ADEQ
Arizona Department of Environmental Quality

# Feasibility Study

## West Central Phoenix North Plume

**Water Quality Assurance Revolving Fund (WQARF) Site**
**Phoenix, Arizona**

**?sesqr 2014**
Contract Number ADEQ14-077538

CALIBRE

Matrix DESIGN GROUP

FEASIBILITY STUDY

West Central Phoenix North Plume WQARF SITE

August 19, 2016

CERTIFICATION

All information, conclusions, and recommendations in this document have been prepared under the supervision of and reviewed by a Registered Professional Engineer.

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**Abbreviations and Acronyms**

| | |
|---|---|
| A.A.C. | Arizona Administrative Code |
| ADEQ | Arizona Department of Environmental Quality |
| A.R.S | Arizona Revised Statutes |
| AS | air sparging |
| AWQS | Aquifer Water Quality Standard |
| bgs | below ground surface |
| COC | contaminant of concern |
| COP | City of Phoenix |
| CSM | conceptual site model |
| DCE | dichloroethene |
| DNAPL | dense non-aqueous phase liquid |
| EOS | edible oil substrate |
| EPA | U.S. Environmental Protection Agency |
| ERA | Early Response Action |
| ERD | enhanced reductive dechlorination |
| ERH | electrical-resistance heating |
| F&B | F&B Manufacturing |
| FS | Feasibility Study |
| $gpd/ft^2$ | gallons per day per square foot |
| GPL | groundwater protection level |
| gpm | gallons per minute |
| GSC | Glenrosa Service Center |
| Hill Brothers | Hill Brothers Chemical Company |
| ISCO | in-situ chemical oxidation |
| LAU | Lower Alluvial Unit |
| MAU | Middle Alluvial Unit |
| MCL | Maximum Contaminant Level |
| µg/L | micrograms per liter |
| MNA | monitored natural attenuation |
| NFA | No Further Action |
| O&M | Operations and Maintenance |
| PA | Preliminary Assessment |
| PCE | tetrachloroethene |
| Pyramid | Pyramid Industries, Inc. |
| redox | oxidation-reduction |
| RI | Remedial Investigation |
| Rinchem | Rinchem Company |
| RO | remedial objective |

| | |
|---|---|
| SI | Site Investigation |
| SRL | soil remediation level |
| SRP | Salt River Project |
| SRVB | Salt River Valley Basin |
| SVE | soil vapor extraction |
| TCA | trichloroethane |
| TCE | trichloroethene |
| UAU | Upper Alluvial Unit |
| VOC | volatile organic compound |
| WCP | West Central Phoenix |
| WQARF | Water Quality Assurance Revolving Fund |

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## EXECUTIVE SUMMARY

This Feasibility Study (FS) for the West Central Phoenix North Plume Water Quality Assurance Revolving Fund Site (Site) has been prepared for the Arizona Department of Environmental Quality, in accordance with Arizona Administrative Code R-18-16-407. This FS identifies a reference remedy and alternative remedial strategies to meet the remedial objectives (ROs) developed for this Site. The proposed remedies have been developed to assure the protection of public health and welfare, provide for the maximum beneficial use of waters of the state (via control, management and/or cleanup of hazardous substances). The proposed remedies comply with the requirements of Arizona Revised Statutes § 49-282.06.

The Site includes four (4) facilities (F&B, Pyramid, Rinchem, and Hills Brothers), which contributed chlorinated volatile organic compounds (VOCs), mainly tetrachloroethene (PCE), to Site soils and groundwater. Multiple site investigations have indicated that soil and groundwater are impacted, with groundwater being the most significantly affected media. The largest release of PCE is associated with the F&B facility. PCE releases from the F&B facility have migrated to groundwater contributing to a dissolved-phase PCE groundwater plume that has traveled approximately 1,100 feet downgradient from the Site. Historical groundwater and soil vapor concentrations at F&B are indicative of a dense, non-aqueous-phase liquid (DNAPL) release. Currently, concentrations of PCE within the groundwater at the Site are greater than 1,000 micrograms per liter (µg/l), which exceeds the Arizona Water Quality Standard of 5 µg/L. A soil vapor extraction (SVE) system to treat PCE in soils has operated at the F&B facility for more than 10 years.

Based on technological limitations, practicable remedies for DNAPL sites must consider source reduction and/or containment of the source areas. All remedial actions considered in this FS have been planned for multiple years of operation. Therefore, it is important to optimize the remedial actions and related performance monitoring for consideration of life-cycle costs.

The reference remedy is a combination of vadose zone source control (SVE at the F&B facility), groundwater plume treatment using biological treatment/enhanced reductive dechlorination (ERD), and plume control via monitored natural attenuation (MNA). The more aggressive remedy includes all elements of the reference remedy with specific enhancements including the addition of a groundwater extraction and treatment system in lieu of MNA for plume control. The less aggressive remedy includes a combination of vadose zone source control (SVE at the F&B facility) and plume control via MNA. All three remedies include a contingency for well-head treatment, if needed at some point in the future.

These remedial alternatives were compared side-by-side regarding achievement of Site ROs, practicability, risk, cost, and benefit and consistency with management plans of local water providers.

Based on the detailed comparative analysis of the three remedial alternatives in this FS, the reference remedy is the proposed remedy for the Site.

Based on the evaluation presented in this FS, the reference remedy has been judged to be protective of human health and the environment, cost-effective and technically feasible. This recommended remedy allows for the maximum beneficial use of the waters of the State and is compliant with applicable State laws.

## 1.0 INTRODUCTION

This report presents a Feasibility Study (FS) for the West Central Phoenix North Plume Water Quality Assurance Revolving Fund (WQARF) Site (Site), located in Phoenix, Arizona. This FS has been prepared for the Arizona Department of Environmental Quality (ADEQ) as a Task Order under contract number ADEQ14-077538. The FS has been prepared in accordance with Arizona Administrative Code (A.A.C.) R-18-16-407.

The Site is located in an industrial area of West Central Phoenix as shown in Figure 1-1. Releases of volatile organic compounds (VOCs) have been documented at four primary locations/facilities within the Site boundaries: F&B Manufacturing (F&B), Pyramid Industries, Inc. (Pyramid), Rinchem Company (Rinchem), and Hill Brothers Chemical Company (Hill Brothers). The primary Site contaminants of concern (COCs) include tetrachloroethene (PCE), trichloroethene (TCE), and 1,1-dichloroethene (DCE). Groundwater is the most widespread contaminated environmental medium at the Site and groundwater remediation is, therefore, the primary focus of this FS. The purpose of this FS is to identify and evaluate remedial alternatives to meet/achieve the remedial objectives (ROs) developed for the Site as part of the 2009 Final RI Report (LFR, 2009).

### 1.1 REPORT ORGANIZATION

This FS is organized into the following Sections:

- Section 1.0 – Introduction – This section presents a summary of the FS objectives and organization.
- Section 2.0 – Site Background and Conceptual Site Model – This section presents a summary of the Site, nature and extent of contamination, remedial action history, regulatory requirements, and conceptual site model.
- Section 3.0 – Identification and Screening of Remediation Technologies and Alternatives – This section presents the ROs, the identification and screening of remedial alternatives considered, and the remedial alternatives retained for further consideration.
- Section 4.0 – Development of a Reference Remedy and Alternative Remedies – This section carries forward those remedial alternatives retained from Section 3.0. It presents a reference remedy, a more aggressive remedy, and a less aggressive remedy.
- Section 5.0 – Comparison of the Reference Remedy and Alternative Remedies – This section outlines the selected remedies and compares them against various criteria such as demonstration of RO achievement, consistency with water management plans, practicability, risk, cost, and benefit.

- Section 6.0 – Proposed Remedy – This section outlines the recommended remedy based on the comparison of the selected remedies in Section 5.0.
- Section 7.0 – References – This section presents the references cited in this FS.

## 2.0 SITE BACKGROUND AND CONCEPTUAL SITE MODEL

The Site is located in an industrialized area of west central Phoenix, covering an area of approximately 65 acres (Figure 2-1). It is approximately bounded by West Highland Avenue to the north, Indian School Road to the south, 37th Avenue to the east, and 43rd Avenue to the west. Releases of VOCs are known to have occurred at four primary locations/facilities at the Site: F&B, Pyramid, Rinchem, and Hill Brothers. Multiple site assessments and Remedial Investigations (RIs) have indicated that the largest VOC release occurred at F&B, which formerly used PCE in a vapor degreaser. Current and anticipated future land use is industrial (LFR, 2009).

PCE is the primary COC identified at the Site. Other COCs identified in the 2009 RI include TCE and 1,1-DCE (LFR, 2009). These COCs have been identified in soil, soil vapor, and groundwater. Additionally, other VOCs have been detected in Site groundwater and soil at concentrations exceeding relevant standards, and certain metals have been detected at concentrations exceeding relevant standards in groundwater at the Pyramid Facility. Groundwater is the most significantly impacted environmental medium based on the areal extent of COCs detected at concentrations above the Aquifer Water Quality Standards (AWQSs). The boundaries of the impacted area of the Site are defined by the current extent of the VOC plume in groundwater covering approximately 30 acres (Figure 2-2).

### 2.1 WATER QUALITY ASSURANCE REVOLVING FUND REGISTRY

In 1982, TCE was detected in several City of Phoenix (COP) municipal supply wells located in west central Phoenix. Subsequent groundwater sampling confirmed the presence of TCE at concentrations above the U.S. Environmental Protection Agency (EPA) Maximum Contaminant Level (MCL). Consequently, ADEQ designated the area of groundwater contamination as the West Central Phoenix (WCP) WQARF Site and recommended further study under the State WQARF program. In 1998, the WCP site was added to the WQARF Registry with an eligibility and evaluation score of 50 out of a possible 120 (ADEQ, 2014).

Characterization data were collected during the initial investigations, and ADEQ identified five discrete sites/subareas in the WCP WQARF Site with separate groundwater plumes: (1) North Plume; (2) North Canal Plume; (3) East Grand Avenue; (4) West Grand Avenue; and (5) West Osborn Complex. This FS has been prepared to address the WCP North Plume WQARF Site.

### 2.2 CHRONOLOGY OF SITE ACTIVITIES

#### 2.2.1 Summary

From 1989 to the present, multiple site investigations (SIs) and cleanup actions have been implemented at the different facilities within the Site. Initial investigations consisted of several site

assessments, soil-gas surveys and groundwater sampling at the F&B, Pyramid, Rinchem, and Hill Brothers facilities. In the late 1990s through 2009, RIs were performed, and additional groundwater monitoring wells were installed. By 2009, a Final RI was completed to define the nature and extent of Site contamination (LFR, 2009). The locations of the groundwater monitoring wells are shown in Figures 2-3 and 2-4.

In 2000 to 2001, excavation of approximately 210 cubic yards of VOC-contaminated soil occurred at F&B in the vicinity of the former vapor degreaser. At the same time, additional monitoring wells were drilled and a soil vapor extraction (SVE) system was installed at F&B in the area of the former vapor degreaser as an early response action (ERA). The SVE system remains in operation and was modified in 2012 with the installation of three additional vapor extraction wells. As of January 2015, the SVE system had removed approximately 47,000 pounds of VOCs. A separate SVE system was installed at Hill Brothers in 2008 and operated until 2010 as an ERA. In 2010, ADEQ issued a No Further Action (NFA) letter for soils underlying the Hill Brothers facility.

A more comprehensive summary of RIs, remedial activities, and early response actions completed at the Site are included in Sections 2.0 and 3.0 of the Final RI Report (LFR, 2009). The results of the 2009 RI, coupled with more recent groundwater data and SVE performance monitoring data are summarized briefly in this FS and those data were used to develop the remedial alternatives considered in this FS.

### 2.2.2 Chronological History by Facility

#### 2.2.2.1 F&B

F&B is an aircraft and spacecraft parts manufacturing facility that used PCE in a vapor degreaser from approximately 1967 to 1987, after which time 1,1,1-trichloroethane (TCA) was used.

**1989:** A Preliminary Assessment (PA)/SI was performed and included soil vapor sampling and groundwater monitoring.

**1990–1994:** Additional SIs were conducted and included soil, soil vapor, and groundwater sampling.

**1999–2009:** RIs were performed and included aquifer pumping tests, additional groundwater monitoring, and soil sampling. PCE has been detected in groundwater at concentrations up to 130,000 micrograms per liter (µg/L). The AWQS for PCE is 5 µg/L. The Final RI concluded that the soil beneath the former vapor degreaser at the F&B facility is the likely source of PCE to the vadose zone and groundwater (LFR, 2009). The SVE system continues to be operated at the location of the former vapor degreaser.

#### 2.2.2.2 Pyramid

Pyramid operated an electrical manufacturing facility from 1977 to 1994. The facility used various chemicals including acids, caustics, heavy metals, paints, and methylene chloride. The 2009 RI notes that PCE use at this facility has not been documented.

**1990–1993:** A PA/SI was performed and included soil and soil vapor sampling.

**1998–2009:** RIs were performed and included groundwater monitoring and additional soil sampling. The highest PCE concentration in groundwater was detected at 28,000 µg/L in a groundwater well along the southern side of the property, directly north of and potentially impacted by the plume from the F&B facility.

#### 2.2.2.3 Rinchem

Rinchem operated a chemical warehouse and distribution facility from 1982 to 1993. The facility handled solvents, oils, and fuels including blended custom solvents. Chemicals were stored in a tank farm located on the western side of the property. A repackaging area and chemical processing area were located immediately adjacent to the tank farm. PCE use was documented at this facility.

**1989–1991:** A PA/SI was performed and included soil and soil vapor sampling.

**1992–1994:** Additional SIs were conducted and included soil, soil vapor, and groundwater sampling.

**1998–2009:** RIs were performed and included installation of additional groundwater monitoring wells, groundwater sampling, and added soil sampling. The highest VOC concentrations in soil and soil vapor were detected near Sump-1 in the former repackaging area, indicating a likely source area. Groundwater samples contained concentrations of PCE and TCE at 60 and 480 µg/L, respectively. The AWQS for both PCE and TCE is 5 µg/L.

#### 2.2.2.4 Hill Brothers

Hill Brothers operates a chemical repackaging and distribution facility. The business started operations at this location in 1969 and remains in operation today. Bulk chemicals are received via railroad cars and tanker trucks and stored in aboveground storage tanks prior to transfer into containers for distribution. Chemicals handled at the facility have included solvents (acetone, methylene chloride, PCE, toluene, and TCA), acids, bases, alcohols, and other compounds. The handling of solvents and repackaging of TCA was discontinued in 1989.

**1989:** A PA/SI was performed and included soil and soil vapor sampling.

**1995–2003:** Additional SIs were conducted and included soil, soil vapor, and groundwater sampling.

**1999–2009:** RIs were performed and included additional groundwater sampling and soil sampling. PCE concentrations in groundwater ranged from 18 to 29 µg/L.

**2008**: A SVE system started as an ERA at Hill Brothers.

**2010:** ADEQ issued an NFA letter for soils underlying the Hill Brothers facility following shutdown of the SVE system (operated from 2008-2010).

## 2.3 CONCEPTUAL SITE MODEL

A conceptual site model (CSM) has been developed for this FS based on information from the Site RI. The CSM presented in Figure 2-5 provides a graphical illustration of Site conditions applicable to the primary contaminant released at the Site (a Dense Non-Aqueous Phase Liquid [DNAPL]) and the related soil and groundwater contamination present[1]. The CSM discussion presented herein differs somewhat from the CSM discussion presented in the RI Report (LFR, 2009); this CSM is revised/streamlined to focus on information relevant to Site remediation. This CSM includes information on operational history, site-specific geology and hydrogeology, contaminated media and potential source areas, groundwater quality, groundwater transport at the Site, potential receptors and exposure pathways, and contaminants of concern and applicable standards. The CSM will ultimately be used in the future to test the performance of proposed and implemented remedies and is intended to evolve as performance monitoring data are collected during remedial actions.

### 2.3.1 Site/Facility History

As previously noted, four industrial facilities have been identified as known, or likely, sources of the soil and groundwater contamination at the Site:

- F&B – Spills at or from the former vapor degreaser/sump at this facility is estimated to be the largest (primary) release of chlorinated solvents to groundwater. PCE was detected in soil to depths of 100 feet below ground surface (bgs). Additionally, very high PCE concentrations have been detected in groundwater samples from multiple wells around the facility.
- Pyramid – Spills associated with waste handling procedures have been previously documented. However, VOCs detected in groundwater and soil vapor (PCE) may be associated with contamination from the adjacent F&B facility.

[1] The graphical depiction of the initial release in the CSM includes separate phase DNAPL at the point of release and as residual in pools on underlying fine-grained layers; this initial condition has not been specifically observed at the Site but is inferred based on other site conditions. SVE remedial actions at the Site, implemented as an ERA and operated for several years, have likely removed any areas with pooled DNAPL in the vadose zone.

- Rinchem – Elevated VOC concentrations in soil, soil vapor, and groundwater occur in the vicinity of the repackaging area and Sump-1. Recent PCE and TCE concentrations in groundwater in this area (approximately 10 to 20 µg/L, respectively) are orders-of-magnitude lower than those found in the immediate vicinity of F&B.
- Hill Brothers – PCE has been detected at low concentrations in soil from 5 to 100 feet bgs in the former solvent repackaging area. ADEQ issued an NFA letter for soil underlying the area of the Hill Brothers property in 2010.

In addition to the sources described above, the COP Glenrosa Service Center (GSC) had a fuel release of unleaded gasoline which was estimated at 420,000 gallons. Fuel-related VOCs have been detected in groundwater since the identified release. The VOC plume from the WCP North Plume WQARF Site comingles with the fuel release from the GSC site (the GSC site is located on the west side of N 40$^{th}$ Avenue between F&B and Rinchem). A groundwater remediation system was installed in response to the fuel release and operated from 1988 to October 2000. In 2002, the COP prepared a Revised Corrective Action Plan for the GSC site that included an air sparging (AS) barrier system, SVE system, and a vacuum-enhanced product recovery system. MNA was selected for off-site petroleum hydrocarbons. The AS/SVE systems were turned off in spring 2014, and the GSC site is in a monitoring phase (i.e., the AS/SVE systems are not presently operating).

### 2.3.2 Geology

The Site is located in the Salt River Valley Basin (SRVB) of central Arizona. The SRVB is part of the overall Basin and Range geologic province, which is characterized by broad alluvial valleys and gently sloping, fault-blocked mountain ranges that trend northwest to southeast. The SRVB fill deposits consist of Quaternary unconsolidated to semi-consolidated layers of fine- to coarse-grained sediments ranging from hundreds to thousands of feet in thickness which overlie mid - Tertiary Period rocks. They are generally divided into three water-bearing hydrogeologic zones, which consist of gravel, sand, silt, clay, and evaporite deposits (Corkhill et al., 1993). These zones are, from oldest to youngest, the Lower Alluvial Unit (LAU), Middle Alluvial Unit (MAU), and Upper Alluvial Unit (UAU).

At the Site, the UAU consists of unsaturated gravel, sand, and silt with fine-grained silty interbeds and is approximately 80 feet thick. The MAU consists of silt, clay, and siltstone with silty-sand and gravel interbeds, which serve as the primary water-yielding sections of the MAU. The MAU is found at approximately 80 feet bgs and up to 598 feet bgs (as observed in monitoring well WCP-36). A higher permeability zone (likely a preferential flow path) has been noted at an interval between 250 and 280 feet bgs (LFR, 2009). The LAU consists of sand, gravel, silt, clay, siltstone, and mudstone and overlies the mid-Tertiary Period bedrock. The LAU varies in thickness from a few feet to over 200 feet thick.

### 2.3.3 Hydrogeology

The principal aquifers at the Site consist of two discrete water-bearing zones within the basin-fill deposits: the LAU and the MAU. As noted above, the UAU is unsaturated at the Site. The groundwater contamination associated with the Site is limited to the MAU; therefore, the summary of specific hydrology and aquifer characteristics in this section is focused on that specific unit.

Groundwater in the upper portion of the MAU generally flows to the northwest (where the primary VOC plume is roughly 1,400 feet in length). Along the southern Site boundary, groundwater has a more westerly flow component, which appears to be influenced by pumping to the west of the Site (LFR, 2009). Groundwater elevations at the Site in the upper MAU have decreased approximately 30 feet since 1995. Current depth to water is approximately 150 feet bgs. Groundwater recharge occurs through infiltration by precipitation (limited), runoff from nearby mountains, releases by reservoirs along the Salt River, canal seepage, agricultural irrigation, and urban/artificial recharge. Rainfall averages approximately 8 inches annually and potential evaporation is approximately 72 inches annually. Regional groundwater declines are attributed to increased groundwater usage, drought conditions, and reduced recharge from the Grand Canal, which was lined in 1998 (and had historically served as a major source of aquifer recharge).

### 2.3.4 Source Area Delineation

As noted in the prior sections, multiple investigations and remedial actions have been implemented at the Site to target potential areas with soil contamination. These include, but are not limited to, excavation of approximately 210 cubic yards of VOC-contaminated soil at the F&B facility, installation of an SVE system at the F&B facility; and installation of a separate SVE system at the Hill Brothers facility. The soil contact exposure pathway was found to be generally in compliance with standards for industrial land use at each of the areas/facilities investigated (i.e., concentrations of COCs were less than the nonresidential soil remediation levels [SRLs]). In addition, contaminated soil is located beneath paved (generally inaccessible) areas at each industrial facility.

COC concentrations in deeper soil samples from F&B exceeded the groundwater protection levels (GPLs). These samples were collected near the area of DNAPL release and significant remedial actions (SVE operations) have occurred since that time (starting in 2001). COC concentrations in soil samples from Rinchem also exceeded GPLs (verifying a release at this facility). COCs were detected in soil samples from Pyramid but did not exceed GPLs. Similarly, COCs were detected in soil samples from Hill Brothers but did not exceed GPLs.

A soil vapor plume extends from the ground surface to the water table (approximately 150 feet bgs) in the source area at F&B. An SVE system has operated at the F&B facility for more than 10 years at the primary area of PCE release (the location of the former vapor degreaser). Historical soil vapor concentrations at F&B are indicative of a DNAPL release. DNAPL is likely present as ganglia (i.e.,

disconnected tiny droplets of PCE trapped in the pore space of the soil) as opposed to a continuous pool with the vadose zone beneath the source area. These PCE residues act as a continuing source of soil vapor and groundwater contamination. A graphical representation of the overall CSM is shown in Figure 2-5.

### 2.3.5 Groundwater Contamination Delineation

The VOC plume in groundwater is primarily present in the upper and middle intervals of the MAU. The highest VOC concentrations are located in the area near the former vapor degreaser at F&B. Lower concentrations are found near the other three identified facilities. As of 2014, approximately 70 percent of the PCE plume footprint (at a 1,000 µg/L contour) had migrated outside the boundary of the F&B property due to groundwater transport (see Figure 2-2, the F&B property extends to the N 40$^{th}$ Avenue approximately 240 feet to the west of the Building outlined). Additionally, both TCE and 1,1- DCE have been detected in the upper interval of the MAU (see Figures 2-6 and 2-7, respectively). The concentration ranges for both TCE and 1,1-DCE are much lower than the range for PCE.

In the middle MAU (approximately 250 feet bgs in the preferential flow path), a smaller lobe of the PCE plume extends to the west (about 900 feet) to the area near the GSC, with lower concentrations of PCE, approximately 30 to 50 µg/L (see Figure 2-8). It also appears that VOC plume migration is continuing in this area (based on concentration trends from WCP-72M and WCP-74).

In the area around the Rinchem facility, ongoing reductive dechlorination processes were identified in the Final RI Report (LFR, 2009). Natural attenuation parameters and the presence of the degradation "daughter products" cis-1,2-DCE and vinyl chloride downgradient from the source area indicate that dechlorination processes are occurring. Although not described in more recent sampling reports, the measured concentrations were less than the AWQS for cis-1,2-DCE, it is important to note because it indicates that dechlorination processes are likely occurring. Analytical data from the 2013 sampling event identified cis-1,2-DCE in and around the Rinchem facility and downgradient toward the Hill Brothers facility. This degradation daughter product (cis-1,2-DCE) was detected in the following wells: GSC-46, WCP-54, WCP-75, WCP-221, WCP-222, and WCP-224. A depiction of the primary degradation pathways for chlorinated ethenes by reductive dechlorination is shown in Figure 2-9.

In general, the VOC plume is not believed to extend below the MAU. While some of the multi-level sampling wells installed in the early 1990s (Westbay Wells) have had VOC detections at depths below the MAU, those detections are thought to be associated with well construction rather than plume migration to those depths.

### 2.3.6 Fate and Transport

Chlorinated VOCs can be persistent in the environment and can travel downgradient significant distances with limited attenuation. Attenuation can occur by adsorption to soil, by biodegradation,

or by dispersion from the core of the plume into surrounding groundwater as it travels downgradient. With biodegradation, the presence of biodegradation "daughter products" such as TCE, cis-1,2-DCE, and vinyl chloride generally indicates that biodegradation is occurring within the plume.

Horizontal contaminant transport throughout the plume occurs by groundwater transport, generally flowing in a northwesterly direction. The regional horizontal gradient has been measured at 0.002 feet/foot, with an estimated groundwater velocity of approximately 90 feet/year (based on a measured hydraulic conductivity of 230 gallons per day per square foot [gpd/ft$^2$] derived from an aquifer pumping test conducted as part of the RI). Groundwater velocity in the less permeable zones will be slower and velocity in the more permeable preferential flow paths is expected to be faster. The transition zone between the coarse-grained sediments of the UAU and the less-permeable finer grained sediments of the MAU may also cause lateral spreading of DNAPL in a limited area beneath the initial source/release area.

As previously discussed in Section 2.3.4, historical soil vapor concentrations are indicative of a DNAPL release. Vertical migration of DNAPL (PCE solvent) and vertical movement of dissolved-phase VOCs (in the form of PCE-saturated water from the former F&B vapor degreaser) are the primary transport mechanisms in soil. As the DNAPL and saturated water infiltrate, DNAPL ganglia are trapped throughout the infiltration pathway within the vadose zone. The depth to groundwater has increased by approximately 30 feet over the past several decades, thereby exposing a new vadose zone interval at depth.

Natural degradation of fuel releases from the COP GSC facility has resulted in degradation of chlorinated VOCs along with the hydrocarbon constituents. Dechlorination processes are occurring near the Rinchem facility as indicated by declining VOC concentrations, and the presence of PCE biodegradation daughter products. Similarly, but to a more limited extent, degradation via dechlorination has been noted at the nearby West Central Phoenix North Canal Plume Site, located to the south.

The 2009 RI (LFR, 2009) indicates that VOC degradation processes in groundwater are generally quite slow at the Site, with the noted exception of the two areas described above (near GSC and Rinchem). Review of more recent data (data collected between 2009 and 2014) indicates that PCE concentrations near the source area at F&B have declined significantly; this is assumed to be the combined result of the SVE ERA and the declining water table (significant generation/creation of degradation daughter products has not been observed).

Recent data near the leading edge of the plume indicate that the PCE plume is migrating. Along West Turney Ave, the existing wells in the upper MAU include GSC-23, GSC-48, GSC-01A, GSC-22A and WCP-91 (see Figure 2-3). The western and eastern bounding wells in this area are GSC-23 and WCP-91 which show stable or declining concentration trends. The wells in the center of the plume in this

area (GSC-48, GSC-01A and GSC-22A) indicate increasing VOC concentrations. In the lower MAU, the plume flow direction is more westerly and at much lower concentrations than the upper MAU (see Figure 2-8). The recent data from WCP-72M and WCP-74 (lower MAU) are more ambiguous than the upper MAU data described above. The data from WCP-72M indicate the lower MAU plume might be stable, but the downgradient point (WCP-74) suggests an increasing trend (recent and current PCE data from WCP-74 are below the AWQS, but appear to be steadily increasing).

### 2.3.7 Potential Receptors and Exposure Pathways

Currently, there are no known private or non-municipal uses of groundwater at the Site. Future use of groundwater in the area is designated for irrigation and municipal use. The COP has two wells within 1 mile of the Site: well No. 69 (inactive, located approximately 2,300 feet northeast of F&B) and well No. 72 (active, located approximately 4,200 feet north of F&B). Both wells are upgradient of the Site.

The Salt River Project (SRP) operates nine irrigation wells and the Grand Canal in the general area of the Site, none of which are within the current plume footprint. The Grand Canal runs east to west and is located south of the Site. SRP well 9.5E-7.7N is within a 1-mile radius of the Site (located approximately 2,500 feet to the south and crossgradient). SRP currently does not plan to install more wells in the area but may add a drinking water treatment plant to the Grand Canal in the future. If the Grand Canal is used as a drinking water supply in the future, discharges to the canal, including those at well 9.5E-7.7N would be held to more stringent water quality criteria.

Potential future exposure pathways at the Site include groundwater use for irrigation purposes (no wells are present in the current plume). Other potential exposure pathways are human contact with soil (construction scenario) and inhalation of vapor if vapor intrusion were to occur. Vapor intrusion is currently being controlled in the source area at F&B by the operation of the SVE system.

Groundwater is not currently used as a potable water source in the area of contamination; however, the resource is designated as a potential source of potable water. The 2009 RI includes a Land and Water Use Survey which indicates that future groundwater uses in the general area of the Site may include the following:

1. The COP anticipates the possible need for well expansion in the WCP area at some time in the future.
2. The SRP owns several wells in the area and will continue to need the wells to be operational in order to supplement surface-water supplies (and there may be a change from irrigation to drinking water).

### 2.3.8 Contaminants of Concern and Applicable Standards

As noted in the beginning of Section 2.0, PCE is the primary COC identified at the Site, along with TCE and 1,1-DCE. These COCs have been identified in soil, soil vapor, and groundwater. Groundwater is the most significantly impacted environmental medium. The relevant soil and groundwater standards for the COCs are shown in Table 2-1.

## 3.0 IDENTIFICATION AND SCREENING OF REMEDIAL MEASURES

This section provides a description of the remedial measures (i.e., specific technologies) screened as part of this FS. The proposed remedial measures include representative active and passive remedial strategies. The active remedial strategies that were evaluated include SVE, thermal treatment for source control, in-situ groundwater treatment via reduction or oxidation, groundwater extraction and treatment, and well-head treatment. Passive remedial strategies (i.e., those that allow contaminants to biologically or chemically degrade over time) include MNA.

Recent analytical data from Site sampling indicate that PCE concentrations in groundwater in some portions of the Site exceed 1,000 µg/L (the AWQS for PCE is 5 µg/L). This area is depicted as the central plume contour (shaded in red) for the upper MAU shown on Figure 2-2. TCE and 1,1-DCE are also present at concentrations that exceed the AWQSs (see Figures 2-6 and 2-7).

In the RI, detections of other compounds are reported in the subsurface media (soil, soil vapor, and/or groundwater). Other VOCs including cis-1,2-dichloroethene (cis-1,2-DCE), TCA, vinyl chloride, benzene, toluene, ethylbenzene, and total xylenes have been detected at concentrations above their respective residential SRLs, GPLs, or AWQSs. In addition, metals including arsenic, beryllium, chromium, lead, and nickel have been detected above residential SRLs and AWQSs at the Pyramid facility. The AWQS exceedances for these other compounds have been limited and sporadic. In general, the concentrations of these secondary compounds are significantly lower than those of the primary COCs and they are not included as COCs in the RI. Remedial actions proposed to address the primary COCs are expected to address any secondary compounds. Recent analytical data from the SVE system operation indicate that VOC contamination in soil vapor remains at the source area of the F&B facility.

Based on these conditions, the general remedial strategies considered in developing alternatives for this FS included the following (adapted from Arizona Revised Statues [A.R.S.] § 49-282.06):

1. Plume remediation to achieve water quality standards for COCs throughout the Site.
2. Physical containment to contain COCs within definite boundaries.
3. Controlled migration to control the direction or rate of migration of COCs in groundwater.
4. Source control to eliminate or mitigate a continuing source of contamination.
5. Monitoring to observe and evaluate the contamination at the Site through the collection of data.
6. No action that consists of no action at the Site.

### 3.1 REMEDIAL OBJECTIVES

The following ROs developed by ADEQ for the Site are described in the Final RI Report (LFR, 2009):

- **ROs for soils and land use in the area of the Site:** *Protect against possible exposure to hazardous substances in surface and subsurface soils that could occur during typical industrial uses.*

- **<u>ROs for current and reasonably foreseeable future groundwater use in and near the Site:</u>** *To protect the supply of groundwater for municipal and irrigation use and for the associated recharge capacity that is threatened by contamination emanating from the WCP North Plume Site. To restore, replace or otherwise provide for the groundwater supply lost due to contamination associated with the WCP North Plume site. This action will be needed for as long as the need for the water exists, the resource remains available and the contamination associated with the WCP North Plume Site prohibits or limits groundwater use.*

## 3.2 ALTERNATIVES SCREENING

This section summarizes the various criteria used to compare remedial measures/technologies in accordance with A.R.S § 49-282.06 and A.A.C R18-16-407(H). A comparative analysis process was used to evaluate and compare the ability of remedial alternatives to achieve the Site ROs. Each remedy is evaluated based on comparison criteria including practicability, cost, risk, and benefit and the capability of achieving the Site ROs. Specific actions (i.e., remedial measures) to be implemented with remedial strategies are described in the following sections.

Based on A.R.S § 49-282.06(A), the remedial actions shall:

1. Assure the protection of public health and welfare and the environment.
2. To the extent practicable, 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.
3. Be reasonable, necessary, cost-effective, and technically feasible.

## 3.3 EXPECTATIONS FOR RESTORATION OF DNAPL SITES

PCE releases from the primary source area at this Site (the former vapor degreaser at the F&B facility) have migrated vertically downward through soil, contributing to the dissolved-phase groundwater plume that has migrated approximately 1,100 feet downgradient. Other smaller source areas have also contributed to the plume, but the release from F&B is the primary source and this VOC plume in groundwater is the primary factor influencing most of the remedial action decisions. The primary hazardous substance release identified at this Site involves chlorinated VOCs released from a vapor degreasing operation. This type of release (i.e., a neat solvent from a degreasing operation), historical groundwater concentrations, and historical soil vapor concentrations indicate the presence of solvent as DNAPL. It is likely that some DNAPL remains as ganglia within finer grained layers in the vadose zone, and it is possible that some may have migrated down to and into the saturated zone. Treatment of DNAPL source areas is challenging because of the difficulty of identifying the location and distribution of DNAPL. In addition, few technologies (if any) have demonstrated a proven ability to effectively remove or destroy sufficient VOC mass from the source zone to fully restore sites in a reasonable time frame.

Experience at hundreds of sites nationally has demonstrated that full restoration at DNAPL sites is often not possible. Based on technological limitations, practicable remedies for DNAPL sites must consider source reduction and/or containment of the source areas.

Source reduction is typically preferred over containment remedies because it will result in a reduction in mass flux, a reduction in source longevity, a reduction in risk, and potential enhancement in post-treatment biodegradation potential. In-situ technologies, such as thermal treatment, have a reasonable chance of significantly reducing the DNAPL mass in source areas (up to 95+ percent reductions are documented) but generally have a much higher cost than other alternatives. In addition, thermal technologies function best where the DNAPL source is well bounded in an area and vertical interval that has been thoroughly delineated.

Even with such large reductions in mass, the remaining contaminant mass (after treatment) can still continue to serve as a continuing source of groundwater contamination. Therefore, additional source-zone treatment, containment, and/or long-term monitoring is often required to achieve compliance with the required cleanup objectives.

### 3.4 PERFORMANCE METRICS

Performance metrics for the Site must be tailored to the specific site conditions and nature of the VOC release. Due to the nature and extent of contamination present, specifically the suspected presence of DNAPL, closure to meet the AWQSs (site-wide) is technically infeasible at this time. Groundwater remediation over the entire footprint of the VOC plume does not appear to be technically feasible, practicable, or cost-effective. Anticipated remedial strategies include source control, plume treatment for higher concentration portions of the VOC plume, and controlled migration (including MNA) for lower concentration areas of the VOC plume. A contingency for well-head treatment options should also be considered if future supply wells are impacted by the VOC plume and are intended for use as a drinking water source.

As a DNAPL site, all remedial actions considered should be planned for multiple years of operation. Therefore, it is important to optimize the remedial actions and related performance monitoring for consideration of life-cycle costs.

### 3.5 DESCRIPTION OF POTENTIAL REMEDIAL MEASURES

The remedial measures that were screened as part of this FS include:

1. No action (as a baseline);
2. SVE;
3. In-situ thermal treatment;
4. In-situ chemical oxidation (ISCO);
5. Biological treatment/enhanced reductive dechlorination (ERD);
6. MNA;
7. Groundwater extraction and treatment; and
8. Well-head treatment.

A brief description of each remedial measure is presented in the following subsections.

### 3.5.1 Remedial Measure 1: No Action

This action would neither involve the implementation of remedial actions to address groundwater contamination nor prevent human or ecological exposure to groundwater contamination. The "no-action" alternative is included for use as a baseline for comparison to other potential remedial alternatives but is not retained for further evaluation because it would not achieve the ROs.

### 3.5.2 Remedial Measure 2: Soil Vapor Extraction

SVE is a proven and effective remedial action that removes VOCs from subsurface soils in the unsaturated (vadose) zone and has been successful in reducing VOC source mass at the Site. SVE can also be effective in reducing DNAPL in the vadose zone when the specific areas of DNAPL have not been precisely identified. SVE uses a vacuum applied to the unsaturated zone by extraction wells near the source of soil contamination. With the applied vacuum, soil vapor containing VOCs is drawn toward the extraction wells, and the extracted vapors are then treated at the surface prior to discharge.

SVE has been retained as a remedial measure for further consideration because it is a proven technology for the removal of chlorinated VOCs from the vadose zone and has been proven to be an effective source removal technology at this Site. The geologic conditions at the Site are conducive to SVE, because the upper vadose zone soils consist primarily of permeable sands. SVE is less effective at removing VOCs from finer grained material, such as silt layers/lenses.

### 3.5.3 Remedial Measure 3: In-Situ Thermal Treatment

Similar to SVE, this remedial technology applies the same principles of vapor extraction, combined with the addition of heat (e.g., typically either steam injection or electrical-resistance heating [ERH]). As the soil is heated, volatile contaminants in the soil are destroyed or volatilized, then extracted via SVE wells and treated at the surface prior to discharge. Thermal treatment can be effective for the partial removal of DNAPLs. The energy required for heating is a significant portion of the remedial action costs (~20 percent), and the energy required to treat (and heat) saturated zone source areas is much higher than that required for vadose zone areas.

In-situ thermal treatment via steam injection or ERH has been proven effective for the removal of volatile contaminants at sites with well-bounded source areas, including DNAPL. Under the right conditions, thermal treatment has demonstrated the ability to remove greater than 95 percent of the source mass in the targeted treatment zone. Thermal treatment can be effectively implemented to the depths of contamination present at this Site, but installation requires open access to the targeted treatment area (nearly unrestricted access to place wells, conduit, and electrical cables on a grid of 15-foot centers). Access can be a significant challenge within operational facilities that have ongoing manufacturing operations. Thermal treatment has a short restoration time frame and contaminant removal from the subsurface is typically completed in 1 year or less of active heating. A thermal treatment application at this Site was considered for the vadose zone source control but not for the saturated zone (due to the much larger impacted area). Therefore, other technologies would be required after the completion of thermal treatment to treat or degrade the groundwater plume.

Thermal treatment has been retained for further evaluation as a source removal technology for the Site because of its effectiveness in chlorinated VOC and DNAPL destruction in a relatively short time period.

### 3.5.4 Remedial Measure 4: In-Situ Chemical Oxidation

This remedial technology is an aggressive technology that involves the injection of a chemical oxidant into groundwater via a series of injection wells (or other injection methods) to destroy or degrade organic compounds, including DNAPL source zones. ISCO consists of chemical reactions that convert contaminants into less toxic or inert compounds. Several different types of oxidants have been used successfully at chlorinated solvent sites, including permanganate, persulfate, hydrogen peroxide and iron, and ozone. Site-specific aquifer oxidation-reduction (redox) conditions and parameters, along with oxidant-specific characteristics, need to be evaluated to determine the oxidant dosing and other critical design parameters. Pilot testing and/or bench testing is necessary to establish the injection spacing, rates, and oxidant dosing. Although targeted for destruction of dissolved VOCs in water, the oxidizing agent will react with the soil matrix; therefore, the radius of influence from the injection points will be limited.

ISCO has not been retained because, at this Site, it is not considered a cost-effective or feasible technology due to complexities associated with oxidant demand from the soil, the depth and size of the plume, the presence of a large source mass (including DNAPL) in the vadose zone, and the depth to groundwater at the Site.

### 3.5.5 Remedial Measure 5: Biological Treatment/Enhanced Reductive Dechlorination

ERD is a remedial technology based on injecting substrates/nutrients into groundwater to promote anaerobic biodegradation. Anaerobic reductive dechlorination is a naturally occurring biodegradation process whereby microbes can degrade chlorinated VOCs in groundwater. The microbes use a primary substrate as a carbon and energy source, producing enzymes and other compounds that degrade the target chlorinated compounds present in groundwater. Most applications use a bio-stimulation substrate to provide a carbon source for driving the aquifer redox conditions lower and at the same time provide a fermentation substrate that releases hydrogen to serve as an electron donor (required for the dechlorination reactions). A variety of compounds have been used as bio-stimulation amendments for ERD applications. Bio-augmentation is a subsequent step, required for some but not all sites, during which a microbial mixture is injected into groundwater to initiate or accelerate key dechlorination steps. Depending on the contaminants present and the subsurface conditions, a variety of microbial cultures have been developed and are marketed by specialty vendors.

As with any in-situ technology, success depends on the ability to deliver the reagent to the impacted areas. ERD is only applicable to the saturated zone, and typically it must be combined with source zone treatment of any VOC residues in the vadose zone. However, with an effective ERD treatment zone in groundwater, the extent of the vadose zone treatment may be reduced because the rapid degradation in groundwater is less sensitive to continuing contributions from the vadose zone.

Biological treatment via ERD has been retained as a viable technology for plume treatment because it has been proven to be effective for enhancing and accelerating the reduction of PCE concentrations in groundwater at similar sites. Natural dechlorination processes have been observed in downgradient portions of the Site plume, so this technology applied in source area(s) would likely accelerate dechlorination processes in other areas of the plume (over a much larger footprint and as a complement to the MNA portion of a remedy). ERD implementation involves periodic injection of substrates and nutrients by means of injection wells and may include bio-augmentation.

### 3.5.6 Remedial Measure 6: Monitored Natural Attenuation

MNA is a remedial process that involves routine groundwater sampling and analysis to monitor the results of one or more naturally occurring physical, chemical, or biological processes that reduce the mass, toxicity, volume, or concentration of chemicals in groundwater. MNA is a mechanism by which COCs are reduced (often slowly) by natural means without other control, removal, treatment, or aquifer-modifying activities. These in-situ processes may include biodegradation, dispersion, dilution, sorption, and volatilization of contaminants. MNA is not typically implemented as a sole remediation method while source areas remain (i.e., DNAPL). This remedial measure typically requires groundwater monitoring over a period of many years to verify that attenuation is occurring and to ensure that progress is made in terms of meeting the ROs.

MNA is not capable of significantly reducing contaminant mass at DNAPL sites and, therefore, cannot meet the Site ROs within a reasonable restoration time frame by itself. However, natural dechlorination is occurring in some downgradient portions of the plume as evidenced by the presence of PCE daughter products (cis-1,2-DCE and vinyl chloride). Therefore, aquifer conditions indicate that natural attenuation processes will continue to occur for most remedial technologies that may be implemented at the Site. This FS includes MNA as one element of the long-term remedy considered for the Site, particularly for downgradient portions of the plume and has been retained for further evaluation.

### 3.5.7 Remedial Measure 7: Groundwater Extraction and Treatment

This remedial technology involves pumping contaminated groundwater from the plume and treating the groundwater ex-situ before discharge. Groundwater extraction and treatment does remove/reduce contaminant mass from the aquifer but it is generally more effective in controlling (or containing) the downgradient migration of the VOC plume. Contaminated groundwater can be treated by activated carbon, air stripping, oxidation, or by some other means prior to discharge. Discharge options that may be considered include discharge to surface water (or a storm drain connected to surface water), a beneficial re-use such as irrigation supply, or reinjection into the aquifer at some location away from the plume.

Groundwater extraction and treatment is not capable of significantly reducing contaminant mass at DNAPL sites and, therefore, cannot meet the Site ROs within a reasonable restoration time frame by itself. However, it is an effective plume containment approach. This FS includes groundwater extraction and treatment as one element of the long-term remedy considered for the Site, and this remedial measure has been retained for further evaluation.

### 3.5.8 Remedial Measure 8: Well-head Treatment

Well-head treatment is a remedial action that involves treating extracted groundwater with an appropriate method (activated carbon, air stripping, oxidation, or some other means) to meet the applicable criteria for safe drinking water. Typically, this remedial measure is used only when the groundwater resource is currently used as a potable water supply but may also be used for irrigation supply wells if the end use at that time exceeds the applicable criteria. Groundwater at the Site is not currently used as a potable water supply.

Well-head treatment is a feasible technology for treatment of a water supply and can be effectively used as a contingency measure if a supply well (drinking water or irrigation water) is installed in the future. Well-head treatment has been retained for future consideration.

## 3.6 RETAINED REMEDIAL MEASURES

Seven remedial measures have been retained for further evaluation:

1. SVE (vadose zone source treatment);
2. In-situ thermal treatment (vadose zone and potentially saturated source treatment);
3. Biological treatment/ERD (saturated zone source treatment);
4. MNA (plume-wide treatment and monitoring for controlled migration);
5. Groundwater extraction and treatment (primarily for plume containment); and,
6. Well-head treatment as a contingency measure.

These remedial measures have been evaluated, assembled as alternatives and further screened in the subsequent sections of this FS. The retained remedial measures were used to develop the proposed reference remedy and the more aggressive and less aggressive alternative remedies. Section 4.0 provides a more detailed evaluation of each of the remedies, including their ability to achieve the groundwater ROs, their compatibility with applicable regulations, their effectiveness at treating the target contaminants, their operational and maintenance requirements, and their overall costs.

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## 4.0 REFERENCE REMEDY AND ALTERNATIVE REMEDIES

This section includes descriptions of a reference remedy (Section 4.1) and two alternative remedies (more aggressive and less aggressive, Sections 4.2 and 4.3 respectively) that were developed to achieve the Site ROs and to satisfy the requirements of A.R.S. § 49-282-06 (A &B).

### 4.1 REFERENCE REMEDY

The reference remedy includes a combination of the remedial measures identified in Section 3.0 that, when combined, are capable of achieving the Site ROs. The proposed reference remedy includes:

1. Vadose zone source control (SVE for the source area soil/soil vapor at F&B)
2. Saturated zone source/plume treatment (using biological treatment/ERD for in-situ plume treatment in groundwater), and
3. Plume migration control/monitoring (MNA to verify degradation of COCs and plume stability)

Following the requirements of A.A.C R18-16-407, the reference remedy for the Site was developed using engineering, geological, and/or hydrogeological standards of practice. The reference remedy considers the information and analytical data presented in the RI, the best available scientific information regarding applicable remedial technologies, and a preliminary review of the comparison criteria.

#### 4.1.1 Vadose Zone Source Control: Soil Vapor Extraction

Continued operation and optimization of the SVE system at F&B should contain the soil vapor plume and will continue to remove VOC mass present in the vadose zone; the benefit derived from this SVE operation is primarily the control/removal of PCE residues from the vadose zone that would otherwise serve as a long-term source of groundwater contamination. The decrease in groundwater elevations at the Site over the past several decades has resulted in a recently exposed vadose zone (at depth near the zone that is a suspected DNAPL source area), and the recent installation of three deeper SVE wells will likely be beneficial for continued mass removal to reduce the source of groundwater impact. As previously mentioned, the SVE system had removed approximately 47,000 pounds of VOCs as of January 2015. Current SVE system operation is removing approximately 12 pounds of VOCs per day (primarily as PCE).

The SVE system consists of eight SVE wells placed at varying depths within the vadose zone beneath the former vapor degreaser at F&B (the primary source of release of PCE to the subsurface). As-built details of the SVE system installation at F&B could not be located; however, the layout of the SVE system based on recent SVE system inspections and operational tests is shown in Figure 4-1. Recent PCE monitoring data from the SVE wells (data that can be used to optimize system performance) are shown in Figure 4-2.

Optimization of the SVE system would likely include the following techniques or combination of techniques:

- **Focused Extraction:** The existing SVE system can be optimized to enhance the removal of the remaining mass by focusing extraction on existing wells that are more effective at extracting source area VOCs (as evidenced by regular field monitoring) and by shutting off extraction wells that no longer appear to be effective in removing VOCs. Routine monitoring will allow periodic shifting of active wells to maximize source removal. This type of remedial optimization is presently underway and an additional planned change is the use of selected SVE vent wells as air infiltration points to change the vapor flow paths.

- **Pulsed Operation:** As the remaining VOC mass becomes more diffusion-limited, SVE operation can be transitioned to a periodic or "pulsed" operation such that active extraction occurs in intervals separated by periods of no extraction. Pulsed extraction is unlikely to increase the mass removal rate but may significantly decrease the operating expense (for a reduced, but sufficiently effective, mass removal rate). The intent of pulsed SVE operation is to allow diffusion from low-permeability lenses into more permeable pathways and then periodically remove the vapors from those more permeable layers. An example is that an SVE system may be operated for 1 week once every 2 months (an ~11 percent run-time operation cycle), which could reduce the operating costs by 75 to 80 percent. Another version of pulsed operation is vapor extraction based on barometric pumping which is similar to vapor extraction but relies on natural variations in barometric pressure rather than a vacuum blower to create the flow of soil gas through the subsurface[2]. Vapor extraction based on barometric pumping would be limited to much lower total airflow rates (compared to current operations) but still may be effective for long-term operations.

- **Additional SVE Wells:** Three SVE wells (SVE-6, SVE-7, and SVE-8) were recently installed deeper than the previously installed SVE vent wells to target the deeper vadose zone because the groundwater elevation has declined approximately 30 feet since the mid-1990s. Recent testing/remedial optimization indicates that these new extraction wells appear to be effective in recovering additional VOC mass that has been more recently exposed. Although not deemed necessary at this time, additional SVE vent wells may be added to the existing system if warranted in the future.

The SVE system will be optimized to allow a more efficient and cost-effective operation and will be operated until asymptotic concentrations are achieved. Because a substantial source mass (including the potential presence of DNAPL) exists in the treatment area, the achievement of asymptotic concentrations is expected to occur over a long period of time, likely 5 to 10 years, or potentially longer. The effectiveness of the SVE system will primarily be evaluated by the total mass of PCE removed from the vadose zone and the related impact on groundwater concentrations in this area (combined with ERD groundwater plume treatment). This FS assumes 7 years of active SVE operation

[2] On a daily basis, barometric pressure varies slightly because of heating/cooling cycles. Wider variations in barometric pressure are typically seen over a span of days as weather fronts move in and out of an area. As the barometric pressure changes, a pressure gradient is established between the atmosphere and air voids in subsurface soil. Air flow to vent wells is created (both into and out of) the subsurface soil in response to the gradient created by changes in barometric pressure. Using a check valve to restrict the flow solely to extraction (rather than both extraction and injection), the pressure gradient created by changes in barometric pressure causes subsurface air to flow to the vent well. The deeper vent wells at this Site are anticipated to take advantage of the greatest pressure differential.

and optimization followed by significantly reduced operations (reduced by approximately 90 percent) over the next 13 years (for a total operation period of 20 years). An example of significantly reduced operations includes operating the SVE system, or portions of the system, for 1 week every 2 to 3 months.

Effective implementation of ERD to treat source area groundwater may also reduce the required operating period for the SVE system. As noted in the initial screening of remedial measures, an effective ERD treatment zone in groundwater may reduce the extent (and related duration) of necessary vadose zone treatment because of the rapid degradation within groundwater. Under these conditions, the underlying groundwater is less sensitive to continuing contributions from the vadose zone sources.

### 4.1.2 Saturated Zone Source/Plume Remediation: Enhanced Reductive Dechlorination

Implementation of an ERD remedy for groundwater plume remediation is proposed for the area of the plume with PCE concentrations greater than 1,000 µg/L in the upper MAU plume (red plume contour shown in Figure 2-2). The proposed ERD injection well layout would consist of three transect lines of injection wells, spaced approximately 40 to 50 feet on center. The downgradient spacing between injection transect lines would be roughly 150 feet. This proposed spacing would require the installation of 30 injection wells, as shown in Figure 4-3. Injection wells would be screened in the upper MAU to target the most impacted groundwater zone, primarily at depths between 150 and 225 feet bgs.

Biological treatment would consist of the injection of a carbon-source electron donor substrate such as a soluble food-grade sucrose-based solution or edible oil substrate (EOS). Bio-augmentation would likely be necessary after substrate injection and would involve the injection of dechlorinating bacteria directly into the aquifer. A pilot test would be necessary to determine the most-appropriate substrate for the Site and the extent of bio-augmentation needed. Substrate injections would occur several times over a period of 2 years (depending on the type of substrate chosen) and then would decrease in frequency or cease once the VOC concentrations have decreased to levels sufficient for MNA processes to control the remaining plume (expected within a 5 to 10-year time frame).

As an expanded option of the reference remedy (described as reference remedy b), an expanded network of injection wells may be placed to target PCE concentrations greater than 100 µg/L (the transect lines would span both the red and brown plume contours shown on Figure 2-2). This expanded option of the reference remedy (hereafter referred to as reference remedy b) is primarily intended to address the next phase of the remedy related to the portion of the plume subject to MNA (i.e., what level of source zone and plume treatment is necessary to make the MNA program successful and reliable). This expanded option of the reference remedy (reference remedy [b]) would also include a fourth row of injection wells as shown in Figure 4-4 (for a total of 43 injection wells). The injection frequency would be consistent with the baseline reference remedy.

### 4.1.3 Plume Control/Monitoring: Monitored Natural Attenuation

Degradation is currently occurring in the downgradient portions of the plume, as documented by the presence of PCE daughter products (TCE, cis 1, 2-DCE, and vinyl chloride) and will continue to be

monitored until the cleanup levels are achieved, which will likely take many years. The combination of MNA in areas of the plume with lower COC concentrations and more active source control (SVE) and plume remediation (ERD) in areas of the plume with higher concentrations would be a reasonable approach to Site remediation.

MNA as part of the reference remedy would involve routine groundwater monitoring of key monitoring wells, including monitoring of natural attenuation parameters and the collection of analytical data for chlorinated VOCs. This is expected to include semi-annual monitoring of key monitoring wells (assumed to be 12 monitoring wells) and annual monitoring that includes a more comprehensive monitoring well network, primarily in the upper and middle MAU (assumed to be approximately 40 monitoring wells) for a period of 10 years. After 10 years of monitoring, the well network would be revised to include a more focused subset of monitoring wells (assumed to be 20), and sampling would continue for an additional 15 to 25 years. The locations of the wells in the current monitoring well network in the upper and middle MAU are shown in Figures 2-3 and 2-4, respectively. As an estimate, this FS assumes that an additional five monitoring wells may be necessary for sufficient monitoring of the upper MAU because several wells have been dry in recent years due to the declining water table. The implementation of ERD combined with MNA in the reference remedy is anticipated to have significant synergistic effects. The benefits from the ERD portion of the remedy are expected to include a 99 percent reduction in source zone concentrations and, at the same time, more rapid dechlorination rates over a wider footprint of the plume, where the MNA will be implemented. The general layout of monitoring wells that may be considered for the MNA element of this remedy is shown in Figure 4-6.

## 4.2 MORE AGGRESSIVE REMEDIAL ALTERNATIVE

Development of the more aggressive remedial alternative includes evaluating a combination of strategies that are primarily intended to achieve the Site ROs in a shorter time period. As proposed, the more aggressive remedial alternative includes elements of the reference remedy with different modifications/enhancements.

For the vadose zone treatment of source area soils, the only practical enhancement beyond the existing SVE included in the reference remedy is thermal treatment (a significant enhancement to the SVE system), which uses heat to accelerate the VOC removal from soils. Thermal treatment is expensive; an application for vadose zone treatment at the Site is expected to cost between $5M and $6M[3]. Thermal treatment was carefully considered for this Site in the late 1990s/early 2000 time frame. A decision was made at that time to implement the SVE system (as it currently exists) as an Early Response Action (ERA). The SVE system has operated effectively, and significant mass removal has been achieved over the operating period. Thermal treatment would accelerate the current mass removal rates and reduce the operating period of vadose zone treatment; however based on the

[3] A price quote was solicited from Thermal Remediation Services (TRS) for the WCP NP Site. Costs for treatment of a vadose zone source were estimated at $3.9M from this subcontractor; including necessary contingencies and other standard fees, the projected costs would be $5M to $6M. The ERH treatment area evaluated would cover approximately 15,000 square feet (100 by 150 feet), with an estimated treatment volume of 28,000 cubic yards of soil. This conceptual design included installation of electrodes and co-located vapor recovery wells, with 15-foot spacing in the treatment area (approximately 77 electrodes and vapor recovery wells) to a depth of 120 feet bgs.

effective SVE operations (already existing at this Site), the incremental expense for enhancements derived from thermal treatment is not cost-effective. Therefore, the vadose zone treatment of source area soils will remain as described in the reference remedy.

Plume treatment would be accomplished using biological treatment/ERD for a large portion of the VOC plume in groundwater. The proposed injection wells would cover the plume out to a 100 µg/L contour. The MNA element of the reference remedy would be replaced with groundwater extraction treatment for plume containment. This more aggressive remedy provides a strategy that would achieve Site ROs with a higher degree of certainty and should achieve the ROs in a shorter time frame. A conceptual depiction of the more aggressive remedy components is provided in Figure 4-5.

The reference remedy includes a combination of remedial measures that, when combined, are capable of achieving the Site ROs. The more aggressive remedy includes:

1. Vadose zone source control (SVE for the source area soil/soil vapor at F&B);
2. Saturated zone source/plume treatment (using biological treatment/ERD) for the VOC plume out to an estimated level of the 100 µg/L contour; and,
3. Plume migration control/monitoring using groundwater extraction and treatment.

### 4.2.1 Vadose Zone Source Control: SVE Operations

Continued operation and optimization of the SVE system at F&B is proposed for the more aggressive remedy. The same remedial optimization steps and tests presented for the source control discussion for the reference remedy (Section 4.1.1) are proposed for the more aggressive remedy.

### 4.2.2 Plume Remediation: Enhanced Reductive Dechlorination

Consistent with the reference remedy, biological treatment/ERD would be applied in the saturated zone. The proposed approach for implementing ERD in the more aggressive remedy is the same as previously presented in the reference remedy (Section 4.1.2), but would be applied to the larger plume footprint that would be treated as shown in Figure 4-5. The ERD treatment would target PCE concentrations greater than 100 µg/L (spanning both the red and brown plume contours). The conceptual design includes a total of 43 injection wells as shown in Figure 4-5. Substrate injections would occur several times over a period of 2 years (depending on the type of substrate chosen), and then the frequency would decrease or the injections would cease once the VOC concentrations have decreased to levels sufficient for other elements of the remedy to control the remaining plume (expected within a 5 to 10 year time frame).

### 4.2.3 Plume Containment: Groundwater Extraction and Treatment

A groundwater extraction and treatment system would be used for plume containment (as opposed to the MNA used in the reference remedy). Multiple extraction wells (four are included in the conceptual design) would be used to contain the plume (the source area and larger plume would be treated by ERD, as described previously). The extraction wells would be located near the downgradient edge of the plume. The extracted groundwater (an approximate total of 50 gallons per minute (gpm) for plume containment) would be treated with granular activated carbon before

discharge. The potential range of discharge options includes a nearby storm water conveyance system, piping and discharge to the Grand Canal, or reinjection to groundwater outside the plume area. The preferred discharge option would be established in the remedial design (based on feasibility and cost considerations).

## 4.3 LESS AGGRESSIVE REMEDIAL ALTERNATIVE

In accordance with A.A.C. R18-16-407 (E)(3), one of the alternative remedies must use a remedial strategy or combination of strategies that is less aggressive than the reference remedy but still be capable of achieving the defined Site ROs, and it may use less intensive or fewer remedial measures than the reference remedy. The proposed less aggressive remedial alternative includes some elements of the reference remedy but relies more heavily (and for a longer term) on MNA for the protection of human health and the environment. A general depiction of the components for the less aggressive remedy is shown in Figure 4-6.

The less aggressive remedy includes a combination of remedial measures that, when combined, are expected to be capable of achieving the Site ROs. The less aggressive remedy includes:

1. Vadose zone source control (SVE for the source area soil/soil vapor at F&B);
2. Plume migration control/monitoring (MNA to verify degradation of COCs and plume stability); and,
3. A contingency for well-head treatment at a supply well at some time in the future.

### 4.3.1 Vadose Zone Source Control: Soil Vapor Extraction

Continued operation and optimization of the SVE system will continue to remove PCE from the vadose zone that otherwise would act as a long-term source of groundwater contamination. The SVE system will be optimized as described for the reference remedy to allow a more efficient and cost-effective operation and would be operated as a source control measure until significant improvements in groundwater quality (via MNA) are observed. Because a significant source mass still exists in this area, groundwater quality improvements are expected to occur slowly over a long period of time, likely 30 to 50 years or more. The effectiveness of the SVE system will primarily be determined by the total mass of PCE removed and the impact on the groundwater concentrations in the plume. Due to the Site conditions (i.e., existing DNAPL source), some form of SVE system operation is expected to be necessary for a long duration. This FS assumes 10 years of active SVE operation and optimization followed by significantly reduced operations (an approximately 90 percent reduction) over the next 40 years. An example of significantly reduced operations includes operating the SVE system, or portions of the system, for 1 week every 2 to 3 months.

### 4.3.2 Plume Control/Monitoring: Monitored Natural Attenuation

For the less aggressive remedial alternative, MNA would be relied upon for plume control and ultimate degradation of chlorinated VOCs for the extent of the plume. MNA would involve routine groundwater monitoring of key monitoring wells, including monitoring of natural attenuation parameters and the collection of analytical data for chlorinated VOCs. This is expected to include annual monitoring that includes a monitoring well network, primarily in the upper and middle MAU

(assumed to include 40 wells) for a period of 10 years. After 10 years of monitoring, the well network would be revised to include a more focused subset of monitoring wells (assumed to include 20 wells), and sampling would continue annually for an additional 40 years. An example of the locations of wells to be included in the MNA monitoring well network is provided in Figure 4-6. As an estimate, this FS assumes that an additional five monitoring wells may be necessary for sufficient monitoring of the upper MAU because several wells have been dry in recent years due to the declining water table.

Full restoration of the Site plume using MNA will be a long process. The MNA element is assumed to continue over a 50-year period. MNA is not expected to fully restore the groundwater at the Site and is not considered capable of achieving the AWQSs within the highest concentration areas of the plume within a reasonable time frame. Based on this expectation, a contingency should be planned in case the plume migrates to a supply well that subsequently needs well-head treatment. This contingency remedial measure using well-head treatment is discussed in Section 4.4

## 4.4 CONTINGENCY REMEDIAL MEASURES

Well-head treatment is a remedial action that involves treating extracted groundwater by an appropriate method (activated carbon, air stripping, oxidation, or some other means) to meet the applicable criteria for its intended use (e.g., drinking water use). In the future, if any potable supply wells are proposed within the Site boundaries or in downgradient areas that may be impacted by plume migration a contingency for well-head treatment is included. A pumping test/yield test and the collection of analytical data from an extraction well would be necessary prior to the activation of the well. These design data for the supply system are necessary to determine the most appropriate method for treatment based on the estimated extraction rates and VOC concentrations.

This FS assumes that treatment using granular activated carbon would likely be the preferred choice and the cost estimate has been developed accordingly. No water supply wells are impacted by the current plume but they could be affected in the future. This FS assumes that this contingent remedial measure may be necessary at some time in the future; for the purpose of the FS cost estimates, a single well-head treatment system is assumed to be necessary in 10 years and then operated for a 20-year period.

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## 5.0 COMPARISON OF THE REFERENCE REMEDY AND ALTERNATIVE REMEDIES

This section summarizes the comparative analysis of the remedies evaluated. It includes an evaluation of the reference remedy, the less aggressive remedy, and the more aggressive remedy in terms of performance relative to the evaluation criteria summarized in A.A.C. R18-16-407. The reference remedy, more aggressive remedy and less aggressive remedies meet the Site ROs and are anticipated to be consistent with long-term plans of local water providers. However, additional input from potentially affected water providers may be required to determine how and when a well-head treatment contingency could be implemented. No active supply wells are currently impacted. Tables summarizing the comparative analysis from this Section are presented in Tables 5-1 and 5-2.

### 5.1 THRESHOLD CRITERIA

Each remedial alternative must meet two threshold requirements:

1. The remedy must achieve the Site ROs (A.A.C. R18-16-407.H.1); and,
2. The remedy must include an evaluation of the consistency with water management plans of affected water providers and the general land use plans of local governments with land use jurisdiction (A.A.C. R18-16-407.H.2).

The following discussion in this section applies to all of the remedial alternatives evaluated. All of the remedies presented have been developed to meet the Site ROs. Based on the Site conditions and relevant exposure pathways, this FS focuses primarily on groundwater contamination, but each of the remedies considered also includes treatment of soil in the primary source area. The remedies include a SVE component (coupled with the existing industrial/commercial land use) to protect against possible exposure to hazardous substances in subsurface soils that may occur during typical future industrial uses.

The Site is a DNAPL site and restoration to meet AWQS in the area near the primary release (i.e., the F&B facility vapor degreaser) is technically infeasible within a reasonable restoration timeframe. The objective is to reduce the source and contain the plume so that wider areas are not impacted for future water supply development options. These actions are anticipated to be consistent with the water management plans of local water providers; no active supply wells are impacted by the current plume and remedial actions are proposed to restore water quality and contain the plume.

With regards to land use and impacts, the proposed remedial actions are expected to be consistent with the existing land use (industrial). The detailed summary of each remedy is presented in Section 4 and the comparative evaluation is summarized in the following Sections.

## 5.2 COMPARISON CRITERIA: PRACTICABILITY, RISK, COST, AND BENEFIT

Based on the objectives outlined in A.A.C. R18-16-407.H.3, each remedy presented is evaluated for practicability, risk, cost, and benefit. The following subsections describe the evaluation and comparison of the remedies in terms of these criteria.

### 5.2.1 Practicability

Each proposed remedy is evaluated in terms of its practicability, including feasibility, short- and long-term effectiveness, and reliability. The site-specific conditions, characteristics of the contamination resulting from the release, t performance capabilities of available technologies, and institutional factors are also considered.

**Reference Remedy:** The reference remedy includes a combination of SVE for source-area soils, hot spot or expanded plume area groundwater treatment (using ERD) and MNA. It is a feasible and practicable remedial solution for the Site. It provides both short- and long-term effectiveness for plume remediation, vadose zone control, and plume monitoring. The reference remedy combines proven and reliable technologies known to effectively reduce contaminant concentrations in both soil and groundwater to meet the ROs. These actions are expected to be generally consistent with plans of potentially affected water providers and their long-term plans.

Given that this remedy uses the currently installed SVE system at F&B, the practicability and effectiveness of continued operation of the SVE system is known. The optimization of the SVE system, including the recent addition of more extraction wells to the network, will increase the overall performance of the system, resulting in greater long-term effectiveness.

The ERD component of this remedy has been used effectively across the United States to substantially reduce chlorinated solvent concentrations in groundwater; concentration reductions of 99+ percent (and up to 99.9 percent) have been documented on large chlorinated solvent plumes. Thus, the technology has been proven and shown to be reliable. By specifically targeting the highest concentrations of PCE in the groundwater plume, this remedial approach will provide both short- and long-term effectiveness in reducing VOC concentrations and plume expansion in groundwater.

The MNA component of this remedy is a proven remedial strategy when the site conditions are appropriate. It provides both short- and long-term effectiveness. The existing Site data indicate that selected downgradient portions of the plume demonstrate attenuation by both degradation and dispersion. Long-term monitoring (the monitoring portion of MNA) has been occurring over the past 20 years, and it is anticipated to continue for years into the future. When coupled with the ERD

component of the plume treatment, the MNA component of the reference remedy is anticipated to provide reliable short-term and long-term effectiveness/performance.

In summary, the reference remedy is a reliable, practicable and feasible remedial alternative that takes into account institutional factors. It provides both short-term and long-term effectiveness in reducing COC concentrations in soil and groundwater. The reference remedy is expected to be generally consistent with plans of local water providers and their long-term plans.

**More Aggressive Remedy:** The more aggressive remedy includes SVE and ERD for source and plume control, and groundwater extraction and treatment for plume containment. This remedy is considered a practicable remedial solution for the Site conditions. SVE, ERD, and extraction/treatment are reliable and proven remedial technologies. By using aggressive source control actions, and plume treatment and containment to the extent technically feasible, this alternative should provide both short-term and long-term effectiveness. Long-term actions include plume containment. These actions are expected to be generally consistent with plans of potentially affected water providers and their long-term plans. The ROs for the Site would be met.

Given that the more aggressive remedy uses all the components of the reference remedy except MNA, while incorporating additional groundwater extraction and treatment, the practicability of the more aggressive remedy meets and exceeds that of the reference remedy discussed previously (reliable short-term and long-term effectiveness/performance).

**Less Aggressive Remedy:** The less aggressive remedy is the reference remedy without the ERD groundwater remediation component and with the addition of well-head treatment as a contingency. The practicability characteristics of the less aggressive remedy are similar to those of the reference remedy but it relies much more heavily on MNA and a contingency for well-head treatment in the future. The MNA element of this remedy will be implemented, but the plume is expected to migrate which may result in future exposure and risk. Based on this condition, a contingency for well-head treatment is considered necessary.

Well-head treatment is considered a practicable remedial solution (as a contingency) if a water supply well is impacted in the future. Well-head treatment is a reliable and proven remedial technology. It would be considered if a local water provider needed to develop groundwater in the vicinity of the Site for potable water supply. Use of well-head treatment would provide both short-term and long-term effectiveness because water supply regulations (and requisite monitoring) would ensure that the water supply is effectively treated. Well-head treatment is expected to be generally consistent with plans of potentially affected water providers and their long-term plans. However, the specific details would need to be established at such time as a potable water supply was to be developed. With the installation of a well-head treatment system, the ROs for the Site would be met.

### 5.2.2 Risk

Each proposed remedy is evaluated for risk, including the overall protectiveness of public health and aquatic and terrestrial biota under reasonably foreseeable scenarios for future use and end uses of water. The comparative analysis of this factor considers the following aspects:

1. Fate and transport of contaminants and concentrations and toxicity over the life of the remediation;
2. Current and future land and resource use;
3. Exposure pathways, duration of exposure, and changes in risk over the life of the remediation;
4. Protection of public health and aquatic and terrestrial biota while implementing the remedial action and after the remedial action; and,
5. Residual risk in the aquifer at the end of remediation.

The primary impacted media at the Site is deep groundwater and no risks/impacts to existing aquatic and terrestrial biota are anticipated.

**Reference Remedy:** As noted, the SVE system is already installed at the Site and operating successfully; therefore, current site risks from a vapor pathway are low and have been mitigated. Multiple site assessments and remedial investigations have defined the nature and extent of VOCs in soil. The fate and transport of soil vapor within the Site is readily predicted under the influence of the SVE system. The SVE system removes contaminants from soil and treats them with granular activated carbon before discharge to air. Future land use at the Site is not expected to change from the current mixed industrial; therefore, the risk of exposure to any other COC residues in subsurface soils is considered low.

The ERD component of the remedy is an in-situ treatment process (no discharges), and the COC degradation would reduce future risks (i.e., the concentration and related toxicity of Site contaminants would be reduced).

The MNA component of the remedy is considered protective of public and ecological health because the current exposure pathway to Site groundwater is incomplete. Based on current and historical groundwater data, PCE appears to be slowly attenuating near the leading edge of the plume as a result of degradation and dispersion. The groundwater in the area of the Site is not used for drinking water; however, groundwater is designated as a potable resource for the future, if needed. Residual risk during implementation and after the completion of remediation is low; there is no current exposure pathway.

In summary, the combined components of the reference remedy are consistent with current and anticipated future land and resource use. All known exposure pathways are addressed, and the remedial actions will reduce concentrations such that future foreseeable use of land and the groundwater resource will meet the acceptable risk thresholds. Groundwater monitoring (as part of MNA) is included to verify that the remedy is protective of public health and aquatic and terrestrial biota during and after remedy implementation. As noted in the basic expectations for DNAPL site restoration, some residual contamination is expected to remain in the aquifer at the completion of remediation.

**More Aggressive Remedy:** The more aggressive remedy is a low-risk remedial alternative that is protective of human health, ecological health, and the environment. Additionally, given that the more aggressive remedy uses all the components of the reference remedy except MNA, while incorporating additional groundwater extraction and treatment (noted below), the risk associated with its implementation is less than or equivalent to that of the reference remedy noted above.

The groundwater extraction and treatment system (used for plume containment) would remove additional contaminants from groundwater and treat them with granular activated carbon before discharge or reinjection. All COCs are treated to applicable standards prior to discharge, and the treatment processes include monitoring to verify effectiveness. Thus, potential human and ecological exposure to Site contaminants is low.

**Less Aggressive Remedy:** Because the less aggressive remedy is similar to the reference remedy (with the exception of the ERD groundwater remediation component) and the addition of well-head treatment (as a contingency), the risk associated with this remedial approach is considered low.

Well-head treatment of a water supply well is a low-risk remedial alternative that is protective of public and ecological health because contaminants are treated to applicable standards prior to delivery into the water supply system. Thus, potential human and ecological exposure to groundwater contamination is mitigated. Well-head treatment would not affect the current and future use of the Site, but residual risk will remain in the aquifer.

### 5.2.3 Cost

Each proposed remedy is evaluated in terms of its costs including: capital costs, operating costs, maintenance costs, transactional costs necessary for implementation, and life-cycle costs. The comparison of costs for the reference remedy, more aggressive remedy, and less aggressive remedy are summarized in Table 5-2. Details of the cost estimates for each remedy are included in Appendix A.

The estimated costs for the proposed remedial actions evaluated in this FS include construction costs that are expended at the initiation of the project (e.g., capital construction costs in the first year) and costs in subsequent years that are required to implement and maintain the remedy (e.g., annual operations and maintenance [O&M] costs and other periodic costs). Present value analysis is the common economic method used to evaluate expenditures, including both capital and O&M costs, which occur over different time periods. This standard methodology allows for cost comparisons of different remedial alternatives on the basis of a single, comparable cost basis for each alternative (i.e., the Net Present Value).

**Reference Remedy :** The active operation of the SVE system is expected to continue for approximately 7 years with additional optimization and reduced operation for the next 13 years. The treatment of the groundwater via ERD is expected to take place over a 5- to 10-year time frame, with groundwater monitoring (MNA) expected over the entire 35-year time frame. The overall costs of the reference remedy (as option a, see Figure 4-3) for installation, O&M, and monitoring over a 35-year period would be approximately $5.43M without a well-head treatment contingency and $10.38M with the well-head treatment contingency (if required). The overall costs of the reference remedy as option b (see Figure 4-4) would be approximately $6.13M without a well-head treatment contingency and $11.08M with the well-head treatment contingency (if required).

**More Aggressive Remedy:** Because the more aggressive remedy includes the additional remedial component of extraction and treatment, it has higher costs than the reference remedy. The additional groundwater treatment system is assumed to operate for 20 years. The overall costs of installation, O&M, and monitoring over a 35-year period would be approximately $8.46M without a well-head treatment contingency and $13.41M with the well-head treatment contingency (if required).

**Less Aggressive Remedy:** The less aggressive remedy combines the components of the reference remedy (except for the ERD groundwater remediation component) with additional well-head treatment, as a contingency. Well-head treatment is expensive, relative to the other remedial technologies for the Site and would be planned as a long-term O&M cost (if the contingency is required). The overall costs of installation and O&M over a 50-year period would be approximately $4.92M without a well-head treatment contingency and $9.87M with the well-head treatment contingency (if required).

### 5.2.4 Benefit

Each proposed remedy is evaluated in terms of the benefit, or value, of the remediation. This comparative analysis includes the following factors:

1. Reduced risk for humans and aquatic and terrestrial biota;
2. Reduced concentration and reduced volume of contaminated water;
3. Decreased liability; acceptance by the public;
4. Aesthetics; preservation of existing uses;
5. Enhancement of future uses; and,
6. Improvements to local economies.

**Reference Remedy:** The combination of SVE, ERD, and MNA in the reference remedy provides substantial benefit. All of the components of this remedial alternative are proven remedial technologies that have been successfully implemented across the United States and accepted by the public stakeholders. This remedy would result in limited impact on current and projected future use of the Site. As noted in Section 5.2.2, the risk for human and ecological receptors associated with this remedy is low.

Operation of the SVE system is expected to continue reducing VOCs in soil, and both the contaminant concentrations in water and the volume of contaminated water will be reduced over time, thereby decreasing future liabilities. The public acceptance of the remedy will be evaluated during the Community Involvement processes. The aesthetics of the project are anticipated to be compatible with the existing and future land use. This remedy is considered to have a neutral impact in terms of enhancement of future land uses and impacts on local economies.

**More Aggressive Remedy:** The more aggressive remedy offers the greatest benefit of the three remedies considered. It lowers future risks for human and ecological receptors by treating all contaminated media, thereby reducing future risks for human and aquatic and terrestrial biota. The more aggressive remedy will also reduce the COC concentrations and reduce the volume of contaminated water to the maximum extent feasible.

Public acceptance of the remedy will be evaluated during the Community Involvement processes. The aesthetics of the project are anticipated to be compatible with the existing and future land use. This remedy is considered to have a neutral impact in terms of enhancement of future land uses and impacts on local economies.

**Less Aggressive Remedy:** This remedy provides the slowest realization of benefits, of the three remedies considered because the highest concentrations of VOCs in groundwater (and thus the overall volume of contaminated groundwater) are not actively treated or reduced. The risk for human and ecological health is monitored (with MNA) and mitigated with a contingency for well-head treatment if a future water supply wells is installed, as necessary. The remediation of soils in the source area included in this remedy effectively reduces the overall Site liabilities (for soils).

With the addition of well-head treatment as a contingency, this remedy offers a benefit comparable to that of the reference remedy. While the principle component of this remedial alternative (MNA) is a proven remedial technology, the acceptance of such a long term remedial approach by public stakeholders will have to be evaluated during the Community Involvement processes. The aesthetics of the project are anticipated to be compatible with the existing and future land use. This remedy is considered to have a neutral impact in terms of enhancement of future land uses and impacts on local economies.

## 6.0 RECOMMENDED REMEDY AND BASIS FOR SELECTION/RECOMMENDATION

Based on the results of the comparative analysis presented in this FS, the reference remedy is the proposed remedy for the Site. As specified in A.A.C. R18-16-407, the rationale for selecting the proposed remedy shall include:

1. How the comparison criteria were considered;
2. How the proposed remedy will achieve the Site ROs; and,
3. How the proposed remedy meets the requirements of A.R.S. § 49-282.06.

### 6.1 COMPARISON CRITERIA

The evaluation criteria, including achievement of the Site ROs, consistency with management plans of local water providers, practicability, risk, cost and benefit, were considered for each of the alternative remedies and discussed in Section 5. The comparison of these criteria, as evaluated in relation to each other, is included in Table 5-1.

All of the remedies considered meet the minimum threshold requirements (meet the ROs, and consider the needs of local water providers that may be impacted in the future). All of the remedies considered effectively address current and anticipated future Site risk. The reference remedy provides the best balance of the practicability, risk, cost and benefit considerations.

### 6.2 ACHIEVEMENT OF THE SITE REMEDIAL OBJECTIVES

As noted in the Introduction, the objective of this FS is to identify and evaluate remedial alternatives to address COCs in soil and groundwater at the Site. Based on the Site conditions and relevant exposure pathways, this FS focuses primarily on groundwater contamination but each of the remedies considered also includes treatment of soil in the primary source area.

The reference remedy meets the Site ROs. The SVE component, coupled with the existing industrial land use, will protect against possible exposure to hazardous substances in subsurface soils that may occur during typical industrial uses. The groundwater component of the remedy (ERD and MNA) are active remedies to restore groundwater quality (the components include source control for mass removal and plume monitoring/migration control). The Site is a DNAPL site and restoration to meet AWQS in the area near the primary release is technically infeasible. The objective is to remove the source and contain the plume so that wider areas are not impacted for future water development options.

### 6.3 REQUIREMENTS OF A.R.S. § 49-282.06

A.R.S § 49-282.06.A requires that remedial actions shall:

1. Assure the protection of public health and welfare and the environment;

2. Provide for the control, management or cleanup of the hazardous substances in order to allow the maximum beneficial use of the [impacted] waters of the state; and,
3. Be reasonable, necessary, cost-effective and technically feasible.

As discussed in this FS Report, the reference remedy meets these requirements. Treatment systems will remove the majority of hazardous substances from soil and groundwater providing for the control and cleanup necessary to allow maximum beneficial use of the groundwater resource. Implementing the reference remedy will be protective of public health and welfare, and the environment. In addition, the reference remedy is reasonable, cost-effective and technically feasible as discussed in this FS Report.

### 6.4 COMMUNITY INVOLVEMENT

The FS Work Plan (Arcadis, 2013) was previously distributed for public review. After ADEQ review of this FS, public notification regarding its completion and availability will be completed in accordance with the Site Community Involvement Plan.

## 7.0 REFERENCES

ADEQ 2014. Fact Sheet for West Central Phoenix WQARF Site, Arizona Department of Environmental Quality, Publication Number: FS 14-05

Arcadis 2013. Final Feasibility Study Work Plan, West Central Phoenix North Plume WQARF Site, Phoenix, Arizona. Prepared for Arizona Department of Environmental Quality. February 2013.

ARCADIS 2014. Summary of Water Level Monitoring and Sampling Activities – September and December 2013, West Central Phoenix North Plume WQARF Site. Prepared for Arizona Department of Environmental Quality. March 2014.

Corkhill, E.F., S. Corell, B.M. Hill, and D.A. Carr. 1993. A Regional Groundwater Flow Model of the Salt River Valley – Phase I Phoenix Active Management Area Hydrogeologic Framework and Basic Data Report, Arizona Department of Water Resources Modeling Report No. 6.

EPA 2000. A Guide to Developing and Documenting Cost Estimates During the Feasibility Study. U.S. Environmental Protection Agency, Office of Emergency and Remedial Response. Washington, D.C. EPA540-R-00-002. July 2000.

LFR 2009. Final Remedial Investigation Report, West Central Phoenix North Plume Site, Phoenix, Arizona. Prepared for Arizona Department of Environmental Quality. January 2009.

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**Tables**

Table 2-1
Summary of Relevant Soil and Groundwater Standards for Primary Contaminants of Concern

| Contaminant of Concern | AWQS (µg/L) | GPL (mg/kg) | Residential SRL (mg/kg) | Non-residential SRL (mg/kg) |
|---|---|---|---|---|
| PCE | 5 | 1.3 | 5.1 | 13 |
| TCE | 5 | 0.61 | 30 | 65 |
| 1,1-DCE | 7 | 0.81 | 120 | 410 |

AWQS – Aquifer Water Quality Standard
DCE – dichloroethene
GPL – groundwater protection limit
PCE – tetrachloroethene
SRL – soil remediation level (A.A.C  R18-7 Appendix A)
TCE – trichloroethene
µg/L – micrograms per liter
mg/kg – milligrams per kilogram

Table 5-1
Summary of Comparison of Reference Remedy and Alternative Remedies

| Remedial Alternative | Will Achieve Site ROs? | Is Action Consistent with Water Management Plans? | Practicability | Risk | Costs | Benefit |
|---|---|---|---|---|---|---|
| **Reference Remedy: SVE (soils),plume treatment with ERD, and MNA** | Yes | Yes (anticipated) | Yes | Low | Moderate | High |
| **More Aggressive Remedy: SVE (soils), plume treatment with ERD, groundwater extraction and treatment (for plume control)** | Yes | Yes (anticipated) | Yes | Low | High | High |
| **Less Aggressive Remedy: SVE (soils), MNA, and well-head treatment as contingency** | Yes | Needs to be determined | Yes | Low to moderate | Moderate (up to high with contingent action) | Medium |

ERD – enhanced reductive dechlorination
MNA – monitored natural attenuation
SVE – soil vapor extraction

Table 5-2

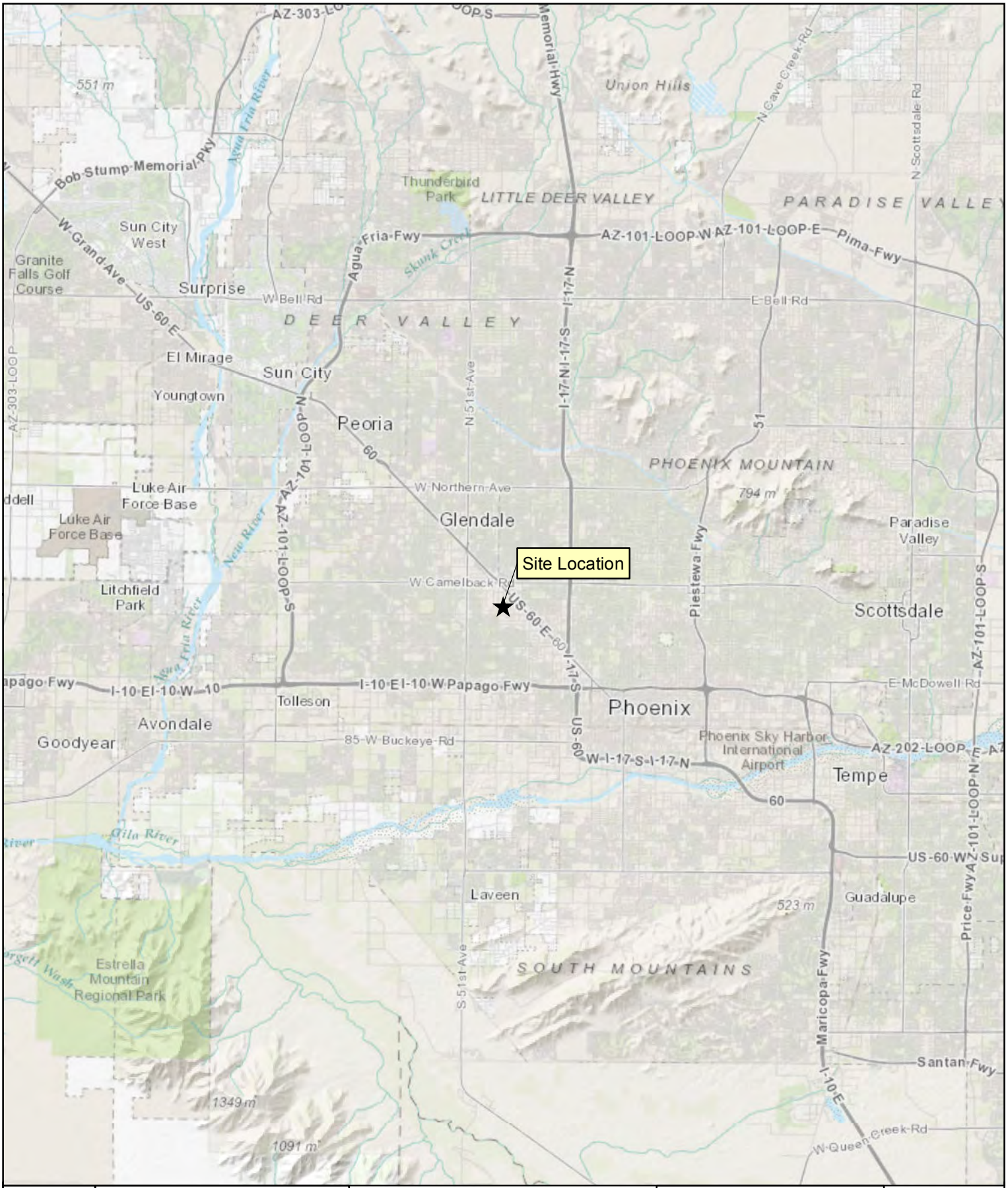
Summary of Relative Cost Comparisons for Remedial Alternatives

| **Alternative** | **Total Cost[1,2]** | **Projected Restoration Timeframe[3]** |
|---|---|---|
| Less Aggressive Remedial Alternative | $4,920,000 | 50 Years |
| Reference Remedy (a) | $5,430,000 | 35 Years |
| Reference Remedy (b) with expanded plume treatment | $6,130,000 | 35 Years |
| More Aggressive Remedial Alternative | $8,470,000 | 30 years |
| Contingency Measure: Well-head Treatment | $4,950,000 | Not Applicable |

Notes:

1. All costs are estimates and should not be interpreted as final construction, or project bid costs. Costs are in present dollars (2016) and do not include inflation.
2. All costs include a 20% markup for project indirect costs (reporting/design/project oversight) and contingency as a FS cost estimate (pre-design).
3. Projected restoration timeframes are estimates to achieve 99% removal/reduction (not AWQS) based on existing Site data and current understanding of the Conceptual Site Model.

**Figures**




Drawn By: JKC

QC'd By:

Drawing Date: 04/03/2015

*Legend*

★ Site Location

0 2 4 Miles

Site Location
West Central Phoenix North Plume
WQARF Site

April 6, 2015

ADEQ Arizona Department of Environmental Quality

Matrix ENVIRONMENTAL

CALIBRE

Figure
1-1

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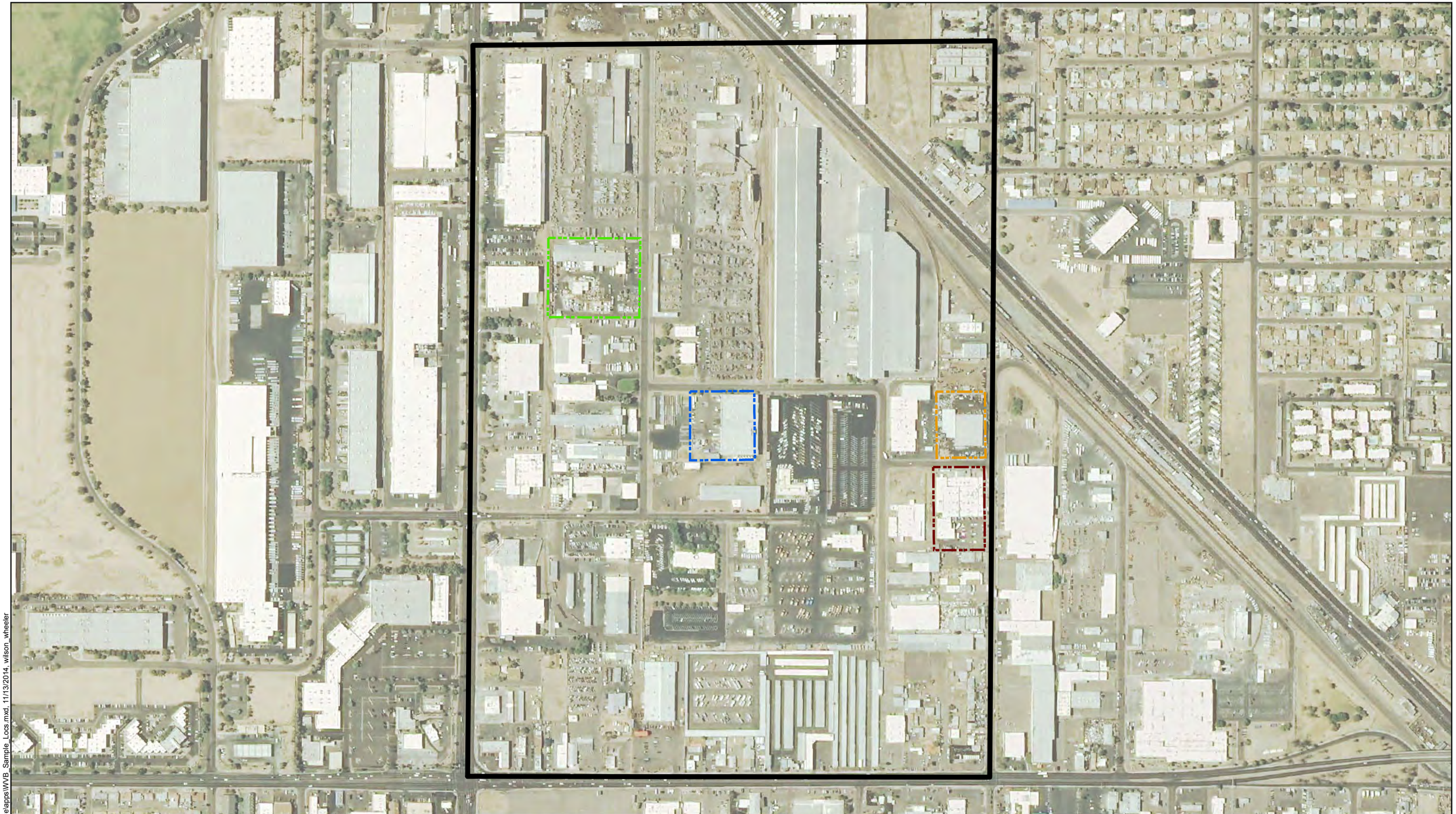


**Legend**

- Site Boundary
- Hill Brothers Facility
- F&B Manufacturing Co. Facility
- Rinchem Facility
- Pyramid Facility

Site Boundary
West Central Phoenix North Plume
WQARF Site
April 6, 2015

ADEQ Arizona Department of Environmental Quality

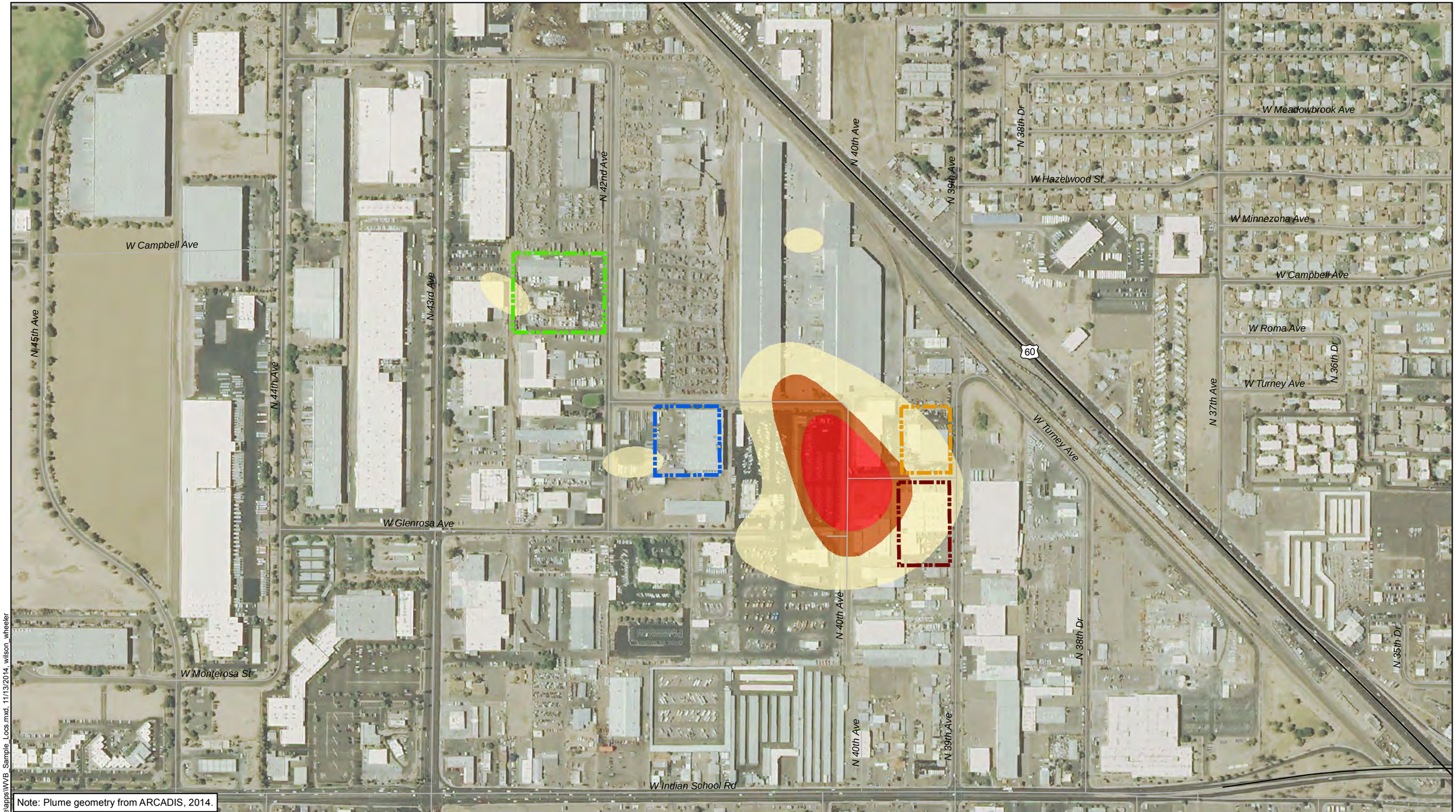
Matrix ENVIRONMENTAL

CALIBRE

0 225 450 Feet

Figure 2-1

FILE: G:\gis_projects\ADEQ\active\apps\WVB_Sample_Locs.mxd, 11/13/2014, wilson, wheeler




Note: Plume geometry from ARCADIS, 2014.

**Legend**

- PCE ≥ 5 µg/L and PCE < 100 µg/L
- PCE ≥ 100 µg/L and PCE < 1,000 µg/L
- PCE ≥ 1,000 µg/L
- F&B Manufacturing Co. Facility
- Pyramid Facility
- Hill Brothers Facility
- Rinchem Facility

Upper MAU PCE Plume (March 2014)
West Central Phoenix North Plume
WQARF Site
April 6, 2015

ADEQ Arizona Department of Environmental Quality

Matrix ENVIRONMENTAL

CALIBRE

0 225 450 Feet

Figure 2-2

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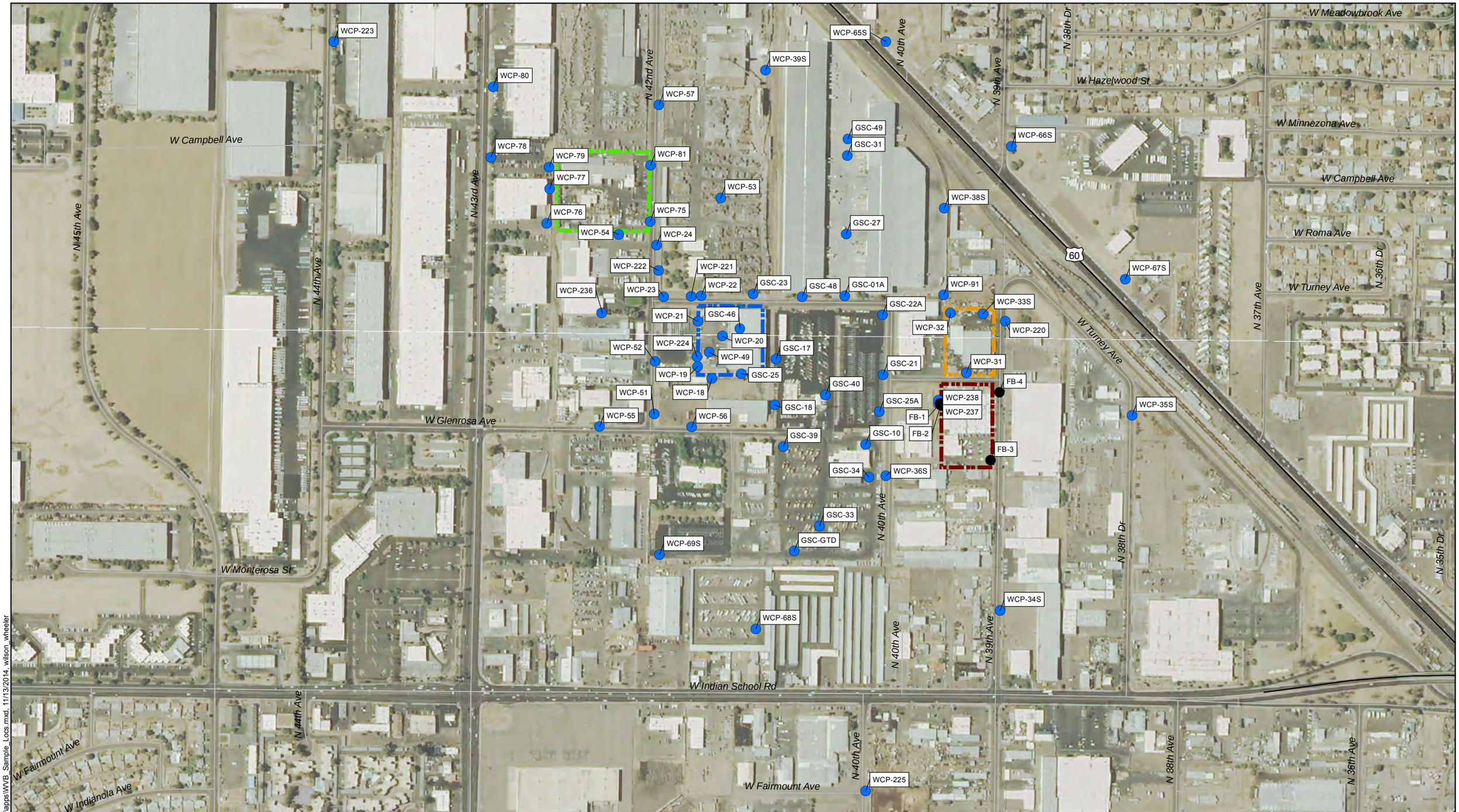



**Legend**

- Upper MAU Wells
- F & B Westbay Wells
- F&B Manufacturing Co. Facility
- Pyramid Facility
- Hill Brothers Facility
- Rinchem Facility

Upper MAU Well Locations
West Central Phoenix North Plume
WQARF Site
April 6, 2015

ADEQ Arizona Department of Environmental Quality
Matrix Environmental
CALIBRE

0 225 450 Feet

Figure 2-3

FILE: G:\gis_projects\ADEQ\activeapps\WVB_Sample_Locs.mxd, 11/13/2014, wilson_wheeler


**Legend**

- Middle MAU Wells
- F & B Westbay Wells
- F&B Manufacturing Co. Facility
- Pyramid Facility
- Hill Brothers Facility
- Rinchem Facility

Middle MAU Well Locations
West Central Phoenix North Plume
WQARF Site
April 6, 2015

ADEQ Arizona Department of Environmental Quality

Matrix ENVIRONMENTAL

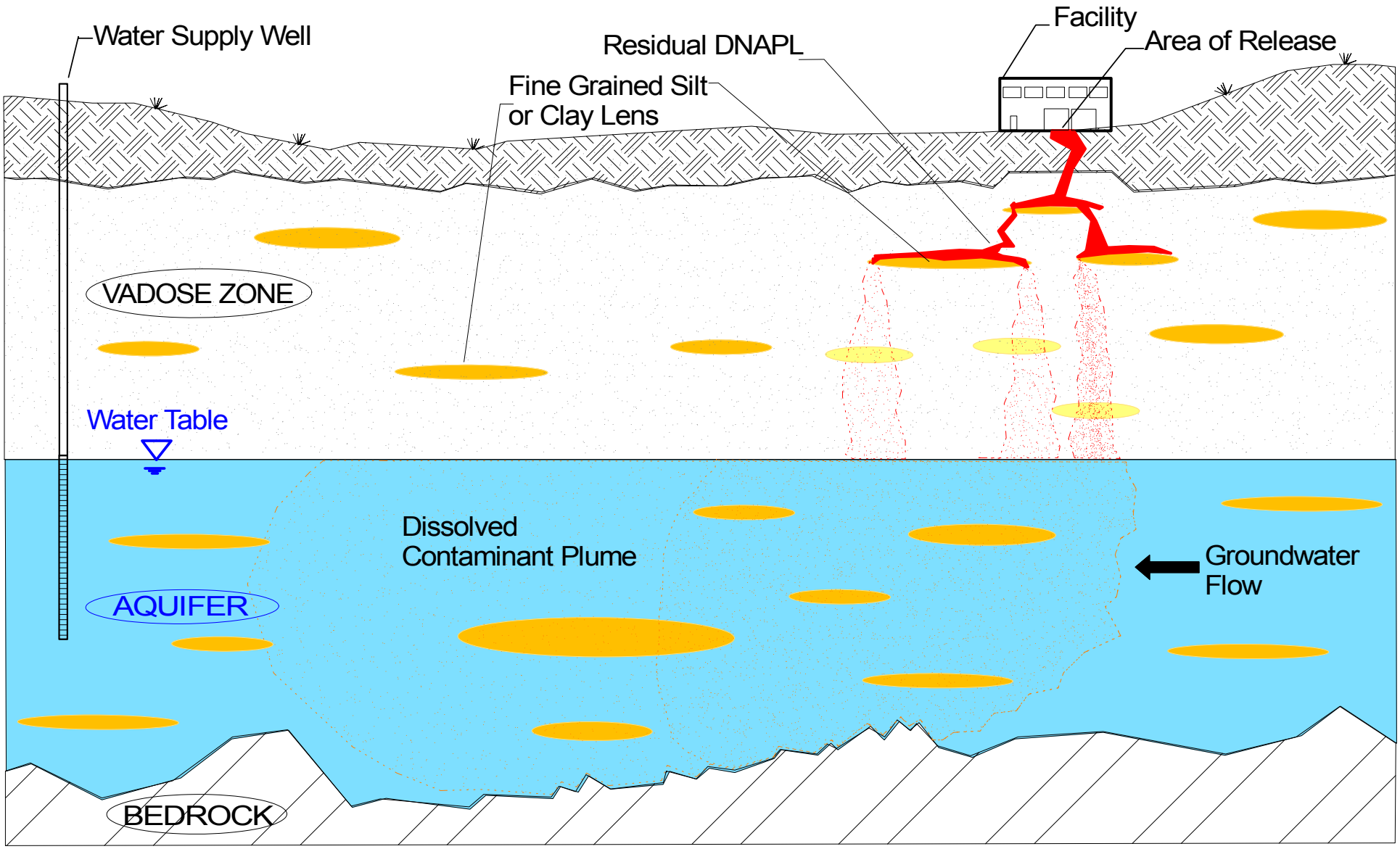
CALIBRE

0 175 350 Feet

Figure 2-4

FILE: G:\gis_projects\ADEQ\activeapps\WVB_Sample_Locs.mxd, 11/13/2014, wilson_wheeler

Note: This graphical depiction of the initial release in the CSM includes separate phase DNAPL at the point of release and as residual in pools on fine-grained layers, this initial condition has not been measured or observed but is inferred based on other site conditions. SVE remedial actions at the Site (as an ERA) have likely removed any DNAPL pools



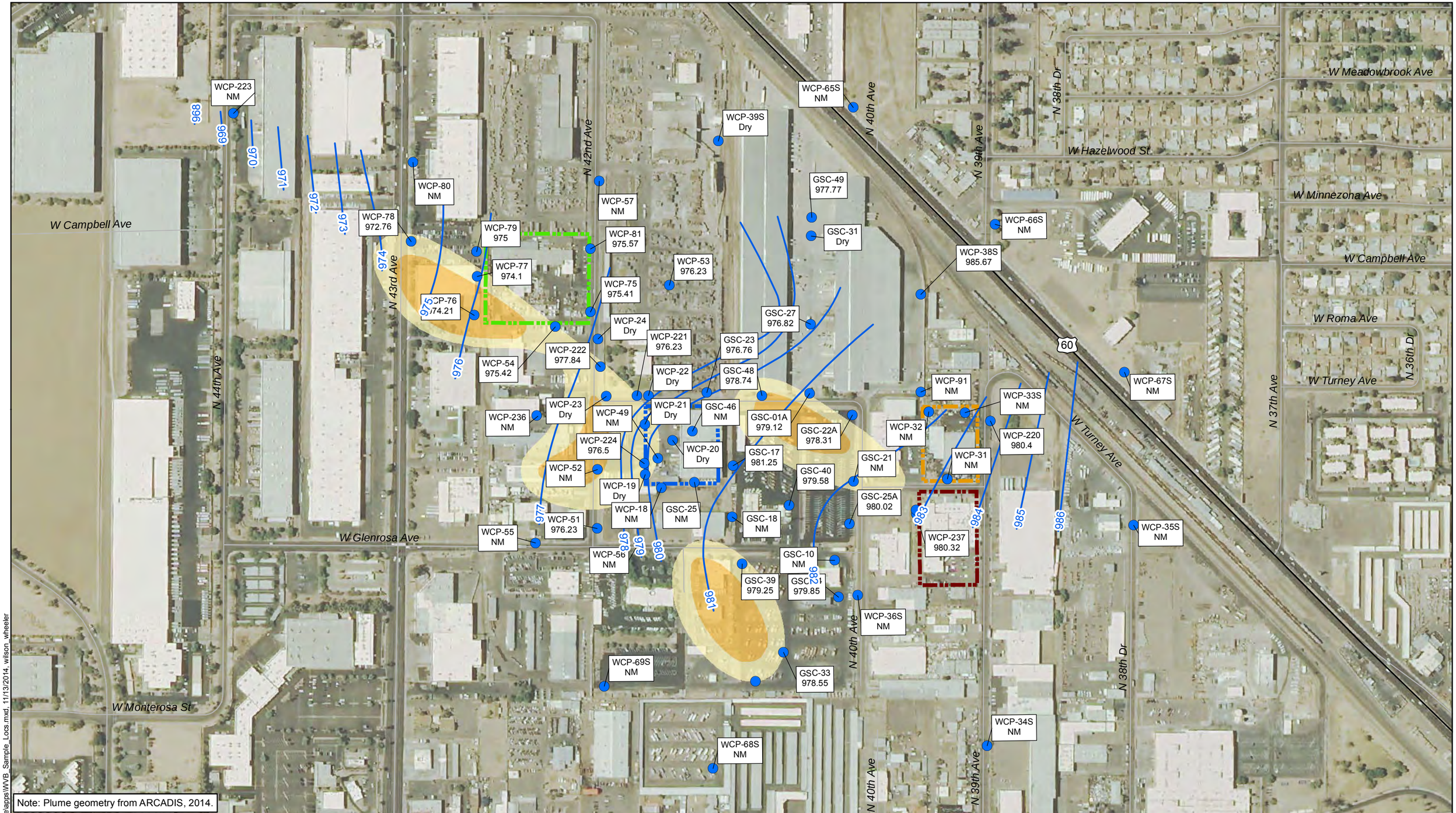

ADEQ Arizona Department of Environmental Quality

Matrix Design Group CALIBRE

Conceptual Site Model of Contaminant Release and Migration in Soil and Groundwater

West Central Phoenix North Plume WQARF Site

Figure 2-5




Note: Plume geometry from ARCADIS, 2014.

**Legend**

- TCE ≥ 5 µg/L and TCE < 10 µg/L
- TCE ≥ 10 µg/L
- Groundwater Elevation Contour
- Shallow MAU Monitoring Well
- F&B Manufacturing Co. Facility
- Pyramid Facility
- Hill Brothers Facility
- Rinchem Facility

Upper MAU TCE Plume (March 2014)
West Central Phoenix North Plume
WQARF Site
April 6, 2015

ADEQ Arizona Department of Environmental Quality

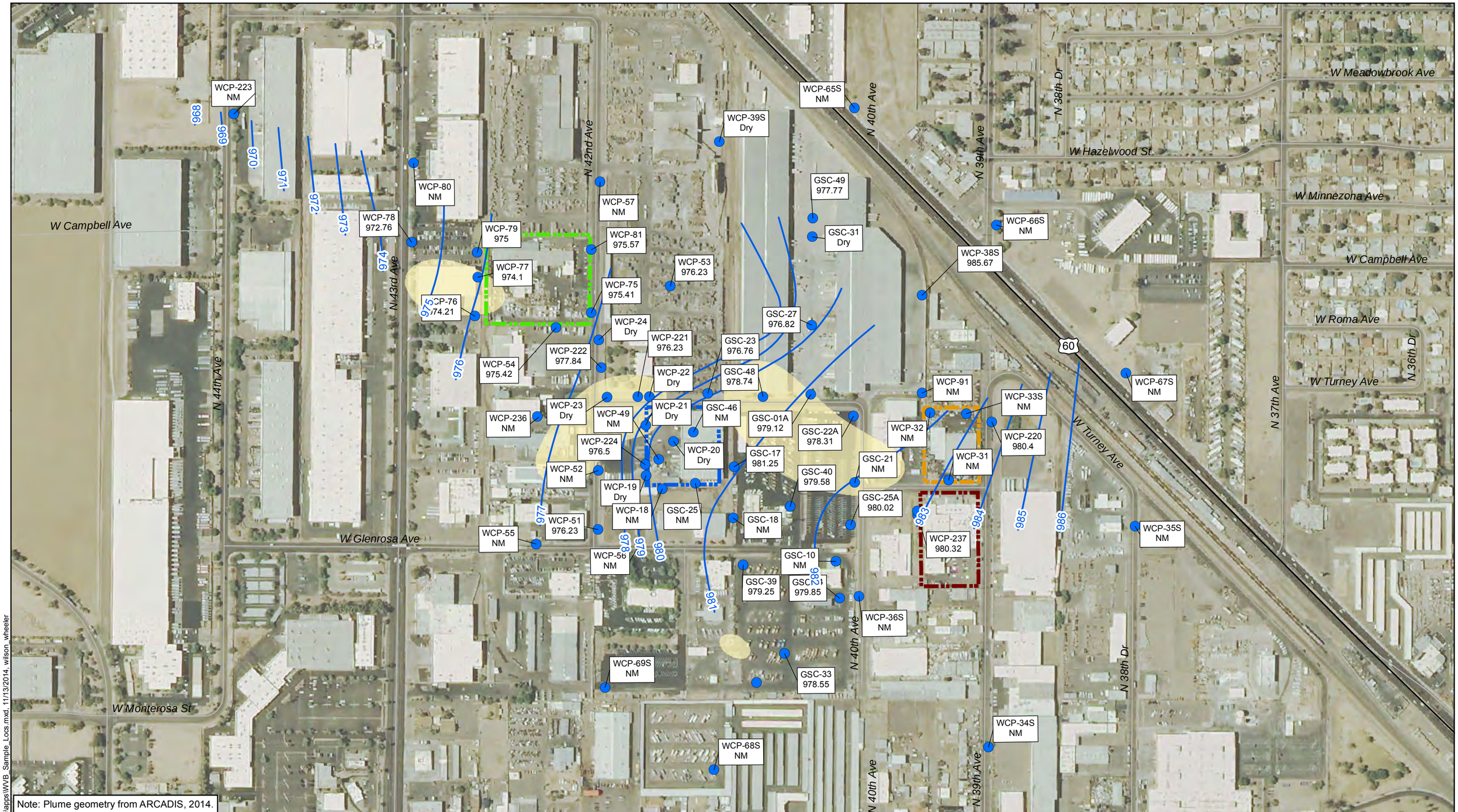
Matrix ENVIRONMENTAL

CALIBRE

0 200 400 Feet

Figure 2-6

FILE: G:\gis_projects\ADEQ\active\apps\WVB_Sample_Locs.mxd, 11/13/2014, wilson_wheeler




**Legend**

- DCE ≥ 5 µg/L and DCE < 10 ug/L
- Groundwater Elevation Contour
- Shallow MAU Monitoring Well
- F&B Manufacturing Co. Facility
- Pyramid Facility
- Hill Brothers Facility
- Rinchem Facility

Upper MAU DCE Plume (March 2014)
West Central Phoenix North Plume
WQARF Site
April 6, 2015

ADEQ Arizona Department of Environmental Quality

Matrix ENVIRONMENTAL

CALIBRE

0 200 400 Feet

Figure 2-7

FILE: G:\gis_projects\ADEQ\active\apps\WVB_Sample_Locs.mxd, 11/13/2014, wilson_wheeler


**Legend**

- PCE ≥ 10 µg/L and PCE < 100 ug/L
- F&B Manufacturing Co. Facility
- Pyramid Facility
- Hill Brothers Facility
- Rinchem Facility

Middle MAU PCE Plume (March 2014)
West Central Phoenix North Plume
WQARF Site
April 6, 2015

ADEQ Arizona Department of Environmental Quality

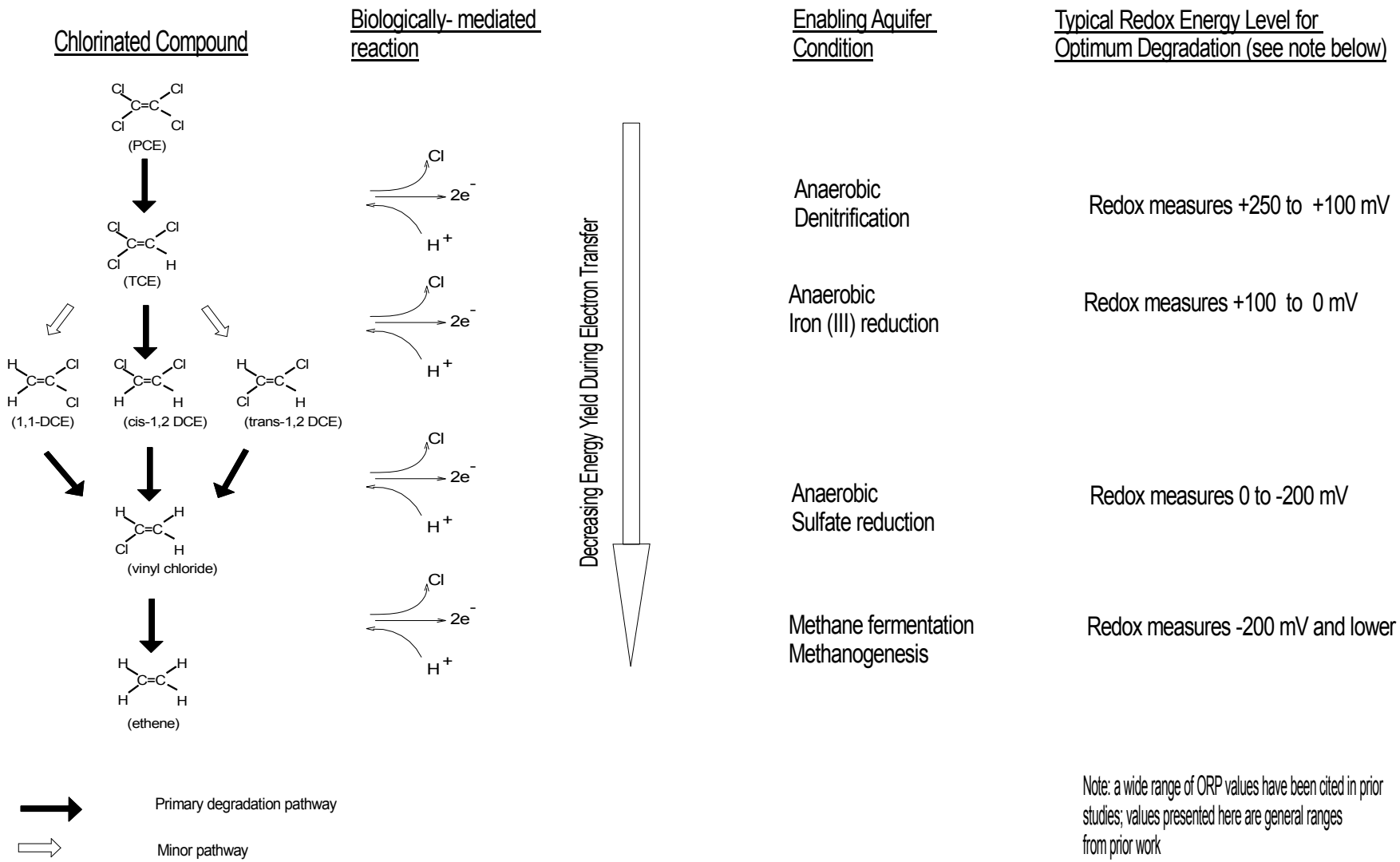
Matrix ENVIRONMENTAL

CALIBRE

0 225 450 Feet

Figure
2-8

FILE: G:\gis_projects\ADEQ\active\apps\WVB_Sample_Locs.mxd, 11/13/2014, wilson_wheeler




ADEQ Arizona Department of Environmental Quality

Matrix DESIGN GROUP CALIBRE

Primary Degradation Pathways of Chlorinated Ethenes by Reductive Dechlorination

West Central Phoenix North Plume WQARF Site

Figure

2-9


**Legend**

SVE Well

SVE Equuipment System

SVE Piping

SVE Well Locations
West Central Phoenix North Plume
WQARF Site
April 6, 2015

ADEQ Arizona Department of Environmental Quality

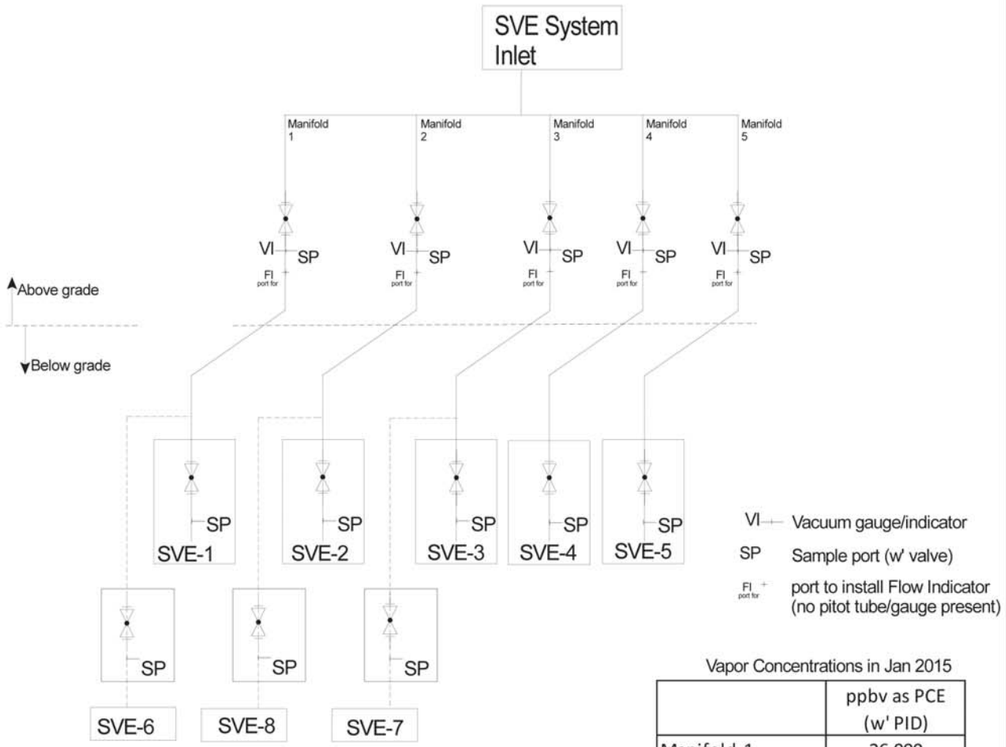
Matrix ENVIRONMENTAL

CALIBRE

0 17.5 35 Feet

Figure
4-1

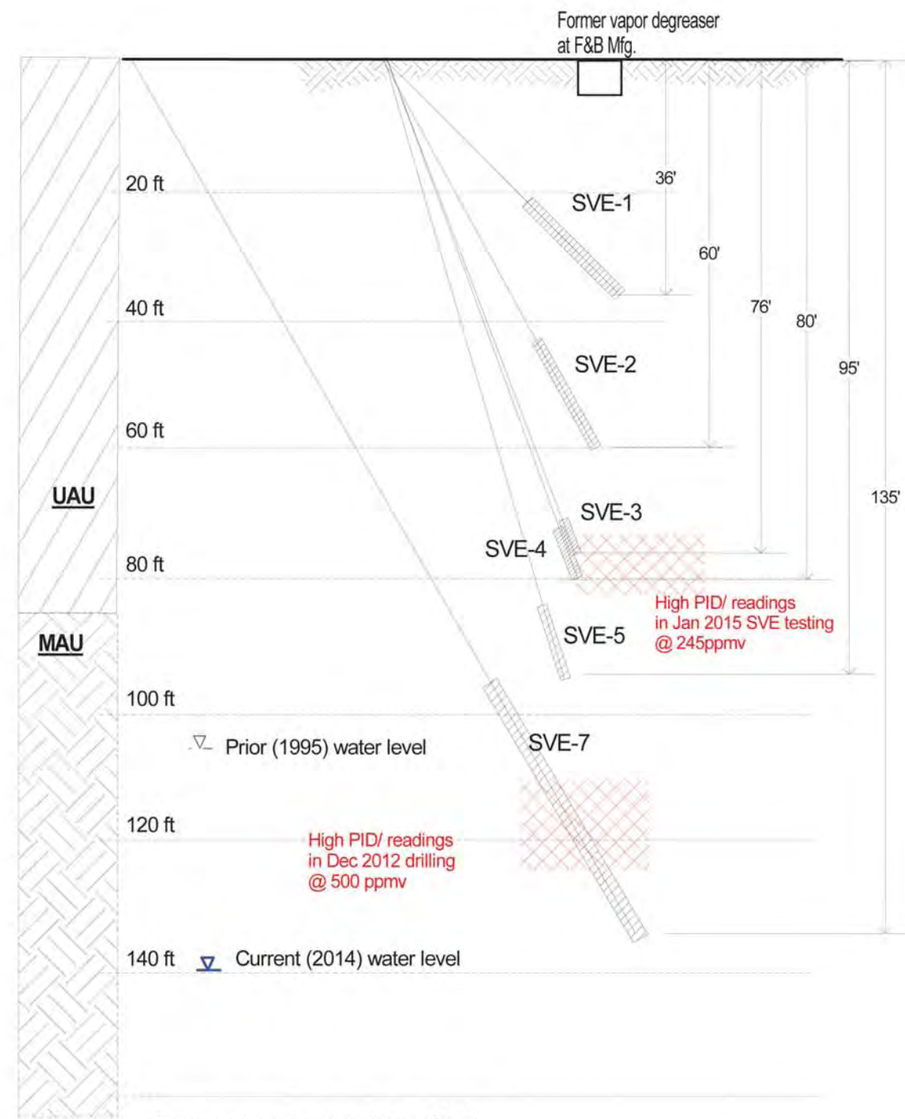
FILE: G:\gis_projects\ADEQ\active\apps\WVB_Sample_Locs.mxd, 11/13/2014, wilson_wheeler




| | Screen Interval Top (bgs) | Screen Interval Bottom (bgs) |
|---|---|---|
| SVE-1 | 20.6 | 34.4 |
| SVE-2 | 42.7 | 60.2 |
| SVE-3 | 71.8 | 76.5 |
| SVE-4 | 85.5 | 95.1 |
| SVE-5 | 75.1 | 79.8 |
| SVE-6 | 95 | 135 |
| SVE-7 | 95 | 135 |
| SVE-8 | 95 | 135 |

Vapor Concentrations in Jan 2015

| | ppbv as PCE (w' PID) |
|---|---|
| Manifold-1 | 26,000 |
| Manifold-2 | 0 |
| Manifold-3 | 2,000 |
| Manifold-4 | 140,000 |
| Manifold-5 | 1,000 |
| | |
| System Inlet | 23,000 |



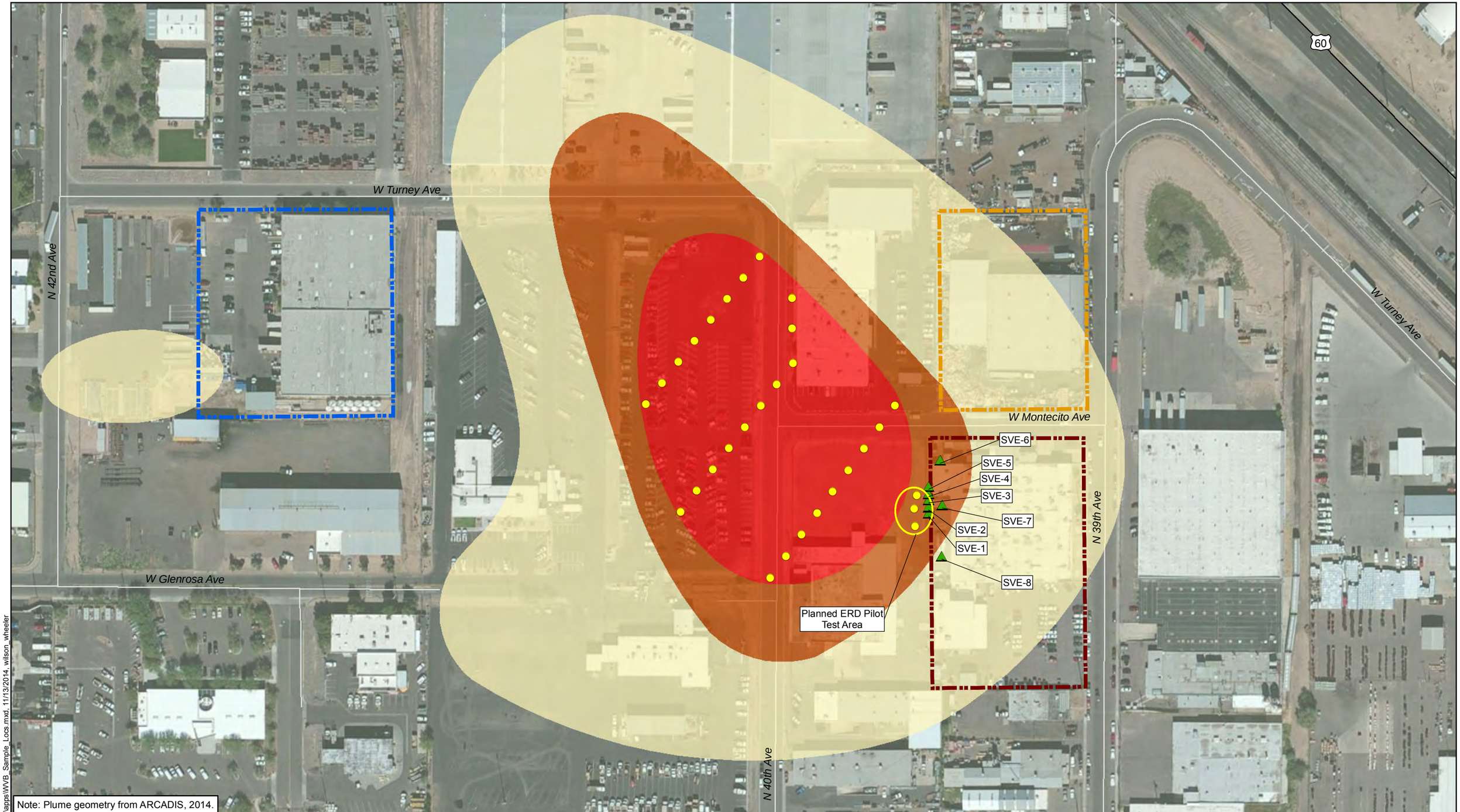

SVE screen intervals and depth from 2009 RI and from 2012 well logs for SVE-7:
SVE-6 and SVE-8 are same as SVE-7 in different areas (~ 75 ft N and S of SVE-7)

SVE Well System Piping and Layout
West Central Phoenix North Plume
WQARF Site
April 6, 2015

ADEQ Arizona Department of Environmental Quality
Matrix ENVIRONMENTAL
CALIBRE

Figure
4-2

FILE: G:\gis_projects\ADEQ\active\apps\WVB_Sample_Locs.mxd, 11/13/2014, wilson_wheeler




**Legend**

- Proposed Injection Well
- SVE Wells
- PCE ≥ 5 µg/L and PCE < 100 µg/L
- PCE ≥ 100 µg/L and PCE < 1,000 µg/L
- PCE ≥ 1,000 µg/L
- F&B Manufacturing Co. Facility
- Pyramid Facility
- Rinchem Facility

Reference Remedy: Soil Vapor Extraction, Enhanced Reductive Dechlorination, and Monitored Natural Attenuation
West Central Phoenix North Plume
WQARF Site
April 6, 2015

ADEQ Arizona Department of Environmental Quality

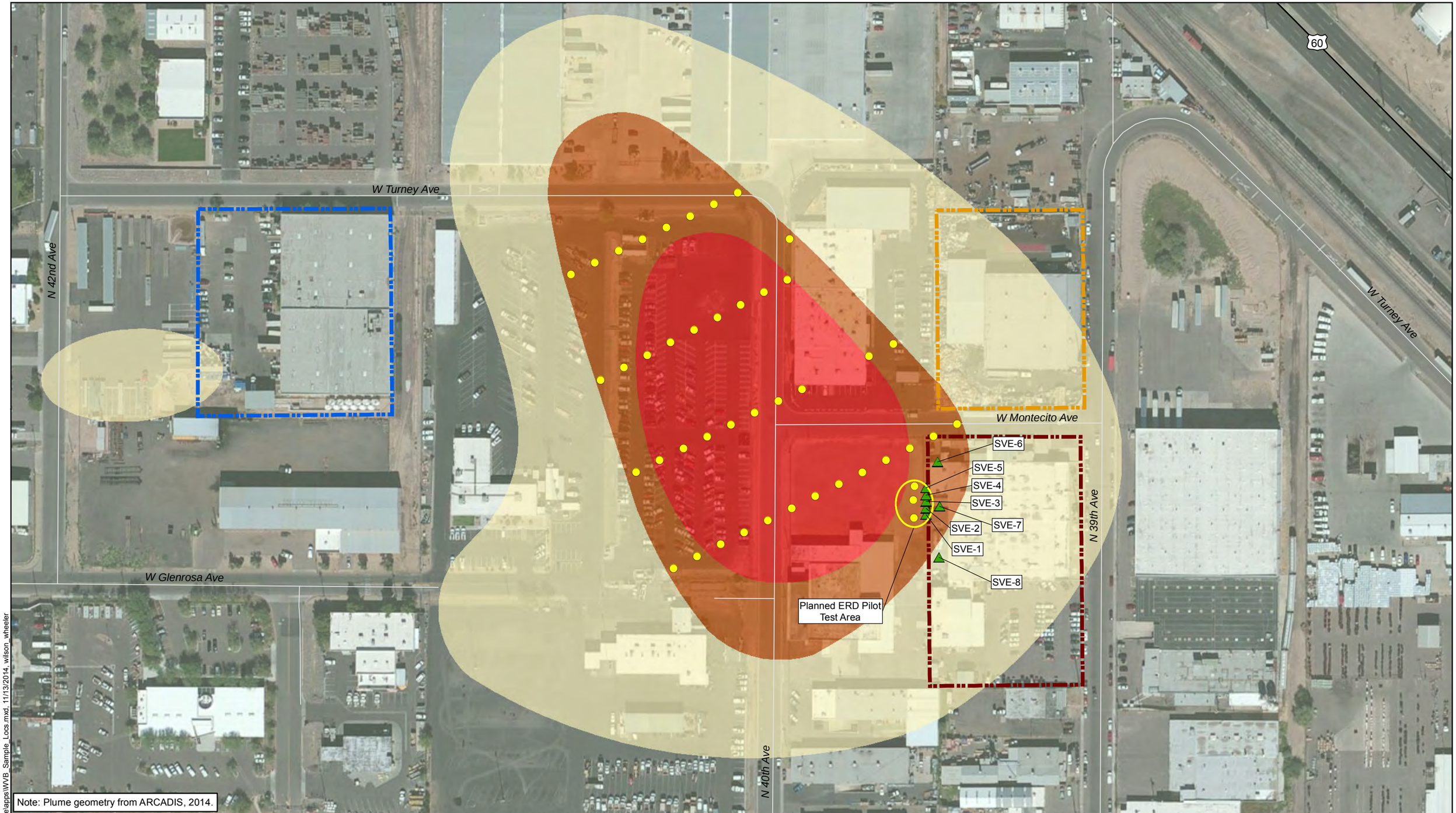
Matrix ENVIRONMENTAL

CALIBRE

0 75 150 Feet

Figure 4-3

FILE: G:\gis_projects\ADEQ\activeapps\WVB_Sample_Locs.mxd, 11/13/2014, wilson_wheeler




**Legend**

- Proposed Injection Wells
- SVE Wells
- PCE ≥ 5 µg/L and PCE < 100 µg/L
- PCE ≥ 100 µg/L and PCE < 1,000 µg/L
- PCE ≥ 1,000 µg/L
- F&B Manufacturing Co. Facility
- Pyramid Facility
- Rinchem Facility

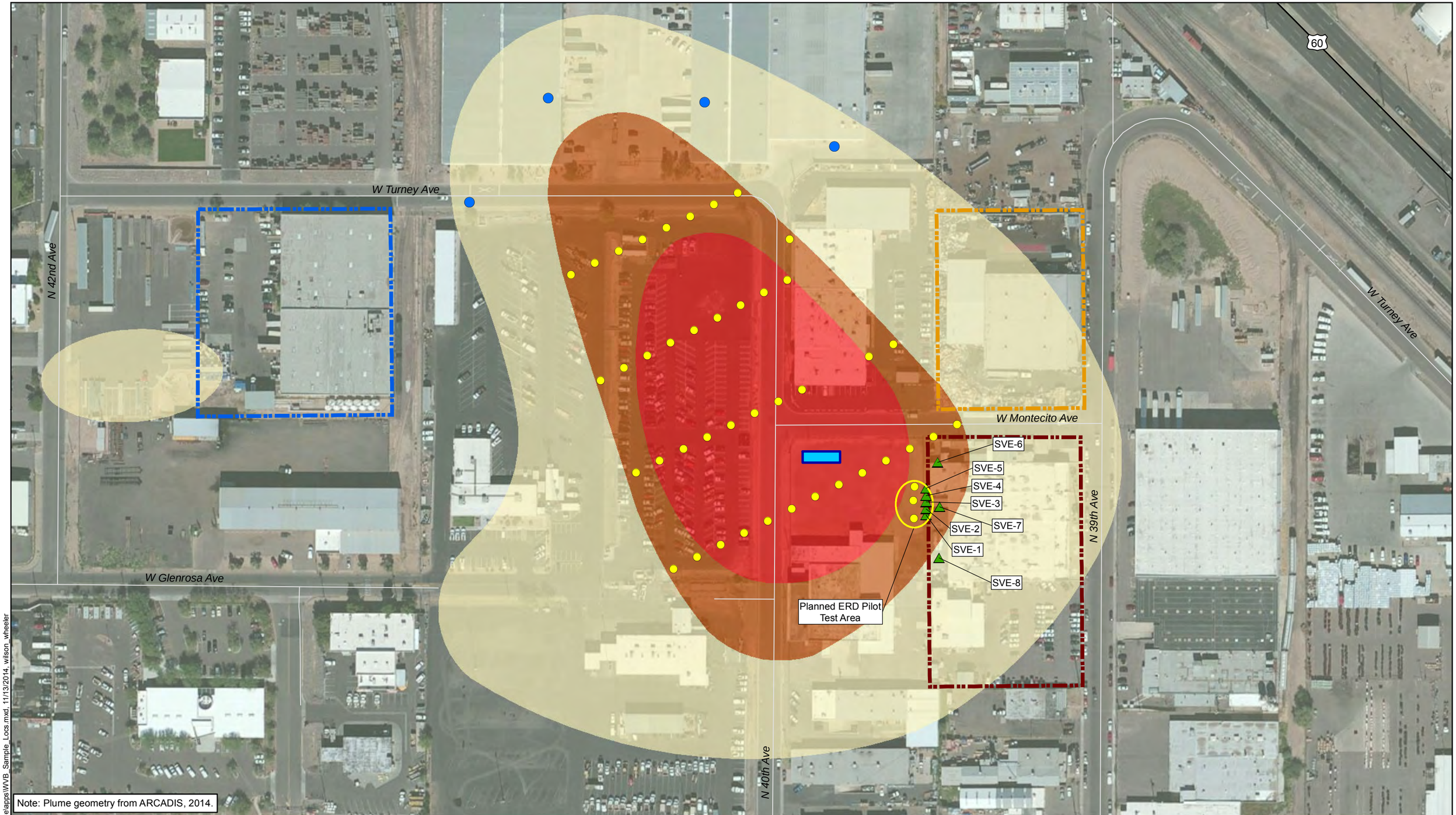
Reference Remedy: More Aggressive Treatment of Larger Plume Footprint
West Central Phoenix North Plume
WQARF Site
April 6, 2015

ADEQ Arizona Department of Environmental Quality
Matrix ENVIRONMENTAL
CALIBRE

0 75 150 Feet

Figure 4-4

FILE: G:\gis_projects\ADEQ\active\apps\WVB_Sample_Locs.mxd, 11/13/2014, wilson_wheeler




**Legend**

- Proposed Injection Wells
- SVE Wells
- Groundwater Extraction Wells
- Water Treatment Plant
- PCE ≥ 5 µg/L and PCE < 100 µg/L
- PCE ≥ 100 µg/L and PCE < 1,000 µg/L
- PCE ≥ 1,000 µg/L
- F&B Manufacturing Co. Facility
- Pyramid Facility
- Rinchem Facility

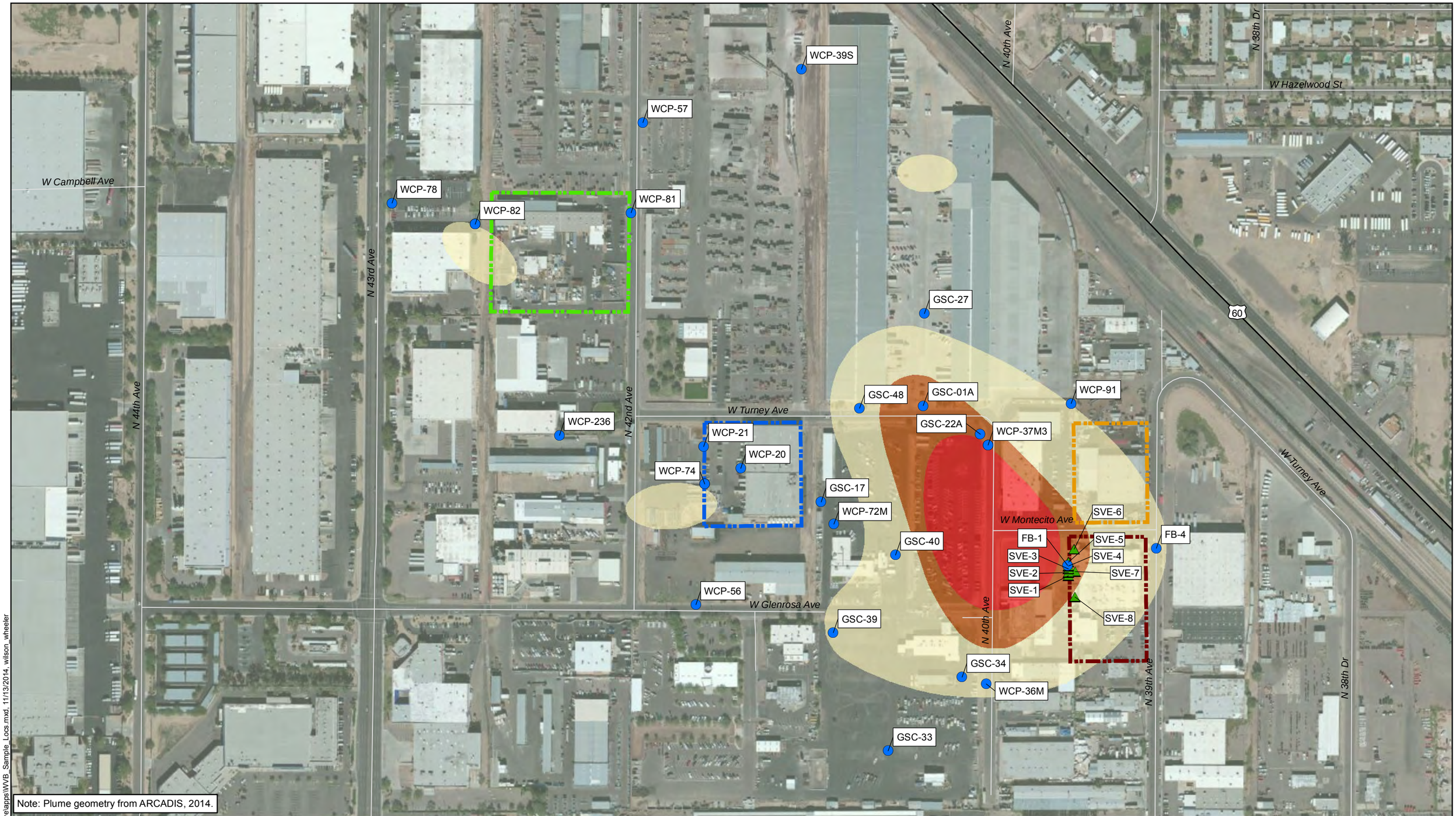
More Aggressive Remedy: Soil Vapor Extraction, Enhanced Reductive Dechlorination, and Groundwater Extraction/Treatment for Containment
West Central Phoenix North Plume
WQARF Site
April 6, 2015

ADEQ Arizona Department of Environmental Quality
Matrix ENVIRONMENTAL
CALIBRE

0 75 150 Feet

Figure 4-5

FILE: G:\gis_projects\ADEQ\active\apps\WVB_Sample_Locs.mxd, 11/13/2014, wilson_wheeler




**Legend**

- SVE Wells
- Wells Included in MNA Monitoring Program
- PCE ≥ 5 µg/L and PCE < 100 µg/L
- PCE ≥ 100 µg/L and PCE < 1,000 µg/L
- PCE ≥ 1,000 µg/L
- F&B Manufacturing Co. Facility
- Pyramid Facility
- Hill Brothers Facility
- Rinchem Facility

Less Aggressive Remedial Alternative:
SVE Optimization and MNA
West Central Phoenix North Plume
WQARF Site
April 6, 2015

ADEQ Arizona Department of Environmental Quality

Matrix ENVIRONMENTAL

CALIBRE

0 150 300 Feet

Figure
4-6

FILE: G:\gis_projects\ADEQ\active\apps\WVB_Sample_Locs.mxd, 11/13/2014, wilson_wheeler

# APPENDIX A

## Backup Details of the Cost Estimates for each Remedy

**Less Aggressive Remedial Alternative—Continued Operation and Optimization of the SVE System, and MNA**

| Source Area Remediation Tasks | Quantity | Unit | Unit Cost [1] | Total Cost [2] | Detail |
|---|---|---|---|---|---|
| **SVE REMEDIATION[3]** | | | | | |
| Optimize, Operate and Maintain SVE System for Vadose Zone | 10 | YR | $ 162,500 | $ 1,625,000 | Assumes active optimization, operation, and maintenance (including carbon and electricity consumption) for 10 years. |
| Equipment Replacement and Maintenance | 1 | LS | $ 31,250 | $ 31,250 | Assumes periodic replacement of SVE components (i.e., blower replacement, hoses, valves, etc.) |
| Limited Operation and Maintenance, Years 10-20 | 10 | YR | $ 16,250 | $ 162,500 | Assumes more limited operation for years 10-20 (run 10% of time) |
| Limited Operation and Maintenance, Years 20-30 | 10 | YR | $ 16,250 | $ 162,500 | Assumes more limited operation for years 20-30 (run 10% of time) |
| Limited Operation and Maintenance, Years 30-40 | 10 | YR | $ 16,250 | $ 162,500 | Assumes more limited operation for years 30-40 (run 10% of time) |
| Limited Operation and Maintenance, Years 40-50 | 10 | YR | $ 16,250 | $ 162,500 | Assumes more limited operation for years 40-50 (run 10% of time) |
| | | | **Remediation Cost** | **$2,306,000** | |
| **LONG TERM MONITORING COSTS (MNA)** | | | | | |
| Mobilization/Demobilization for Well Install | 1 | LS | $ 1,875 | $ 1,880 | |
| Monitoring Well Installation | 5 | Well | $ 17,500 | $ 87,500 | Assumes 170-foot monitoring wells. Per well cost from vendor. |
| Monitoring Well Development | 5 | Well | $ 1,250 | $ 6,250 | Esimate from driller |
| Field Oversight for Monitoring Well Install and Development | 13 | Day | $ 1,875 | $ 24,380 | Includes 1 FTE for 10 hours per day. 2 days per well install, 2 wells/day development. |
| IDW Management and Disposal (soil, Subtitle D) | 20 | Drum | $ 188 | $ 3,750 | Assume transport and disposal at Subtitle D landfill. |
| IDW Management and Disposal (water) | 75 | Drum | $ 188 | $ 14,070 | Assumes disposal of well development water and purge water. |
| Semi-Annual Key Monitoring Well Sampling (Years 0-10) | 10 | Event | $ 11,250 | $ 112,500 | Monitoring of 12 key wells to be completed semi-annually, years 0-10. Includes labor, equipment, and laboratory analysis. |
| Annual Key Monitoring Well Sampling (Years 0-10) | 10 | Event | $ 33,750 | $ 337,500 | Monitoring of 40 key wells to be completed annually. Includes labor, equipment, and laboratory analysis. Assumes 10 year timeframe. |
| Semi-Annual Key Monitoring Well Sampling (Years 11-50) | 40 | Event | $ 11,250 | $ 450,000 | Monitoring of 12 key wells to be completed semi-annually, years 11-50. Includes labor, equipment, and laboratory analysis. |
| Annual Key Monitoring Well Sampling (Years 11-50) | 40 | Event | $ 18,750 | $ 750,000 | Monitoring of 20 key wells to be completed annually. Includes labor, equipment, and laboratory analysis. Assumes 40 year timeframe. |
| ***Subtotal:*** | | | | ***$1,788,000*** | |
| **INDIRECT REMEDIATION COSTS** | | | | | |
| Reporting/Design/Project Oversight[4] | 1 | LS | $ 818,800 | $ 820,000 | Assumes 20% of overall cost for project oversight, management, permits, work plans, reporting, regulatory interaction, etc., over the 50-year project period. |
| ***Subtotal:*** | | | | ***$820,000*** | |
| | | | **Remediation Cost (Plus IDCs and LTM)** | **$4,914,000** | |
| | | | | | |
| | | | **TOTAL REMEDIATION COST** | **$4,920,000** | |

Notes:
1 All cost values are estimates and should not be interpreted as final construction or project costs. Costs are in present dollar and do not include inflation costs.
2 Total values are rounded up to the nearest $10,000.
3 SVE system cost estimates are based on experience from past site operations and current estimates for SVE operations.
4 Anticipated indirect costs are assumed as 20% of the estimated remediation cost.
Contingency included for feasibility-level planning and may be adjusted during the remedial design phase of the project.

Abbreviations:
bgs Below ground surface
IDC Indirect Cost
LS Lump Sum
SVE Soil vapor extraction
YR Year

**Reference Remedy (a)—Enhanced Reductive Dechlorination and Continued Operation and Optimization of SVE System, and MNA**

| Source Area Remediation Tasks | Quantity | Unit | Unit Cost [1] | Total Cost [2] | Detail |
|---|---|---|---|---|---|
| **SITE PREPARATION** | | | | | |
| Mobilization/Demobilization | 1 | LS | $ 1,875 | $ 1,875 | |
| Site Survey/Utility Locate | 1 | LS | $ 12,500 | $ 12,500 | |
| ***Subtotal:*** | | | | ***$14,000*** | |
| **ERD REMEDIATION** | | | | | |
| ERD Injection Well Installation | 30 | Well | $ 19,688 | $ 591,000 | Assumes 4-inch diameter injection wells to be installed to depth of 175 feet bgs; wells are to be screened at multiple depth intervals to allow for injections to be completed throughout the well depth column. |
| ERD Injection Well Development | 30 | Well | $ 1,250 | $ 37,500 | Based on drillers estimate |
| Field Oversight for Injection Well Install and Development | 75 | Day | $ 1,875 | $ 141,000 | Includes 1 FTE for 10 hours per day. 2 days per well installation, development of 2 wells/day. |
| IDW Management and Disposal (soil, Subtitle C) | 10 | drum | $ 375 | $ 3,750 | Assume transport and disposal at Subtitle C landfill. |
| IDW Management and Disposal (soil, Subtitle D) | 40 | ton | $ 150 | $ 6,000 | Assume rental of roll-off container, transport and disposal at Subtitle D landfill. |
| IDW Management and Disposal (water) | 1 | LS | $ 12,500 | $ 12,500 | Assumes frac tank and carbon treatment system rental, treatment and discharge to sanitary sewer. |
| Pre-Design Characterization | 1 | LS | $ 62,500 | $ 62,500 | |
| Pilot Study | 1 | LS | $ 62,500 | $ 62,500 | Assumes 3-well pilot test, with 3 injections per well. |
| Bioaugmentation , Year 1 | 1 | Event | $ 112,500 | $ 112,500 | Bioaugmentation , Year 1, one time after all wells are at reducing condition |
| Perform ERD Injections , Years 0-2 | 4 | Event | $ 133,750 | $ 535,000 | Substrate injections to be performed semiannually for the 2 years. |
| Perform ERD Injections , Years 3-5 | 3 | Event | $ 192,500 | $ 577,500 | Substrate injections to be performed annually as needed, years 3-5. |
| Perform ERD Injections , Years 6-10 | 1 | Event | $ 133,750 | $ 133,750 | Focused substrate injections for hot spot treatment(s), years 6-10. |
| ***Subtotal:*** | | | | ***$2,276,000*** | |
| **SVE REMEDIATION IN MAIN SOURCE AREA[4]** | | | | | |
| Optimize, Operate and Maintain SVE System for Vadose Zone, Years 1-7 | 7 | YR | $ 162,500 | $ 1,137,500 | Assumes active optimization, operation, and maintenance (including carbon and electricity consumption) for 1-7 years. |
| Limited Operation and Maintenance, Years 7-20 | 13 | YR | $ 16,250 | $ 211,250 | Assumes limited operation for years 7-20. (run 10% of time) |
| Equipment Replacement and Maintenance | 1 | LS | $ 12,500 | $ 12,500 | Assumes periodic replacement of SVE components (ie blower replacement, hoses, valves, etc.) |
| ***Subtotal:*** | | | | ***$1,361,000*** | |
| | | | **Remediation Cost** | **$3,651,000** | |
| **LONG TERM MONITORING COSTS (MNA)** | | | | | |
| Monitoring Well Installation | 5 | Well | $ 17,500 | $ 87,500 | Assumes 170-foot monitoring wells. Per well cost from vendor. |
| Monitoring Well Development | 5 | Well | $ 1,250 | $ 6,250 | |
| Field Oversight for Monitoring Well Install and Development | 13 | Day | $ 1,875 | $ 24,380 | Includes 1 FTE for 10 hours per day. 2 days per well install, 2 wells/day development. |
| IDW Management and Disposal | 50 | Drum | $ 188 | $ 9,380 | Assumes disposal of well development water and purge water. |
| Semi-Annual Key Monitoring Well Sampling/ERD Performance Monitoring | 10 | Event | $ 11,250 | $ 112,500 | Monitoring of 12 key wells to be completed semi-annually, years 0-10. Includes labor, equipment, and laboratory analysis. |
| Annual Key Monitoring Well Sampling (Years 0-10) | 10 | Event | $ 33,750 | $ 337,500 | Monitoring of key wells (assume 40) to be completed annually, years 0-10. Includes labor, equipment, and laboratory analysis. |
| Annual Key Monitoring Well Sampling (Years 11-20) | 10 | Event | $ 18,750 | $ 187,500 | Monitoring of key wells (assume 20) to be completed annually, years 11-20. Includes labor, equipment, and laboratory analysis. |
| Annual Key Monitoring Well Sampling (Years 21-35) | 15 | Event | $ 6,325 | $ 94,880 | Monitoring of key wells (assume 10) to be completed annually, years 21-35. Includes labor, equipment, and laboratory analysis. |
| ***Subtotal:*** | | | | ***$860,000*** | |
| **INDIRECT REMEDIATION COSTS** | | | | | |
| Permitting/Design/Project Oversight[5] | 1 | LS | $ 902,200 | $ 910,000 | Assumes 20% of overall cost for design, project oversight, management, permits, work plans, confirmational sampling, reporting, regulatory interaction, etc., over the 35-year project period. |
| ***Subtotal:*** | | | | ***$910,000*** | |
| | | | **Remediation Cost (Plus IDCs and LTM)** | **$5,421,000** | |
| | | | | | |
| | | | **TOTAL REMEDIATION COST** | **$5,430,000** | |

Notes:
1 All cost values are estimates and should not be interpreted as final construction or project costs. Costs are in present dollar and do not include inflation costs.
2 Total values are rounded up to the nearest $10,000.
3 ERD cost estimates are based on current interim action costs and additional vendor information.
4 SVE system cost estimates are based on experience from past site operations and current estimates for SVE operations.
5 Anticipated costs for permitting, engineering design, reporting, and construction oversight are assumed as 20% of the estimated source area remediation cost. Contingency included for feasibility-level planning and may be adjusted during the remedial design phase of the project.

Abbreviations:
bgs Below ground surface
ERD Enhanced Reductive Dechlorination
IDC Indirect Cost
LS Lump Sum
SVE Soil vapor extraction
YR Year

**Reference Remedy (b) Expanded Plume Coverage—Enhanced Reductive Dechlorination, Continued Operation and Optimization of SVE System, and MNA**

| Source Area Remediation Tasks | Quantity | Unit | Unit Cost [1] | Total Cost [2] | Detail |
|---|---|---|---|---|---|
| **SITE PREPARATION** | | | | | |
| Mobilization/Demobilization | 1 | LS | $ 1,875 | $ 1,875 | |
| Site Survey/Utility Locate | 1 | LS | $ 12,500 | $ 12,500 | |
| ***Subtotal:*** | | | | ***$15,000*** | |
| **ERD REMEDIATION** | | | | | |
| ERD Injection Well Installation | 43 | Well | $ 19,688 | $ 847,000 | Assumes 4-inch diameter injection wells to be installed to depth of 175 feet bgs; wells are to be screened at multiple depth intervals to allow for injections to be completed throughout the well depth column. |
| ERD Injection Well Development | 43 | Well | $ 1,250 | $ 53,750 | Based on drillers estimate |
| Field Oversight for Injection Well Install and Development | 108 | Day | $ 1,875 | $ 202,500 | Includes 1 FTE for 10 hours per day. 2 days per well installation, development of 2 wells/day. |
| IDW Management and Disposal (soil, Subtitle C) | 10 | drum | $ 375 | $ 3,750 | Assume transport and disposal at Subtitle C landfill. |
| IDW Management and Disposal (soil, Subtitle D) | 70 | ton | $ 150 | $ 10,500 | Assume rental of roll-off container, transport and disposal at Subtitle D landfill. |
| IDW Management and Disposal (water) | 1 | LS | $ 12,500 | $ 12,500 | Assumes frac tank and carbon treatment system rental, treatment and discharge to sanitary sewer. |
| Pre-Design Characterization | 1 | LS | $ 62,500 | $ 62,500 | |
| Pilot Study | 1 | LS | $ 62,500 | $ 62,500 | Assumes 3-well pilot test, with 3 injections per well. |
| Bioaugmentation , Year 1 | 1 | Event | $ 161,250 | $ 161,250 | Bioaugmentation , Year 1, one time after all wells are at reducing condition |
| Perform ERD Injections , Years 0-2 | 4 | Event | $ 192,500 | $ 770,000 | Substrate injections to be performed semiannually for the 2 years. |
| Perform ERD Injections , Years 3-5 | 3 | Event | $ 192,500 | $ 578,000 | Substrate injections to be performed annually as needed, years 3-5. |
| Perform ERD Injections , Years 6-10 | 1 | Event | $ 192,500 | $ 192,500 | Focused substrate injections for hot spot treatment(s), years 6-10. |
| ***Subtotal:*** | | | | ***$2,957,000*** | |
| **SVE REMEDIATION IN MAIN SOURCE AREA[4]** | | | | | |
| Optimize, Operate and Maintain SVE System for Vadose Zone, Years 1-10 | 7 | YR | $ 162,500 | $ 1,137,500 | Assumes active optimization, operation, and maintenance (including carbon and electricity consumption) for 1-10 years. |
| Limited Operation and Maintenance, Years 10-20 | 13 | YR | $ 16,250 | $ 211,250 | Assumes limited operation for years 11-20. (run 10% of time) |
| Equipment Replacement and Maintenance | 1 | LS | $ 12,500 | $ 12,500 | Assumes periodic replacement of SVE components (ie blower replacement, hoses, valves, etc.) |
| ***Subtotal:*** | | | | ***$1,362,000*** | |
| | | | **Remediation Cost** | **$4,334,000** | |
| **LONG TERM MONITORING COSTS (MNA)** | | | | | |
| Monitoring Well Installation | 5 | Well | $ 17,500 | $ 87,500 | Assumes 170-foot monitoring wells. Per well cost from vendor. |
| Monitoring Well Development | 5 | Well | $ 1,250 | $ 6,250 | |
| Field Oversight for Monitoring Well Install and Development | 13 | Day | $ 1,875 | $ 24,380 | Includes 1 FTE for 10 hours per day. 2 days per well install, 2 wells/day development. |
| IDW Management and Disposal | 45 | Drum | $ 188 | $ 8,440 | Assumes disposal of well development water and purge water. |
| Semi-Annual Key Monitoring Well Sampling/ERD Performance Monitoring | 10 | Event | $ 11,250 | $ 112,500 | Monitoring of 12 key wells to be completed semi-annually, years 0-10. Includes labor, equipment, and laboratory analysis. |
| Annual Key Monitoring Well Sampling (Years 0-10) | 10 | Event | $ 33,750 | $ 337,500 | Monitoring of key wells (assume 40) to be completed annually, years 0-10. Includes labor, equipment, and laboratory analysis. |
| Annual Key Monitoring Well Sampling (Years 11-20) | 10 | Event | $ 18,750 | $ 94,880 | Monitoring of key wells (assume 20) to be completed annually, years 11-20. Includes labor, equipment, and laboratory analysis. |
| Annual Key Monitoring Well Sampling (Years 21-35) | 15 | Event | $ 6,325 | $ 94,880 | Monitoring of key wells (assume 10) to be completed annually, years 21-35. Includes labor, equipment, and laboratory analysis. |
| ***Subtotal:*** | | | | ***$767,000*** | |
| **INDIRECT REMEDIATION COSTS** | | | | | |
| Permitting/Design/Project Oversight[5] | 1 | LS | $ 1,020,200 | $ 1,030,000 | Assumes 20% of overall cost for SVE system design, project oversight, management, permits, work plans, confirmational sampling, reporting, regulatory interaction, etc., over the 35-year project period. |
| ***Subtotal:*** | | | | ***$1,030,000*** | |
| | | | **Remediation Cost (Plus IDCs and LTM)** | **$6,131,000** | |
| | | | | | |
| | | | **TOTAL REMEDIATION COST** | **$6,131,000** | |

Notes:
1 All cost values are estimates and should not be interpreted as final construction or project costs. Costs are in present dollar and do not include inflation costs.
2 Total values are rounded up to the nearest $10,000.
3 ERD cost estimates are based on current interim action costs and additional vendor information.
4 SVE system cost estimates are based on experience from past site operations and current estimates for SVE operations.
5 Anticipated costs for permitting, engineering design, reporting, and construction oversight are assumed as 20% of the estimated source area remediation cost. Contingency included for feasibility-level planning and may be adjusted during the remedial design phase of the project.

Abbreviations:
bgs Below ground surface
ERD Enhanced Reductive Dechlorination
IDC Indirect Cost
LS Lump Sum
SVE Soil vapor extraction
YR Year

**More Aggressive Remedy Enhanced Reductive Dechlorination, Continued Operation and Optimization of SVE System, and GW Extraction and Treatment**

| GW Extraction and Remediation Tasks | Quantity | Unit | Unit Cost [1] | Total Cost [2] | Detail |
|---|---|---|---|---|---|
| Land Purchase Price | 1 | LS | $ - | $ - | Installed on F& B |
| Capital Costs for Treatment System | 1 | LS | $ 150,000 | $ 150,000 | Includes carbon units, electrical drop, and plumbing associated with up to 75 gpm GAC carbon system |
| Site development and building for treatment system | 1 | LS | $ 31,250 | $ 31,250 | Includes site work, small building for controls |
| Control Systems | 1 | LS | $ 56,000 | $ 56,000 | Instrumentation, PLC, Programming, etc. |
| Installation and Start-up of System | 1 | LS | $ 18,750 | $ 18,750 | Includes startup tests, monitoring work plans and reporting |
| Extraction Well Drilling | 4 | Well | $ 24,688 | $ 99,000 | Assumes 4-inch diameter extraction wells to be installed to depth of 220 feet bgs |
| Well Development | 4 | Well | $ 1,250 | $ 5,000 | Based on drillers estimate |
| Field Oversight for Injection Well Install and Development | 10 | Day | $ 1,500 | $ 15,000 | Includes 1 FTE for 10 hours per day. 2 days per well installation, development of 2 wells/day. |
| Well vault install | 4 | EA | $ 7,500 | $ 30,000 | 4 ft by 4 ft, diamond plate, rated for H-20 wheel load |
| Pump install | 4 | EA | $ 9,375 | $ 38,000 | 4 Grundfos 3 hp pumps with riser for 210 ft, 10 gauge pump wire |
| IDW Management and Disposal (soil, Subtitle C) | 0 | drum | $ 375 | $ - | Assume transport and disposal at Subtitle C landfill); none all extraction wells are a distance downgradient. |
| IDW Management and Disposal (soil, Subtitle D) | 10 | ton | $ 150 | $ 1,500 | Assume rental of roll-off container, transport and disposal at Subtitle D landfill. |
| IDW Management and Disposal (water) | 1 | LS | $ 6,250 | $ 6,250 | Assumes frac tank and carbon treatment system rental, treatment and discharge to sanitary sewer. |
| Power supply to pumps | 4 | EA | $ 3,125 | $ 13,000 | |
| Trenching/conduit for power | 1600 | ft | $ 31 | $ 50,000 | to each well for power |
| Trenching/piping for supply to treatment | 1600 | ft | $ 38 | $ 60,000 | 4 1.5 inch lines |
| Trenching/piping for discharge from treatment | 3000 | ft | $ 50 | $ 150,000 | 1 3 inch line |
| Construction oversight | 50 | Day | $ 1,500 | $ 75,000 | |
| Well Testing/ ROI /Containment verification | 1 | LS | $ 18,750 | $ 18,750 | |
| Equipment Replacement and Maintenance | 1 | LS | $ 43,750 | $ 43,750 | Includes periodic replacement costs such as meters, valves, pump, hoses, etc. |
| Operation and Maintenance, Years 0-10 | 10 | YR | $ 62,500 | $ 625,000 | Assumes routine operation and maintenance (including carbon and electricity consumption) for 10 years after construction. |
| Operation and Maintenance, Years 11-20 | 10 | YR | $ 46,875 | $ 468,750 | Assumes routine operation and maintenance (including carbon and electricity consumption) for years 11-20 years after construction. |
| **Subtotal:** | | | | **$1,955,000** | |
| ***ERD Element from Reference Remedy*** | | | | ***$2,972,000*** | |
| **COMPLIANCE MONITORING COSTS (discharge only)** | | | | | |
| Annual Compliance Monitoring, Years 0-20 | 20 | YR | $ 7,500 | $ 150,000 | Assumes 4 sampling events per year (for 20 years post-construction) for influent, mid-point, and effluent. |
| ***Subtotal:*** | | | | ***$150,000*** | |
| **SVE REMEDIATION IN MAIN SOURCE AREA[4]** | | | | | |
| Optimize, Operate and Maintain SVE System for Vadose Zone, Years | 7 | YR | $ 162,500 | $ 1,137,500 | Assumes active optimization, operation, and maintenance (including carbon and electricity consumption) for 1-7 years. |
| Limited Operation and Maintenance, Years 7-20 | 13 | YR | $ 16,250 | $ 211,250 | Assumes limited operation for years 7-20 (run 10% of time) |
| Equipment Replacement and Maintenance | 1 | LS | $ 19,500 | $ 19,500 | Assumes periodic replacement of SVE components (i.e. blower replacement, hoses, valves, etc.) |
| ***Subtotal:*** | | | | ***$1,368,000*** | |
| ***Reduced Monitoring from Reference Remedy*** | | | | | |
| Semi-Annual Key Monitoring Well Sampling/ERD Performance Monitori | 10 | Event | $ 11,250 | $ 112,500 | Monitoring of 12 key wells to be completed semi-annually, years 0-10. Includes labor, equipment, and laboratory analysis. |
| Annual Key Monitoring Well Sampling (Years 0-10) | 10 | Event | $ 33,750 | $ 337,500 | Monitoring of key wells (assume 40) to be completed annually, years 0-10. Includes labor, equipment, and laboratory analysis. |
| Bi-annual Key Monitoring Well Sampling (Years 11-20) | 5 | Event | $ 18,750 | $ 93,750 | Monitoring of key wells (assume 20) to be completed bi annually, years 11-20, containment extraction system is in operating |
| Annual Key Monitoring Well Sampling (Years 21-30) | 10 | Event | $ 6,325 | $ 63,250 | Monitoring of key wells (assume 10) to be completed annually, years 21-30. Includes labor, equipment, and laboratory analysis. |
| ***Subtotal:*** | | | | ***$607,000*** | |
| | | | **Remediation Cost** | **$7,052,000** | |
| **INDIRECT REMEDIATION COSTS** | | | | | |
| Reporting/Design/Project Oversight[3] | 1 | LS | $ 1,410,400 | $ 1,410,000 | Assumes 20% of overall cost for project oversight, management, permits, work plans, reporting, regulatory interaction, etc. |
| ***Subtotal:*** | | | | ***$1,410,000*** | |
| **Remediation Cost (Plus IDCs and LTM)** | | | | **$8,462,000** | |
| | | | | | |
| **TOTAL REMEDIATION COST** | | | | **$8,462,000** | |

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1 All cost values are estimates and should not be interpreted as final construction or project costs. Costs are in present dollar and do not include inflation costs.
2 Total values are rounded up to the nearest $10,000.
3 Anticipated indirect costs are assumed as 20% of the estimated remediation cost.
Contingency included for feasibility-level planning and may be adjusted during the remedial design phase of the project.

Abbreviations:

GPM Gallons per Minute
IDC Indirect Cost
LS Lump Sum
MO Month
YR Year

**Contingency Measure—Well-head Treatment at Supply Well**

| Contingency Remediation Tasks | Quantity | Unit | Unit Cost [1] | Total Cost [2] | Detail |
|---|---|---|---|---|---|
| **Well-head Treatment** | | | | | |
| Land Purchase Price | 1 | LS | $ 187,500 | $ 187,500 | Includes acquisition of property for treatment system. |
| Capital Costs for Treatment System | 1 | LS | $ 312,500 | $ 312,500 | Includes carbon units, electrical drop, and plumbing associated with up to 750 gpm wellhead treatment system. |
| Site development and building for treatment system | 1 | LS | $ 88,750 | $ 88,750 | Includes site work and building |
| Control Systems | 1 | LS | $ 62,500 | $ 62,500 | Instrumentation, PLC, Programming, other miscell. controls, etc. |
| Installation and Start-up of System | 1 | LS | $ 31,250 | $ 31,250 | Includes monitoring workplan,startup tests, and reporting |
| Equipment Replacement and Maintenance | 1 | LS | $ 31,250 | $ 31,250 | Includes periodic replacement costs such as meters, valves, pumps, hoses, miscell., etc. |
| Operation and Maintenance, Years 0-10 | 10 | YR | $ 187,500 | $ 1,875,000 | Assumes routine operation and maintenance (including carbon & electricity consumption) for 10 years after construction. |
| Operation and Maintenance, Years 11-20 | 10 | YR | $ 140,625 | $ 1,406,250 | Assumes routine operation and maintenance (including carbon & electricity consumption) for years 11-20 years after construction. |
| | | | **Remediation Cost** | **$3,995,000** | |
| **COMPLIANCE MONITORING COSTS** | | | | | |
| Annual Compliance Monitoring, Years 0-10 | 10 | YR | $ 9,375 | $ 93,750 | Assumes monthly sampling events per year (for 10 years post-construction) for influent, mid-point, and effluent. |
| Annual Compliance Monitoring, Years 11-20 | 10 | YR | $ 3,125 | $ 31,250 | Assumes quarterly sampling events per year (for years 11-20 post construction) for influent, mid-point, and effluent. |
| ***Subtotal:*** | | | | ***$125,000*** | |
| **INDIRECT REMEDIATION COSTS** | | | | | |
| Reporting/Design/Project Oversight[3] | 1 | LS | $ 824,000 | $ 830,000 | Assumes 20% of overall cost for project oversight, management, permits, work plans, reporting, regulatory interaction, etc., |
| ***Subtotal:*** | | | | ***$830,000*** | |
| **Remediation Cost (Plus IDCs and LTM)** | | | | **$4,950,000** | |
| | | | | | |
| **TOTAL REMEDIATION COST** | | | | **$4,950,000** | |

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2 Total values are rounded up to the nearest $10,000.
3 Anticipated indirect costs are assumed as 20% of the estimated remediation cost.
Contingency included for feasibility-level planning and may be adjusted during the remedial design phase of the project.

Abbreviations:

GPM Gallons per Minute
IDC Indirect Cost
LS Lump Sum
MO Month
YR Year

CALIBRE

Matrix DESIGN GROUP