FINAL
FEASIBILITY STUDY

Broadway Pantano
Water Quality Assurance Revolving Fund Site
Tucson, Arizona

Prepared on behalf of:

ADEQ
Arizona Department
of Environmental Quality

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Date: June 28, 2017
Project No. 14-2016-2026

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LIST OF ACRONYMS AND ABBREVIATIONS

%	percent
§	Section
µg/L	micrograms per liter
A.A.C.	Arizona Administrative Code
A.R.S.	Arizona Revised Statute
ADEQ	Arizona Department of Environmental Quality
ADWR	Arizona Department of Water Resources
AI	air injection
Amec Foster Wheeler	Amec Foster Wheeler Environment & Infrastructure, Inc.
amsl	above mean sea level
AWQS	Aquifer Water Quality Standard
bgs	below ground surface
Blvd	Boulevard
BNL	Broadway North Landfill
BP	Broadway Pantano
BSL	Broadway South Landfill
CAB	Community Advisory Board
Clear Creek	Clear Creek Associates, P.L.C.
COC(s)	contaminant(s) of concern
CSM	conceptual site model
CWF	Central Well Field
DCE	cis-1,2-dichloroethene
DEUR	Declaration of Environmental Use Restriction
DHC	Dehalococcoides
EC	engineering controls
ERA	early response action
FS	Feasibility Study
ft	feet
ft/day	feet per day
ft/ft	feet per foot
GAC	granular activated carbon
GOU	Groundwater Operable Unit
GPL	Groundwater Protection Levels
gpm	gallons per minute
GRO	Groundwater Remedial Objectives
HGL	HydroGeologic, Inc.
HRA	health risk assessment
IC	institutional control
ISBR	in situ biological reduction
ISCO	in situ chemical oxidation
ISCR	in situ chemical reduction
ISTR	in situ thermal remediation
K_H	horizontal hydraulic conductivity
K_v	vertical hydraulic conductivity

LIST OF ACRONYMS AND ABBREVIATIONS

kW/Hr	kilowatt(s) per hour
lb(s)	pound(s)
L-GAC	liquid phase granular activated carbon
LOU	Landfill Operable Unit
M	million
MCL	Maximum Contaminant Levels
mg/m^3	milligrams per cubic meter
MNA	monitored natural attenuation
MSW	municipal solid waste
No.	Number
O&M	operation and maintenance
OMM	operation and maintenance manual
P&T	pump-and-treat
PCE	tetrachloroethene
PDB	passive diffusion bag
PRAP	Proposed Remedial Action Plan
PRB	permeable reactive barrier
QAPP	Quality Assurance Project Plan
RAO	remedial action objectives
Rd	Road
RI	Remedial Investigation
RO	Remedial Objective
ROD	Record of Decision
SAP	Sampling and Analysis Plan
Site	The Broadway Pantano Water Quality Assurance Revolving Fund Site
SRL	Soil Remediation Levels
St	Street
Stantec	Stantec Consulting Corporation
SVE	soil vapor extraction
TCE	trichloroethene
TEP	Tucson Electric Power
TW	Tucson Water
VC	vinyl chloride
V-GAC	vapor phase granular activated carbon
VOC	volatile organic compound
WCS	Western Containment System
WQARF	Water Quality Assurance Revolving Fund
ZVI	zero valent iron

1.0 INTRODUCTION

This Feasibility Study (FS) Report was developed for the Broadway Pantano (BP) Water Quality Assurance Revolving Fund (WQARF) site (the "Site") located in Tucson, Arizona (see **Figure 1-1**). Amec Foster Wheeler Environment & Infrastructure, Inc. (Amec Foster Wheeler) prepared the FS with direction from the Arizona Department of Environmental Quality (ADEQ) in accordance with the scope of work and terms and conditions of Arizona Superfund Response Action Contract Number (No.) ADEQ14-077536 between Amec Foster Wheeler and ADEQ and ADEQ Task Order No. ADEQ14-077536:33.

1.1 Purpose and Scope of Feasibility Study Report

The FS documented herein was prepared in accordance with Arizona's remedial action criteria per Arizona Revised Statutes (A.R.S.) Section (§) 49-282.06 and Arizona's requirements for Feasibility Studies at WQARF sites per Arizona Administrative Code (A.A.C.) R18-16-407. The FS relies on data and findings of previous investigations, including those documented in the following reports:

- Final Remedial Investigation (RI) Report, Groundwater Operable Unit (GOU) (Stantec, 2012);
- Final RI Report, Landfill Operable Unit (LOU) (Clear Creek Associates [Clear Creek], 2015a);
- Groundwater Model Report Supporting Remedial Alterative Evaluation (**Appendix A**);
- In Situ Chemical Oxidization (ISCO) Pilot Study Report (**Appendix B**);
- Sitewide Groundwater Monitoring Report, December 2014 through March 2015 (**Appendix C**); and
- Shallow and Deep Soil Gas Investigation Report, Broadway South Landfill (BSL) - March 2015 (**Appendix D**).

The objectives of this FS are as follows:

- Identify remedial measures[1] and strategies[2] that will achieve Site Remedial Objectives (ROs), and
- Develop a reference remedy[3] and alternative remedies using identified measures and strategies that are capable of achieving Site ROs, evaluate the remedies, and select a

[1] A.C.C. R18-16-401-- "remedial measure" is a specific action taken in conjunction with remedial strategies as part of the remedy to achieve one or more of the remedial objectives. For example, remedial measures may include well replacement, well modification, water treatment, provision of replacement water supplies, and engineering controls.

[2] A.C.C. R18-16-401--"Remedial strategy" means one or a combination of the six general approaches described in R18-16-407(F) which may be employed in conjunction with remedial measures as part of the remedy to achieve the remedial objectives. See Section 5.0 for additional explanation.

[3] A.C.C. R18-16-401--"Reference remedy" means a combination of remedial strategies and remedial measures which, as a whole, is capable of achieving remedial objectives. The reference remedy is compared with the alternative remedies for purposes of selecting a proposed remedy at the conclusion of the feasibility study. See Section 3.0 for additional explanation.

Proposed Remedy that achieves the ROs and complies with the requirements of A.R.S. § 49-282.06.

The Proposed Remedy will present recommendations, consistent with A.R.S. § 49-282.06, that:

- Assure the protection of public health and welfare and the environment;
- 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;
- Are reasonable, necessary, cost-effective and technically feasible;
- Are consistent with the soil remediation standards adopted pursuant to A.R.S. § 49-152; and
- Address, at a minimum, any well that at the time of selection either supplies water for municipal, domestic, industrial, irrigation or agricultural uses or is part of a public water system if the well would now or in the reasonably foreseeable future produce water that would not be fit for its current or reasonably foreseeable end uses without treatment due to the release of hazardous substance.

1.2 Report Organization

The FS Work Plan (ADEQ, 2015), developed pursuant to A.A.C. R18-16-407(B), outlines a table of contents for the FS Report. This FS Report is organized according to the structure identified in the FS Work Plan and was augmented as necessary into the following sections:

- **Section 1.0 – Introduction.** This section outlines the purpose, scope and organization of the FS Report.
- **Section 2.0 – Site Background.** This section describes background information applicable to the Site and presents a conceptual site model (CSM) for Site contamination.
- **Section 3.0 – Feasibility Study Scoping.** This section presents the regulatory requirements for the FS process identified in statute and rule, delineates Site remediation areas, and presents the ROs identified in the RI.
- **Section 4.0 – Identification and Screening of Remedial Measures and Remedial Strategies.** This section presents the evaluation and screening of various remedial measures and strategies related to contamination in soil and groundwater at the Site and lists the measures that have been retained for evaluation as part of the reference and alternative remedies pursuant to A.A.C. R18-16-407 (E) and (F).
- **Section 5.0 – Development of Reference Remedy and Alternative Remedies.** This section identifies the reference remedy and the alternative remedies, including a more aggressive remedy and a less aggressive remedy. Each remedy includes a discussion of the associated remedial measures and remedial strategies pursuant to A.A.C. R18-16-407(E).
- **Section 6.0 – Detailed Comparison of the Reference Remedy and the Alternative Remedies.** In this section, the remedies are compared to each other based on the

comparison criteria of practicability, cost, risk, and benefit. Uncertainties, if identified, associated with each remedy or comparison criteria are discussed pursuant to A.A.C. R18-16-407(H).

- **Section 7.0 – Proposed Remedy.** This section presents the proposed remedy as required in A.A.C. R18-16-407(I), and discusses how it will achieve the ROs, how the comparison criteria were considered, and how the proposed remedy will meet the requirements of A.R.S. § 49-282.06.
- **Section 8.0 – Community Involvement.** This section documents the community involvement activities conducted in association with the FS.
- **Section 9.0 – References.** This section documents the references that were used to develop this FS Report.

2.0 SITE BACKGROUND

2.1 Site Description

The Site is located in east-central Tucson, Arizona within a heavily urbanized area that is characterized by residential development between major thoroughfares and light commercial development along major road corridors. Approximate boundaries of the Site are Speedway Boulevard (Blvd) to the north, Pantano Wash to the east, 22nd Street (St) to the south, and Craycroft Road (Rd) to the west (**Figure 1-1**).

For the purpose of RI activities, the Site was divided into two operable units:

- The LOU – which includes the closed 83-acre Broadway North Landfill (BNL), the closed 42-acre BSL, and the vadose zone directly beneath, and in close proximity to, the BNL and BSL boundaries; and
- The GOU – which includes the volume of the saturated zone containing contaminant concentrations exceeding State of Arizona Aquifer Water Quality Standards (AWQSs) at the Site.

This FS addresses both operable units. As depicted in **Figure 1-1**, the LOU footprint is smaller than the GOU footprint and has been identified as the source of contaminant impacts in the GOU. The GOU is predominantly located in parts of Sections 7, 8 and 17 of Township 14 South, Range 15 East.

2.1.1 Current Nature and Extent of Site Contamination

The contaminants of concern (COCs)[4] in the GOU are volatile organic compounds (VOCs) and include tetrachloroethene (PCE), trichloroethene (TCE), vinyl chloride (VC), methylene chloride, and dichloroethene (DCE). These contaminants have been detected at some time in the past at concentrations that exceed the respective Arizona AWQS. PCE is the predominant COC and the estimated extent of this compound at 5 micrograms per liter (µg/L; the AWQS) defines the limits of the GOU (**Figure 2-1**). The only other COC currently present at the Site at concentrations exceeding the AWQS is TCE (**Figure 2-2**). The highest concentrations of COCs in the GOU are detected at and near (within one-third of a mile of) the BNL; however, the GOU extends from the BNL and BSL almost 2.5 miles to the west with a small detached plume[5] located near Speedway Blvd and Craycroft Rd. Approximately the upper 80 to 105 feet (ft) of the aquifer in the GOU are impacted with VOCs. During recent groundwater monitoring events conducted using passive diffusion bag (PDB) samplers in 2015 (**Figures 4** and **5** in **Appendix C**) and 2016 (**Figures 2-1** and **2-2**), groundwater in the vicinity of BNL contained maximum PCE and TCE concentrations of 120 µg/L (2015) and 35 µg/L (2015), respectively. Beyond one-third of a mile downgradient of the BNL, the highest concentration of PCE found in the GOU was 17 µg/L (2015). Near the BSL, the

[4] A COC, as defined by A.A.C. R18-16-401, "means a hazardous substance that results from a release and that has been identified by the Department as the subject of remedial action at a site." COCs are those contaminants that have been detected with some consistency in groundwater, soil or soil gas at concentrations above regulatory or risk-based levels.

[5] "Plume" is defined as the portion of the groundwater which contains a contaminant concentration exceeding the AWQS.

highest concentration of PCE detected was 47 µg/L (2016).

In addition to the VOC contamination referenced above, another type of waste containing high concentrations of metals has been identified at the Site. This waste is referred to as dross material and contamination is limited to near surface soils located in the southern portion of the BNL. To simplify report organization, the main text of this FS Report addresses vadose zone and aquifer contamination derived from VOC-impacted waste and is referenced throughout as “VOCs in Landfill Waste,” and **Appendix E** separately documents the feasibility process for the dross material and is referenced throughout as “Metals in Dross Material”.

2.1.2 Landfill History

Both the BNL and BSL are unlined landfills constructed before federal regulations were promulgated that established minimum technical standards and guidelines for the management of nonhazardous municipal solid waste (MSW) (i.e., the Resource Conservation and Recovery Act Subtitle D). Summary information regarding past operations and landfill construction are presented below. Unless otherwise noted, information is abstracted from the LOU RI Report (Clear Creek, 2015a).

Broadway North Landfill. Beginning in the mid-1940s, the region currently occupied by BNL was used for sand and gravel mining operations. Various portions of the former gravel pits at BNL were filled with MSW and/or construction debris from approximately 1959 to 1972 but the area was known to be used as a “wildcat” (i.e., uncontrolled) dump prior to 1959. Sand and gravel quarrying continued simultaneously with landfilling in separate portions of the BNL into the early 1970s. As part of landfill closure, the waste was covered with soil.

Residential, agricultural, commercial, and industrial wastes (including industrial solvents) were deposited at BNL with disposal rates ranging from a few tons per day to 300 tons per day; there were no restrictions on the types of waste deposited (HydroGeoLogic, Inc. [HGL], 2012) and there was limited oversight of waste placement.

Based on the results of past site investigation activities, three separate regions of landfill waste are present at BNL (**Figure 2-3**):

- The northernmost area (14 acres) is situated north of the 5th Street alignment and east of the Tucson Electric Power (TEP) power substation. MSW was placed in this region at thicknesses ranging from approximately 10 to 30 ft. The thickness of soil cover over the waste is 1 to 10 ft thick.
- The middle landfill area (65 acres) is situated between the northernmost and southernmost areas. MSW in this region generally ranges from 0 to 20 ft thick but in some areas, the waste can be up to 24 ft thick. Soil cover over the waste ranges from less than 1 ft to 14 ft in thickness.
- The southernmost area (4 acres) is a construction debris waste site located north of Broadway Blvd. The thickness of waste in this region is 0 to 20 ft with less than 1.5 ft of soil cover. A portion of the construction debris waste site (3.5 acres) is covered by the Broadway Star Plaza (a retail shopping strip mall) and associated parking lot. Dross material (a metallic waste of unknown origin) was identified in a portion of the construction

debris waste site during an effort to redevelop the property in the mid-1990s. The dross material disposal area is approximately 1.9 acres in extent and ranges from a few inches to a few feet in thickness (see **Appendix E**).

A methane mitigation system was installed at BNL in the early 1980s; this system originally used a passive vent/barrier trench located along limited areas of the west and south perimeters of the BNL. The system was dismantled before 1995. The current methane collection system uses shallow soil vent wells and a blower; the system is operated on a routine schedule by the property owner (HSL Properties, Inc.).

Broadway South Landfill. Prior to 1953, the BSL property was used for agriculture and then leased for sand and gravel operations. Precise dates of these operations are not known. The landfill at BSL was operated from 1953 to 1962 (HGL, 2012 and URS, 2004). Landfilling at BSL progressed from north to south. Approximately 200 tons of waste were deposited in the landfill per day. Green waste and debris were separated from MSW. Aerial photographs (URS, 2004) show that most of the pits at BSL were filled and graded by 1958, but that the final cover had not been completed. A 1962 aerial photo shows the area as smoothed and graded. Landfill operators placed warning signs at BSL in response to wildcat dumping, a practice that continued after closure (HGL, 2012).

Unlike BNL, there was only one waste placement region at BSL (**Figure 2-3**). Gollob Park and portions of properties occupied by Broadway Proper (a retirement community), a Hilton Hotel, and a Culver’s restaurant facility are constructed on top of BSL; waste was reportedly removed prior to building construction at these properties but the extent of removal is not well documented. Site investigation activities indicate that the thickness of waste in BSL is variable but thickest (up to 30 ft) in the center portion of the landfill. Soil cover over the waste ranges in thickness from 0.5 to 12 ft.

A methane mitigation system was installed at BSL in 1986 (Clear Creek, 2015a). It consisted of 37 wells, a collection header located near the perimeter of the waste, and a series of gas monitoring probes along Prudence Rd, Broadway Blvd, under the Hilton Hotel, and around the Broadway Proper Retirement Community facility. The current status of operations is unknown. Both the Hilton and the Broadway Proper buildings are equipped with methane sensor/alarm devices.

2.1.3 Current Land and Groundwater Use

Land Use. In general, the BNL and the parcels on which it is located are currently undeveloped and unoccupied (**Figure 2-3**). **Figure 2-4** identifies Pima County parcel numbers (Nos.) and indicates different parcel ownership with distinguishing colors (i.e., there are three different colored parcels at BNL which refer to three different property owners). Although there are multiple unimproved roads that crisscross the landfill and provide access to site monitoring wells, the only development on associated parcels consists of the Broadway Star Plaza (a retail shopping strip mall which faces Broadway Blvd) and a TEP Substation located west of the most northern waste placement area of BNL. Full time workers are limited to those who work at the Broadway Star Plaza. The TEP substation is typically unmanned.

The waste placement areas at BNL are surrounded by a perimeter fence line on the southern and western boundaries of the landfill (adjacent to off-site residential areas). The BNL landfill soil cap is in generally good condition but there are some localized low lying areas where surface water ponding and/or erosion is occurring. Small amounts of trash are present at the surface but do not appear to be exposed landfill waste. Native vegetation is present over most of the landfill extent. Run-on surface water from residential areas is directed to a manmade channel that runs along the western and northern boundary of the BNL before discharging into Pantano Wash. On the landfill, a drainage channel directs storm water north from Prudence Rd and northeast to Pantano Wash. There is evidence that unauthorized trespassers are entering the fenced-in part of BNL. Vandalism and wildcat dumping are common; transients and recreational users have been observed.

The BNL is surrounded by a variety of land uses. To the east, on the other side of the Pantano Wash, from north to south, are single family residences, multi-family residences, and commercial properties, the closest one being a Home Depot store. Surrounding the southwest quadrant of the BNL is single family housing. To the northwest of the BNL are offices and a medical center.

At BSL, land uses include undeveloped property, a Hilton Hotel at the northeast corner, a Culver's restaurant at the northwest corner, the Broadway Proper retirement community to the southwest, and Gollob Park at the south end of the BSL (**Figure 2-3**). **Figure 2-4** indicates that there are six different owners of BSL parcels. A YMCA is located west of Gollob Park and is not considered to be in the LOU. Kenyon Terrace, a townhome development, is located immediately south of the YMCA and Gollob Park and is outside the LOU boundary. Another landfill that is not part of the LOU (Prudence Landfill) is located south of Gollob Park, adjacent to Pantano Wash.

BSL is not fenced and some improvements have been made to the landfill surface in support of redevelopment. Limited information is available regarding surface water drainage at BSL. The undeveloped portions of the landfill are covered with native vegetation and include localized areas of landfill cap cracking, erosion, and trash disposal.

Adjacent property uses are single family homes on the west side of the LOU across Prudence Rd, and multi-family homes across Pantano Wash on the east side of the LOU and south of the LOU.

Groundwater Use. BNL and BSL are located in the Tucson Water (TW) Central Well Field (CWF) which supplies drinking water to Tucson residents. Multiple private wells which supply domestic water to landowners are also located in the area. **Figure 2-5** identifies water supply wells with Site monitoring wells and designates whether TW production wells are active, standby, inactive, or abandoned water supply wells. TW has designated five of their production wells as standby wells (i.e., C-020B, C-025B, C-58B, D-018A and D-49A); these wells have restricted-use operational status because of their proximity to the GOU.

2.1.4 Early Response Actions Conducted to Date

Shutdown of Production Wells. The first evidence of VOCs in groundwater beneath the LOU was in the D-022A well at BNL (see **Figure 2-5**) in 1983. In response, TW took production wells D-022A, C-021A, and D-021A out of service between 1987 and 1991 due to the presence of PCE in groundwater samples collected from these wells. TW production well C-026B was taken out of service due to PCE contamination in 1998.

Wellhead Treatment. In April 1994, St. Joseph's hospital detected PCE and TCE in groundwater samples collected from their private water supply well (411-P). Wellhead treatment was implemented at this well to treat VOCs from 1997 through 2009 (the well has been off-line since that time due to a well casing issue). The hospital plans to replace the well by 2020. When operational, this system operated at flow rates ranging from approximately 50 to 90 gallons per minute (gpm).

Site Cleanup. To date, cleanup activities conducted to address elevated concentrations of VOCs in the vadose zone and groundwater at the Site include implementation of soil vapor extraction (SVE) with air injection (AI) at BNL and construction and operation of a pump-and-treat (P&T) containment system referred to as the Western Containment System (WCS).

After VOCs present in soil gas underlying BNL were identified as a source of groundwater contamination at the Site, SVE/AI was conducted in the BNL from June 2000 to September 2002 and successfully removed almost 2,000 pounds (lbs) of non-Freon VOCs. **Figure 2-6** identifies the wells that were used for SVE/AI operations and presents select data from wells that demonstrate the impacts of treatment on PCE concentrations in deep soil gas at BNL (i.e., 50 to 300 ft below land surface). In 2001, HydroGeoChem, Inc. developed soil vapor concentrations protective of groundwater at BNL that were referred to as soil gas remedial action objectives (RAOs)[6]. Based on site characteristics, the soil gas RAOs for PCE and TCE were 14 and 6 milligrams per cubic meter (mg/m^3), respectively. SVE operations decreased COC concentrations to levels that were less than RAOs developed for BNL. Deep soil vapor sampling conducted during the LOU RI indicated no appreciable rebound of VOCs in the vadose zone since the SVE/AI system was turned off. These data suggest that operations effectively removed the source of VOCs in the vadose zone below BNL which could adversely affect groundwater quality.

The WCS was constructed approximately 1.5 miles downgradient of BNL and operated from March 2003 to October 2012. The WCS extracted and treated 800 gpm of groundwater from two extraction wells (R-092A and C-026B) located near Wilmot Rd, south of Speedway Blvd (**Figure 2-5)**. P&T operations were conducted to prevent, to the extent feasible, further migration of groundwater contamination within the TW CWF. In 2012, WCS operations were suspended because operations effectively reduced concentrations in the vicinity of the extraction wells to less than the AWQS. **Figure 2-7** shows the estimated extent of the PCE groundwater plume in March 2003 when WCS operation began, in April 2007 during WCS operation, and in February/March of 2015 and 2016 after WCS operations had been shut down for multiple years. As depicted in **Figure 2-7**, a small detached plume, currently located near WR-704A, containing low concentrations of PCE (5.2 µg/L in February 2016), was not treated by WCS operations and continued to migrate west with groundwater flow during and after containment operations.

[6] Revision of the Soil Rule in 2007 (A.C.C. Title 18, Chapter 7, Article 2, Soil Remediation Standards) provided for the conversion of VOC soil gas concentrations to soil equivalent concentrations (R18-7-203[C]), and, henceforth, soil equivalents need to meet soil remediation standards.

2.2 Conceptual Site Model

The CSM is a multi-dimensional representation of site conditions that illustrates contaminant distribution, release mechanisms, exposure pathways/migration routes, and potential receptors. A CSM that combines known site information into a comprehensive understanding of site conditions is a necessary tool for comparison of potential remedial technologies. CSMs must be reevaluated and modified as needed to continually evaluate the relationship between the sources of contaminants, release mechanisms, migration pathways, and receptors as new data become available.

The following summary CSM is abstracted from the LOU and GOU RIs for easy reference; a graphical depiction is provided in **Figure 2-8**. More detailed information is presented in the LOU and GOU RI Reports.

2.2.1 Environmental Setting

Climate and Topography. The Site is located in the arid Sonoran Desert, which has long, hot summers and mild winters. The average annual rainfall in Tucson, Arizona is 11.6 inches (based on the period of 1981 through 2010). The Tucson area has experienced sustained drought conditions since 1994.

The highest elevation within the LOU is at the southeast corner of the Broadway Proper parcel, which has an elevation of 2,620 ft above mean sea level (amsl). The lowest elevation in the LOU is 2,530 ft amsl at an excavated area (a former gravel pit) at the northwest corner of BNL. Slopes are gradual over most of the LOU except at the previously-mentioned pit, a concrete-lined drainage channel (installed in 1998) that directs storm water across BNL, and along Pantano Wash where a steep embankment (over 10 ft high) borders the wash.

Pantano Wash flows from south to north along the east side of BNL and BSL. Flow is ephemeral and occurs in response to runoff from precipitation events, primarily during summer monsoon storms. The wash likely serves as the closest source of groundwater recharge at the LOU to the GOU.

Hydrogeology. The Site is located within the Tucson Basin, a northwest trending structural basin filled with alluvial sediments and bounded by multiple mountain ranges. Site sediments consist predominantly of sand/sandy gravel and are relatively unconsolidated down to approximately 500 ft below ground surface (bgs). Discontinuous lenses of clayey and silty sands are present at BNL in the upper 300 ft and in the upper 300 to 400 ft at BSL. At approximately 500 ft bgs, marked consolidation is observed with a corresponding decrease in aquifer transmissivity.

The depth to groundwater at the Site ranges from approximately 300 to 375 ft bgs. Groundwater below the BSL flows in a north-northwesterly direction and then turns more westerly toward the north end of the BSL (**Figure 2-5**). Groundwater flow is generally consistent with the natural groundwater gradient in the Tucson Basin (i.e., toward the northwest) and is likely influenced locally at the Site by mountain front recharge and groundwater extraction by TW in the CWF. The approximate horizontal gradient at BSL is 0.004 feet per foot (ft/ft). Groundwater below and downgradient of the BNL flows generally west to northwest at a gradient of 0.002 to 0.003 ft/ft.

Based on aquifer testing of TW production wells located in or near the GOU, the horizontal hydraulic conductivity (K_H) of the Site aquifer is on the order of 54 to 118 feet per day (ft/day) (Stantec, 2012). Vertical hydraulic conductivity (K_V) was measured at well C-026B and K_H:K_V was estimated to be approximately 15:1 (Stantec, 2012).

The groundwater table at the Site has risen since TW began introducing a recovered blend of Central Arizona Project and Avra Valley groundwater to the drinking water supply of Tucson in 2001. This alternate source of water allowed TW to turn off or significantly curtail pumping of its CWF. In general, water levels in the GOU have risen by approximately 20 to 30 ft since 2001 (**Figure 2-9**). At monitoring well WR-274A (located near the western boundary of BNL), the water table has risen by 25 ft with most of this increase occurring after 2006.

2.2.2 Contaminant Fate and Transport

VOCs derived from placement of contaminated landfill waste and wildcat dumping in the LOU are the primary source of groundwater impacts at the Site. The following bulleted list summarizes the likely mechanisms responsible for the fate and transport of these contaminants to potential receptors.

- As waste was placed in BNL and BSL (from circa 1953 to 1972), the natural breakdown of waste by microbial processes likely produced heat which contributed to the volatilization of VOCs, primarily chlorinated solvents, present in contaminated waste and created soil vapor with elevated concentrations of methane, carbon dioxide, and VOCs in the landfill. No evidence of dense non-aqueous phase liquids at the Site has been detected.
- Pressure and temperature gradients generated by the microbial production of landfill gas in the landfills resulted in both lateral and vertical migration of VOC-impacted soil vapor from the landfills to the region surrounding the landfill waste. Density driven transport of chlorinated solvent vapors may also have contributed to the downward migration of VOCs. In the LOU RI Report, migration of VOC contamination from the landfills to the surrounding vadose zone and groundwater interface is referred to as the ‘active release phase’ of the landfill. As landfills age, these gradients decrease and the contaminant flux from the landfill declines.
- During the active release phase of the landfill, the primary fate and transport mechanisms for contaminants in the vadose zone are volatilization from impacted waste, vapor advection, vapor diffusion, adsorption, and biodegradation. The vadose zone at the Site is primarily composed of sand and gravel and this lithology is conducive to vapor migration. Near the surface, atmospheric or barometric pumping[7] contributes to the dispersion and dilution of impacted vapors (Auer et al., 1996) and over time results in lower concentrations of VOCs in the soil gas of the landfill and shallow soils compared to those observed in the soil gas of deep soils. At depth, diffusion of contaminated soil vapors due to concentration gradients becomes a dominant transport mechanism for VOCs in the vadose zone.

[7] Atmospheric or barometric pumping refers to the effects of diurnal pressure variations that contribute to the exchange of air between the atmosphere and the subsurface. As pressure decreases, soil gas is drawn out of permeable soils; as pressure increases, air is pushed into the subsurface.

- In regions of the site where treatment of vapors has occurred (i.e. at BNL), lower concentrations would result in smaller concentration gradients and declining rates of contaminant mass transfer from the vadose zone to the groundwater. **Figure 2-10** depicts the significant decrease in groundwater PCE concentrations observed at one of the historically most contaminated wells at the Site (R-068A) post SVE/AI at BNL.
- There is evidence that microbially mediated reductive dechlorination (i.e., biodegradation) of PCE has occurred at the site. Reductive dehalogenation daughter products including TCE, cis-1,2-DCE, and VC have been detected in soil vapor collected from beneath the landfills. It is likely that these transformations occurred either in the landfills or in the vadose zone near the landfills where a carbon source (i.e., organic waste or landfill gas), moisture and reducing conditions are present. Reductive dehalogenation may also have occurred in groundwater underlying the landfills in the past (URS, 2002) but current groundwater monitoring (**Appendix C**) indicates that conditions in groundwater underlying the landfills are aerobic and not favorable for this process.
- Vapor-phase VOCs may enter groundwater by dissolving into infiltrated water that passes through contaminated soil vapor in the vadose zone as a result of infiltration from heavy rainstorms. However, advective transport of aqueous phase VOCs in infiltrating soil water is not considered to be a significant source of groundwater contamination based on low net infiltration rates and limited impacts observed from landfill leachate at the Site.
- At the vadose zone-groundwater interface, contaminants likely dissolve directly from the contaminated soil vapor into the groundwater present in the capillary fringe of the water table, as governed by Henry's Law. Over time, contaminants present in soil vapor can also diffuse into and/or adsorb onto fine-grained soils (present in discontinuous layers at depth under both BNL and BSL). Since the groundwater table has risen significantly (**Figure 2-9**), the VOCs present in these fine grained soils (adsorbed onto solids and present as either vapor or moisture in soil pores) can slowly dissolve into groundwater and contribute to the sustained release of contamination over significant durations. The LOU RI indicates that increasing PCE concentrations observed at groundwater well WR-274A from 2004 to 2011 (**Figure 2-10**) may be attributable to this mechanism. As shown in **Figure 2-10**, PCE concentrations at this well began to decline as of the beginning of 2013. Further decreases were observed after conducting a limited ISCO pilot-study immediately upgradient of the well in 2016 (**Appendix B**).
- Once contamination is dissolved into groundwater, contaminants migrate with groundwater flow through advection, dispersion, and diffusion processes or are retained via sorption onto soil, degraded by abiotic or biotic mechanisms, and volatized from groundwater at the water table surface. Site soils likely contain limited amounts of organic carbon and thus adsorption and biodegradation of PCE are probably negligible downgradient of the LOU. Based on the current and historical shape of the contaminant plumes and the likely effect of historical and current production well pumping, advection and dispersion appear to be the primary contaminant transport mechanisms in Site groundwater. In general, the average linear velocity of groundwater is estimated to be approximately 0.96 ft/day based on a K_H of 75 ft/day, a specific yield of 0.25, and a hydraulic gradient of 0.003 ft/ft (Stantec, 2012).

2.2.3 Risk Evaluation Summary

A receptor comes into contact with site COCs only if a complete or potentially complete exposure pathway exists under current (or future) land use or groundwater use conditions. For an exposure pathway to be considered complete, it must be possible for a chemical to be transported via an environmental medium to a potential receptor location (i.e., exposure point) and then for the receptor to come in contact with the chemical and assimilate it into their bodies via one or more exposure routes (for instance, ingestion, inhalation, or dermal contact).

Multiple investigations into site contamination have been conducted at BNL and BSL to evaluate the risks that VOCs in the landfill waste, surface soil, contaminated soil vapor, and groundwater pose to site users and nearby residents. Unless otherwise noted, these investigations are documented in the LOU RI Report (Clear Creek, 2015a). Based on these analyses, **Figure 2-11** summarizes current and potential future Site exposure pathways for VOCs derived from landfill waste. As indicated, risks associated with current completed pathways are within risk management thresholds. A discussion of each pathway follows.

Waste. Although there has been limited characterization of VOC concentrations in waste present in the landfills, soil vapor samples have been collected from the Site waste placement areas to evaluate whether VOCs remain present in the landfills. Concentrations have been low relative to historical values and recent levels of PCE detected in samples collected from methane monitoring probes and temporary shallow soil gas probes installed in the landfills suggest that the waste placed in the landfills no longer serves as a significant source of VOC contamination to the environment. The maximum PCE concentration detected at the Site during shallow soil gas probe monitoring conducted in 2013 was 0.19 mg/m^3 at BNL at 5 ft bgs[8]. It is possible that the landfills could still contain VOC waste in sealed containers that may be released into the vadose zone in the future but, with the passage of time, this scenario becomes less likely. Regardless of VOC concentrations, landfill waste is covered with soil which currently renders the dermal and ingestion exposure routes from the waste to outdoor site users and trespassers incomplete as long as the waste remains unexposed (soil gas is evaluated separately below). If the landfills are not properly maintained or are redeveloped without adequate engineering controls (ECs), the soil cover may erode or become compromised in the future which could theoretically result in a complete exposure pathway to individuals that come into contact with the exposed waste.

Soil. Surface soil and shallow soil vapor samples have been collected from both the BNL and BSL to evaluate the risk that Site soil poses to potential receptors. Analytes in soil samples were either not detected or were present at concentrations that were less than applicable Soil Remediation Levels (SRLs) and Groundwater Protection Levels (GPLs). These risk-based thresholds evaluate human exposure to impacted soil and the potential for mobilization of contamination in soil to groundwater by leaching, respectively. Contaminant concentrations that are less than these threshold values suggest that the surface soils do not pose a current or future threat to likely receptors (e.g., outdoor site users and trespassers). Given that the COCs are VOCs, one of the approaches used to evaluate the risk of Site soil involved converting shallow

[8] Clear Creek Associates (2015) calculated a soil equivalent concentration of 0.000295 mg/kg for this maximum observed PCE vapor concentration. This soil equivalent concentration is less than the minimum GPL for PCE of 0.80 mg/kg and the Residential SRL of 0.51 mg/kg.

soil vapor VOC concentrations in soil gas collected from BNL and BSL to soil equivalent VOC concentrations according to ADEQ guidance (ADEQ, 2011) as provided for in A.A.C. R18-7-203(C). The soil equivalent concentrations did not exceed the most stringent applicable SRLs or GPLs, which supports the assessment that, although VOCs may be present in Site soil, the concentrations would be expected to be low and within acceptable risk management thresholds for the protection of human health and groundwater.

Shallow Soil Gas. At sufficient concentrations, impacted soil vapor can pose a vapor intrusion risk to indoor air. Given the presence of buildings constructed on BNL and BSL and the prevalence of residential structures around the landfills, shallow soil vapor data have been evaluated using a variety of approaches to assess the potential for vapor intrusion into nearby structures. A human health risk assessment (HRA) evaluating this pathway using shallow soil vapor data collected from BNL in 2002 and 2006 was conducted by Stantec in 2010. The results of this assessment found no unacceptable health effects to current adjacent residents (Stantec, 2010). An HRA using shallow soil vapor data collected from both the BNL and BSL in 2013 was also conducted during the LOU RI; this HRA evaluated both vapor intrusion risk to indoor air and risk due to the exposure to VOC contamination in outdoor air. Risks were found to be less than the ADEQ and US Environmental Protection Agency target risk range (1 E-06 to 1 E-04 and a hazard index of 1) for all scenarios evaluated (Copeland & Associates, 2015). Shallow soil vapor monitoring conducted at the BSL in 2015 by Amec Foster Wheeler included risk calculations that supported this conclusion (**Appendix D**). These assessments provide evidence that although the vapor intrusion and outdoor air exposure pathways to indoor site users and nearby residents may be complete, the assessed predicted risk is within risk management thresholds. Based on the expected decline in shallow soil vapor concentrations due to ongoing dispersion/dilution of contamination, risks due to vapor intrusion are anticipated to remain within risk management thresholds in the future.

Groundwater via Deep Soil Gas. Based on deep soil vapor sampling conducted for the LOU RI in 2013 at BNL, there was no appreciable rebound in VOC concentrations in the vadose zone after the SVE/AI system was turned off in September 2002. Furthermore, observed concentrations were less than soil vapor RAOs calculated for the protection of groundwater at BNL. These data suggest that there is no significant ongoing vapor source of vadose zone VOCs below BNL that could adversely affect groundwater quality. It is likely that residual contamination submerged in the saturated zone underlying BNL is the primary source of groundwater impacts in GOU. With respect to BSL, recent groundwater monitoring indicates that VOC concentrations in groundwater are increasing in the central region of this landfill. **Figure 2-10** presents this trend over time in groundwater at BP-23 (located within the central portion of BSL). Deep soil vapor concentrations in this vicinity are elevated and are likely contributing to groundwater contamination at BSL (**Appendix D**).

Despite groundwater impacts that define the extent of the GOU, no operating TW or private water supply wells are currently known to be contaminated with PCE from the Site. When PCE was initially discovered in TW drinking water wells downgradient of the landfills in the late 1980s and 1990s, TW shut down impacted wells to prevent contaminant exposure to residents and commercial users of Site groundwater. Based on groundwater elevation data, the current direction of groundwater flow is towards regional groundwater withdrawal. If attenuation mechanisms controlling the fate and transport of COCs present in groundwater from the Site are not sufficient or the quantity of mass released to groundwater over time is significant, COCs in groundwater may migrate to downgradient TW or private groundwater supply wells in the future. On this basis, potential future receptors of site contamination via exposure to extracted groundwater through inhalation, ingestion, or dermal exposure routes (during drinking/commercial water use) include recipients of groundwater extracted from existing water supply wells downgradient of the Site if the contaminated groundwater plume migrates to these wells.

3.0 FEASIBILITY STUDY SCOPING

This section presents FS regulatory requirements, ROs developed to scope the Site FS, and the delineation of remediation areas that must be addressed to meet ROs.

3.1 Regulatory Requirements

This FS is written to meet regulatory requirements set out in A.R.S. § 49-287.03 and further defined in A.A.C. R18-16-407. A.R.S. § 49-287.03 grants the ADEQ authority to conduct an RI and FS of a scored site: the RI collects the data necessary to adequately characterize the site and assess the risks to humans, and the FS uses the results of the RI and an alternative screening step to select a reasonable number of alternatives in a manner consistent with the remedial action criteria and rules in A.R.S § 49-282.06.

A.A.C 18-16-407 requires the FS to identify a reference remedy and at least two alternative remedies. All remedies need to be capable of achieving all of the site ROs. The reference remedy must be developed based upon best engineering, geological, and/or hydrological judgement following standards of practice, considering the information in the RI, best available scientific information concerning the available remedial technologies, and a preliminary analysis of the comparison criteria and ability of the reference remedy to comply with A.R.S. § 49-282.06. At least one of the alternative remedies must be more aggressive than the reference remedy, and at least one must be less aggressive. "Aggressive" is defined as a strategy that requires fewer remedial measures to achieve ROs, a strategy that achieves ROs in a shorter period of time, or a strategy that is more certain in the long term and requires fewer contingencies. With ADEQ's approval, one of the alternative remedies may use the same strategy as the reference remedy but use different viable technologies or a more intensive use of the same technology utilized in the reference remedy.

3.2 Remedial Objectives

The ROs developed for the Site as part of the RI Process, pursuant to A.A.C. R18-16-406 (I), were based on field investigation results, land and water use surveys, risk evaluations, ADEQ guidance and input from the community during the draft RO report public comment periods (ADEQ, 2012; Clear Creek, 2015b). The following sections identify Site ROs for land, groundwater, and surface water use.

3.2.1 ROs for Land Use

The LOU Remedial Objectives Report (Clear Creek, 2015b) incorporates the findings of the Site Land Use Study (Clear Creek, 2015a) and indicates that current and reasonable foreseeable uses of land at BNL and BSL include both residential (A.R.S. § 49-151[6]) and non-residential (A.R.S. § 49-151[3]) land use. On this basis, ROs for land use at the Site include:

- **Residential:** The RO for existing and future residential use of LOU properties is to protect against exposure to COCs within or released from the LOU waste. This action is needed at the present time and for as long as the landfilled and dross wastes remain at the property (Clear Creek, 2015b).

- **Non-Residential:** The RO for existing and future non-residential use of LOU properties is to protect against exposure to COCs within or released from the LOU waste. This action is needed at the present time and for as long as the landfilled and dross wastes remains at the property (Clear Creek, 2015b).

3.2.2 ROs for Groundwater Use

A Final Groundwater Remedial Objectives (GRO) Report (ADEQ, 2012) was prepared based on the BP Water Use Study and written GRO proposals and comments from the public. The GROs for the Site were developed as required by A.C.C. R18-16-406 of the Remedy Section rules of the A.A.C. and established for the current and reasonably foreseeable uses of the waters of the state that have been or are threatened to be affected by release of a hazardous substance. The reasonably foreseeable uses of water are those likely to occur within 100 years, unless a longer time period is shown to be reasonable based on site-specific circumstances (A.C.C. R18-16-406 [D]).

The regional aquifer known as the CWF is primarily used by TW. TW is the City of Tucson water department and primary municipal water provider for the area. TW shut down four wells in the last 20 years and wellhead treatment was installed on the St. Joseph's Hospital water supply well due to contamination from the Site (see Section 2.1.4). At a minimum, there are 13 public or private water supply wells that either have been impacted (i.e., C-021A, C-026B, D-021A, D-022A, and 411-P) or are potentially threatened by Site contamination (i.e., C-020B, C-025B, C-051B, C-058B, D-018A, CVA, Swain, and Mayo).

ROs are separated into objectives for potable and non-potable water. "Potable" is defined here as water which is required to meet state and federal primary drinking water standards (a.k.a. Maximum Contaminant Levels [MCLs]) and Arizona AWQSs. "Non-potable" is defined here as water which is not required to meet state and federal primary drinking water standards or Arizona AWQSs.

- **For potable water:** The GRO will be to restore, replace or otherwise provide for the current and future potable use of the regional aquifer threatened or impacted by PCE, TCE, and VC contamination emanating from the WQARF Site. ["Potable" is defined here as water which meets state and federal primary drinking water standards (a.k.a. MCLs) and Arizona AWQSs.] This action is needed for as long as the level of contamination in the groundwater resource prohibits its use as a potable water supply (ADEQ, 2012).
- **For non-potable water:** The GRO will be to protect for the future non-potable use of the regional aquifer threatened by PCE, TCE, and VC contamination emanating from the WQARF Site. ["Non-potable" is defined here as water which is not required to meet state and federal primary drinking water standards (a.k.a. MCLs) and Arizona AWQSs.] This action is needed for the present time and for as long as the level of contamination in the groundwater resource threatens its use as a non-potable water supply (ADEQ, 2012).

3.2.3 ROs for Surface Water Use

There is no appreciable surface water within the Site boundaries and no anticipated future surface water uses within the Site area. Therefore, no surface water ROs are necessary at this time.

3.3 Delineation and Description of Remediation Areas

There are two sources of contamination at the Site that are subject to ROs: VOCs in Landfill Waste which contribute to the contaminated groundwater plume in the GOU and Metals in Dross Material landfilled at BNL. **Appendix E** defines the remediation area associated with Metals in Dross Material. The remainder of this section delineates and describes remediation areas for VOCs in Landfill Waste.

As discussed in Section 2.2.3, landfill waste remains at the Site and VOCs that may continue to be present in the waste have the potential to impact Site receptors if not properly managed. The extent of area subject to ROs based on risk posed by landfill waste is defined by the waste placement areas at BNL and BSL (i.e., the LOU shown in **Figure 1-1**).

VOCs derived from landfill waste have also impacted soil vapor and groundwater at the Site at concentrations that may pose a current or future risk to Site receptors. At present, the primary risk posed by soil vapor is as a continuing source of groundwater contamination, particularly at BSL where no treatment of impacted soil vapor has occurred to date. Recent increases in groundwater PCE concentrations at BNL have also been observed and are likely attributable to increasing groundwater levels which may have mobilized VOC contamination present in saturated fine-grained soils at depth. On the basis that the landfill placement areas were the source of soil vapors that impacted underlying groundwater, the remediation area corresponding to this risk is defined by the intersection of the waste placement areas at BNL and BSL (i.e., the LOU) and the GOU shown in **Figure 1-1**.

Groundwater impacted with VOCs has migrated from the LOU towards the TW CWF. The current extent of groundwater subject to ROs based on risk posed by contaminated groundwater is defined by the extent of the GOU (**Figure 1-1**). Without any further action, this remediation area is anticipated to spread over time as the impacted groundwater migrates with groundwater flow towards water supply wells in the region.

4.0 IDENTIFICATION AND SCREENING OF REMEDIAL MEASURES

This section identifies remedy selection criteria, screens applicable remedial measures and presents retained remedial measures for VOCs in Landfill Waste present at the Site. Remedial measures for Metals in Dross Material are discussed in **Appendix E**. "Remedial measures are remediation technologies or methodologies, and are screened based on anticipated removal or reduction of contaminants at the site and the ability to achieve the ROs. Selected remedial measures will be assembled with selected strategies to develop the reference remedy and alternative remedies" (ADEQ, 2015).

4.1 Remedy Selection Criteria

A.R.S. § 49-282.06 states that the following factors must be considered in the selection of remedial actions:

- Population, environment, and welfare concerns at risk.
- Routes of exposure.
- Amount, concentration, hazardous properties, environmental fate (such as the ability to bioaccumulate, persistence, and probability of reaching the waters of the state), and the form of the substance present.
- Physical factors affecting human and environmental exposure, such as hydrogeology, climate, and the extent of previous and expected migration.
- The extent to which the amount of water available for beneficial use will be preserved by a particular type of remedial action.
- The technical practicality, cost-effectiveness, and necessity of alternative remedial actions applicable to a site.
- The availability of other appropriate federal or state remedial action and enforcement mechanisms, including funding sources established under the Comprehensive Environmental Response, Compensation, and Liability Act, to respond to the release.

4.2 Basis for Identification of Applicable Remedial Measures

The basis for identifying applicable remedial measures for VOCs in Landfill Waste is summarized below:

- Waste disposed of in the LOU is the source of VOC contamination at the Site. The waste is currently landfilled and covered with soil and/or development in the areas defined as the LOU (**Figure 2-3**). The results of RI activities conducted in support of this FS indicate low concentrations of VOCs present in soil vapor collected from the landfills at this time; however, there is a potential that VOC-containing waste remains in the landfill in sealed containers. The risk posed by this waste is mitigated to the extent practicable as long as the landfill is properly maintained, intrusive site work in waste placement areas is managed, and there are limits on development for as long as the waste remains on-site.

- There was little or no restriction on the types of commercial, industrial, agricultural, medical and residential wastes that were buried at the landfills (HGL, 2012). ADEQ has assessed the lateral and vertical extent of the waste at the BNL and BSL, but has not characterized the waste itself. ADEQ has concluded that complete characterization of the significant acreage of mixed landfill waste is not feasible, nor cost-effective. Thus, there is some potential risk of exposure to hazardous substances (VOCs and other) if receptors come into direct contact with this waste.
- PCE present in the vadose zone at BSL is contributing to Site groundwater contamination. Although PCE concentrations in BSL groundwater are relatively low when compared to those historically observed at BNL, the levels in the BP-23 well exceed the AWQS and have been increasing for some time (**Figure 2-10**). Without addressing the source of this contamination, the duration that concentrations will exceed the AWQS is difficult to predict.
- At BNL, there is a region in the saturated zone upgradient of monitoring well WR-274A that appears to be releasing PCE to the GOU. An early response action (ERA) consisting of SVE/AI at BNL has resulted in reducing the estimated extent of the BNL source area but impacts are anticipated to continue for some time without remedial action (this duration is difficult to predict). An ISCO pilot study conducted immediately upgradient of this well in 2016 resulted in a significant decrease in PCE concentrations at this location. The extent of impacts from the ISCO pilot study is unknown.
- At a minimum, there are three separate groundwater plumes present at the Site as defined by the extent of the GOU (**Figure 1-1**). The plumes are relatively dilute, spread across wide areas, and estimated to be limited to the upper 80 to 105 ft of the aquifer. These plumes are anticipated to continue to migrate with groundwater flow toward water supply wells in the TW CWF without remedial action.

An existing groundwater model was updated as part of this FS and used to evaluate various remedial approaches for the Site. The results of the modeling were used in the development and screening of applicable remedial measures discussed in this section. **Appendix A** presents the model report documenting this effort.

4.3 Identification of Remedial Measures

Remedial measures applicable to VOCs in Landfill Waste are:

- Institutional controls (ICs)
- ECs
- Inspections and Monitoring
- Monitored Natural Attenuation (MNA)
- SVE
- In Situ Biological Reduction (ISBR)
- In Situ Thermal Treatment
- ISCO

- In Situ Chemical Reduction (ISCR) with a Permeable Reactive Barrier (PRB)
- Groundwater P&T
- Wellhead Treatment
- Provision of Replacement Water Supply

4.4 Screening of Remedial Measures

Remedial measures are typically screened based on the anticipated ability of the measure to address site ROs and reduce contaminant concentration, mass or toxicity. In this FS, screening criteria used to assess how well the ROs would be addressed by remedial measures were as follows:

- Effectiveness – may include compatibility with current and reasonably foreseeable land or water uses, COC treatment effectiveness (as applicable), effectiveness at controlling contaminant exposure (as applicable) and the ability to meet regulatory requirements.
- Implementability – may include constructability, operations and maintenance requirements, and generation and management of waste products.
- Health and safety considerations – includes an assessment of any potential health and safety issues associated with implementation of the measure.
- Flexibility and/or expandability – includes and evaluation of how easy or difficult the measure is to respond to change.
- Cost – this is a qualitative assessment; measures that do not require a significant amount of new site infrastructure are generally scored as ‘low’; measures requiring new site infrastructure were assessed as either ‘medium’ or ‘high’ based on the quantity/extent of required infrastructure improvements, the duration the measures are required, and the cost efficiency of the measure.

Table 4-1 evaluates the remedial measures presented in Section 4.3 against these criteria and identifies those retained. No one measure by itself will be sufficient for this site to meet the ROs. Further discussion of remedial measure screening is provided below.

Institutional Controls. ICs are laws or rules or legal/administrative instruments that prevent or limit unacceptable site receptor exposure to contaminants and/or protect the integrity of the remedy (for example, ECs). Examples of applicable ICs include Arizona Department of Water Resources (ADWR) restrictions on installation of new wells and ADEQ’s Declaration of Environmental Use Restrictions (DEURs).

A.R.S. § 45-454(C) limits installation of new exempt water supply wells (with a pump capacity of less than 35 gpm) within Active Management Areas (the Site is located within the Tucson Active Management Area) where a water provider already exists. Also, when a property owner or well driller applies to ADWR for a well drilling permit for a location within one (1) mile of a WQARF site or site plume, ADWR informs the property owner that their planned well location is near or within the site and sends them a map of the site/site plume boundaries.

An ADEQ DEUR is a restrictive covenant designed to do the following:

- Allow closure of a site with contamination above residential SRL;
- Inform future property owners regarding the contamination on the property;
- Document ICs and ECs;
- Ensure appropriate future uses of the contaminated site to protect residents, workers, and other potential receptors; and
- Provide for the management, maintenance, and inspection of existing (or future) ECs located on the parcel.

If the site has ECs, the IC will include an associated EC plan. The DEUR is recorded on the parcel deed by the property owner.

ICs are retained. These measures would be required to be implemented with other remedial measures to adequately address Site ROs.

Engineering Controls (Capping/Fencing). BNL and BSL currently have soil cover and/or overlying development (near the edges of the landfills) that serve as ECs and limit exposure of VOCs present in landfill waste to Site receptors.

Capping and fencing are retained. Capping with either soil cover or development has already been implemented in the LOU. BNL only has fencing around its southern and western perimeter, so additional fencing at BNL would be needed. BSL presently has no fencing, so it would need fencing.

Inspections and Environmental Sampling. Periodic inspections of the Site would be conducted to verify implemented ICs and ECs are working as intended. Environmental sampling is conducted to provide evidence that active remedial measures are operating as intended.

Inspections and environmental sampling are retained.

Monitored Natural Attenuation. MNA relies on natural processes to decrease or attenuate concentrations of contaminants in soil and groundwater. Besides intrinsic biodegradation, natural attenuation includes natural physical processes that can immobilize contaminants and natural chemical reactions that can destroy contaminants. Some processes that occur during natural attenuation can transform contaminants to less harmful forms or immobilize them to reduce risks. Such transformation and immobilization processes result from biological, chemical, and physical reactions that take place in the subsurface. It also includes dilution, dispersion, volatilization, adsorption, and other processes that destroy or immobilize the contaminant. The concept that natural attenuation processes can, under the proper conditions, cause the destruction or transformation of contaminants in the environment is valid. The natural attenuation approach is not a ”no further action” approach. The cause-and-effect link between a decrease in contaminant concentration and the process or processes causing it must be appropriately evaluated, monitored and documented throughout the period that natural attenuation is retained as a remedy. For MNA to be implemented, it must be demonstrated that the natural attenuation processes occurring at the site protect human health and the environment; this generally implies that the contaminated groundwater plume is stable (i.e., not increasing in size) and does not pose a threat to potential receptors of contamination. Long-term groundwater monitoring programs that evaluate natural attenuation typically include monitoring wells that evaluate whether the behavior of the plume is changing and point of compliance wells that detect plume migration and trigger an action to manage the risk associated with this expansion. Long-term monitoring must continue to occur for as long as is necessary to protect human health and the environment.

> *MNA is retained as a remedial measure for the Site; however, it will require contingency remedial measures to be incorporated to ensure ROs can be met. Based on the proximity of the contamination to water supply wells, MNA alone is not an acceptable option to meet ROs.*

Soil Vapor Extraction. SVE remediates contaminated soil in the vadose zone through an in situ physical removal process conducted by extracting soil vapors from the subsurface, treating them at the surface, and then discharging the treated vapors to the atmosphere. The process involves the installation of a series of extraction wells in impacted soil above the water table and applying vacuum to pull soil vapors containing VOCs from the vadose zone. SVE works best in coarser grained soils where air permeabilities are high. When the extraction wells are properly located, this approach has the advantage of creating a capture zone which contains and prevents the contamination from migrating to surrounding soils and into the groundwater. For Site contaminants and concentrations in soil vapor at BSL, the presumptive treatment technology for SVE vapors is carbon absorption.

> *SVE is retained as a remedial measure for elevated VOC concentrations serving as a source of groundwater contamination at BSL. SVE was an effective ERA at BNL and is anticipated to be highly effective for source control in the vadose zone of BSL. SVE is a cost effective approach to remove VOC mass from contaminated sites and is considered moderately implementable at the Site.*

In Situ Biological Reduction. Highly oxidized chlorinated solvents such as PCE and TCE are known to undergo a variety of microbially mediated biodegradation reactions. In anaerobic environments, PCE and TCE can undergo reductive dechlorination (dehalorespiration) if the environment is conducive to microbial growth, an electron donor (e.g., hydrogen, methanol, etc.) is available to promote microbial activity and competing electron acceptors (e.g., oxygen, nitrate, iron, and sulfate) are absent. The electron transfer occurs either metabolically (providing the microorganisms with energy for population growth and maintenance) or cometabolically (without energy benefit to the microorganisms). The predominant reductive dechlorination pathway is noted below:

$$\text{PCE} \rightarrow \text{TCE} \rightarrow \text{cis-1,2-DCE} \rightarrow \text{VC} \rightarrow \text{ethene}$$

A variety of microorganisms reduce PCE to TCE and TCE to DCE including Dehalospirillium multivorans, Dehalobacter restrictus, and Dehalococcoides (DHC) etheneogenes. Dehalospirillium multivorans and Dehalobacter restrictus are reported to express only one of the two required corrinoid enzymes required to biodegrade TCE completely to ethene. In contrast, DHC is the only known halo-respiring microorganism reported to catalyze complete dechlorination and may not be present in all subsurface environments. When present, DHC cells may not be initially active or in sufficiently high number to promote complete dechlorination without a significant lag phase before activity.

Biostimulation and bioaugmentation are commonly used strategies employed to implement ISBR. Biostimulation is the addition of amendments such as electron donors or nutrients to promote microbial activity. Bioaugmentation, or the addition of a microbial culture that degrades the chlorinated solvent, promotes bioremediation at sites where complete dechlorination reactions would not otherwise occur. Bioaugmentation with non-indigenous microbial consortia has been successfully demonstrated at other contaminated sites.

> *ISBR is not retained as a remedial measure on the basis that existing aquifer conditions are carbon limited and aerobic which are not favorable for this process. It is possible that biostimulation involving the effective distribution of an electron donor (i.e., a carbon source) could be successful with adequate time and effort. However, the process is complex and requires the growth of appropriate organisms at suitable densities and an environment where competing electron acceptors do not impede electron transfer to the COCs. Thus, for the deep and relatively dilute groundwater plume present at the Site, the issue with ISBR is not only distribution of amendments but maintenance of an appropriate chemical, physical, and biological environment for biodegradation to occur.*

In Situ Thermal Remediation. In situ thermal remediation (ISTR) is an aggressive treatment method most applicable to the remediation of high VOC concentrations in a source area. The most common ISTR technologies are steam injection, electrical resistance heating and thermal conduction heating. The technologies vary but the general method involves heating of the subsurface in order to volatilize and mobilize the VOCs. The VOCs must then be extracted from the subsurface via soil vapor and/or groundwater and treated by standard methods such as SVE or P&T for groundwater.

> *ISTR is not retained as a remedial measure because it would not be cost effective for the concentrations of COCs present at the Site.*

In Situ Chemical Oxidation. ISCO is the injection of oxidizing agents directly into the subsurface to degrade contamination. These reagents increase the oxidation state of certain materials. As a result, they convert hazardous contaminants to non-hazardous or less toxic compounds. ISCO can be applied to groundwater and a variety of soil types and sizes. It can also be used to treat chlorinated ethenes, including PCE and TCE. In order for destruction of COC mass to occur, sufficient contact with the oxidant must be achieved. Typical oxidizing agents include permanganate, persulfate, ozone, and hydrogen peroxide:

- The most common forms of permanganate are potassium permanganate and sodium permanganate. Application of permanganate causes the rapid and complete destruction of many chlorinated ethenes. The process results in the formation of manganese oxides, carbon dioxide, and various ions.
- Sodium persulfate is typically applied together with an activating agent such as temperature (thermal activation), sodium hydroxide (caustic activation), and/or a chemical activator such as a modified Fenton's reagent, chelated iron, or zero valent iron (ZVI).

Activation of persulfate results in the formation of a sulfate radical, which directly oxidizes contaminants.

- Ozone and/or hydrogen peroxide, along with a catalyst (typically iron), can be used to oxidize organic materials in groundwater. When mineralization of the COC mass is achieved, this process results in the production of carbon dioxide, water, and salts.

*ISCO is retained as a remedial measure for the Site. It is an effective remedial measure that is highly implementable and moderately cost effective in targeted areas with either higher concentrations of COCs in groundwater or limited natural oxidant demand. Pilot study testing was completed in 2016 to evaluate the effectiveness of ISCO at the Site. In summary, ISCO was found to be a viable technology for addressing residual Site contamination in the BNL source area (**Appendix B**).*

In Situ Chemical Reduction with a ZVI Permeable Reactive Barrier. A PRB using ZVI would consist of creating a subsurface secant pile wall by injecting or trenching ZVI into the ground in a line perpendicular to the groundwater flow. The PRB would need to be located on the downgradient edge of the plume to intercept and remediate the COCs as the groundwater flowed through the barrier.

ISCR with a PRB is not retained as a remedial measure because it would not be cost effective for the widths (500 to 2000 ft) and depths (greater than 300 ft bgs) of the contaminant plumes located at the Site.

Groundwater Pump-and-Treat. Groundwater P&T systems remediate contaminated groundwater through extraction, treatment of the water at the surface, and then either discharge to an appropriate end use or reinjection of the treated groundwater back into the aquifer. When the extraction wells are properly located, this approach has the advantage of creating a capture zone which contains and prevents the contamination from migrating. Pumping is an important aspect for recovery of contaminants that are not easily degraded or attenuated in the subsurface. Treatment technologies are selected based on the types of contaminants present. For the Site contaminants and concentrations in groundwater, the presumptive treatment technology is liquid phase granular activated carbon (L-GAC).

Groundwater P&T is retained as a remedial measure for the Site. It is a commonly used, cost and time effective method of groundwater containment of VOC plumes like those at the Site and may reduce overall remediation timeframes. This measure also provides containment of plumes from migration to water supply wells. Groundwater P&T was previously used successfully as a downgradient containment remedy for the Site (i.e., the WCS).

Wellhead Treatment. Wellhead treatment remediates contaminated groundwater with a treatment system at or very near a well impacted by contamination. The groundwater is pumped to the surface by the existing well infrastructure, then treated by a technology based on contaminants in the groundwater. The presumptive treatment technology for Site contaminants and concentrations is L-GAC. The treated water is discharged to the end use that the well was designed for.

Wellhead treatment is retained as a remedial measure for existing private and production wells impacted by the Site plume.

Provision of Replacement Water Supply. Provision of a replacement water supply provides an alternative potable water supply to replace the water provided by a private or production well impacted by contamination. The water supply would be brought in via pipeline from the municipal water provider, TW.

Provision of replacement water supply is retained as a remedial measure for existing private or production wells impacted by the Site plume.

4.5 Retained Remedial Measures and Strategies

Measures retained for application at the Site are:

- ICs
- ECs (fencing/capping)
- Inspections and Environmental Sampling
- MNA
- SVE
- ISCO
- P&T
- Wellhead Treatment
- Provision of a Replacement Water Supply

5.0 DEVELOPMENT OF THE REFERENCE REMEDY AND ALTERNATE REMEDIES

Using the retained remedial measures developed in Section 4.0, a Reference Remedy has been developed along with a less aggressive remedial alternative and a more aggressive remedial alternative for comparison. The Reference Remedy and the alternative remedies must consist of remedial measures and corresponding remedial strategies capable of meeting all ROs for the Site. Remedies may incorporate more than one remedial strategy or include contingent remedial strategies to address reasonable uncertainties regarding the achievement of ROs, including uncertain time frames for implementation. Remedial strategies identified in A.A.C. R18-16-407(F) and a brief discussion of applicability to VOCs in Landfill Waste at the Site follows:

- Plume remediation – this strategy is used to achieve water quality standards for COCs in waters of the state throughout the Site. *P&T and wellhead treatment use this strategy to reduce the concentration and toxicity of impacted groundwater.*
- Physical containment – this strategy contains contaminants within definite boundaries. C*apping uses this strategy to limit exposure of contamination present in landfill waste to environmental and human receptors and achieve land use ROs. ICs are remedial measures that increase the effectiveness of this strategy.*
- Controlled migration – this strategy controls the direction or rate of migration but not necessarily contains migration of contaminants. *P&T may use this strategy to mitigate the migration of groundwater plumes at the Site.*
- Source control – this strategy eliminates or mitigates a continuing source of contamination. *SVE and ISCO would use this strategy to address the source of groundwater contamination present at the Site.*
- Monitoring – this strategy is used to observe and evaluate contamination at the Site through the collection of data. *MNA, inspections, and environmental sampling are monitoring strategies that increase the effectiveness of plume remediation, physical containment, controlled migration and source control strategies.*
- No action – this strategy consists of no action at the Site. *This strategy is generally not applicable to VOCs in Landfill Waste because, given time, contaminated groundwater will migrate towards water supply wells in the CWF.*

The following sections identify remedial measures and strategies used to develop the Reference, Less Aggressive, and More Aggressive Remedies. The remedial measures and strategies are defined by their ability to achieve ROs and maintain consistency with applicable land use plans. A description of the design, installation, inspection and maintenance of the remedies is also presented.

5.1 Reference Remedy

The Reference Remedy must be developed based on the best engineering, geological and hydrological standards of practice. Source control must also be incorporated into the Reference Remedy.

5.1.1 Remedial Measures and Strategies

The Reference Remedy for VOCs in Landfill Waste combines the remedial measures of ECs, ICs, MNA, inspections/environmental sampling, SVE, and ISCO with wellhead treatment and the provision of a replacement water supply as contingency measures for downgradient drinking water supply wells that could become impacted. These remedial measures use the remedial strategies of plume remediation, physical containment, source control and monitoring to achieve ROs. **Table 6-1** presents these remedial measures and remedial strategies for each evaluated remedy and also includes a summary description of the alternatives. To quantitate the effects of MNA and ISCO as part of the Reference Remedy, groundwater modeling was used to provide estimates of how long the plume would persist in the aquifer and when downgradient water supply wells would be impacted. **Appendix A** documents the results of groundwater modeling and the model scenario corresponding to the Reference Remedy is Scenario 23 (MNA with ISCO).

Further description of the remedy is as follows:

- ECs – The existing landfill waste soil cover and development caps (e.g., asphalt parking lots, buildings, sidewalks) would be incorporated into the remedy as ECs to control exposure to the landfill waste. The fence line at BNL would be expanded to completely enclose this landfill and the BSL parcels which are not beneath a development cap would be fenced. The fencing would include warning signs.
- ICs – A DEUR needs to be placed on the parcels where landfilled waste is present to ensure that current and future property uses are protective of potential receptors and that current and future ECs are properly managed, maintained, and inspected. New water supply well installation would also be limited within the WQARF Site pursuant to A.R.S. § 45-454(C). As of the date of this Report, there are DEURs in process for 10 of the 13 BNL parcels needing DEURs and there are already-existing DEURs at 2 of the 11 BSL parcels needing DEURs[9].
- MNA – MNA would consist of routine groundwater monitoring and would be conducted to track groundwater contamination in the GOU, downgradient of the LOU, for as long as COC concentrations exceed applicable AWQSs. Based on the results of groundwater modeling, the PCE groundwater plume is predicted to still exist (and be impacting potable wells) after 100 years (**Appendix A**). Plumes would be routinely monitored to assess the extent of attenuation and evaluate when the plume has migrated to water supply wells.
- Inspections/Environmental Sampling – Inspections would be conducted to evaluate whether ECs continue to limit waste exposure to Site receptors and would be required by the DEUR at a frequency defined in associated documents. Environmental sampling including deep soil vapor monitoring would be conducted to assess the performance of SVE operations and evaluate the rebound in concentrations after SVE. In addition to the groundwater monitoring conducted throughout the GOU as part of MNA, focused groundwater monitoring would also be conducted to assess the performance/efficacy of ISCO in the BNL source area and SVE in the BSL source area.

[9] There are DEURs *in process* for all BNL parcels labeled on Figure 2-4 except parcels 133-23-0970, 133-23-098B, and 133-23-110C. The only DEURs existing on BSL parcels are on parcels 134-27-002A and 134-27-003A (Figure 2-4).

- SVE – SVE at BSL would target elevated concentrations of VOCs in deep soil vapor near BSDP-2 and BSDP-4 (concentrations at one or more depths monitored were increasing as of January 2015; **Appendix D, Figure 1**) and increasing PCE concentrations observed in groundwater at BP-23 (**Figure 2-10**). The SVE system would include up to 4 new wells that could serve as either vapor extraction or monitoring wells (**Figure 5-1**), above ground temporary piping, a rented SVE blower with temporary power, and vapor phase granular activated carbon (V-GAC) for treatment of extracted vapors. Extraction well EX-01 has been located south of BSDP-2, near BP-11 to address a data gap at the Site. Although BP-11 indicates that groundwater is not impacted at this location, the well screen is significantly submerged. The screened interval ranges from 378 to 478 ft bgs and the depth to water at BP-11 was 343 ft bgs in February 2015 (**Appendix C**). EX-01 would include an appropriately screened piezometer to monitor groundwater.
- ISCO – ISCO in the BNL source area would target elevated levels of PCE between WR-274A and R-068A (**Figure 2-1**). On the basis of ISCO pilot study testing (**Appendix B**), a downgradient recirculation strategy would be implemented with a minimum of 5 new wells that could be used as either extraction or injection wells (**Figure 5-2**), connective piping, and a secure treatment compound to store and meter oxidant. Using the sustainable extraction rate derived from the pilot study (i.e., 40 gpm), particle tracking analysis with the Site groundwater model was used to evaluate ISCO treatment durations and develop a conceptual operating sequence for ISCO implementation (see **Appendix B** for further discussion). Although the groundwater model predicts that treatment of the BNL source area would be achieved in 5 years using ISCO (**Appendix A**), conceptual design and associated costs presented in this FS are based on an operating period of 7 years to achieve three circulations of groundwater in the target treatment area and promote effective distribution of oxidant.
- Wellhead Treatment (Contingency) – Wellhead treatment would be a contingency measure and consist of adding L-GAC treatment to existing water supply wells when COC concentrations extracted from the well exceed three-quarters of the applicable AWQS (i.e., 3.75 µg/L for PCE). The list of wells predicted to be impacted and span of years for the predicted impact are shown in **Table 6-1** as part of the Description of Alternative. In general, wellhead treatment would be performed on relatively large impacted water supply wells (i.e., those owned by TW or St. Joseph's Hospital [411-P]).
- Provision of Replacement Water (Contingency) – As an alternative to wellhead treatment if a well is predicted to be impacted, provision of replacement water would be used as a contingency measure if it is more cost effective. This approach applies to small (private) water supply well users with negligible groundwater withdrawals (i.e., less than 35 gpm) and would include providing city water to users of existing water supply wells when COC concentrations extracted from the well exceed three-quarters of the applicable AWQS (i.e., 3.75 µg/L for PCE). **Table 6-1** identifies which wells would receive replacement water.

5.1.1.1 Achievement of Remedial Objectives

The Reference Remedy would achieve ROs for land use by restricting environmental and human exposure to landfill waste with landfill cover, development cap, and perimeter fencing ECs and ICs for intrusive site work. ICs would also be put in place to make certain that the ECs remain effective for as long as the landfilled waste remains at the site and would require inspections to ensure that the ECs are properly maintained.

Groundwater modeling, summarized in **Figure 5-3** and documented in **Appendix A**, was used to predict the effectiveness and efficiency of the Reference Remedy to meet GROs. As indicated in **Figure 5-3**, groundwater modeling indicates that after 100 years, the PCE plume (i.e., the extent of PCE present at concentrations that exceed the AWQS) would still exist and be impacting potable wells. Since the Reference Remedy would not remediate the GOU within the duration of foreseeable uses of water (i.e., 100 years), achievement of GROs (i.e., to restore, replace or otherwise provide for the current and future potable use of the regional aquifer) would be based on treating impacted drinking water supply wells (or supplying an alternative source of water for impacted wells). Ongoing monitoring would be required to ensure this exposure pathway remains incomplete. ISCO, SVE, and MNA would promote achieving GROs by mitigating the amount of contaminant mass that can migrate to and impact water supply wells.

Continued achievement of the GROs after 100 years would require ongoing monitoring and wellhead treatment/provision of an alternative water supply for impacted wells for as long as the PCE concentrations exceed the AWQS.

5.1.1.2 Consistency with Land Use and Consideration of Water Management Plans

The current use of the LOU includes both non-residential and/or commercial properties but possible future uses allowed by the zoning include office, commercial recreation, commercial service, commercial general, residential (including single-family residences for BNL), research and development, and a golf course (Clear Creek, 2015a). A DEUR implemented as part of the remedy would control the type of development that can occur in the LOU but would not necessarily limit land use if ECs are maintained.

The current use of the GOU is the TW CWF and as a water supply to the private commercial and residential entities at and near the Site. Although not desired by TW, treating extracted groundwater for Site COCs prior to direct customer use would maintain the supply of water needed to comply with TW water management plans.

ICs for groundwater use would only apply to new, future users and would reduce the likelihood that new exempt groundwater wells (producing less than 35 gpm) are installed at the Site. This would help limit future groundwater use until the plume no longer poses a threat to water supplies. Entities planning to install new (not replacement) groundwater wells within a mile of the Site would be informed of the existence of the groundwater contamination when they apply to ADWR for the drilling permit. If an entity chooses to install a well after the Record of Decision (ROD) is finalized for this Site, the entity would be proceeding at their own risk.[10]

[10] Tenet Healthcare (the current owner of St. Joseph's Hospital) has the right under ADWR law to install a replacement well for their previously-closed water supply well (411-P). Tenet Healthcare already has informed ADEQ of their plans and the final remedy will include remedial action to ensure that St. Joseph's Hospital either has wellhead treatment for this new well or water from an alternate source.

5.1.2 System Design and Installation

MNA. The existing Site groundwater monitoring network would be used to monitor contamination in the GOU as part of implementing MNA. For the purpose of developing costs for this FS, it was assumed that monitoring well replacement at a frequency of one well every 10 years, monitoring well abandonment at a frequency of two wells every 5 years, and abandonment of remaining wells at the end of 100 years would be required.

SVE. As identified in Section 5.1.1, SVE for source control in BSL will consist of at least four new, deep wells that could serve as either vapor extraction or monitoring wells (identified as two SVE wells and two vapor monitoring wells in **Figure 5-1**), above ground piping and a temporary SVE treatment system. The placement locations for these wells are based on the PCE concentration trends seen in the BSL groundwater and soil gas wells (see BP-23 in **Figure 2-10**; see BDSP-2 and BDSP-4 in **Figure 4** of **Appendix D**). The temporary SVE treatment system would be comprised of a rented SVE blower skid to create vacuum on the SVE wells and a series of granular activated carbon (GAC) vessels to treat the VOCs in the extracted process air. A temporary electrical power connection would be required to operate the system. **Figure 5-1** shows the preliminary SVE system layout, including the locations of the existing soil vapor probes, new SVE wells and the treatment system process equipment.

ISCO. ISCO treatment in the BNL source area will be targeted between WR-274A and R-068A and will include the use of existing well BP-27 as an extraction well, existing well R-068A as an injection well, at least four new extraction/injection wells (**Figure 5-2**) that could also be used for monitoring, and connective piping and transfer pumps to convey water from the wells to/from the ISCO treatment compound. An additional new extraction/injection well has been scoped but not located at this time (an ISCO Work Plan would be developed to properly site new wells using a phased installation approach). The treatment compound would require installation of a concrete slab and masonry walls to contain the equalization and oxidant storage tanks, metering equipment, transfer pumps and process appurtenances. An electrical power connection would be required for system operations. A permanent, secure compound was scoped on the basis that BNL is relatively isolated and equipment/infrastructure located at the property are subject to vandalism. The ISCO system conceptual design is based on information gathered during the recent ISCO pilot study (**Appendix B**). In general, a recirculation strategy using sodium permanganate as the oxidant was assumed; however, these details would be further evaluated during development of the Proposed Remedial Action Plan (PRAP).

Wellhead Treatment/Supply of Replacement Water (Contingencies). These contingencies would only occur if private or TW wells in the path of the Site groundwater plume become impacted. As identified in Section 5.1.1, wellhead treatment would include the addition of L-GAC to larger production wells (i.e., those owned by TW or St. Joseph's Hospital [411-P]) at impacted well sites and supply of city water to small private wells through new or existing connections. Further detail regarding thresholds for these contingencies and which wells may become impacted is discussed in **Section 5.1.3**.

5.1.3 Operation and Monitoring

MNA. The site groundwater model indicates that PCE concentrations in the GOU will exceed the AWQS for this contaminant for the reasonably foreseeable use of water at the Site (at least 100 years) if no plume remediation is implemented (**Appendix A**). For the purpose of developing costs for this FS, site wide groundwater monitoring was assumed over the course of the next 100 years to include biannual water level monitoring of up to 70 wells (with stepped reductions at Year 30 and Year 50), PDB groundwater sampling of 16 semiannual wells, 23 annual wells, and 28 biannual wells (with stepped reductions at Year 30 and Year 50), annual reporting, and Sampling and Analysis Plan (SAP)/Quality Assurance Project Plan (QAPP) updates every 5 years.

Environmental Sampling. Deep soil vapor monitoring would utilize new and existing wells and be conducted at BSL at a high frequency during SVE operations (i.e., quarterly for 1 year) and at a reduced frequency (i.e., every 5 years) following the suspension of BSL SVE operations for up to 20 years at both BSL and BNL. The purpose of this sampling would be to verify that concentrations have not rebounded after SVE has removed impacted soil vapor that contributed to groundwater contamination at the Site. Vapor wells would be abandoned after monitoring is suspended if these assessments show that there are no remaining soil vapor impacts to groundwater at the Site. Groundwater monitoring to evaluate the effectiveness and the post treatment impacts of SVE and ISCO would be incorporated into the site wide groundwater monitoring effort but would include increased frequencies of sample collection for monitoring wells in target treatment zones.

SVE. Based on the performance of the SVE/AI ERA at BNL, the projected operation of the SVE treatment system at the BSL is one year. The system would be operated and maintained by a qualified system operator. To ensure the system is operating effectively, an operation and maintenance manual (OMM) would be created. The OMM would include a monitoring and reporting plan to meet likely air permit requirements and demonstrate system performance. SVE process monitoring would include collection of samples from process wells and the carbon adsorption system.

ISCO. Over the anticipated seven year operating period, the ISCO system would be operated and maintained by a qualified system operator. To ensure the system is operating effectively, an OMM would be created and would include a monitoring and reporting plan to demonstrate system performance. ISCO process monitoring would include collection of samples from process wells.

Wellhead Treatment/Supply of Replacement Water (Contingencies). The plume is expected to continue to migrate in the GOU and therefore local private or production wells will likely require contingency measures to be implemented to ensure these water supplies do not contain Site contaminants at concentrations that exceed risk management thresholds. The threshold criterion for wellhead treatment or replacement water at impacted wells used in this FS is three-quarters of the AWQS or 3.75 µg/L. Based on time-concentration data derived from Site groundwater modeling (see **Figure 100** in **Appendix A**), wellhead treatment is predicted to be needed for St. Joseph's Hospital 411-P well (2023 through 2061, 39 years) and TW production well C-051B (2096 through 2115, 20 years). A provision of replacement water is predicted to be needed for private well CVA from 2099 through 2115 (17 years) and private well Swain from 2095 through 2108 (14 years). **Figure 5-3** presents the locations of these wells and summarizes groundwater model projections. Wellhead treatment systems would be operated and maintained by a qualified and appropriately certified potable water treatment system operator. To ensure the systems are operating effectively, OMMs would be created for each system and would include monitoring and reporting plans for performance sampling.

5.2 Less Aggressive Remedy

5.2.1 Remedial Measures and Strategies

The Less Aggressive Remedy for VOCs in Landfill Waste is similar to the Reference Remedy but does not include ISCO at BNL. This remedy combines the remedial measures of ECs, ICs, MNA, inspections/environmental sampling, and SVE with wellhead treatment and the provision of a replacement water supply as contingency measures for downgradient drinking water supply wells that could become impacted. These remedial measures use the remedial strategies of plume remediation, physical containment, source control and monitoring to achieve ROs (**Table 6-1**). The groundwater model was used to provide estimates of how long the plume would persist in the aquifer and when downgradient water supply wells would be impacted while attenuating under natural hydraulic gradients with assumed water supply pumping. **Appendix A** documents the results of groundwater modeling and the model scenario corresponding to the Less Aggressive Remedy is Scenario 1 (MNA – Base Case).

Retained remedial measures are the same as the Reference Remedy. See Section 5.1.1 for a more detailed description of individual components.

5.2.1.1 Achievement of Remedial Objectives

Like the Reference Remedy, the Less Aggressive Remedy would achieve ROs for land use by restricting environmental and human exposure to landfill waste with landfill cover, development cap, and perimeter fencing ECs and ICs for intrusive site work. ICs would also be put in place to make certain that the ECs remain effective for as long as the landfilled waste remains at the site and would require inspections to ensure that the ECs are properly maintained.

Groundwater modeling, summarized in **Figure 5-4** and documented in **Appendix A**, was used to predict the effectiveness and efficiency of the Less Aggressive Remedy to meet GROs. As indicated in **Figure 5-4**, groundwater modeling indicates that after 100 years, the PCE plume (i.e., the extent of PCE present at concentrations that exceed the AWQS) would still exist and be impacting potable wells. Since the Less Aggressive Remedy would not remediate the GOU within the duration of foreseeable uses of water (i.e., 100 years), achievement of GROs (i.e., to restore, replace or otherwise provide for the current and future potable use of the regional aquifer) would be based on treating impacted water supply wells (or supplying an alternative source of water for impacted wells). Ongoing monitoring would be required to ensure this exposure pathway remains incomplete. SVE and MNA would promote achieving GROs by mitigating the amount of contaminant mass that can migrate to and impact water supply wells.

Continued achievement of the GROs after 100 years would require ongoing monitoring and wellhead treatment/provision of an alternative water supply for impacted wells for as long as the PCE concentrations exceed the AWQS.

5.2.1.2 Consistency with Land Use and Consideration of Water Management Plans

The current use of the LOU includes both non-residential and/or commercial properties but possible future uses allowed by the zoning include office, commercial recreation, commercial service, commercial general, residential (including single-family residences for BNL), research and development, and a golf course (Clear Creek, 2015a). A DEUR implemented as part of the remedy would control the type of development that can occur in the LOU but would not necessarily limit land use if ECs are maintained.

The current use of the GOU is the TW CWF and as a water supply to the private commercial and residential entities at and near the Site. Although not desired by TW, treating extracted groundwater for Site COCs prior to direct customer use would maintain the supply of water needed to comply with TW water management plans.

ICs for groundwater use would only apply to new, future users and would reduce the likelihood that new exempt groundwater wells (producing less than 35 gpm) are installed at the Site. This would help limit future groundwater use until the plume no longer poses a threat to water supplies. Entities planning to install new (not replacement) groundwater wells within a mile of the Site would be informed of the existence of the groundwater contamination when they apply to ADWR for the drilling permit. If an entity chooses to install a well after the ROD is finalized for this Site, the entity would be proceeding at their own risk.

5.2.2 System Design and Installation

MNA. System design and installation for MNA would be the same as described for the Reference Remedy in Section 5.1.2.

SVE. System design and installation would be the same as described for the Reference Remedy in Section 5.1.2.

Wellhead Treatment/Supply of Replacement Water (Contingencies). System design and installation for wellhead treatment and supply of replacement water would be the same as described for the Reference Remedy in Section 5.1.2.

5.2.3 Operation and Monitoring

MNA. The site groundwater model indicates that PCE concentrations in the GOU will exceed the AWQS for this contaminant for the reasonably foreseeable use of water at the Site (at least 100 years) if no plume remediation is implemented (**Appendix A**). Operation and monitoring for MNA would be the same as described for the Reference Remedy in Section 5.1.3.

Environmental Sampling. Environmental sampling design and installation would be the same as described for the Reference Remedy in Section 5.1.3 with the exception that groundwater monitoring to evaluate ISCO would not be required.

SVE. Operation and monitoring for SVE would be the same as described for the Reference Remedy in Section 5.1.3.

Wellhead Treatment/Supply of Replacement Water (Contingencies). The plume is expected to continue to migrate in the GOU and therefore local private or production wells will likely require contingency measures to be implemented to ensure these water supplies do not contain Site contaminants at concentrations that exceed risk management thresholds. The threshold criterion for wellhead treatment or replacement water at impacted wells used in this FS is three-quarters of the AWQS or 3.75 µg/L. Based on time-concentration data derived from Site groundwater modeling (see **Figure 30** in **Appendix A**), wellhead treatment is predicted to be needed for St. Joseph's Hospital 411-P well (2024 through 2068, 45 years) and TW production wells C-051B (2096 through 2115, 20 years) and C-058B (2085 through 2115, 31 years). A provision of replacement water is predicted to be needed for private well CVA from 2098 through 2115 (18 years), private well Mayo from 2098 through 2115 (18 years), and private well Swain from 2094 through 2108 (15 years). **Figure 5-4** presents the locations of these wells and summarizes groundwater model projections. Wellhead treatment systems would be operated and maintained by a qualified and appropriately certified potable water treatment system operator. To ensure the systems are operating effectively, OMMs would be created for each system and would include monitoring and reporting plans for performance sampling.

5.3 More Aggressive Remedy

5.3.1 Remedial Measure and Strategies

The More Aggressive Remedy for VOCs in Landfill Waste includes many of the components of the Reference Remedy but generally replaces MNA with P&T as the primary remedial approach to address downgradient groundwater plumes. However, dilute, detached plumes bifurcated during extraction that are not expected to impact downgradient drinking water supply wells would be allowed to naturally attenuate. Thus, this remedy combines the remedial measures of ECs, ICs, P&T, MNA, inspections/environmental sampling, SVE, and ISCO. Contingency wellhead treatment (for one water supply well that is predicted to be impacted) would also be included. These remedial measures use the remedial strategies of plume remediation, physical containment, controlled migration, source control and monitoring to achieve ROs (**Table 6-1**).

The groundwater model was used to provide estimates of how long the plume would persist in the aquifer and if downgradient water supply wells would be impacted while attenuating under natural hydraulic gradients with assumed water supply pumping. **Appendix A** documents the results of groundwater modeling and the model scenario corresponding to the More Aggressive Remedy is Scenario 25 (Accelerated-E with ISCO).

Further description of the remedy is as follows:

- ECs – *Same as Reference Remedy* – See Section 5.1.1 for a more detailed description of individual components.
- ICs – *Same as Reference Remedy* – See Section 5.1.1 for a more detailed description of individual components.
- P&T – P&T would target the existing 10 µg/L PCE groundwater concentration contour at the Site (**Figure 2-1**) for groundwater remediation (using the existing WCS treatment system) and the installation of a replacement extraction well at the location of current TW

production well C-022A (i.e., C-022A-R), installation of a new extraction well (referred to as EX-02) at the western edge of BSL, use of existing WCS extraction well R-092A, and use of existing WCS injection well R-090A. Selection of these groundwater extraction locations was based on an evaluation of multiple P&T scenarios during FS development using the Site groundwater model (**Appendix A**). Scenario 25 (Accelerated-E with ISCO) was selected because it effectively contained groundwater plumes and cleaned up the aquifer in the shortest amount of time.

- MNA - MNA would consist of routine groundwater monitoring and would be conducted to track groundwater contamination in the GOU, downgradient of the LOU, for as long as COC concentrations exceed applicable AWQSs. Based on the results of groundwater modeling (**Appendix A**), most of the PCE groundwater plume is contained by extraction activities under this scenario (except for a small dilute plume in the northwest that is downgradient of the WCS and the detached plume located downgradient of groundwater extraction at BSL would be allowed to naturally attenuate). Plumes would be routinely monitored to assess the extent of containment, natural attenuation of detached plumes and plume migration to water supply wells.
- Inspections/Environmental Sampling – *Same as Reference Remedy* – See Section 5.1.1 for a more detailed description of individual components. Based on the results of groundwater modeling, groundwater monitoring is anticipated to be required for approximately 29 years (**Appendix A**).
- SVE – *Same as Reference Remedy* – See Section 5.1.1 for a more detailed description of individual components.
- ISCO – *Same as Reference Remedy* – See Section 5.1.1 for a more detailed description of individual components.
- Wellhead Treatment (Contingency) – Wellhead treatment would be a contingency measure and consist of adding L-GAC treatment to existing water supply wells when COC concentrations extracted from the well exceed three-quarters of the applicable AWQS (i.e., 3.75 µg/L for PCE). The list of wells predicted to be impacted and span of years for the predicted impact are shown in **Table 6-1** as part of the Description of Alternative.

5.3.1.1 Achievement of Remedial Objectives

Like the Reference Remedy, the More Aggressive Remedy would achieve ROs for land use by restricting environmental and human exposure to landfill waste with landfill cover, development cap, and perimeter fencing ECs and ICs for intrusive site work. ICs would also be put in place to make certain that the ECs remain effective for as long as the landfilled waste remains at the site and would require inspections to ensure that the ECs are properly maintained.

Unlike the Less Aggressive Remedy and the Reference Remedy, groundwater modeling summarized in **Figure 5-5** and documented in **Appendix A** predicts that the More Aggressive Remedy would clean up the GOU to levels that are less than the AWQS in 29 years. Thus, the More Aggressive Remedy would achieve GROs by treating the source of contamination to the GOU with SVE and ISCO and using P&T and MNA to remediate the groundwater plume (the small detached plume located downgradient of the P&T system and the detached plume located downgradient of groundwater extraction at BSL would be allowed to naturally attenuate). Groundwater modeling, documented in **Appendix A**, was used to predict the effectiveness and efficiency of this remedy to meet GROs. Groundwater monitoring (performed as part of Environmental Sampling) and wellhead treatment process sampling would be used to confirm that GROs are being met.

5.3.1.2 Consistency with Land Use and Consideration of Water Management Plans

The current use of the LOU includes both non-residential and/or commercial properties but possible future uses allowed by the zoning include office, commercial recreation, commercial service, commercial general, residential (including single-family residences for BNL), research and development, and a golf course (Clear Creek, 2015a). A DEUR implemented as part of the remedy would control the type of development that can occur in the LOU but would not necessarily limit land use if ECs are maintained.

The current use of the GOU is the TW CWF and as a water supply to several private commercial and residential entities. Treating the groundwater plume upgradient of most of these water supply wells is consistent with water management plans.

ICs for groundwater use would only apply to new, future users and would reduce the likelihood that new exempt groundwater wells (producing less than 35 gpm) are installed at the Site. This would help limit future groundwater use until the plume no longer poses a threat to water supplies. Entities planning to install new (not replacement) groundwater wells within a mile of the Site would be informed of the existence of the groundwater contamination when they apply to ADWR for the drilling permit. If an entity chooses to install a well after the ROD is finalized for this Site, the entity would be proceeding at their own risk.

5.3.2 System Design and Installation

P&T System. The P&T system would utilize existing WCS treatment infrastructure with new and existing wells for extraction and injection (**Figure 5-5**). The scenario includes pumping from new extraction well C-022A-R at 225 gpm, new extraction well EX-02 at 100 gpm, and existing WCS well R092A at 400 gpm. The pumped water would be treated at the existing WCS and injected into existing WCS injection well R090A. The WCS uses L-GAC to treat VOCs in the groundwater. Due to uncertainties regarding the current condition of the WCS, it was assumed that L-GAC vessels and sediment pre-filters would need to be replaced to bring the WCS into operational condition. Cost contingencies for additional upgrades to the WCS to accommodate the planned configuration of wells and retrofitting/maintenance to rehabilitate the WCS were also included. New conveyance pipelines would be required to convey extracted groundwater from new extraction wells to the WCS; the routing presented in **Figure 5-5** is likely conservative and based on experience installing remediation system conveyance pipelines in urban settings.

MNA. System design and installation would be the same as described for the Reference Remedy in Section 5.1.2.

SVE. System design and installation would be the same as described for the Reference Remedy in Section 5.1.2.

ISCO. System design and installation would be the same as described for the Reference Remedy in Section 5.1.2.

Wellhead Treatment (Contingency). System design and installation for wellhead treatment would be the same as described for the Reference Remedy in Section 5.1.2. However, fewer water supply wells would be impacted, see Section 5.3.3.

5.3.3 Operation and Monitoring

P&T. The site groundwater model indicates that the projected operational timeframe for the P&T system is 29 years. The PCE plume distribution maps show that the northwest plume will migrate slightly to the west and quickly disperse in approximately 10 years. The BSL plume is mostly captured by pumping from EX-02, with the western portion of the BSL plume migrating slowly to the west-northwest and slowly dispersing within approximately 25 years (**Figure 5-5**). The extraction wells will not all be continuously operating during this time. Extraction well C-022A-R will operate at 225 gpm from 2016 through 2044 (29 years), EX-02 will operate at 100 gpm from 2016 through 2030 (15 years), and R-092A will operate at 400 gpm from 2035 through 2044 (10 years). **Figure 5-5** presents the locations of these wells and summarizes groundwater model projections. The P&T treatment system would be operated and maintained by a qualified water treatment system operator. To ensure the system is operating effectively, an OMM would be created for the system and would include monitoring and reporting plans for performance sampling.

MNA. For the purpose of developing costs for this FS, site wide groundwater monitoring for the More Aggressive Remedy was assumed over the course of the next 30 years to include biannual water level monitoring of up to 70 wells (includes some wells that are not sampled), PDB groundwater sampling of 16 semiannual wells, 23 annual wells, and 28 biannual wells, annual reporting, and SAP/QAPP updates every 5 years.

SVE. Based on the performance of the SVE/AI ERA at BNL, the projected operation of the SVE treatment system at the BSL is one year. Operation and monitoring for SVE would be the same as described for the Reference Remedy in Section 5.1.3.

ISCO. The anticipated duration of ISCO operations is seven years. Operation and monitoring for ISCO would be the same as described for the Reference Remedy in Section 5.1.3.

Environmental Sampling. Environmental sampling design and installation would be the same as described for the Reference Remedy in Section 5.1.3.

Wellhead Treatment (Contingency). Based on time-concentration data derived from Site groundwater modeling (see **Figure 112** in **Appendix A**), the plume is expected to migrate to private water supply well 411-P (St. Joseph's Hospital) within the remedial timeframe for the More Aggressive Remedy. Using the threshold criterion for wellhead treatment developed for this FS of 3.75 µg/L for PCE, the groundwater plume is expected to impact St. Joseph's Hospital 411-P well requiring wellhead treatment be provided from 2027-2035 (9 years). The wellhead treatment system would be operated and maintained by a qualified and appropriately certified potable water treatment system operator. To ensure the system is operating effectively, an OMM would be created for the system and would include monitoring and reporting plans for performance sampling.

6.0 DETAILED EVALUATION AND COMPARISON OF THE REMEDIES

6.1 Comparison Criteria

Based on the preceding demonstration that the remedial alternatives are capable of achieving the ROs and are generally consistent with land and water use plans for affected users, this section presents a comparative evaluation of the Reference Remedy and the alternative remedies for VOCs in Landfill Waste at the Site based on practicability, risk, cost and benefit in accordance with A.A.C. R18-16-407(H) as the primary criteria. An overview of these evaluation criteria is as follows:

- Practicability: Feasibility, short and long term effectiveness, and reliability.
- Risk: Overall protectiveness of public health and aquatic and terrestrial biota under reasonably foreseeable use scenarios and end uses of water.
- Cost: Expenses and losses including capital, operating, maintenance, and life cycle[11] costs.
- Benefit: Value of the remedy in terms of lowered risk, reduced concentrations or volume of contamination, decreased liability, aesthetics, enhancement of future uses, and improvements to local economies.

This comparison for Metals in the Dross Material area is presented in **Appendix E**.

6.2 Detailed Evaluation of Remedies

An evaluation of the remedy alternatives using the criteria of practicability, risk, cost and benefit is summarized in **Table 6-1**. Since ECs and ICs are a component of all remedies, these remedial measures were not used to distinguish the remedies and are not included in the evaluation presented herein. The sections below further describe how each remedy alternative performs against the criteria.

6.2.1 Reference Remedy

6.2.1.1 Practicability

Overall, the Reference Remedy is moderately feasible. The installation and operation of SVE and ISCO systems for treatment in the source areas are feasible because they are easily implemented, located on the landfill properties and anticipated to operate for relatively short periods of time. The less feasible portion of the remedy is the contingency remedial measure of wellhead treatment for potable water supply wells impacted by the Site. Wellhead treatment is easily implementable but would be difficult to manage for the multiple wells over the extended period of time which these distributed treatment systems are anticipated to operate (**Section 5.1.3** and **Figure 5-3)**.

[11] For this FS, life cycle costs include environmental monitoring/sampling, associated plan updates/reporting, and non-process well replacement/abandonment

The SVE and ISCO systems are anticipated to be effective and reliable remedial measures for treatment of VOC contamination present in the LOU over the short term these systems are active. The SVE and ISCO systems are anticipated to operate for one and seven years, respectively (**Section 5.1.3**). It is difficult to estimate how much impact these systems would have on long-term groundwater remediation but they are anticipated to reduce the quantity of mass introduced to the groundwater and moreover the duration the LOU source areas contribute to groundwater contamination in the GOU.

Although the groundwater model did not specifically forecast the impacts of SVE[12], the groundwater model (**Appendix A**) was used to estimate the quantity of mass removed from the BNL source area during groundwater recirculation with ISCO. This quantity (76 lbs of PCE) was based on projected extraction flows and current groundwater concentrations present at the Site (Scenario 23 in **Table 4** of **Appendix A**). Since the BNL source area targeted for treatment with ISCO likely contains retained PCE in/on submerged sediments that continue to release PCE, the estimate of mass treated with ISCO based on current groundwater concentrations is probably low. Injected oxidant would be expected to treat retained contamination in situ. Accurate prediction of how much retained mass is present and for how long the retained mass will impact groundwater under BNL is currently not feasible.

End point analysis was used during the groundwater modeling effort (**Appendix A**) to estimate the relative percentage of the existing PCE plume footprint (excluding the northwest detached plume) that wellhead treatment operations would remove from the aquifer. Based on this analysis, only 2 percent (%) BNL plume footprint would be captured by wellhead treatment operations. Wellhead treatment operations would not be expected to contain any of the BSL plume footprint because the model does not predict that the BSL plume will migrate to currently operating extraction wells. It is important to understand that this capture estimate corresponds to containment of the areal plume extent; it is not a measure of the percentage of plume contaminant mass removed by wellhead treatment operations. Although this assessment suggests that the Reference Remedy does not significantly remediate the groundwater plume, wellhead treatment would likely be effective and reliable in reducing the concentration of COCs to less than risk management thresholds in groundwater provided to end users.

6.2.1.2 Risk

The results of groundwater modeling indicate that over the duration that the Reference Remedy will be implemented (100 years), PCE concentrations in one or more of the Site groundwater plumes are anticipated to exceed the AWQS (**Appendix A**). Risks associated with this contamination would be mitigated through the provision of an alternative water supply to users of impacted wells or the treatment of extracted groundwater from impacted wells prior to use. However, since groundwater extracted from drinking water supply wells would be treated for COCs prior to discharge into the potable water supply for end user consumption, there is a potential for increased risk if there is a lapse in treatment. Another source of increased risk associated with the Reference Remedy is the long-term operation of wellhead treatment systems

[12] The source term used at both BNL and BSL assumed a rate of groundwater concentration decline comparable to PCE concentrations in groundwater at BNL after SVE was conducted. Thus, the source term assumes that soil vapor contributing to groundwater is treated because all alternatives included SVE at BSL.

which could be adversely affected by changes in CWF pumping. The transport and disposal of spent GAC materials used in treatment (i.e., cross-media contamination) could also contribute to the magnitude of risk associated with the Reference Remedy. Finally, the risk due to aquifer contamination at the end of remedy implementation is high because the plume will not be remediated to levels consistent with no further action after 100 years (**Figure 5-3**).

6.2.1.3 Cost

The total cost of new remedial measure construction (i.e., capital costs), remedial measure operations and maintenance, and associated lifecycle costs for the Reference Remedy is estimated to total \$21.7 million (M) or \$126.4M with projected inflation of 3% over 100 years (**Table 6-1**). This duration was selected as the "reasonably foreseeable" use of the groundwater resource impacted by the Site since a finite number of years is needed for cost estimation[13]. An inflation rate of 3% (without any discounting) was used for consistency in the ADEQ WQARF program. Operation and maintenance (O&M) costs include system operations personnel, cleaning and mechanical maintenance, materials, and operational utility costs at \$0.14 per kilowatt per hour (kW/Hr). Life cycle costs include monitoring, reporting, well installation, and well abandonments. A breakdown of each cost can be found in **Appendix F** in **Tables F-1, F-4, F-5, F-6, F-7 and F-8**.[14]

6.2.1.4 Benefit

The benefit of the Reference Remedy is the protection of the potable water supply at wells downgradient from the contaminant plume. Inclusion of the remedial measures that address source area remediation (i.e., SVE and ISCO) will decrease the concentrations of contamination contributing to the groundwater plume from the vadose and saturated zones which have the potential to reduce the size and concentration of the plume over time. Implementing ISCO in particular reduces uncertainty associated with how much retained mass is present and for how long the retained mass will impact groundwater under BNL.

6.2.2 Less Aggressive Remedy

6.2.2.1 Practicability

Overall, the Less Aggressive remedy is similar to the Reference Remedy in that it is moderately feasible. The installation and operation of the SVE system for treatment in the BSL source area is feasible because it is easily implemented, located on the landfill property and anticipated to operate for one year. The less feasible portion of the remedy is the contingency remedial measure of wellhead treatment for potable water supply wells impacted by the Site. Wellhead treatment is easily implementable but would be difficult to manage for the multiple wells over the extended

[13] This does not imply that the groundwater resource will not be needed or used after 100 years.

[14] DEUR costs are borne by the property owner or the prospective property owner who agrees to place a DEUR on the property as a "public benefit" as part of a Prospective Purchaser Agreement with ADEQ. ADEQ will expect the BNL property owners to maintain the BNL fencing (and thus bear the fencing O&M costs).

period of time which these distributed treatment systems are anticipated to operate (**Section 5.2.3** and **Figure 5-4)**.

SVE is anticipated to be an effective and reliable remedial measure for treatment of VOC contamination present in the deep vadose zone over the short term this system is anticipated to be active. It is difficult to estimate how much impact this system would have on long-term groundwater remediation but it is expected to reduce the quantity of mass introduced to the aquifer and moreover the duration the BSL source area contributes to groundwater contamination in the GOU.

End point analysis was used during the groundwater modeling effort (**Appendix A**) to estimate the relative percentage of the existing PCE plume footprint that wellhead treatment operations would remove from the aquifer. Based on this analysis, excluding the small plume in the vicinity of WR-704A, only 1.8% of the remaining BNL plume would be captured by wellhead treatment operations. Wellhead treatment operations would not be expected to remove any mass associated with the BSL plume because the model does not predict that the BSL plume will migrate to currently operating extraction wells. It is important to understand that this capture estimate corresponds to containment of the areal plume extent; it is not a measure of the percentage of plume contaminant mass removed by wellhead treatment operations. Although this assessment indicates that the Less Aggressive Remedy does not remediate the groundwater plume, wellhead treatment would likely be effective and reliable in reducing the concentration of COCs to less than risk management thresholds in groundwater provided to end users.

6.2.2.2 Risk

In general, the types of risks associated with the Less Aggressive Remedy mirror those described for the Reference Remedy in Section 6.2.1.2. However, the relative magnitude of the risk of not treating the source area at BNL may be assessed by considering how many more downgradient wells are impacted with the Less Aggressive Remedy when compared to the Reference Remedy (based on groundwater modeling). For the Less Aggressive Remedy, one additional well requires wellhead treatment and the combined duration of wellhead treatment operations increases by 37 years. One additional well also requires an alternative water supply and the combined duration that an alternative water supply is needed for downgradient wells increases by 20 years. Thus, by treating the highest concentrations of the groundwater plume and likely decreasing the duration of time that retained contamination at BNL serves as a source of groundwater contamination, the magnitude of risk to downgradient water supply wells is reduced.

6.2.2.3 Cost

The total cost of new remedial measure construction (i.e., capital costs), remedial measure operations and maintenance, and associated lifecycle costs for the Less Aggressive Remedy is estimated to be $24.2M or $178.5M with projected inflation of 3% over 100 years (**Table 6-1**). This duration was selected as the “reasonably foreseeable” use of the groundwater resource impacted by the Site since a finite number of years is needed for cost estimation. An inflation rate of 3% (without any discounting) was used for consistency in the ADEQ WQARF program. O&M costs include system operations personnel, cleaning and mechanical maintenance, materials, and operational utility costs at $0.14/kW/Hr. Life cycle costs include monitoring, reporting, well installation, and well abandonments. A breakdown of each cost can be found in **Appendix F** in **Tables F-2, F-4, F-5,** and **F-6**.

6.2.2.4 Benefit

The benefit of the Less Aggressive Remedy is the protection of the potable water supply at wells downgradient of the contaminant plume. Inclusion of SVE to remediate the BSL source area should decrease the concentrations of contamination contributing to the plume from the vadose zone. This is anticipated to reduce the size and concentration of the plume over time.

6.2.3 More Aggressive Remedy

6.2.3.1 Practicability

The More Aggressive Remedy is also considered moderately feasible but the reasons for this assessment generally differ from those used to evaluate the other remedies. The installation and operation of SVE and ISCO systems for source area treatment are highly feasible because they are easily implementable, located on the landfill properties, and anticipated to operate for a relatively short period of time. Updating and operation of the existing WCS for this remedy, installing new on-site wells, and including wellhead treatment at one well for a nine-year treatment period are also feasible. The less feasible portion of the remedy is the installation of a new off-Site well and pipelines to convey the water from the wells to the treatment system. Feasibility for these activities is impacted by stakeholder involvement and the constraints of public right-of-ways where the pipelines would be located.

The SVE and ISCO systems are anticipated to be effective and reliable remedial measures for VOC contamination present in the source areas of the LOU and GOU, respectively, over the short term these systems are active. It is difficult to estimate how much impact these systems would have on long-term groundwater remediation but they are anticipated to reduce the quantity of mass introduced to the aquifer and moreover the duration the source areas contribute to groundwater contamination in the GOU. Based on groundwater modeling (**Appendix A**), the combination of ISCO, P&T, and wellhead treatment operations is anticipated to remove 487 lbs of PCE from the GOU.

P&T system effectiveness is anticipated to be moderately effective for long term plume remediation on the basis that although the treatment technologies are highly conventional and dependable, required treatment durations for P&T remediation efforts are difficult to reliably estimate and can be adversely impacted by mischaracterized residual contamination in aquifer environments and/or sources that continue to feed groundwater plumes. Source area remediation is integral to ensuring P&T systems do not operate in perpetuity.

End point analysis was used during the groundwater modeling effort (**Appendix A**) to estimate the relative percentage of the existing PCE plume footprint that ISCO, P&T, and wellhead treatment operations would capture. Based on this analysis, excluding the small plume in the vicinity of WR-704A, 100% of the remaining BNL and BSL plumes would be captured by these treatment operations.

6.2.3.2 Risk

The overall risk associated with the More Aggressive Remedy is low relative to the other evaluated remedies, principally because the remedy cleans up the aquifer within 29 years of operation. Given the direct use of water extracted from 411-P after wellhead treatment as part of this remedy, there is a potential for increased risk if there is a lapse in treatment. This potential risk is limited because treatment would likely not be required for an extended time period. The transport and disposal of spent GAC materials used for treatment is a potential source of risk but is considered to be comparable to the other alternatives evaluated. Finally, the risk due to aquifer contamination at the end of remedy implementation is low because the plume would be remediated to levels consistent with no further action after 29 years (**Figure 5-5**).

6.2.3.3 Cost

The total cost of new remedial measure construction (i.e., capital costs), remedial measure operations and maintenance, and associated lifecycle costs for the More Aggressive Remedy is estimated to be $19.1M or $27.4M with projected inflation of 3% over 29 years. This duration was based on the duration that COC concentrations in groundwater are anticipated to exceed the AWQS at the Site based on groundwater modeling. O&M costs include system operations personnel, cleaning and mechanical maintenance, materials, and operational utility costs at $0.14/kW/Hr. Life cycle costs include monitoring, reporting, well installation, and well abandonments. A breakdown of each cost can be found in **Appendix F** in **Tables F-3, F-4, F-5, F-6, F-7 and F-8**.

6.2.3.4 Benefit

The benefit of the More Aggressive Remedy is the protection of the water supply for wells located downgradient of the contaminant plume though the remediation of the groundwater plume to concentrations that are less than AWQSs. Inclusion of the remedial measures that address source area remediation (i.e., SVE and ISCO) will decrease the concentrations of contamination contributing to the groundwater plume from the vadose and saturated zones which have the potential to reduce the size and concentration of the plume over time. Implementing ISCO in particular reduces uncertainty associated with how much retained mass is present and for how long the retained mass will impact groundwater under BNL.

6.3 Comparison of Remedies

6.3.1 Practicability

All of the evaluated remedy alternatives are practicable and moderately feasible. The Reference and the Less Aggressive remedies are both expected to be effective in the short term but these remedies may be less effective in the long term because they do not clean up the plume in a reasonable timeframe. The More Aggressive Remedy is more effective than the other evaluated remedies in both the short and long term because it remediates the groundwater plume and impacts a fewer number of downgradient water supply wells over a shorter duration. The remedial measures that comprise the various remedies are anticipated to be comparably reliable.

6.3.2 Risk

The Reference and Less Aggressive Remedies have similar types of risk to public health and because they do not remediate the groundwater plume and rely on contingency measures such as wellhead treatment and the provision of an alternative water source to provide potable water to end users of impacted wells. Since less wells are impacted for shorter durations, the Reference Remedy would be anticipated to have less risk than the Less Aggressive Remedy. The More Aggressive Remedy would remediate the groundwater plume and requires minimal wellhead treatment to provide potable water to end users of impacted wells. Limited use of wellhead treatment mitigates risk associated with treated water being used by end users for consumption.

6.3.3 Cost

The Less Aggressive Remedy has the lowest capital cost so it would be the least expensive to implement; however, the O&M and life cycle costs over the anticipated time frame of operations make it the highest cost overall (**Table 6-1**). The More Aggressive Remedy has the most expensive capital cost compared to the alternative remedies but since this remedy will operate for a substantially shorter period of time frame, the overall cost is the lowest. This cost disparity is magnified when inflation is considered. **Appendix F** presents a more detailed presentation of costs.

It is notable that when the costs for MNA with ISCO (i.e., the Reference Remedy) are compared to MNA without ISCO (i.e., the Less Aggressive Remedy) it is apparent that the $2.11M cost of implementing ISCO results in overall cost savings on the order of $2.5M.

6.3.4 Benefit

All remedy alternatives provide the benefit of protection of the water supply. However, the More Aggressive Remedy with a timeframe of about 30 years is the only alternative evaluated that achieves compliance with AWQSs for the aquifer and in a reasonable timeframe.

6.4 Uncertainties

The most significant uncertainties impacting the comparison of remedies presented in **Section 6.3** are:

- *The quantity of residual COC mass present in BNL and BSL waste is unknown*. Municipal records indicating the mass of all COC that went into the landfills are unavailable and historical sampling data are insufficient to estimate the mass of each COC that has been released from the landfills.
- *The distribution of contamination in the source areas currently impacting groundwater.* There is limited definition of contamination extent in deep soil vapor at BSL and in groundwater near WR-274A at BNL due to the spacing of monitoring wells (and the shallow screening in the groundwater of the WR-274A well). Also, it is unknown how much of the COC mass is being retained in sediments that could be mobilized if/when groundwater table rises. Inferences from available data were used to develop conceptual designs for the BNL ISCO system (**Figure 5-2**) and BSL SVE system (**Figure 5-1**) to be

costed as part of this FS; however, to address this uncertainty prior to development of the PRAP, monitoring/planned process wells could be installed to refine target treatment areas. For BNL, new wells advanced in between WR-274A and R-068A, north of planned well INJ-1 and east of existing well R-068A at BNL (**Figure 5-2**) would provide additional information within, to the north and to the east of the ISCO target treatment zone. These wells would also be useful monitoring wells to assess ISCO performance during implementation. At BSL, installation of planned wells MW-01, EX-01 (with a collocated groundwater piezometer), and MW-02 (**Figure 5-1**) would better define the northern and southern extent of the SVE target treatment zone. The results of these additional well installation efforts would be useful in evaluating whether expansion of these planned systems is warranted.

- *The durations required to cleanup Site groundwater contamination*. The Site groundwater model is a useful tool employed to provide relative cleanup periods for alternative analysis in this FS. There are significant uncertainties in estimated timeframes because they are highly impacted by assumptions made regarding the magnitude and duration of the contaminant source term used to model the input of contamination into groundwater under the LOU. Assumptions regarding this source term were derived from the observed decline of PCE concentrations in groundwater at BNL after SVE was conducted.
- *Future impacts of water supply wells.* Regional pumping affects the direction of groundwater flow and rate of plume migration. The transport model relied upon for this comparison of remedies is based on a calibrated flow field that assumes regional water supply pumping will remain comparable to the 2014 period of record supplied by TW for their production wells. If new wells are installed and/or existing wells are operated substantially differently than assumed in the model, the cleanup requirements derived from the model could be adversely impacted. The most significant change that could affect the remedies considered in this analysis is likely an alteration in the direction/gradient of groundwater flow due to increased pumping of existing wells or extraction from a well that is not currently downgradient of the groundwater plume (e.g., D-018A, C-025B or C-020B). Extraction from TW standby wells would likely result in the lateral spreading of the plume which could have impacts on how many water supply wells become impacted in the future and how effective containment pumping is in capturing Site groundwater plumes.
- *The vertical distribution of VOCs in groundwater*. The site groundwater model used a uniform distribution of PCE in the layers assumed to be impacted. This uncertainty would affect the modeled concentrations in downgradient wells and the durations required for operation of treatment systems if the assumed distribution is not representative of actual conditions.
- *Site aquifer characteristics.* Aquifer parameters describing groundwater flow and contaminant transport in groundwater such as porosity, hydraulic conductivity, transmissivity, contaminant retardation, dispersivity and saturated thickness impact the effectiveness of modeled remedial measures and remedy duration requirements estimated by the groundwater model. If actual Site conditions vary substantially from the parameters used in the model, the extent of capture, peak concentrations observed at downgradient water supply wells, and plume migration timeframes estimated by the model would vary.

- *The availability of the C-022A well site for a new replacement well and the condition of the WCS and associated infrastructure*. The More Aggressive Remedy relies to a significant extent on existing infrastructure to control costs. The status of this infrastructure and availability for incorporation into the remedy has not been evaluated as part of this FS.
- *ROW constraints along the proposed extracted groundwater conveyance piping run.* Uncertainty regarding ROW constraints for routing the proposed conveyance piping has the potential to significantly affect the location, length and cost of this remedy component.

7.0 PROPOSED REMEDY

7.1 Process and Reason for Selection

The More Aggressive Remedy is the proposed remedy for the Site. This remedy for VOCs in waste includes the following remedial measures:

- ECs – The existing landfill waste soil cover and development caps (e.g., asphalt parking lots, buildings, sidewalks) would be incorporated into the remedy as ECs to control exposure to the landfill waste. The fence line at BNL would be expanded to completely enclose this landfill and the BSL parcels which are not beneath a development cap would be fenced. The fencing would include warning signs.
- ICs – A DEUR needs to be placed on the parcels where landfilled waste is present to ensure that current and future property uses are protective of potential receptors and that current and future ECs are properly managed, maintained, and inspected. New water supply well installation would also be limited within the WQARF Site pursuant to A.R.S. § 45-454(C).
- P&T – P&T would target the existing 10 µg/L PCE groundwater concentration contour at the Site (**Figure 2-1**) for groundwater remediation (using the existing WCS treatment system) and the installation of a replacement extraction well at the location of current TW PW C-022A (i.e., C-022A-R), installation of a new extraction well (referred to as EX-02) at the western edge of BSL, use of existing WCS extraction well R-092A, and use of existing WCS injection well R-090A. Selection of these groundwater extraction locations was based on an evaluation of multiple P&T scenarios during FS development using the Site groundwater model (**Appendix A**). Scenario 25 (Accelerated-E with ISCO) was selected because it effectively contained groundwater plumes and cleaned up the aquifer in the shortest amount of time.
- MNA - MNA would consist of routine groundwater monitoring and would be conducted to track groundwater contamination in the GOU, downgradient of the LOU, for as long as COC concentrations exceed applicable AWQSs (approximately 29 years). Based on the results of groundwater modeling (**Appendix A**), most of the PCE groundwater plume is contained by extraction activities under this scenario (except for a small dilute plume in the northwest of the GOU that is downgradient of the WCS). Plumes would be routinely monitored to assess the extent of containment, natural attenuation of detached plumes and plume migration to water supply wells.
- Inspections/Environmental Sampling – Inspections would be conducted to evaluate whether ECs continue to limit waste exposure to Site receptors and would be required by the DEUR at a frequency defined in associated documents. Environmental sampling including deep soil vapor monitoring would be conducted to assess the performance of SVE operations and evaluate the rebound in concentrations after SVE. In addition to the groundwater monitoring conducted throughout the GOU as part of MNA, focused groundwater monitoring would also be conducted to assess the performance/efficacy of ISCO in the BNL source area and SVE in the BSL source area.
- SVE – SVE at BSL would target elevated concentrations of VOCs in deep soil vapor near BSDP-2 and BSDP-4 (concentrations at one or more depths monitored were increasing

as of January 2015; **Appendix D, Figure 1**) and increasing PCE concentrations observed in groundwater at BP-23 (**Figure 2-10**). The SVE system would include up to 4 new wells that could serve as either vapor extraction or monitoring wells (**Figure 5-1**), above ground temporary piping, a rented SVE blower with temporary power, and vapor phase granular activated carbon (V-GAC) for treatment of extracted vapors. Extraction well EX-01 has been located south of BSDP-2, near BP-11 to address a data gap at the Site. Although BP-11 indicates that groundwater is not impacted at this location, the well screen is significantly submerged. The screened interval ranges from 378 to 478 ft bgs and the depth to water at BP-11 was 343 ft bgs in February 2015 (**Appendix C**). EX-01 would include an appropriately screened piezometer to monitor groundwater.

- ISCO – ISCO in the BNL source area would target elevated levels of PCE between WR-274A and R-068A (**Figure 2-1**). On the basis of ISCO pilot study testing (**Appendix B**), a downgradient recirculation strategy would be implemented with a minimum of 5 new wells that could be used as either extraction or injection wells (**Figure 5-2**), connective piping, and a secure treatment compound to store and meter oxidant. Using the sustainable extraction rate derived from the pilot study (i.e., 40 gpm), particle tracking analysis with the Site groundwater model was used to evaluate ISCO treatment durations and develop a conceptual operating sequence for ISCO implementation (see **Appendix B** for further discussion). Although the groundwater model predicts that treatment of the BNL source area would be achieved in 5 years using ISCO (**Appendix A**), conceptual design and associated costs presented in this FS are based on an operating period of 7 years to achieve three circulations of groundwater in the target treatment area and promote effective distribution of oxidant.
- Wellhead Treatment (Contingency) – Wellhead treatment would be a contingency measure and consist of adding L-GAC treatment to existing water supply wells when COC concentrations extracted from the well exceed three-quarters of the applicable AWQS (i.e., 3.75 µg/L for PCE). Based on the results of groundwater modeling (Appendix A), St. Joseph's Hospital well 411-P will require wellhead treatment from 2027 to 2035 (9 years).

This remedy for VOCs in Waste was selected based on the comparison of practicability, risk, cost and benefit of the remedy alternatives discussed in **Section 6.0**. The More Aggressive Remedy was selected because it provides superior effectiveness, risk control, and benefit when compared to the other evaluated remedies. The More Aggressive Remedy was also assessed as the least expensive to implement.

As indicated in **Appendix E**, the More Aggressive Remedy was also selected as the proposed remedy for Metals in Dross Material. This remedy includes the following remedial measures:

- ICs – A DEUR needs to be placed on the parcels where dross material is present to control development, identify requirements for intrusive site work in areas where dross material exists and require appropriate inspection and maintenance of implemented ECs.
- ECs – An asphalt cap would be constructed over the extent of dross material present in the northern portion of the dross material disposal area currently covered by soil (see **Figure E5-3** in **Appendix E**). The building and asphalt-covered parking area of Broadway

Star Plaza would be incorporated into the remedy as an existing development cap over dross material in the southern portion of the dross material disposal area.

- Inspections – Inspections would be conducted to evaluate whether the asphalt cap and development cap continue to limit contaminant exposure to Site receptors. Inspections would be required by the DEUR at a defined frequency.

This remedy for Metals in Dross Material was selected based on the comparison of the practicability, risk, cost and benefit of the remedy alternatives discussed in **Section 6.0** of **Appendix E**. The More Aggressive Remedy was selected because it provides superior effectiveness, risk control, and benefit when compared to the other evaluated remedies. The More Aggressive Remedy was assessed as comparable in capital expenditure to the Reference Remedy (which included an engineered soil cap).

7.2 Achievement of Remedial Objectives

The More Aggressive Remedy for VOCs in Waste would achieve ROs for land use by restricting environmental and human exposure to landfill waste with landfill cover, development cap, and perimeter fencing ECs and ICs for intrusive site work. ICs would also be put in place to make certain that the ECs remain effective for as long as the landfilled waste remains at the site and would require inspections to ensure that the ECs are properly maintained.

Groundwater modeling summarized in **Figure 5-5** and documented in **Appendix A** predicts that the More Aggressive Remedy for VOCs in Waste would clean up the GOU to levels that are less than the AWQS in 29 years. Thus, this remedy would achieve GROs by treating the source of contamination to the GOU with SVE and ISCO and using P&T and MNA to remediate the groundwater plume (the small detached plume located downgradient of the P&T system and the detached plume located downgradient of groundwater extraction at BSL would be allowed to naturally attenuate). Groundwater modeling, documented in **Appendix A**, was used to predict the effectiveness and efficiency of this remedy to meet GROs. Groundwater monitoring (performed as part of Environmental Sampling) and wellhead treatment process sampling would be used to confirm that GROs are being met.

The More Aggressive Remedy for Metals in Dross Material achieves ROs for land use through source control, physical containment, and monitoring. Implemented ICs, ECs, and inspections would protect Site receptors from exposure to Metals in the Dross Material by restricting environmental and human exposure to the dross material. To ensure the continued integrity of the ECs (and thus continued achievement of the ROs), DEURs should be placed on Pima County parcel numbers 133-23-1570 and 133-23-110C. As of the finalization of this FS report, a DEUR was in process for parcel number 133-23-1570.

7.3 Achievement of Remedial Action Criteria Pursuant to A.R.S. 49-282.06

The More Aggressive Remedy for VOCs in Waste would achieve the remedial action criteria detailed in A.R.S. 49-282.06 by:

- Assuring the protection of public health and welfare of the environment by physical containment of hazardous materials to prevent contact with Site receptors, remediation of contributing sources to groundwater contamination in source areas, and cleanup of the groundwater plume exceeding AWQSs within a reasonably foreseeable time frame.

- Controlling and cleaning up contaminated groundwater to allow public and private users of groundwater downgradient of the Site to provide potable and non-potable water to their respective end users.
- Injecting groundwater treated by the P&T system back into the aquifer.
- Providing necessary groundwater plume clean up with a reasonable, cost effective and technically feasible remediation method.

The More Aggressive Remedy for Metals in Dross Material would achieve the remedial action criteria detailed in A.R.S. 49-282.06 by:

- Assuring the protection of public health and welfare of the environment by providing physical containment and source control of hazardous materials to prevent contact with Site receptors.
- Limiting the mobilization of metals present in the dross material to groundwater so that public and private production wells downgradient of the Site can provide potable water to their respective end users.
- Providing necessary containment of metals in dross material with a reasonable, cost-effective and technically feasible remedial strategy.
- Providing a potentially beneficial use of the land.

7.4 Consistency with Current and Future Land and Water Use

The current use of the LOU includes both non-residential and/or commercial properties but possible future uses allowed by the zoning include office, commercial recreation, commercial service, commercial general, residential (including single-family residences for BNL), research and development, and a golf course (Clear Creek, 2015a). A DEUR implemented as part of the remedy would control the type of development that can occur in the LOU but would not necessarily limit land use if ECs to prevent exposure to receptors of landfill waste and dross material are maintained. In the future, with a DEUR modification, the property owner could replace the asphalt cap with an appropriate development cap (i.e. buildings, parking lot).

The current use of the GOU is the TW CWF and is a water supply to several private commercial and residential entities. Treating the groundwater plume upgradient of most of these water supply wells is consistent with water management plans.

ICs for groundwater use would only apply to new, future users and would reduce the likelihood that new exempt groundwater wells (producing less than 35 gpm) are installed at the Site. This would help limit future groundwater use until the plume no longer poses a threat to water supplies. Entities planning to install new (not replacement) groundwater wells within a mile of the Site would be informed of the existence of the groundwater contamination when they apply to ADWR for the drilling permit. If an entity chooses to install a well after the ROD is finalized for this Site, the entity would be proceeding at their own risk.

8.0 COMMUNITY INVOLVEMENT

Community involvement requirements for remedy selection are identified in A.A.C. R18-16-404. For the Site, community involvement activities conducted to date have included:

- Public review and comment on the Site RI Reports prepared for the GOU and LOU (ROs reports are inclusive of these reports);
- Posting of the availability of the FS Work Plan for public review in April 2015; and
- Routine participation by ADEQ in Community Advisory Board (CAB) meetings (an overview of this FS was presented to the CAB in November 2016).

Although this FS report will not be provided to public for comment, a PRAP will be prepared for the proposed remedy (which will include estimated costs for the remedy) and will be issued for 90-day public comment after the FS Report is finalized. A public meeting will also be scheduled during the PRAP public comment period.

Remedy selection will be documented in a ROD, which is deemed a final administrative decision as defined by A.R.S. § 41-1092 for the Site. The ROD will contain a description of the remedy, a responsiveness summary regarding all comments received on the PRAP, a time for completing the remedy, a total estimated cost, and a time frame for review. This FS Report forms the basis for the selection of the remedy for the Site and will provide the information necessary to support the development of the ROD.

9.0 REFERENCES

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TABLES

Table 4-1
Screening of Remedial Measures for VOCs in Waste

Measure	Description	Effectiveness(1)	Implementability(1)	Health and Safety Considerations(1)	Flexibility/ Expandability(1)	Cost(1)	Retained	Comments
Institutional Controls	Restrictions on land use and future well installation; requirement for protection from landfilled waste for intrusive site work; requirement for maintenance of engineering controls.	Medium	High	Low	Medium	Low	✓	Does not remediate contamination but helps control contaminant exposure
Engineering Controls	Use of a separation barrier (i.e., soil cover) to minimize exposure to landfilled waste.	Medium	High	Low	High	Low	✓	Does not remediate contamination but helps control contaminant exposure
Inspections and Monitoring	Inspections/monitoring used to ensure institutional and/or engineering controls are maintained.	Low	High	Low	High	Low	✓	Does not remediate contamination but helps control contaminant exposure
Monitored Natural Attenuation (MNA)	Long term groundwater monitoring to demonstrate the attenuation of contamination.	Low	High	Low	High	Low	✓	Demonstrates the intrinsic remediation of contamination
Soil Vapor Extraction (SVE)	Use of vadose zone soil vapor extraction wells to remove VOCs from soil. Extracted vapors are treated with activated carbon.	High	Medium	Low	Medium	Medium	✓	Would remove a likely source of groundwater contamination at BSL.
In Situ Biological Reduction (ISBR)	Degradation of VOCs through reductive dechlorination by stimulating or augmenting microorganisms in the groundwater	Medium	Medium	Low	Medium	Medium	No	Aquifer is carbon-limited and aerobic which is not conducive to this process for a deep and dilute plume.
In Situ Thermal Treatment (ISTT)	Aquifer is heated to volatilize and mobilize VOCs. Extracted vapors and/or groundwater are treated by standard methods.	Medium	Low	High	Low	High	No	Primarily cost effective in source areas; can be cost prohibitive.
In Situ Chemical Oxidation (ISCO)	Injection of an oxidizing agent directly into the aquifer to degrade VOCs present in groundwater.	Medium	Medium	Medium	Medium	Medium	✓	Primarily cost effective in source areas.
In Situ Chemical Reduction (ISCR) with a Permeable Reactive Barrier (PRB)	Installation of a permeable wall comprised of zero valent iron in the aquifer, just downgradient of or within the groundwater plume to react with and degrade VOCs.	Medium	Low	Low	Low	High	No	Primarily effective as a flow through in situ treatment system in shallow aquifers; not cost effective for deep groundwater plumes.
Groundwater Pump and Treat (P&T)	Extraction of contaminated groundwater, treatment of VOCs at the surface and reinjection of treated water.	Medium	Medium	Low	Low	Medium	✓	Effective at removing contamination from the subsurface; can also provide containment of the plume.
Wellhead Treatment	Treatment of extracted production well water impacted by the site at the wellhead prior to distribution.	High	Medium	Low	Medium	Medium	✓	Effective at removing contamination from the subsurface; provides containment of the plume.
Provision of Replacement Water Supply	City of Tucson potable water provided to replace water supply impacted by the site.	High	Medium	Low	High	Medium	✓	Does not remediate contamination but helps control contaminant exposure

Notes (only acronyms that are not defined in the table are listed below):
BSL = Broadway South Landfill
RO = remedial objectives
VOC(s) = volatile organic compound(s)
WQARF = Water Quality Assurance Revolving Fund
(1) See description of this criterion in Section 4.4 (Screening of Remedial Measures) of the report

Table 6-1
Comparison of Remedial Alternatives for VOCs in Waste

Remedial Alternative	Remedial Measures	Incorporated Remedial Strategies per A.A.C. R18-16-407(F)	Remedial Strategy	Description of Alternative	Practicability[(1)]	Risk[(2)]	Cost[(3)]						Benefit[(4)]
							Type	GWTS	SVE	ISCO	Total (Without Inflation)	Total (3% Inflation)	
Reference Remedy *MNA, SVE, and ISCO with Contingencies for Impacted Water Supply Wells*	• ECs • ICs • MNA • Inspections/ Environmental Sampling • SVE • ISCO • Wellhead Treatment (Contingency) • Provision of Replacement Water Supply (Contingency)	1,2,4,5	• Plume Remediation • Physical Containment • Source Control • Monitoring	• ECs (landfill cover, development caps and perimeter fencing) would be maintained/installed where absent. • ICs would control development and maintain ECs. • BNL and BSL PCE plumes are allowed to disperse and attenuate under natural hydraulic gradients with assumed water supply well pumping. • MNA would include routine groundwater well network monitoring throughout for the scenario duration (100 years) to evaluate changes that may occur and ongoing natural attenuation. • SVE would be implemented at BSL (1 year of operation). • ISCO would be implemented at BNL (7 years of operation). • Wellhead treatment or provision of a replacement water supply would be implemented should drinking water supply wells be affected. Based on groundwater modeling, the following wells (and years of estimated impact) would receive wellhead treatment: 411-P (2023-2061) and C-051B (2096-2115). CVA (2099-2115) and Swain (2095-2108) would be provided with water from TW.	• Moderately feasible • Moderately implementable • Potentially effective • Not cleaned up in 100 years	• Highly impacted by changing conditions • Some potential risk to safety, cross-media contamination and exposure to residual contamination	Capital:	$1.249M	$0.34M	$0.745M	---	---	• Protects water supply • ISCO decreases uncertainty associated with how long retained mass will impact groundwater at BNL
							O&M:	$6.195M	$0.2M	$1.232M	---	---	
							O&M Annualized:	$0.06M	$0.2M	$0.18M	---	---	
							Lifecycle:	$9.91M	$1.718M	$0.13M	---	---	
							Lifecycle Annualized:	$99K	$89K	$0.02M	---	---	
							Total:	$17.35M	$2.26M	$2.11M	**$21.7M**	**$126.4M**	
Less Aggressive Remedy *MNA and SVE with Contingencies for Impacted Water Supply Wells*	• ECs • ICs • MNA • Inspections/ Environmental Sampling • SVE • Wellhead Treatment (Contingency) • Provision of Replacement Water Supply (Contingency)	1,2,4,5	• Plume Remediation • Physical Containment • Source Control • Monitoring	• ECs (landfill cover, development caps and perimeter fencing) would be maintained/installed where absent. • ICs would control development and maintain ECs. • BNL and BSL PCE plumes are allowed to disperse and attenuate under natural hydraulic gradients with assumed water supply well pumping. • MNA would include routine groundwater well network monitoring throughout for the scenario duration (100 years) to evaluate changes that may occur and ongoing natural attenuation. • SVE would be implemented at BSL (1 year of operation). • Wellhead treatment or provision of a replacement water supply would be implemented should drinking water supply wells be affected. Based on groundwater modeling, the following wells (and years of estimated impact) would receive wellhead treatment: 411-P (2024-2068) and C-051B (2096-2115), and C-058B(2085-2115). CVA (2098-2115), Mayo (2098-2115), and Swain (2094-2108) would be provided with water from TW.	• Moderately feasible • Moderately implementable • Potentially effective • Not cleaned up in 100 years	• Highly impacted by changing conditions • Some potential risk to safety, cross-media contamination and exposure to residual contamination	Capital:	$1.669M	$0.34M	---	---	---	• Protects water supply
							O&M:	$10.355M	$0.2M	---	---	---	
							O&M Annualized:	$0.10M	$0.2M	---	---	---	
							Lifecycle:	$9.94M	$1.718M	---	---	---	
							Lifecycle Annualized:	$99K	$89K	---	---	---	
							Total:	$21.96M	$2.26M	---	**$24.2M**	**$178.6M**	

Table 6-1
Comparison of Remedial Alternatives for VOCs in Waste

Remedial Alternative	Remedial Measures	Incorporated Remedial Strategies per A.A.C. R18-16-407(F)	Remedial Strategy	Description of Alternative	Practicability[(1)]	Risk[(2)]	Cost[(3)] Type	GWTS	SVE	ISCO	Total (Without Inflation)	Total (3% Inflation)	Benefit[(4)]
More Aggressive Remedy *Accelerated P&T, MNA, SVE, and ISCO with Contingencies for Impacted Water Supply Wells*	• ECs • ICs • P&T • MNA • Inspections/ Environmental Sampling • SVE • ISCO • Wellhead Treatment (Contingency)	1,2,3,4,5	• Plume Remediation • Physical Containment • Controlled Migration • Source Control • Monitoring	• ECs (landfill cover, development caps and perimeter fencing) would be maintained/installed where absent. • ICs would control development and maintain ECs. • Accelerated P&T includes pumping from new extraction well C-022A-R at 225 gpm (2016-2044), new extraction well EX-02 at 100 gpm (2016-2030), and existing WCS well R092A at 400 gpm (2035-2044). The pumped water would be conveyed to (via new transmission lines) and treated at the WCS and injected into existing WCS injection well R090A. • Two plumes bifurcated by previous and planned extraction (the northwest plume and the downgradient BSL plume, respectively) would be allowed to naturally attenuate. • SVE would be implemented at BSL (1 year of operation). • ISCO would be implemented at BNL (7 years of operation). • Wellhead treatment would be implemented should drinking water supply wells be affected. Based on groundwater modeling, the only well (and years of estimated impact) that would receive wellhead treatment is 411-P (2027-2035).	• Moderately feasible • Least implementable • Likely effective • Cleaned up in 29 years	• Likely impacted by changing conditions • Some potential risk to safety, cross-media contamination and exposure to residual contamination	Capital:	$4.142M	$0.34M	$0.745M	---	---	• Protects water supply • ISCO decreases uncertainty associated with how long retained mass will impact groundwater at BNL • Returns aquifer to usable resource in shortest period of time
							O&M:	$5.707M	$0.2M	$1.232M	---	---	
							O&M Annualized:	$0.20M	$0.2M	$0.18M	---	---	
							Lifecycle:	$4.896M	$1.718M	$0.13M	---	---	
							Lifecycle Annualized:	$0.17M	$89K	$0.02M	---	---	
							Total:	$14.75M	$2.26M	$2.11M	**$19.1M**	**$27.4M**	

Notes:

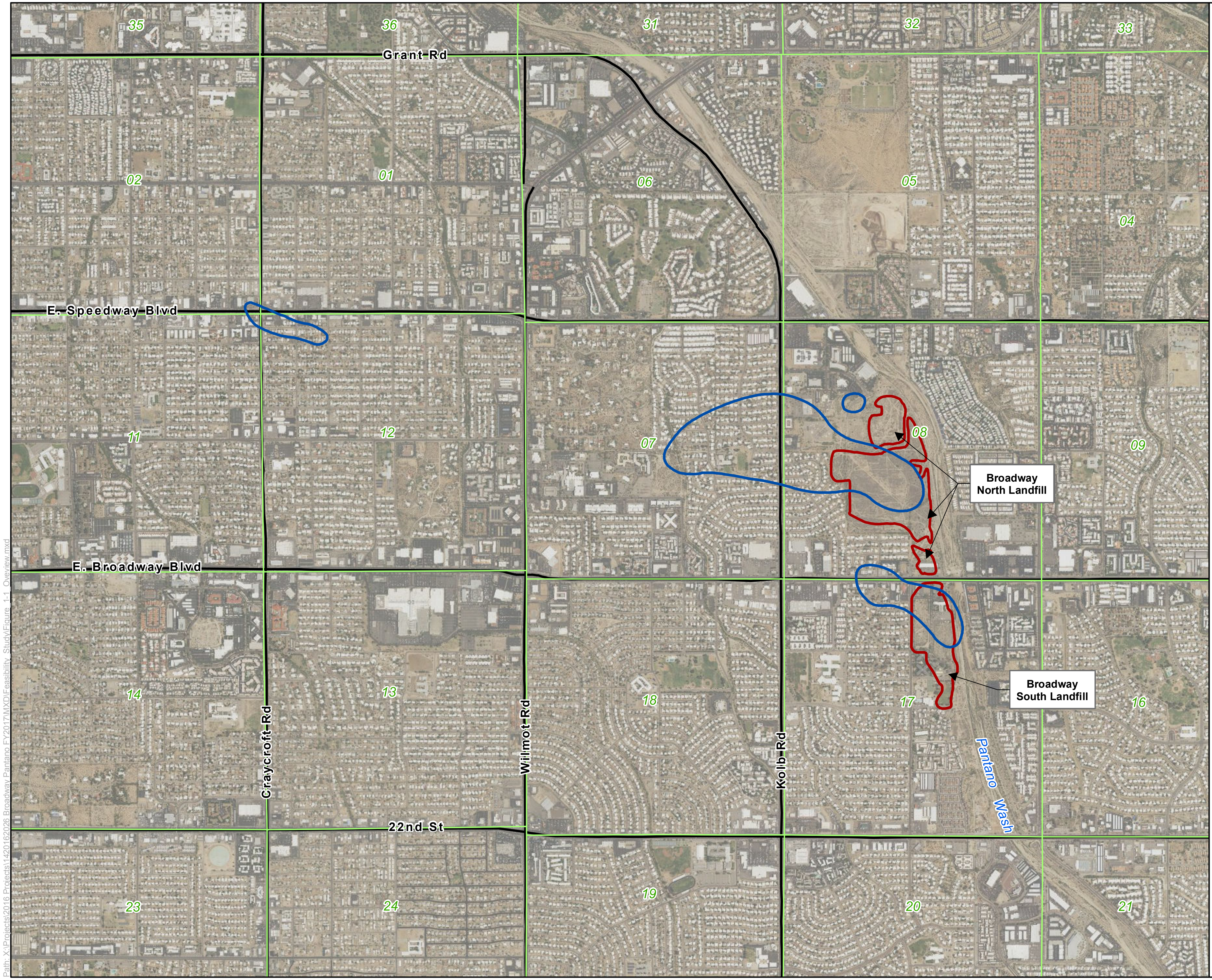
A.C.C.: Arizona Administrative Code
BNL: Broadway North Landfill
BSL: Broadway South Landfill
ECs: engineering controls
ICs: institutional controls
gpm: gallons per minute
GWTS: groundwater treatment system (includes costs for wellhead treatment, provision of an alternative water supply, and P&T, as applicable)
ISCO: in-situ chemical oxidation
K: thousand
M: million
MNA: monitored natural attenuation
O&M: operations and maintenance
P&T: pump-and-treat system
PCE: tetrachloroethylene
SVE: soil vapor extraction
TW: Tucson Water
WCS: Western Containment System

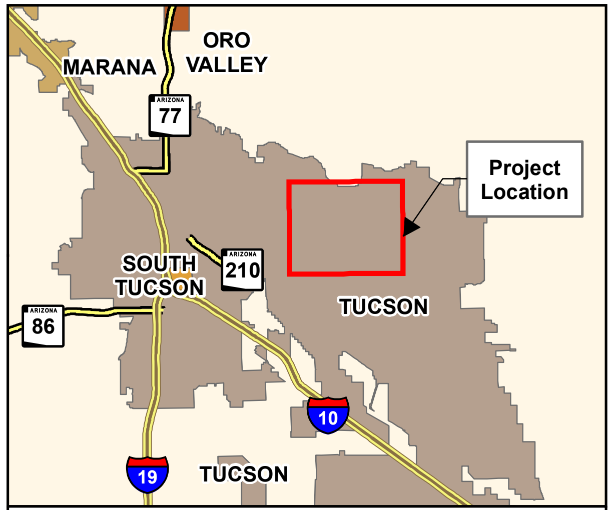
(1) Practicability: feasibility, short-term effectiveness, long-term effectiveness, reliability
(2) Risk: Overall protection of human health and environment
(3) Cost: Per Arizona Department of Environmental Quality direction, this criterion only includes capital costs for the dross material feasibility study evaluation
(4) Benefit: e.g. Lowered risk to human health and environment, reduction in COC concentration and/or volume, decreased liability, public acceptance, aesthetics, preservation of existing uses, enhancement of future uses, and improvement to local economy

Remedial Strategies per A.A.C. R18-16-407(F):

1. Plume remediation is a strategy to achieve water quality standards for contaminants of concern in waters of the state throughout the site.
2. Physical containment is a strategy to contain contaminants within definite boundaries.
3. Controlled migration is a strategy to control the direction or rate of migration but not necessarily to contain migration of contaminants.
4. Source control is a strategy to eliminate or mitigate a continuing source of contamination.
5. Monitoring is a strategy to observe and evaluate the contamination at the site through the collection of data.
6. No action is a strategy that consists of no action at a site.

FIGURES





Area of Detail

Legend

- Approximate Extent of Groundwater Operable Unit Based on 2016 Data
- Approximate Extent of Landfill Operable Unit
- 12 Section and Number

Notes:
LOU Extent from Clear Creek Associates, 2015
Aerial Imagery: National Agriculture Imagery Program (NAIP), 2015

0 1,000 2,000 4,000
Feet
N

Feasibility Study
Broadway Pantano WQARF Site
Tucson, Arizona

Site Location Map

FIGURE
1-1

Job No.:	14-2016-2026
PM:	NC
Date:	5/18/2017
Scale:	1" = 2000'

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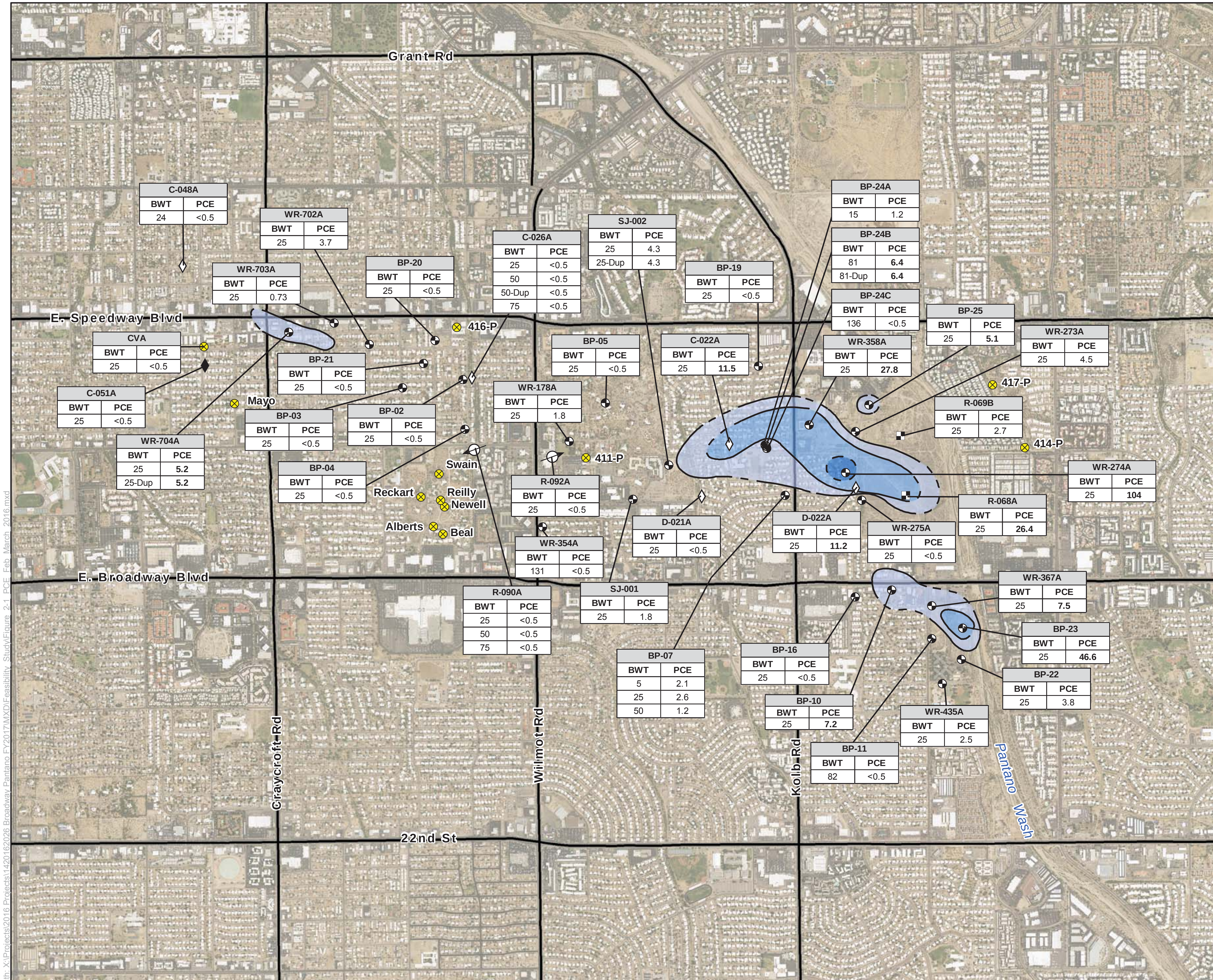

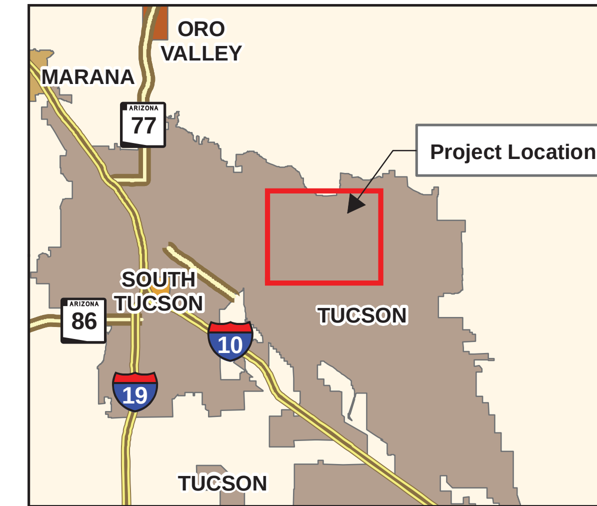

Area of Detail

Legend

Key to Well Symbology

- Active Monitoring Well
- Active Production Well
- Inactive Production Well
- Air Injection/Monitoring Well
- Western Containment Injection Well
- Western Containment Extraction Well
- Private Well

PCE Concentration (Dashed Where Inferred)

- 5µg/L
- 10µg/L
- 100µg/L

Results that are **BOLD** are equal to or exceed the AWQS of 5 µg/L limit.

Notes:

WR-274A	Well Identification
BWT	Below water table
PCE	Tetrachloroethene - Sampling Interval: 2/15/2016 - 3/1/2016
µg/L	Micrograms per liter
AWQS	Arizona Aquifer Water Quality Standards
Aerial Imagery:	National Agriculture Imagery Program (NAIP), 2015

0 1,000 2,000 4,000 Feet

N

Feasibility Study
Broadway Pantano WQARF Site
Tucson, Arizona

Estimated Extent of Groundwater PCE Plume, February-March 2016

FIGURE **2-1**

Job No.:	14-2016-2026
PM:	NC
Date:	6/27/2017
Scale:	1" = 2000'

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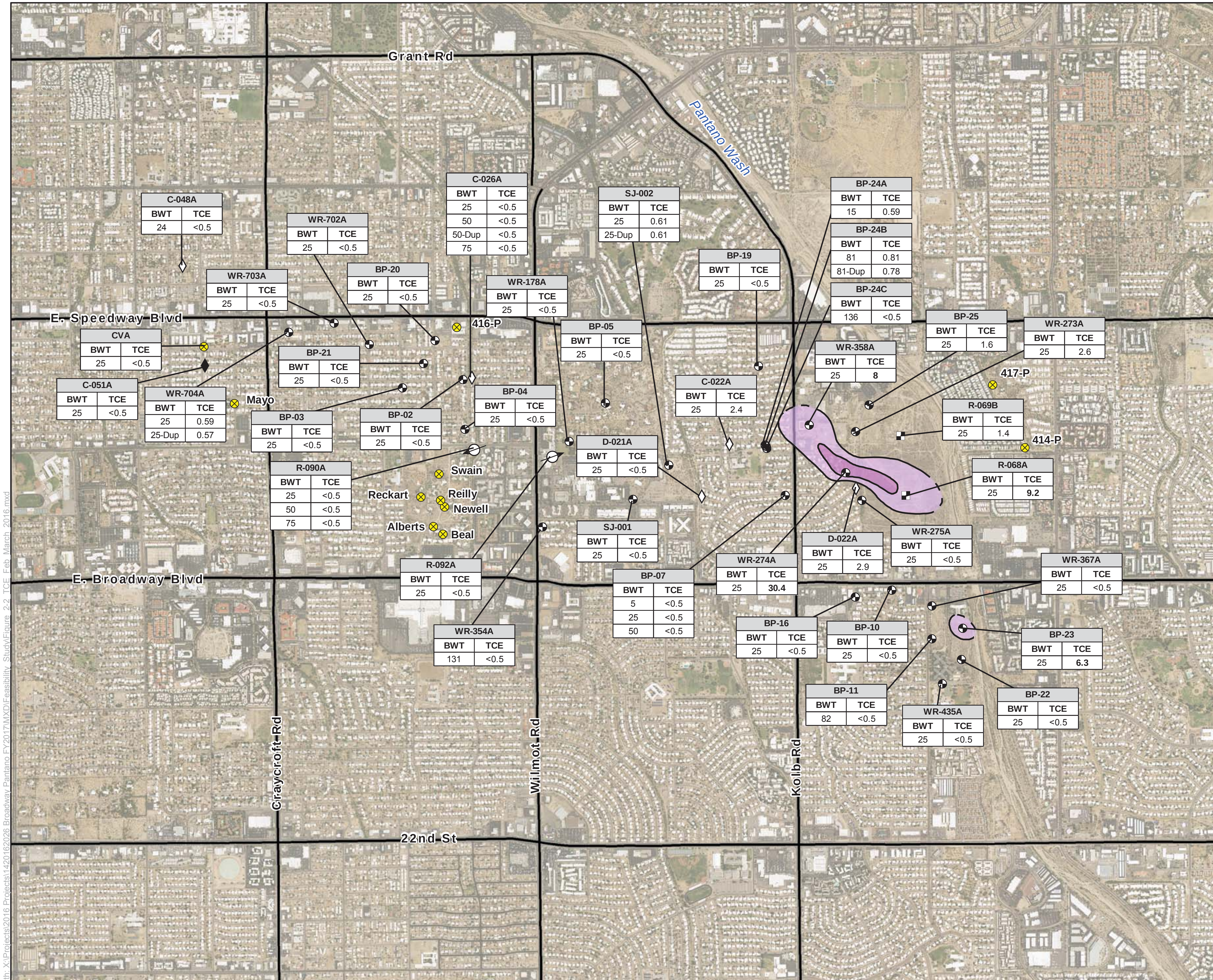

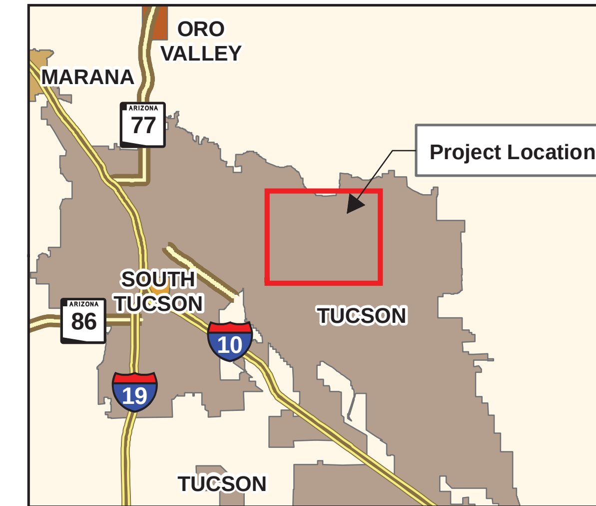

Area of Detail

Legend

Key to Well Symbology

- Active Monitoring Well
- Active Production Well
- Inactive Production Well
- Air Injection/Monitoring Well
- Western Containment Injection Well
- Western Containment Extraction Well
- Private Well

TCE Concentration (Dashed Where Inferred)

- 5µg/L
- 10µg/L

Results that are **BOLD** are equal to or exceed the AWQS of 5 µg/L limit.

Notes:

WR-274A	Well Identification
BWT	Below water table
TCE	Trichloroethene - Sampling Interval: 2/15/2016 - 3/1/2016
µg/L	Micrograms per liter
AWQS	Arizona Aquifer Water Quality Standards
Aerial Imagery:	National Agriculture Imagery Program (NAIP), 2015

0 1,000 2,000 4,000 Feet

N

Feasibility Study
Broadway Pantano WQARF Site
Tucson, Arizona

Estimated Extent of Groundwater TCE Plume, February-March 2016

FIGURE **2-2**

Job No.:	14-2016-2026
PM:	NC
Date:	6/27/2017
Scale:	1" = 2000'

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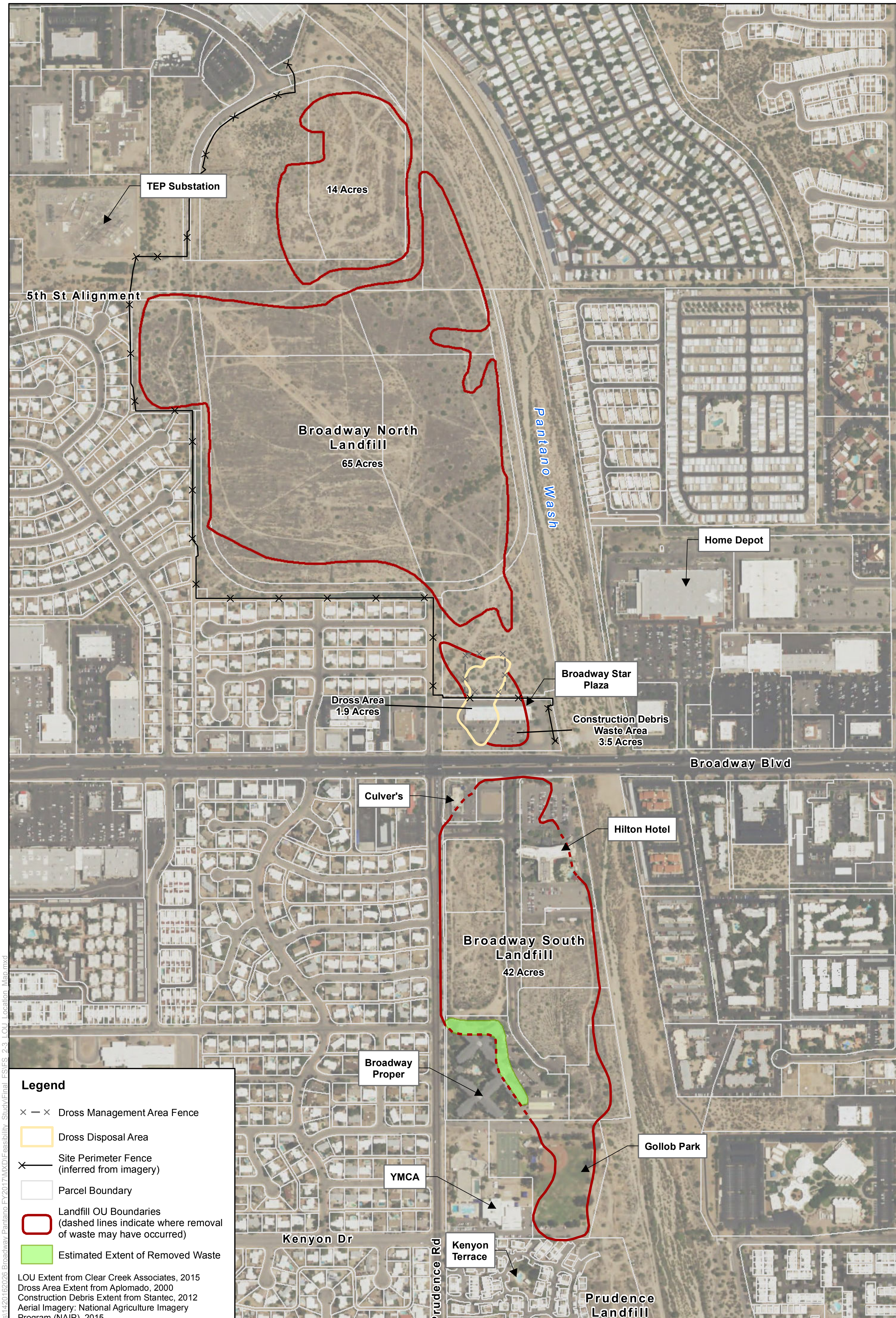

0 250 500 1,000 Feet

Job No.: 14-2016-2026
PM: NC
Date: 6/5/2017
Scale: 1" =500'

N

The map shown here has been created with all due and reasonable care and is strictly for use with Amec Foster Wheeler Project Number 14-2016-2026. This map has not been certified by a licensed land surveyor, and any third party use of this map comes without warranties of any kind. Amec Foster Wheeler assumes no liability, direct or indirect, whatsoever for any such third party or unintended use.

Feasibility Study
Broadway Pantano WQARF Site
Tucson, Arizona

Landfill Operable Unit Location Map

FIGURE
2-3

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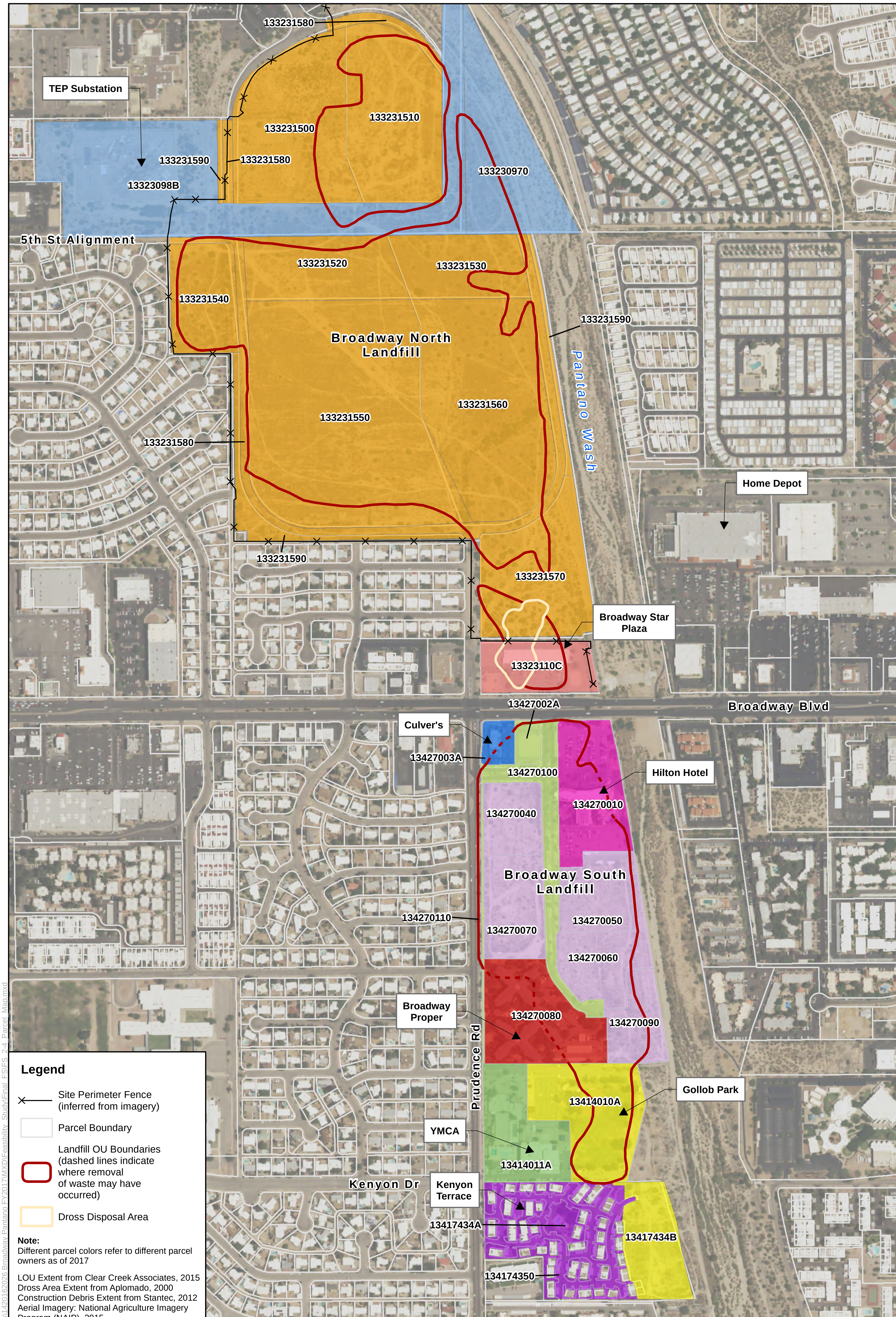

0 250 500 1,000 Feet

Feasibility Study
Broadway Pantano WQARF Site
Tucson, Arizona

Job No.: 14-2016-2026
PM: NC
Date: 6/16/2017
Scale: 1" =500'

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Landfill Parcel Map

FIGURE
2-4

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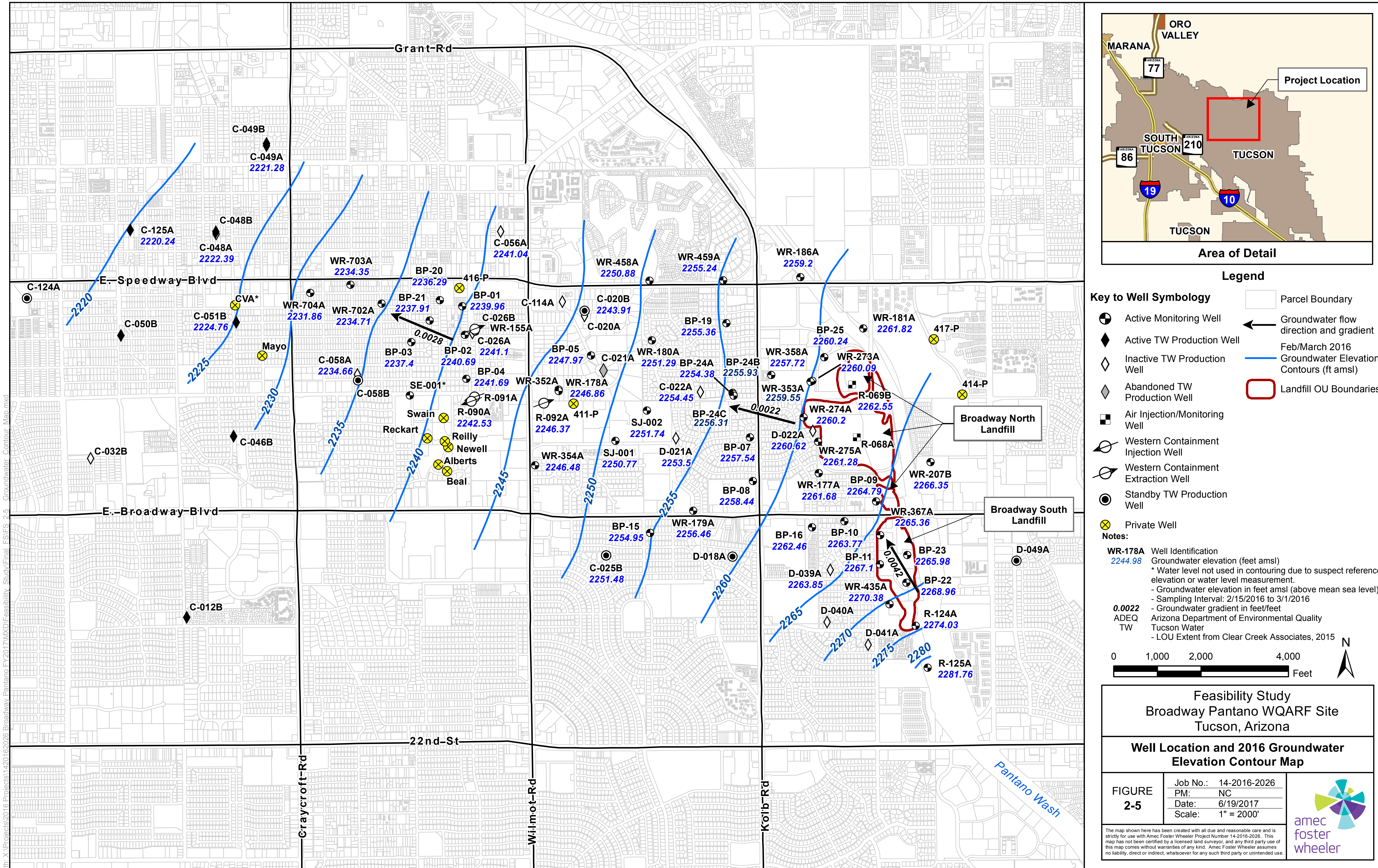
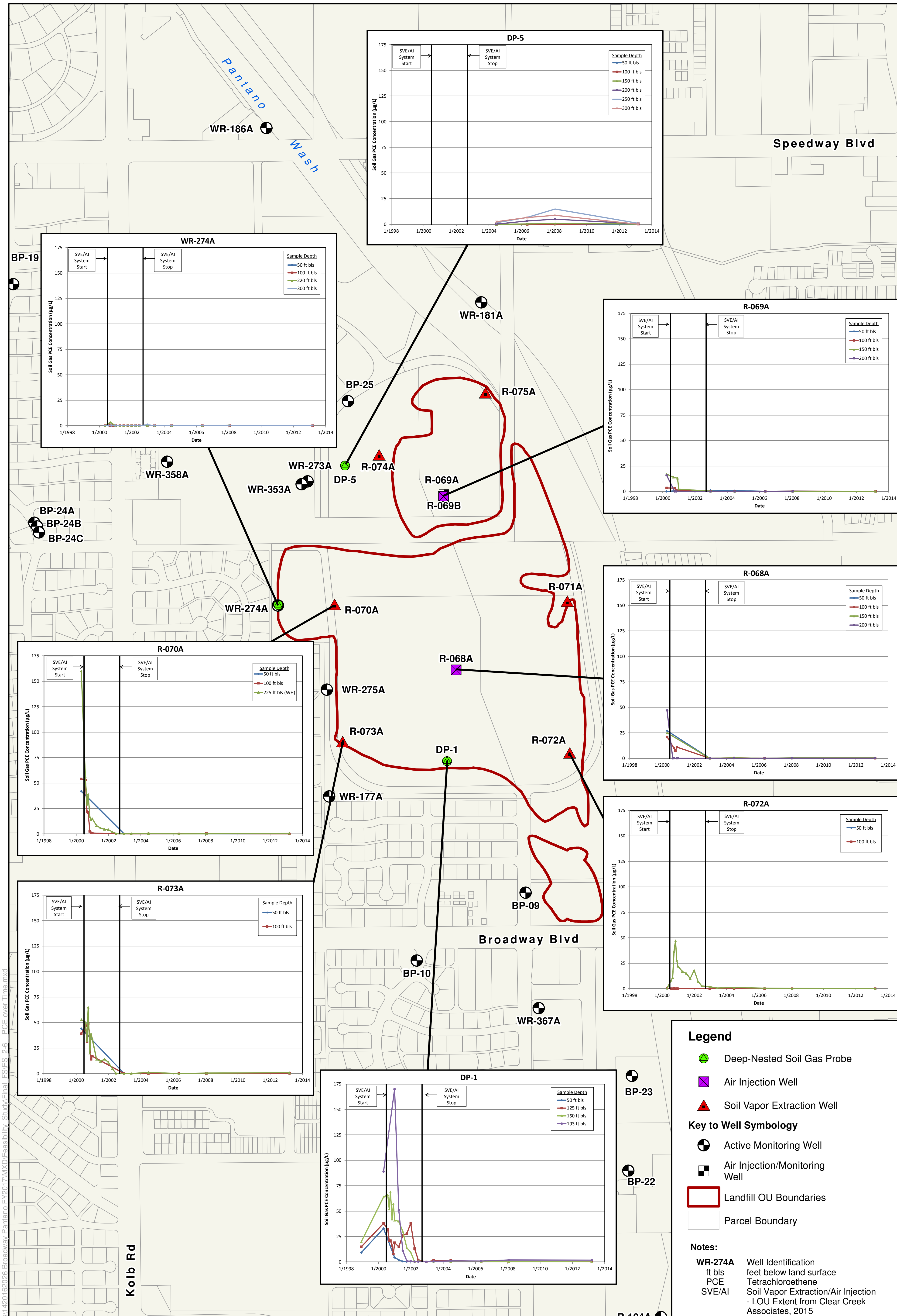


Grant Rd
E. Speedway Blvd
E. Broadway Blvd
22nd St
Craycroft Rd
Wilmot Rd
Kolb Rd
Pantano Wash
Broadway North Landfill
Broadway South Landfill
2220
2225
2230
2235
2240
2245
2250
2255
2260
2265
2270
2275
2280
0.0028
0.0022
0.0042
ORO VALLEY
MARANA
SOUTH TUCSON
TUCSON
Project Location
Area of Detail
Legend
Key to Well Symbology
Active Monitoring Well
Active TW Production Well
Inactive TW Production Well
Abandoned TW Production Well
Air Injection/Monitoring Well
Western Containment Injection Well
Western Containment Extraction Well
Standby TW Production Well
Private Well
Parcel Boundary
Groundwater flow direction and gradient
Feb/March 2016 Groundwater Elevation Contours (ft amsl)
Landfill OU Boundaries
Notes:
WR-178A Well Identification
2244.98 Groundwater elevation (feet amsl)
* Water level not used in contouring due to suspect reference elevation or water level measurement.
- Groundwater elevation in feet amsl (above mean sea level)
- Sampling Interval: 2/15/2016 to 3/1/2016
0.0022 - Groundwater gradient in feet/feet
ADEQ Arizona Department of Environmental Quality
TW Tucson Water
- LOU Extent from Clear Creek Associates, 2015
0 1,000 2,000 4,000
Feet
N
Feasibility Study
Broadway Pantano WQARF Site
Tucson, Arizona
Well Location and 2016 Groundwater Elevation Contour Map
FIGURE 2-5
Job No.: 14-2016-2026
PM: NC
Date: 6/19/2017
Scale: 1" = 2000'
amec foster wheeler



Legend

- Deep-Nested Soil Gas Probe
- Air Injection Well
- Soil Vapor Extraction Well

Key to Well Symbology

- Active Monitoring Well
- Air Injection/Monitoring Well
- Landfill OU Boundaries
- Parcel Boundary

Notes:

WR-274A	Well Identification
ft bls	feet below land surface
PCE	Tetrachloroethene
SVE/AI	Soil Vapor Extraction/Air Injection
	- LOU Extent from Clear Creek Associates, 2015
µg/L	Micrograms per liter

0 300 600 1,200
Feet

N

Job No.: 14-2016-2026
PM: NC
Date: 5/19/2017
Scale: 1" = 600'

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Feasibility Study
Broadway Pantano WQARF Site
Tucson, Arizona

PCE Concentrations Over Time in Deep Soil Gas at Broadway North Landfill

FIGURE **2-6**

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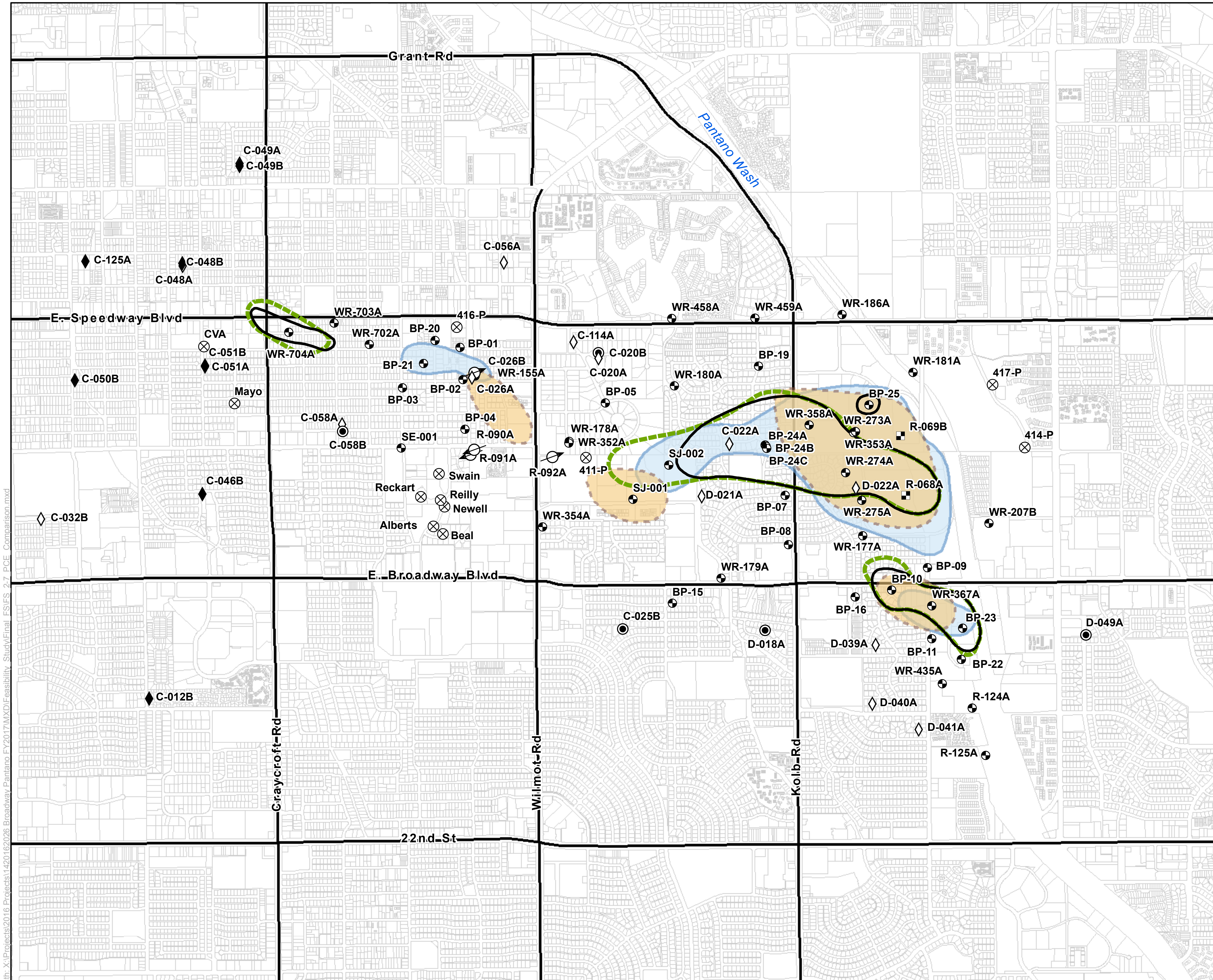

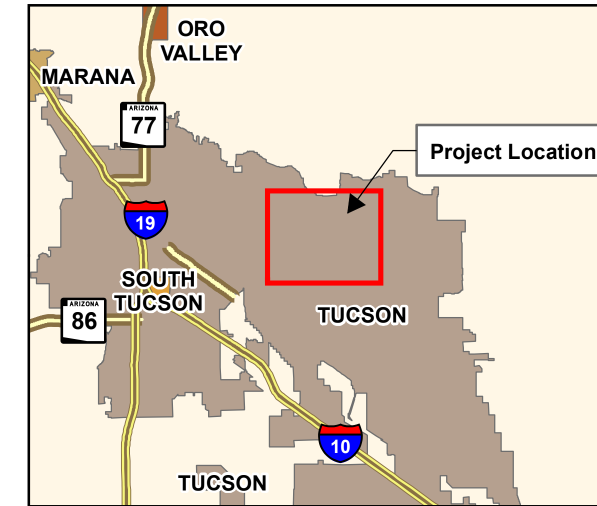

Area of Detail

Legend

Key to Well Symbology

- Active Monitoring Well
- Active Production Well
- Inactive Production Well
- Air Injection/Monitoring Well
- Western Containment System* Injection Well
- Western Containment System* Extraction Well
- Standby Well
- Private Well

Parcel Boundary

February-March 2016 PCE Concentration
5µg/L

February-March 2015 PCE Concentration
5µg/L

April 2007 PCE Concentration
5µg/L

March 2003 PCE Concentration**
5µg/L

Notes:

WR-274A	Well Identification
PCE	Tetrachloroethene
µg/L	Micrograms per liter

*The Western Containment System operated from March 2003 to October 2012

**As of 2003, monitoring wells BP-20, BP-21, WR-702A, WR-703A, and WR-704A had not been installed; the extent of the plume downgradient of BP-2 was unknown.

0 1,000 2,000 4,000 Feet

N

Feasibility Study
Broadway Pantano WQARF Site
Tucson, Arizona

Estimated Extent of the Groundwater PCE Plume from 2003 to 2016

FIGURE **2-7**

Job No.:	14-2016-2026
PM:	NC
Date:	5/18/2017
Scale:	1" = 2000'

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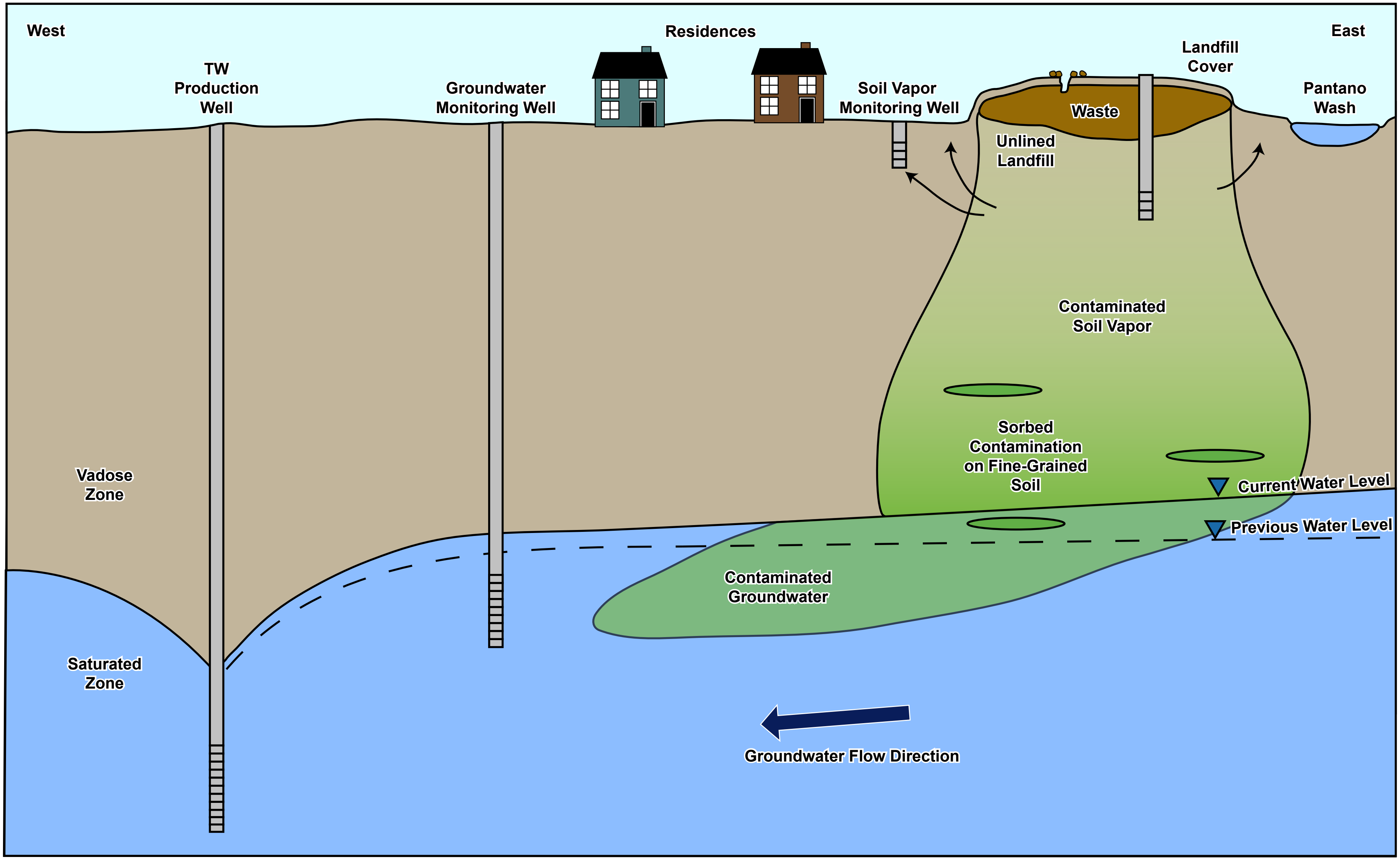


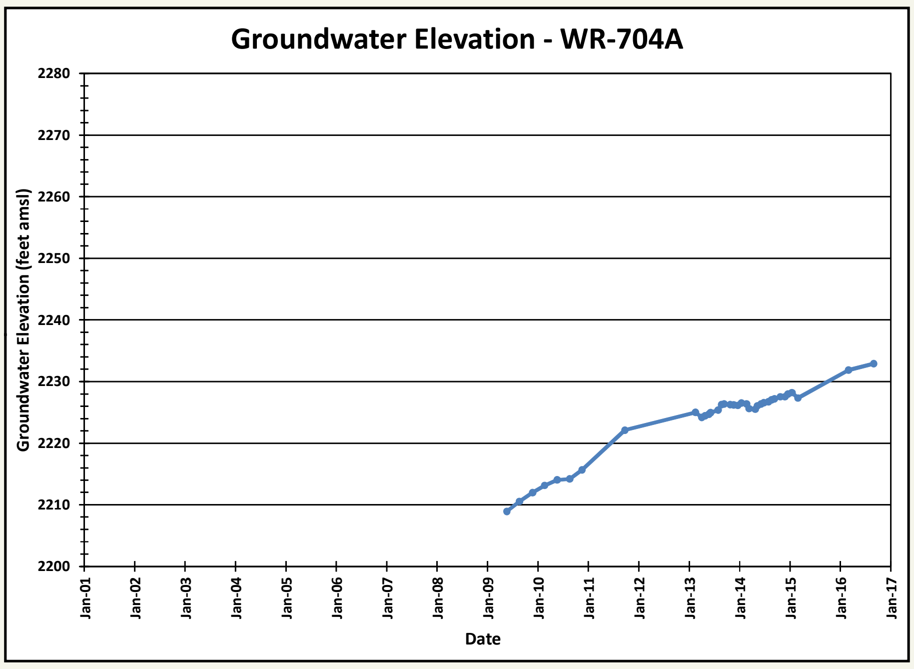
Note: Generalized depiction; not to scale

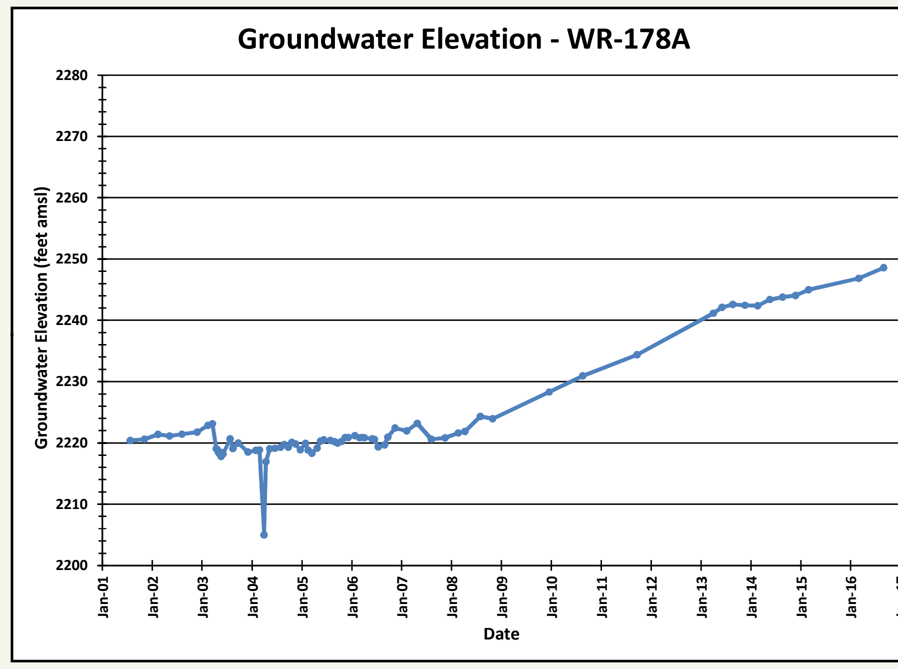
Job No.:	1420142029
PM:	NC
Date:	12/8/2016
Scale:	Not to scale

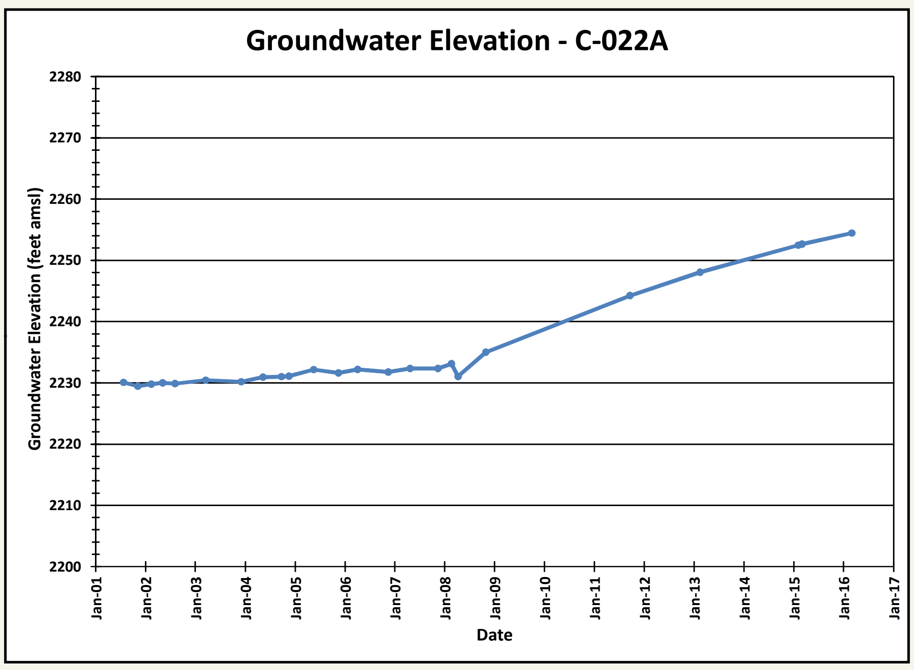
Feasibility Study
Broadway Pantano WQARF Site
Tucson, Arizona

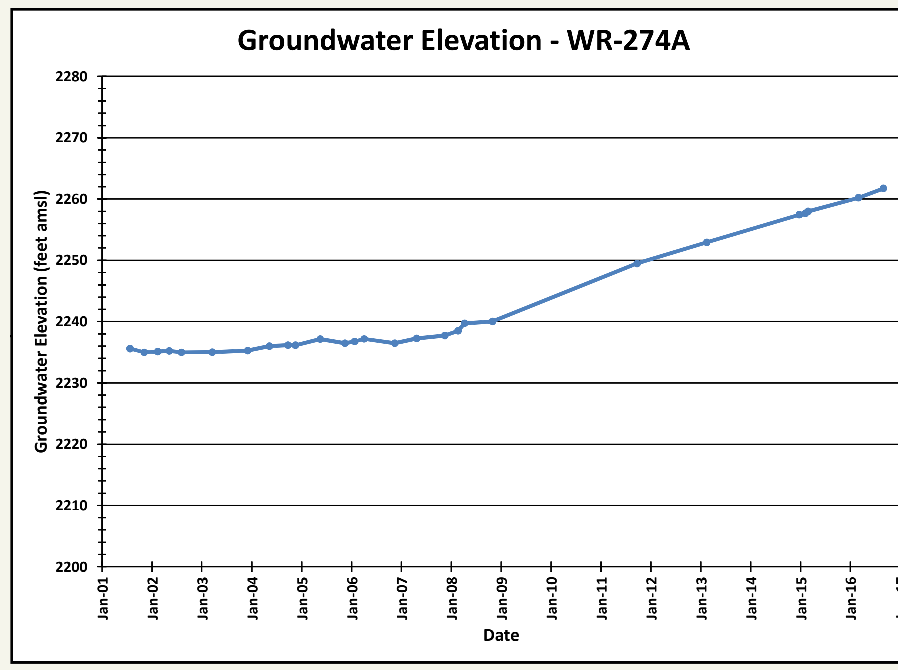
Figure 2-8
Conceptual Site Model

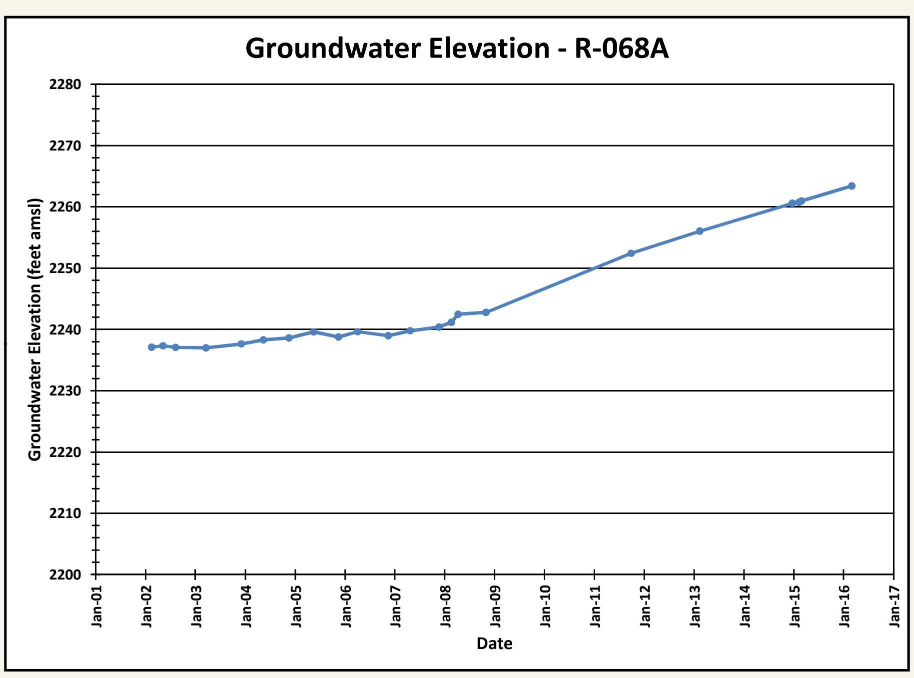
amec
foster
wheeler

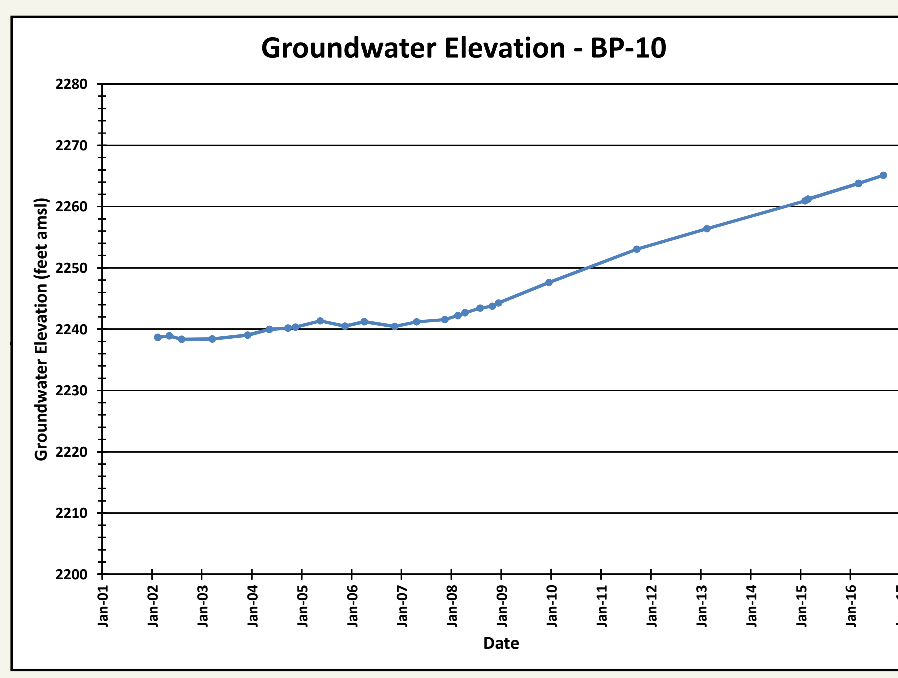


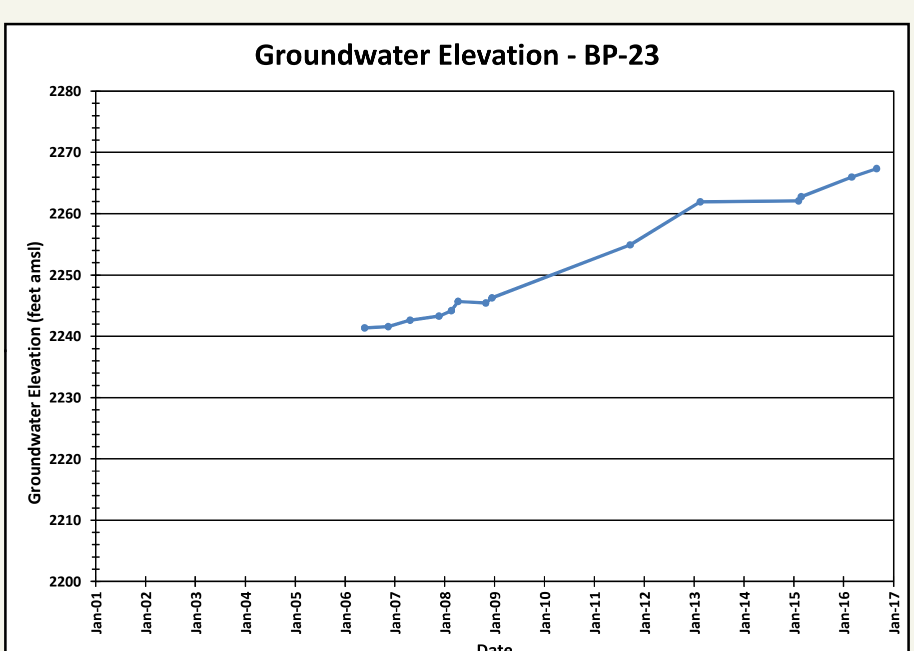


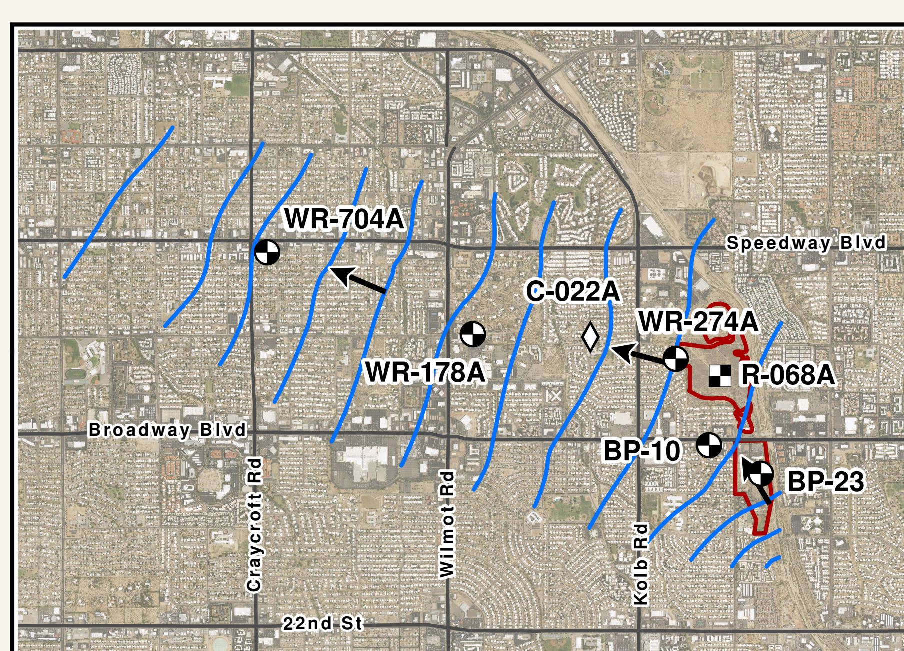












Notes:
amsl - above mean sea level

Job No.:	14-2016-2026
PM:	NC
Date:	5/19/2017
Scale:	NA

N

Feasibility Study
Broadway Pantano WQARF Site
Tucson, Arizona

Groundwater Hydrographs for Select Wells

FIGURE
2-9

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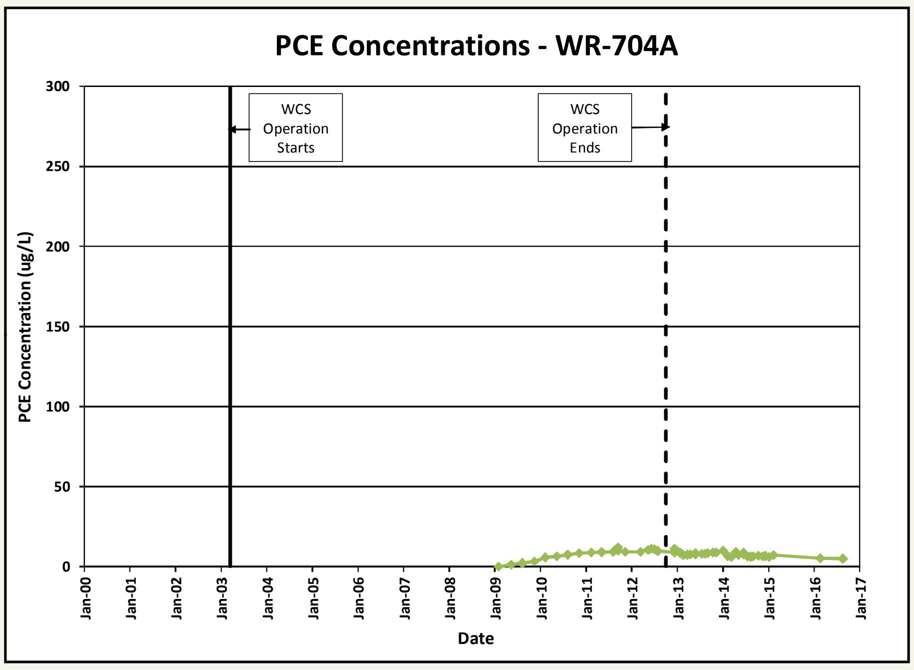

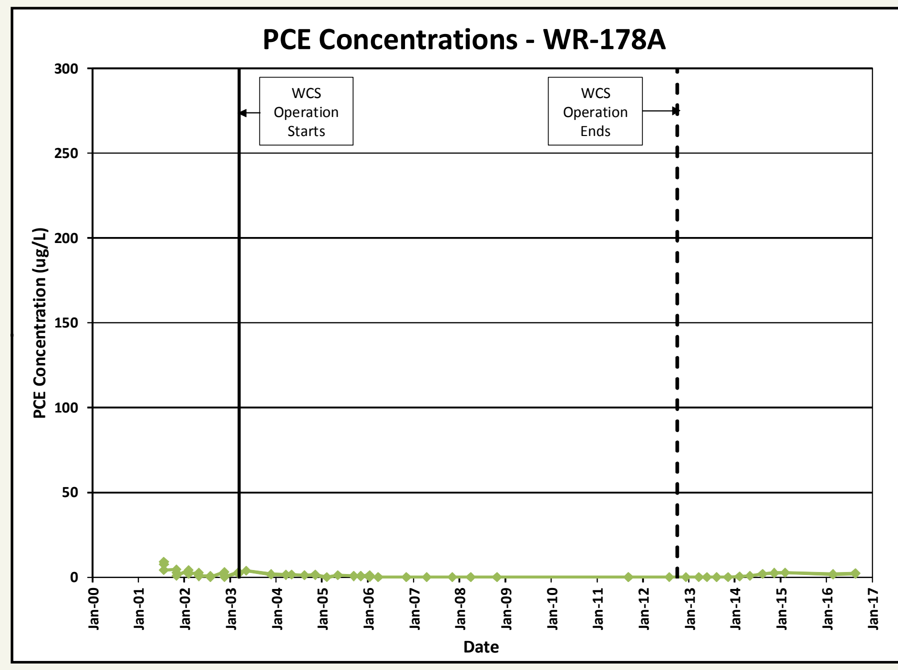

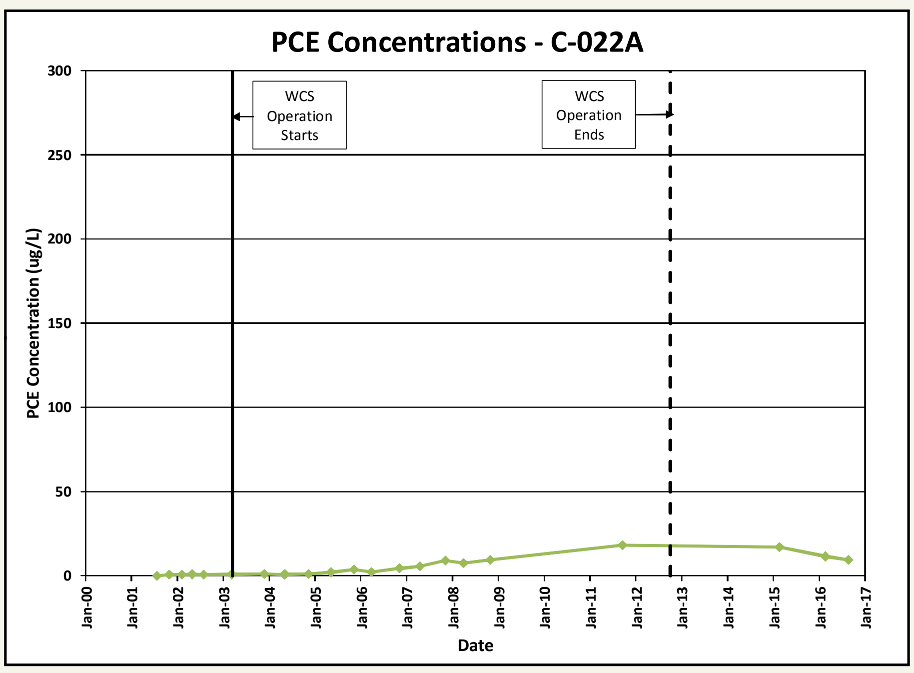

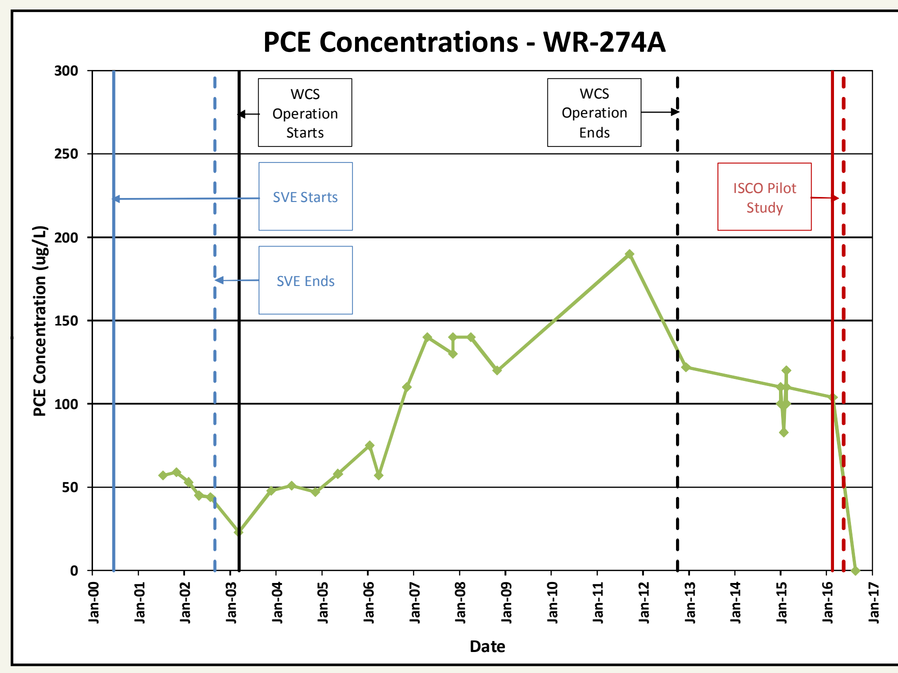

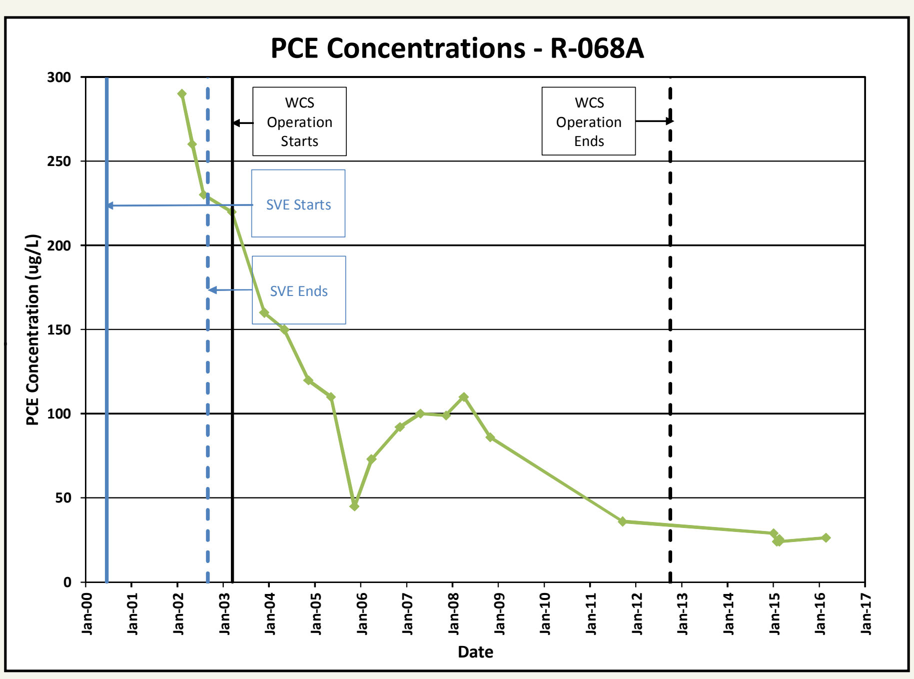

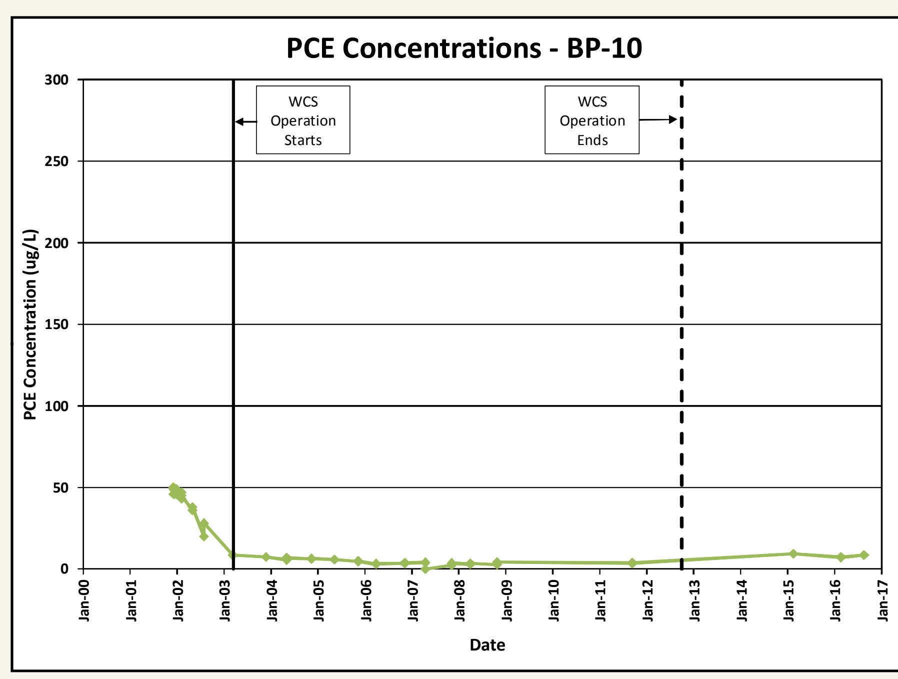

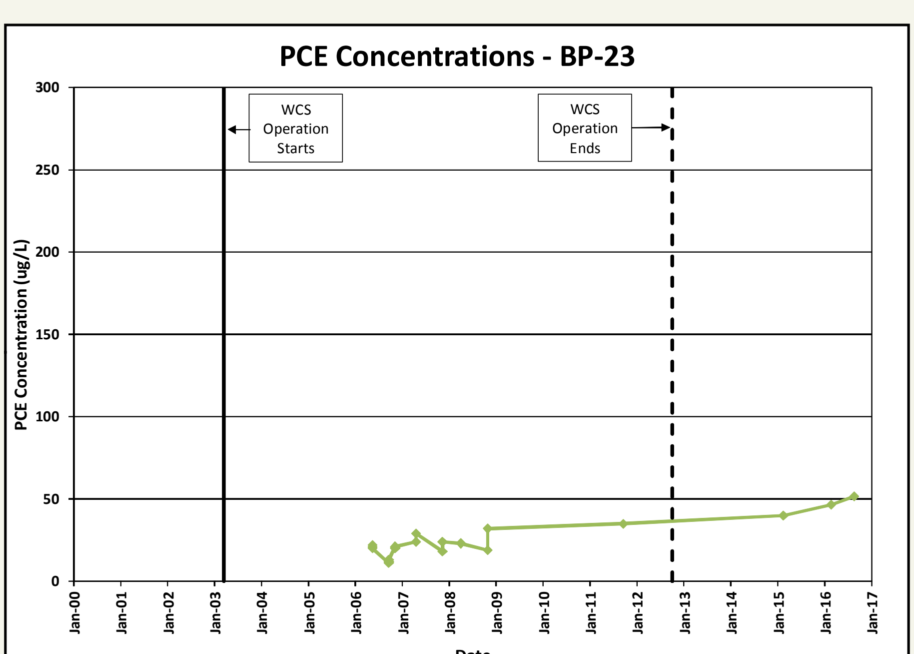

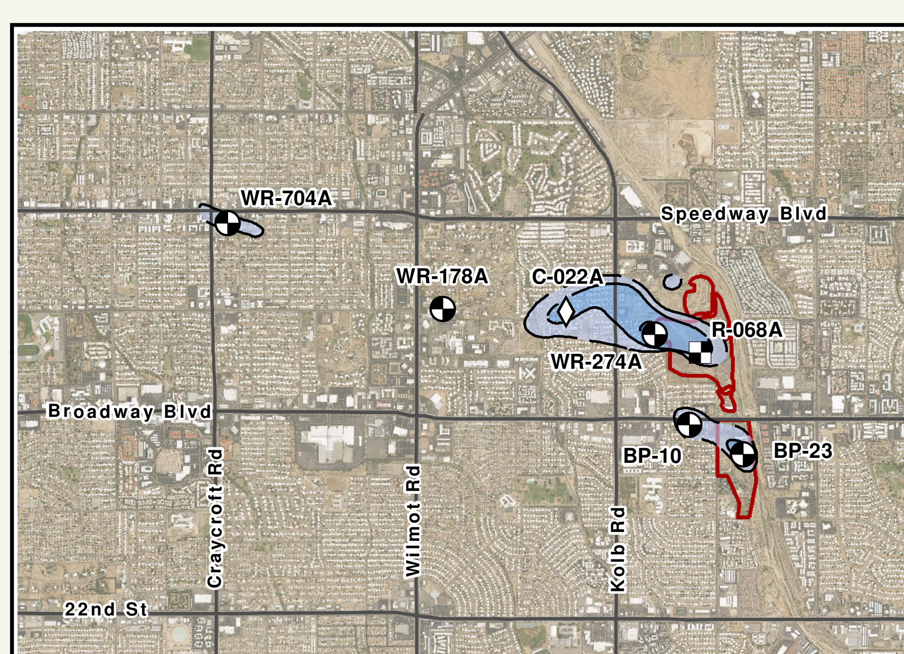

Notes:

BNL - Broadway North Landfill
ISCO - In Situ Chemical Oxidation
µg/L - micrograms per liter

PCE - Tetrachloroethene
SVE - Soil Vapor Extraction
WCS - Western Containment System

BNL SVE Operations: 6/26/2000-9/10/2002
WCS Operations: 3/24/2003-10/12/2012
BNL ISCO Pilot Study: 2/29/2016-5/27/2016

Job No.:	14-2016-2026
PM:	NC
Date:	6/16/2017
Scale:	NA

N

Feasibility Study
Broadway Pantano WQARF Site
Tucson, Arizona

PCE Concentration Trends at Select Wells

FIGURE
2-10

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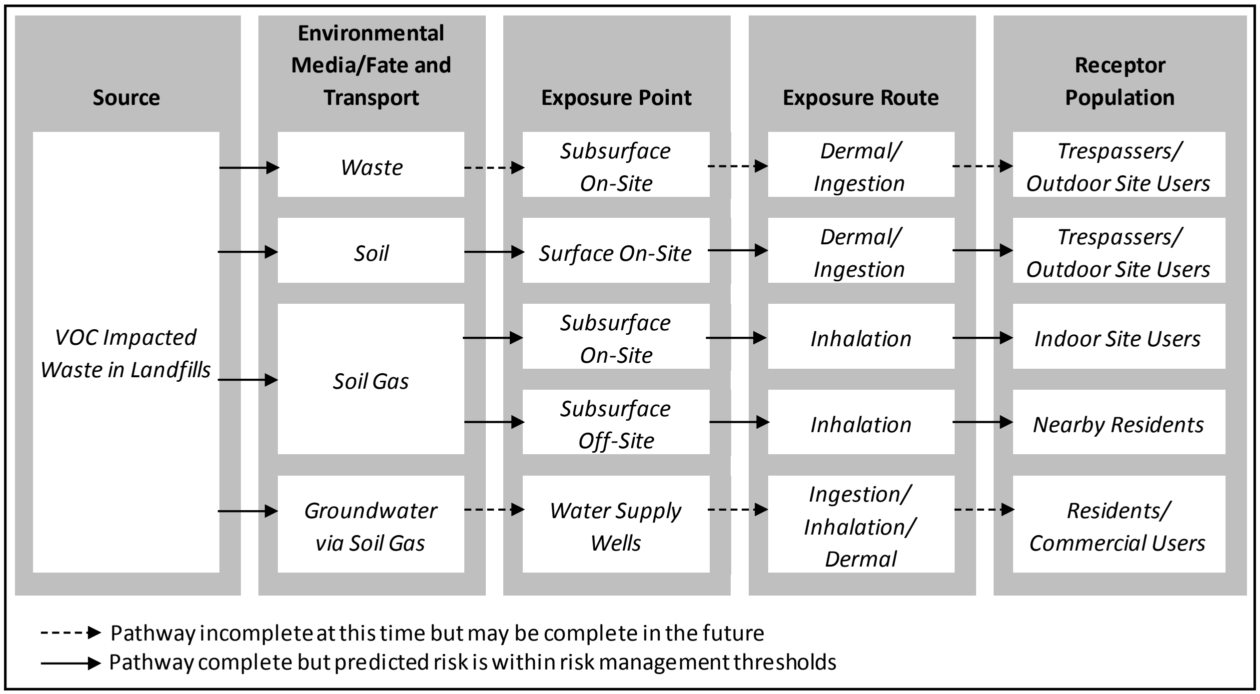
Volatile Organic Compounds in Landfill Waste



Job No.:	14-2016-2026
PM:	NC
Date:	6/12/2017
Scale:	NA

N

Feasibility Study
Broadway Pantano WQARF Site
Tucson, Arizona

Exposure Pathway Summary

FIGURE
2-11

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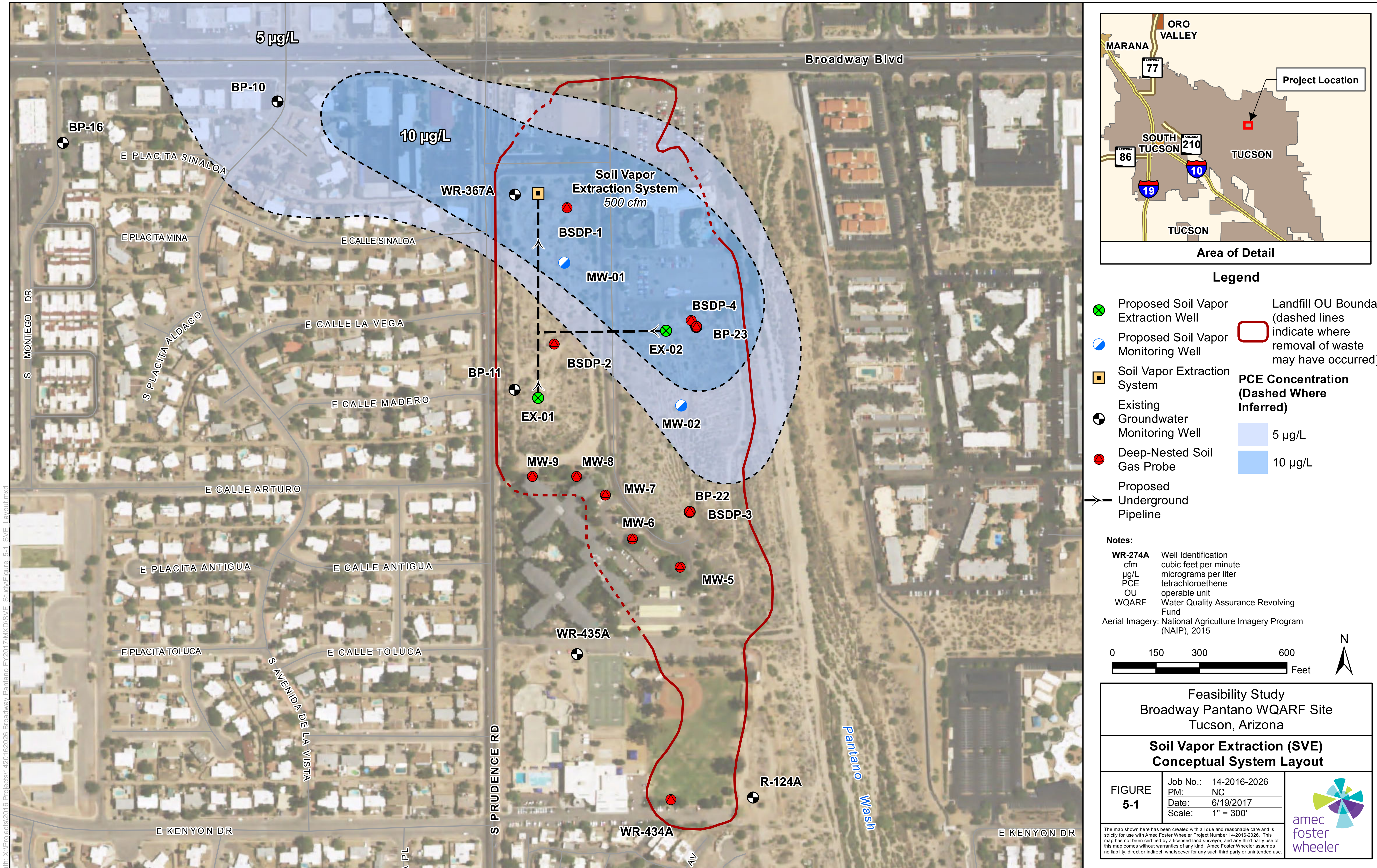

5 µg/L
10 µg/L
Broadway Blvd
BP-10
BP-16
E PLACITA SINALOA
WR-367A
Soil Vapor Extraction System
500 cfm
BSDP-1
MW-01
E PLACITA MINA
E CALLE SINALOA
BSDP-4
BP-23
EX-02
BSDP-2
E CALLE LA VEGA
S PLACITA ALDACO
S MONTEGO DR
BP-11
EX-01
E CALLE MADERO
MW-02
MW-9
MW-8
MW-7
BP-22
BSDP-3
E CALLE ARTURO
MW-6
MW-5
E PLACITA ANTIGUA
E CALLE ANTIGUA
WR-435A
E PLACITA TOLUCA
E CALLE TOLUCA
S AVENIDA DE LA VISTA
S PRUDENCE RD
Pantano Wash
R-124A
WR-434A
E KENYON DR
E KENYON DR
ORO VALLEY
MARANA
77
Project Location
SOUTH TUCSON
210
86
TUCSON
10
19
TUCSON
Area of Detail
Legend
Proposed Soil Vapor Extraction Well
Proposed Soil Vapor Monitoring Well
Soil Vapor Extraction System
Existing Groundwater Monitoring Well
Deep-Nested Soil Gas Probe
Proposed Underground Pipeline
Landfill OU Boundary (dashed lines indicate where removal of waste may have occurred)
PCE Concentration (Dashed Where Inferred)
5 µg/L
10 µg/L
Notes:
WR-274A Well Identification
cfm cubic feet per minute
µg/L micrograms per liter
PCE tetrachloroethene
OU operable unit
WQARF Water Quality Assurance Revolving Fund
Aerial Imagery: National Agriculture Imagery Program (NAIP), 2015
0 150 300 600 Feet
N
Feasibility Study
Broadway Pantano WQARF Site
Tucson, Arizona
Soil Vapor Extraction (SVE)
Conceptual System Layout
FIGURE 5-1
Job No.: 14-2016-2026
PM: NC
Date: 6/19/2017
Scale: 1" = 300'
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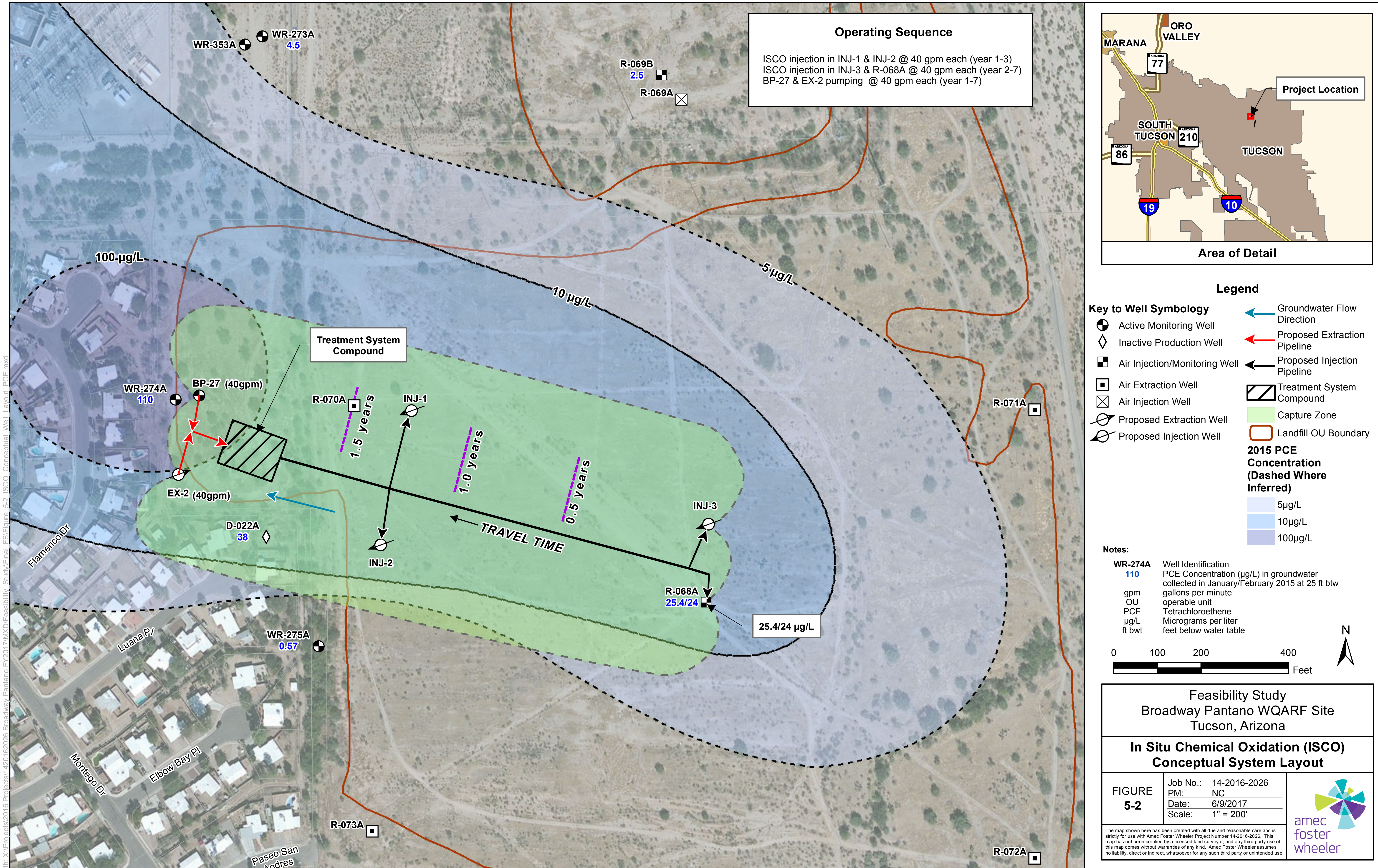

Operating Sequence
ISCO injection in INJ-1 & INJ-2 @ 40 gpm each (year 1-3)
ISCO injection in INJ-3 & R-068A @ 40 gpm each (year 2-7)
BP-27 & EX-2 pumping @ 40 gpm each (year 1-7)
WR-353A
WR-273A
4.5
R-069B
2.5
R-069A
100-µg/L
10 µg/L
5 µg/L
Treatment System Compound
WR-274A
110
BP-27 (40gpm)
R-070A
INJ-1
1.5 years
1.0 years
0.5 years
TRAVEL TIME
EX-2 (40gpm)
D-022A
38
INJ-2
INJ-3
R-068A
25.4/24
25.4/24 µg/L
R-071A
WR-275A
0.57
R-073A
R-072A
Flamenco Dr
Luana Pl
Montego Dr
Elbow Bay Pl
Paseo San Andres
ORO VALLEY
MARANA
77
Project Location
SOUTH TUCSON
210
86
TUCSON
19
10
Area of Detail
Legend
Key to Well Symbology
Active Monitoring Well
Inactive Production Well
Air Injection/Monitoring Well
Air Extraction Well
Air Injection Well
Proposed Extraction Well
Proposed Injection Well
Groundwater Flow Direction
Proposed Extraction Pipeline
Proposed Injection Pipeline
Treatment System Compound
Capture Zone
Landfill OU Boundary
2015 PCE Concentration (Dashed Where Inferred)
5µg/L
10µg/L
100µg/L
Notes:
WR-274A Well Identification
110 PCE Concentration (µg/L) in groundwater collected in January/February 2015 at 25 ft btw
gpm gallons per minute
OU operable unit
PCE Tetrachloroethene
µg/L Micrograms per liter
ft bwt feet below water table
0 100 200 400
Feet
N
Feasibility Study
Broadway Pantano WQARF Site
Tucson, Arizona
In Situ Chemical Oxidation (ISCO) Conceptual System Layout
FIGURE 5-2
Job No.: 14-2016-2026
PM: NC
Date: 6/9/2017
Scale: 1" = 200'
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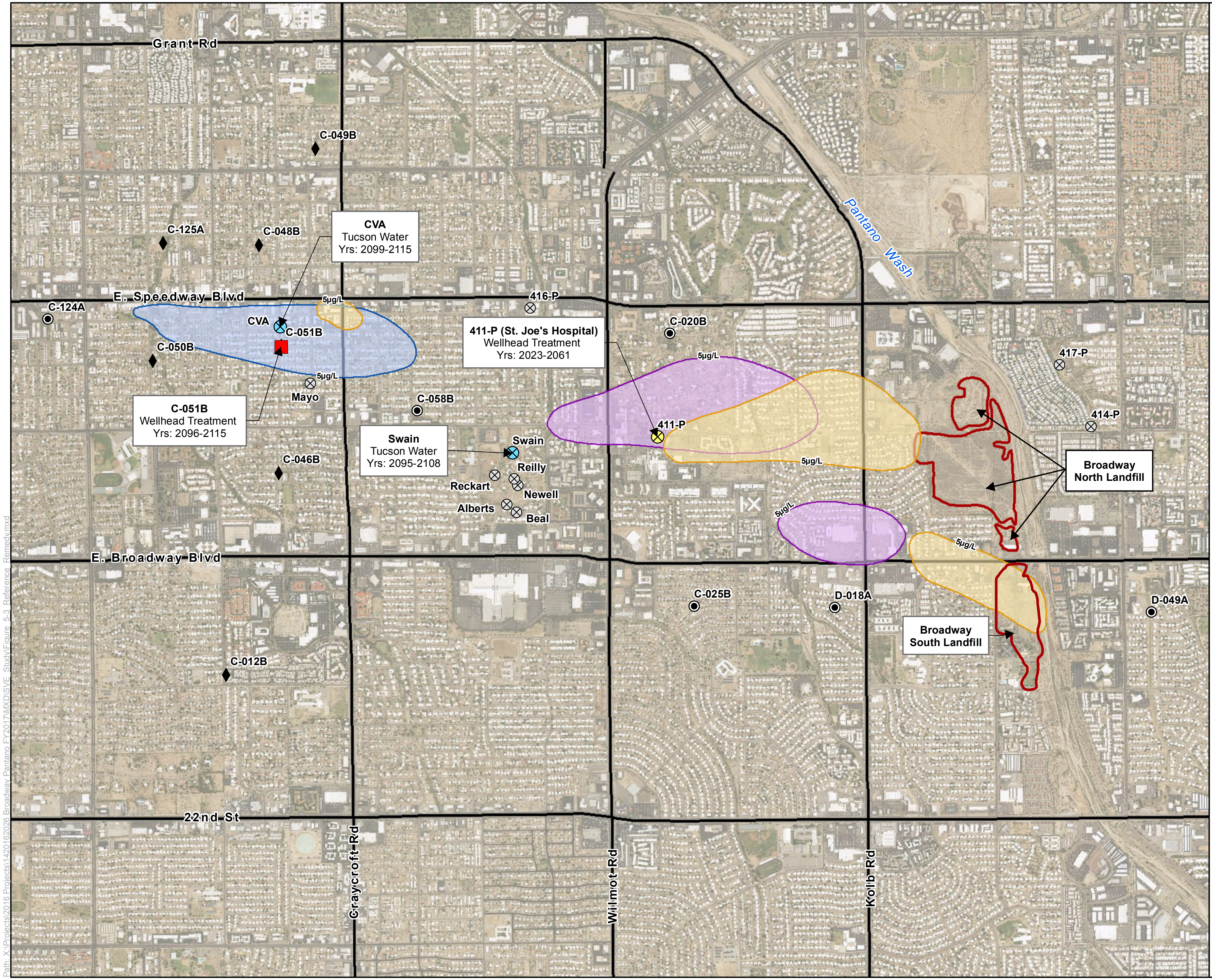

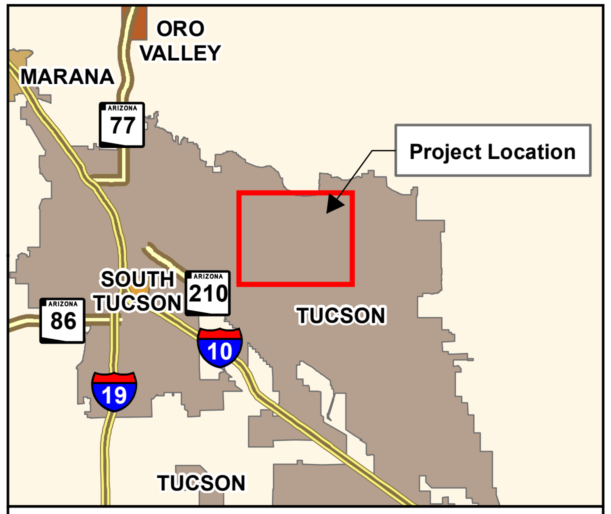

Area of Detail

Legend

- TW Production Well (WHT)
- Private Well (TW Supplied)
- Private Well (WHT)
- Active TW Production Well
- Standby TW Production Well
- Private Well
- Landfill OU Boundaries

Extent of 5µg/L PCE Plume

- 5 Years (2020)
- 30 Years (2045)
- 100 Years (2115)

Notes:

WR-274A	Well Identification
TW	Tucson Water
WHT	Wellhead Treatment
µg/L	micrograms per liter
PCE	tetrachloroethene
OU	operable unit
WQARF	Water Quality Assurance Revolving Fund
Aerial Imagery:	National Agriculture Imagery Program (NAIP), 2015

Source: Draft Groundwater Model Report Supporting Remedial Alternative Evaluation, Broadway Pantano WQARF Site, Tucson Arizona prepared by Amec Foster Wheeler in December 2016.

0 1,000 2,000 4,000 Feet

N

Feasibility Study
Broadway Pantano WQARF Site
Tucson, Arizona

Reference Remedy Modeling Summary

FIGURE **5-3**

Job No.:	14-2016-2026
PM:	NC
Date:	6/28/2017
Scale:	1" = 2000'

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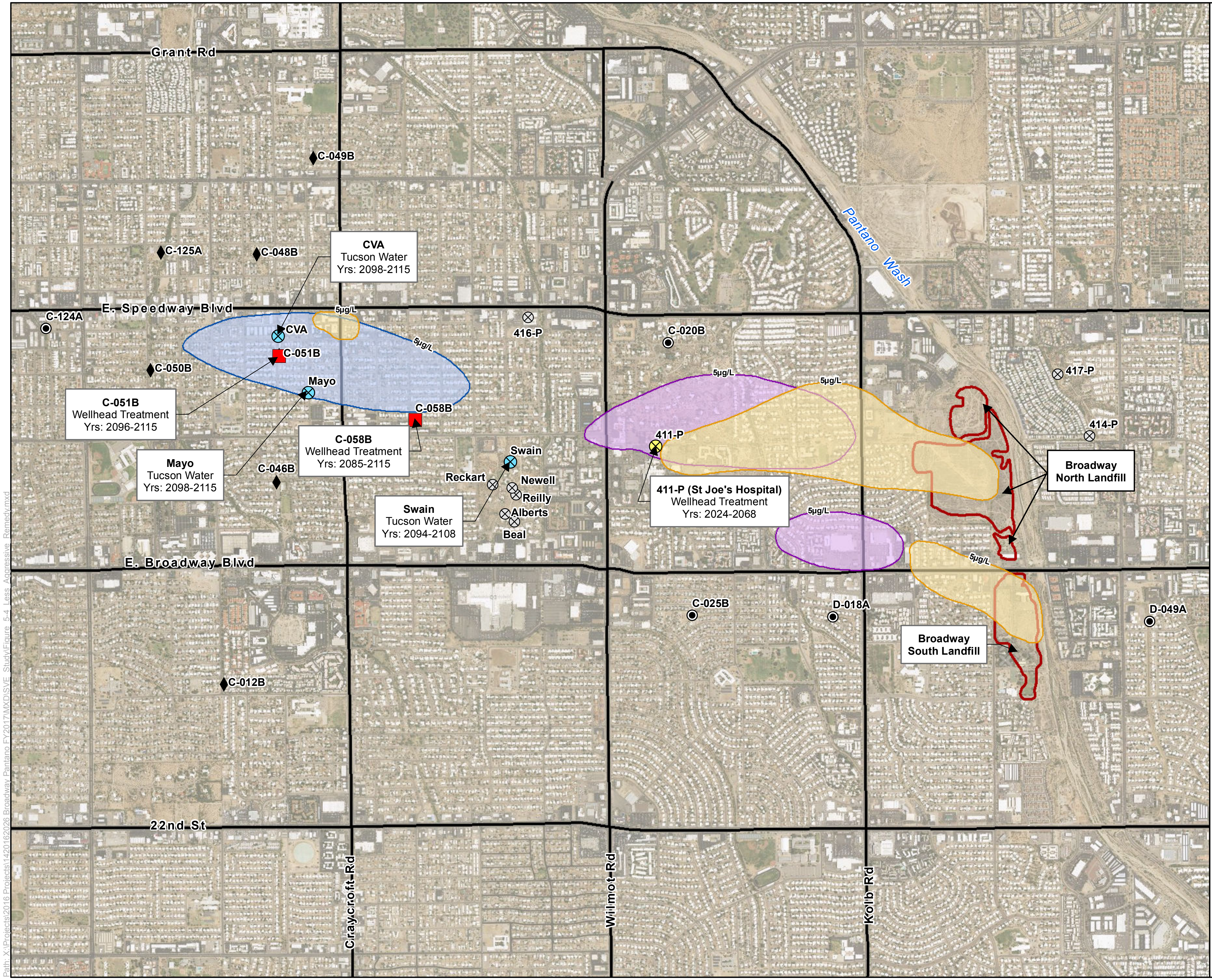

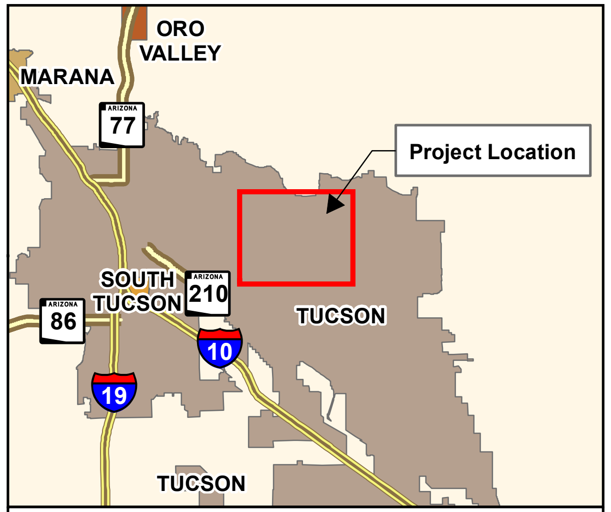

Area of Detail

Legend

- TW Production Well (WHT)
- Private Well (TW Supplied)
- Private Well (WHT)
- Active TW Production Well
- Standby TW Production Well
- Private Well
- Landfill OU Boundaries

Extent of 5µg/L PCE Plume

- 5 Years (2020)
- 30 Years (2045)
- 100 Years (2115)

Notes:

WR-274A	Well Identification
TW	Tucson Water
WHT	Wellhead Treatment
µg/L	microgram per liter
PCE	tetrachloroethene
OU	operable unit
WQARF	Water Quality Assurance Revolving Fund
Aerial Imagery:	National Agriculture Imagery Program (NAIP), 2015

Source: Draft Groundwater Model Report Supporting Remedial Alternative Evaluation, Broadway Pantano WQARF Site, Tucson Arizona prepared by Amec Foster Wheeler in December 2016.

0 1,000 2,000 4,000 Feet

N

Feasibility Study
Broadway Pantano WQARF Site
Tucson, Arizona

Less Aggressive Modeling Summary

FIGURE
5-4

Job No.:	14-2016-2026
PM:	NC
Date:	6/28/2017
Scale:	1" = 2000'

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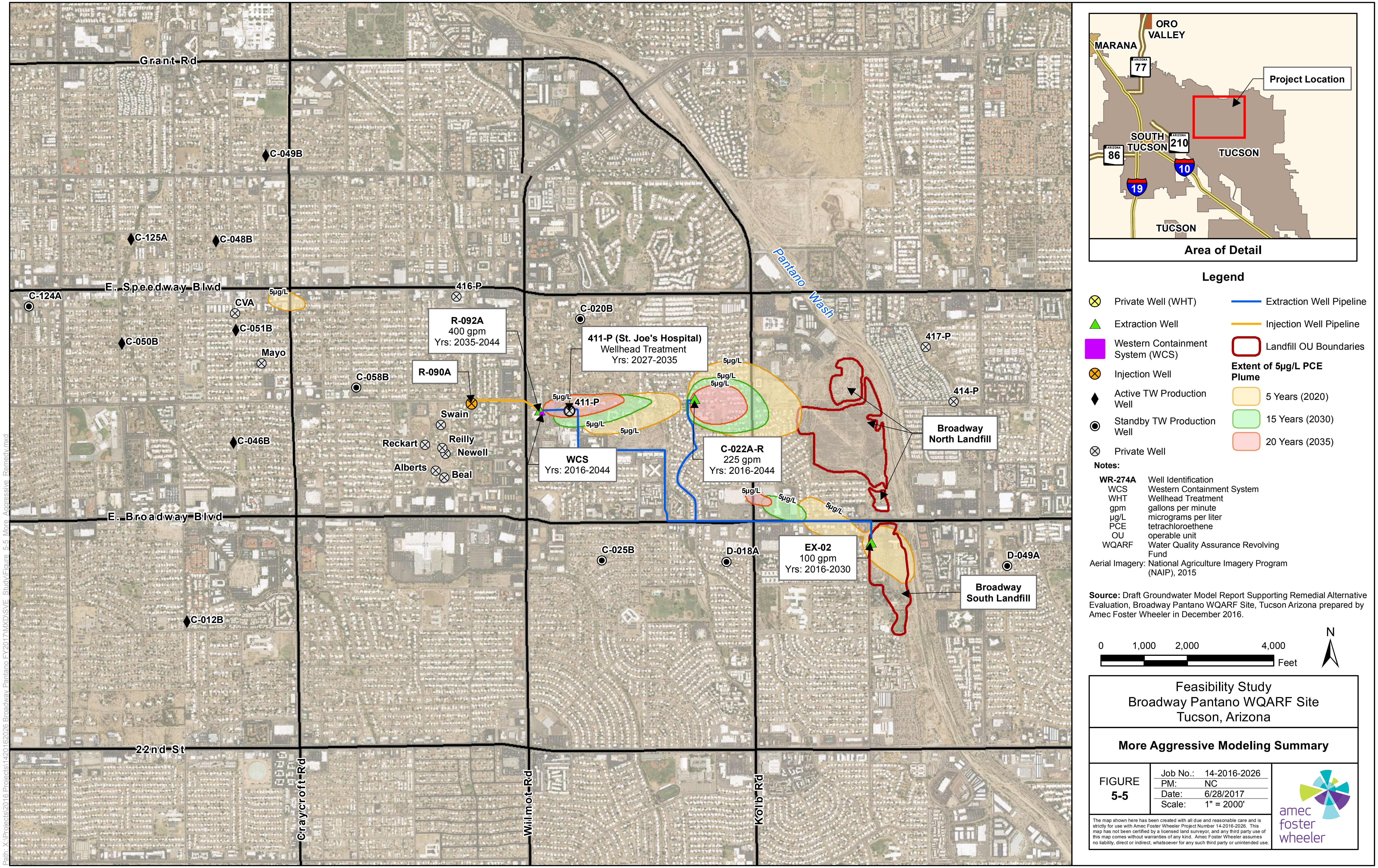

Grant Rd
E. Speedway Blvd
E. Broadway Blvd
22nd St
Craycroft Rd
Wilmot Rd
Kolb Rd
Pantano Wash
C-049B
C-125A
C-048B
C-124A
CVA
C-051B
C-050B
Mayo
C-058B
C-046B
C-012B
416-P
C-020B
417-P
414-P
C-025B
D-018A
D-049A
Swain
Reckart
Reilly
Newell
Alberts
Beal
411-P
5μg/L
R-092A
400 gpm
Yrs: 2035-2044
R-090A
411-P (St. Joe's Hospital)
Wellhead Treatment
Yrs: 2027-2035
WCS
Yrs: 2016-2044
C-022A-R
225 gpm
Yrs: 2016-2044
EX-02
100 gpm
Yrs: 2016-2030
Broadway North Landfill
Broadway South Landfill
ORO VALLEY
MARANA
77
Project Location
SOUTH TUCSON
210
86
TUCSON
10
19
Area of Detail
Legend
Private Well (WHT)
Extraction Well
Western Containment System (WCS)
Injection Well
Active TW Production Well
Standby TW Production Well
Private Well
Extraction Well Pipeline
Injection Well Pipeline
Landfill OU Boundaries
Extent of 5μg/L PCE Plume
5 Years (2020)
15 Years (2030)
20 Years (2035)
Notes:
WR-274A Well Identification
WCS Western Containment System
WHT Wellhead Treatment
gpm gallons per minute
μg/L micrograms per liter
PCE tetrachloroethene
OU operable unit
WQARF Water Quality Assurance Revolving Fund
Aerial Imagery: National Agriculture Imagery Program (NAIP), 2015
Source: Draft Groundwater Model Report Supporting Remedial Alternative Evaluation, Broadway Pantano WQARF Site, Tucson Arizona prepared by Amec Foster Wheeler in December 2016.
N
0 1,000 2,000 4,000
Feet
Feasibility Study
Broadway Pantano WQARF Site
Tucson, Arizona
More Aggressive Modeling Summary
FIGURE 5-5
Job No.: 14-2016-2026
PM: NC
Date: 6/28/2017
Scale: 1" = 2000'
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APPENDIX F

COST TABLES

Table F-1
VOCs in Waste
Reference Remedy Groundwater Treatment
Capital Costs

Item	Estimated Unit Cost	Estimated Quantity	Units	Total Estimated Cost
411-P Wellhead Treatment System (75 GPM)				
Subgrade Preparation	$ 1,000	1	Ea	$ 1,000
ABC Backfill	$ 7	6	SY	$ 40
Slab-on-Grade	$ 200	3	CY	$ 600
Rebar Reinforcement	$ 300	1	Ea	$ 300
CMU Wall	$ 5,000	1	Ea	$ 5,000
Carbon System (2 vessels)(1)	$ 60,000	1	Ea	$ 60,000
Bag Filters	$ 3,000	2	Ea	$ 6,000
Valves	$ 3,000	1	Ea	$ 3,000
Instrumentation	$ 5,000	1	Ea	$ 5,000
Piping	$ 5,000	1	Ea	$ 5,000
Booster Pump	$ 2,000	1	Ea	$ 2,000
Flow Meter	$ 1,000	1	Ea	$ 1,000
Contractor Labor Mechanical	$ 10,000	1	Ea	$ 10,000
			System Subtotal	$ 99,000
C-051B Wellhead Treatment System (350 GPM)				
Subgrade Preparation	$ 1,000	1	Ea	$ 1,000
ABC Backfill	$ 7	65	SY	$ 400
Slab-on-Grade	$ 200	11	CY	$ 2,200
Rebar Reinforcement	$ 5,000	1	Ea	$ 5,000
CMU WALL	$ 15,000	1	Ea	$ 15,000
Carbon System (2 Vessels)(1)	$ 170,000	1	Ea	$ 170,000
Bag Filters	$ 15,000	2	Ea	$ 30,000
Valves	$ 10,000	1	Ea	$ 10,000
Instrumentation	$ 10,000	1	Ea	$ 10,000
Piping	$ 10,000	1	Ea	$ 10,000
Booster Pump	$ 2,000	1	Ea	$ 2,000
Flow Meter	$ 2,000	1	Ea	$ 2,000
Contractor Labor Mechanical	$ 30,000	1	Ea	$ 30,000
Electrical	$ 15,000	1	Ea	$ 15,000
			System Subtotal	$ 303,000
Perimeter Fencing				
Broadway North Landfill	$ 44	5300	L.F.	$ 233,200
Broadway South Landfill	$ 44	6000	L.F.	$ 264,000
			Fencing Subtotal	$ 497,200
			Const. Subtotal	*$ 899,000*

Table F-1
VOCs in Waste
Reference Remedy Groundwater Treatment
Capital Costs

Item	Estimated Unit Cost	Estimated Quantity	Units	Total Estimated Cost
Contractor Markups				
Survey		2%	of Const. Subtotal	$ 18,000
QA/QC		4%	of Const. Subtotal	$ 36,000
Mobilization		8%	of Const. Subtotal	$ 72,000
General Conditions		10%	of Const. Subtotal	$ 90,000
			Const. Total	$ 1,115,000
Engineering		6%	of Const. Total	$ 67,000
Construction Management		6%	of Const. Total	$ 67,000
			Total	**$ 1,249,000**

Notes:
- Costs are presented in 2016 US Dollars ($US 2016) and total and subtotal costs are rounded to the nearest $1,000
- The estimated unit costs presented are for planning purposed only, at the feasibility study level (-30% to +50%).
- The remedial approach and associated costs summarized here will be refined during the design and construction contracting phase.
- Costs were developed using 2016 RS Means and cost information from similar projects

(1) Includes initial granular activated carbon

% - percent
Const. - Construction
C.Y. - cubic yards
Ea - each
GPM - gallons per minute
QA/QC - quality assurance/quality control
S.Y. - square yards

Table F-2
VOCs in Waste
Less Aggressive Remedy Groundwater Treatment
Capital Costs

Item	Estimated Unit Cost	Estimated Quantity	Units	Total Estimated Cost
411-P Wellhead Treatment System (75 GPM)				
Subgrade Preparation	$ 1,000	1	Ea	$ 1,000
ABC Backfill	$ 7	6	S.Y.	$ 39
Slab-on-Grade	$ 200	3	C.Y.	$ 600
Rebar Reinforcement	$ 300	1	Ea	$ 300
CMU Wall	$ 5,000	1	Ea	$ 5,000
Carbon System (2 Vessels)(1)	$ 60,000	1	Ea	$ 60,000
Bag Filters	$ 3,000	2	Ea	$ 6,000
Valves	$ 3,000	1	Ea	$ 3,000
Instrumentation	$ 5,000	1	Ea	$ 5,000
Piping	$ 5,000	1	Ea	$ 5,000
Booster Pump	$ 2,000	1	Ea	$ 2,000
Flow Meter	$ 1,000	1	Ea	$ 1,000
Contractor Labor Mechanical	$ 10,000	1	Ea	$ 10,000
			System Subtotal	$ 99,000
C-051B Wellhead Treatment System (350 GPM)				
Subgrade Preparation	$ 1,000	1	Ea	$ 1,000
ABC Backfill	$ 7	65	S.Y.	$ 426
Slab-on-Grade	$ 200	11	C.Y.	$ 2,200
Rebar Reinforcement	$ 5,000	1	Ea	$ 5,000
CMU WALL	$ 15,000	1	Ea	$ 15,000
Carbon System (2 Vessels)	$ 170,000	1	Ea	$ 170,000
Bag Filters	$ 15,000	2	Ea	$ 30,000
Valves	$ 10,000	1	Ea	$ 10,000
Instrumentation	$ 10,000	1	Ea	$ 10,000
Piping	$ 10,000	1	Ea	$ 10,000
Booster Pump	$ 2,000	1	Ea	$ 2,000
Flow Meter	$ 2,000	1	Ea	$ 2,000
Contractor Labor Mechanical	$ 30,000	1	Ea	$ 30,000
Electrical	$ 15,000	1	Ea	$ 15,000
			System Subtotal	$ 303,000

Table F-2
VOCs in Waste
Less Aggressive Remedy Groundwater Treatment
Capital Costs

Item	Estimated Unit Cost	Estimated Quantity	Units	Total Estimated Cost
C-058B Wellhead Treatment System (450 GPM)				
Subgrade Preparation	$ 1,000	1	Ea	$ 1,000
ABC Backfill	$ 7	67	S.Y.	$ 439
Slab-on-Grade	$ 200	11	C.Y.	$ 2,200
Rebar Reinforcement	$ 5,000	1	Ea	$ 5,000
CMU WALL	$ 15,000	1	Ea	$ 15,000
Carbon System (2 Vessels)	$ 170,000	1	Ea	$ 170,000
Bag Filters	$ 15,000	2	Ea	$ 30,000
Valves	$ 10,000	1	Ea	$ 10,000
Instrumentation	$ 10,000	1	Ea	$ 10,000
Piping	$ 10,000	1	Ea	$ 10,000
Booster Pump	$ 2,000	1	Ea	$ 2,000
Flow Meter	$ 2,000	1	Ea	$ 2,000
Contractor Labor Mechanical	$ 30,000	1	Ea	$ 30,000
Electrical	$ 15,000	1	Ea	$ 15,000
			System Subtotal	$ 303,000
Perimeter Fencing				
Broadway North Landfill	$ 44	5300	L.F.	$ 233,200
Broadway South Landfill	$ 44	6000	L.F.	$ 264,000
			Fencing Subtotal	$ 497,200
			Const. Subtotal	*$ 1,202,000*
Contractor Markups				
Survey		2%	of Const. Subtotal	$ 24,000
QA/QC		4%	of Const. Subtotal	$ 48,000
Mobilization		8%	of Const. Subtotal	$ 96,000
General Conditions		10%	of Const. Subtotal	$ 120,000
			Const. Total	$ 1,490,000
Engineering		6%	of Const. Total	$ 89,000
Construction Management		6%	of Const. Total	$ 89,000
			Total	**$ 1,668,000**

Notes:

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- The remedial approach and associated costs summarized here will be refined during the design and construction contracting phase.
- Costs were developed using 2016 RS Means and cost information from similar projects

(1) Includes initial granular activated carbon
% - percent
Const. - Construction
C.Y.- cubic yards
Ea - each
GPM - gallons per minute
QA/QC - quality assurance/quality control
S.Y. - square yards

Table F-3
VOCs in Waste
More Aggressive Remedy Groundwater Treatment
Capital Costs

Item	Estimated Unit Cost	Estimated Quantity	Units	Total Estimated Cost
Extraction Well (EX-02) Installation				
Well Installation	$ 112,275	1	Ea	$ 112,275
Pump and Pump Casing	$ 22,520	1	Ea	$ 22,520
Well Development	$ 6,000	1	Ea	$ 6,000
Pump Installation	$ 8,000	1	Ea	$ 8,000
Electrical	$ 20,000	1	Ea	$ 20,000
Vault	$ 5,000	1	Ea	$ 5,000
Wellhead Instrumentation	$ 2,000	1	Ea	$ 2,000
Flow Meter	$ 2,000	1	Ea	$ 2,000
Wellhead Construction Costs	$ 8,000	1	Ea	$ 8,000
IDW and Site Security	$ 7,500	1	Ea	$ 7,500
Extraction Well (EX-02) Conveyance Pipe Installation				
Excavation, Trench	$ 10	3,519	B.C.Y.	$ 34,657
Piping and Valves	$ 33	9,500	L.F.	$ 308,975
ABC Backfill	$ 39	352	CY	$ 13,828
Compaction	$ 2	3,519	E.C.Y.	$ 8,726
Asphalt Paving	$ 21	2111	S.Y.	$ 43,489
Trench Plate	$ 5,000	1	Ea	$ 5,000
Traffic Control	$ 10,000	1	Ea	$ 10,000
Horizontal Boring - Broadway Rd.	$ 457	200	L.F.	$ 91,500
Horizontal Boring - Kolb Rd.	$ 450	250	L.F.	$ 112,500
Utility Conflicts	$ 5,000	30	Ea	$ 150,000
Extraction Well (C-022A) Installation				
Well Installation	$ 112,275	1	Ea	$ 112,275
Pump and Pump Casing	$ 22,520	1	Ea	$ 22,520
Well Development	$ 6,000	1	Ea	$ 6,000
Pump Installation	$ 8,000	1	Ea	$ 8,000
Electrical	$ 20,000	1	Ea	$ 20,000
Vault	$ 5,000	1	Ea	$ 5,000
Wellhead Instrumentation	$ 2,000	1	Ea	$ 2,000
Flow Meter	$ 2,000	1	Ea	$ 2,000
Wellhead Construction Costs	$ 8,000	1	Ea	$ 8,000
IDW and Site Security	$ 7,500	1	Ea	$ 7,500

Table F-3
VOCs in Waste
More Aggressive Remedy Groundwater Treatment
Capital Costs

Item	Estimated Unit Cost	Estimated Quantity	Units	Total Estimated Cost
Extraction Well (C-022A) Pipeline Connected to EX-02 Conveyance Pipeline Installation				
Excavation, Trench	$ 10	1,667	B.C.Y.	$ 16,420
Piping and Valves	$ 30	4,500	L.F.	$ 136,300
ABC Backfill	$ 39	167	CY	$ 6,550
Compaction	$ 2	1,667	E.C.Y.	$ 4,131
Asphalt Paving	$ 21	1000	S.Y.	$ 20,600
Trench Plate	$ 5,000	1	Ea	$ 5,000
Traffic Control	$ 10,000	1	Ea	$ 10,000
Utility Conflicts	$ 5,000	10	Ea	$ 50,000
411-P Wellhead Treatment System (75GPM)				
Subgrade Preparation	$ 1,000	1	Ea	$ 1,000
ABC Backfill	$ 7	6	S.Y.	$ 39
Slab-on-Grade	$ 200	3	C.Y.	$ 600
Rebar Reinforcement	$ 300	1	Ea	$ 300
CMU Wall	$ 5,000	1	Ea	$ 5,000
Carbon Vessels	$ 60,000	1	Ea	$ 60,000
Bag Filters	$ 3,000	2	Ea	$ 6,000
Valves	$ 3,000	1	Ea	$ 3,000
Instrumentation	$ 5,000	1	Ea	$ 5,000
Piping	$ 5,000	1	Ea	$ 5,000
Booster Pump	$ 2,000	2	Ea	$ 4,000
Flow Meter	$ 1,000	1	Ea	$ 1,000
Contractor Labor Mechanical	$ 10,000	1	Ea	$ 10,000
WCS System Modifications				
Carbon Vessels	$ 320,000	2	Ea	$ 640,000
Bag Filters	$ 15,000	4	Ea	$ 60,000
Contractor Labor Mechanical	$ 10,000	1	Ea	$ 10,000
Control System	$ 80,000	1	Ea	$ 80,000
Initial Fill of Carbon	$ 120,000	1	Ea	$ 120,000
Injection Well Rehabilitation	$ 60,000	1	Ea	$ 60,000

Table F-3
VOCs in Waste
More Aggressive Remedy Groundwater Treatment
Capital Costs

Item	Estimated Unit Cost	Estimated Quantity	Units	Total Estimated Cost
Perimeter Fencing				
Broadway North Landfill	$ 44	5300	L.F.	$ 233,000
Broadway South Landfill	$ 44	6000	L.F.	$ 264,000
			Fencing Subtotal	$ 497,000
			Const. Subtotal	$ 2,982,000
Contractor Markups				
Survey		2%	of Const. Subtotal	$ 60,000
QA/QC		4%	of Const. Subtotal	$ 119,000
Mobilization		8%	of Const. Subtotal	$ 239,000
General Conditions		10%	of Const. Subtotal	$ 298,000
			Const. Total	$ 3,698,000
Engineering		6%	of Const. Total	$ 222,000
Construction Management		6%	of Const. Total	$ 222,000
			Total	**$ 4,142,000**

Notes:

- Costs are presented in 2016 US Dollars ($US 2016) and rounded to the nearest $1,000
- The estimated unit costs presented are for planning purposed only, at the feasibility study level (-30% to +50%).
- The remedial approach and associated costs summarized here will be refined during the design and construction contracting phase.
- Costs were developed using 2016 RS Means and cost information from similar projects

-Capital Cost for 411-P Wellhead Treatment Occur in Year 2027

% - percent
B.C.Y. - bank cubic yards
C.Y. - cubic yards
CMU - concrete masonry unit
E.C.Y. - embankment cubic yards
Ea - each
GPM - gallons per minute
L.F. - linear feet
QA/QC - quality assurance/quality control
S.Y. - square yards

Table F-4
VOCs in Waste
Groundwater Treatment
O&M and Lifecycle Costs

Year	Reference Remedy		Less Aggressive Remedy		More Aggressive Remedy	
	O&M (1)	Life Cycle (2)	O&M (1)	Life Cycle (2)	O&M (1)	Life Cycle (2)
2016	$ -	$ 83,000	$ -	$ 83,000	$ 162,000	$ 94,000
2017	$ 1,000	$ 90,000	$ 1,000	$ 90,000	$ 163,000	$ 100,000
2018	$ 1,000	$ 72,000	$ 1,000	$ 72,000	$ 163,000	$ 83,000
2019	$ 1,000	$ 90,000	$ 1,000	$ 90,000	$ 163,000	$ 100,000
2020	$ 1,000	$ 195,000	$ 1,000	$ 195,000	$ 163,000	$ 205,000
2021	$ 1,000	$ 90,000	$ 1,000	$ 90,000	$ 163,000	$ 100,000
2022	$ 1,000	$ 77,000	$ 1,000	$ 72,000	$ 163,000	$ 83,000
2023	$ 68,000	$ 95,000	$ 1,000	$ 95,000	$ 163,000	$ 100,000
2024	$ 68,000	$ 77,000	$ 68,000	$ 77,000	$ 163,000	$ 83,000
2025	$ 68,000	$ 312,000	$ 68,000	$ 312,000	$ 163,000	$ 318,000
2026	$ 68,000	$ 77,000	$ 68,000	$ 77,000	$ 162,000	$ 83,000
2027	$ 68,000	$ 95,000	$ 68,000	$ 95,000	$ 231,000	$ 100,000
2028	$ 68,000	$ 77,000	$ 68,000	$ 77,000	$ 230,000	$ 83,000
2029	$ 68,000	$ 95,000	$ 68,000	$ 95,000	$ 230,000	$ 100,000
2030	$ 68,000	$ 200,000	$ 68,000	$ 200,000	$ 230,000	$ 205,000
2031	$ 68,000	$ 95,000	$ 68,000	$ 95,000	$ 201,000	$ 100,000
2032	$ 68,000	$ 77,000	$ 68,000	$ 77,000	$ 201,000	$ 82,000
2033	$ 68,000	$ 95,000	$ 68,000	$ 95,000	$ 200,000	$ 100,000
2034	$ 68,000	$ 77,000	$ 68,000	$ 77,000	$ 200,000	$ 82,000
2035	$ 68,000	$ 312,000	$ 68,000	$ 312,000	$ 284,000	$ 317,000
2036	$ 68,000	$ 77,000	$ 68,000	$ 77,000	$ 215,000	$ 82,000
2037	$ 68,000	$ 95,000	$ 68,000	$ 95,000	$ 214,000	$ 100,000
2038	$ 68,000	$ 77,000	$ 68,000	$ 77,000	$ 213,000	$ 82,000
2039	$ 68,000	$ 95,000	$ 68,000	$ 95,000	$ 212,000	$ 100,000
2040	$ 68,000	$ 200,000	$ 68,000	$ 200,000	$ 212,000	$ 205,000
2041	$ 68,000	$ 95,000	$ 68,000	$ 95,000	$ 211,000	$ 100,000
2042	$ 68,000	$ 77,000	$ 68,000	$ 77,000	$ 211,000	$ 82,000
2043	$ 68,000	$ 95,000	$ 68,000	$ 95,000	$ 210,000	$ 100,000
2044	$ 68,000	$ 77,000	$ 68,000	$ 77,000	$ 210,000	$ 1,529,000
2045	$ 68,000	$ 287,000	$ 68,000	$ 287,000	$ 1,000	$ -
2046	$ 68,000	$ 72,000	$ 68,000	$ 72,000	$ 1,000	$ -
2047	$ 67,000	$ 72,000	$ 67,000	$ 72,000	$ -	$ -
2048	$ 67,000	$ 72,000	$ 67,000	$ 72,000	$ -	$ -
2049	$ 67,000	$ 72,000	$ 67,000	$ 72,000	$ -	$ -
2050	$ 67,000	$ 192,000	$ 67,000	$ 192,000	$ -	$ -
2051	$ 67,000	$ 72,000	$ 67,000	$ 72,000	$ -	$ -
2052	$ 67,000	$ 72,000	$ 67,000	$ 72,000	$ -	$ -
2053	$ 67,000	$ 72,000	$ 68,000	$ 72,000	$ -	$ -
2054	$ 67,000	$ 72,000	$ 68,000	$ 72,000	$ -	$ -
2055	$ 67,000	$ 287,000	$ 68,000	$ 287,000	$ -	$ -
2056	$ 67,000	$ 72,000	$ 68,000	$ 72,000	$ -	$ -
2057	$ 67,000	$ 72,000	$ 68,000	$ 72,000	$ -	$ -
2058	$ 67,000	$ 72,000	$ 68,000	$ 72,000	$ -	$ -

Table F-4
VOCs in Waste
Groundwater Treatment
O&M and Lifecycle Costs

Year	Reference Remedy		Less Aggressive Remedy		More Aggressive Remedy	
	O&M (1)	Life Cycle (2)	O&M (1)	Life Cycle (2)	O&M (1)	Life Cycle (2)
2059	$ 67,000	$ 72,000	$ 67,000	$ 72,000	$ -	$ -
2060	$ 67,000	$ 192,000	$ 67,000	$ 192,000	$ -	$ -
2061	$ 67,000	$ 72,000	$ 67,000	$ 72,000	$ -	$ -
2062	$ -	$ 67,000	$ 67,000	$ 72,000	$ -	$ -
2063	$ -	$ 67,000	$ 67,000	$ 72,000	$ -	$ -
2064	$ -	$ 67,000	$ 67,000	$ 72,000	$ -	$ -
2065	$ -	$ 257,000	$ 67,000	$ 262,000	$ -	$ -
2066	$ -	$ 45,000	$ 67,000	$ 50,000	$ -	$ -
2067	$ -	$ 45,000	$ 67,000	$ 50,000	$ -	$ -
2068	$ -	$ 45,000	$ 67,000	$ 50,000	$ -	$ -
2069	$ -	$ 45,000	$ -	$ 45,000	$ -	$ -
2070	$ -	$ 162,000	$ -	$ 162,000	$ -	$ -
2071	$ -	$ 45,000	$ -	$ 45,000	$ -	$ -
2072	$ -	$ 45,000	$ -	$ 45,000	$ -	$ -
2073	$ -	$ 45,000	$ -	$ 45,000	$ -	$ -
2074	$ -	$ 45,000	$ -	$ 45,000	$ -	$ -
2075	$ -	$ 257,000	$ -	$ 257,000	$ -	$ -
2076	$ -	$ 45,000	$ -	$ 45,000	$ -	$ -
2077	$ -	$ 45,000	$ -	$ 45,000	$ -	$ -
2078	$ -	$ 45,000	$ -	$ 45,000	$ -	$ -
2079	$ -	$ 45,000	$ -	$ 45,000	$ -	$ -
2080	$ -	$ 162,000	$ -	$ 162,000	$ -	$ -
2081	$ -	$ 45,000	$ -	$ 45,000	$ -	$ -
2082	$ -	$ 45,000	$ -	$ 45,000	$ -	$ -
2083	$ -	$ 45,000	$ -	$ 45,000	$ -	$ -
2084	$ -	$ 45,000	$ -	$ 45,000	$ -	$ -
2085	$ -	$ 257,000	$ 79,000	$ 257,000	$ -	$ -
2086	$ -	$ 45,000	$ 79,000	$ 45,000	$ -	$ -
2087	$ -	$ 45,000	$ 79,000	$ 45,000	$ -	$ -
2088	$ -	$ 45,000	$ 79,000	$ 45,000	$ -	$ -
2089	$ -	$ 45,000	$ 79,000	$ 45,000	$ -	$ -
2090	$ -	$ 162,000	$ 79,000	$ 162,000	$ -	$ -
2091	$ -	$ 45,000	$ 79,000	$ 45,000	$ -	$ -
2092	$ -	$ 45,000	$ 79,000	$ 45,000	$ -	$ -
2093	$ -	$ 45,000	$ 79,000	$ 45,000	$ -	$ -
2094	$ -	$ 45,000	$ 144,000	$ 45,000	$ -	$ -
2095	$ 65,000	$ 257,000	$ 144,000	$ 257,000	$ -	$ -
2096	$ 141,000	$ 45,000	$ 221,000	$ 45,000	$ -	$ -
2097	$ 141,000	$ 45,000	$ 221,000	$ 45,000	$ -	$ -
2098	$ 142,000	$ 45,000	$ 351,000	$ 45,000	$ -	$ -
2099	$ 206,000	$ 45,000	$ 351,000	$ 45,000	$ -	$ -
2100	$ 207,000	$ 162,000	$ 351,000	$ 162,000	$ -	$ -
2101	$ 207,000	$ 45,000	$ 351,000	$ 45,000	$ -	$ -

Table F-4
VOCs in Waste
Groundwater Treatment
O&M and Lifecycle Costs

Year	Reference Remedy		Less Aggressive Remedy		More Aggressive Remedy	
	O&M (1)	Life Cycle (2)	O&M (1)	Life Cycle (2)	O&M (1)	Life Cycle (2)
2102	$ 207,000	$ 45,000	$ 351,000	$ 45,000	$ -	$ -
2103	$ 207,000	$ 45,000	$ 351,000	$ 45,000	$ -	$ -
2104	$ 207,000	$ 45,000	$ 351,000	$ 45,000	$ -	$ -
2105	$ 207,000	$ 257,000	$ 351,000	$ 257,000	$ -	$ -
2106	$ 207,000	$ 45,000	$ 351,000	$ 45,000	$ -	$ -
2107	$ 207,000	$ 45,000	$ 351,000	$ 45,000	$ -	$ -
2108	$ 207,000	$ 45,000	$ 351,000	$ 45,000	$ -	$ -
2109	$ 142,000	$ 45,000	$ 286,000	$ 45,000	$ -	$ -
2110	$ 142,000	$ 162,000	$ 286,000	$ 162,000	$ -	$ -
2111	$ 142,000	$ 45,000	$ 286,000	$ 45,000	$ -	$ -
2112	$ 142,000	$ 45,000	$ 286,000	$ 45,000	$ -	$ -
2113	$ 142,000	$ 45,000	$ 286,000	$ 45,000	$ -	$ -
2114	$ 142,000	$ 45,000	$ 286,000	$ 45,000	$ -	$ -
2115	$ 142,000	$ 651,000	$ 286,000	$ 651,000	$ -	$ -
Total	**$ 6,195,000**	**$ 9,910,000**	**$ 10,355,000**	**$ 9,940,000**	**$ 5,708,000**	**$ 4,898,000**

Notes:

- Costs are presented in 2016 US Dollars ($US 2016)
- The estimated unit costs presented are for planning purposed only, at the feasibility study level (-30% to +50%).

- The remedial approach and associated costs summarized here will be refined during the design and construction contracting phase.

O&M - operations and maintenance

(1) O&M costs include system operations personnel, cleaning and mechanical maintenance, materials, and operations utility costs at $0.14/kW/Hr.

(2) Lifecycle costs include monitoring, reporting, well installation, and well abandonments

Table F-5
VOCs in Waste
Soil Vapor Extraction (SVE)
Capital Costs

Item	Estimated Unit Cost	Estimated Quantity	Units	Total Estimated Cost
Well Installation				
SVE Extraction Well Installation (EX-01)	$ 120	300	L.F.	$ 36,000
SVE Extraction Well Installation (EX-02)	$ 120	375	L.F.	$ 45,000
SVE Monitoring Well Installation (MW-01)	$ 120	300	L.F.	$ 36,000
SVE Monitoring Well Installation (MW-02)	$ 120	300	L.F.	$ 36,000
System Installation				
Slab	$ 200	11	C.Y.	$ 2,200
Subgrade Preparation	$ 1,000	1	Ea	$ 1,000
ABC Backfill	$ 7	67	S.Y.	$ 439
Electrical	$ 15,000	1	Ea	$ 15,000
Misc. Piping/Equipment	$ 10,000	1	Ea	$ 10,000
Piping	$ 15	1,300	L.F.	$ 19,500
Equipment Rental	$ 1,667	12	Months	$ 20,000
Labor				
Labor	$ 50	480	hrs	$ 24,000
			Subtotal	*$ 245,000*
Contractor Markups				
Survey		2%	of Subtotal	$ 4,900
QA/QC		4%	of Subtotal	$ 9,800
Mobilization		8%	of Subtotal	$ 19,600
General Conditions		10%	of Subtotal	$ 24,500
			Subtotal	$ 304,000
Engineering		6%	of Subtotal	$ 18,240
Construction Management		6%	of Subtotal	$ 18,240
			Total	**$ 340,000**

Notes:

- Costs are presented in 2016 US Dollars ($US 2016)
- The estimated unit costs presented are for planning purposed only, at the feasibility study level (-30% to +50%).
- The remedial approach and associated costs summarized here will be refined during the design and construction contracting phase.
- Costs were developed using 2016 RS Means and cost information from similar projects

% - percent
C.Y. - cubic yards
Ea - each
L.F. - linear feet
Misc. - Miscellaneous
QA/QC - quality assurance/quality control
SVE - soil vapor extraction
S.Y. - square yards

Table F-6
VOCs in Waste
Soil Vapor Extraction (SVE)
O&M and Lifecycle Costs

Year	O&M	Life Cycle
2016	$ -	$ 168,000
2017	$ 200,000	$ 154,000
2018	$ -	$ 70,000
2019	$ -	$ 37,000
2020	$ -	$ 37,000
2021	$ -	$ -
2022	$ -	$ 5,000
2023	$ -	$ 33,000
2024	$ -	$ -
2025	$ -	$ 28,000
2026	$ -	$ -
2027	$ -	$ -
2028	$ -	$ 25,000
2029	$ -	$ -
2030	$ -	$ 28,000
2031	$ -	$ -
2032	$ -	$ -
2033	$ -	$ 745,000
2034	$ -	$ -
2035	$ -	$ 388,000
Total	**$ 200,000**	**$ 1,718,000**

Notes:

- Costs are presented in 2016 US Dollars ($US 2016)

- The estimated unit costs presented are for planning purposed only, at the feasibility study level (-30% to +50%).

- The remedial approach and associated costs summarized here will be refined during the design and construction contracting phase.

O&M - operation and maintenance

(1) O&M costs include system operations personnel, cleaning and mechanical maintenance, materials, and operations utility costs at $0.14/kW/Hr.

(2) Lifecycle costs include monitoring, reporting, well installation, and well abandonments

Table F-7
VOCs in Waste
In Situ Chemical Oxidation (ISCO)
Capital Costs

Item	Estimated Unit Cost	Estimated Quantity	Units	Total Estimated Cost
Well Installation				
Well Installation	$ 41,000	5	Ea	$ 205,000
Extraction Well Pump and Pipe	$ 10,942	3	Ea	$ 32,826
System Installation				
Transfer Pump	$ 1,000	1	Ea	$ 1,000
Equipment	$ 6,000	1	Misc.	$ 6,000
Valves/Fittings	$ 51,228	1	Misc.	$ 51,228
Pipe Trench Excavation	$ 9.85	300	B.C.Y.	$ 2,955
Pipe Trench Compaction	$ 2.48	375	E.C.Y.	$ 930
Electrical Service	$ 123,239	1	Misc.	$ 123,239
Electrical Trench Excavation	$ 9.85	450	B.C.Y.	$ 4,433
Electrical Trench Compaction	$ 2.48	563	E.C.Y.	$ 1,396
Electrical Controls	$ 20,000	1	Ea	$ 20,000
Tanks	$ 6,650	2	Ea	$ 13,300
Meters	$ 500	5	Ea	$ 2,500
Slab Installation	$ 507	27	C.Y.	$ 13,695
Secondary Containment	$ 482	5	C.Y.	$ 2,412
System Compound	$ 15.50	1400	S.F.	$ 21,695
Labor				
Labor	$ 55	600	hrs	$ 33,000
			Subtotal	*$ 536,000*
Construction Markups				
Survey		2%	of Subtotal	$ 10,720
QA/QC		4%	of Subtotal	$ 21,440
Mobilization		8%	of Subtotal	$ 42,880
General Conditions		10%	of Subtotal	$ 53,600
			Subtotal	$ 665,000
Engineering		6%	of Subtotal	$ 39,900
Construction Management		6%	of Subtotal	$ 39,900
			Total	**$ 745,000**

Notes:
- Costs are presented in 2016 US Dollars ($US 2016)
- The estimated unit costs presented are for planning purposed only, at the feasibility study level (-30% to +50%).
- The remedial approach and associated costs summarized here will be refined during the design and construction contracting phase.
- Costs were developed using 2016 RS Means and cost information from similar projects

% - percent
B.C.Y. - banked cubic yards
C.Y. - cubic yards
Ea - each
E.C.Y - embankment cubic yards
hrs - hours
Misc. - Miscellaneous
S.F. - square feet

Table F-8
VOCs in Waste
In Situ Chemical Oxidation (ISCO)
O&M and Lifecycle Costs

Year	O&M	Life Cycle
2016	$ -	$ -
2017	$ 176,000	$ 15,000
2018	$ 176,000	$ 15,000
2019	$ 176,000	$ 15,000
2020	$ 176,000	$ 15,000
2021	$ 176,000	$ 15,000
2022	$ 176,000	$ 15,000
2023	$ 176,000	$ 40,000
Total	**$ 1,232,000**	**$ 130,000**

Note:

- Costs are presented in 2016 US Dollars ($US 2016)
- The estimated unit costs presented are for planning purposed only, at the feasibility study level (-30% to +50%).
- The remedial approach and associated costs summarized here will be refined during the design and construction contracting phase.

O&M - operation and maintenance

(1) O&M costs include system operations personnel, cleaning and mechanical maintenance, materials, and operations utility costs at $0.14/kW/Hr.

(2) Lifecycle costs include monitoring, reporting, well installation, and well abandonments

Table F-9
VOCs in Waste
Remedy Costs Including Inflation
3% Annual Inflation

Year	Reference		Less Aggressive		More Aggressive	
	$US 2016	3% Inf.	$US 2016	3% Inf.	$US 2016	3% Inf.
2016	$ 942,000	$ 942,000	$ 942,000	$ 942,000	$ 4,426,000	$ 4,426,000
2017	$ 1,716,000	$ 1,769,000	$ 781,000	$ 805,000	$ 1,888,000	$ 1,945,000
2018	$ 335,000	$ 355,000	$ 143,000	$ 151,000	$ 507,000	$ 538,000
2019	$ 319,000	$ 348,000	$ 128,000	$ 157,000	$ 491,000	$ 537,000
2020	$ 424,000	$ 477,000	$ 233,000	$ 261,000	$ 596,000	$ 671,000
2021	$ 282,000	$ 327,000	$ 91,000	$ 123,000	$ 454,000	$ 527,000
2022	$ 274,000	$ 328,000	$ 78,000	$ 92,000	$ 442,000	$ 528,000
2023	$ 550,000	$ 676,000	$ 129,000	$ 158,000	$ 513,000	$ 631,000
2024	$ 145,000	$ 184,000	$ 283,000	$ 357,000	$ 246,000	$ 311,000
2025	$ 409,000	$ 533,000	$ 409,000	$ 532,000	$ 509,000	$ 664,000
2026	$ 145,000	$ 195,000	$ 145,000	$ 194,000	$ 245,000	$ 329,000
2027	$ 163,000	$ 225,000	$ 163,000	$ 224,000	$ 468,000	$ 648,000
2028	$ 171,000	$ 243,000	$ 171,000	$ 242,000	$ 338,000	$ 483,000
2029	$ 163,000	$ 239,000	$ 163,000	$ 238,000	$ 331,000	$ 485,000
2030	$ 296,000	$ 448,000	$ 296,000	$ 447,000	$ 463,000	$ 700,000
2031	$ 163,000	$ 254,000	$ 163,000	$ 252,000	$ 301,000	$ 468,000
2032	$ 145,000	$ 233,000	$ 145,000	$ 232,000	$ 283,000	$ 454,000
2033	$ 908,000	$ 1,501,000	$ 908,000	$ 1,499,000	$ 1,045,000	$ 1,728,000
2034	$ 145,000	$ 248,000	$ 145,000	$ 246,000	$ 282,000	$ 480,000
2035	$ 769,000	$ 1,348,000	$ 769,000	$ 1,347,000	$ 989,000	$ 1,735,000
2036	$ 145,000	$ 263,000	$ 145,000	$ 261,000	$ 297,000	$ 536,000
2037	$ 163,000	$ 303,000	$ 163,000	$ 301,000	$ 313,000	$ 583,000
2038	$ 145,000	$ 279,000	$ 145,000	$ 277,000	$ 295,000	$ 566,000
2039	$ 163,000	$ 322,000	$ 163,000	$ 320,000	$ 312,000	$ 616,000
2040	$ 268,000	$ 545,000	$ 268,000	$ 543,000	$ 416,000	$ 846,000
2041	$ 163,000	$ 341,000	$ 163,000	$ 339,000	$ 311,000	$ 651,000
2042	$ 145,000	$ 314,000	$ 145,000	$ 312,000	$ 293,000	$ 631,000
2043	$ 163,000	$ 362,000	$ 163,000	$ 360,000	$ 310,000	$ 688,000
2044	$ 145,000	$ 333,000	$ 146,000	$ 331,000	$ 1,738,000	$ 3,977,000
2045	$ 355,000	$ 837,000	$ 355,000	$ 835,000	$ 1,000	$ 2,000
2046	$ 141,000	$ 341,000	$ 141,000	$ 339,000	$ 1,000	$ 2,000
2047	$ 140,000	$ 349,000	$ 140,000	$ 349,000	$ -	$ -
2048	$ 140,000	$ 360,000	$ 140,000	$ 360,000	$ -	$ -
2049	$ 140,000	$ 370,000	$ 140,000	$ 371,000	$ -	$ -
2050	$ 259,000	$ 709,000	$ 260,000	$ 709,000	$ -	$ -
2051	$ 140,000	$ 393,000	$ 140,000	$ 393,000	$ -	$ -
2052	$ 140,000	$ 405,000	$ 140,000	$ 405,000	$ -	$ -
2053	$ 140,000	$ 417,000	$ 140,000	$ 418,000	$ -	$ -
2054	$ 140,000	$ 429,000	$ 140,000	$ 430,000	$ -	$ -
2055	$ 354,000	$ 1,122,000	$ 355,000	$ 1,123,000	$ -	$ -
2056	$ 140,000	$ 455,000	$ 140,000	$ 456,000	$ -	$ -
2057	$ 140,000	$ 469,000	$ 140,000	$ 470,000	$ -	$ -
2058	$ 140,000	$ 483,000	$ 140,000	$ 484,000	$ -	$ -

Table F-9
VOCs in Waste
Remedy Costs Including Inflation
3% Annual Inflation

Year	Reference		Less Aggressive		More Aggressive	
	$US 2016	3% Inf.	$US 2016	3% Inf.	$US 2016	3% Inf.
2059	$ 139,000	$ 497,000	$ 140,000	$ 499,000	$ -	$ -
2060	$ 259,000	$ 952,000	$ 260,000	$ 953,000	$ -	$ -
2061	$ 139,000	$ 527,000	$ 140,000	$ 529,000	$ -	$ -
2062	$ 67,000	$ 262,000	$ 140,000	$ 544,000	$ -	$ -
2063	$ 67,000	$ 270,000	$ 140,000	$ 560,000	$ -	$ -
2064	$ 67,000	$ 278,000	$ 140,000	$ 577,000	$ -	$ -
2065	$ 257,000	$ 1,094,000	$ 329,000	$ 1,401,000	$ -	$ -
2066	$ 45,000	$ 197,000	$ 117,000	$ 513,000	$ -	$ -
2067	$ 45,000	$ 203,000	$ 117,000	$ 528,000	$ -	$ -
2068	$ 45,000	$ 209,000	$ 117,000	$ 544,000	$ -	$ -
2069	$ 45,000	$ 215,000	$ 45,000	$ 215,000	$ -	$ -
2070	$ 162,000	$ 799,000	$ 162,000	$ 799,000	$ -	$ -
2071	$ 45,000	$ 228,000	$ 45,000	$ 228,000	$ -	$ -
2072	$ 45,000	$ 235,000	$ 45,000	$ 235,000	$ -	$ -
2073	$ 45,000	$ 242,000	$ 45,000	$ 242,000	$ -	$ -
2074	$ 45,000	$ 249,000	$ 45,000	$ 249,000	$ -	$ -
2075	$ 257,000	$ 1,470,000	$ 257,000	$ 1,470,000	$ -	$ -
2076	$ 45,000	$ 265,000	$ 45,000	$ 265,000	$ -	$ -
2077	$ 45,000	$ 272,000	$ 45,000	$ 272,000	$ -	$ -
2078	$ 45,000	$ 281,000	$ 45,000	$ 281,000	$ -	$ -
2079	$ 45,000	$ 289,000	$ 45,000	$ 289,000	$ -	$ -
2080	$ 162,000	$ 1,073,000	$ 162,000	$ 1,073,000	$ -	$ -
2081	$ 45,000	$ 307,000	$ 45,000	$ 307,000	$ -	$ -
2082	$ 45,000	$ 316,000	$ 45,000	$ 316,000	$ -	$ -
2083	$ 45,000	$ 325,000	$ 45,000	$ 325,000	$ -	$ -
2084	$ 45,000	$ 335,000	$ 45,000	$ 335,000	$ -	$ -
2085	$ 257,000	$ 1,975,000	$ 756,000	$ 5,815,000	$ -	$ -
2086	$ 45,000	$ 355,000	$ 124,000	$ 983,000	$ -	$ -
2087	$ 45,000	$ 366,000	$ 124,000	$ 1,013,000	$ -	$ -
2088	$ 45,000	$ 377,000	$ 124,000	$ 1,044,000	$ -	$ -
2089	$ 45,000	$ 388,000	$ 124,000	$ 1,075,000	$ -	$ -
2090	$ 162,000	$ 1,443,000	$ 241,000	$ 2,150,000	$ -	$ -
2091	$ 45,000	$ 412,000	$ 124,000	$ 1,141,000	$ -	$ -
2092	$ 45,000	$ 424,000	$ 124,000	$ 1,175,000	$ -	$ -
2093	$ 45,000	$ 437,000	$ 124,000	$ 1,210,000	$ -	$ -
2094	$ 45,000	$ 450,000	$ 189,000	$ 1,898,000	$ -	$ -
2095	$ 322,000	$ 3,325,000	$ 401,000	$ 4,145,000	$ -	$ -
2096	$ 607,000	$ 6,455,000	$ 686,000	$ 7,302,000	$ -	$ -
2097	$ 186,000	$ 2,043,000	$ 266,000	$ 2,915,000	$ -	$ -
2098	$ 186,000	$ 2,104,000	$ 396,000	$ 4,469,000	$ -	$ -
2099	$ 251,000	$ 2,923,000	$ 396,000	$ 4,603,000	$ -	$ -
2100	$ 368,000	$ 4,412,000	$ 513,000	$ 6,143,000	$ -	$ -
2101	$ 251,000	$ 3,102,000	$ 396,000	$ 4,884,000	$ -	$ -

Table F-9
VOCs in Waste
Remedy Costs Including Inflation
3% Annual Inflation

Year	Reference		Less Aggressive		More Aggressive	
	$US 2016	3% Inf.	$US 2016	3% Inf.	$US 2016	3% Inf.
2102	$ 251,000	$ 3,195,000	$ 396,000	$ 5,031,000	$ -	$ -
2103	$ 252,000	$ 3,292,000	$ 396,000	$ 5,182,000	$ -	$ -
2104	$ 252,000	$ 3,391,000	$ 396,000	$ 5,338,000	$ -	$ -
2105	$ 464,000	$ 6,437,000	$ 608,000	$ 8,442,000	$ -	$ -
2106	$ 252,000	$ 3,598,000	$ 396,000	$ 5,663,000	$ -	$ -
2107	$ 252,000	$ 3,706,000	$ 396,000	$ 5,834,000	$ -	$ -
2108	$ 252,000	$ 3,818,000	$ 396,000	$ 6,009,000	$ -	$ -
2109	$ 187,000	$ 2,918,000	$ 331,000	$ 5,175,000	$ -	$ -
2110	$ 304,000	$ 4,888,000	$ 448,000	$ 7,213,000	$ -	$ -
2111	$ 187,000	$ 3,096,000	$ 331,000	$ 5,490,000	$ -	$ -
2112	$ 187,000	$ 3,189,000	$ 331,000	$ 5,655,000	$ -	$ -
2113	$ 187,000	$ 3,285,000	$ 331,000	$ 5,825,000	$ -	$ -
2114	$ 187,000	$ 3,383,000	$ 331,000	$ 6,000,000	$ -	$ -
2115	$ 793,000	$ 14,801,000	$ 938,000	$ 17,497,000	$ -	$ -
Total(1)	**$ 21,700,000**	**$ 126,500,000**	**$ 24,200,000**	**$ 178,600,000**	**$ 19,100,000**	**$ 27,400,000**

Note:

- 2016 US Dollars ($US 2016)

(1) Rounded to the nearest $10,000

% - percent

Inf. - inflation

Table F-10
VOCs in Waste
Reference Remedy
Lifecycle Cost Assumptions

Task	Assumptions	
	Frequency	Description
SAP/QAPP Update	Every 5 years, starting Year 1 (2016)	Update to SAP and QAPP detailing locations/wells to be sampled for a five year period, updated to SOPs and or laboratory requirements
Water Level Monitoring	Two events per year beginning Year 1 (2016) through Year 100 (2115), 25% reduction at Year in 30 (2045) and additional 25% reduction in year 50 (2065)	Water level monitoring to be conducted semi-annually prior to passive sampling - 70 well elevations collected in 5 days per event
Groundwater Sampling	Annual Event (Odd Years): Includes Semi [16 wells] & Annual [23 wells] Events and Biannual Event (Even Years): Includes Semi & Annual Events + Biannual Event [28 wells] beginning in Year 1 though Year 29. 25% reduction of LOE at Year 30 (2045) and additional 25% reduction of LOE at Year 50 (2065) (based on sampling reduction as plume begins to dilute)	Groundwater Sampling to be conducted semi-annually (16 wells), annually (23 wells) and biannually (28 wells) with PDBs. Semi-annual frequency wells will be focused around potentially affected COT wells and source areas. Annual frequency wells are inside and around edges of 5 ppb plume. Biannual frequency wells are outside of plume or century wells. Sampling locations (frequency) will be reevaluated as plume moved down gradient addressed in SAP/QAPP Updates every five years. i.e. Sample ~69 samples per year (Year 1 to Year 29) Sample ~48 samples per year (Year 30 to Year 49) Sample ~32 samples per year (Year 50 to Year 100) - possible reduction of amount of wells but increased frequency at each well for well head protection
Reporting	Annually, Starting Year 1 (2016) 25% reduction of LOE at Year 30 (2045) and additional 25% reduction of LOE at Year 50 (2065) (based on sampling reduction)	One annual report prepared per year, includes results from semi-annual & annual sampling (and biannual, if applicable) - includes cost for preparation, GIS, data validation and data management
Groundwater Monitoring Well Replacement	One monitoring well installed every 10 years, Starting Year 10 (2025)	Installation of groundwater monitoring wells (replacement of damaged or abandoned well)- Subcontracted drilling (5" dia., ~350 ft), permitting, & waste disposal, 6 days each well
Groundwater Monitoring Well Abandonment	Two monitoring wells abandoned every 5 years, starting Year 5 (2020)	Abandonment of groundwater monitoring wells - Subcontracted over drilling/grouting (~300 ft), permitting, & waste disposal, 3 days each well
Final Groundwater Monitoring Well Abandonments	Once, Following Year 100 (2115)	Final removal of all wells associated with monitoring well network (10 remain at Year 100)

Table F-11
VOCs in Waste
Less Aggressive Remedy
Lifecycle Cost Assumptions

Task	Assumptions	
	Frequency	Description
SAP/QAPP Update	Every 5 years, starting Year 1 (2016)	Update to SAP and QAPP detailing locations/wells to be sampled for a five year period, updated to SOPs and or laboratory requirements
Water Level Monitoring	Two events per year beginning Year 1 (2016) through Year 100 (2115), 25% reduction at Year in 30 (2045) and additional 25% reduction in year 50 (2065)	Water level monitoring to be conducted semi-annually prior to passive sampling - 70 well elevations collected in 5 days per event
Groundwater Sampling	Annual Event (Odd Years): Includes Semi [16 wells] & Annual [23 wells] Events and Biannual Event (Even Years): Includes Semi & Annual Events + Biannual Event [28 wells] beginning in Year 1 though Year 29. 25% reduction of LOE at Year 30 (2045) and additional 25% reduction of LOE at Year 50 (2065) (based on sampling reduction as plume begins to dilute)	Groundwater Sampling to be conducted semi-annually (16 wells), annually (23 wells) and biannually (28 wells) with PDBs. Semi-annual frequency wells will be focused around potentially affected COT wells and source areas. Annual frequency wells are inside and around edges of 5 ppb plume. Biannual frequency wells are outside of plume or century wells. Sampling locations (frequency) will be reevaluated as plume moved down gradient addressed in SAP/QAPP Updates every five years. i.e. Sample ~69 samples per year (Year 1 to Year 29) Sample ~48 samples per year (Year 30 to Year 49) Sample ~32 samples per year (Year 50 to Year 100) - possible reduction of amount of wells but increased frequency at each well for well head protection
Reporting	Annually, Starting Year 1 (2016) 25% reduction of LOE at Year 30 (2045) and additional 25% reduction of LOE at Year 50 (2065) (based on sampling reduction)	One annual report prepared per year, includes results from semi-annual & annual sampling (and biannual, if applicable) - includes cost for preparation, GIS, data validation and data management
Groundwater Monitoring Well Replacement	One monitoring well installed every 10 years, Starting Year 10 (2025)	Installation of groundwater monitoring wells (replacement of damaged or abandoned well)- Subcontracted drilling (5" dia., ~350 ft), permitting, & waste disposal, 6 days each well
Groundwater Monitoring Well Abandonment	Two monitoring wells abandoned every 5 years, starting Year 5 (2020)	Abandonment of groundwater monitoring wells - Subcontracted over drilling/grouting (~300 ft), permitting, & waste disposal, 3 days each well
Final Groundwater Monitoring Well Abandonments	Once, Following Year 100 (2115)	Final removal of all wells associated with monitoring well network (10 remain at Year 100)

Table F-12
VOCs in Waste
More Aggressive Remedy
Lifecycle Cost Assumptions

Task	Assumptions	
	Frequency	Description
SAP/QAPP Update	Every 5 years, starting Year 1 (2016)	Update to SAP and QAPP detailing locations/wells to be sampled for a five year period, updated to SOPs and or laboratory requirements
Water Level Monitoring	Two events per year beginning Year 1 (2016) through Year 29 (2044) - Termination in Year 29	Water level monitoring to be conducted semi-annually prior to passive sampling - 70 well elevations collected in 5 days per event
Groundwater Sampling	Annual Event (Odd Years): Includes Semi [16 wells] & Annual [23 wells] Events and Biannual Event (Even Years): Includes Semi & Annual Events + Biannual Event [28 wells] beginning in Year 1 though Year 29. - Termination Year 29	Groundwater Sampling to be conducted semi-annually (16 wells), annually (23 wells) and biannually (28 wells) with PDBs. Semi-annual frequency wells will be focused around potentially affected COT wells and source areas. Annual frequency wells are inside and around edges of 5 ppb plume. Biannual frequency wells are outside of plume or century wells. Sampling locations (frequency) will be reevaluated as plume moved down gradient addressed in SAP/QAPP Updates every five years.
Operational Sampling Analytical Cost	Monthly & Weekly Samples - Termination Year 29	5 Monthly Operational Samples & 1 Weekly Sample + QAQC from Containment System - VOC Analytical Cost Only
Reporting	Annually, Starting Year 1 (2016)	One annual report prepared per year, includes results from semi-annual & annual sampling (and biannual, if applicable) - includes cost for preparation, GIS, data validation and data management
Groundwater Monitoring Well Replacement	One monitoring well installed every 10 years, Starting Year 10 (2025)	Installation of groundwater monitoring wells (replacement of damaged or abandoned well)- Subcontracted drilling (5" dia., ~350 ft), permitting, & waste disposal, 6 days each well
Groundwater Monitoring Well Abandonment	Two monitoring wells abandoned every 5 years, starting Year 5 (2020)	Abandonment of groundwater monitoring wells - Subcontracted over drilling/grouting (~300 ft), permitting, & waste disposal, 3 days each well
Final Groundwater Monitoring Well Abandonments	Once, Following Year 29 (2045)	Final removal of all wells associated with monitoring well network (30 remain at Year 2045)

Table F-13
VOCs in Waste
Reference Remedy Groundwater Treatment
O&M Costs

Task	Assumptions	
	Frequency	Description
Routine Inspections	Weekly	Eight (8) hrs of operator time and truck to conduct routine operations and maintenance activities at each well site (411-P and C-051B).
Alarm Callouts	Once per month	Eight (8) hrs of operator time and truck to respond to non-routine alarm callouts at each well site (411-P and C-051B).
Vessel Maintenance	Once every 5 years	Spot repair vessel lining caused by corrosion. Assumed $5,000 for 411-P and $15,000 for C-051B.
Quarterly Maintenance	Quarterly	Perform quarterly maintenance activities and repair equipment as needed. Sixteen hours (16) of operator time and annual costs of $1,000 in materials for 411-P and $3,000 for C-051B.
Materials	As Needed	Assumed various general materials will be purchased (e.g. paint, hardware) in the amount of $1,000 per well site (411-P and C-051B).
Carbon Replacement	As Needed	Carbon usage based on mass loading data obtained from the 2015 Groundwater Modeling Report. Assumed $1.50/lb of GAC usage.
Pump Replacements	Once every 5 years	Assumed pumps would need to be replaced every 5 years (Booster pump in C-051B [$15,000] and booster pump in 411-P[$3,000]).
Sediment Pre-Filters	As Needed	Assumed bag pre-filters will need to be replaced periodically and allocated $1,000 annually.
Autodialer	Monthly	Cost for autodialer at each well site ($50/month).
Electricity Cost	Continuous	Electricity Cost based on a booster pump size at each well site (C-051B [10HP] and 411-P [2HP)) and ancillary equipment.
Tucson Supplied Water	Continuous	Water replacement cost ($2.64/ccf) for well sites CVA, Mayo, and SWAIN

Table F-14
VOCs in Waste
Less Aggressive Remedy Groundwater Treatment
O&M Costs

Task	Assumptions	
	Frequency	Description
Routine Inspections	Weekly	Eight (8) hrs of operator time and truck to conduct routine operations and maintenance activities at each well site (411-P, C-051B, and C-058B).
Alarm Callouts	Once per month	Eight (8) hrs of operator time and truck to respond to non-routine alarm callouts at each well site (411-P and C-051B).
Vessel Maintenance	Once every 5 years	Spot repair vessel lining caused by corrosion. Assumed $5,000 for 411-P, $15,000 for C-051B, $15,000 for C-058B.
Quarterly Maintenance	Quarterly	Perform quarterly maintenance activities and repair equipment as needed. Sixteen hours (16) of operator time and annual costs of $1,000 in materials for 411-P, $3,000 for C-051B, and $3,000 for C-058B.
Materials	As Needed	Assumed various general materials will be purchased (e.g. paint, hardware) in the amount of $1,000 per well site (411-P, C-051B, and C-058B).
Carbon Replacement	As Needed	Carbon usage based on mass loading data obtained from the 2015 Groundwater Modeling Report. Assumed $1.50/lb of GAC.
Pump Replacements	Once every 5 years	Assumed pumps would need to be replaced every 5 years (Booster pump in C-051B [$15,000], C-058B [$15,000] and booster pump in 411-P[$3,000]).
Sediment Pre-Filters	As Needed	Assumed bag pre-filters will need to be replaced periodically and allocated $1,000 annually.
Autodialer	Monthly	Cost for autodialer at each well site ($50/month).
Electricity Cost	Continuous	Electricity Cost based on a booster pump size at each well site (C-051B [10HP], C-058B [10HP] and 411-P [2HP)) and ancillary equipment.
Tucson Supplied Water	Continuous	Water replacement cost ($2.64/ccf) for well sites CVA, Mayo, and SWAIN

Table F-15
VOCs in Waste
More Aggressive Remedy Groundwater Treatment
O&M Costs

Task	Assumptions	
	Frequency	Description
Routine Inspections	Weekly	Eight (8) hrs of operator time and truck to conduct routine operations and maintenance activities at WCS and well site 411-P.
Alarm Callouts	Once per month	Eight (8) hrs of operator time and truck to respond to non-routine alarm callouts at WCS and well site 411-P.
Vessel Maintenance	Once every 5 years	Spot repair vessel lining caused by corrosion. Assumed $15,000 for WCS vessels and $5,000 for 411-P.
Quarterly Maintenance	Quarterly	Perform quarterly maintenance activities and repair equipment as needed. Sixteen hours (16) of operator time and annual costs of $3,000 in materials for WCS and $1,000
Materials	As Needed	Assumed various general materials will be purchased (e.g. paint, hardware) in the amount of $1,000 for WCS and well site (411-P), and $500 for each well location (EX-02, C-022A, R-092A)
Carbon Replacement	As Needed	Carbon usage based on mass loading data obtained from the 2015 Groundwater Modeling Report. Assumed $1.50/lb of GAC.
Well Cleaning	Once every 5 years	Assume well sites (EX-02 [$20,000], C-022A [$20,000], R-092 [20,000], and Injection Well [$25,000]) will require routine cleaning.
Pump Replacements	Once every 5 years	Assumed pumps would need to be replaced every 5 years. Booster pump in 411-P[$3,000], Tank Return Pump at WCS ($15,000) and well pumps in EX-02, C-022A, and R-092A each at a cost of $15,000.
Sediment Pre-Filters	As Needed	Assumed bag pre-filters will need to be replaced periodically and allocated $1,000 annually for WCS and 411-P.
Autodialer	Monthly	Cost for autodialer at each WCS and 411-P ($50/month).
Electricity Cost	Continuous	Electricity Cost based on a booster pump at well site 411-P [2HP), Tank Return Pump at WCS, and extraction wells (EX-02 [20HP], C-022A [40HP], and R-092A [75HP] and ancillary equipment at each location.

Table F-16
VOCs in Waste
Soil Vapor Extraction (SVE)
Lifecycle Costs

Location	Task		Assumptions	
			Frequency	Description
Broadway North Landfill	Deep Soil Vapor Monitoring	SAP/QAPP Update	Once every 5 years - Starting Year 3 (2018) until Year 18 (2033)	Update to SAP and QAPP detailing locations/wells to be sampled for each monitoring event (once per five years), updated to SOPs and or laboratory requirements
		Deep Soil Vapor Sampling	One event every 5 years for 20 years - 50% reduction in sampling locations in Year 13 (2028).	Soil vapor samples to be collected from existing soil vapor locations deeper than 150 ft bgs in/near footprint of GW plume within the BNL - 30 soil vapor samples collected during Year 3 (2018) & Year 8 (2023) 15 soil vapor samples collected during Year 13 (2028) & Year 18 (2033)
		Reporting	Once every 5 years - Starting Year 3 (2018) until Year 18 (2033)	One report prepared per event (once per 5 years), includes - includes cost for preparation, GIS, data validation and data management
		Soil Vapor Monitoring Well Replacement	Once - Year 2 (2017)	Replacement of damaged DP-6: Abandonment of DP-6 and subcontracted drilling (1" nested probes, ~250 ft), permitting, & waste disposal
		Final Vapor Well Abandonments	Once - Following Year 20 (2033+)	Final removal of all wells associated with monitoring well network (18)

Table F-16
VOCs in Waste
Soil Vapor Extraction (SVE)
Lifecycle Costs

Location	Task		Assumptions: Frequency	Assumptions: Description
Broadway South Landfill	Deep Soil Vapor Monitoring	SAP/QAPP Update	Once every 5 years - Year 1 (2016) through Year 20 (2035)	Update to SAP and QAPP detailing locations/wells to be sampled for each monitoring event (once per five years), updated to SOPs and or laboratory requirements
		Deep Soil Vapor Sampling	Annually -Year 1 (2016) through Year 5 (2020) then every 5 years until Year 20 (2035) - Year 10 (2025), Year 15 (2030) & Year 20 (2035)	Soil vapor samples to be collected from existing soil vapor locations - in/near footprint of the GW plume at BSL 44 soil vapor samples (11 locations 9 existing and 2 new multiport wells) collected annually during Year 1 (2016) through Year 5 (2020) 22 soil vapor samples collected every 5 years during Year 10 (2025), Year 15 (2030) & Year 20 (2035) - reduction 50% based on GW plume foot print reduction at BSL
		Reporting	Annually -Year 1 (2016) through Year 5 (2020) then every 5 years until Year 20 (2035) - Year 10 (2025), Year 15 (2030) & Year 20 (2035)	One report prepared per event includes - includes cost for preparation, GIS, data validation and data management
		Soil Vapor Monitoring Well Installation	Once - Year 1 (2016)	Installation of two new nested monitoring vapor monitoring wells within BSL. Includes subcontracted drilling (six 1" nested probes, ~350 ft), permitting, & waste disposal
		Final Vapor Well Abandonments	Once - Following Year 20 (2035+)	Final removal of all wells associated with soil vapor monitoring network (9)
	Shallow Soil Vapor Monitoring	Final Vapor Well Abandonments	Once, Following Year 6 (2021+)	Final removal of all wells associated with monitoring well network (13)

Table F-17
VOCs in Waste
In-Situ Chemical Oxidation (ISCO)
Lifecycle Costs

Task	Assumptions	
	Frequency	Description
Well Sampling	Quarterly	Assume 10 wells will be sampled with 50% vertical profiling for the first 3 years of operations over a one week period.
Final Well Abandonment	Once	Wells will be abandoned at the end of the program.
Equipment	Quarterly	Equipment used for sampling activities include a colorimeter, groundwater parameter meter, ORP meter, water level sounder, flow through cell, and passive diffusion bags.

Table F-18
VOCs in Waste
Soil Vapor Extraction (SVE)
O&M Assumptions

Task	Assumptions	
	Frequency	Description
Routine Inspections	2 times per week	Eight (8) hrs of operator time and truck to conduct routine operations and maintenance activities.
Carbon Vessels Rental/Carbon Usage	One changeout per month	Assume each changeout is 1,000 lbs of vapor phase carbon
Process Sampling	2 samples per month	Sampling carbon vessel inlet and outlet.
Condensate Disposal	2 time per year	Total condensate disposal fee estimated at $10,000.
General Maintenance	As Needed	Annual costs of general materials estimated at $6,000.
Autodialer	Monthly	Cost for autodialer at each well site ($50/month).
Electricity Cost	Continuous	Electricity usage based on a 30 HP rental blower.

Table F-19
VOCs in Waste
In-Situ Chemical Oxidation (ISCO)
O&M Costs

Task	Assumptions	
	Frequency	**Description**
Routine Inspections	2 times per week	Eight (8) hrs of operator time and truck to conduct routine operations and maintenance activities.
Sodium Permanganate	Continuous	7,700 gallons of 40% solution used during treatment.
Well Maintenance	As Needed	Allocation of $15,000 for as needed well maintenance annually.
General Maintenance	As Needed	Annual costs of general materials estimated at $6,000.
Autodialer	Monthly	Cost for autodialer at each well site ($50/month).
Electricity Cost	Continuous	Electricity usage based on 3-10 HP and 1-5HP pump motors.