquifer parameter values within Subunit B were estimated based on aquifer tests conducted on extraction well EB-01. However, based on the recent lithologic data collected south of I-10, extraction well EB-01 may be screened within the upper portion of Subunit C. As such, the published values of transmissivity and hydraulic conductivity that have been estimated are more than likely not reflective of Subunit B. However, data collected from aquifer tests that will be conducted using Subunit C extraction wells and the proposed Subunit B monitor wells (EPA MW-4B, EPA MW-5B, and EPA MW-28B) as observation points will help establish aquifer parameters for this Subunit.

Similar to Subunit A, in the vicinity of the PGA-North Site, the vertical hydraulic conductivity values identified from laboratory analysis are several orders of magnitude lower than the horizontal hydraulic conductivity values.

1.3.3.3 Subunit C

Subunit C is composed of interbedded mixtures of silty sands, sandy silts, and sands. The absence of gravel dominant deposits in the unit and presence of well sorted sands suggest medium energy type deposits that may represent mid-fan facies of an alluvial fan sequence with braided channels, or it may represent braided distributaries of the ancestral Agua Fria River and Bullard Wash which lacked the energy to transport gravel (Figure 4). On average, Subunit C is approximately 120 feet thick and extends from about 230 to 350 feet bgs. The unit is fully saturated and is generally considered to be a semi-confined aquifer with locally leaky to confined conditions.

The heterogeneous and anisotropic nature of the deposits in Subunit C results in variable aquifer properties. Previously, Geomatrix reported several localized transmissivity values for Subunit C that were estimated based on aquifer testing and borehole dilution testing activities conducted at the PGA-North Site (Geomatrix, 2002). Transmissivity values from these field tests ranged from 4,400 to 8,300 square feet per day (ft^2/day). In 2006, ARCADIS G&M performed an aquifer test on Subunit C extraction well EC-01. The estimated hydraulic conductivity values ranged from 21 to 77 ft/day using leaky aquifer solutions, and 36 to 138 ft/day using confined solutions (ARCADIS G&M, 2008a).

A Subunit C investigation is currently underway in the area south of I-10 to refine the understanding of the hydrogeology in this area. As of April 2013, monitor wells EPA MW-4C, EPA MW-7C, EPA MW-12C, EPA MW-13C, EPA MW-19C, EPA MW-27C, EPA MW-28C, and EPA MW-63C have been installed with one additional Subunit C monitor well currently proposed (EPA MW-18C). During drilling of the Subunit C monitor wells, soil cores will continue to be collected using sonic drilling methodology and used to accurately identify the thickness and grain size distribution within each subunit. Additionally, depth-specific groundwater samples will be collected within each subunit to identify the TCE distribution with depth.

Since mid-2006, most Subunit C monitor wells that have been installed have had aquifer tests performed as part of the Year 1, Year 2, and Year 3 Groundwater Investigations.

- Aquifer testing performed on Year 1 Subunit C monitor wells (EPA MW-1C, EPA MW-6C, EPA MW-9C, EPA MW-10C, and EPA MW-24C) yielded hydraulic conductivity values ranging from 2 to 47 ft/day.

- Aquifer tests performed on Year 2 Subunit C monitor wells (EPA MW-14C, EPA MW-15C, and EPA MW-17C) yielded hydraulic conductivity values ranging from approximately 0.13 to 8 ft/day.

- Aquifer testing performed on Year 3 Subunit C monitor wells (EPA MW-8C, EPA MW-39C, and EPA MW-40C) yielded hydraulic conductivity values ranging from 0.3 to 35 ft/day.

Based on the spatial relationship of the hydraulic conductivity values, the results of these aquifer tests suggest that generally the transmissivity in Subunit C north of I-10 is low with hydraulic conductivity values up to 15 ft/day. Conversely, the results of aquifer tests south of I-10 indicate that Subunit C is slightly more transmissive with hydraulic conductivity values as high as 138 ft/day.

Typically, the vertical hydraulic conductivity values identified from laboratory analysis are more than an order of magnitude less than horizontal hydraulic conductivity values.

1.4 Baseline Risk Assessment

In general, baseline risk assessments provide an evaluation of the potential threat to human health and the environment in the absence of any remedial action. The baseline risk assessment included in the ROD for the PGA-North Site identified and assessed three potential human exposure pathways to the PGA-North Site groundwater (USEPA, 1989). These exposure pathways are summarized below:

- Ingestion by private residents who use private wells for potable water supply;

- Inhalation of volatiles stripped from drinking water during in-home uses such as bathing and cooking; and

- Dermal contact with contaminated groundwater from resident's private wells.

Relative to remediation of source area groundwater (Figure 2), completion of these exposure pathways is not possible because the source area is wholly located on site in Subunit A to the south of Van Buren Street, where there is no residential or commercial activity aside from a portion of the plume that is located beneath the Goodyear Financial Center parking lot. Regardless of the groundwater remedial action implemented in the source area, these exposure pathways will remain incomplete. In addition, a vapor intrusion exposure pathway was considered for the Site. Indoor air sampling has been previously conducted and no significant risk was identified (ARCADIS, 2005b).

In November 2012, a "Final Source Areas, Soils, and Facility Structures Baseline Human Health Risk Assessment" (HHRA) Report (AMEC, 2012) was completed. In the final step of the risk assessment process, a risk characterization was completed. In this step, the results of the exposure and toxicity assessments are integrated into quantitative or qualitative estimates of potential health risks. In general, the conclusions associated with this Final HHRA were consistent with the finding from the ROD and the indoor sampling results.

1. Source area groundwater is being actively remediated and the baseline evaluation of this hypothetical worst-case exposure scenario suggests on-site groundwater is not currently suitable for use as tap water.

2. Predicted exposure to volatile chemicals in indoor air of future buildings using data collected from 2007 to 2011 are within or below the acceptable risk range and below the acceptable hazard index for future indoor commercial/industrial workers. This indicates that the SVE system has been successful at reducing potential health risks (predicted risk and hazard indexes) in source areas.

3. Predicted exposure to soil is below the de minimis risk level or within the acceptable risk range for potential trespassers, future construction workers, and future outdoor commercial/industrial workers.

1.5 History of Source Area Groundwater Remediation Activities – Treatability and Pilot Studies

Remediation technologies for source area groundwater in the vicinity of the source area at the PGA-North Site have been tested in the laboratory and field as described below. Table 3 provides detailed information regarding these remediation activities.

1.5.1 Microcosm Study

Biological treatment of VOCs and perchlorate in the soil and groundwater was evaluated in October 2004 by adding an organic carbon reagent (corn syrup) to serum bottle microcosms prepared with soil and groundwater from the PGA-North Site (ARCADIS, 2005a). Soil and groundwater samples were collected from the PGA-North Site from 30 August through 3 September 2004 in accordance with the "Revised In-Situ Reactive Zone™ Treatability Study Work Plan for the Phoenix-Goodyear Airport North Superfund Site" (ARCADIS, 2004). Four microcosm test groups were prepared: (1) abiotic controls, (2) un-amended biological controls, (3) low-dose corn syrup treatment, and (4) high-dose corn syrup treatment. Perchlorate and TCE were added to the groundwater to reach planned concentrations of 150 μg/L and 6,000 μg/L, respectively. Headspace samples collected at six weeks did not contain detectable concentrations of TCE daughter products 1,1-dichloroethylene (1,1-DCE) or vinyl chloride (VC). These results indicated that minimal TCE degradation had occurred.

1.5.2 Nano-scale ZVI Column Study

Column studies were conducted in December 2004 to evaluate the effectiveness of nano-scale Zero Valent Iron (nZVI) in chemically reducing VOC and perchlorate concentrations (ARCADIS, 2005a). Four columns prepared with homogenized PGA-North Site soil were treated with four nZVI dosages media: (1) 0.5 percent by weight nZVI, (2) 1 percent by weight nZVI, (3) 2 percent by weight nZVI, and (4) 0.5 percent by weight nZVI plus trace palladium catalyst. Perchlorate and TCE were added to the groundwater to reach planned concentrations of 150 μg/L and 6,000 μg/L, respectively. The amended groundwater was pumped through the columns at 0.13 milliliters per minute.

Effluent samples were collected at 5, 10, and 15 pore volumes after approximately 3.5, 7, and 10 days, respectively. Significant TCE reductions were reported for each condition at 5 pore volumes and remained low after 10 and 15 pore volumes had been pumped through the columns. TCE concentrations after 5 pore volumes ranged from 459 μg/L to 930 μg/L. Perchlorate concentrations did not change significantly.

Based on the results of this study, nZVI treatments were effective in rapidly reducing TCE concentrations by up to 83 percent. The level of TCE reduction was similar across the nZVI loading levels and did not appear to be effected by the addition of palladium catalyst.

1.5.3 Phase I Field Study

The Phase I field study was conducted between September 2005 and January 2006 and consisted of a baseline sampling event, a tracer injection test, and nZVI injection test (ARCADIS, 2006a). The well network included two injection wells screened from 110 to 120 feet bgs and four monitor wells screened from 115 to 130 feet bgs. Following baseline depth-discrete groundwater sampling for VOCs, sampling depths exhibiting the highest VOC concentrations were selected for each monitor well for further monitoring.

The tracer injection test used a solution of potassium bromide, Fluorescent FLT Green/Yellow Dye, and water to quantify the radius of influence, groundwater flow velocity, dilution effects, and connectivity between monitor wells and the injection zone. Results of the tracer test indicated an effective porosity of 0.07, an injection pressure of 31 pounds per square inch (psi) to achieve a flow rate of 10 gpm, a 10-foot radius of influence, and dilutions of 52 to 58 percent at the injection well and 20 to 40 percent at monitor well IRZ-MW-B.

The nZVI injection solution was prepared with treated PGA-North Site groundwater to a targeted concentration of 30 grams per liter (g/L) of nZVI and 2.6 g/L of sodium bromide tracer. The nZVI solution was injected over three days through the 0.030 stainless steel wire-wrap screen. The nZVI agglomerated into larger-sized particles and clogged the injection well screens. The injection rate remained low following brushing of the well screen. Of the planned 1,000 pounds of nZVI, approximately 46 pounds of nZVI were injected into the subsurface.

Following the nZVI injection, TCE concentrations decreased in groundwater samples collected from the injection wells and one monitor well (IRZ-MW-C). Perchlorate concentrations decreased in groundwater samples collected from monitor well IRZ-MW-C.

1.5.4 nZVI Particle Size Distribution Testing

Four samples of nZVI particles were prepared and submitted for particle size distribution analysis in April 2006 (ARCADIS, 2006b). Three nZVI samples were prepared with: (1) a dispersing agent, (2) a colloid mill, and (3) both a dispersing agent and colloid mill. The fourth nZVI sample was an untreated, four-month old sample. The particle sizes of all of the samples were determined to be small enough to be injected. Particle sizes of the three treated samples were measured to be between 50 to 100 nanometers and were smaller than the untreated, aged sample which was measured to be between 125 to 300 nanometers.

1.5.5 Additional nZVI Column Testing

The mobility of nZVI through a sand column was tested after select chemical and physical particle modifications (ARCADIS, 2006b). Twelve sand column tests were conducted consisting of four treatments and three nZVI loading levels for each treatment. The four nZVI treatments included: (1) nZVI and water; (2) nZVI, water, and a suspending agent (sodium hexametaphosphate [SHMP]); (3) nZVI and water processed through a colloid mill; and (4) nZVI, water, and the suspending agent processed through a colloid mill. The three nZVI loading levels were 5 g/L, 25 g/L, and 50 g/L.

The use of SHMP as a dispersing agent resulted in higher hydraulic conductivities and faster run times than solutions with only nZVI and water, and appeared to control agglomeration of nZVI particles. Colloid milling solutions resulted in clogging (5 g/L nZVI loading level) or yielded results similar to non-milled solutions (25 g/L and 50 g/L nZVI loading levels). Processing of nZVI through a colloid mill did not appear to provide benefits. Travel distance of the nZVI in the columns was not measured in this study.

1.5.6 Phase II Field Study

The Phase II nZVI field test was conducted in 2008 (ARCADIS, 2009). The nZVI injection solution was prepared with a 10 percent approximate concentration of dispersing agent (SHMP) on a dry weight basis of nZVI. In addition, the water was purged of oxygen prior to mixing.

Three batches of nZVI solution were injected. The average concentrations in the 2,751 gallons injected were 2.1 g/L nZVI and 2,175 milligrams per liter (mg/L) bromide tracer. The solution was injected over a total of 27.6 hours at an average flow rate of 1.7 gpm. Approximately 50 pounds of nZVI were injected.

TCE concentrations decreased and bromide and dissolved hydrogen concentrations increased in the injection well and the observation well located 5 feet downgradient from the injection zone. TCE, bromide, and dissolved hydrogen concentrations fluctuated in wells 10 and 14 feet downgradient of the injection well. At 22 weeks post-injection, bromide and dissolved hydrogen concentrations remained elevated in the injection well and the 5-foot downgradient observation well, indicating that a portion of the nZVI mass was still reactive at 22 weeks.

Since there was no physical or chemical evidence of working strength nZVI being transmitted to or beyond 5 feet of the injection well, the investigators concluded that decreases in TCE and increases in bromide and hydrogen concentrations in downgradient groundwater were attributable to treated groundwater flowing out of the injection zone past the observation wells.

Falling head aquifer tests showed decreased hydraulic conductivity from pre-injection (5 to 11 ft/day) to post-injection (0.15 to 0.18 ft/day), indicating that the injected nZVI solution decreased the permeability of the nearby aquifer material and the injection well by approximately two orders of magnitude.

1.5.7 Phase III Pilot Test

The Phase III nZVI pilot test was conducted in 2010 (Haley & Aldrich, 2011a). This pilot test was designed to demonstrate that a pressurized injection method (jet-assisted injection) can increase the nZVI mass applied at each point and increase the radius of influence of injected nZVI as compared to the Phase I and II pilot test results.

Two blank cased wells were installed for use as injection points. The nZVI injections were conducted using a combination of a jet lance injection tool and pressurized packer isolation of the target injection zone. The jet-assisted injection of anaerobic water using a 10,000-psi, tri-plex pump was alternated with injection of nZVI using a piston pump. The 10,000-psi jetted water was applied to the lance to carve approximately 1/16- to 1/8-inch diameter holes through the PVC casing and through the annular grout to create 10 jetted conduits into the formation. The injectate piston pump then pressurized the

casing between the packers to 100 to 160 psi, forcing the nZVI into the jetted conduit and creating fractures as the injectate pressure exceeded the overburden pressure. Periodic application of the water jets was used to create high pressure turbulence to further mix the nZVI with soil in the vicinity of the jetted conduit and clear the casing of nZVI particles. After completion of the lower injection interval, the packers were pulled up to the next injection interval and the process was repeated. Two intervals, 113 to 118 feet bgs and 108 to 113 feet bgs, were completed at each injection well.

The pilot test delivered 7,421 gallons of highly reducing (-500 to -800 milliVolt) nZVI particles to injection intervals of 108 to 113 feet bgs and 113 to 118 feet bgs. The injectate contained approximately 1,400 pounds of nZVI.

TCE mass in the treatment area decreased by 63 percent to 96 percent within one month following completion of the nZVI injections. Immediate degradation effects were observed at least 29 feet from the injection locations during the one- and three-week post-injection groundwater sampling events. Iron and hydrogen concentrations indicated that nZVI and treated groundwater migrated as far as 45 feet downgradient by the six-month post-injection sampling event.

Injections also temporarily mobilized TCE mass within the radius of influence of the injection wells, and additionally, downgradient extraction wells were operating at the time of the pilot test. Note that the jet-assisted injection method is comprised of two stages: during the first stage, the high pressure pump is used to create holes in the injection well casing with water. The first high-pressure injection is more likely to disturb and mobilize mass due to the high pressure and potential for high disturbance of the formation. It is more likely that the injection of water under high pressure was responsible for the mobilization of mass than the injection of the nZVI.

1.6 Source Area Groundwater Remediation Design Framework

This focused feasibility study has been developed within a framework consisting of the CSM (Section 1.3), the data collected from previous and ongoing remediation activities (Section 1.5), and site-specific design elements. This framework is common to all of the proposed source area groundwater remediation alternatives, with particular importance to those that involve the placement of treatment amendments in the subsurface. This section provides a broad overview of the general design concepts that are expected to form the underpinning of the final design. The design concepts and methods to collect the data necessary to implement the source area groundwater remedy will be documented in the final design report. The basic framework described in this section provides a proposed approach for filling in the data gaps identified during the feasibility study agency review process. Specific data gaps include, but are not limited to, the definition of the horizontal and vertical extent of the treatment area, optimization of the methods used to implement the remediation technologies, including developing methods for better understanding the distribution and behavior characteristic associated with proposed treatment amendments, and methods and approach for monitoring the effectiveness of the remedy.

Use of the Triad approach will support development of a more accurate CSM to "…distinguish and delineate contaminant populations for which decisions about risk and remediation will differ (USEPA, 2004)" and allow for targeted application of the chosen remedy. Elements of the Triad approach include systematic project planning or strategic project planning, dynamic work strategies, and real-time measurement technologies. For PGA-North, this includes incorporation of agency concerns in the approach to optimization of the remediation technology, use of real-time data collection methods during execution of the data collection phase of each remedial alternative, and inclusion of decision goals,

decision trees, mechanisms to address data uncertainties, and predetermined decision criteria in the design and field work plan (Interstate Technology and Regulatory Council [ITRC], 2003). A Triad project is defined by: consensus from the USEPA, stakeholders, and Crane Co. (the project team) on project goals and methods, an approach that allows the project team to anticipate site-specific heterogeneities and distribution limitations and support ongoing refinement of the CSM, and finally, a system to manage sampling and analytical uncertainties. Design of a site-specific approach will be conducted in accordance with ITRC and USEPA guidance documents, such as those available at http://www.triadcentral.org, a website sponsored by the USEPA, Argonne National Laboratory, U.S. Army Corps of Engineers, U.S. Navy, U.S. Air Force, State of New Jersey, and the ITRC.

With regard to performance monitoring, use of the Triad approach also applies to the determination of appropriate points of compliance and methods to measure the success of the source area groundwater remedy relative to the RAOs and points of compliance jointly defined by the project team and stated in Section 2.1. The number of monitoring locations, sample collection method (i.e. passive flux meters, low flow, passive diffusion bag, hydrasleeve), and its configuration will be determined by the size and location of the treatment area relative to the hydraulic barrier at Van Buren Street and the data quality metrics and requirements. The numbers, types, and locations of monitor wells cannot be determined with any specificity at this stage in the remediation process, especially when the remedy may include jet-assisted injection, the method used to deliver amendment to the subsurface during the most recent field pilot test. Use of the jet-assisted injection method would adversely affect any existing monitor wells within the effective radius of influence of injection points and render them purposeless. Therefore, the number of monitor wells was determined based upon the configuration of the remedy assumed for each of the proposed alternatives with the assumption that these details would be determined as an outcome of the site-specific Triad approach.

Finally, an important design element of each of the proposed remediation alternatives is the assumption of successful hydraulic capture at Van Buren Street. The achievement of hydraulic capture to prevent further migration of COCs from the source area, and potentially treatment amendments, is an essential part of each of the proposed remediation alternatives. Although it is likely that hydraulic capture is occurring, the current configuration of extraction wells along Van Buren Street is currently being assessed to determine if the system has achieved hydraulic capture within Subunit A. It is likely that this determination will be made prior to implementation of a source area groundwater remedy and on an ongoing basis after that. If augmentation of the hydraulic barrier is deemed necessary, this issue can be addressed in the design phase of the source area remedy.

2. IDENTIFICATION AND SCREENING OF TECHNOLOGIES

The Feasibility Study (FS) process includes a series of qualitative and semi-quantitative steps, beginning with the establishment of RAOs and ending with an evaluation of specific remedial alternatives. The study process is generally comprised of the following seven steps:

- Identify RAOs;
- Identify potential general response actions;
- Identify potential remedial technology process options;
- Screen remedial technologies to eliminate less practical options;
- Develop potential remedial alternatives that pass the screening test (combining process options);
- Develop a detailed analysis of potential remedial alternatives; and
- Evaluate alternative(s) with respect to Comprehensive Environmental Response, Compensation, and Liability Act criteria (USEPA, 1988).

In this focused FS, the evaluation process was guided by specific USEPA, ADEQ, and stakeholder input through interactive presentation of the remediation technologies, followed by the incorporation of comments from the USEPA, ADEQ, and stakeholders into the FS Work Plan and this SARFFS. This section of the SARFFS includes a presentation and discussion of the first four steps of the FS process.

2.1 Remedial Action Objectives for Groundwater Remediation

The groundwater remedial response objectives provided in the 1989 ROD remain as follows:

- Protect public health and the environment from exposure to contaminated groundwater;
- Eliminate further migration of contaminated groundwater; and
- Restore the quality of the Subunit B/C aquifer with respect to contaminant levels that can be attributed to industrial activities.

The remediation goals for the Site selected in the 1989 ROD include removal and containment of site COCs and aquifer restoration. The USEPA's overall goal with this focused FS is to augment and accelerate remediation of the source area of the PGA-North plumes to achieve the maximum reduction of contaminant mass/mass flux in the source area as technically achievable in a reasonable time. Permanent mass flux and concentration reduction will result in shrinkage and stabilization of the area of impacted groundwater, thus contributing to reaching the goals established in the original ROD.

The RAOs for the source area groundwater remedy are:

- Achieve permanent mass flux reduction of at least 80 percent;
- Achieve permanent concentration reduction of at least 80 percent; and
- Mass removal within the source area.

Containment of mass within the source area that may become mobilized as a result of these remediation activities is a secondary RAO and will be monitored closely.

As agreed to by the Agency Team at the 15 September 2011 CSM/RAO Meeting, a specific timeframe for achievement of the RAOs will remain conceptual during the pre-design (SARFFS) phase. As more information is learned about the source area using the Triad approach, the Agency Team and Crane Team will further discuss the assessment of timeframes for measuring RAO success or failure. The RAOs for this SARFFS enhance the original RAOs from the 1989 ROD in the following manner:

- Of the remedial alternatives presented in Section 2.9 of this SARFFS, Alternatives 3, 4, and 5 have the most potential to be protective of public health and the environment from exposure to contaminated groundwater;

- The inclusion of the hydraulic barrier concept in each of the alternatives described in Section 2.9 of this SARFFS support the original RAO to eliminate further migration of contaminated groundwater; and

- All remedial alternatives presented in Section 2.9 of this SARFFS are focused on the restoration of the quality of the Subunit A aquifer with respect to contaminant levels that can be attributed to industrial activities, and focused restoration of the Subunit A aquifer may further reduce contaminant migration to the Subunit B and C aquifers.

2.2 Contaminants of Concern

TCE and perchlorate have been identified to be the COCs for source area groundwater at the PGA-North Site. Perchlorate has been identified at low concentrations throughout the Subunit A aquifer. Near the source area, TCE and perchlorate concentrations remain above the cleanup levels of 5 μg/L, and 14 μg/L, respectively. TCE and perchlorate in Subunit A groundwater is currently being remediated by air stripping and ion exchange, respectively, at the MTS. Furthermore, the effectiveness of retained remediation alternatives to treat these two COCs will be evaluated and compared among the alternatives.

2.3 Allowable Exposure per Baseline Risk Assessment

None of the potential direct exposure pathways are complete when evaluating the scenario of applying a remediation alternative in the source area. The source area is limited and entirely contained on the former UPI facility. During any remediation activity that occurs north of the UPI property boundary, exposure would be controlled through existing health and safety measures. Remedial alternatives evaluated in this document have no additional potential for completion of any of the exposure pathways.

As an example, in the event that additional groundwater extraction is needed north of the UPI property boundary, the treatment system would be constructed in accordance with an approved work plan and operated in accordance with an approved operations and maintenance plan such that, under normal operation, there would be no completed exposure pathway to contaminants in the extracted groundwater.

2.4 Applicable or Relevant and Appropriate Requirements

The PGA-North Site groundwater remedy was chosen through the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) process as documented in the ROD and ESDs (USEPA, 1991, 1993, 1995, 1998, 2002b, 2006b). Under CERCLA, a remedial action, must meet

Applicable or Relevant and Appropriate Requirements (ARARs). The ARARs are requirements in promulgated environmental laws as they relate to on-site remedial actions. On-site includes the areal extent of contamination and all suitable areas in proximity to the contamination necessary for implementation of the response action at the Site (40 Code of Federal Regulations [CFR] §300.5). Off-site actions are not addressed through this ARARs evaluation and must comply with all applicable local, state, and federal administrative and substantive requirements including CERCLA Section 121(d)(3), 42 U.S.C. § 9621(d)(3), 40 CFR § 300.440 also known as the Off-site Rule.

In some situations, ARARs may not be available or adequately address protection of human health and the environment. Where ARARs do not sufficiently address a situation, to-be-considered (TBC) requirements (e.g., non-promulgated advisories, criteria, guidance, or proposed standards) issued by federal and state agencies were identified (40 CFR § 300.400.g.3). These TBCs are not enforceable nor are they legally binding unto themselves and do not have the same status as ARARs. However, TBCs are considered when developing cleanup levels and evaluating risks to human health or the environment, and TBCs are used to develop enforceable remedial requirements. Meeting ARARs and overall protection of human health and the environment form the threshold criteria (i.e., threshold, primary balancing, and modifying criteria) to evaluate remedial alternatives and meet when selecting a remedial action. Balancing criteria are long-term effectiveness and permanence; short-term effectiveness and protectiveness; reduction in contaminant volume, toxicity, and mobility; implementability; and cost. The modifying criteria are community and state acceptance. The ARARs and TBCs identified during the focused FS are for all of the potential alternatives. The final determination of ARARs will be made when the remedy for the PGA-North source area groundwater is documented in a ROD amendment.

ARARs are defined in CERCLA to include: any standard, requirement, criterion, or limitation under federal environmental law and any promulgated standard, requirement, criterion, or limitation under a state environmental or facility-siting law that is more stringent than the associated federal standard, requirement, criterion, or limitation. An ARAR may be either "applicable," or "relevant and appropriate." These terms are defined in the National Oil and Hazardous Substance Contingency Plan (referred to as the National Contingency Plan; 40 CFR § 300.5) to include: applicable requirements are those cleanup standards, standards of control, or other substantive environmental protection requirements, criteria, or limitations promulgated under federal or state environmental or facility siting laws that specifically address a hazardous substance, pollutant, contaminant, re medial action, location, or other circumstance found at the site, or relevant and appropriate requirements are those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal or state environmental or facility siting laws that are not "applicable" to the site but address problems or situations sufficiently similar to those encountered at the CERCLA site that their use is well suited to the particular site.

Although non-environmental laws such as worker safety laws are not ARARs, the hazardous waste worker safety regulations must be complied with as part of any remedial activity.

2.4.1 ARAR Waiver Provisions

CERCLA provides specific circumstances in which ARARs may be legally waived (CERCLA § 121.d.4). There are six waiver criteria available, including interim measures, greater risk to health and the environment, technical impracticability, equivalent standard of performance, inconsistent application of state requirements, and fund balancing.

The criteria and circumstances in which a waiver may be applied are:

- Interim Measure – The remedial action selected is only a part of the total remedial action that will attain such level or standard of control when completed;
- Greater Risk to Health and the Environment – Compliance with the requirement will result in greater risk to human health and the environment than alternative operations;
- Technical Impracticability – Compliance with the requirement is technically impracticable from an engineering perspective;
- Equivalent Standard of Performance – The remedial action selected will attain a standard of performance that is equivalent to that required under alternative applicable standards, requirements, criteria, or limitations, through use of another remedial action;
- Inconsistent Application of State Requirements – With respect to state standards, requirements, criteria, or limitations, the state has not consistently applied (or demonstrated the intention to consistently apply) the standard, requirement, criterion or limitation in similar circumstances at other remedial actions within the state; or

2.4.2 Site-Specific ARARs

The identification and documentation of potential ARARs and TBCs was accomplished using USEPA guidance and review of a draft ARARs table in conjunction with a review of federal and state laws, regulations, and policies (USEPA, 1988). A draft ARARs table was submitted to the USEPA during the 7 February 2013 Technical Working Group Meeting and was commented upon in the USEPA's letter dated 22 March 2012. TBCs were identified using guidance documents available from federal and state agencies and engineering judgment.

Potential ARARs are presented in three categories based in the manner in which they are applied to the Site; chemical-, location-, and action-specific ARARs. The ARARs documentation provides rationale for the decision that chemical-, location-, and action-specific requirements are applicable, or are relevant and appropriate for the Site, for each remedial action alternative that passed through the screening process and into the detailed analysis. This includes Alternative 1, the no action alternative, which assumes continued operation of the existing SVE and pump and treat systems. Within the three categories, the requirements are further organized by federal ARARs followed by state ARARs and TBCs. A description of categories followed by the principal requirements within each category is provided below. A list of potential chemical-, location-, and action-specific ARARs is provided in Table 4. Table 4 includes a description of the ARARs and the rationale for whether the ARAR applies or are to be considered for the alternatives in this FS.

2.4.3 Chemical-Specific ARARs

The potential chemical-specific ARARs and TBCs are health- or risk-based concentration limits, numerical values, or methodologies for determining risk-based concentrations limits for various environmental media (e.g., groundwater and soil) and establish the acceptable amount or concentration of a chemical that may be found in or discharged to the environment. Chemical-specific requirements are available and are presented for the contaminated aquifer; because this is not a soil remedy, there are no chemical-specific ARARs for soils alone are provided in this focused FS. However, where the soils present a potential source of continuing groundwater contamination, chemical-specific soil requirements are provided for protection of the aquifer.

Federal primary MCLs (40 CFR Part 141) under the Safe Drinking Water Act protect the public from contaminants that may be found in drinking water. The MCLs are only applicable "at the tap" for drinking water provided to 25 or more people or water systems with 15 or more service connections. Because groundwater underlying the Site is not used as a drinking water source but is identified by the state as a potential source of drinking water, the requirements are relevant and appropriate to the aquifer underlying the PGA-North Site. The federal MCLs for the Site COCs are presented in Table 2.

2.4.4 Location-Specific ARARs

The potential location-specific ARARs are substantive restrictions placed on the chemical contaminant or the remedial activities based on the Site's geographic or ecological features. Examples of location-specific features include floodplains, seismic faults, wetlands, historic places, and sensitive ecosystems or habitats.

2.4.5 Action-Specific ARARs

The potential action-specific ARARs are usually technology- or activity-based requirements for remedial activities.

2.4.6 To-Be-Considered Documents

A large number of state and federal criteria, advisories, and guidance documents are used in the development of the baseline risk assessment. For the sake of brevity and eliminating redundancy in listing TBC documents, the human health and ecological risk assessment guidance documents and health advisories are referenced in the baseline risk assessment document for PGA-North source area groundwater and are not identified as TBC documents in this section. The TBCs presented are intended to address the state and federal guidance documents not associated with risk assessments.

To document all the potential ARARs, a comprehensive tabular summary of ARARs applied to the Site is provided in Table 4.

2.5 Development of Remediation Goals

The primary remedial goals are containment of COC mass and aquifer restoration. The method to achieve these goals is to treat source area groundwater in Subunit A to enhance the reduction of future mass discharge to the extended Subunit A groundwater plume. The final remediation timeframe for reaching the primary goals for treatment of source area groundwater will be based on the results of solute transport modeling of the effects of the recommended remediation alternative. Solute transport modeling will be conducted to determine effects of mass reduction within the source area on the downgradient plume at PGA-North as part of the design phase for the source area remedy.

Mass discharge of COCs via advective and dispersive flow would be tied to the achievement of a specific percent reduction in COC concentration within the treatment area defined in the next section of this SARFFS. The modeling process optimizes the remediation design by delineating the remediation target area for groundwater treatment by predicting the effectiveness of mass removal relative to the location of high COC concentrations, the plume axis, and the lithology and characteristics of subsurface soils. The percent mass reduction necessary to prevent continued mass discharge will be determined based on model results relative to the effect of treatment on the morphology of the downgradient groundwater plume. Changes in plume morphology would be visually represented through reductions in COC concentrations projected spatially and into the future.

2.6 General Response Actions for Groundwater

For remediation of source area groundwater given the RAOs defined in Section 2.2, the General Response Action is to recommend no action, or a groundwater containment and/or treatment remedy in Subunit A. This General Response Action will be identified following completion of the comparative analysis in the SARFFS.

The final treatment area (lateral extent) and volume (depth) of the source area will be determined in the Remedial Design Work Plan phase following selection of the source area remedial alternative. This final area for the remedial action will be based on additional pre-design characterization (both horizontal and vertical) as well as solute transport modeling to evaluate the effectiveness of the source area treatment on the larger groundwater plume and overall remedy. In addition, the final area to be treated will likely change during the execution of the source area remedy based on iterative data collected during the implementation phase.

However, for the purposes of performing the comparative analysis, the following is a summary of the estimated areas and volumes for which the treatment and containment technologies will be applied.

In general, the source area treatment will be applied in the saturated portion of the Subunit A aquifer covering an aerial extent as outlined on Figure 6. This area is estimated to be roughly 350,000 square feet. A similar summary figure was presented during the 15 September 2011 CSM review meeting, the only change being the extent of the treatment area being extended north to West Van Buren Street and east into the Goodyear Financial Center parking lot, as agreed upon during this meeting.

Generally, this aerial extent as shown was developed based on the extent of groundwater impacts exceeding 1 mg/L of TCE in one or more depth intervals. The extent has also been limited at West Van Buren Street to the north due to access restrictions, and has been limited to the east to cover only areas located in the parking lot of the Goodyear Financial Center property.

Given the assumed area of source area treatment outlined, the total volume of treatment can be estimated using the thickness of the saturated zone in Subunit A of roughly 60 feet, resulting in a total source area treatment volume of 21,000,000 cubic feet. Alternatively, the volume of groundwater to be treated in the source area is estimated to be roughly 50,000,000 gallons, assuming a 30 percent total porosity.

Given the limited amount of soil and depth-specific groundwater data available for the source area at this time, no estimate of the total mass of TCE present can be made at this time. The starting TCE mass estimate related to the RAOs will be updated based on the findings of pre-design characterization outlined above and the results of additional characterization during the implementation phase.

2.7 Identification and Screening of Technologies

The technologies identified for remediation of source area groundwater were selected based on the results of previous pilot tests, and PGA-North site-specific hydrogeologic and geochemical conditions. A draft of the initial list of remediation technologies was presented in the SARFFS Work Plan and modified based on comments from the USEPA, the ADEQ, and other stakeholders. Tables presenting the list of groundwater remediation technologies, the results of the screening, and the list of retained technologies combined into alternatives were presented in draft format to the USEPA and other stakeholders on 14 October 2011 (Appendix A). Final modifications to the list were made in an email from USEPA Remedial Project Manager, Catherine Brown, to Dr. Anthony Pantaleoni of Crane Co., on 21 October 2011 (Appendix B). One of the USEPA modifications was the addition of in-well air-

stripping (IWAS) to the list of groundwater remediation alternatives. Additional modifications to the alternatives include the addition of macro-scale ZVI to the nZVI alternative, and refocusing the treatment area for the electric resistive heating (ERH)/steam alternative to the higher concentration axis of the Subunit A groundwater plume. These comments were received from the USEPA and its contractors during the SARFFS Technical Working Group Meetings held on 9 March 2012, 11 July 2012, and 15 August 2012.

Finally, case studies utilizing specific applications of each of the remediation technologies under consideration in this FS are provided in Appendix C. The lessons learned in the case studies have been applied to the conceptual designs of each of the remediation technologies carried forward for evaluation.

2.7.1 Physical Mass Removal

Groundwater remediation technologies that result in physical mass removal of the two COCs are identified and described in this subsection as part of the screening step for this SARFFS.

Extraction and Aboveground Treatment

Groundwater extraction pumps groundwater from wells located in regions of high concentration and removes VOC and perchlorate mass by treating the extracted groundwater (pump and treat). Pump and treat results in hydraulic control of the impacted groundwater within the area of influence of the pumping system. Extracted source area groundwater would be processed through the MTS and ion exchange system, or another treatment system, and re-injected consistent with past actions. Ion exchange and bioreactor units are the only above groundwater treatment technologies capable of removing perchlorate from groundwater. The existing pump and treat remedy will remain in place under each of the identified remedial alternatives.

Dual-phase Extraction, Pump and Treat, and SVE

Dual-phase extraction removes VOC soil vapor and groundwater by applying a vacuum to a well screened across the vadose zone into the saturated zone. The removal of groundwater draws down the water table, forming a cone of depression around the extraction well. VOC vapor extraction (VE) can then be performed on the void volume previously occupied by groundwater. However, VE is not effective in removing perchlorate due to its low vapor pressure and high solubility.

SVE applies a vacuum to the unsaturated zone. The vapor phase contaminants are captured by vacuum, which enhances partitioning of the VOCs from soil particles into the vapor phase. The VOCs in soil vapor are then removed from the unsaturated zone through the extraction system piping. The soil vapor is then pumped through an air treatment unit, typically GAC. The treated air is discharged to the atmosphere following removal of VOCs pursuant to the ARARs found in Table 4. The existing SVE system will remain in place under each of the identified remedial alternatives.

Air Sparging and SVE

Air sparging injects air into the groundwater to enhance VOC volatilization. This process enhances the transfer of VOCs from the aqueous phase in the saturated zone to the gaseous phase in the unsaturated zone by inducing a constant concentration gradient at the VOC air interface. The VOCs volatilized from the groundwater are then captured and treated via an SVE system as outlined above. It is also

possible to amend the injected air with a co-metabolite such as methane to biologically enhance the air sparging. However, air sparging and SVE are not effective in removing perchlorate due to its low vapor pressure and high solubility. The existing SVE system will remain in place under each of the identified remedial alternatives.

IWAS

IWAS can also be performed within the water column of a well that is constructed with two well screens, separated by at least 20 feet and a packer. Groundwater is extracted from the bottom screen and pumped to the top of the well, where it is released to free-fall down the well casing. This process aerates the water and enhances volatilization of the VOCs from the extracted water. The aerated water is then allowed to flow back into the formation through the top well screen, often resulting in mounding of the water table. VOC vapors released within the well casing are removed under vacuum and piped to a GAC air treatment unit, where the VOCs are removed and the treated air is released. Connection of flow paths within the formation results in the formation of a circulation treatment cell where treatment time is determined by the number of times groundwater must pass through the well to result in mass removal within the formation. IWAS is not effective in removing perchlorate due to its low vapor pressure and high solubility.

2.7.2 Physical Barrier

Installation of a physical barrier, such as a slurry wall or sheet piles, can be used to contain or divert contaminated groundwater and limit further off-site migration. A slurry wall can be installed via direct high pressure grout injection or the excavation of a vertical trench that is immediately filled with slurry. The slurry is typically a mixture of bentonite and water. The slurry serves to hydraulically shore the trench to prevent collapse and temporarily reduce groundwater flow. Slurry walls are typically used when the contaminant mass is too large to treat or when soluble and mobile contaminants are an imminent threat to a drinking water source.

2.7.3 Barrier Systems

Barrier-type groundwater remedies can take the form of passive or active systems. An example of a passive system is the emplacement of a treatment media in crossgradient trench designed to intercept and remove VOCs from groundwater as they migrate under natural flow conditions. Treatment media, such as mixtures of macro-scale ZVI and sand, or humic matter, such as mulch, are often used to create a permeable reactive barrier (PRB). The PRB is installed in a trench or can be mixed into the existing formation using large diameter augers or within caissons to create a higher permeability zone through which impacted groundwater must flow. Media such as ZVI chemically reduce TCE upon contact and form as little as 5 percent chlorinated byproducts. A mulch or bioremediation barrier requires enough retention time within the treatment barrier or “zone” to create anaerobic and reducing conditions, and for microbially-mediated dechlorination to occur. Retention time is a function of seepage velocity and choice of an appropriate design thickness of the treatment zone is an important design factor for both chemical and bioremediation PRBs.

Active barrier systems include the forced movement of groundwater in the aquifer to either prevent downgradient migration or enhance remediation amendment distribution within the saturated subsurface. Hydraulic migration control is achieved through the configuration of extraction wells to intercept and capture flow and prevent contaminants from downgradient migration. The evaluation of current field data demonstrates that the capture zone for the existing network of extraction wells (EA-03 and PZ-01) more than likely extends to the east just beyond Litchfield Road except for a small area

north of Van Buren Street and south of the I-10, to the west and east of EA-02's capture zone, that potentially is not being captured by the MTS extraction wells but may be captured by the EA-05 extraction system (AMEC, 2013). In an effort to increase hydraulic capture of the Subunit A TCE plume along West Van Buren Street, Crane Co. has installed extraction well EA-09 north of West Van Buren Street along Celebrate Life Way (formerly referred to as Filmore Street). A primary objective of extraction well EA-09 is to provide enhanced hydraulic control of Subunit A groundwater flow as it relates to the source area remediation. It is anticipated that the existing Subunit A MTS extraction well network (EA-01, EA-02, EA-03, and PZ-01), along with the addition of new extraction well EA-09, will serve as an effective hydraulic barrier for any source area treatment amendment that is selected. Once new extraction well EA-09 is operational, the hydraulic capture zone along West Van Buren Street will be continually evaluated and recommendations for additional extraction (if needed) will be made during the design phase of the source area remedy. Active recirculation of chemical oxidant or bioremediation amendment within the subsurface using a series of injection and extraction wells can be used to create a treatment zone or barrier. In-well recirculation can also be viewed as a type of active barrier by capturing VOC- and perchlorate-impacted groundwater and creating a treatment zone defined by the recirculation cell.

2.7.4 In-Situ Chemical Reduction

In-situ chemical reduction (ISCR) is the injection of reducing agents directly into the subsurface to degrade specific target COCs. These amendments decrease the oxidation state of energetically susceptible materials. As a result, they convert hazardous contaminants to non-hazardous or less toxic compounds that are more stable, less mobile, and/or inert. However, under reducing conditions, certain naturally occurring metals such as arsenic can be converted to a more mobile oxidation state. ISCR can be applied to groundwater and to a variety of soil types and grain sizes. It has been demonstrated to be effective in destroying VOCs, including TCE, TCE daughter products, and perchlorate. TCE reduction occurs upon contact with the short-lived formation of chloroacetylene and acetylene as intermediates, and 5 percent or less of less-chlorinated daughter products. In order for destruction of VOC mass to occur, sufficient contact with the reductant must be maintained. ISCR can be effective in enhancing the biological degradation of perchlorate. Perchlorate can be biologically reductively dechlorinated to chlorate and chlorite before finally be degraded to CO2 under anaerobic conditions. The presence of ZVI has been observed to facilitate this process (CAL EPA, 2004).

Typical reducing agents include both chemical and metal-based. Both ZVI and nZVI are strong chemical reductants. nZVI is typically injected as a particulate suspension in water together with a dispersant to assist in maintaining particle separation during mixing and injection. nZVI can be injected using direct-push technology or, as in the case of the PGA-North Phase III Pilot Test, jet-assisted technology (Haley & Aldrich, 2011a). ZVI is typically injected as a slurry using high pressure direct push injection. At greater target depths, or in heterogeneous stratigraphy, hydraulic or pneumatic fracturing can be used to enhance the effective radius of influence of ZVI. In addition to ZVI, dithionate solutions have been tested as chemical reducing agents; however, field testing has yielded mixed results (United States Department of Energy, 2000; Pacific Northwest National Laboratory, 2000).

2.7.5 In-Situ Chemical Oxidation

In-situ chemical oxidation (ISCO) is the injection of oxidizing agents directly into the subsurface to degrade specific target COCs. These reagents increase the oxidation state of certain materials. As a result, they convert hazardous contaminants to non-hazardous or less toxic compounds that are more

stable, less mobile, and/or inert. ISCO can be applied to groundwater and a variety of soil types and sizes. It can also be used to treat VOCs, including TCE. In order for destruction of VOC mass to occur, sufficient contact with the oxidant must be maintained. ISCO is not effective in destroying perchlorate due to its already high oxidation state.

Typical oxidizing agents include permanganate, persulfate, ozone, and hydrogen peroxide.

- The most common forms of permanganate are potassium permanganate and sodium permanganate.

- Application of permanganate causes the rapid and complete destruction of many VOCs, including TCE, cis-1,2-dichloroethene (cis-1,2-DCE), and VC. The process results in the formation of manganese oxides, carbon dioxide, and various ions.

- Sodium persulfate is typically applied together with an activating agent such as temperature (thermal activation), extreme basic chemical conditions (sodium hydroxide), and/or a chemical activator such as modified Fenton's reagent, chelated iron, or ZVI. Activation of persulfate results in the formation of a sulfate radical, which directly oxidizes contaminants.

- Ozone and/or hydrogen peroxide, along with ultraviolet light as a catalyst (ferrous or ferric iron, etc.), can be used to oxidize organic materials in groundwater. When complete destruction is achieved, this process results in the production of carbon dioxide, water, and salts.

2.7.6 Anaerobic Reductive Dechlorination

Chlorinated solvents such as TCE are known to undergo a variety of microbially mediated biodegradation reactions. In anaerobic environments, TCE can undergo reductive dechlorination, which involves the same reaction mechanisms described above for chloroethanes. TCE is reduced to cis-1,2-DCE, cis-1,2-DCE to VC, and VC to benign end products such as ethene, ethane, carbon dioxide, water, and chloride. A variety of microorganisms reduce the highly chlorinated compounds tetrachloroethene (PCE) and TCE to cis-1,2-DCE. A number of anaerobic, halo-respiring bacteria have been characterized, including Dehalospirillium multivorans, Dehalobacter restrictus, and Dehalococcoides etheneogenes (DHC). Dehalospirillium multivorans and Dehalobacter restrictus are reported to express only one of the two required corrinoid enzymes required to biodegrade TCE completely to ethene. In contrast, DHC is the only halo-respiring microorganism reported to catalyze complete dechlorination. DHC may not be present in all subsurface environments. When present, DHC cells may not be initially active or in sufficiently high number to promote complete dechlorination without a significant lag phase before activity. Anaerobic reductive dechlorination (ARD) is effective in reducing perchlorate concentrations under anaerobic conditions. Autotrophic indigenous bacteria have been shown to be capable of degrading perchlorate to sequentially lesser chlorinated chlorate and chlorate. This process is enhanced in the presence of ZVI (Yu et. al., 2006) and is the only in-situ remedy capable of degrading perchlorate. Perchlorate can be biologically reductively dechlorinated to chlorate and chlorite before finally be degraded to chloride and O_2 under anaerobic conditions.

Bioaugmentation, or the addition of a microbial degrader culture, promotes TCE bioremediation and related chlorinated solvents at sites where complete dechlorination reactions would not otherwise occur. Bioaugmentation with non-indigenous microbial consortia has been successfully and extensively demonstrated at other sites.

2.7.7 In-Situ Thermal Remediation with Steam

Thermal remediation relies on increasing subsurface temperature to volatilize VOCs. Electrodes and/or steam injection wells would be installed in vertical wells to heat the subsurface. Electrodes would be placed and volatilized gases would be collected by extraction wells spaced throughout the treatment zone and connected to the existing SVE system, which will likely need to be modified. Alternatively, steam injection wells would be installed and use the same processes for gas and liquid collection. Liquids, vapors, and gases collected from the treatment area would be treated in an aboveground treatment system which would include condensation of vapors and separation of fluids. As part of the thermal treatment system, a groundwater hydraulic control system may need to be installed around the treatment zone to minimize the influx of groundwater and increase the efficiency of the treatment system. Thermal remediation is not effective for treating perchlorate due to its low vapor pressure and high solubility.

2.7.8 Evaluation of Technologies and Selection of Remedial Technologies

Each remediation technology described above has been screened using three broad criteria, which include: effectiveness, implementability, and cost. This preliminary remediation technology screening is provided in Table 5, together with the final conclusion of whether the technology has been retained as a potential process option for combination with other technologies, or if it has been eliminated as a potential remediation technology/process option. Other information used in the screening evaluation included the level to which the technology has been bench-scale or pilot tested in groundwater at the PGA-North Site, and the compatibility of the technology with existing geochemical and hydraulic conditions within Subunit A. Below is a summary of technologies that have been retained:

- IWAS;
- Hydraulic barrier using pump and treat;
- ARD;
- nZVI;
- ZVI;
- ISCO using permanganate; and
- ERH with steam (ERH/Steam).

2.8 Development of Alternatives

The objective of this section is to apply a screening process to develop each potential groundwater remediation alternative which may involve a combination of remediation technologies. The screening process for the alternatives is described in Section 2.7. The alternatives will be evaluated in detail using the nine criteria provided in the National Contingency Plan as outlined in the USEPA RI/FS guidance (USEPA, 1988).

The retained remedial technologies, after the initial screening, have been assembled into alternatives using the results of past treatability and pilot testing together with engineering judgment. No one remediation technology would adequately address source area groundwater impacts and enable achievement of the RAOs established for the PGA-North Site. For example, the only alternatives that will address perchlorate are Alternative No. 1 (because of the ongoing operation of the pump and treat system), and Nos. 3, 4, and 5, because they include ARD in combination with a remediation technology that is also effective with TCE. The technologies were combined to provide a more effective source area treatment and containment alternative. The following remedial alternatives have been assembled from the initial screening of groundwater remediation technologies:

- Alternative 1 – No Action;
- Alternative 2 – IWAS + Hydraulic Barrier;
- Alternative 3 – ARD + Hydraulic Barrier;
- Alternative 4 – nZVI + ZVI + ARD + Hydraulic Barrier;
- Alternative 5 – ZVI + ARD + Hydraulic Barrier;
- Alternative 6 – ISCO + Hydraulic Barrier;
- Alternative 7 – ERH with Steam + Hydraulic Control.

2.9 Detailed Analysis of Alternatives

This section provides an evaluation of the remedial alternatives using nine evaluation criteria established by the USEPA (USEPA, 1988). The first seven USEPA criteria serve as the basis for conducting the detailed analyses during the FS. Following the issuance of the Proposed Plan, state and community acceptance will be evaluated for subsequently selecting an appropriate remedial action (USEPA, 1989) during the ensuing public comment period. The remedial alternatives are evaluated using the nine USEPA criteria:

1. Overall protection of human health and the environment;
2. Compliance with the ARARs;
3. Long-term effectiveness and permanence;
4. Reduction of toxicity, mobility, or volume;
5. Short-term effectiveness;
6. Implementability;
7. Cost;
8. State acceptance; and,
9. Community acceptance.

An engineer's costs estimate has been prepared for each alternative based on assumptions made in the conceptual designs. The cost estimate is presented as a range of -30 percent to +50 percent. A detailed evaluation of each alternative using these criteria is summarized in Table 6.

The relative sustainability performance of each remediation alternative was considered within this evaluation of alternatives under the criterion of long-term effectiveness and permanence.

Design and monitoring assumptions are included for costing purposes and will be refined for the chosen remedy during the design phase.

2.9.1 Alternative 1 – No Action

Under this scenario, the current groundwater remedy of SVE in the source area together with pump and treat for groundwater will remain in place and no active remedial efforts will be employed to reduce contaminant mass in the source area. This alternative is used as a baseline that allows for a comparison of the active alternatives.

2.9.2 Alternative 2 – IWAS + Hydraulic Barrier

This alternative combines IWAS to treat source area VOC impacts and a hydraulic barrier along West Van Buren Street to prevent off-site migration of contaminants. The current groundwater remedy of SVE in the source area together with pump and treat for groundwater throughout the Site will remain in place to continue remediation and to support hydraulic control at the Van Buren barrier and throughout the Site. The effectiveness of the current pumping well configuration located along West Van Buren Street is currently being assessed and will be optimized if necessary prior to implementation of additional source area remedial activities. Additional information on the hydraulic barrier can be found in the "Final Subunit A Capture Zone Report", dated 11 April 2013 (AMEC, 2013). It should be noted that the IWAS alternative is not effective in removing perchlorate.

IWAS combines modified in-situ air stripping, air sparging, SVE, enhanced bioremediation/oxidation, and groundwater flushing technologies in each wellhead system. This methodology is generally implemented using a network of extraction wells with capture zones that engulf the defined treatment zone. Groundwater flow upward is achieved by an airlift effect or a submersible groundwater circulation pump. The VOC-stripped water returns to the aquifer near the capillary fringe and migrates down to the pump for repeated VOC stripping. Groundwater circulation therefore occurs from the top of the formation to the bottom. Depths of the well screens will be placed using the Triad approach (ITRC, 2003) to allow for data discovery and flexibility during implementation of this alternative. The in-well pumping and air stripping has a flushing effect caused by removing groundwater from the base of the well, stripping VOCs from the water within the well (similar to a stripping tower), and then returning the water to the aquifer near the top of the screened zone at the air-water interface. This process is considered to result in effective flushing of the saturated zone in the immediate vicinity of the extraction well. The VOC-laden vapors are collected and treated using an SVE system. The existing SVE system would be adapted and optimized to suit this remedy.

This alternative utilizes modified IWAS technology that incorporates a shallow tray or compact air stripper housed in a shallow vault, a blower for the air stripper, and a sump pump to re-inject treated water. This modification was necessary to provide improved VOC removal efficiency relative to traditional in-well air-stripping. A pilot program is recommended for this approach prior to full-scale installation to determine the actual radius of influence, extent to which recirculation can be achieved, and the effects of physical and biological fouling on the overall effectiveness of the system. This alternative could be effective for TCE removal, but will not treat perchlorate in the groundwater.

The radius of influence relies on the hydraulic properties of the aquifer and treatment zone geometry. Based on current knowledge of subsurface lithology, hydrogeologic conditions, and Subunit A impacts, a preliminary recirculation well field was designed. It is assumed the radius of influence will be 100 feet around each well. The well network and treatment compound configuration are presented in Figure 7. The conceptual design assumptions are provided in Table 7 below.

Table 7 Conceptual Design Summary for IWAS + Hydraulic Barrier
Site Characteristics – Site located in Goodyear, Arizona. – COCs are TCE and perchlorate. Treatment area defined by TCE concentration greater than 1 mg/L but constrained by West Van Buren Street to the north and the Goodyear Financial Center parking lot to the east. – Source area treatment is focused on saturated portion of the Subunit A aquifer. – The source area is approximately 250 feet wide and 700 feet long. – Depth to groundwater is 90 feet bgs. – Targeted vertical treatment is 60 feet thick (from 90 to 150 feet bgs).
Design Assumptions – Existing extraction wells (three extraction wells) will provide a sufficient hydraulic barrier along West Van Buren Street. – 17 groundwater circulation wells (GCWs) to capture targeted source area and provide overlapping coverage in case complete recirculation is not achieved. – 12 new monitor wells installed with additional monitor wells as necessary during the design phase. – 100-foot GCW radius of influence. – 9 GCWs will have a pair of nested piezometers in the same borehole. – The GCW system at each well can sustain a recirculation flow rate of 75 gpm. – Each screen will be 15 feet long. – The GCW extraction screen will be from 135 to 150 feet bgs. The GCW injection screen will be from 90 to 105 feet bgs. – The recirculation ratio (ratio of water captured from upgradient to recirculation water) will be 45 percent. – Time for one pore volume flush through the radius of influence is estimated at 150 days. – Each GCW well will be 18-inch inside diameter drilled to a depth of 150 feet bgs. – GCW well will be constructed of PVC casing and stainless steel screens. The screens will be wire wrapped with a likely slot size of 0.030-inch. – A 12-inch inflatable packer will isolate the two screens. – A 4-inch submersible pump (Grundfos or equivalent) rated to deliver 75 gpm at 100 feet of water head. – A shallow tray or compact air stripper rated to treat 75 gpm of 10 parts per million influent TCE with >90 percent removal efficiency. – A sump pump to inject treated water back to the GCW. – A sub-surface vault to house the air stripper. – An aboveground shed to house the blower, GAC for vapor treatment, and control panel. – One 500 standard cubic feet per minute blower connected to each GCW for treatment of vapors by GAC. – Below ground conveyance piping from each GCW to the blower. – Miscellaneous instruments (analog flow meter/totalizer, vacuum and pressure gauges, level sensors, etc.) – Chemical and biological fouling of the well screens and the air stripper trays may reduce the performance and increase operations and maintenance (O&M). – Sieve analysis of soil cores from targeted screen intervals will be required to correctly size and specify the screen slot size and sand pack. – Adaptation and expansion of current SVE system footprint and treatment units may be required.

Table 7 Conceptual Design Summary for IWAS + Hydraulic Barrier
Performance Groundwater Monitoring – Groundwater samples collected from 12 wells and analyzed for VOCs, perchlorate, and general chemistry parameters (methane, ethane, ethene, chloride, bicarbonate, sulfate, calcium, sodium, nitrate ammonia, phosphate, magnesium, dissolved and total iron, dissolved and total manganese, and total organic carbon [TOC]). – Field measurements collected from 13 monitor wells, including pH, dissolved oxygen (DO), conductivity, temperature, turbidity, and oxidation reduction potential (ORP). – One baseline groundwater monitoring event prior to Phase 1 well installation. – Three quarterly groundwater monitoring events after implementation of each phase of well installations. – Three years of semiannual groundwater monitoring after completion of the IWAS program. – Long-term O&M program initiated for life of the system (20 years).
Vapor Monitoring – Vapor samples collected from 17 GCWs, as well as the treatment system inlet and outlet on a monthly basis. Samples analyzed for VOCs. – Field measurements collected from the well field and system components include vacuum, temperature, and TOC on a weekly basis.

2.9.3 Alternative 3 – ARD + Hydraulic Barrier

This alternative combines ARD with a hydraulic barrier along West Van Buren Street to treat and contain source area impacts of VOCs and perchlorate. The hydraulic barrier will not be described further as stated above. Additional information on the hydraulic barrier can be found in the "Final Subunit A Capture Zone Report", dated 11 April 2013 (AMEC, 2013). The current groundwater remedy of SVE in the source area together with pump and treat for groundwater throughout the Site will remain in place.

ARD occurs when microbial organisms transfer electrons from the electron donor to the chlorinated organic chemicals, causing a dechlorination reaction that ultimately reduces the parent and daughter products to non-toxic ethene, ethane, and carbon dioxide as described in Section 2.4.5.

Bioaugmentation is required at the PGA-North Site since indigenous microbes are considered insufficient or ineffective. Bioaugmentation involves studying the indigenous varieties present at the location to determine if biostimulation is possible. If the indigenous varieties do not have the metabolic capability to perform the remediation process, the addition of a microbial degrader culture capable of the required metabolic process is required.

ARD in the source area would involve both bioaugmentation, the injection of a group of natural microbial strain or a genetically engineered variant predisposed to the degradation of chlorinated organic compounds, and biostimulation, the injection of an electron donor to stimulate microbial populations. A biostimulant would be required at the PGA-North Site because of the low organic carbon content of native soils. Bioaugmentation and biostimulation, herein referred to as bioamendments, will facilitate the biodegradation of chlorinated organic chemicals such as TCE and inorganic compounds such as perchlorate.

- Biostimulation: Anaerobic microbes metabolize the emulsified oil, producing hydrogen, which serves as the electron donor for reductive dechlorination of chemicals such as TCE and perchlorate. Edible vegetable oils such as soybean oil are mixed with food-grade emulsifiers,

such as lecithin, using a high shear industrial mixer to create micron-sized droplets. The emulsified oil droplets are small enough to migrate with groundwater through soil pores, until it is retained through attachment on to soil particles. A grid of injection points will be required for effective distribution.

- Bioaugmentation: Bioaugmentation is the process by which a commercial microbial culture is injected into a target area. The microbial culture contains specific species capable of performing sequential reductive dechlorination of PCE, TCE, cis-1,2-DCE, and VC to nontoxic ethene, carbon dioxide, water, and chloride. If specific bacteria, such as DHC, are absent from a treatment area, incomplete dechlorination of PCE and TCE with accumulation of cis-1,2-DCE may occur. This incomplete biodegradation pathway can be avoided through bioaugmentation with the introduction of DHC and a variety of supporting microorganisms. Perchlorate is degraded under anaerobic conditions by a variety of microorganisms which are commonly found in groundwater (CAL EPA, 2004); therefore bioaugmentation is typically not necessary to facilitate degradation of this compound.

For reductive dechlorination, bioamendments are used to create an environment in the subsurface suitable for reductive dechlorination. A typical bioremediation approach includes injection of emulsified oil and a commercially grown bioaugmentation culture as summarized below.

A treatability study and pilot test would be required to better define the injection program for this treatment option. The pilot test would provide specific information regarding the length of the acclimation period, that is, the time necessary for anaerobic and reducing conditions to be produced in the treatment area. Bioaugmentation would be performed in the theoretical pilot test area if conditions are anaerobic and reducing, conducive to survival of the degrader microorganisms.

It is likely that jet-assisted injection would need to be used to ensure proper distribution of the bioamendments and enhance the radius of influence of each injection. Based on current knowledge of subsurface lithology, hydrogeologic conditions, and Subunit A impacts, a preliminary injection distribution program was developed. For the purpose of this SARFFS, the injection locations will be placed in a barrier configuration with the number of lifts determined by the extent of impacted groundwater. Preliminary injection spacing was chosen based on radius of influence measurements collected during the Phase III pilot test. The Triad approach will be used when determining the placement of the injection lifts so that flexibility is built into the injection program (ITRC, 2003). Implementation of the Triad approach (ITRC, 2003) during the remedy requires that time be built into the process in order to allow for: identification of injection intervals based on the concentrations measured using boring installations; development and real-time adjustment to the potential mobilization of mass during injection activities; calculation of dosages in accordance with the VOC concentrations detected from the Triad hydropunch samples; soil types identified in the borings; and optimization and adjustment of the chosen remedy on a real-time basis.

The volume of microbial culture is based upon the anticipated volume within the radius of influence of injection, the doubling rate of growth for the bacterial population, and the timeframe needed to see results. Performance monitoring would require analyses of groundwater samples for a variety of analytes to assess the distribution of the amendment, the reduction oxidation state of the aquifer, and the success of introduction and proliferation of the degrader microorganisms after bioaugmentation.

The injection program is presented in Figure 8. The conceptual design assumptions are provided in Table 8 below. Volumes of amendments are proposed for costing purposes and do not represent final volumes for remediation. Final remediation volumes will be determined based on site specific sampling conducted during Triad investigation and evaluation phases.

Table 8 Conceptual Design Summary for ARD + Hydraulic Barrier
Site Characteristics – Site located in Goodyear, Arizona. – COCs are TCE and perchlorate. Treatment area defined by TCE concentration greater than 1 mg/L but constrained by Van Buren Street to the north and the Goodyear Financial Center parking lot to the east. – Source area treatment is focused on saturated portion of the Subunit A aquifer. – The source area is approximately 250 feet wide and 700 feet long. – Depth to groundwater is 90 feet bgs. – Targeted vertical treatment is 60 feet thick (from 90 to 150 feet bgs).
Design Assumptions – A sufficient hydraulic barrier exists along Van Buren Street. – 12 new groundwater monitor wells installed over three years (approximately three per year); additional monitor wells will be added as necessary during the design phase. – 25-foot injection well spacing. – 150-foot spacing between injection lines. – Lifts spaced 5 feet apart. – Phase I - Year 1 Injections 8 injection points with 11 lifts. 8 injection points with 9 lifts. – Phase II - Year 2 Injections 16 injection points with 6 lifts. – Phase III and IV - Year 3 and 4 Injections 32 injection points with 3 lifts. – Phase V - Year 5 Injections 6 injection points with 6 lifts. – 20 liters of microbial culture containing DHC per injection point. – Approximately 565 pounds of emulsion per injection point. – Injections phased over five years. – Primary injections occur the first four years. Re-injections at 10 percent of locations during the fifth year.
Post-Injection Performance Groundwater Monitoring – Groundwater samples collected from 12 monitor wells and analyzed for VOCs, perchlorate, and general chemistry parameters (methane, ethane, ethene, chloride, bicarbonate, sulfate, calcium, sodium, nitrate ammonia, phosphate, magnesium, dissolved and total iron, dissolved and total manganese, and TOC). – Field measurements collected from 12 wells including pH, DO, conductivity, temperature, turbidity, and ORP. – One baseline groundwater monitoring event prior to Phase I injections. – Three quarterly groundwater monitoring events after each phase. – Three years of semiannual groundwater monitoring after completion of the injection program.

2.9.4 Alternative 4 – nZVI + ZVI + ARD + Hydraulic Barrier

This alternative combines the injection of nZVI, ZVI, and bioamendments to treat source area impacts, and a hydraulic barrier along West Van Buren Street to prevent off-site migration of contaminants. The current extraction wells located along Van Buren Street provide a sufficient hydraulic barrier and as such will not be described further. Additional information on the hydraulic barrier can be found in the "Final Subunit A Capture Zone Report", dated 11 April 2013 (AMEC, 2013). The current groundwater remedy of VE in the source area together with pump and treat for groundwater throughout the Site will remain in place.

nZVI and ZVI enhance the abiotic reductive dechlorination of chlorinated organic chemicals such as TCE and inorganic chemicals such as perchlorate. The byproducts of this process are hydrogen gas, chloride, and hydroxide. Combined with bioamendments, the nZVI and ZVI will stimulate reducing conditions in the source area.

nZVI acts as a rapid reaction and significantly reduces contaminant concentrations in the short term. Rapid in-situ reactions have been observed with TCE reduction up to 99 percent within a few days after injection (Zhang, 2003). nZVI particles are best suited to remediation of source zones, where they can degrade relatively large quantities of VOCs in a short period of time (ITRC, 2011). This alternative can be effective in degrading perchlorate (see Section 2.7.4 for a description of chemical reduction of perchlorate).

The ZVI particles will increase the longevity of the chemical reduction degradation process in the source area. The larger particle size has been shown to last longer than nano-scale particles in contaminated aquifers. The United States Navy conducted three field demonstrations using different applications and sizes of zero valent iron (Gavaskar, et. al, 2005). While less reactive than nano-scale particles, the micron-sized ZVI particles were found to be more persistent.

Multiple injections of ZVI will be placed between the source area and the hydraulic barrier. For over 15 years, ZVI, in PRB configurations, has been installed and performing in a variety of geochemical settings for the remediation of chlorinated VOC plumes (ITRC, 2011). For cost estimating purposes, the ZVI dose for this alternative was calculated based upon a soil to ZVI mass ratio of 0.004. This ratio is the lower end of a dosage range of 0.004 to 0.008 determined through column testing of macro-scale ZVI in preparation for field testing conducted by the Naval Facilities Engineering Command (NAVFAC, 2005)

The nZVI will be formulated with SHMP and other potential dispersants, including carboxymethyl cellulose. The SHMP polyacrylate is added to the nZVI prior to transport to the PGA-North Site which has shown in pilot testing to improve the dispersion of the nZVI particles (ARCADIS 2008a and 2009). This is anticipated to assist in re-suspension of the nZVI particles after the 4-day transport time prior to injection. The addition of SHMP to the nZVI is expected to increase migration into the soil pore space after emplacement with the jet-injection method without passivating the nZVI.

The nZVI dose was derived by calculating the stoichiometric hydrogen demand of major electron acceptors, including target VOCs, sulfate, nitrate, and oxygen within a 25-foot radius of the injection point. The half reactions for the reduction of the compounds were matched with the oxidation half reaction for nZVI to calculate a ratio of electron equivalents. The maximum concentrations of the PGA-North site-specific compounds together with the calculated ratios were used to calculate the mass of nZVI necessary to meet the electron demand exerted by the compounds. This is the same

methodology used to determine the dosage for the pilot test conducted in February 2010. Due to the addition of macro-scale ZVI this dosage was reduced to 40 percent of the demand based upon the decreased demand due to the presence of additional macro-scale ZVI.

The amounts of nZVI and ZVI injected will vary by treatment area and implementation phase. For injections in the source area where TCE concentrations are highest, the total iron dose will be composed of a mixture. ZVI alone will be injected along the edges of the plume.

A pilot program was completed in the source area using jet-assisted injection of nZVI. Jet-assisted injection utilizes the kinetic energy of high-pressure water jets to distribute an injectate throughout the soil matrix. This method creates mixing and secondary porosity from hydraulic fracturing phenomena that occur simultaneously. The jet-assisted injection technique increases the radius of influence around an injection point and enhances mixing (USEPA, 2008b). Improvements to the jet-assisted injection method will be built into the implementation of this and all other alternatives using this injection technology. Optimization methods will include an evaluation of injection port orientation and spacing relative to the distribution of iron in the subsurface. Geophysical methods and soil borings may also be employed to determine the distribution of iron in the subsurface using different injection spacing and port configurations and help refine subsequent injections.

Based on pilot test results, current knowledge of subsurface lithology, hydrogeologic conditions, and Subunit A impacts, a preliminary injection distribution program was developed. The preliminary injection locations will be placed in a configuration that covers a majority of the source area with the number of lifts determined by the extent of impacted groundwater. A Triad approach will be used to determine the actual vertical placement of the injection lifts and will include collection of TCE samples during hydropunch activities. The ongoing collection of TCE concentration data and overall distribution of COCs will be used to build responsive flexibility into the injection program (ITRC, 2003).

The description of ARD is presented as Alternative 3. The volume of microbial culture is based upon the anticipated volume within the radius of influence of injection, the doubling rate of growth for the bacterial population, and the timeframe needed to see results. The addition of ARD to this alternative will increase contaminant reduction in the source area. Both ARD and ISCR result in TCE and perchlorate degradation. However, the initial degradation rate of TCE has been shown to be faster in microcosm studies when bioaugmentation was combined with nZVI, compared with nZVI alone (Rajasekar, 2011).

At a former manufacturing site in Passaic, New Jersey, a pilot test was conducted to treat groundwater contaminated with TCE. nZVI and emulsified oil were injected using pneumatic fracturing and hydraulic injection methods. At the end of the pilot test, there was a 90 percent to 100 percent reduction in TCE concentrations throughout the plume (USEPA, 2008b).

nZVI and ZVI injections used in conjunction with ARD would provide both short- and long-term treatment of source area impacts. The injections of ZVI along the edges of the plume will provide additional longer term treatment before groundwater reaches the hydraulic barrier along West Van Buren Street.

The injection program is presented in Figure 9. The conceptual design assumptions are provided in Table 9 below. Volumes of amendments are proposed for costing purposes and do not represent final volumes for remediation. Final remediation volumes will be determined based on site specific sampling conducted during Triad investigation and evaluation.

Table 9 Conceptual Design Summary for nZVI + ZVI + ARD + Hydraulic Barrier
Site Characteristics – Site located in Goodyear, Arizona. – COCs are TCE and perchlorate. Treatment area defined by TCE concentration greater than 1 mg/L but constrained by Van Buren Street to the north and the Goodyear Financial Center parking lot to the east. – Source area treatment is focused on saturated portion of the Subunit A aquifer. – The source area is approximately 250 feet wide and 700 feet long. – Depth to groundwater is 90 feet bgs. – Targeted vertical treatment is 60 feet thick (from 90 to 150 feet bgs).
Design Assumptions – A sufficient hydraulic barrier exists along West Van Buren Street. – 12 new groundwater monitor wells installed over four years additional monitor wells will be added as necessary during the design phase. – 60-foot injection well spacing. – 60-foot spacing between injection lines. – Lifts spaced 5 feet apart. – Triad approach will be used to determine injection intervals.
– Phase I - Year 1 Injections Follow-up soil sampling. Optimization of injection tooling. Evaluation of the use of a suspension agent. Determination of the orientation of injection jet nozzles. 3 nZVI + ZVI + bioamendment injection points with 6 lifts. 9 ZVI injection points with 6 lifts. – Phase II - Year 2 Injections (Main Dry Wells area) 3 nZVI + ZVI + bioamendment injection points with 11 lifts. 9 nZVI + ZVI + bioamendment injection points with 9 lifts. – Phase III - Year 3 Injections 4 nZVI+ZVI+bioamendment injection points with 3 lifts. 8 ZVI+bioamendment injection points with 3 lifts. – Phase IV - Year 4 Injections 1 nZVI+ZVI+bioamendment injection points with 3 lifts. 8 ZVI+bioamendment injection points with 3 lifts. – Phase V - Year 5 Injections 3 to 4 injection points with 6 lifts. – Pressurized injection method (jet-assisted). – Combination of a jet lance injection tool and pressurized packer isolation of specific depth intervals. – Anaerobic water injected with 10,000-psi tri-plex pump to carve 1/16- to 1/8-inch diameter holes through the PVC casing and through the grout to create 10 jetted conduits into the formation. – nZVI and ZVI injected using a piston pump (~300 psi). – Injection points will be permanent blank cased wells for jet-assisted injections. The well will be packed off to target-specific depth intervals. – The injection nozzle will be about 1 millimeter in diameter and the number of nozzles and their orientation will be optimized. – Estimated radius of influence is 35 feet. – Between 89,000 and 133,560 pounds of nZVI to be injected. – Approximately 1,604,016 pounds of ZVI to be injected into treatment area, based on .004 iron-to-soil ratio.

Table 9 Conceptual Design Summary for nZVI + ZVI + ARD + Hydraulic Barrier
– 20 liters of microbial culture (DHC) per injection point. – Approximately 565 pounds of emulsified oil per injection point. – Injections phased over five years. – Primary injections occur the first four years. Re-injection at 10 percent of locations during the fifth year.
Post-Injection Performance Groundwater Monitoring – Groundwater samples collected from 12 monitor wells and analyzed for VOCs, perchlorate, and general chemistry parameters (methane, ethane, ethene, chloride, bicarbonate, sulfate, calcium, sodium, nitrate ammonia, phosphate, magnesium, dissolved and total iron, dissolved and total manganese, and TOC). – Field measurements collected from 15 monitor wells including pH, DO, conductivity, temperature, turbidity, and ORP. – One baseline groundwater monitoring event prior to Phase I injections. – Three quarterly groundwater monitoring events after each phase. – Three years of semiannual groundwater monitoring after completion of the injection program.

2.9.5 Alternative 5 – ZVI + ARD + Hydraulic Barrier

This alternative combines the injection of ZVI and bioamendments to treat source area impacts and a hydraulic barrier along Van Buren Street to prevent off-site migration of contaminants. The current extraction wells located along Van Buren Street provide a sufficient hydraulic barrier and as such will not be described further. Additional information on the hydraulic barrier can be found in the "Final Subunit A Capture Zone Report", dated 11 April 2013 (AMEC, 2013).

ISCR will be stimulated using a mixture of ZVI and a controlled-release carbon substrate. The mixture can be injected into the subsurface; however, due to the heterogeneity of Subunit A, hydraulic fracturing would be used to enhance mixing and increase the radius of influence. Injection of the mixture creates very strong reducing conditions that stimulate reductive dechlorination of organic solvents such as TCE. This alternative can be effective in reducing perchlorate concentrations.

Bioaugmentation as previously described in Alternative 3 would be used to supplement the native microbial population. The volume of microbial culture is based upon the anticipated volume within the radius of influence of injection, the doubling rate of growth for the bacterial population, and the timeframe needed to see results. The carbon release compound may create a nutrient rich, hydrophilic environment ideal for stimulation of microbial populations.

A pilot program is recommended to evaluate the effectiveness of this alternative. Based on current knowledge of subsurface lithology, hydrogeologic conditions, and Subunit A impacts, a preliminary injection distribution program was developed. The preliminary injection locations will be placed in a barrier configuration with the number of lifts determined by the extent of impacted groundwater. The Triad approach will be used when determining the placement of the injection lifts so that flexibility is built into the injection program (ITRC, 2003). The ZVI particles persist in the environment and provide a reactive surface that also stimulates reductive dechlorination.

This alternative was proposed in a barrier configuration due to the longevity of the ZVI, and the impracticality of the injection spacing if the remedy were to be implemented in a gridded configuration. The injection spacing would need to be 10 feet or less due to the injection characteristics of the ZVI particulate slurry.

The injection program is presented in Figure 10. The conceptual design assumptions are provided in Table 10 below. Volumes of amendments are proposed for costing purposes and do not represent final volumes for remediation. Final remediation volumes will be determined based on site specific sampling conducted during investigation and evaluation phases.

Table 10 Conceptual Design Summary for ZVI + ARD + Hydraulic Barrier
Site Characteristics – Site located in Goodyear, Arizona. – COCs are TCE and perchlorate. Treatment area defined by TCE concentration greater than 1 mg/L but constrained by Van Buren Street to the north and the Goodyear Financial Center parking lot to the east. – Source area treatment is focused on saturated portion of the Subunit A aquifer. – The source area is approximately 250 feet wide and 700 feet long. – Depth to groundwater is 90 feet bgs. – Targeted vertical treatment is 60 feet thick (from 90 to 150 feet bgs).
Design Assumptions – A sufficient hydraulic barrier exists along West Van Buren Street. – 12 new groundwater monitor wells installed over three years additional monitor wells will be added as necessary during the design phase. – 15-foot injection well spacing. – EHC, a ZVI plus fermentable organic substrate, is dosed at a 0.61 percent substrate to soil ratio. – Injections will be distributed into a permeable reactive barrier configuration spaced 150 feet apart. – Lifts spaced 5 feet apart. – Triad approach will be used to determine injection intervals. – Phase I - Year 1 Injections 12 injection points with 11 lifts. 12 injection points with 9 lifts. – Phase II - Year 2 Injections 24 injection points with 6 lifts. – Phase III and IV - Year 3 and 4 Injections 48 injection points with 3 lifts. – Phase V - Year 5 Injections 9 injection points with 6 lifts. – Pressurized injection method (jet-assisted injection). – Injection points will be non-permanent wells for hydraulic fracturing. – Estimated radius of influence is 15 feet. – 20 liters of microbial culture (DHC) per injection point. – Dosage is based on a 0.61 percent soil to amendment ratio. – Injections phased over five years. – Primary injections occur the first four years. Re-injections at 10 percent of locations during the fifth year.
Post-Injection Performance Groundwater Monitoring – Groundwater samples collected from 12 monitor wells and analyzed for VOCs, perchlorate, and general chemistry parameters (methane, ethane, ethene, chloride, bicarbonate, sulfate, calcium, sodium, nitrate ammonia, phosphate, magnesium, dissolved and total iron, dissolved and total manganese, and TOC). – Field measurements collected from 14 monitor wells including pH, DO, conductivity, temperature, turbidity, and ORP.

Table 10 Conceptual Design Summary for ZVI + ARD + Hydraulic Barrier
– One baseline groundwater monitoring event prior to Phase I injection. – Three quarterly groundwater monitoring events after each phase. – Five years of semiannual groundwater monitoring after completion of the injection program.

2.9.6 Alternative 6 – ISCO + Hydraulic Barrier

This alternative includes a source area injection program using potassium permanganate to treat source area impacts and a hydraulic barrier to prevent off-site migration of impacted groundwater. The current extraction wells located along West Van Buren Street provide a sufficient hydraulic barrier to mitigate off-site migration of contaminants, and as such will not be described further. Additional information on the hydraulic barrier can be found in the "Final Subunit A Capture Zone Report", dated 11 April 2013 (AMEC, 2013).

ISCO using permanganate is a process that injects a chemical reagent into temporary injection points. Potassium permanganate solutions can be injected into the subsurface; however, due to the heterogeneity of Subunit A, hydraulic fracturing would be used to enhance mixing and increase the injection radius of influence. Permanganate is a powerful oxidizer with an oxidation potential of 1.7 volts. The oxidizing reaction is relatively slow and, according to pH conditions, includes direct electron transfer or free radical advanced oxidation. Permanganate reactions can occur in the pH range of approximately 3.5 to 12 (Siegrist et. al., 2001). Byproducts of the reaction include solid manganese dioxide, carbon dioxide, and potassium ions. Permanganate has a unique affinity for destroying compounds that contain carbon-carbon double bonds of chlorinated alkenes such as PCE, TCE, dichloroethene, and VC. A potential advantage for the ISCO alternative is the diffusion of the solution into the fine-grained and no-flow zones, thereby rescuing the potential for back diffusion of TCE over time. A potential deleterious effect of permanganate oxidation is that residual manganese dioxide can interfere with biodegradation processes (Hrapovic et al., 2005). It is thought that significant biodegradation is not currently occurring at the PGA-North Site. ISCO using permanganate is not effective for treating or degrading perchlorate.

Permanganate chemical oxidation provides flexibility in implementation via the addition of new injection points, adjusting the injection volume or concentration, and/or varying the injection duration to better remediate impacts. The injection locations will be placed in a barrier configuration with the number of lifts determined by the extent of impacted groundwater. The Triad approach will be used when determining the placement of the injection lifts so that flexibility is built into the injection program (ITRC, 2003).

A pilot injection program is recommended to refine the injection program. It is thought that the permanganate injection program will be phased with one injection event per year over a period of four years. The injection locations will be placed in a barrier configuration with the number of lifts determined by the extent of impacted groundwater. The Triad approach will be used when determining the placement of the injection lifts so that flexibility is built into the injection program (ITRC, 2003). The program will be evaluated after each phase to adjust the number of injections and lifts, injection locations, and volumes. Based on current knowledge of subsurface lithology, hydrogeologic conditions, and Subunit A impacts, a preliminary injection distribution program was developed. Low TOC content in Subunit A soils would result in low oxidant demand and lesser amounts of reagent to be injected. The injection barriers will be spaced 150 feet apart and each injection point will be spaced on

50-foot centers. Approximately 64 injection points and 388 lifts are considered appropriate to provide effective distribution and contact of permanganate with VOCs over a five-year period. Injections would likely require approximately three months of field injection time per phase. The injection program is presented in Figure 11.

Groundwater monitor well installations would be required to supplement the current groundwater monitor network. A performance monitoring program will be implemented to evaluate effectiveness and appropriateness of the injection program. This method can be applied with moderate PGA-North Site disruption. This alternative would require soil oxidant demand testing, bench-scale testing, and pilot testing.

The conceptual design assumptions are provided in Table 11 below. Volumes of amendments are proposed for costing purposes and do not represent final volumes for remediation. Final remediation volumes will be determined based on site specific sampling conducted during investigation and evaluation phases.

Table 11 Conceptual Design Summary for ISCO + Hydraulic Barrier
Site Characteristics – Site located in Goodyear, Arizona. – COCs are TCE and perchlorate. Treatment area defined by TCE concentration greater than 1 mg/L but constrained by West Van Buren Street to the north and the Goodyear Financial Center parking lot to the east. – Source area treatment is focused on saturated portion of the Subunit A aquifer. – The source area is approximately 250 feet wide and 700 feet long. – Depth to groundwater is 90 feet bgs. – Targeted vertical treatment is 60 feet thick (from 90 to 150 feet bgs).
Design Assumptions – A sufficient hydraulic barrier exists along West Van Buren Street. – 12 new groundwater monitor wells installed over three years (approximately 3 per year); additional monitor wells will be added as necessary during the design phase. – 50-foot injection well spacing. – 50-foot spacing between injection lines. – Lifts spaced 5 feet apart. – Phase I - Year 1 Injections 12 injection points with 6 lifts. – Phase II - Year 2 Injections 3 injection points with 11 lifts 9 injection points with 9 lifts. – Phase III and IV - Year 3 and 4 Injections 21 injection points with 3 lifts. – Phase V - Year 5 Injections 6 injection points with 6 lifts. – Approximately 488,060 pounds of potassium permanganate to be injected. – The total volume of injection fluid is approximately 2,658,422 gallons – Average of approximately 1,774 pounds and 10,631 gallons injected per lift. – Injections phased over five years. – Primary injections occur the first four years. Re-injections at 10 percent of locations during the fifth year.

Table 11 Conceptual Design Summary for ISCO + Hydraulic Barrier
Post-Injection Performance Groundwater Monitoring – Groundwater samples collected from 12 monitor wells and analyzed for VOCs, perchlorate, and general chemistry parameters (methane, ethane, ethene, chloride, bicarbonate, sulfate, calcium, sodium, nitrate ammonia, phosphate, magnesium, dissolved and total iron, dissolved and total manganese, and TOC). – Field measurements collected from 12 monitor wells including pH, DO, conductivity, temperature, turbidity, and ORP. – One baseline groundwater monitoring event prior to Phase I injection. – Three quarterly groundwater monitoring events after each phase. – Three years of semiannual groundwater monitoring post-injection.

2.9.7 Alternative 7 – ERH / Steam + Hydraulic Control

ERH and/or steam injection is a remedial technology used to address source areas with the highest concentrations. Electrodes and/or steam injection wells would be installed in vertical wells to heat the subsurface and volatilize VOCs and other COCs. As the subsurface is heated, vapors are formed, recovered, and treated through an aboveground treatment process. Groundwater may also be extracted through dual-phase extraction wells and treated through an aboveground treatment process. The power supply demands and fluid capacity/treatment needs are proportional to the volume of area being treated and groundwater velocity. Hydraulic control may be necessary to reduce influx of groundwater into the treatment area. ERH is most effective for source areas of lower permeability and other defined areas of highest concentration, including potential non-aqueous phase liquid. Steam injection is also most effective in defined areas of highest concentration, including potential non-aqueous phase liquid; however, it is more applicable in higher permeability zones. ERH is not effective for treatment of perchlorate.

This alternative includes the use of in-situ thermal heating via ERH and/or steam injection with hydraulic control. A single technology or the combination of these two heating methods would be used to remediate VOCs in the source area groundwater. Hydraulic control would be used to increase the efficiency of the treatment system by limiting the influx of groundwater to the treatment zone. The current groundwater remedy is SVE in the source area together with pump and treat for groundwater throughout the Site will remain in place.

Electrodes would be placed on 15- to 20-foot centers, gases would be collected from the modified existing SVE system, and newly installed extraction wells spaced throughout the treatment zone. Electrode spacing is based on average electrode spacing used on recent thermal applications for sites with similar geology (Environmental Security Technology Certification Program, 2010). Steam injection wells would also be installed on 15- to 45-foot centers. The high concentration zone targeted for treatment is assumed to be 10 feet thick and located approximately 170 feet bgs. A treatment thickness of 100 feet is assumed to include the 10-foot thick target zone, a 10-foot thick hot floor beneath the target zone, 80 feet of thickness to the 90-foot depth to water, and 10 feet above the depth to water to minimize condensation of contaminants. The treatment thickness may be decreased if only electrodes are used for heating the treatment area, and will be decreased if contaminants only reach 150 feet bgs.

During the installation of the thermal treatment system, any wells or subsurface features of incompatible materials (PVC, etc.) would be abandoned or removed. Samples of vapors and gases collected from the treatment area will be analyzed for VOCs. Liquids, vapors, and gases collected from the treatment area would be treated in an aboveground treatment system which would include condensation of vapors and separation of fluids. As part of the thermal treatment system, a groundwater hydraulic control system including extraction wells may need to be installed around the treatment zone to minimize the influx of groundwater. Groundwater samples will be collected and analyzed for VOCs, perchlorate and general chemical parameters (chloride, bicarbonate, sulfate, calcium, sodium, nitrate, ammonia, phosphate, magnesium, dissolved and total iron, dissolved and total manganese, and TOC). Extracted fluids would be treated and discharged to an approved and permitted water discharge location.

In-situ thermal heating technologies are not considered for locations outside of the highest concentration areas due to high energy demands and cost. Therefore, only a portion of the source area would be treated with this alternative.

Based on present knowledge of the PGA-North Site, a schematic of this alternative was prepared (Figure 12). The conceptual design assumptions are provided in Table 12 below.

Table 12 Conceptual Design Summary for ERH with Steam + Hydraulic Control
Site Characteristics – Site located in Goodyear, Arizona. – COCs are TCE and perchlorate. Treatment area defined by TCE concentration greater than 1 mg/L but constrained by West Van Buren Street to the north and the Goodyear Financial Center parking lot to the east. – Source area treatment is focused on saturated portion of the Subunit A aquifer. – The source area is approximately 150 feet wide and 350 feet long. – Depth to groundwater is 90 feet bgs. – Targeted vertical treatment is 100 feet thick (from 80 to 180 feet bgs).
Design Assumptions – A sufficient hydraulic barrier exists along West Van Buren Street. – 12 new groundwater monitor wells installed for performance monitoring which will include pressure and temperature monitoring. Additional monitor wells will be added as necessary during the design phase. – 15- to 20-foot electrode spacing. – 137 vapor and/or groundwater extraction wells for vapor and condensate recovery. – 49 steam injection wells. – An aboveground equipment building to house the blower, GAC/thermal oxidizer for vapor treatment, adsorption system for groundwater treatment, and control panel. – Below ground conveyance piping from each extraction well to the treatment system. – Miscellaneous instruments (analog flow meter/totalizer, vacuum and pressure gauges, level sensors, etc.). – Thermal system will take 6 months to install. The system will be operated in a single phase. – Application will operate for 6 to 10 months.
Performance Monitoring – Groundwater samples collected from up to 12 monitor wells/co-located recovery wells and analyzed for VOCs, perchlorate, and general chemistry parameters (methane, ethane, ethene, chloride, bicarbonate, sulfate, calcium, sodium, nitrate ammonia, phosphate, magnesium, dissolved and total iron, dissolved and total manganese, and TOC). – Vapor samples collected from the above ground treatment system and analyzed for VOCs.

Table 12 Conceptual Design Summary for ERH with Steam + Hydraulic Control
– Field measurements collected from 12 monitor wells including pH, DO, conductivity, temperature, turbidity, and ORP. – One baseline groundwater monitoring event prior to the first phase of remediation. – Quarterly groundwater monitoring during system operation. – Four years of semiannual groundwater monitoring after completion of the remedial program.

2.10 Comparative Analysis

This section evaluates each alternative in relation to each specific evaluation criterion. The purpose of this comparative analysis is to identify the advantages and disadvantages of each alternative relative to one another. The evaluations presented in the following subsections are summarized in Table 6. The costs for each alternative are summarized in Table 14.

Overall protection of human health and the environment and compliance with ARARs generally serve as threshold determinations and must be met by an alternative for it to be eligible for selection. The sustainability evaluation is discussed in the long-term effectiveness and permanence section and the results are provided in Appendix D. The No Action alternative was retained as a baseline for comparison purposes only.

2.10.1 Overall Protection of Human Health and the Environment

Findings of the 2010 Five Year Review (FYR) indicated that the PGA-North Site remedy was not protective of human health and the environment. Since completion of the FYR, however, progress at the Site has mitigated or has planned to mitigate the expanding Subunit A groundwater plume to the north and northeast (USEPA & ADEQ, 2010; AMEC, 2013b). The analysis presented in the paragraphs below for overall protection of human health and the environment is presented for that alternative's ability to be protective with respect to the source area remediation which is the subject of this SARFFS.

Alternative 1 (No Action) does not change the current conditions in the source area and does not provide additional protection of human health or the environment beyond the existing remedy. This alternative involves continuing the current remedy and taking no additional action toward a source area remedy, implying that achievement of the original PGA-North RAOs would occur far into the future. There are currently no direct pathways that impact human health. The elevated concentrations of hazardous constituents present in groundwater would not be addressed beyond the current groundwater remedy and, consequently, there would be no additional reduction in potential health risks or hazards or time to clean up.

Alternative 2 (IWAS/Hydraulic Barrier) is expected to be protective of human health but not protective of the environment since this alternative will not be effective in treating perchlorate.

Alternative 3 (ARD) is expected to be protective of human health and the environment. This alternative will be effective in treating TCE and perchlorate. Implementation of this remedial alternative would not contribute to the development of exposure pathways discussed in the baseline risk assessment (Section 1.2.4). All exposure pathways identified in the baseline risk assessment were to receptors located in neighboring residential communities which will not be affected by implementation of any of the remedial alternatives. ARD could result in a temporary increase in VC concentrations if the reductive chlorination process is not complete, which may in turn volatilize into the vadose zone.

However, ARD is not likely to cause persistent elevated VC concentrations if bioaugmentation is successful. Under reducing conditions, it is also possible that arsenic could be mobilized, and hydrogen sulfide and methane may be released as dissolved gases due to biological activity. Anaerobic water created by Alternative 3 could be persistent in the environment, but may be mixed with aerobic groundwater as it migrates downgradient of the treatment area.

Alternatives 4 (nZVI/ZVI/ARD) and 5 (ZVI/ARD) would be protective of human health and the environment since nZVI and ZVI injections would result in mass reduction of COCs. These alternatives would be effective in treating TCE and perchlorate. Implementation of these remedial alternatives would not contribute to the development of exposure pathways discussed in the baseline risk assessment (Section 1.2.4). Chemical reduction and/or ARD could result in a temporary increase in VC concentrations if the reductive chlorination process is not complete, which may in turn volatilize into the vadose zone. However, these alternatives are not likely to cause persistent elevated VC concentrations if bioaugmentation is successful. Under reducing conditions, it is also possible that arsenic could be mobilized, and hydrogen sulfide and methane may be released as dissolved gases due to biological activity. Anaerobic water created by Alternatives 4 or 5 could be persistent in the environment, but may be mixed with aerobic as it migrates downgradient of the treatment area.

Alternative 6 (ISCO/Hydraulic Barrier) would be moderately protective of human health and the environment; however, permanganate could be persistent in the environment. Permanganate will be effective in treating TCE but not perchlorate. In addition, if permanganate-impacted water reaches the hydraulic barrier and is recirculated in the aboveground water treatment systems, there is the low level health risk to treatment system workers. Finally, the application of an oxidizing technology may result in the conversion of trivalent chromium to hexavalent chromium, which is more mobile and exhibits a higher toxicity. Uranium and selenium are metals that also may be mobilized under oxidative conditions.

Alternative 7 (ERH/Steam) would be moderately protective of human health and the environment. TCE mass would be reduced and treated ex-situ by the MTS providing resource protection but this alternative would not be effective in treating perchlorate. Health and safety plans and process controls implemented during treatment would provide protective measures for environmental workers.

2.10.2 Compliance with ARARs

All alternatives except Alternative 1 (No Action) have the potential to meet and comply with ARARs; however, Alternatives, 2, 6, and 7 may not meet ARARs due to the lack of perchlorate treatment.

2.10.3 Long-term Effectiveness and Permanence

The criterion of long-term effectiveness and permanence is evaluated with respect to achievement of the RAOs over the expected lifetime of a groundwater remedial alternative, which is typically 30 years.

Alternative 1 (No Action) is not effective at achieving all of the RAOs in the long term. The No Action alternative does not meet the mass reduction RAO within the source area.

Alternative 2 (IWAS) relies on flushing a portion of the aquifer within the influence of the extraction well to strip VOCs from groundwater. Effectiveness of the approach is dependent on the radius of influence, number of extraction wells used, hydraulic properties of the aquifer, and the treatment zone dimensions. This technology relies on the heterogeneity of the aquifer for horizontal migration of

re-injected groundwater. However, the presence of contiguous cemented layers in Subunit A may be prohibitive to the effectiveness of this technology since this technology assumes 45 percent of the captured water is recirculated. Water that is returned to the aquifer may not be recaptured by the lower extraction component of the system. Due to the subsurface heterogeneity in Subunit A, this alternative is expected to be low to moderately effective at achieving the RAOs in the long term.

Alternatives 3 (ARD), 4 (nZVI/ZVI/ARD), 5 (ZVI/ARD), 6 (ISCO), and 7 (ERH/Steam) would likely be moderate to highly effective at permanently reducing source area COC concentrations in the long term; however, each alternative has issues that would need to be addressed. The alternatives that operate or require reducing conditions are also effective in treatment of perchlorate in groundwater. Alternative 6 (ISCO) and Alternative 7 (ERH/Steam) are not effective in degrading perchlorate because the perchlorate molecule is highly oxidized and/or is resistant to thermal destruction, but for removal of VOCs this alternative has the highest likelihood of success.

Additionally, any alternative that involves injection of amendments such as Alternatives 3 (ARD), 4 (nZVI/ZVI/ARD), 5 (ZVI/ARD), and 6 (ISCO), may result in initial mass reductions followed by localized and or temporary rebound of COC concentrations. The hydraulic barrier combined with repeat amendment injections is included in the design of these alternatives to address this possibility.

Alternative 3 (ARD/Hydraulic Barrier) would require a longer time period in order to establish high population of degrader bacteria, since native soil has a very low organic content and microbial count. For Alternative 7 (ERH/Steam) initial mass removal would occur over a 0.5 year timeframe; however, although rebound is less likely for Alternative 7 than for ARD or ISCO, it is an unknown quantity that could necessitate additional remedial efforts.

Alternatives 4 (nZVI/ZVI/ARD) and 5 (ZVI/ARD) would provide the most effective and permanent long-term mass reduction and containment because it is likely that RAOs will be met in the short term since TCE will be destroyed through contact with nZVI and ZVI. The nZVI injections will also provide a reducing environment in the source area that will bolster effectiveness of ARD in the long term. These alternatives are also expected to reduce perchlorate concentrations.

The effectiveness of Alternatives 3 (ARD/Hydraulic Barrier), 4 (nZVI/ZVI/ARD), and 5 (ZVI/ARD), which depend on chemical reduction, and Alternative 6 (ISCO), are more or less dependent on distribution and contact between the injected amendment and the target VOCs. The ability to completely distribute the amendments, particularly the bioaugmentation culture, because it is a lower volume injection is not certain given the geologic heterogeneity. All of these alternatives result in changes to the reduction oxidation state of the aquifer and produce temporary increases in secondary water quality parameters. Reduced groundwater produced through application of nZVI, ZVI, and/or ARD eventually will be diluted with aerobic groundwater some distance downgradient of the treatment area. Oxidized groundwater will also be subject to eventual dilution; however, a change in reduction oxidation state is less likely because Subunit A is already an oxidizing aquifer. None of these remediation technologies have been pilot-tested to the extent of understanding their ability to create a comprehensive reactive zone in the source area.

Permanganate, the Alternative 6 (ISCO) amendment, has been known to persist in local aquifers due to the naturally low organic carbon and high dosing concentrations. Permanganate, when dosed in sufficient quantity may diffuse into fine-grained and no flow zones, thereby reducing the potential for back diffusion of TCE over time. This persistence would allow it to diffuse into lower permeability zones within the aquifer; however, if permanganate-laden groundwater were to reach the extraction

wells, the aboveground treatment process may be negatively affected. This is also true for groundwater that has been affected by anaerobic and reducing conditions due to the potential presence of metals, sulfide, and methane which affect the aesthetic qualities of the water. Follow-up injections are included in the conceptual design for all of the alternatives involving jet-assisted injection as the delivery method (Alternatives 2, 3, 4, 5, and 6).

Recirculation and injection of extracted groundwater may prevent negative impacts to the aboveground treatment system from secondary water quality affects. The potential for fouling in the extraction and injection wells adds additional costs for well rehabilitation and replacement over the long term. The likelihood of biofouling is higher for those alternatives including ARD due to the potential presence of organic carbon in the extracted groundwater.

The relative sustainability performance of each remediation alternative was considered under this criterion. While sustainability is not one of the nine criteria for the alternatives evaluation, it seemed most appropriate discussing sustainability performance as part of this criterion, since Protection of Human Health and the Environment directly addresses many societal and environmental elements of sustainability. The following sustainability indicators were considered in the sustainability evaluation:

- Air emissions, including:
  - Greenhouse gas emissions; and
  - Nitrogen oxides, sulfur oxides, particulate matter, and hazardous air pollutant emissions.

- Water, including:
  - Potable water consumption; and
  - Groundwater extraction.

- Materials and waste, including:
  - Raw material consumption;
  - Non-hazardous solid waste production; and
  - Wastewater production.

The sustainability evaluation methodology and results are provided in Appendix E. The sustainability indicator-specific results were estimated in tons and gallons, and are compared for each remedial alternative. A summary table of results is provided Table 13 below.

Table 13. Sustainability Evaluation Summary

Output	Unit	Alternative 1 No Action	Alternative 2 IWAS	Alternative 3 ARD	Alternative 4 nZVI/ZVI/ARD	Alternative 5 ZVI/ARD	Alternative 6 ISCO	Alternative 7 ERH/Steam
Greenhouse Gas Emissions	tons CO_2e	0	1,032	1,066	1,689	1,518	871	7,603
Total NO_x, SO_x, and PM Emissions	lbs	0	16,305	11,518	29,939	18,165	11,560	135,146

Table 13. Sustainability Evaluation Summary								
Output	Unit	Alternative 1 No Action	Alternative 2 IWAS	Alternative 3 ARD	Alternative 4 nZVI/ZVI/ARD	Alternative 5 ZVI/ARD	Alternative 6 ISCO	Alternative 7 ERH/Steam
Total HAP Emissions	lbs	0	204	35	284	156	39	2,623
Potable Water Consumption	gallons	0	7,500	15,000	615,000	615,000	1,390,020	1,458,000
Groundwater Injection	gallons	0	0	0	600,000	600,000	1,375,020	1,440,000
Groundwater Extraction	gallons	0	44,928,000	44,928,000	44,928,000	44,928,000	44,928,000	44,928,000
Raw Material Consumption	tons	0	183	301	1,109	631	347	285
Non-Hazardous Solid Waste Production	tons	0	234	374	330	440	380	350
Wastewater Production	gallons	0	8,500	17,900	13,500	26,300	14,650	7,500

Notes:
NO_x = nitrogen oxides; SO_x = sulfur oxides; PM = particulate matter; HAP = hazardous air pollutant

2.10.4 Reduction of Toxicity, Mobility, or Volume

Alternative 1 (No Action) would not expedite the reduction of toxicity, mobility, or volume.

Alternative 2 (IWAS) would result in low to moderate reduction in toxicity, mobility, or contaminant volume. IWAS may not address high TCE concentrations in deeper Subunit A groundwater. If the recirculation path is not complete, impacts may be re-injected to the upper aquifer zone. Plume migration from the source area would be mitigated by the existing hydraulic barrier. The transportation and off-site treatment and/or disposal of liquid phase carbon for vapor phase treatment could result in an accidental release, increasing the potential for the added mobility of COCs at the PGA-North Site.

Alternatives 3 (ARD), 4 (nZVI/ZVI/ARD), and 5 (ZVI/ARD) have the potential to treat perchlorate in addition to VOCs. Alternative 7 (ERH/Steam) has no effect on perchlorate due to its high boiling point.

Implementation of ARD may result in the temporary production of VC and mobilization of arsenic. The use of emulsified oil as the carbon substrate will temporarily reduce mobility as VOCs will preferentially dissolve into oil that is adsorbed onto soil particles.

Alternatives 3 (ARD), 4 (nZVI/ZVI/ARD), 5 (ZVI/ARD), and 6 (ISCO) would likely result in moderate to high reduction in toxicity, mobility, or contaminant volume. Use of jet-assisted injection for delivery of amendments in Alternatives 3, 4, 5, and 6 may establish new flow paths that could mobilize sorbed phase mass and expand the size of the plume. In each case, the hydraulic barrier would adequately control plume migration from the source area.

Alternative 6 (ISCO) may locally and temporarily mobilize chromium, uranium, and selenium. Persistence of permanganate will be dependent on dosage, reaction with naturally-occurring and anthropogenic organic carbon and minerals, and mixing with untreated groundwater and dispersion as groundwater travels downgradient. This alternative will not treat perchlorate.

Alternative 7 (ERH/Steam) would provide the highest reduction in toxicity and contaminant mass which could reach 90 percent to 99 percent reduction in mass. There exists a slight possibility that the higher temperature could mobilize VOCs both in the gaseous and dissolved phase; however, this alternative would be implemented in concert with SVE and hydraulic control systems.

2.10.5 Short-term Effectiveness

Alternative 1 (No Action) would not be effective at achieving the RAOs in the short term.

Alternative 2 (IWAS) would be low to moderately effective in the short term. The IWAS system would be effective at treating impacts within the influence of the extraction well; however, the degree to which stripping can occur will depend on the achievable recirculation ratio.

Alternative 3 (ARD) is not effective in the short term. Current groundwater chemistry and microbial populations are not conducive to ARD. It would require a significant acclimation period of at least six months to a year to reach anaerobic and reducing conditions, and grow sufficient degrader populations to observe significant degradation rates. This technology is likely to be effective with enhancing the degradation of perchlorate at similar rates to TCE. Perchlorate degradation has been strongly related to denitrification, indicating that perchlorate would likely begin degrading before TCE. Additionally, ARD could result in a temporary increase in VC concentrations if the reductive chlorination process is not complete, which may in turn volatilize into the vadose zone. However, ARD is not likely to cause persistent elevated VC concentrations if bioaugmentation is successful. Under reducing conditions, it is also possible that arsenic could be mobilized, and hydrogen sulfide and methane may be released as dissolved gases due to biological activity. Anaerobic water created by Alternative 3 could be persistent in the environment, but may be mixed with aerobic groundwater as it migrates downgradient of the treatment area.

Alternatives 4 (nZVI/ZVI/ARD), 6 (ISCO), and 7 (ERH/Steam) would be effective at reducing TCE contaminant mass in the short term. Chemical reduction and/or ARD could result in a temporary increase in VC concentrations if the reductive chlorination process is not complete, which may in turn volatilize into the vadose zone. However, these alternatives are not likely to cause persistent elevated VC concentrations if bioaugmentation is successful. Under reducing conditions, it is also possible that arsenic could be mobilized, and hydrogen sulfide and methane may be released as dissolved gases due to biological activity. Anaerobic water created by Alternatives 4 or 5 could be persistent in the environment, but may be mixed with aerobic groundwater as it migrates downgradient of the treatment area. Alternative 6 (ISCO) and 7 (ERH/Steam) would not be effective in reducing perchlorate contaminant mass. Additionally, ISCO increases the potential risk to worker safety due to potential exposure to permanganate during shipment to and handling at the treatment area.

The short-term effectiveness of Alternative 4 (nZVI/ZVI/ARD) would be dependent on the pattern of distribution of the ZVI particles resulting from jet-assisted injection and mass flux through the treatment zone. Use of a high pressure injection method also creates the potential for short circuiting and creation of preferential pathways. Additionally, nZVI has been shown to be effective in quickly degrading perchlorate to chloride in laboratory studies (Cao et al., 2005).

Additionally, both of these alternatives would be implemented in phases. Alternatives 4, 5 (ZVI/ARD), and 6 would require use of jet-assisted injection methods which represents a minor risk to overlying land use and a slight risk to workers due to the high pressures used during the injection process. These risks are available through implementation of monitoring, and safe worker training and practices. The potential off-site transport of permanganate represents a slight potential risk to treatment system workers and downgradient residents. Alternative 7 (ERH/Steam) could achieve 90 percent TCE mass removal within a half year depending on the results of a pilot program, but would not be effective for perchlorate mass removal.

2.10.6 Implementability

Alternative 1 (No Action) could be readily implemented with no difficulty or added technology or equipment other than what would be necessary to optimize the current remedy.

Alternative 2 (IWAS) would involve installation of modified extraction wells for adequate coverage of source area impacts. Installation of the IWAS equipment will involve moderate PGA-North Site disruption. IWAS has the potential for scale formation in the well. It is recommended that a pilot program be implemented to determine the effectiveness of this remedial approach.

Alternative 3 (ARD) would require both a treatability study and pilot program to evaluate effectiveness of this alternative as a standalone remedial option. Bioamendments can be injected using direct-push methods, which are relatively rapid and straightforward to implement; however, hydraulic fracturing may be required to enhance amendment distribution and the presence of gravel and cobbles in Subunit A will likely impede direct-push methods. A liquid culture containing degrader microorganisms should be injected during a separate event, after the electron donor has created the geochemical conditions necessary for its survival and growth. The bioaugmentation culture only needs to be injected once, as the microbes will multiply as long as an electron donor and reducing conditions are present. It is possible that the bioaugmentation culture may fail to thrive. This would only occur if anaerobic and reducing conditions cannot be maintained in the treatment area due to continued influx of electron acceptors from upgradient sources. Extensive evaluation of early performance monitoring data is recommended prior to completion of a full five year injection program. This injection program would result in low to moderate PGA-North Site disruption. Since the injection programs will be phased over a five-year period, the injection program would be optimized as necessary during each phase of the injections.

The implementability of Alternative 4 (nZVI/ZVI/ARD) is scored as moderate to high because the jet-assisted injection methodology would be used to enhance distribution of the nZVI and ZVI particles. The distribution of amendments will be monitored in groundwater from performance monitoring wells and used to optimize the injection program. Re-suspension of the nZVI through a physical mixing process is a necessary and additional step prior injection. This injection program would result in low to moderate PGA-North Site disruption. Since the injection programs will be phased over a five-year period, the injection program would be optimized as necessary during each phase of the injections.

The implementability of Alternative 5 (ZVI/ARD) is graded as moderate to high. It is recommended that a pilot program be implemented to determine the effectiveness of this remedial approach prior to full scale implementation. Jet-assisted injection would be used to enhance the distribution of both ZVI particles and bioamendments. This injection program would result in low to moderate PGA-North Site disruption. Since the injection programs will be phased over a five-year period, the injection program would be optimized as necessary during each phase of the injections.

Alternative 6 (ISCO) could be readily implemented. It is likely that the heterogeneity in Subunit A would result in preferential pathways that would hinder distribution of the reagent. Jet-assisted injection would likely be required to ensure the reagent is evenly distributed throughout the aquifer. This injection program would result in low to moderate PGA-North Site disruption. Since the injection programs will be phased over a five-year period, the injection program would be optimized as necessary during each phase of the injections.

The implementability of Alternative 7 (ERH/Steam) is low to moderate since this technology is generally applied at shallow depths over a smaller footprint. Thermal treatment capacity may be reduced because of the system power requirements relative to local availability. This technology requires a significant amount of cabling, piping, and installation of controls and checkpoints. In addition, existing incompatible subsurface features such as wells will need to be abandoned, removed, or replaced during construction. Monitoring wells would need to be installed after application of this remedy in order to monitor for residual COC concentrations in groundwater. Any residual contamination would be characterized and addressed depending on the extent and magnitude of the remaining mass.

2.10.7 Cost

Cost estimates have been prepared for each of the alternatives listed above according to USEPA guidance. Total costs including capital, O&M, and closure costs are presented below with an accuracy of -30 percent to +50 percent (Table 14). Detailed costing spreadsheets have been included in Appendix E.

Costs would not be incurred for Alternative 1 (No Action).

Table 14. Cost Estimate Summary

Alternative	Operational Life (Years)	Construction & Material Costs *(x1,000)*	O&M Costs *(x1,000)*	Total Costs *(x1,000)*	Cost Range	
					(-30%)	(+50%)
Alternative 2 IWAS Hydraulic Barrier	20	$5,160	$1,540	$6,700	$5,154	$10,050
Alternative 3 ARD Hydraulic Barrier	8	$7,470	$820	$8,290	$6,377	$12,435
Alternative 4 nZVI/ZVI/ ARD Hydraulic Barrier	8	$10,320	$820	$11,140	$8,570	$16,710
Alternative 5 ZVI/ARD Hydraulic Barrier	11	$11,290	$1,360	$12,650	$9,730	$18,975

Table 14. Cost Estimate Summary						
Alternative	Operational Life (Years)	Construction & Material Costs *(x1,000)*	O&M Costs *(x1,000)*	Total Costs *(x1,000)*	Cost Range	
					(-30%)	(+50%)
Alternative 6 ISCO Hydraulic Barrier	8	$6,210	$820	$7,030	$5,408	$10,545
Alternative 7 ERH/Steam Hydraulic Control	1	$10,470	$15,620	$26,090	$20,070	$39,135

Costs for the alternatives fall into three categories; low, moderate, high.

Construction and Material Costs

- Alternatives 2 (IWAS), 3 (ARD), and 6 (ISCO) have the lowest construction and material costs.
- Alternatives 4 (nZVI/ZVI/ARD), 5 (ZVI/ARD), and 7 (ERH/Steam) have moderate construction and material costs.

O&M Costs

- Alternatives 3 (ARD), 4 (nZVI/ZVI/ARD), 5 (ZVI/ARD), and 6 (ISCO) are primarily injection programs with low O&M costs.
- Alternative 2 (IWAS) has moderate O&M costs mainly associated with analytical testing, reporting, and maintaining and replacing equipment over a 20-year system lifespan.
- Alternative 7 (ERH/Steam) has high O&M costs primarily driven by electrical usage.

Total Costs

- Alternatives 2 (IWAS), 3 (ARD), and 6 (ISCO) have the lowest total costs.
- Alternatives 4 (nZVI/ZVI/ARD) and 5 (ZVI/ARD) have moderate total costs because of the combined injection programs of bioamendments and a variant of ZVI.
- Alternative 7 (ERH/Steam) has the highest total cost mainly due to the number of electrodes and depths required to heat the impacted aquifer.

2.10.8 State Acceptance

State acceptance will be assessed following the issuance of the Proposed Plan by USEPA.

2.10.9 Community Acceptance

Community acceptance will be assessed following the issuance of the Proposed Plan by USEPA. Several best management practices and strategies would be implemented as part of the chosen alternative to ensure effective public participation and to minimize community disturbance.

2.10.10 Comparative Analysis Summary

A comparative evaluation of the advantages and disadvantages of each groundwater remedial alternative is provided in this section.

2.10.11 Alternative 1 - No Action

Advantages

This alternative is equally protective of human health and the environment because with existing hydraulic control there are no human or ecological risks associated with the presence of COCs in groundwater within the property boundaries of the former UPI facility. The main dry wells area is the ongoing source of TCE in groundwater at the PGA-North Site; however, downgradient mass migration is currently being prevented through the operation of extraction wells located along the downgradient property boundary. This is a component of almost all of the remediation alternatives, with the exception of Alternative 7, In-Situ Thermal Heating, which includes hydraulic control as part of the remedy within the source area.

Disadvantages

The no-action alternative will not be effective in decreasing the time necessary for the pump and treat remedy to be effective. The operation, maintenance, and pump monitoring in the property boundary extraction wells and the MTS will be required for at least 50 years or longer, resulting in long-term costs.

2.10.12 Alternative 2 - IWAS + Hydraulic Barrier

Advantages

This technology is ideal for application in Subunit A due to the significant thickness of the saturated interval. TCE and other VOCs present in groundwater would be easily removed via volatilization through air-stripping within the recirculation well. Construction of the recirculation system of dual-screened wells, vapor and liquid transport piping and aboveground vapor phase treatment system is straightforward, well-understood, and may be easily tied into the existing SVE system. Based on the capture zones exhibited by existing Subunit A extraction wells, the radius of influence is expected to be at least 100 feet, reducing the number of subsurface borings necessary for source area treatment. Over the short term, TCE mass removal will be moderate, depending on the concentration of dissolved mass in groundwater. It is the least expensive alternative, with the exception of the Alternative 1 (No Action).

Disadvantages

This remedial alternative will experience the same difficulties over the long term as that associated with applying groundwater extraction and treatment to remove high concentrations of mass in a source area, and is at a distinct disadvantage when compared to Alternatives 4 and 7, both which directly target TCE that may be present as sorbed phase mass. Perchlorate cannot be removed from groundwater using this technology. The heterogeneity of the geology makes it uncertain that complete recirculation may be achieved; the presence of less permeable layers would prevent groundwater from travelling vertically within the aquifer, which would then result in incomplete pore volume replacement and lack of mass removal. After recirculation is initiated, equilibrium will eventually be reached and the removal of VOCs will depend upon the dissolution rate of sorbed phase VOCs resulting in decreased effectiveness over time. It is estimated that these wells will need to be operated over a 20-year period in order to have completed sufficient pore volume replacement to reach RAOs, which is a significantly longer time frame than all of the other remedial alternatives. A pilot test will be required to determine if complete recirculation may be achieved.

2.10.13 Alternative 3 - ARD + Hydraulic Barrier

Advantages

TCE and perchlorate are biodegradable under anaerobic and reducing conditions. Subunit A groundwater is highly buffered due to alkaline conditions, resulting in pH maintenance in the ideal range for ARD. This technology is compatible with the anaerobic and reducing conditions created by the previously conducted nZVI pilot tests. A bioremediation bench test was conducted using site soils and groundwater with molasses as the bioamendment. This remediation technology effectively and permanently destroys COCs over the long term and rebound is unlikely with this technology. The presence of the hydraulic barrier will prevent any mobilization of mass during amendment injections. This remedial alternative is fourth in cost after the no action, ISCO, and IWAS alternatives.

Disadvantages

The presence of high sulfate concentrations in Subunit A will require a higher dosage of bioamendment than at sites with similar concentrations of COCs, and will require a long acclimation period for sulfate reduction to occur before VOCs can be degraded. Incomplete contact between the nZVI + ZVI particles and target COCs is likely during application of this alternative. In addition, the high groundwater velocity will further increase the required dosage of bioamendment by introducing additional sulfate into the treatment zone. The low TOC content of Subunit A and lack of cis-1,2-DCE and VC in groundwater means that a low bacterial count is likely and bioaugmentation will likely be necessary, which will require the injection of bioaugmentation culture as an additional amendment. Bench and pilot testing will likely be necessary to determine site-specific factors such as longevity of electron donor and to determine if bioaugmentation is necessary. This remedial alternative is not effective over the short term, as the microbial populations require an acclimation period to mature and establish significant populations in the subsurface, especially in the presence of high sulfate concentrations. This remedial alternative is likely to require less time than Alternative 2 IWAS and Hydraulic Control to reach RAOs, but will still require an extended performance monitoring period with repeated amendment injections resulting in a longer performance timeframe than remedial Alternatives 4 through 7, which include the use of an amendment that immediately reacts with COCs. Finally, a better understanding for the potential to mobilize arsenic, a common metal found in Arizona groundwater and soil, should be developed prior to full-scale implementation of this remedy. The

enhanced microbial activity caused by this alternative may lead to bio-fouling of wells. Under the reducing conditions formed within the treatment area, arsenic can become transiently mobile; however, as it migrates with groundwater outside the treatment area and into more aerobic conditions, the arsenic will likely adsorb to iron hydroxides returning to its former, immobile state.

2.10.14 Alternative 4 – nZVI + ZVI + ARD + Hydraulic Barrier

Advantages

The high activity of the nZVI destroys TCE upon contact and facilitates the biodegradation of perchlorate. This has been proven through bench and pilot testing for TCE, with less effectiveness in destroying perchlorate. However, the reducing conditions created by nZVI facilitate the bioremediation of perchlorate. The jet-assisted injection method used during the Phase III Pilot Test would allow for increased contact and distribution, especially in comparison with the injection methods used for other remedial amendments. Initial bench and pilot testing activities have been completed for this remedial alternative. This alternative can be used to treat specific depth intervals and treat higher mass concentration areas. nZVI is highly effective in degrading TCE upon contact; the results of the pilot test showed mass degradation between 63 percent and 96 percent one month after the Phase III Pilot Test injection was completed. The injection of macro-scale ZVI together with nZVI increases the longevity of the destructive life of the iron, and lengths the effective treatment time of the remedy. When combined with ARD, this remedial alternative allows for terminal electron acceptor demand to be shared between the nZVI, ZVI, and bioamendment dose, and ARD will provide a polishing step for the remaining VOCs after nZVI has been oxidized and is no longer active. The presence of the hydraulic barrier will prevent any mobilization of mass during amendment injections. Remedial injections would be completed over a five-year period, with the fifth year including reinjection areas with lingering COC concentrations.

Disadvantages

The cost of this remedial alternative is the fifth highest when compared to the other remedial alternatives. The presence of high sulfate concentrations requires a larger dosage of bioamendment and nZVI. Incomplete contact between the nZVI + ZVI particles and target COCs is possible during application of this alternative. The injection port configuration and resulting nZVI distribution will require some investigation in order to optimize the injection methodology, due to the uncertainty associated with the distribution pattern. The distribution of nZVI in the subsurface and the physical processes, including potential for agglomeration after jet-assisted injection, needs to be better understood in order to optimize the injection process. This may also require development of a better understanding of the interaction of nZVI with dispersants and/or surfactants in assisting with keeping the particles suspended and enhancing their distribution characteristics. The creation of anaerobic and reducing groundwater will degrade water quality by increasing the concentration of TOC, methane, and sulfide and decreasing the pH. Biofouling of downgradient extraction wells may result if this water is allowed to enter the aboveground treatment system; however, because prevailing conditions in Subunit A are aerobic, eventually the water quality impacts may be mitigated as mixing with untreated water occurs. Finally, a better understanding for the potential to mobilize arsenic, a common metal found in Arizona groundwater and soil, should be developed prior to full-scale implementation of this remedy. Under the reducing conditions formed within the treatment area, arsenic can become transiently mobile; however, as it migrates with groundwater outside the treatment area and into more aerobic conditions, the arsenic will likely adsorb to iron hydroxides returning its former, immobile state.

2.10.15 Alternative 5 – ZVI + ARD, + Hydraulic Barrier

Advantages

ZVI is highly effective in degrading TCE upon contact and will likely be partially effective in reducing perchlorate. A macro-scale ZVI will be active for a longer period of time than nZVI. When combined with ARD, this remedial alternative allows for terminal electron acceptor demand to be shared between the ZVI and bioamendment dose, and ARD will provide a polishing step for remaining VOCs. The presence of the hydraulic barrier will prevent any mobilization of mass during amendment injections. Remedial injections would be completed over a five-year period.

Disadvantages

This remedy relies on contact with TCE after injection and mass flux to carry the COCs through the multiple treatment walls. This is a sensible approach based upon the longer active life of the ZVI; however, because ZVI distribution is limited to the extent of fractures formed during injection this approach relies on dissolution of mass located on soil particles in between the ZVI injection areas, resulting in a longer treatment timeframe. This alternative is slightly more expensive than the nZVI alternative due to the additional cost of hydraulic fractured injection of ZVI, bioamendment, and biopolymer slurry when compared to jet-assisted injection, and the longer performance monitoring period. Pilot testing will be necessary to develop a better understanding of injection patterns and the spacing between the treatment barriers. The creation of anaerobic and reducing groundwater will degrade water quality by increasing the concentration of TOC, methane, and sulfide and decreasing the pH. Biofouling of downgradient extraction wells may result if this water is allowed to enter the aboveground treatment system; however, because prevailing conditions in Subunit A are aerobic, eventually the water quality impacts may be mitigated as mixing with untreated water occurs. Finally, a better understanding for the potential to mobilize arsenic, a common metal found in Arizona groundwater and soil, should be developed prior to full-scale implementation of this remedy. Under the reducing conditions formed within the treatment area, arsenic can become transiently mobile; however, as it migrates with groundwater outside the treatment area and into more aerobic conditions, the arsenic will likely adsorb to iron hydroxides returning its former, immobile state.

2.10.16 Alternative 6 - ISCO + Hydraulic Barrier

Advantages

Potassium permanganate is highly effective in degrading TCE upon contact. This technology is compatible with the existing reduction oxidation state of the Subunit A. Although it has not been tested, permanganate oxidant demand is likely very low for Subunit A soil and groundwater; therefore, the required dosage will be reasonable. Permanganate is completely soluble in water and therefore migrates and is diluted upon contact with groundwater. It is purple in color when active and forms a brown precipitate when it has been reduced, which makes it easy to track in the subsurface. This remedial alternative is the third least expensive, after the no action alternative and IWAS.

Disadvantages

Perchlorate in groundwater is a highly oxidized and stable form, which is not susceptible to oxidation; therefore permanganate does not interact with or degrade perchlorate. Permanganate has been known to linger in groundwater for many years due to the generally low oxidant demand in desert southwest

soil resulting from the lack of organic content. Lingering permanganate concentrations in groundwater may negatively impact the groundwater quality of Subunit A and if any connection between Subunits A, B, and C exist, will migrate with groundwater and present a long-term water quality issue. Unlike the other remediation technologies involving components that become inactive and immobile over time, the solubility, mobility, and strong purple color of the permanganate may result in long-term degradation of water quality. Migration of permanganate to the hydraulic barrier may negatively impact the treatment efficiency of the ion exchange resin used to treat perchlorate. Additionally, chromium in soil and groundwater may be converted from trivalent to hexavalent valence state, which increases the mobility and toxicity of the metal and may potentially be spread as groundwater is re-injected to avoid impacts to the aboveground treatment system. However, it is possible that hexavalent chromium may convert back to its trivalent valence state when ISCO influenced groundwater is mixed with untreated aquifer water. Precipitation of metals and carbonate compounds in downgradient extraction wells and treatment system units may result if this water is allowed to enter the aboveground treatment system. Cross gradient pumping to improve distribution is typically necessary to ensure complete treatment due to the development of preferential flow paths, especially in the local geology, which is characterized by the braided stream outwash. The remedial alternatives using ZVI and ARD avoid this issue due to the pervasiveness of low Eh in close proximity to ZVI combined with the solubility of carbon substrate and mobility of the degrading bacteria. Because direct contact between permanganate and COCs is required in this alternative, it is possible that incomplete treatment of the source area will occur; therefore multiple injections of permanganate may be required to reach remediation goals.

2.10.17 Alternative 7 – ERH with Steam + Hydraulic Control

Advantages

This technology is very effective over the short and long term with TCE. TCE would likely be volatilized first because it has a lower boiling point.

Disadvantages

Perchlorate would be transformed to a precipitate at the temperatures reached during thermal treatment. After treatment, the precipitate would likely dissolve back into groundwater; therefore, this alternative would not be effective in treating perchlorate. If steam is used in this alternative, perchlorate would likely be driven ahead of the steam front. This technology requires a high density of electrodes, and depends of the availability of electricity in this locale, which also results in a high cost. Additionally, this technology has not been implemented in a system as deep or over as large an area as the source area. The current SVE system components would require replacement with stainless steel and high temperature resistant components, also adding to the cost. The cost for this alternative is twice that of the next highest cost.

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TABLE 1
SUMMARY OF RECORD OF DECISION AND EXPLANATION OF SIGNIFICANT DIFFERENCES
PHOENIX-GOODYEAR AIRPORT-NORTH SUPERFUND SITE
GOODYEAR, ARIZONA

1989 Record of Decision Site Clean-up Plan	ESD #1 January 1991	ESD #2 May 1993	ESD #3 December 1995	ESD #4 March 1998	ESD #5 September 2002
PGA-North					
Soils					
SVE with vapor phase carbon emission controls.	● Clarifies the soil target area to include areas B and C defined by all four circles in Figure 5-7 of the ROD. ● Clarifies the role of soil excavation as a remedy option should SVE prove ineffective.	● Same as 1989 ROD except treat extracted contaminant vapors by thermal oxidation and wet scrubbing.			● Returns the soil gas remedy to that selected in the 1989 ROD from the alterations made in ESD #2.
Deep Groundwater					
Pump and treat at a centralized air stripping/liquid-phase carbon treatment plant with vapor-phase carbon emission controls. Provide treated water to City of Goodyear.	● No change from 1989 ROD.	● Same as the 1989 ROD except reinject treated water back into deep groundwater zone.			
Shallow Groundwater					
Incorporated 1987 ROD requirement for pump and treat at a centralized air stripping plant/liquid phase carbon treatment plant with vapor-phase carbon emission controls. Reinject treated water.	● No change from 1989 ROD.	● Same as the 1989 ROD except suspend implementation of the liquid phase carbon unit until warranted.	● Allow air sparging of Subunit A groundwater in areas where the sve system can collect and treat VOC vapors. ● Allow use of a metal adsorption wellhead treatment system, where appropriate, for wells connected to the existing groundwater treatment plant.		
PGA-South					
Soils					
Soil vapor extraction with vapor phase carbon emission controls.	● No change from 1989 ROD.	● No change from 1989 ROD.			
Deep Groundwater					
Pump and treat at a centralized air stripping plant. Provide treated water to City of Goodyear.	● Revises the selected remedy for the "Phillips Well" from wellhead treatment to routine water quality monitoring.	● Pump and treat at decentralized liquid-phase GAC water treatment units and reinject treated water back into deep groundwater zone.			

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SUMMARY OF RECORD OF DECISION AND EXPLANATION OF SIGNIFICANT DIFFERENCES
PHOENIX-GOODYEAR AIRPORT-NORTH SUPERFUND SITE
GOODYEAR, ARIZONA

1989 Record of Decision Site Clean-up Plan	ESD #1 January 1991	ESD #2 May 1993	ESD #3 December 1995	ESD #4 March 1998	ESD #5 September 2002
Shallow Groundwater					
Incorporated 1987 ROD requirement for pump and treat at a centralized air stripping plant with vapor-phase carbon emission controls. Reinjection of treated water.	● No change from 1989 ROD.	● No change from 1989 ROD.	● Allow air sparging of Subunit A groundwater in areas where the SVE system can collect and treat VOC vapors. ● Allow use of a metal adsorption wellhead treatment system, where appropriate, for wells connected to the existing groundwater treatment plant.		
Additional Site-wide Requirements					
	● Revises MCL for MEK from 170 µg/L to 350 µg/L.	● Liquid-phase carbon treatment at the well-head for drinking water wells contaminated by Airport or Unidynamics areas.		● Contains updated site-wide cleanup levels base on proposed 1989 MCLs, for antimony, 1,2-dichloropropane, xylenes, barium, beryllium, cadmium, chromium, and selenium. The MCL for chromium increased from 50 µg/L to 100 µg/L.	
	● Sets MCL for acetone at 700 µg/L.	● Adds four new MCLs: benzene - 5 µg/L, ethylbenzene - 700 µg/L, 1,1,2,2-tetrachloroethane - 0.18 µg/L, and tetrachloroethane - 5 µg/L			

Notes:
"Site-wide" includes both the northern and southern operable units
µg/L - microgram per liter
ESD - Explanation of Significant Difference
GAC - granular activated carbon
MCL - maximum contaminant level
MEK - methyl ethyl ketone
SVE - soil vapor extraction
VOC - volatile organic compound

Table 2

Original Legally Applicable State & Federal Requirements and Other Criteria for Groundwater
(Concentrations in µg/L)

Source: Table 2-5 of the 1989 ROD for the PGA Federal Superfund Site

Compound	Legally Applicable SDWA MCL	*Other Criteria*				Clean-Up Level
		AWQC--Drinking Water Only		ADEQ Action Level Water	Proposed MCL (1989)	
		Toxicity	*Cancer 10^{-6} Risk*			
1,1-Dichloroethylene	7		0.033	1		7
1,2-Dichloropropane				1	5	1
Chloroform	100		0.19	3	200	100
Toluene		15,000		340		340
Trichloroethylene	5		2.8	5		5
Trichlorofluoromethane				1		1
Carbon Tetrachloride	5			5		5
Methylene Chloride				1		1
Methyl Ethyl Ketone			170	170		170
Xylenes				440	10,000	440
Antimony		1.46				1.46
Arsenic	50		0.0025			50
Barium	1,000				5,000	1,000
Beryllium			0.0039		5,000	0.0039
Cadmium	10	10			5	10
Chromium	50	50			100	50
Lead	50	50			5	50
Mercury	2	10				2
Nickel		15.4				15.4
Selenium	10	10			50	10
Silver	50	50				50
Zinc		5,000				5,000

Notes: (Source: U.S. EPA, 1987, IRIS Database. Proposed MCLs - Federal Register, May 22, 1989)

ADEQ: Arizona Department of Environmental Quality
MCL: Maximum Contaminant Level
MCLG: Maximum Contaminant Level Goal
AWQC: Ambient Water Quality Criteria; adjusted for consumption of drinking water only; fish ingestion component removed (U.S. EPA, 1986).
AWQC (10^{-6}): The Ambient Water Quality Criteria resulting in a 10^{-6} excess lifetime cancer risk (U.S. EPA, 1986)
SDWA: Safe Drinking Water Act, 40 CFR 141, November 15, 1985

Remediation Activity	Dates Implemented	Detailed Description	References
Microcosm Study	October 2004	**Objectives:** Evaluate biological treatment of volatile organic compounds (VOCs) and perchlorate via the addition of an organic carbon reagent using microcosms prepared with site soil and groundwater. **Investigation:** Serum bottle microcosms containing site soil and groundwater were prepared to represent four study groups: 1. Abiotic controls 2. Un-amended biological controls 3. Low-dose corn syrup treatment 4. High-dose corn syrup treatment Per the Work Plan, perchlorate and trichloroethylene (TCE) were added to the groundwater sample to reach planned concentrations of 150 micrograms per liter (µg/L) and 6,000 µg/L, respectively. Headspace samples were collected at six weeks and analyzed for TCE daughter products dichloroethene (DCE) and vinyl chloride (VC). **Results:** Neither DCE nor VC was detected in the microcosms. **Conclusions:** Minimal TCE degradation had occurred. This was consistent with aquifer characteristics (aerobic and high level of sulfates).	Arcadis, 01/31/2005. Technical Memorandum—Progress of IRZ Treatability Studies, PGA-North Superfund Site, Goodyear, Arizona.
Nano-scale ZVI Column Study	December 2004	**Objectives:** Evaluate chemical reduction of VOCs and perchlorate using nano-scale Zero Valent Iron (nZVI). **Investigation:** Site soils were homogenized, loaded into four up-flow columns, and treated with four conditions of Polyflon PolyMetallix nZVI media: 1. 0.5% by weight nZVI 2. 1% by weight nZVI 3. 2% by weight nZVI 4. 0.5% by weight nZVI and trace palladium catalyst Groundwater from the site (amended to TCE and perchlorate concentrations of 6,000 µg/L and 150 µg/L) was pumped through the columns at 0.13 milliliters per minute. Effluent water was collected at 5, 10, and 15 pore volumes and analyzed for VOCs and perchlorate. **Results:** Bench-testing was still underway at the time of this memorandum. Results so far: ▪ Column lengths were approximately 8.5 inches. ▪ Sampling at 5, 10, and 15 pore volumes occurred at approximately 3.5, 7, and 10.5 days. ▪ Influent TCE concentration was 5,990 µg/L. ▪ Effluent TCE concentration ranges for the columns were: - 5 pore volumes: 459 to 930 µg/L - 10 pore volumes: 347 µg/L to 526 µg/L - 15 pore volumes: 463 to 528 µg/L ▪ No noticeable reductions in perchlorate. **Conclusions:** ▪ nZVI treatment resulted in rapid chemical reduction of TCE. ▪ TCE reduction was similar for all nZVI loading levels. ▪ The addition of palladium catalyst did not alter treatment kinetics or overall TCE reduction. ▪ TCE reduction of up to 83% was likely limited by residence time in the columns.	Arcadis, 01/31/2005. Technical Memorandum—Progress of IRZ Treatability Studies, PGA-North Superfund Site, Goodyear, Arizona.

Remediation Activity	Dates Implemented	Detailed Description	References
Phase I Field Study - nZVI Field Pilot Test	September 2005 – January 2006	**Objectives:** ▪ Inject 1,000 lbs nZVI **Investigation:** Two injection wells (IRZ-IW-1, IRZ-IW-2) and four monitoring wells (IRZ-MW-A, IRZ-MW-B, IRZ-MW-C, IRZ-MW-D). Injection wells screened 110-120 feet below ground surface (ft bgs); monitoring wells screened 115-130 ft bgs. Injection wells 4-inch polyvinyl chloride (PVC) casing and 0.03-inch slot stainless steel wire-wrapped well screen. Baseline sampling to determine depths of highest VOC concentrations: multiple passive diffusion bags per monitoring well. Tracer injection test to quantify radius of influence, groundwater flow velocity, dilution effects, connectivity between monitoring wells and injection zone. nZVI injection over 3 days followed by groundwater sampling. **Results:** ▪ Depths of highest VOC concentrations: 110 ft bgs in MW-A, MW-B, MW-D; 120 ft bgs in MW-C. ▪ Tracer test: - 600 gal (15 lbs sodium bromide (NaBr); 1 pint Fluorescent FLT Green/Yellow Dye; water) injected at IRZ-IW-2 - 31 pounds per square inch (psi) needed to achieve 10 gallons per minute (gpm) flowrate - 0.07 effective porosity - 10-foot radius of influence for injection of 1,600-gallon solution - 52-58% dilution at injection well; 20-40% dilution at monitor well ▪ nZVI injection: - 46 lbs of the planned 1,000 lbs of nZVI were injected. - IRZ-IW-1, 84 gallons injected (18.75 lb nZVI, 1.61 lbs NaBr), Day 1. o Solution concentrations: 30 grams per liter (g/L) nZVI, 2.6 g/L NaBr tracer o 0-2 minutes: 20 gpm injection rate, injection zone pressure increased to 10 psi o 2-29 minutes: 2.3 gpm; increase to 55 psi o 29-31 minutes: 1.3 gpm; increase to 100 psi - IRZ-IW-2, 140 gallons injected (27.34 lbs nZVI, 3 lbs NaBr), Days 2-3. o Solution concentrations: 26 g/L nZVI, 2.6 g/L NaBr tracer o Day 2: 70 minutes: 0.2 gpm, 24 psi o Day 3: well was brushed and bailed to remove particles from well screen; injection resumed, but flow rate remained low - Groundwater results 14 days post injection. o Field parameters: large oxidation reduction potential (ORP) reduction, pH 9 in injection wells o TCE: IW-01 1400 milligrams per liter (mg/L) pre-injection to 770 mg/L; IW-02 700 mg/L pre-injection to 960 mg/L; MW-C 8,100 mg/L pre-injection to 9,400 mg/L o Perchlorate (adjusted for dilution): MW-C 48.6 mg/L pre-injection to 25.2 mg/L **Summary:** ▪ nZVI injection not successful due to clogging of injection wells caused by agglomeration of nZVI into large sized ZVI particles; only a small portion of planned nZVI was delivered to subsurface. ▪ TCE concentrations decreased within injection wells and monitor well MW-C. ▪ Perchlorate concentration decreased in monitor well MW-C.	Arcadis, 01/30/2007. Revised Nano-Scale Zero Valent Iron (NZVI) Kinetic and Phase II Field Testing Work Plan, Phoenix-Goodyear Airport North Superfund Site, Goodyear, Arizona. Arcadis, 02/28/2006. Draft Technical Memorandum for the Nano-Scale Zero Valent Iron (ZVI) Field Pilot Test - Phoenix-Goodyear Airport - North Superfund Site, Goodyear, AZ.

Remediation Activity	Dates Implemented	Detailed Description	References
nZVI Particle Size Distribution Testing	April 2006	**Objective:** Determine if treated PolyMetallix nZVI particles are small enough to be injected. **Investigation:** Four samples of nZVI were prepared and submitted for particle size distribution (PSD): 1. nZVI treated with dispersing agent (sodium hexametaphosphate) 2. nZVI treated with a colloid mill after manufacture 3. nZVI treated with both the dispersing agent and colloid mill 4. Untreated nZVI (sample had been in storage at the Site for 4 months) **Results:** ▪ 50-100 nanometer particle size range for samples 1, 2, and 3 ▪ 125-300 nanometer particle size range for sample 4 **Conclusions:** All samples were small enough to move through the injection well screen, sand pack, and formation materials. Freshly manufactured nZVI particle sizes were smaller than older nZVI.	Arcadis, 07/05/2006. Response to Agency Review of Response to Comments Regarding the Draft Technical Memorandum for the Nano-Scale Zero Valent Iron (ZVI) Field Pilot Test - Phoenix-Goodyear Airport - North Superfund Site, Goodyear, Arizona.
Polymetallix nZVI Column Testing	June 2006	**Objective:** Assess nZVI mobility through sand column after select chemical and physical particle modifications. **Investigation:** 12 sand column tests incorporated four combinations of nZVI treatment and three nZVI loading levels. Four treatments: 1. nZVI and water 2. nZVI, water, and suspending agent (sodium hexametaphosphate) 3. nZVI and water processed through a colloid mill 4. nZVI water, and suspending agent processed through a colloid mill Three nZVI loading levels for each treatment: 5, 25, and 50 g/L. **Results:** ▪ Increasing nZVI concentration did not correspond directly to increased travel time or to decreased hydraulic conductivity. For 25 g/L nZVI loading, three of four treatments had highest hydraulic conductivity; all four treatments had fastest total run time. ▪ Solutions with dispersion agent had higher final conductivity and faster run times than solutions with only nZVI and water. ▪ Colloid milling – 5 g/L column became clogged; run times in 25 and 50 g/L columns were similar to “no treatment”. ▪ Dispersion agent and milling columns – 5 and 50 g/L column results were similar to dispersion-only treatment; 25 g/L column had higher permeability and shorter run time than dispersion-only column. ▪ nZVI oxidated overnight during the two day test. **Conclusions:** ▪ Use of sodium hexametaphosphate as dispersing agent appears to control agglomeration. ▪ No benefit observed with processing nZVI through a colloid mill.	Arcadis, 07/05/2006. Response to Agency Review of Response to Comments Regarding the Draft Technical Memorandum for the Nano-Scale Zero Valent Iron (ZVI) Field Pilot Test - Phoenix-Goodyear Airport - North Superfund Site, Goodyear, Arizona.

Remediation Activity	Dates Implemented	Detailed Description	References
Phase II Field Study - nZVI Field Pilot Test	April – December 2008	**Objectives:** ▪ Further evaluation of nZVI technology to treat TCE and perchlorate in the saturated zone at the Site. ▪ Determination and verification of the nZVI injection radius of influence. ▪ Evaluation on mobility of nZVI within the pilot test area and lifespan (longevity) of the nZVI reactive zone. ▪ Quantification of percent reduction of targeted VOCs in the dissolved phase within the pilot test area. ▪ Evaluation of whether rebound of sorbed compounds occurs in the treated water. **Investigation:** ▪ Pre-injection falling head tests and clean water injection test to investigate hydraulic connection between injection well IRZ-MW-05 and the aquifer and to estimate the proximal hydraulic conductivity of the Subunit A aquifer. ▪ Baseline sampling of the injection well and four observation wells for VOCs, major cations and anions, dissolved gases, alkalinity, total organic carbon, injector tracer compound (bromide), and standard field parameters. ▪ nZVI injection from June 4 through 6, 2008. ▪ nZVI injection solution: 6,000 gallons of water were purged of oxygen by bubbling nitrogen gas; 2,000 mg/L approximate concentration of bromide tracer; 10% approximate concentration of dispersing agent, SHMP, on a dry weight basis of nZVI. ▪ Post-injection sampling of injection and observation wells. ▪ Post-injection falling head slug tests. ▪ Injection well performance evaluation. **Results:** ▪ Three batches of nZVI solution injected over 27.6 hours at average flow rate of 1.7 gallons/minute. Approximately 50 pounds of nZVI were injected. 2,751 gallons of nZVI solution injected; 2.1 g/L average nZVI concentration; 2,175 mg/L average bromide tracer concentration. ▪ After the first injection, bromide tracer arrived between 2-5 days 5 feet downgradient of the injection well; and between 5-8 days 14 feet downgradient of the injection well. ▪ TCE, bromide, and hydrogen: - Injection well TCE concentrations decreased from 2,850 µg/L to as low as 11 µg/L (22 days post-injection) and to 89 µg/L (22 weeks post-injection). Bromide tracer concentration at 22 weeks was 588 times greater than background concentrations. Dissolved hydrogen peaked after 8 days and remained elevated relative to background after 22 weeks. - 5-foot downgradient observation well: TCE decreased from 11,000 µg/L to 1,400 µg/L (15 days) and 6,200 µg/L (22 weeks). Bromide concentrations peaked at 15 days post-injection and remained stable at 22 weeks. Dissolved hydrogen concentrations peaked at 15 days post-injection and remained stable from 22 days to 22 weeks post-injection. - 10-foot downgradient observation well: TCE decreased from 7,100 µg/L to 310 µg/L (22 days), rebounded to 4,500 µg/L (17 weeks), and decreased to 540 µg/L (22 weeks). Bromide concentrations peaked at 24 times the background concentration 17 weeks post-injection and returned to pre-injection concentrations at 22 weeks. Dissolved hydrogen concentrations peaked at 22 weeks and were one order of magnitude lower than in the injection well. - 14-foot downgradient observation well: TCE decreased from 11,000 µg/L to 2,500 µg/L (15 days), rebounded to 10,000 µg/L (week 9 through week 22). Bromide concentrations peaked at 120 times the background concentration 22 days post-injection and remained at trace levels after 22 weeks. Dissolved hydrogen concentrations peaked at 15 days and remained stable through week 22. Peak dissolved hydrogen concentrations were an order of magnitude lower than in injection well. ▪ Field parameters trends observed at injection well (dissolved oxygen and ORP decreased). Short-lived changes in pH, DO, and ORP at nearest observation well; no changes in other observation wells. ▪ Falling head slug tests showed decreased hydraulic conductivity at injection well. Pre-injection 5 to 11 feet/day versus 0.15 to 0.18 feet/day post-injection.	Arcadis, 01/27/2009. Final Technical Memorandum #5 – Summary of Field Implementation and Results for the Phase II Nano-Scale Zero Valent Iron Field Testing Program, Phoenix-Goodyear Airport-North Superfund Site Goodyear, Arizona.

Remediation Activity	Dates Implemented	Detailed Description	References
Phase II Field Study - nZVI Field Pilot Test (continued)		**Conclusions:** ▪ Bromide and geochemical parameter results for observation wells indicated nZVI was not transported downgradient of the injection well at significant concentrations. ▪ The delayed bromide tracer concentrations suggest mostly advective transport of bromide and dissolved hydrogen. ▪ No evidence that working strength nZVI was transported to or beyond 5 feet from the injection well. Therefore, decreases in TCE and increases in bromide and hydrogen concentrations in groundwater beyond the injection zone were likely the result of chemically altered groundwater flowing out of the injection zone past the observation wells. ▪ A portion of the nZVI mass was still reactive 22 weeks post-injection.	
Phase III Pilot Test - nZVI Field Pilot Test	February 2010	**Objectives:** ▪ Demonstrate that a pressurized injection method (jet-assisted injection) can increase the nZVI mass applied at each point and increase the ROI of injected nZVI as compared to the Phase I and II PT results; ▪ Reduce TCE and perchlorate concentrations within the PT area; ▪ Evaluate the persistence of the nZVI in the PT area; and ▪ Asses the technical and economic feasibility of using this injection technique with PolyMetallix for potential future treatment of the source area at the site. **Investigation:** ▪ Two blank-cased wells were installed for use as injection points. Two injection intervals per well: 108-113 ft bgs and 113-118 ft bgs. nZVI was mixed with anaerobic water, 21 g/L concentration, 1,400 lbs nZVI, 7421 gallons water. The nZVI solution included sodium hexametaphosphate as a dispersing agent. ▪ nZVI injections were conducted using a combination of a jet lance injection tool and pressurized packer isolation of the target injection zones. Jet-assisted injection of anaerobic water using 10,000-psi tri-plex pump alternated with injection of nZVI using a piston pump. 10,000-psi jetted water was applied to the jet lance injection tool to carve ten 1/16- to 1/8-inch diameter holes through PVC casing and grout into the formation. The injectate piston pump then pressurized the casing between the packers to 100 to 160 psi, forcing the nZVI into the jetted conduit and creating fractures as the injectate pressure exceeded the overburden pressure. The water jets were applied periodically to create high pressure turbulence to further ix the nZVI with the soil in the vicinity of the jetted conduit and clear the casing of nZVI particles. ▪ 7,421 gallons of -500 to -800 mV nZVI particles were injected. ▪ pH, ORP, temperature, and groundwater levels were monitored with downhole equipment from pre-injection through six months post-injection. Groundwater samples from monitoring wells were analyzed for VOCs, perchlorate, chlorate, chlorite, hydrogen, total and dissolved iron, manganese, chloride, sulfate, nitrate, alkalinity, sodium, phosphate, and total organic carbon. **Results and Conclusions:** ▪ Jet-assisted injection in blank cased wells proved to be an effective method to deliver large quantities of PolyMetallix nZVI particles to the subsurface. ▪ Groundwater data within the treatment area shows a decrease in TCE mass ranging between 63 percent and 96 percent one month after injection. ▪ Immediate (weeks 1 and 3) degradation effect were observed at least 29 feet from injection locations. ▪ Iron and hydrogen data shows migration of nZVI and treated groundwater as far as 45 feet downgradient, six months after injections. ▪ Injections also mobilized TCE concentrations downgradient of the injected nZVI particles for capture at downgradient extraction wells. ▪ Jet-assisted injection of PolyMetallix nZVI was determined to be an effective technology for future in situ treatment of TCE in and nearby the source area at the site.	Haley & Aldrich, 02/28/2011. Draft Phase III Nano-Scale Zero-Valent Iron Pilot Test Report, Former Unidynamics Facility, Phoenix-Goodyear Airport-North Superfund Site, Goodyear, Arizona.

TABLE 4
APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS EVALUATION
Phoenix-Goodyear Airport-North Superfund Site
Former Unidynamics Facility
Goodyear, Arizona

Requirement	Citation	Description	Preliminary Determination	Comments
CHEMICAL-SPECIFIC				
Safe Drinking Water Act (SDWA) Maximum Contaminant Levels (MCLs)[(1)]	40 Code of Federal Regulations (CFR) Part 141	The National Primary Drinking Water Regulations provide a list of MCLs established by the SDWA.	Applicable	Trichloroethylene (TCE) in groundwater will be compared to the Federal MCL of 5 micrograms per liter (µg/L). No MCL has been established for perchlorate.
Arizona Department of Health Services (ADHS) Perchlorate Health-Based Guidance Level (HBGLs)	ADHS, 2000	HBGLs are risk-based levels developed by ADHS to represent concentrations of contaminants in drinking water that are protective of public health during long-term exposure. The ADHS process for determining HBGLs accounts for exposure to children.	To Be Considered (TBC)	These values are TBC for all contaminants of concern (COCs). Arizona's HBGL for perchlorate is 14 parts per billion (ppb). See reference below.
Water Quality Criteria (WQC)[(1)]	Clean Water Act (CWA) 304	WQC are developed under the CWA and are based on the latest scientific knowledge about the effects of pollutants on aquatic life and human health. WQC is used by Arizona to protect the uses of their waters based on designated use.	TBC	Groundwater below the MDWSA has been designated as a drinking water source, therefore WQC should be considered in implementation of the remedy.
Regional Screening Levels (RSLs)	U.S. Environmental Protection Agency (USEPA) Region 9	The USEPA Region 9 has developed RSLs for soil, ambient air, and tap water. These screening levels are chemical specific concentrations for individual contaminants that may warrant further investigation or site cleanup.	TBC	There is the potential for discovery of COC mass in vadose zone soil during implementation of the Main Dry Wells Source Area (MDWSA) groundwater remedy, therefore RSLs may be used to determine additional need for site investigation or cleanup.
Site-Specific Action Levels	USEPA, 2008	A site-specific action level of 14 ppb (µg/L) based upon the Arizona HBGL has been established for perchlorate.	TBC	The site-specific action limit was decided in a Removal Action Memorandum dated 22 May 2008.
Chemical-of-Interest Listing	Department of Homeland Security, 6 CFR Part 27, including Section (§) 27.210(a)(1)(i)	Provides specific requirements for transport and storage of potassium permanganate, the primary amendment to be used in the Source Area Remediation Focused Feasibility Study (SARFFS) Alternative 6.	Applicable	If the use of potassium permanganate is selected as the remedy, all requirements must be met prior to transport and storage of the oxidant.
State of Arizona[(1)]	Arizona Administrative Code (A.A.C.) § R18-7-202	The State of Arizona has established Soil Remediation Levels (SRLs) to apply to persons legally required to conduct soil remediation under the following programs: • The Aquifer Protection Permit (APP) Program • The Hazardous Waste Management Program • The Solid Waste Management Program • The Special Waste Management Program • The Underground Storage Tank Program • The Water Quality Assurance Revolving Fund • Any other program under Arizona Revised Statutes (A.R.S.) Title 49 that regulates soil remediation.	Applicable	Non-residential SRLs are those found in A.A.C. R18-7, Appendix A. They will only apply if TCE is found in soil during subsurface investigation activities associated with implementation of the chosen remediation alternative. The SRL for TCE is 65 milligrams per kilogram (mg/kg).
LOCATION-SPECIFIC				
Resource Conservation and Recovery Act (RCRA) Solid Waste Disposal General Provisions	42 USC § 6901 et seq. A.R.S. § 49-921 et seq. 40 CFR § 141.5b	Design, construction, operation, and maintenance requirements for new facilities and expansion of old facilities to prevent damage due to earthquakes or washout of any hazardous waste by a 100-year flood.	Relevant and Appropriate	Provides requirements for the design of treatment facilities that may be constructed or modified as a result of the implementation of a MDWSA groundwater remedy.
Aquifer Water Quality Standards (AWQS)	A.R.S. § 49-223	Recharged or reinjected groundwater must meet Arizona AWQS. A discharge shall not cause a pollutant to be present in an aquifer classified as protected for drinking water in a concentration which endangers human health, or if it could impair existing or reasonably foreseeable uses of water in an aquifer.	Applicable	Subunit A groundwater does not currently meet AWQS standards and is not considered potable regardless of the presence of site COCs; however, it is still classified as a potential source of drinking water.
Aquifer Identification, Classification and Reclassification	A.R.S. § 49-224	Aquifers in the State identified and defined under this statute, and other aquifers subsequently discovered, identified, and defined, shall be classified for drinking water protected use.	Applicable	Subunit A groundwater does not currently meet AWQS standards and is not considered potable regardless of the presence of site COCs; however, it is still classified as a potential source of drinking water.

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Requirement	Citation	Description	Preliminary Determination	Comments
Arizona Historic Preservation and Archaeological Discovery	A.R.S. §§ 41-841-847, 865	This Arizona state law and guidelines require that if archaeological artifacts are found during excavation, construction or other activities, the activity must temporarily stop to allow for investigation and preservation of artifacts.	Applicable	The probability of this occurring is very low, as this property has been developed and operated on a commercial basis since 1963.
National Historic Preservation Act (NHPA)	16 U.S.C. 470	Requires action to take into account effects on properties included in or eligible for the National Register of Historic Places and to minimize harm to National Historic Landmarks.	Applicable	The probability of this occurring is very low, as this property has been developed and operated on a commercial basis since 1963.
Minimum Design Criteria	A.A.C. §§R18-5-501 and 502	Requirements for new treatment units including appropriate siting	Applicable	Applies to the design of new treatment units, if necessary for implementation of the MDWSA groundwater remedy.
ACTION-SPECIFIC				
Arizona Clean Air Act	A.R.S. § 49-402	The federal program under the Clean Air Act (CAA) 42 USC § 7410 has been delegated to the State. 41 A.R.S. § 49-402 gives jurisdiction over air quality to the county in which the property is located. State ambient air quality standards are anticipated to be relevant and appropriate to activities that would result in "major sources" of emissions.	Relevant and Appropriate	Emissions may result from the on going soil vapor extraction (SVE) system which is part of Alternative 1 (No Action), and also Alternative 2 (in-well air stripping [IWAS] + hydraulic barrier) and Alternative 7 (electric resistive heating [ERH] with steam injection + hydraulic barrier). With implementation of these alternatives, emissions treatment and monitoring requirements would be relevant and appropriate under this regulation.
Facility Discharge Permits	A.R.S. § 49-480.04 Subsection C	State air pollution control statutes require the counties to establish air quality control programs. Requires an installation permit for specified sources that may cause or contribute to air pollution or the use of which may eliminate, reduce, or control the emission of air pollutants.	Relevant and Appropriate	Air emissions from the aboveground treatment systems at the Phoenix-Goodyear Airport North (PGA-N) site are exempt from the local permitting requirement under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) § 121(e), but must meet substantive requirements for operation, performance, and monitoring of air emissions. Emissions may result from the ongoing SVE system which is part of Alternative 1, and also Alternative 2 and Alternative 7.
Maricopa County Air Quality Department (MCAQD) Air Pollution Control Rules and Regulations	Regulation II see below for rule and section numbers	Arizona air quality statutes include a program for county air pollution control. The Maricopa County Bureau of Air Pollution Control Rules and Regulations establish a permit system for new sources of air pollution, and establish criteria and requirements to limit emissions from these sources. Rule 300 et. seq. provides for the control of sources of fugitive dust and volatile organic compound (VOC) emissions.	Relevant and Appropriate	The Maricopa County program has been approved and operates in lieu of the state program. (These rules are an applicable requirement for sources of emissions, such as excavations and treatment systems.) Air emissions from the aboveground treatment systems at the Phoenix-Goodyear Airport North (PGA-N) site are exempt from the local permitting requirement under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) § 121(e), but must meet substantive requirements for operation, performance, and monitoring of air emissions.
	Rule #200: § 303 § 305	Potentially applicable permits: Non-Title 5 Permit and Dust Control Permit	Relevant and Appropriate	Rule 200 lists the types of permits and standards, and guidelines of each. If the selected remedy has the potential to emit regulated air pollutants, the Site will be required to meet the substantive portions of this rule.
	Rule #270	Includes supportive data for good maintenance and operating practices, performance test requirements, and testing criteria of stationary sources.	Relevant and Appropriate	Rule 270 establishes performance testing requirements for air emission sources. If the selected remedy includes a technology that emits regulated pollutants, it would be subject to the substantive portions of this rule.

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Requirement	Citation	Description	Preliminary Determination	Comments
	Rule #370 § 400	Describes emission tests, frequency, methods, and testing criteria for federally listed hazardous air pollutants (HAPs).	Relevant and Appropriate	Rule 370 set emissions standards (by reference) for federally listed HAPs. Pollutants that have been or are present in the source area are included in this list. Dependent on the selected remedy, there is a potential to emit these HAPs; therefore the substantive portions of this Rule would apply.
	Rule #372 § 214.1 § 304 § 305 § 306	Describes Maricopa County's program for the regulation of HAPs. A physical change in, or change in the method of operation of, a source that increases the actual emissions of any Maricopa County HAP emitted by the source by more than any de minimis amount listed in Table 2-Maricopa County HAPs De Minimis Levels, or which results in the emission of any HAP not previously emitted by the source by more than any de minimis amount listed in Table 2- Maricopa County HAPs De Minimis Levels. The de minimis HAP level for TCE is 0.10 pounds per year. Case-by-case A.R.S. 49-480.04 County Air Pollution Control-County Program for Control of Hazardous Air Pollutants determination. Permit Application will include demonstration that all available control options are met in accordance with measures cited in the Definition of Arizona Maximum Achievable Control Technology. Risk Management Analyses as described in this section may be used to demonstrate why a permit is not necessary.	Relevant and Appropriate	Rule 372 To implement/establish procedures for a Maricopa County program for the regulation of federally listed HAPs. Because TCE is a HAP, the Site is subject to the substantive portions of this Rule.
Arizona Groundwater Management Act	A.R.S. § 45-454.01, §§ 45-594, 595, 596, 600 and 605	Statute exempts new well construction and withdrawal, treatment, and reinjection of groundwater into the aquifer that occur as a part of, and on the site of, a remedial action undertaken pursuant to CERCLA from needing to obtain Arizona Department of Water Resources (ADWR) approval to extract groundwater except that a well that is exempt is subject to §§45-594, 595, 596, 600 and 605 but authorization to drill is not needed before drilling .	Relevant and Appropriate	By its own terms, this statute does not apply to CERCLA remedial actions; however the substantive requirements of these well construction and operation regulations apply for wells installed during implementation of the MDWSA groundwater remedy.
Arizona Remedial Action Criteria; rules	A.R.S. § 49-282.06(A)(2)	To the extent practicable, CERCLA response actions shall provide for the control, management, or cleanup of the hazardous substances in order to allow the maximum beneficial use of the waters of the state.	Applicable	
Hazardous Waste Determination	40 CFR § 262.11 and A.A.C. § R18-8-262	Establishes procedures to determine if wastes are hazardous wastes. Generators of waste from construction and operation of remedial actions are required to follow procedures to determine if wastes are hazardous wastes.	Applicable	Both solid and liquid wastes will be generated during drilling activities associated with all the SARFFS alternatives.
Safe Drinking Water Act	42 USC § 300f et seq. 40 CFR § 144.12 through § 144.16	Regulates the reinjection of groundwater through establishment of criteria and standards for the Underground Injection Control Program. These criteria include current and future use, yield and water quality characteristics and are applicable for determining exempt aquifers. Sets forth design construction, operation, and maintenance requirements for injection wells.	Relevant and Appropriate	Many of the MDWSA groundwater remedial alternatives require the reinjection of treated water to the aquifer and these regulations apply to design, construction, operation, and maintenance of Class V injection wells. While a UIC permit would not be required, the substantive portion of these regulations may be relevant and appropriate.
Well Permitting, Construction and Drilling Standards	A.R.S. § 45-591 through § 45-604; A.A.C. § R12-15-801,822	State statutes and rules specify requirements for the permitting, drilling, construction, and abandonment of wells, including monitoring, supply and injection wells.	Applicable	Applies to monitoring wells and groundwater withdrawal wells. These requirements are applicable for drilling and abandoning wells.

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Requirement	Citation	Description	Preliminary Determination	Comments
Protection of the Environment, Solid Wastes	40 CFR Part 261 A.A.C. § R18-8-261	Establishes procedures and numeric limits for identification and management of characteristic hazardous wastes, listed hazardous wastes, and State-only (non-RCRA) hazardous wastes.	Relevant and Appropriate	These requirements are relevant and appropriate to management of waste materials generated as a result of construction and operation of the selected response action.
Hazardous Waste Regulations Accumulation Time	40 CFR § 262.34	Regulate temporary accumulation of hazardous waste on site. Specifies procedures for accumulation of hazardous wastes on site for limited quantities of hazardous waste and for limited time periods under generator status.	Relevant and Appropriate	The substantive requirement of this section is relevant and appropriate to management of waste materials generated as a result of implementation of any of the MDWSA groundwater remedial alternatives.
Standards Applicable to Generators of Hazardous Waste	40 CFR § 262.11	Requires waste generators to determine whether wastes are hazardous wastes, and establishes procedures for such determinations. Requirement for management of waste material generated as a result of construction of the selected action or operation of any groundwater treatment units.	Relevant and Appropriate	The substantive requirement of this section is relevant and appropriate to management of waste materials generated as a result of implementation of any of the MDWSA groundwater remedial alternatives.
RCRA Hazardous Waste and Arizona Hazardous Waste Management Requirements	40 CFR § 264.18(a) and (b) A.A.C. § R18-8-264 A.R.S. § 49-901 - § 49-973	Both the USEPA and the State have comprehensive rules for the management of hazardous wastes. These requirements include container storage, secondary containment, and leak detection. Off-site disposal of hazardous waste must also meet the requirements in these sections, including those for notification, disposal methods, and transport. Keeping an operating record as described in 40 CFR § 264.73 is required for hazardous waste facilities where the waste is stored and or treated in the same place as it is generated. This substantive requirement is likely applicable to the MDWSA groundwater remedy.	Relevant and Appropriate	These requirements could be relevant and appropriate to any impacted soil excavated or groundwater withdrawn during remedy implementation that contains a hazardous waste or exhibits a hazardous waste characteristic. Historically, drilling waste has been characterized as non-hazardous and has been manifested and disposed of as such; however, the possibility exists that drilling in the MDWSA could yield soil that exceeds SRLs, and in that case, these regulations would apply to the characterization, handling, and disposal of that soil.
RCRA Standards for Owners and Operators of Hazardous Waste Treatment, Storage and Disposal Facilities	40 CFR § 264.1(j)(2-6, 10-12) A.A.C. § R18-8-264(j) (2-6, 10-12) A.R.S. § 49-921 et seq.	Requirements for waste management sites, specifically waste analysis, inspection requirements, personnel training requirements, and contingency and emergency plans.	Relevant and Appropriate	These requirements could be relevant and appropriate to any impacted soil excavated or groundwater withdrawn during remedy implementation that contains a hazardous waste or exhibits a hazardous waste characteristic.
RCRA Hazardous Waste Management	40 CFR § 264.600 - 603	Requirement for operation of treatment, storage, and disposal facilities. Miscellaneous treatment units must satisfy environmental performance standards by protection of groundwater, surface water, and air quality, and by limiting surface and subsurface migration.	Relevant and Appropriate	The substantive requirements in 40 CFR § 264 and A.A.C. § R18-8-264 may be relevant and appropriate to storage and disposal of hazardous wastes generated on site.
RCRA Hazardous Waste Management	40 CFR § 264.73 A.R.S. § 49-921 et seq.	Keeping an operating record as described in 40 CFR § 264.73 is required for hazardous waste facilities where the waste is stored and or treated in the same place as it is generated. This substantive requirement is likely applicable to the MDWSA groundwater remedy.	Relevant and Appropriate	The substantive requirements in 40 CFR § 264 and A.A.C. § R18-8-264 may be relevant and appropriate to storage and disposal of hazardous wastes generated on site.
RCRA Tank Systems	40 CFR Subpart J, except § 264.192(a) A.A.C. § R18-8-264.190 et seq, except §§ R18-264.192(a) A.R.S. § 49-921 et seq.	Requirements for tank systems used to store or treat hazardous waste, including design and installation, containment and detection of releases, operating requirements, inspections, responses to leaks or spills, and closure and post-closure. Substantive provisions apply.	Relevant and Appropriate	The substantive requirements in 40 CFR § 264 and A.A.C. § R18-8-264 may be relevant and appropriate to storage and disposal of hazardous wastes generated on site.
Hazardous Waste Transportation	49 CFR Subchapter C; 10 CFR § 71; 10 CFR § 20.2006	Transportation of contaminated media constituting a hazardous waste to an off-site treatment or disposal facility is subject to federal and state hazardous materials transportation requirements.	Applicable	These rules could apply to any impacted soil excavated or groundwater withdrawn during remedy implementation that contains a hazardous waste or exhibits a hazardous waste characteristic.

TABLE 4
APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS EVALUATION
Phoenix-Goodyear Airport-North Superfund Site
Former Unidynamics Facility
Goodyear, Arizona

Requirement	Citation	Description	Preliminary Determination	Comments
Well Location	A.A.C. § R12-15-818	Prohibits new well construction, except for monitor wells and piezometer wells, within 100 feet of any septic tank system, sewage disposal area, landfill, hazardous waste facility, storage area of hazardous material or petroleum storage areas and tanks, unless authorized in writing by the Director.	Relevant and Appropriate	The location of potential new wells, other than monitor wells and piezometer wells, relative to potential hazardous waste facilities will be considered during implementation of the chosen groundwater remedy. The substantive portions of this regulation may be relevant and appropriate.
AWQS Reinjection Standards	A.R.S. § 49-223	Recharged or reinjected groundwater must meet AWQS.	Applicable	Subunit A groundwater does not currently meet AWQS standards and is not considered potable regardless of the presence of site COCs; however, it is still classified as a potential source of drinking water.
Aquifer Water Quality Standards	A.A.C. § R18-11-405(a) and (c)	Narrative AWQS requiring that 1) a discharge not cause a pollutant to be present in an aquifer classified for a protected drinking water used in a concentration which endangers human health; and 2) a discharge not cause a pollutant to be present in an aquifer which impairs existing or reasonably foreseeable uses of water in an aquifer.	Applicable	Requires that the use of amendments, such as those included in MDWSA groundwater remedial Alternatives 3, 4, 5, and 6, not negatively impact current or future use of the water.
Aquifer Protection Permit	A.R.S. § 49-241 et. seq.	The APP program requires that, unless exempted under A.R.S. §49-250, any facility that discharges a pollutant either directly to an aquifer or to the land surface above the vadose zone in such a manner that the pollutant has a reasonable probability to reach the aquifer must obtain an APP from the Arizona Department of Environmental Quality (ADEQ) in accordance with A.A.C. R18-9-101. Individual permit requirements include use of best available control technology and showing that the discharge would not cause AWQS to be violated at a point of compliance.	Relevant and Appropriate	Facilities used in response or remedial actions undertaken pursuant to CERCLA are exempt from obtaining an APP by A.R.S. §49-250(18)(b). Remedial actions performed on-site also are exempt from obtaining State permits by CERCLA §121(e). However the substantive portions of these regulations may be relevant and appropriate.
Anti-degradation	A.R.S. § 49-243	Prohibits discharges that cause or contribute to a violation of AWQS. In aquifers where standards have been exceeded, no further degradation is permitted.	Applicable	Subunit A groundwater does not currently meet AWQS standards and is not considered potable regardless of the presence of site COCs; however, it is still classified as a potential source of drinking water.

(1) = USEPA, 1989. Record of Decision: Phoenix-Goodyear Airport Area, Arizona. AZ980695902, OU 01. September 26.

TABLE 5
PRELIMINARY REMEDIAL TECHNOLOGY SCREENING
FORMER UNIDYNAMICS FACILITY
PHOENIX-GOODYEAR AIRPORT-NORTH SUPERFUND SITE
GOODYEAR, ARIZONA

Description:
The following table summarized the groundwater remediation options considered for compounds of concern (COCs) detected above Environmental Protection Agency (EPA) Maximum Contaminant Levels (MCLs) in the Source Area at the PGA-North Site. The COCs at PGA-North are trichloroethylene (TCE) and perchlorate.
This table provides a screening of groundwater remediation technologies for application in the source area.

Remedial Action Objectives (RAO)[1]
1) Eighty percent reduction of mass concentration within treatment area.
2) Reduction of mass flux from the treatment area to prevent COC migration within Subunit A and into Subunit C.
3) Sustained concentration reduction within the treatment area after the first five years of implementation.

General Response Action Area[2]:
The Subunit A aquifer within the 1,000 µg/L TCE concentration contour.

Legend:

	Retained for FFS
	Retained for FFS, although preliminary screening indicates technology exhibits greater uncertainty or is generally considered less favorable or more costly than other options.
	Eliminated from further consideration in FF

Technology Class	Process Option	Technical Approach	Effectiveness	Implementability	Cost	Screening Outcome
Physical Mass Removal (Extraction and Aboveground Treatment)	Pump and Treat (P&T)	Install series of groundwater (GW) extraction wells, piping network, and expand the Main Treatment System (MTS)	Not suited for removal of high concentration mass in source area. Unlikely to meet RAO in reasonable timeframe due to high life cycle costs and low anticipated effectiveness for TCE and perchlorate mass removal in source area, especially considering presence of low permeability zones. It is generally accepted that in most cases, hydraulic containment will not be very effective for source remediation due to limited solubilities of most COCs and due to limitations in mass transfer to the aqueous phase (NRC, 1994, 1999; EPA, 1996; Illangesekare and Reible, 2001). This is especially true in source areas where dense non-aqueous phase liquids may be present in saturated soils.	This technology is currently being used to prevent downgradient mass flux at property boundary along Van Buren Street. The aboveground treatment train is proven for removal of dissolved target COCs from extracted groundwater. Potentially requires expansion of treated water re-injection system. See hydraulic barrier option for alternate use of this technology.	Low capital cost, but high long term monitoring cost due to length of required operation.	Eliminated due to ineffectiveness at source remediation

TABLE 5
PRELIMINARY REMEDIAL TECHNOLOGY SCREENING
FORMER UNIDYNAMICS FACILITY
PHOENIX-GOODYEAR AIRPORT-NORTH SUPERFUND SITE
GOODYEAR, ARIZONA

Technology Class	Process Option	Technical Approach	Effectiveness	Implementability	Cost	Screening Outcome
Physical Mass Removal (continued) (Belowground Treatment)	Dual Phase Extraction (hi-vac or vacuum-assisted pumping depending on conductivity)	Install a series of GW extraction wells with piping network to connect to existing Soil Vapor Extraction (SVE) wells and above ground treatment system.	Recent Pneu-log testing results show TCE in soil gas is likely from groundwater diffusion (Matrix New World, 2011). The greatest mass of TCE is located at a depth beyond the dewatering capabilities of a DPE (dual-phase extraction) system, thereby preventing achievement of RAOs.	Some existing infrastructure for implementation of this technology is present at the site in the form of the existing SVE and P&T systems.	Moderate capital cost, but high long term monitoring cost due to length of required operation.	Eliminated due to innability to achieve RAOs
	Air Sparge	Installation of vertical air sparge wells with piping network to connect to existing SVE wells and above ground treatment system.	Will not meet RAOs due to thickness and heterogeneous lithology of Subunit A. Limited radius of influence, especially in low permeability deposits, resulting in development of preferential pathways within the high permeability zones. Not effective with perchlorate.	This technology would be implementable in the source area at PGA-North and may be comblined with existing SVE system.	Moderate capital cost, but high long term monitoring cost due to length of required operation.	Eliminated due to innability to achieve RAOs
	In-well Recirculation	Installation of vertical dual-screened wells: one screen located above the water table, and close to the bottom of Subunit A. Groundwater would be removed from the bottom and recirculated to the top of the well. The water columne between the two screens would be sparged with air to volatilize target VOCs, which would then be captured and removed from the airstream via vapor-phase carbon in an aboveground treatment system.	Effectiveness will likely be impacted by heterogeneous lithology which may result in lack of hydraulic connectivity between upper and lower screen interval, preventing completion of the circulation cell.	Easily implemented in this subsurface environment. Requires installation of many piezometers to monitor completion of recirculation cells within the formation.	Moderate capital and operation cost.	Retained - may achieve RAOs
Containment	Slurry wall	Encircling the target area, thus limiting mass transfer to extended plume. Possible source control measure or use in conjunction with P&T or zero valent iron (ZVI) permeable reactive barrier (PRB) as a funnel and gate system.	Passive measure. Control mass discharge but will not reduce mass within source area. Will provide same result as currently operated extraction wells located at Van Buren Street. Unless integrated with funnel and gate concept this option will not meet RAOs.	Difficult to implement due to depth of Subunit A treatment zone.	Cost prohibitive for source area remediation due to depth of TCE impacts in saturated zone within source area.	Eliminated due to inability to achieve RAOs

TABLE 5
PRELIMINARY REMEDIAL TECHNOLOGY SCREENING
FORMER UNIDYNAMICS FACILITY
PHOENIX-GOODYEAR AIRPORT-NORTH SUPERFUND SITE
GOODYEAR, ARIZONA

Technology Class	Process Option	Technical Approach	Effectiveness	Implementability	Cost	Screening Outcome
Barrier Systems (migration control)	Zero valent iron (ZVI) PRB (abiotic reduction pathway)	Barrier to intercept plume migrating off Site.	Potentially applicable, reduced mass flux from source area, but will not reduce mass within Main Dry Wells area. Will provide same result as currently operated extraction wells located at Van Buren Street. High mineral content may influence long-term efficacy of granular ZVI. Column study would be necessary to determine longevity, thickness, and safety factor. Will not meet RAOs.	Difficult to implement due to depth of Subunit A treatment zone.	High capital cost, low performance monitoring cost.	Eliminated due to innability to achieve RAOs
	Anaerobic Bioremediation Barrier	Bio-reactive zone as a barrier to intercept plumes migrating off Site.	Potentially applicable, reduced mass flux from source area, but will not reduce mass within Main Dry Wells area. Will provide same result as currently operated extraction wells located at Van Buren Street. High sulfate concentrations in site groundwater will reqire high electron donor loading. Will not meet RAOs.	Easily implemented in this subsurface environment. However this technology is prone to high operation costs due to biofouling of wells and exterior equipment. Increased methane and arsenic concentrations may result from implementation of this technology.	Low to moderate capital and performance monitoring cost.	Eliminated due to innability to achieve RAOs
	Chemical Oxidation Barrier (see chemical oxidation for configuration)	Numerous potential configurations for this barrier. Option 1: periodic injection of oxidant with subsurface recirculation and aboveground mixing and injection stations. Option 2: subsurface injection of persulfate to create a horizontal permeable treatment zone.	Potentially applicable, reduced mass flux from source area, but will not reduce mass within Main Dry Wells area. Will provide same result as currently operated extraction wells located at Van Buren Street. Longevity, distribution, and effectiveness of barrier untested in a field setting. Will not meet RAOs.	Option 1 will require significant infrastructure and system operation and maintenance. High likelihood of inadequate distribution due to presence of low permeability deposits within Subunit A. Option 2 is being studied in Dr. Paul Johnson's lab at ASU. Implementation of this technology as a permeable treatmet barrier is currently being assessed. See discussion regarding In-Situ Chemical Oxidation (ISCO) below.	Moderate capital and performance monitoring cost.	Eliminated due to innability to achieve RAOs
	Hydraulic barrier (P&T)	Series of pumping wells to capture plume at boundary.	This technology is currently being applied at PGA-North and is successfully intercepting mass discharge from the source area. Effective for plume migration control, but not for high VOC concentrations in groundwater.	There is a potential for this option to be used in combination with other source mass removal technologies.	No cost	Eliminated as a stand-alone alternative/ Retained as a component technology

TABLE 5
PRELIMINARY REMEDIAL TECHNOLOGY SCREENING
FORMER UNIDYNAMICS FACILITY
PHOENIX-GOODYEAR AIRPORT-NORTH SUPERFUND SITE
GOODYEAR, ARIZONA

Technology Class	Process Option	Technical Approach	Effectiveness	Implementability	Cost	Screening Outcome
Chemical Reduction	Nano-scale ZVI (nZVI) (abiotic reduction pathway)	Injection of iron particles (~30-250 nanometers)	Successful bench-test and extensive pilot-testing within the source area. Injection using jet injection required for distribution as demonstrated through previous pilot tests. Pilot test results have demonstrated high mass reduction percentages, ranging between 60 - 93%. Additional optimization step required for implementation of this technology. Shown in the literature to be effective at destroying perchlorate. Pilot test results are inconclusive. By products of reduction of perchlorate have been detected in the form of chlorate and chlorite.	Extensively pilot-tested within the source area. Jet-assisted injection is highly implementable, with radius of influence possible greater than 35 feet.	High capital cost, low performance monitoring cost.	Retained - likely to achieve RAOs
	Micro-scale ZVI (abiotic reduction pathway)	Injection of iron particles (>1 micrometer)	Exhibits a longer active life than nZVI, but reactivity is not as high. Shown in the literature to be effective at destroying perchlorate.	Distribution limited by particle size and hydraulic fracturing will be required for emplacement. Increased arsenic concentrations may result from implementation of this technology.	Moderate to high capital cost, low performance monitoring cost.	Retained - likely to achieve RAOs
Chemical Oxidation	Permanganate	Injection grid with manifold and possibly recirculation. Aboveground station for securing chemicals and pumps. Also potential application using horizontal wells.	Low total organic carbon content in Subunit A soils results in primary and low oxidant demand from target compounds. Not effective with perchlorate. Not compatible with previously pilot-tested nZVI technology.	Will require soil oxidant demand (SOD) testing, bench-testing, and pilot-testing. At least two horizontal wells per treatment transect would be necessary to adequately distribute soluble amendment.	Moderate capital cost, but high long term monitoring cost due to length of required operation. High caplital cost if horizontal wells are used for injection of amendment.	Eliminated as a stand-alone alternative/ Retained as a component technology
	Persulfate	Injection grid with manifold and recirculation, Aboveground station for securing and mixing chemicals and housing pumps.	Will require SOD testing, bench-testing and pilot-testing. A stronger oxidant than permanganate but still not effective with perchlorate. Production of sulfate radicals requires activation with a base, EDTA-Fe (ethylenediaminetetracetic acid iron), ZVI, hydrogen peroxide, or heat (ITRC 2005). Additional oxidizing potential not necessary. Permanganate is easier to handle in the field and is just as effective with the oxidation of chlorinated organic compounds.	Will require SOD testing, bench-testing, and pilot-testing.	Moderate capital cost, but high long term monitoring cost due to length of required operation.	Eliminated due to increased cost and handling issues relative to permanganate.

TABLE 5
PRELIMINARY REMEDIAL TECHNOLOGY SCREENING
FORMER UNIDYNAMICS FACILITY
PHOENIX-GOODYEAR AIRPORT-NORTH SUPERFUND SITE
GOODYEAR, ARIZONA

Technology Class	Process Option	Technical Approach	Effectiveness	Implementability	Cost	Screening Outcome
Chemical Oxidation	Ozone	Grid of sparge points with injection manifold and soil vapor recovery system. Aboveground station for securing chemicals and pumps.	Will require SOD testing, bench-testing and pilot testing. Unlikely to meet clean-up goals due to the thickness and heterogeneous lithology of Subunit A. Limited radius of influence, especially in low permeability deposits, resulting in development of preferential pathways within the higher permeability zones. Likely to increase concentrations in soil gas (recontamination of vadose zone), which have been declining and are currently very low. Not effective with perchlorate.	Will require SOD testing, bench-testing, and pilot-testing. This technology would be implementable in the source area at PGA-North and may be comblined with existing SVE system.	Moderate capital cost, but high long term monitoring cost due to length of required operation.	Eliminated due to difficulty meeting RAOs and potential to increase COC concentrations in soil gas.
	Advanced Oxidation (ozone + hydrogen peroxide)	Grid of sparge points with injection manifold and soil vapor recovery system. Aboveground station for securing chemicals and pumps.	Unlikely to meet clean-up goals due to the thickness and heterogeneous lithology of Subunit A. Limited radius of influence, especially in low permeability deposits, resulting in development of preferential pathways within the higher permeability zones. Likely to increase concentrations in soil gas (recontamination of vadose zone), which have been declining are currently very low. Not effective with perchlorate.	Will require SOD testing, bench-testing, and pilot-testing. This technology would be implementable in the source area at PGA-North and may be comblined with existing SVE system.	Moderate capital cost, but high long term monitoring cost due to length of required operation.	Eliminated due to difficulty meeting RAOs and potential to increase COC concentrations in soil gas.

TABLE 5
PRELIMINARY REMEDIAL TECHNOLOGY SCREENING
FORMER UNIDYNAMICS FACILITY
PHOENIX-GOODYEAR AIRPORT-NORTH SUPERFUND SITE
GOODYEAR, ARIZONA

Technology Class	Process Option	Technical Approach	Effectiveness	Implementability	Cost	Screening Outcome
Bioremediation	Anaerobic Reductive Dechlorination (ARD)	Passive (Injection Grid) Active (Recirculation)	Applicable and effective with TCE, cis-1,2-DCE and vinyl chloride. High likelihood of success in removing TCE mass, but will require a longer treatment time that other technologiessuch as ISCO or Electrical Resistivity Heating (ERH). Treatability study was conducted using two concentrations of corn syrup in 2005. Results of the study showed that bioaugmentation may be necessary to stimulate reductive dechlorination. This technology has been shown to be effective in degrading perchlorate.	This technology would be implementable in the source area at PGA-North and may be comblined with existing SVE system. Increased methane and arsenic concentrations may result from implementation of this technology.	Moderate capital and performance monitoring cost.	Retained - likely to achieve RAOs
In Situ Thermal Remediation	Electrical Resistivity Heating / Steam Injection (ERH)	Installation of electrical elements and stainless-steel vapor recovery system	Very effective for TCE and perchlorate in source zone (NAVFAC, 2007). However, hydraulic conductivity gradients across the site and potential interference from previously injected nZVI may disrupt thermal distribution and will require further evaluation and design consideration. This technology preferentially heats silt/clay dominant deposits and groundwater flow may limit its effectiveness.	Will require pilot-testing. Few ERH applications have been completed at this depth or this large an area.	Very High. Technology is very expensive and is energy intensive.	Retained - likely to achieve RAOs

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[1] As agreed upon by Crane Co., the EPA, and other stakeholders on 15 September 2011.
[2] This area was selected for FS remedial alternative comparative analysis only, the actual treatment area will be determined during implementation of final remediation alternative.

TABLE 6
DETAILED COMPARATIVE ANALYSIS
FEASIBILITY SCREENING RESULTS
PHOENIX-GOODYEAR AIRPORT-NORTH SUPERFUND SITE
GOODYEAR, ARIZONA

Evaluation Criteria	Alternative 1 No Action	Alternative 2 In-Well Air Stripping + Hydraulic Barrier	Alternative 3 ARD + Hydraulic Barrier	Alternative 4 nZVI + ZVI + ARD + Hydraulic Barrier	Alternative 5 ZVI + ARD + Hydraulic Barrier	Alternative 6 ISCO (Permanganate) + Hydraulic Barrier	Alternative 7 ERH + Steam + Hydraulic Control
Protection of Human Health and the Environment	**LOW-MODERATE** Not protective of the environment. There is no change in human health impacts if no treatment of the Main Dry Wells Source Area (MDWSA) is implemented. There are currently no complete human exposure pathways for contaminants of concern (COCs) located on the former Unidynamics property.	**LOW-MODERATE** Protective of human health, however may not be protective of the environment since heterogeneity of a lithologic layers may limit recirculation pathway. Potential for spreading of contaminants.	**MODERATE** Protective of human health and the environment over the long-term. May result in temporary increases in vinyl chloride (VC) concentrations, although recent changes in understanding place the toxicity of trichloroethene (TCE) equivalent to that of VC. Is protective, but has risk of generating vinyl chloride that may create a vapor intrusion issue. Dissolution of iron hydroxides under anaerobic and reducing conditions may result in temporary release of arsenic. Fermentation and sulfate reduction processes may also release hydrogen sulfide and methane, respectively.	**HIGH** Immediately more protective of human health and the environment. May result in temporary increases in VC concentrations, although recent changes in understanding place the toxicity of TCE equivalent to that of VC. Similar to the anaerobic reductive dechlorination (ARD) alone, but with a lower likelihood of generating VC. Dissolution of iron hydroxides under anaerobic and reducing conditions may result in temporary release of arsenic. Fermentation and sulfate reduction processes may also release hydrogen sulfide and methane, respectively.	**HIGH** Immediately more protective of human health and the environment. May result in temporary increases in VC concentrations, although recent changes in understanding place the toxicity of TCE equivalent to that of VC. Dissolution of iron hydroxides under anaerobic and reducing conditions may result in temporary release of arsenic. Fermentation and sulfate reduction processes may also release hydrogen sulfide and methane, respectively.	**HIGH** Protective provided pilot test results are positive. The use of an oxidant may locally mobilize chromium, uranium, and selenium. This technology may result in temporary production of chromium(VI) at concentrations higher than the maximum contaminant level (MCL).	**HIGH** Protective provided pilot test results are positive. Thermal remediation systems incorporate process controls during implementation that monitor the treatment system(s) and emissions to assure that the risks to construction works, on-site workers, off-site residents, and the environment are maintained at or below allowable levels.
Compliance with Applicable or Relevant and Appropriate Requirements (ARARs)	**LOW** Complies with ARARs; however, remedial action objectives (RAOs) would not be met.	**HIGH** Complies with ARARs; however, does not treat perchlorate.	**HIGH** Complies with ARARs.	**HIGH** Complies with ARARs.	**HIGH** Complies with ARARs.	**HIGH** Complies with ARARs; however, does not treat perchlorate.	**HIGH** Complies with ARARs.
Long-Term Effectiveness and Permanence	**LOW** Not effective in the long term due to presence of high concentrations and lack of intrinsic degradation.	**LOW-MODERATE** Effective, however degree of effectiveness and permanence would be determined after implementation of a pilot test. Will likely be limited by the solubility of TCE and the varied lithology. Presence of less permeable layers will likely result in incomplete recirculation of groundwater between upper and lower screens. Formation of preferential flow paths are likely given the site lithology potentially preventing access to low permeability portions of the aquifer.	**MODERATE** More effective over the long term than the short term. Degree of effectiveness and permanence would be better understood after implementation of a treatability and pilot study. Once reductive dechlorination processes are established, the reduction in mass is permanent. Multiple injections of electron donor will likely be necessary due to the very low organic carbon content of native soils at the site.	**MODERATE-HIGH** Successful bench and pilot testing has been completed for nano-scale zero valent iron (nZVI) injections. nZVI is very reactive for a short period of time (likely less than 3 months) at which time ARD would be the primary treatment technology. An ARD treatability study is needed to determine design factors critical to the degree of long-term effectiveness and permanence of this alternative.	**MODERATE-HIGH** Effective, however degree of effectiveness and permanence would be determined after implementation of a pilot program. Distribution of micro-scale ZVI is limited by particle size, however micro-scale ZVI is persistent in the environment allowing for effective long-term treatment.	**MODERATE** Effective, however degree of effectiveness and permanence would be determined after implementation of a pilot program. Direct contact between the permanganate and TCE molecules are necessary for this technology to be successful. Residual TCE contained in lower permeability zones are likely to remain untreated. Multiple injections of oxidant will likely be necessary due to the high VOC mass concentrations.	**HIGH** Effective, however degree of effectiveness and permanence would be determined after implementation of a pilot program. A portion of the source zone will not be treated using electric resistive heating (ERH) and/or Steam Injection. The overall removal efficiency of thermal applications is typically greater than 90% if the entire source area is treated.

Evaluation Criteria	Alternative 1 No Action	Alternative 2 In-Well Air Stripping + Hydraulic Barrier	Alternative 3 ARD + Hydraulic Barrier	Alternative 4 nZVI + ZVI + ARD + Hydraulic Barrier	Alternative 5 ZVI + ARD + Hydraulic Barrier	Alternative 6 ISCO (Permanganate) + Hydraulic Barrier	Alternative 7 ERH + Steam + Hydraulic Control
Long-Term Effectiveness and Permanence (continued)		This technology has a low-moderate likelihood of attaining the total mass removal goal due to geologic heterogeneities.	The ability to completely distribute the amendments, particularly the inoculum of DHC is not certain, given the heterogeneity. The alternative will results in long-term aesthetic impact to the aquifer (anaerobic water). Potential for biodegradation of perchlorate. Anaerobic water will migrate and at some distance from the treatment area eventually will be mixed with aerobic water downgradient of the injection zone. This mixing process will result in re-oxygenation of the water and will control the migration of anaerobic water, arsenic, iron, and manganese out of the source area. The mixing will be enhanced by the presence of extraction wells from the hydraulic barrier.	The use of macro-scale ZVI in addition to nZVI increases the longevity of the chemical reduction degradation process while maintaining the destructive strength of the smaller particle size ZVI. The alternative has slight advantage over ARD alone in that the nZVI and mZVI will assist in developing conditions for reductive dechlorination and will contribute mass reduction. The alternative will result in long-term aesthetic impact to the aquifer (anaerobic water). Potential for biodegradation of perchlorate. Anaerobic water will migrate and at some distance from the treatment area eventually will be mixed with aerobic water downgradient of the injection zone. This mixing process will result in re-oxygenation of the water and will control the migration of anaerobic water, arsenic, iron, and manganese out of the source area. The mixing will be enhanced by the presence of extraction wells from the hydraulic barrier.	The conceptual design for this alternative relies on mass flux to complete treatment of dissolved phase TCE and perchlorate in groundwater together with biodegradation over the long term. The injection design does not rely on injection facilitated contact which may result in less contact under the varied stratigraphic condition present at the site. Potential for biodegradation of perchlorate. Similar to Alternative 4, but granular or ZVI from iron filings has a longer active life than nZVI. Has higher likelihood of success than Alts 2-4. The alternative will result in long-term aesthetic impact to the aquifer (anaerobic water). Anaerobic water will migrate and at some distance from the treatment area eventually will be mixed with aerobic water downgradient of the injection zone. This mixing process will result in re-oxygenation of the water and will control the migration of anaerobic water, arsenic, iron, and manganese out of the source area. The mixing will be enhanced by the presence of extraction wells from the hydraulic barrier.	Due to low oxidant demand typical of aquifers in Arizona persistence of permanganate in Subunit A is very high, leading to concerns regarding longevity and need for strict migration control. Not effective with perchlorate. Rebound is typically high with implementation of this technology due to lack of adequate distribution. Channeling of injectate in preferential flowpath is common in implementation of this technology in desert aquifers, leading to inadequate distribution. Persistence of permanganate allows diffusion into low-permeability materials, but this will have a considerable time factor. Has possibility to persist if dosing is too large. Multiple injections may be needed to fully treat all target areas. Has moderate to high likelihood of success. The alternative will result in long-term aesthetic impact to the aquifer (colored water). No potential for oxidation of perchlorate. Potential for oxidized hexavalent chromium to stay in solution due to naturally oxidized state of Subunit A.	The removal of this mass is expected to occur over a relatively short period of time (approximately six to nine months of operation) with a two to three month installation period. Has highest likelihood of success.

Evaluation Criteria	Alternative 1 No Action	Alternative 2 In-Well Air Stripping + Hydraulic Barrier	Alternative 3 ARD + Hydraulic Barrier	Alternative 4 nZVI + ZVI + ARD + Hydraulic Barrier	Alternative 5 ZVI + ARD + Hydraulic Barrier	Alternative 6 ISCO (Permanganate) + Hydraulic Barrier	Alternative 7 ERH + Steam + Hydraulic Control
Long-Term Effectiveness and Permanence (continued)			Anaerobic water could migrate with groundwater and be extracted and processed through the ex-situ treatment system. If it reaches the extraction wells, it may cause fouling of the extraction wells and air-stripping unit. The aboveground treatment units may need to be periodically sanitized to remove biological growth and precipitates, and may eventually result in either adding a treatment unit to deliberately oxygenate the water to remove the high oxygen demand and precipitates. This would result in additional replacement costs for extraction wells and system treatment components. Addition of a recirculation line for reinjection of impacted water will remove potential impacts to the Main Treatment System (MTS). This will add additional costs for implementation due to the installation of injection wells and extraction wells.	Anaerobic water could migrate with groundwater and be extracted and processed through the ex-situ treatment system. If it reaches the extraction wells it may cause fouling of the extraction wells and air-stripping unit. The aboveground treatment units may need to be periodically sanitized to remove biological growth and precipitates, and may eventually result in either adding a treatment unit to deliberately oxygenate the water to remove the high oxygen demand and precipitates. This would result in high replacement costs for extraction wells and system treatment components. Addition of a recirculation line for reinjection of impacted water will remove potential impacts to the MTS.	Anaerobic water could migrate with groundwater and be extracted and processed through the ex-situ treatment system. If it reaches the extraction wells it may cause fouling of the extraction wells and air-stripping unit. The aboveground treatment units may need to be periodically sanitized to remove biological growth and precipitates, and may eventually result in either adding a treatment unit to deliberately oxygenate the water to remove the high oxygen demand and precipitates. This would result in high replacement costs for extraction wells and system treatment components. Addition of a recirculation line for reinjection of impacted water will remove potential impacts to the MTS.	Permanganate could migrate with groundwater and be extracted and processed through the ex-situ treatment system. Reaction with organic carbon or minerals, mixing, and dispersion will reduce permanganate concentrations with downgradient migration. If it reaches the extraction wells it may cause fouling of the extraction wells and air-stripping unit, and may eventually result in either adding a treatment unit to neutralize the oxidized, permanganate-laden purple water and or high replacement costs for extraction wells and system treatment components. Addition of a recirculation line for reinjection of impacted water will remove potential impacts to the MTS. This will add additional costs for implementation due to the installation of injection wells and extraction wells. Furthermore, since ISCO will not treat perchlorate, the mounding associated with the recirculation system will spread perchlorate contamination and the ISCO amendment upgradient from the source area.	
Reduction of Toxicity, Mobility, or Volume	**LOW** No reduction of toxicity, mobility or volume would occur.	**LOW-MODERATE** Pilot program needed to determine the degree of mass reduction that can be achieved. Reduces toxicity by stripping TCE from groundwater, reduces mobility by extracting impacted groundwater from the aquifer. May not address high VOC concentrations present in lower permeability zones.	**MODERATE** The degree to which contaminant mass would be reduced would be determined by a new treatability study. The hydraulic barrier would be effective at preventing off-Site plume migration. Potential for biodegradation of perchlorate.	**MODERATE-HIGH** Pilot testing has demonstrated 60 – 93% reduction in contaminant mass in a limited area of the MDWSA. With full-scale implementation of this remedial alternative to the MDWSA the rebound observed during the pilot test is anticipated to be less and follow-up injection are included as part of the multi-year design. Additionally, the hydraulic barrier would	**MODERATE-HIGH** The degree to which contaminant mass would be reduced would be determined by the pilot program. The hydraulic barrier would be effective at preventing off-Site plume migration. Potential for biodegradation of perchlorate.	**MODERATE-HIGH** The degree to which contaminant mass would be reduced would be determined by the pilot program. The hydraulic barrier would be effective at preventing off-Site plume migration. This alternative would not be effective at treating perchlorate.	**HIGH** The degree to which contaminant mass would be reduced would be determined by the pilot program. It is expected that this alternative would remove and/or oxidize most of the VOCs in the treatment zone. The overall removal efficiency is estimated to be at least 90% based on similar sites.

Evaluation Criteria	Alternative 1 No Action	Alternative 2 In-Well Air Stripping + Hydraulic Barrier	Alternative 3 ARD + Hydraulic Barrier	Alternative 4 nZVI + ZVI + ARD + Hydraulic Barrier	Alternative 5 ZVI + ARD + Hydraulic Barrier	Alternative 6 ISCO (Permanganate) + Hydraulic Barrier	Alternative 7 ERH + Steam + Hydraulic Control
				prevent downgradient mass flux.			
Reduction of Toxicity, Mobility, or Volume (continued)		This technology would not be effective in treatment of perchlorate. Biological degradation of perchlorate occurs under anaerobic and reducing conditions. Has a low-moderate likelihood to remove significant amounts of mass. Has a risk to increase volume of contaminated water through vertical transfer and mixing.	Provides a permanent reduction in contaminant concentrations and partitioning of VOCs into emulsified oil reduces mobility. May increase the toxicity through temporary production of VC and local mobilization of arsenic. Injection may affect plume flow paths resulting in slight expansion of plume. Anaerobic water will migrate and will be mixed with aerobic water downgradient of the injection zone. This mixing process will result in re-oxygenation of the water and will control the migration of anaerobic water, arsenic, iron and manganese out of the source area. The mixing will be enhanced by the presence of extraction wells from the hydraulic barrier.	Potential for biodegradation of perchlorate. The alternative provides more reduction in contaminant toxicity than Alternative 2 due to the reaction with nZVI. Still has the reduction in mobility resulting from partitioning to oil, but has potential to alter flowpaths. Anaerobic water will migrate and will be mixed with aerobic water downgradient of the injection zone. This mixing process will result in re-oxygenation of the water and will control the migration of anaerobic water, arsenic, iron and manganese out of the source area. The mixing will be enhanced by the presence of extraction wells from the hydraulic barrier.	Similar to Alternative 4. Anaerobic water will migrate and will be mixed with aerobic water downgradient of the injection zone. This mixing process will result in re-oxygenation of the water and will control the migration of anaerobic water, arsenic, iron, and manganese out of the source area. The mixing will be enhanced by the presence of extraction wells from the hydraulic barrier.	There would be a reduction in contaminant toxicity. The injection may slightly increase volume of contaminant plume due to spreading, has potential to alter flowpaths and may locally mobilize chromium, uranium, and selenium. Reaction with organic carbon and minerals, mixing, and dispersion will reduce permanganate concentrations with downgradient migration. Potential for oxidized hexavalent chromium to stay in solution due to naturally oxidized state of Subunit A.	The design of the in-situ thermal heating application would include measures to reduce the potential for contaminant mobilization. During operation, the volume of water within the treatment zone will be reduced. Greatest reduction in volume and mobility. Does have some slight risk of translating contaminant outside treatment zone. Thermal does not remove perchlorate because of its high boiling point.
Short-term Effectiveness	**LOW** Not effective in the short term.	**LOW – MODERATE** In-well air stripping would be moderately effective at reducing dissolved phase mass in the short term. Not immediately effective as significant change may require a longer time frame. This technology has the potential for short circuiting and the creation of preferential pathways.	**LOW** ARD is not considered effective in the short term. The high sulfate concentrations in groundwater will require a long acclimation time for the site to reach anaerobic and reducing conditions necessary for degrader populations to grow and degrade significant mass. This technology is likely to be effective with enhancing degradation of perchlorate at similar rates to TCE. Perchlorate degradation has been strongly related to methane generation, indicating that perchlorate would likely degrade before	**HIGH** nZVI would be effective at reducing contaminant mass in the short term. This technology is likely to be effective with enhancing degradation of perchlorate at similar rates to TCE. Will still require several years to implement, but the nZVI will allow more rapid reductions in the contaminant concentrations. There is minor risk to overlying land use due to fracturing and slight risk to workers due to the high pressures used during injection. There a slight potential for short circuiting and the creation of preferential pathways.	**MODERATE-HIGH** ZVI would be moderately effective at reducing contaminant mass in the short term. This technology is likely to be effective with enhancing degradation of perchlorate at similar rates to TCE. This has similar time-frame for benefits as Alternative 4; there are slight risks to overlying land use associated with the fracturing and worker risks exist due to high pressures used, and has the potential for short circuiting and the creation of preferential pathways.	**HIGH** Permanganate would be effective at reducing readily available contaminant mass in the short term. Not effective with perchlorate. Reactions occur more quickly, but still take time to complete. Dispersion and diffusion still required to reach contaminant between some injection points. There are slight risks to overlying land use associated with the fracturing and worker risks exist due to high pressures used during the injection process, and has the potential for short-circuiting and the creation of preferential pathways.	**HIGH** Site preparation and ERH and/or Steam Injection system operation is expected to require approximately one year (including installation and demobilization). Will take several years to implement, but will achieve fastest and most complete mass removal, with the exception of perchlorate.

Evaluation Criteria	Alternative 1 No Action	Alternative 2 In-Well Air Stripping + Hydraulic Barrier	Alternative 3 ARD + Hydraulic Barrier	Alternative 4 nZVI + ZVI + ARD + Hydraulic Barrier	Alternative 5 ZVI + ARD + Hydraulic Barrier	Alternative 6 ISCO (Permanganate) + Hydraulic Barrier	Alternative 7 ERH + Steam + Hydraulic Control
			TCE.				
Short-term Effectiveness (continued)			The application will take several years to fully begin to address that contamination and has the potential for short-circuiting and the creation of preferential pathways; may result in the mobilization of arsenic.	The risk to workers can be mitigated through worker awareness training. It is a manageable risk. The depth of the high pressure injection prevents surface effects.	The risk to workers can be mitigated through worker awareness training. It is a manageable risk. The depth of the high pressure injection prevents surface effects.	The risk to workers can be mitigated through worker awareness training. It is a manageable risk. The depth of the high pressure injection prevents surface effects. The transport process represents a slight potential risk to MTS workers and downgradient residents.	
Implementability	**HIGH** This alternative is easily implementable.	**MODERATE-HIGH** Implementation requires use of well understood design and installation practices. Additionally, modification of current SVE system would be needed to treat vapors. There are no space constraints for the conveyance piping and treatment compound; however, two GCWs would be in the Goodyear Financial Center parking lot. Significant operation and maintenance effort would be required to keep these wells running, especially since fouling is likely due to high hardness of water. This requires less drilling than other alternatives, but requires more piping for ex-situ treatment.	**MODERATE** This alternative is implementable with minimal disruption to locations outside of the treatment area. Injections of electron donor would be injected over a 5-year period. Installation of twelve groundwater monitoring wells would be required to augment the existing groundwater well network. Can be implemented using well-established best practices. Distribution of electron donor may need to be enhanced through use of hydraulic fracturing to overcome variability in stratigraphy. The alternative will require a significant drilling effort.	**MODERATE-HIGH** This alternative is implementable with minimal disruption to locations outside of the treatment area. Injections would be achieved using a jet-assisted method to achieve appropriate distribution of nZVI and mZVI particles and ARD amendments as proven in the Phase III Pilot Test. Optimization of the injection delivery system is warranted and would be performed as necessary during execution of each injection phase. Injections would occur over a 5-year period. Installation of twelve groundwater monitoring wells would be required to augment the existing groundwater well network. Relative to ARD alone, this alternative has the added difficulty of managing the nZVI to avoid agglomeration and to distribute the material. Granular ZVI or iron filings are injected as slurry which creates the need for higher weight tolerance and wear on the equipment and staff.	**MODERATE-HIGH** This alternative is implementable with minimal disruption to locations outside of the treatment area. Hydraulic fracturing is likely to be required to achieve appropriate distribution of ZVI particles and ARD amendments and create the treatment zones necessary to intercept and treat TCE and perchlorate mass flux. Injections would occur over a 5-year period. Installation of twelve groundwater monitoring wells would be required to augment the existing groundwater well network. Similar to Alternative 4 but slightly easier to manage ZVI than nZVI. Granular ZVI or iron filings are injected as slurry which creates the need for higher weight tolerance and wear on the equipment and staff.	**HIGH** This alternative is implementable with minimal disruption to locations outside of the treatment area. Jet-assisted injection is likely to be required to achieve appropriate distribution of permanganate as a concentrate. Injections would occur over a 5-year period. Installation of twelve groundwater monitoring wells would be required to augment the existing groundwater well network. Easier to handle and implement as only one amendment needed. Will require filing notice with the Department of Homeland Security for storage and management of large quantities. Off-site storage will be necessary and the oxidant will need to be transported via City of Goodyear Streets to the site for injection.	**LOW-MODERATE** In-situ thermal technologies and groundwater hydraulic control systems have been installed and operated for many years by a number of contractors, although few ERH applications of this size and depth have been completed. This size and depth of this system will significantly increase the cost and complexity of the heating system. Additionally, the geology at the site has high hydraulic conductivity gradients which may affect the ability of the in-situ thermal heating to achieve boiling temperatures. The above ground surface features and infrastructure would be relatively unaffected; however, any underground utilities would need to be rerouted. For thermal treatment, capacity issues that may arise would be minimized by starting up the thermal system in phases to confirm the VOC mass removal rates can be adequately treated per the design. Requires above-ground treatment and cabling/piping significant power supply.

TABLE 6
DETAILED COMPARATIVE ANALYSIS
FEASIBILITY SCREENING RESULTS
PHOENIX-GOODYEAR AIRPORT-NORTH SUPERFUND SITE
GOODYEAR, ARIZONA

Evaluation Criteria	Alternative 1 No Action	Alternative 2 In-Well Air Stripping + Hydraulic Barrier	Alternative 3 ARD + Hydraulic Barrier	Alternative 4 nZVI + ZVI + ARD + Hydraulic Barrier	Alternative 5 ZVI + ARD + Hydraulic Barrier	Alternative 6 ISCO (Permanganate) + Hydraulic Barrier	Alternative 7 ERH + Steam + Hydraulic Control
Cost	**HIGH** No capital or O&M costs would be incurred; however, the costs and negative impacts inherent in opposition from the USEPA and the community members can be considered significant, although non-quantifiable. Not treating the Main Dry Wells Source Area will result in extended operation and maintenance costs for the pump and treat systems currently operating to control migration of the extended plume.	**MODERATE-HIGH** Total costs (-30% to +50%): $5.15MM to $10.05MM Average Capital Costs: $5.16MM NPV O&M Costs: $1.54MM over 20 years Average Closure Costs: $6.70MM	**MODERATE-HIGH** Total costs (-30% to +50%): $6.37MM to $12.43MM Average Capital Costs: $7.47MM NPV O&M Costs: $0.82MM over 8 years Average Closure Costs: $8.29MM	**LOW-MODERATE** Total costs (-30% to +50%): $8.57MM to $16.71MM Average Capital Costs: $10.32MM NPV O&M Costs: $0.82MM over 8 years Average Closure Costs: $11.14MM	**LOW-MODERATE** Total costs (-30% to +50%): $9.73MM to $18.96MM Average Capital Costs: $11.29MM NPV O&M Costs: $1.36MM over 11 years Average Closure Costs: $12.65MM	**MODERATE-HIGH** Total costs (-30% to +50%): $5.40MM to $10.55MM Average Capital Costs: $6.21MM NPV O&M Costs: $0.82MM over 8 years Average Closure Costs: $7.03MM	**LOW** Total costs (-30% to +50%): $20.07MM to $39.14MM Average Capital Costs: $10.47MM O&M Costs: $15.62MM over 1 year Average Closure Costs: $26.09MM
State and Federal Acceptance	Unknown at this time.	Unknown at this time.	Unknown at this time.	Unknown at this time.	Unknown at this time.	Unknown at this time.	Unknown at this time.
Community Acceptance	Unknown at this time.	Unknown at this time.	Unknown at this time.	Unknown at this time.	Unknown at this time.	Unknown at this time.	Unknown at this time.

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GOODYEAR
MARICOPA COUNTY, ARIZONA

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SITE LOCATION MAP

DRAWN BY: AR	DESIGNED BY: HB	APPROVED BY: HB	PROJECT NUMBER: 11-100E-01
DATE: 11-30-2011	DATE: 11-30-2011	DATE: 11-30-2011	SCALE: 1" = 2000'

FIGURE NUMBER: 1

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Legend:

- EPA MW-6A — Subunit A monitor well
- EA-03 — Subunit A extraction well
- EPA MW-1C — Subunit C monitor well
- MAU monitor well
- IRZ IW-01 — Injection well (IRZ)
- EPA MW-28M / IA-03 — Injection well (treated water)
- PSDW — Park Shadows production well
- OW-B — Observation Well
- AEIW — Avondale Elementary Irrigation well
- COG-18A — City of Goodyear supply well
- EB-01 — Subunit B extraction well
- EC-01 — Subunit C extraction well
- PI-01 — Piezometer
- Cross section across Treatment Area

500' 0 500' 1000'

SCALE: 1"=500'

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CONCEPTUAL HYDROGEOLOGIC CROSS-SECTION LOCATION MAP

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AR	CT / PC	PC / HB	11-100E-01
DATE: 11-30-2011	DATE: 11-30-2011	DATE: 11-30-2011	SCALE: 1" = 150'

FIGURE NUMBER: 2

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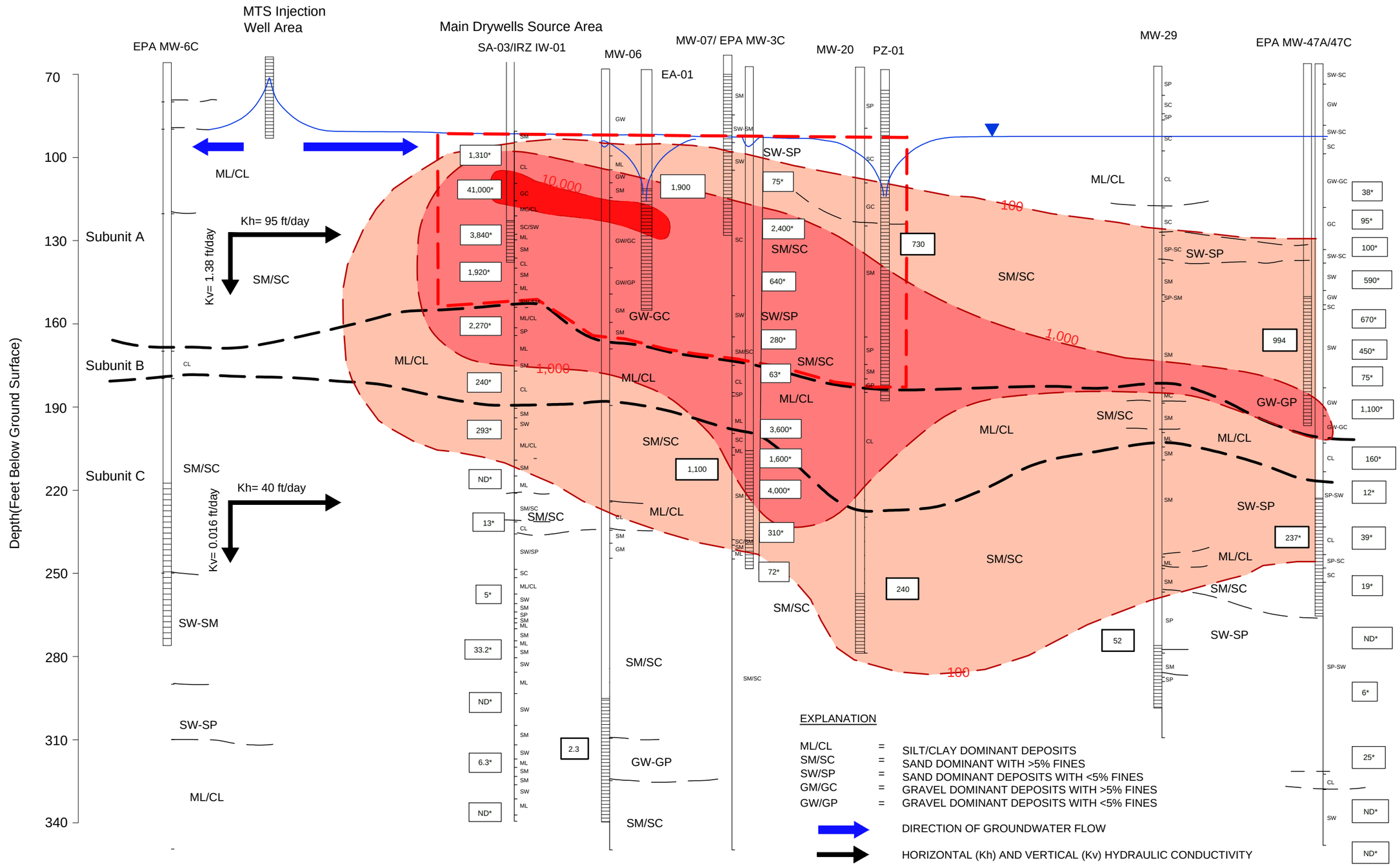

EXPLANATION

ML/CL	=	SILT/CLAY DOMINANT DEPOSITS
SM/SC	=	SAND DOMINANT WITH >5% FINES
SW/SP	=	SAND DOMINANT DEPOSITS WITH <5% FINES
GM/GC	=	GRAVEL DOMINANT DEPOSITS WITH >5% FINES
GW/GP	=	GRAVEL DOMINANT DEPOSITS WITH <5% FINES

DIRECTION OF GROUNDWATER FLOW

HORIZONTAL (Kh) AND VERTICAL (Kv) HYDRAULIC CONDUCTIVITY

2.3 — TCE RESULT (AUGUST 2011) IN ug/L (* INDICATES HYDROPUNCH)

INFERRED EXTENT OF TCE CONTAMINATION TO 100 ug/L BASED ON DEPTH SPECIFIC AND MONTHLY GROUNDWATER SAMPLING - MICROGRAMS PER LITER (ug/L)

SOURCE AREA TREATMENT BOUNDARY

NO.	DESCRIPTION	DATE:	BY:	APR:
	REVISIONS			

DRAWN BY: AR DATE: 11-30-2011
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APPROVED BY: HB DATE: 11-30-2011

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CONCEPTUAL HYDROGEOLOGIC CROSS-SECTION SHOWING TCE CONTAMINATION MIGRATION AND SOURCE TREATMENT AREA

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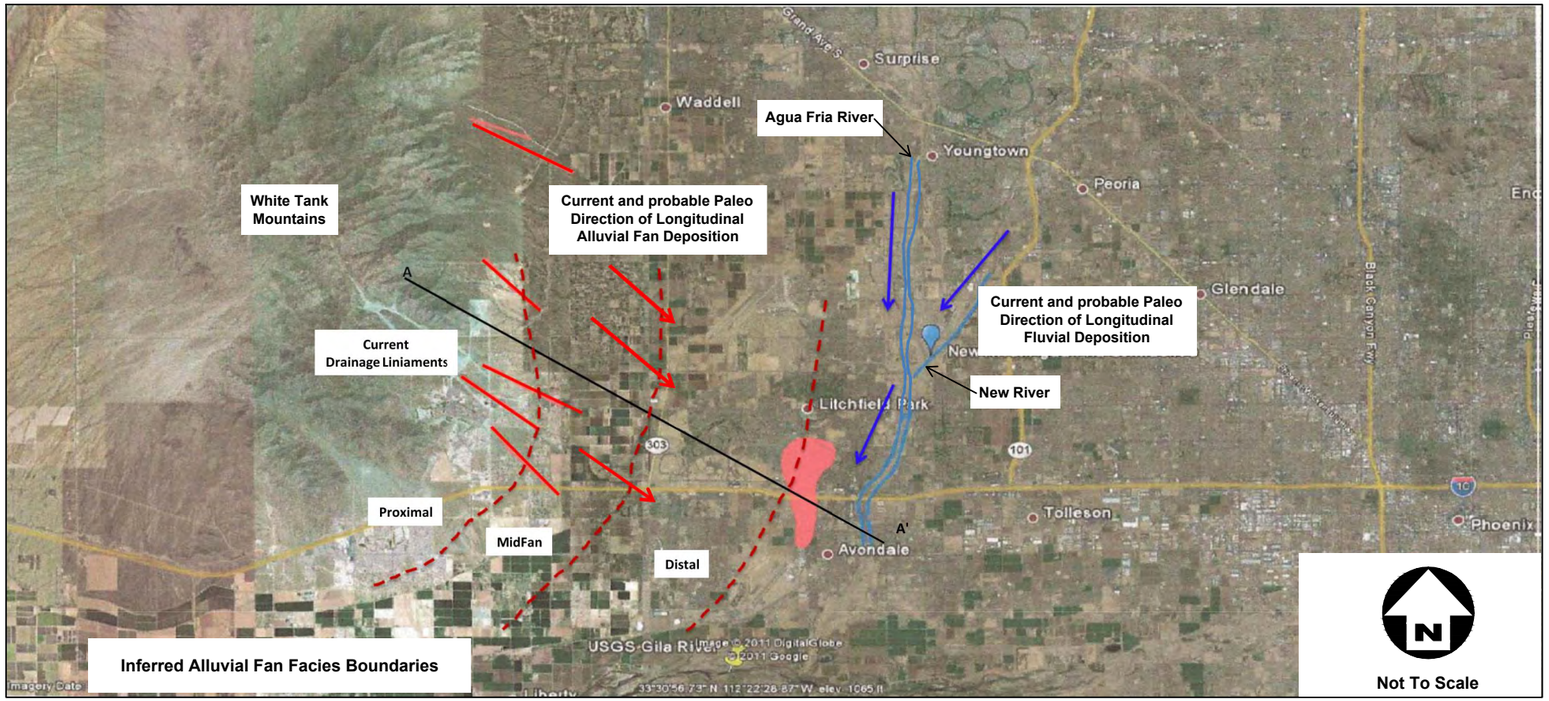
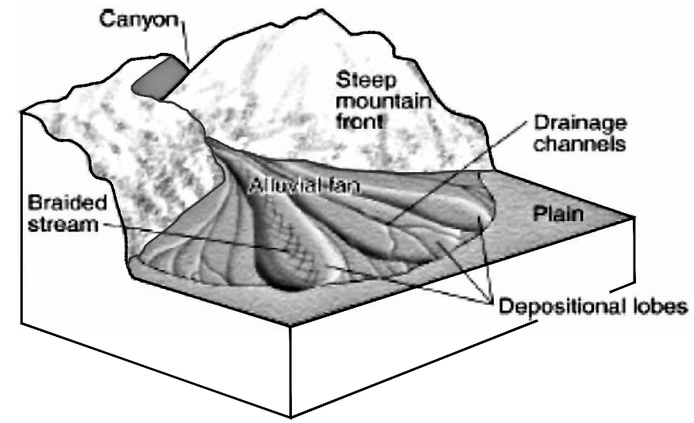
GOODYEAR, MARICOPA COUNTY, ARIZONA

PROJECT NUMBER: 11-100E

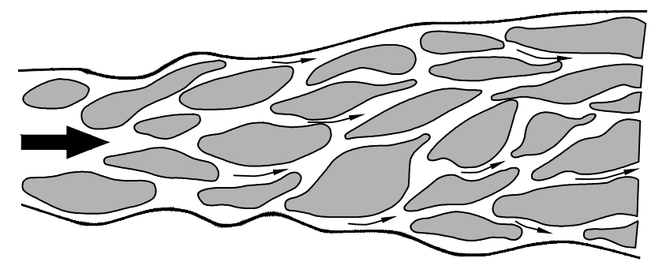
SCALE: NTS

3

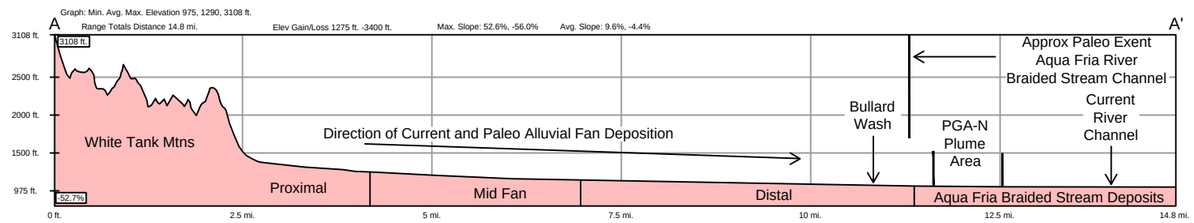




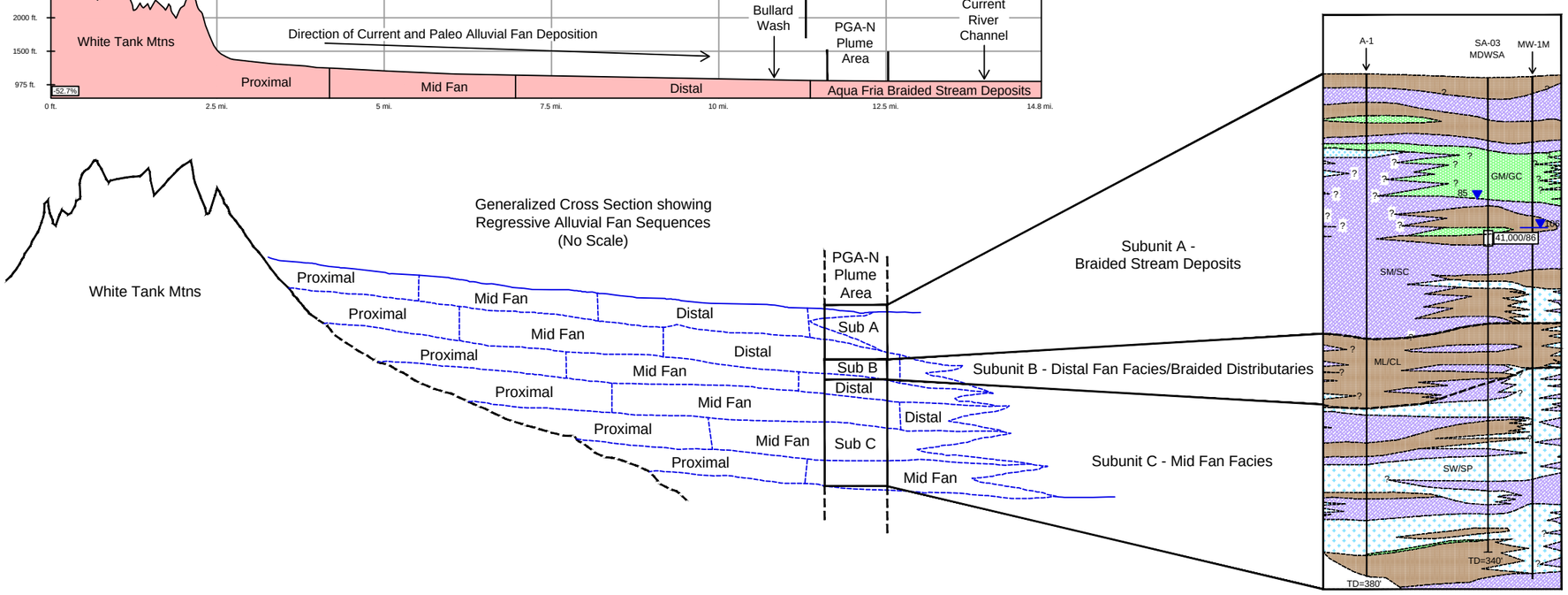
Typical Alluvail Fan Depositional Environment (Plummer and MCGeary, 1988)



Typical Braided Stream Depostional Environment (Plummer and MCGeary, 1988)



Lithologic Profile Main Drywells Source Area (Arcadis 2006)



NO.	DESCRIPTION	DATE:	BY:	APR:
	REVISIONS			

DRAWN BY: AR DATE: 11-30-2011
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APPROVED BY: HB DATE: 11-30-2011

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DEPOSITIONAL ENVIRONMENT CONCEPTUAL SITE MODEL

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GOODYEAR, MARICOPA COUNTY, ARIZONA

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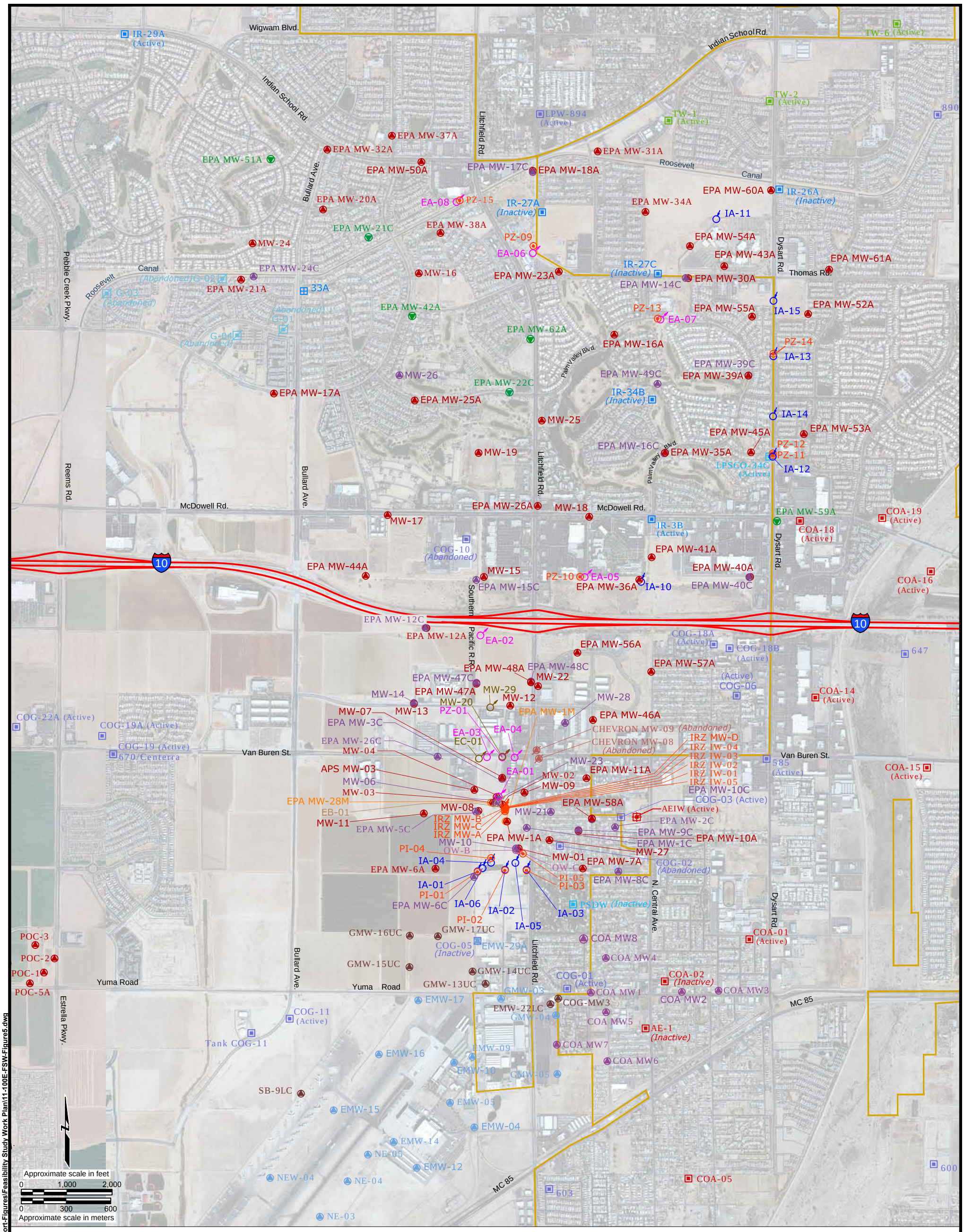
SCALE: NTS

4



Explanation

- EPA MW-62A — Proposed remaining Subunit A monitor well
- EPA MW-55A — Subunit A monitor well
- EA-07 — Subunit A extraction well
- EMW-29A — Subunit A monitor well - PGA - South site
- COA MW1 — Subunit A monitor well Western Ave. Plume site
- PZ-13 — Piezometer
- IA-13 — Injection well (treated water)
- IRZ IW-01 — Injection well (IRZ)
- 33A — UPI treatment system well
- IR-3B — Irrigation well
- COG-18A — City of Goodyear supply well
- LPSCO-34C — Litchfield Park Services Co. production well
- PSDW — Park Shadows production well
- LPW-894 — City of Litchfield Park supply well
- EPA MW-22C — Proposed remaining Subunit C monitor well
- EPA MW-48C — Subunit C monitor well
- EPA MW-28M — MAU monitor well
- EB-01 — Subunit B extraction well
- EC-01 — Subunit C extraction well
- COG-MW3 — Subunit C monitor well - PGA - South site
- OW-B — Observation well
- COA-02 — City of Avondale supply well
- AEIW — Avondale Elementary irrigation well
- TW-1 — Algonquin water services well

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WELL LOCATION MAP
SUBUNITS A, B, C, AND MAU

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FIGURE NUMBER: 5

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Legend:

EPA MW-55A	Subunit A monitor well
EA-07	Subunit A extraction well
EPA MW-48C	Subunit C monitor well
EPA MW-28M	MAU monitor well
IRZ IW-01	Injection well (IRZ)

150' 0 150' 300'
SCALE: 1"=150'

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GENERAL RESPONSE ACTION AREA

DRAWN BY:	DESIGNED BY:	APPROVED BY:	PROJECT NUMBER:
AR	CT / PC	PC / HB	11-100E-01
DATE:	DATE:	DATE:	SCALE:
11-30-2011	11-30-2011	11-30-2011	1" = 150'

FIGURE NUMBER:
6

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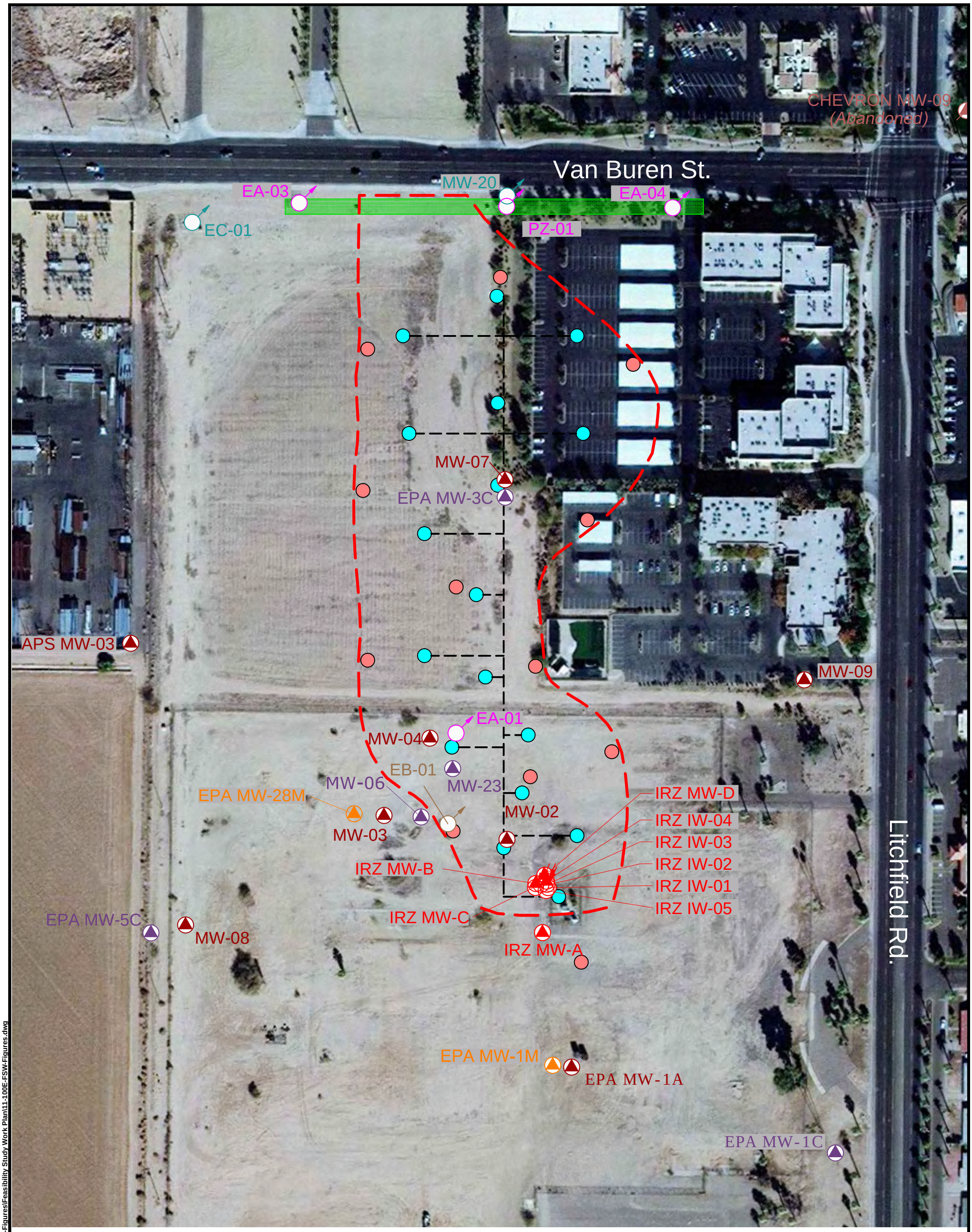

Legend:

- Existing Hydraulic Barrier Location
- Existing Monitoring Well Location
- New Monitoring Well Location
- Recirculation Well Location
- SVE Conveyance Piping

Assumptions:

- 200 ft. re-circulation well influence
- Target depth 90 - 150 ft. bgs.
- Existing extraction wells along Van Buren are sufficient as a hydraulic barrier

150' 0 150' 300'
SCALE: 1"=150'

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Alternative 2 - In-well Air Stripping Hydraulic Barrier
Conceptual Aerial Extent
of Source Area Treatment

DRAWN BY:	DESIGNED BY:	APPROVED BY:	PROJECT NUMBER:
AR	CT / PC	PC / HB	11-100E-01
DATE: 11-30-2011	DATE: 11-30-2011	DATE: 11-30-2011	SCALE: 1" = 150'

FIGURE NUMBER:
7

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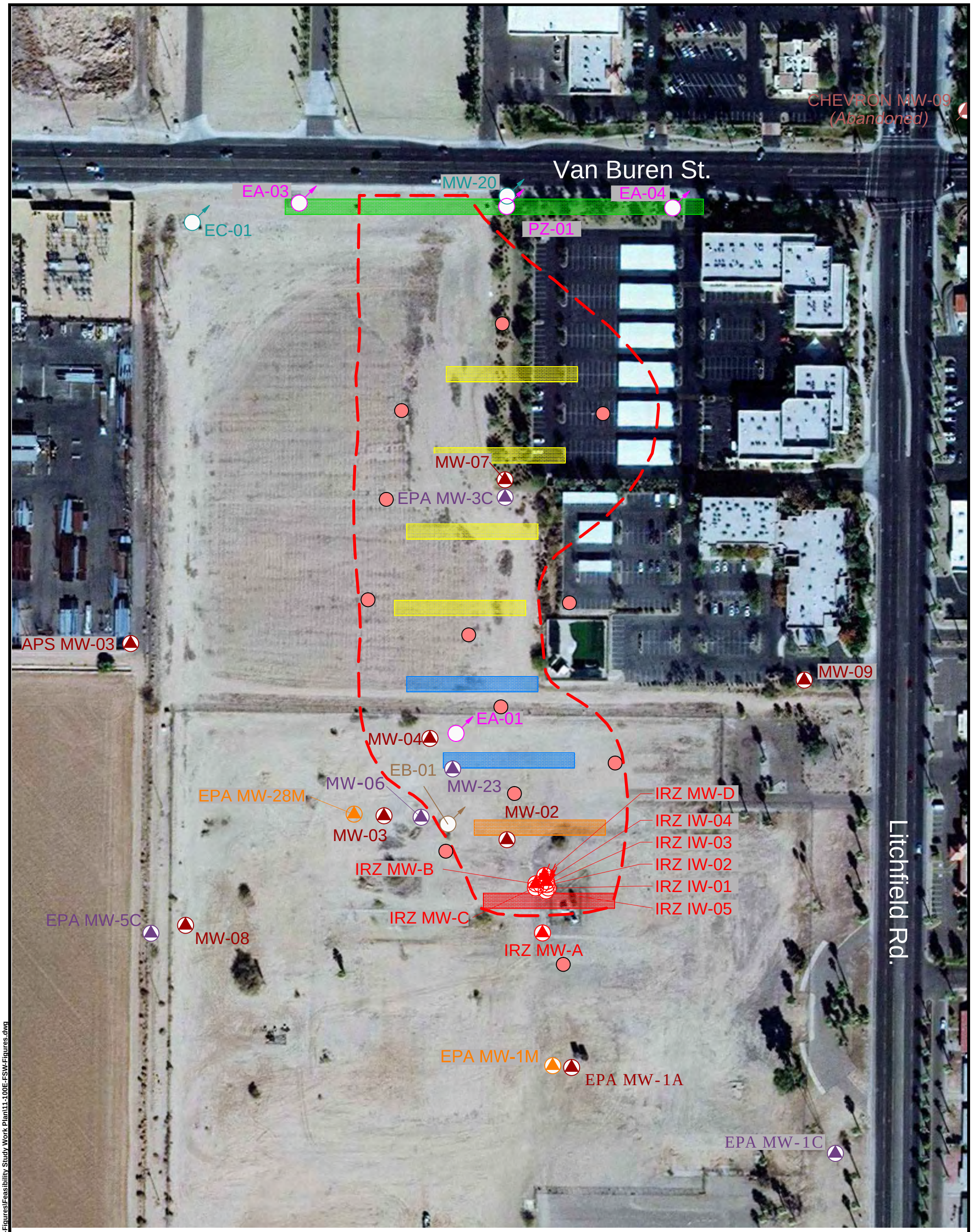

Legend:

- Existing Hydraulic Barrier Location
- Existing Monitoring Well Location
- New Monitoring Well Location
- Injection Location - 11 Lifts
- Injection Location - 9 Lifts
- Injection Location - 6 Lifts
- Injection Location - 3 Lifts

Assumptions:

- ARD uses Emulsified Oil and DHC Culture Injections
- 25 ft. injection well spacing, @ 5 ft. lift intervals
- Target depth 90 - 150 ft. bgs.
- Existing extraction wells along Van Buren are sufficient as a hydraulic barrier
- Primary injections phased over 4 years
- 1 year for follow-up injections at approximately 10% of locations

150' 0 150' 300'
SCALE: 1"=150'

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Alternative 3 - ARD + HB
Conceptual Aerial Extent
of Source Area Treatment

DRAWN BY:	DESIGNED BY:	APPROVED BY:	PROJECT NUMBER:
AR	CT / PC	PC / HB	11-100E-01
DATE: 11-30-2011	DATE: 11-30-2011	DATE: 11-30-2011	SCALE: 1" = 150'

FIGURE NUMBER:
8

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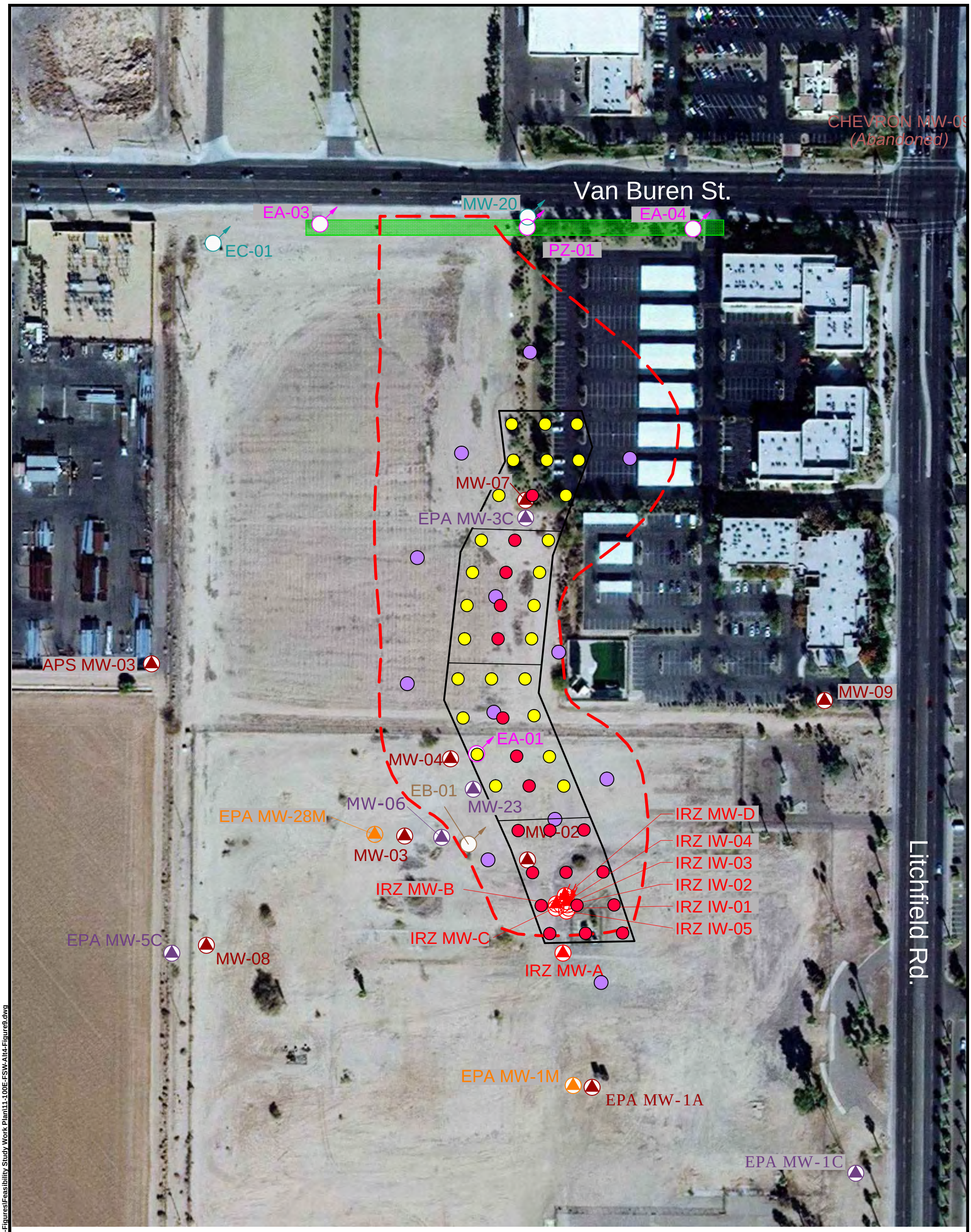

Legend:

- EPA MW-55A — Subunit A monitor well
- EA-07 — Subunit A extraction well
- EPA MW-48C — Subunit C monitor well
- EPA MW-28M — MAU monitor well
- IRZ IW-01 — Injection well (IRZ)
- Existing Hydraulic Barrier Location
- New Injection Well 50% mZVI, 50% nZVI
- New Injection Well 100% mZVI
- New Monitoring Well Location

Assumption:

- 60 ft. injection well spacing, @ 5 ft. lift intervals
- Target depth 90 - 150 ft. bgs.
- Existing extraction wells along Van Buren are sufficient as a hydraulic barrier
- Primary injections phased over 4 years
- 1 year for follow-up injections at approximately 10% of locations

150' 0 150' 300'
SCALE: 1"=150'

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ALTERNATIVE 4 - NZVI + ZVI + ARD + HB
CONCEPTUAL AERIAL EXTENT OF SOURCE AREA TREATMENT

DRAWN BY:	DESIGNED BY:	APPROVED BY:	PROJECT NUMBER:
AR	CT / PC	PC / HB	11-100E-01
DATE: 11-30-2011	DATE: 11-30-2011	DATE: 11-30-2011	SCALE: 1" = 150'

FIGURE NUMBER: 9

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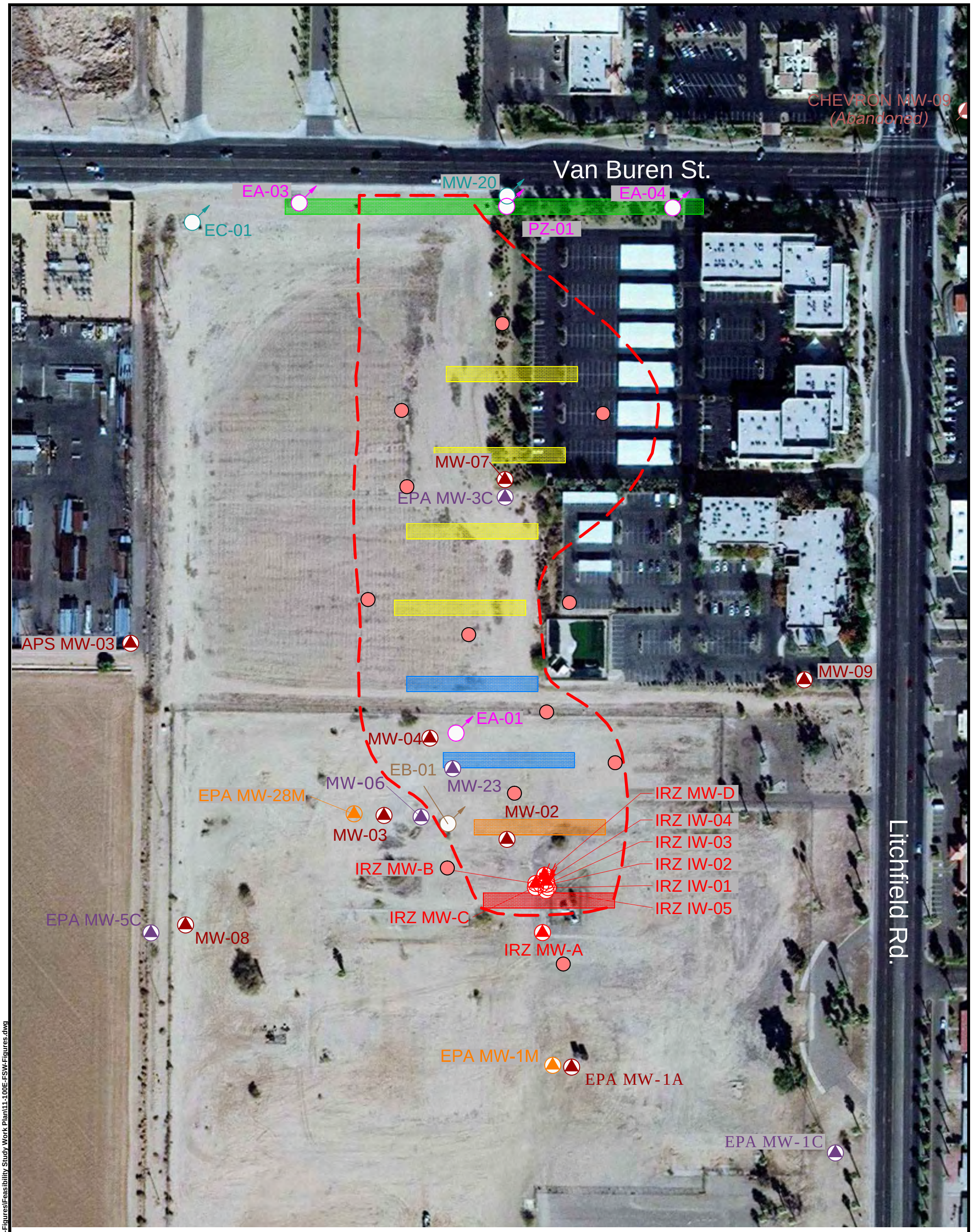

Legend:

- Existing Hydraulic Barrier Location
- Existing Monitoring Well Location
- New Monitoring Well Location
- Injection Location - 11 Lifts
- Injection Location - 9 Lifts
- Injection Location - 6 Lifts
- Injection Location - 3 Lifts

Assumptions:

- EHC used for ZVI/Emulsified Oil Injections
- 15 ft. injection well spacing, @ 5 ft. lift intervals
- Target depth 90 - 150 ft. bgs.
- Existing extraction wells along Van Buren are sufficient as a hydraulic barrier
- Primary injections phased over 4 years
- 1 year for follow-up injections at approximately 10% of locations

150' 0 150' 300'
SCALE: 1"=150'

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Alternative 5 - ZVI + ARD + HB
Conceptual Aerial Extent
of Source Area Treatment

DRAWN BY:	DESIGNED BY:	APPROVED BY:	PROJECT NUMBER:
AR	CT / PC	HB	11-100E-01
DATE: 11-30-2011	DATE: 11-30-2011	DATE: 11-30-2011	SCALE: 1" = 150'

FIGURE NUMBER:
10

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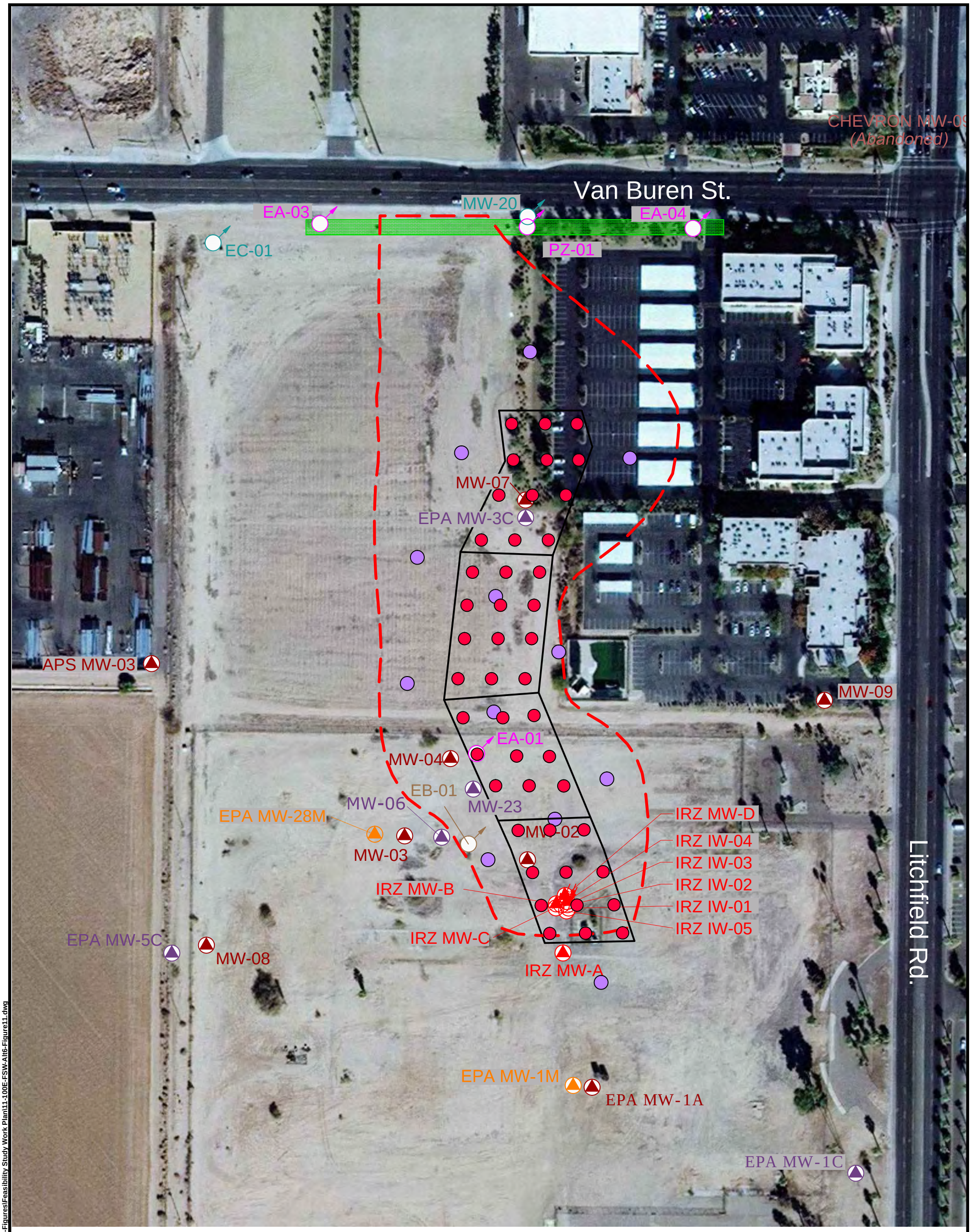

Legend:

- EPA MW-55A — Subunit A monitor well
- EA-07 — Subunit A extraction well
- EPA MW-48C — Subunit C monitor well
- EPA MW-28M — MAU monitor well
- IRZ IW-01 — Injection well (IRZ)
- Existing Hydraulic Barrier Location
- New Injection Well
- New Monitoring Well Location

Assumption:

- 60 ft. injection well spacing, @ 5 ft. lift intervals
- Target depth 90 - 150 ft. bgs.
- Existing extraction wells along Van Buren are sufficient as a hydraulic barrier
- Primary injections phased over 4 years
- 1 year for follow-up injections at approximately 10% of locations

150' 0 150' 300'
SCALE: 1"=150'

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ALTERNATIVE 6 - ISCO + HB
CONCEPTUAL AERIAL EXTENT OF SOURCE AREA TREATMENT

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AR	CT / PC	PC / HB	11-100E-01
DATE: 11-30-2011	DATE: 11-30-2011	DATE: 11-30-2011	SCALE: 1" = 150'

FIGURE NUMBER: 11

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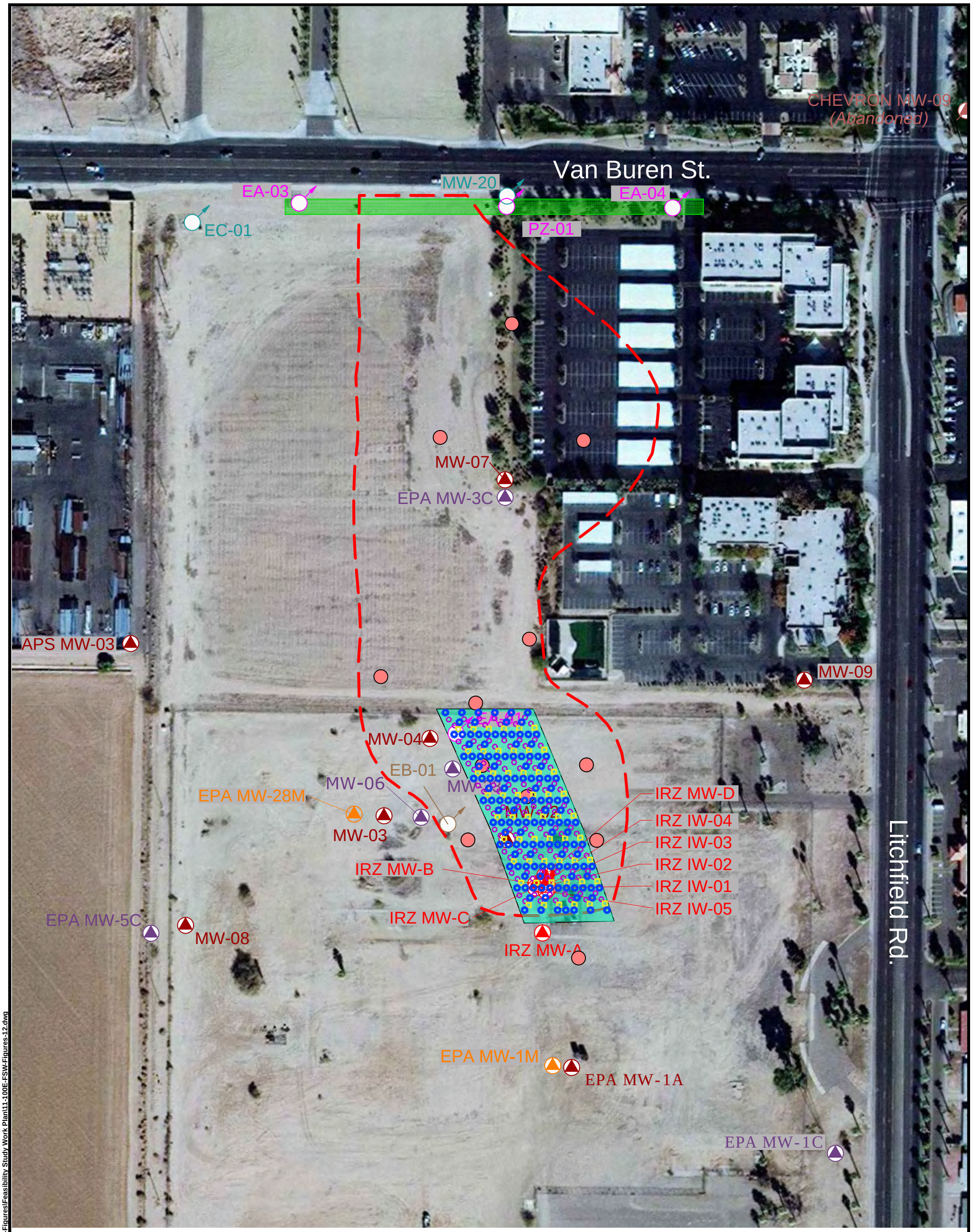

Legend:

- Existing Hydraulic Barrier Location
- Existing Monitoring Well Location
- New Monitoring Well Location
- ERH Treatment Area
- ERH Electrode
- Steam Injection Well
- Vapor Recovery Well

Assumptions:

- 137 electrodes
- 15 - 20 ft. electrode spacing
- Target depth 80 - 150 ft. bgs.
- Existing extraction wells along Van Buren are sufficient as a hydraulic barrier
- Installation and treatment completed in 1 phase within 10 months.

150' 0 150' 300'
SCALE: 1"=150'

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Alternative 7 - ERH with Steam and Hydraulic Control
Conceptual Aerial
Extent of Source Area Treatment

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DATE: 11-30-2011	DATE: 11-30-2011	DATE: 11-30-2011	SCALE: 1" = 150'

FIGURE NUMBER: 12

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