Remedial Investigation Report
Groundwater Operable Unit

Arizona Department of
Environmental Quality
Broadway-Pantano Water Quality
Assurance
Revolving Fund Registry Site,
Tucson, Arizona

June 1, 2012

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TABLE OF CONTENTS

VOLUME I

LIST OF TABLES

Note: Tables appear at the end of report.

LIST OF FIGURES

LIST OF FIGURES (cont'd)

Note: Figures appear at the end of report.

VOLUME II

LIST OF APPENDICES

GLOSSARY OF ABBREVIATIONS & ACRONYMS

A.A.C.	Arizona Administrative Code
ADEQ	Arizona Department of Environmental Quality
AI	air injection
amsl	above mean sea level
ASRAC	Arizona Superfund Remedial Action Contract
ASTM	American Society for Testing and Materials
AWQS	Aquifer Water Quality Standard
AWT	above the water table
bgs	below ground surface
BNL	Broadway North Landfill
BSL	Broadway South Landfill
BWT	below the water table
CAP	Central Arizona Project
CAVSARP	Central Avra Valley Storage and Recovery Project
CDM	Camp Dresser & McKee
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CERCLIS	Comprehensive Environmental Response, Compensation, and Liability Act Information System
cfs	cubic feet per second
cis-1,2-DCE	cis-1,2-dichloroethene
Collins	John S. Collins & Associates, Inc.
COCs	Contaminants of Concern (synonymous with Chemicals of Concern)
COPCs	Contaminants of Potential Concern (synonymous with Chemicals of Potential Concern)
COT	City of Tucson
COTEM	City of Tucson Environmental Management
CSM	Conceptual Site Model
CWF	Central Well Field
DIS	discrete interval sampler
DNAPL	dense non-aqueous phase liquid
EPA	U.S. Environmental Protection Agency
ERA	Early Response Action
ERNS	Emergency Response Notification System
feet/day	feet per day
ft/ft	vertical feet per horizontal feet
ft/min	feet per minute
ft/sec	feet per second
Freon 11	fluorotrichloromethane
FS	Feasibility Study
GAC	granular activated carbon
gpd/ft^2	gallons per day per square foot
gpm	gallons per minute
GOU	Groundwater Operable Unit
HGC	Hydro Geo Chem, Inc.

GLOSSARY OF ABBREVIATIONS & ACRONYMS (cont'd)

HGL	Hydrogeologic, Inc.
K_d	soil water partition coefficient
K_H	horizontal hydraulic conductivity
K_{oc}	organic carbon coefficient
K_{ow}	octanol-water coefficient
K_V	vertical hydraulic conductivity
LOFO	last on, first off
LOU	Landfill Operable Unit
LUST	leaking underground storage tank
MCL	Maximum Contaminant Level
MDL	Method Detection Limit
MeCl	methylene chloride, a.k.a. dichloromethane
mg/L	milligrams per liter
MNA	monitored natural attenuation
MSW	municipal solid waste
µg/L	micrograms per liter, directly equivalent to parts per billion in liquids
MRL	Method Reporting Limit
OD	outside diameter
PA/SI	Preliminary Assessment/Site Inspection
PAG	Pima Association of Governments
PCBs	polychlorinated biphenyls
PCE	tetrachloroethene [a.k.a. perchloroethene, perchloroethylene, tetrachloroethylene]
ppb	parts per billion
PVC	polyvinyl chloride
RAP	Remedial Action Plan
RCRA	Resource Conservation and Recovery Act
RCRA 8	RCRA 8 metals (arsenic, barium, beryllium, cadmium, chromium, copper, lead, and mercury)
RI	Remedial Investigation
RO	Remedial Objective
SARA	Superfund Amendments and Reauthorization Act
SAVSARP	Southern Avra Valley Storage and Recovery Project
SECOR	SECOR International Incorporated
Site	Broadway-Pantano WQARF Registry Site
SVE/AI	Soil Vapor Extraction/Air Injection
TCE	trichloroethene [a.k.a. trichloroethylene]
TDS	total dissolved solids
TOC	total organic carbon
Turner	Turner Laboratories, Inc.
TSS	total suspended solids
TW	Tucson Water (City of Tucson, Water Department, a.k.a. Tucson Water)
URS	URS Corporation
USGS	United States Geological Survey

GLOSSARY OF ABBREVIATIONS & ACRONYMS (cont'd)

UST	underground storage tank
VOC	volatile organic compound
WCS	Western Containment System
WQARF	Water Quality Assurance Revolving Fund

EXECUTIVE SUMMARY

INTRODUCTION

In January 1983, the volatile organic compound (VOC) fluorotrichloromethane (Freon 11) was detected in an active City of Tucson Water Department [a.k.a. Tucson Water (TW)] groundwater production well (D-022A) in TW's main potable water supply well field (called the Central Well Field, or CWF). This well is located immediately adjacent to, and downgradient of, the Broadway North Landfill (BNL). Between 1987 and 1991, TW took this well and two others (C-021A and D-021A) out of service due to detectable concentrations of tetrachloroethene (PCE) and trichloroethene (TCE) in samples of groundwater collected from the wells. Wells C-021A and D-021A are located between one-half and one mile hydraulically downgradient (toward the west) of the BNL. In 1991, the BNL and Broadway South Landfill (BSL) were entered into the federal Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS) as potential hazardous waste sites. In 1995, ADEQ completed Preliminary Assessment/Site Inspection (PA/SI) Reports for the BNL and BSL sites for the U.S. Environmental Protection Agency, Region 9 (EPA) under the federal Superfund authorities. The PA/SI report indicated that VOC contamination from the BNL and BSL sites had migrated downward through the vadose zone to the groundwater in the regional aquifer. Also in 1995, EPA designated the Broadway-Pantano Site (Site) as "state-lead," but still a federal concern. In 1998, the Site was listed on the state Water Quality Assurance Revolving Fund (WQARF) Registry.

The Site has been divided into two operable units: (1) Landfill Operable Unit (LOU), which includes the closed 100+ acre BNL, the northern part of the closed 50+ acre BSL, and the vadose zone directly beneath, and in close proximity to, the BNL and BSL boundaries; and (2) Groundwater Operable Unit (GOU) plume, which includes the volume of the saturated zone containing VOC concentrations exceeding the State of Arizona Aquifer Water Quality Standards (AWQSs). The City of Tucson ("City of Tucson" or "COT" as used in this Remedial Investigation [RI] refers to City of Tucson department which manages its landfills and environmental investigations and remediations, previously called Environmental Management, and presently called Environmental Services) investigated the BNL portion of the LOU between 1996 and 1998, culminating in issuance of a Revised Draft Final Broadway North Landfill Remedial Investigation (BNL RI) Report. In 2000, based on the results of the BNL investigations, which showed PCE, TCE, and other contaminants in the vadose zone soil gas, COT installed a soil vapor extraction/air injection (SVE/AI) system at the BNL to remove VOCs from the vadose zone. This system was operated until 2002 (removing over 1,200 pounds of PCE), at which time the performance monitoring data indicated that continued running of the system was no longer warranted. COT performed groundwater investigations in the latter 1990s through 2000 and presented these results in a GOU RI Report in 2002.

In 2001, COT and ADEQ executed a work share agreement under which COT would install, operate, and maintain a Western Containment System (WCS) with ADEQ funding and oversight. The WCS is located near the western part of the GOU. The purpose of the WCS was to prevent, to the extent feasible, further migration of the groundwater contamination within TW's CWF. This system has been operating since 2003. With execution of this work share agreement, ADEQ also assumed lead responsibility for completing the RI for the Site.

As a result, this GOU RI was conducted at the Site under the WQARF program with goals to assess the following:

1. Sources of the groundwater contamination;
2. Physical characteristics of the Site, including the geology, surface water hydrology, and hydrogeology;
3. Nature and extent of contamination in the groundwater;
4. Fate and transport of the contaminants in the groundwater; and
5. Potential risk to public health from exposure to contaminants identified in the GOU.

Prior to conducting the RI, ADEQ completed, in 2001, a review of regulatory agency databases and available historical records for the Site and Site vicinity. Based on the review, the BNL and BSL were found to be the only sources of VOC groundwater contamination. However, additional potential source research conducted by ADEQ indicates that the former sand and gravel pits at the BNL and BSL properties are another source of VOC contamination because of historic wildcat/illegal dumping that occurred at the pits.

Additionally, ADEQ completed a Water Use Study for the Site (included as an appendix) to define current and foreseeable future uses of waters (both surface water and groundwater) that have been, or are threatened to be, impacted by the contamination. Along with the Water Use Study for the Site, this RI report has been used to establish the GOU Remedial Objectives for the Site.

The LOU and other investigations are ongoing, and the results will be published in a separate RI report at a later date.

LOCATION

The Site is located in east-central Tucson, Arizona and is approximately bounded by Speedway Boulevard to the north, Pantano Wash to the east, Calle Madero to the south (south of Broadway Boulevard), and Craycroft Road to the west, or Kolb Avenue for the portion of the Site to the south of Broadway Boulevard (Figure 1). The Site is located within TW's CWF within a heavily urbanized area that is characterized by residential development between the major north-south and east-west thoroughfares and light commercial development along the major road corridors.

METHODOLOGY

Activities undertaken to achieve the RI goals included the following: (1) evaluating historical Site uses, particularly the timing and extent of landfilling of municipal solid waste (MSW) refuse, construction debris; (2) determining, to the degree possible using historical data, the vertical and lateral extent of the various landfilled solid wastes (these activities will be summarized in a separate report); (3) discrete-depth soil gas sampling and discrete-depth groundwater sampling;

(4) installing groundwater monitor wells throughout the GOU; (5) video-logging numerous water wells; (6) measuring depth-specific groundwater flow characteristics and water temperature changes with depth (in select groundwater monitor wells); (7) compiling and evaluating available environmental data for the Site generated by numerous consultants, COT, and ADEQ; and (8) developing a Conceptual Site Model (CSM) for the GOU. Additionally, ADEQ completed a focused investigation to evaluate the need for an Early Response Action (ERA) to protect or provide for the use of the two CWF production wells (C-025B and D-018A). As noted above, ADEQ also identified current and future water uses in the Site vicinity.

SITE HISTORY AND SOURCES OF GROUNDWATER CONTAMINATION

Beginning in the mid-1940s, the BNL was used for sand and gravel mining operations. Various portions of the former gravel pits at the BNL were filled with MSW refuse and/or construction debris from approximately 1959 to 1972. Sand and gravel quarrying continued simultaneously with landfilling in separate portions of the BNL into the early 1970s. Presently, the BNL is fenced to prevent trespass and wildcat dumping. Operation of the BSL began approximately in 1953 and continued until approximately 1962. MSW refuse and/or construction debris was deposited in former gravel pits where sand and gravel quarrying had occurred [Hydrogeologic, Inc. (HGL), 2012]. Additionally, as noted by HGL (2012), solvent wastes (described as spent or ”dirty” solvents) from industries that used PCE, TCE, and methylene chloride were disposed of in the Broadway Pantano Landfills. Three different types of contaminants are present in the saturated subsurface at the Site, and particularly within the BNL and/or BSL: (1) industrial solvents, such as PCE, TCE, and other chlorinated VOCs; (2) aromatic and aliphatic petroleum hydrocarbon VOCs, such as benzene; and (3) leachable toxic metals, contained in MSW refuse and construction debris.

AQUIFER CONTAMINATION

The contaminants of concern (COCs) in the GOU are those contaminants which have been detected with some consistency in groundwater above either a regulatory standard (the Arizona AWQS) or a risk-based standard. The COCs in the GOU are PCE, TCE, vinyl chloride, methylene chloride, and cis-1,2-dichloroethene (cis-1,2-DCE). The GOU extends from the BNL and BSL almost 2.5 miles to the west. The highest concentrations of COCs in the GOU have been detected at and near (within one-third of a mile of) the BNL. During the most recent groundwater monitoring event (September 2011), the BNL groundwater contained maximum concentrations of PCE, TCE, and vinyl chloride of 190 micrograms per liter (µg/L) PCE (AWQS =5 µg/L), 50 µg/L TCE (AWQS = 5 µg/L), and 2.6 µg/L vinyl chloride (AWQS = 2 µg/L). At the BSL, the highest concentration of PCE detected was 35 µg/L. Beyond one-third of a mile downgradient of the BNL, the highest concentration of PCE found in the GOU was 18 µg/L. Cis-1,2-DCE and MeCl were not detected in concentrations greater than the respective AWQSs of 70 µg/L and 5 µg/L.

CONTAMINANT MIGRATION

The VOC constituents of the plume are primarily PCE and to a lesser extent TCE, and vinyl chloride. The elongation of the VOC plume downgradient, indicates that advective groundwater transport is the primary mode of contaminant transport in the regional aquifer. The vertical extent of the groundwater plume appears to be approximately 100 feet below the water table (BWT), and may be as little as 80 feet BWT in some areas of the GOU. Where large-capacity CWF production wells are present, the advective flow patterns can be perturbed significantly when the CWF wells are pumping. However, TW has taken all of the CWF production wells within the GOU out of service. Other significant fate and transport processes that are affecting the groundwater plume in the GOU include hydrodynamic dispersion, dilution, sorption, and biodegradation. Reductive dechlorination of PCE has resulted in the generation of biodegradation daughter products TCE, cis-1,2-DCE, and vinyl chloride. Additionally, according to HGL (2012), solvent wastes from industries using PCE, TCE and methylene chloride were deposited into the “Broadway Pantano Landfills”. With the exception of the PCE plume, the other chlorinated solvent plumes have extended no more than one-third of a mile to the west of the BNL. The only groundwater plume emanating from the BSL is the PCE plume.

POTENTIAL HUMAN HEALTH RISKS

A potential human health risk can occur when humans are exposed to a contaminant. At the Site GOU, there is no current potential health risk from groundwater contamination because (1) none of the CWF production wells located within the GOU (all of which tap the regional water table aquifer) are being pumped by TW for potable water supply at this time, (2) TW’s policy is to shut down any public water supply well containing more than one-half the federal drinking water standard of a VOC, and (3) groundwater withdrawn from contaminated well 411-P, located at St. Joseph’s Hospital, is treated at the well head.

WATER USE

There are a number of TW CWF production wells, and one private water supply well (receiving wellhead treatment), located in the GOU. Four TW wells were removed from operation in the late 1980s and 1990s due to the presence of VOCs, and a fifth well was found to be contaminated after it was removed from service in late 1975. In addition, TW has placed six active water supply wells in, or near, the GOU on “last-on/first-off” (LOFO) or severely restricted-use status because of the presence of VOCs in the nearby GOU. These six wells were last pumped in late 2006 to meet system demand. TW has future plans to resume pumping of these six LOFO wells if TW ever achieves maximum resource utilization. Also, TW needs to be able to use these six LOFO wells during emergencies and to meet peak summer demand.

CONCLUSIONS

This RI report summarizes field investigations conducted by ADEQ and other parties to identify and assess groundwater contamination at the Site GOU. The ADEQ RI has adequately identified the contaminants, the nature and extent of contamination in environmental media (groundwater), the contaminant sources, fate and transport of COCs in groundwater, and associated potential public health risks.

Along with the current and future groundwater uses identified in the RI report, and other information received from the public, this RI report establishes cleanup goals for the GOU in the Remedial Objective Report that is included as an appendix.

1.0 INTRODUCTION

This is the Remedial Investigation (RI) Report for the Broadway-Pantano Water Quality Assurance Revolving Fund (WQARF) Registry Site (Site) Groundwater Operable Unit (GOU), located in Tucson, Arizona. The Broadway North Landfill (BNL) and Broadway South Landfill (BSL), which are the major sources of the groundwater contamination and, together, comprise the Landfill Operable Unit (LOU), will be addressed in a subsequent RI. The GOU RI Report has been prepared by Stantec Consulting Services, Inc. (Stantec), formerly SECOR International Incorporated (SECOR) for the Arizona Department of Environmental Quality (ADEQ). This work was completed in accordance with ADEQ Task Assignment 00-0183, dated September 8, 2000, under the Arizona Superfund Remedial Action Contract (ASRAC), Version C (ADEQ Contract No. 99-0017), dated August 10, 2000; and ADEQ Task Assignment 04-0050, dated November 24, 2003, under the ASRAC Revision 2, ADEQ Contract No. EV03-0073, dated July 28, 2003 and EV09-0100 dated May 19, 2009. The GOU RI presents the findings, conclusions, and recommendations resulting from groundwater remedial investigations conducted by SECOR (now Stantec), under the direction of ADEQ, from June 2001 through September 2011. For consistency throughout this report, work conducted by SECOR prior to the acquisition by Stantec (May 2008) will be referenced as SECOR.

The draft GOU RI report was made available for public review and comment between April 4, 2007 and May 29, 2007. ADEQ has prepared a Responsiveness Summary to address the written comments received regarding the draft GOU RI report. Both the written comments and ADEQ's responses to those comments can be found in Appendix I of this RI report.

Until 2005, much of the work concentrated on the GOU and the BNL portion of the LOU. The BSL portion of the LOU originally (as of July 2001) was excluded from investigation because an initial focused investigation (see Section 3.1.4) had not found evidence for commingling of the BNL and BSL groundwater plumes. Thereafter, the BSL site was referred to ADEQ's Site Assessment Unit for further evaluation as a separate site. In 2005, on the basis of subsequent groundwater sampling, ADEQ determined that the BSL plume was commingling with the BNL groundwater plume. The BSL was then added to the LOU, and investigations of the BSL commenced in 2006.

1.1 PURPOSE OF THE RI REPORT

This GOU RI was conducted at the Site under the WQARF program with goals to assess the following:

1. Sources of the groundwater contamination;

2. Physical characteristics of the Site, including the geology, surface water hydrology, and hydrogeology;

3. Nature and extent of contamination in the groundwater;

4. Fate and transport of the contaminants in the groundwater; and

5. Potential risk to public health from exposure to contaminants identified in the GOU.

Additionally, ADEQ completed a Water Use Study for the Site to define current and foreseeable future uses of waters (both surface water and groundwater) that have been, or are threatened to be, impacted by the contamination. Along with the Water Use Study for the Site (Appendix A), this RI report has been used to establish the GOU Remedial Objectives (ROs) for the Site (Appendix H).

1.2 SCOPE OF WORK

The scope of work for this RI Report is as follows: (1) provide a summary of groundwater investigations performed through to September 2011; and (2) to present the findings, conclusions, and recommendations resulting from groundwater remedial investigations conducted by SECOR and Stantec, under the direction of ADEQ, from June 2001 through September 2011. The following topics are covered in this report:

- Site background;
- Physical, geological, hydrological, and hydrogeological characteristics of the Site;
- Identification of sources of contamination at the Site;
- Identification of the GOU contaminants of concern (COCs) and contaminants of potential concern (COPCs);
- Discussion of the nature and extent of the groundwater contamination at the Site;
- Contaminant fate and transport within the GOU;
- Exposure and toxicity assessments of identified COCs;
- Description of the Early Response Actions (ERAs) undertaken as of the date of this report; and
- Summary and conclusions.

1.3 SITE BACKGROUND

The Site is located in east-central Tucson and is approximately bounded by Speedway Boulevard to the north, Pantano Wash to the east, Calle Madero to the south (south of Broadway Boulevard), and Craycroft Road to the west, or Kolb Avenue for the portion of the Site to the south of Broadway Boulevard (Figure 1). Figure 2 is a map of the LOU and the locations of water wells within and near the WQARF Site boundaries. The Site is located in parts of Sections 7, 8, and 17, Township 14 South, Range 15 East, and the northeastern portion of Section 12, Township 14 South, Range 14 East. Figure 2, Figure 3 and Figure 4 depict the BNL and BSL. The Site is located within Tucson Water's (TW) central municipal water well field, hereafter referred to as the Central Well Field (CWF) in this RI Report. Appendix A provides a detailed discussion of water use for the Site.

The Site has been divided into the LOU and the GOU. The LOU consists of the closed 100+ acre BNL, the northern part of the closed 50+ acre BSL, as well as the unsaturated (vadose) zones directly beneath, and in close proximity to, the closed landfills. The terms “BNL” and “BSL” refer to the landfilled areas within the property boundaries. The GOU is the volume of the aquifer (saturated zone) containing concentrations of volatile organic compounds (VOCs) exceeding the State of Arizona Aquifer Water Quality Standards (AWQSs). Since tetrachloroethene (PCE) is the only VOC constituent that is present in groundwater in concentrations exceeding the AWQS at significant distances downgradient of the LOU, the horizontal boundary of the GOU is equivalent to the lateral extent of groundwater containing concentrations of PCE exceeding the AWQS of 5 micrograms per liter (µg/L), as currently defined (SECOR, 2006b).

The GOU currently (as of September 2011) extends approximately 2.5 miles from the western edge of the BNL (Figure 5). Figure 6 depicts the extent of the GOU in September 2000. Groundwater at the Site flows generally toward the west/northwest. The groundwater table has risen approximately 15 to 20 feet during this RI. In 2001 and 2002, the depth to groundwater in monitoring wells ranged from approximately 310 feet below ground surface (bgs) to 395 feet bgs (Table 1). During the September 2011 groundwater monitoring event, the depth to groundwater ranged from approximately 290 feet bgs to 385 feet bgs. Although the groundwater table in the area has risen, the gradient has remained consistently to the west/northwest.

Based on monitoring events conducted during this RI, the GOU consists of two distinct plumes, one emanating from the BNL and one emanating from the BSL (Figure 5). No evidence of dense non-aqueous phase liquid (DNAPL) has been observed in groundwater within the plumes. In this RI Report, all references to concentrations of contaminants in groundwater are “dissolved phase”. The plumes are primarily PCE; however, trichloroethene (TCE) and vinyl chloride are also present near the BNL as shown on Figures 34 and 35 (May 2002), Figures 38 and 39 (December 2003), Figures 42 and 43 (May 2005), Figures 45 and 46 (April 2006), and Figures 50 and 51 (September 2011). At times the BNL and BSL plumes have been commingled. The BSL plume extends northwest from the BSL. The BNL plume extends westerly from the BNL and consists of discontinuous areas where PCE exceeds the AWQS (5 ug/L). The PCE concentrations in wells 411-P, C-022A, SJ-002 fluctuate above and below the AWQS, and thus the shape of the downgradient portions of the BNL plume changes over time. PCE in exceedance of AWQSs is also present in the vicinity of monitor wells BP-21, WR-702A, and WR-704A; this impact is interpreted to be part of the primary plume that migrated through the area before operation of the WCS began in March 2003 (PCE in concentrations greater than 5 ug/L has not been detected in well BP-21 since May 2010). To date, the highest concentrations of COCs found in groundwater have been at the BNL. Presently, the other COCs in groundwater at the Site are cis-1,2-dichloroethene (cis-1,2-DCE) and methylene chloride (MeCl); however, these COCs have not been detected in concentrations greater than the AWQSs of 5 µg/L MeCl and 70 µg/L cis-1,2-DCE since November 2005 (MeCl in WR-273A and cis-1,2-DCE in R-068A).

1.4 SITE HISTORY

A chronology of events that have occurred at the Site is provided in Table 2. The entries for the period 1976 through January 2001 were taken from Table 1-1, Chronology of Events [for the] Site GOU, that was presented in URS Corporation, or URS (2002a).

In January 1983, a concentration of 16.2 µg/L (Freon 11) was detected in a groundwater sample collected from City of Tucson Water Department [a.k.a. Tucson Water (TW)] production well D-022A (URS, 2002a). Well D-022A is located immediately adjacent to, and downgradient of, the BNL (Figure 2). Between 1987 and 1991, TW took production wells C-021A, D-021A, and D-022A out of service because of laboratory-detected concentrations of PCE in groundwater samples collected from these wells (Camp Dresser & McKee, [CDM]; 1998). Wells C-021A and D-021A are located one-half mile to one mile hydraulically downgradient (toward the west) of the BNL (Figure 2).

Portions of the BNL property were operated as a municipal landfill at various times from approximately 1959 to 1972 by the Sanitary District No. 1 of Pima County, City of Tucson (COT), and Pima County (CDM, 1998). According to an April 4, 2012 letter report prepared by HGL, all kinds of agricultural, commercial, and industrial wastes (including chemicals) were deposited at the BNL, with disposal rates ranging from a few tons per day to 300 tons per day, and there were no restrictions on the types of waste deposited (HGL, 2012). After closure, the BNL property was covered with soil, and, with the exception of a strip mall and parking lot constructed at its far southeastern edge, has been left undeveloped (Aplomado Environmental Inc., 2001; HGL, 2012). In 2003, the property owner installed security fencing along the southern, western, and northern borders of the BNL to prevent wildcat dumping and other unauthorized accessing (in other words, “trespassing”) of the property. The Pantano Wash forms the eastern border of the BNL. Detailed information regarding BNL land use history and selected historical aerial photographs and figures of the BNL vicinity are included in Appendix B.

Portions of the BSL property were operated as a municipal landfill from 1953 to 1962 by Pima County and by Sanitary District No. 1 of Pima County; however, the precise date that operation began is unknown (HGL, 2012). Landfilling operations began in 1953 at the north end of BSL, along East Broadway Boulevard, and progressed southward, ending in 1961 or 1962. Refuse was deposited at a rate of about 200 tons per day (Pima Association of Governments [PAG], 1997; HGL, 2012). There were no restrictions placed on the types of refuse that were deposited into the BSL (HGL, 2012). According to Dooley (1993), cover material was obtained from Pantano Wash, and the southern 300 feet of the property was used for dumping construction material. Since the southern boundary of the BSL moved as the operation progressed southward, the location of the area where construction material was landfilled is uncertain. A recycling operation was also active in the late 1950s and early 1960s and was used to extract metal from the refuse for recycling; however, the location of this facility is not known (Dooley, 1993). Since closure, the BSL has remained undeveloped, except, in the northeastern portion, where a Hilton Hotel property was developed, and, the northwestern portion, where a Culvers Restaurant was developed.

In 1991, the BNL and BSL were identified as potential hazardous waste sites (specifically, as possible sources of groundwater contamination found in certain downgradient TW production wells) and entered into the Comprehensive Environmental Response, Compensation, and

Liability Information System (CERCLIS) on August 2, 1992 [#AZD983471426]. In 1995, ADEQ completed Preliminary Assessment/Site Inspection (PA/SI) Reports of the BNL (ADEQ, 1995a) and BSL (ADEQ, 1995b) sites for the U.S. Environmental Protection Agency, Region 9 (EPA) under the authority of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) and the Superfund Amendments and Reauthorization Act of 1986 (SARA). In 1999, a Site Reassessment was completed. In 2000, EPA designated the Site as "state-lead," but still a federal concern (personal communication, Dawn Richmond, of EPA Region 9 Superfund, April 19, 2004).

In April 1994, PCE and TCE were detected in groundwater samples collected from a private supply well (411-P) located at St. Joseph's Hospital (Figure 2; URS, 2002a). TW supplied water to the hospital until a wellhead treatment system was installed on the St. Joseph's Hospital well in 1997. The Site was listed on the WQARF Registry in 1998 (ADEQ, 1998). COT and Pima Country submitted the BNL RI Report, which was prepared by Camp Dresser & McKee (CDM), to ADEQ in March 1998. Analytical results from deep soil gas testing beneath the landfill (BNL) were submitted to ADEQ in July 1998. COT's findings and conclusions in the BNL RI Report were that vapor phase VOCs were migrating from the base of the BNL landfilled areas and slowly dissolving into the underlying groundwater (CDM, 1998). Depth to groundwater in the vicinity of the landfill during the most recent monitoring event (September 2011) ranged from approximately 290 to 383 feet bgs.

To remove the vapor phase VOCs beneath the closed BNL, COT and Pima County installed, as an ERA, a soil vapor extraction/air injection (SVE/AI) remediation system. The SVE/AI system began operating in June 2000; and the system remained operational through September 2002 and removed almost 2000 pounds of non-Freon VOCs (SECOR, 2003c).

Throughout the 1990s, COT, with Pima County assistance, conducted groundwater investigative activities at the Site. These activities are documented in the aforementioned BNL RI Report (CDM, 1998); the COT GOU RI Report in 2002 (URS, 2002a); and the conceptualization of the Interim Groundwater Containment Plan in 2000 (URS, 2000).

In 2001, ADEQ and COT executed a work share agreement (ADEQ & COT, 2001) under which:

1. COT would design and install the groundwater Western Containment System (WCS) with ADEQ oversight and funding,
2. COT would operate the WCS [with ADEQ oversight and funding],
3. ADEQ would conduct the WCS performance monitoring,
4. ADEQ would operate the SVE system at the BNL, and
5. All of the above work would be done with regular consultation between ADEQ and COT.

In addition to the SVE/AI ERA undertaken at the BNL, COT completed the design and installation of the WCS. Elements of the WCS ERA include two groundwater recovery wells (R-092A and C-026B), two injection wells (R-090A and R-091A), and a groundwater treatment facility (inside compound with the R-092A extraction well) located in the vicinity of Wilmot Road between Speedway Boulevard and Broadway Boulevard (Figure 2). The WCS became fully operational on March 24, 2003. During its first year of operation, the WCS treated over 360 million gallons of contaminated water. However, the main purpose of the WCS is to prevent, to the extent feasible, further westward migration of the contaminant plume within the CWF.

The reinjection of the treated water aids in maintaining this hydraulic containment by “pushing” contaminated water toward the recovery wells, most particularly toward well C-026B. Figure 8 depicts the WCS portion of the GOU after six months of WCS operation.

Until 2005, ADEQ considered the only source of the VOC groundwater plume to be the BNL (Appendix C). The BSL was referred to ADEQ’s Site Assessment Unit for further evaluation as a separate site, because an initial focused investigation (see Section 3.1.4) had not found evidence for commingling of the BNL and BSL groundwater plumes. In 2005, on the basis of subsequent groundwater sampling, ADEQ determined that the BSL plume was commingling with the BNL groundwater plume. The BSL was then added to the LOU for the Site, and investigations of the BSL commenced in 2006.

1.5 REPORT ORGANIZATION

The remainder of this RI Report is organized in the following manner:

- Section 2.0 summarizes the physical characteristics of the Site.
- Section 3.0 presents the GOU RI activities conducted between July 2001 and September 2011. A comprehensive discussion of historical groundwater investigative activities completed prior to the current RI is also included.
- Section 4.0 summarizes the results and presents conclusions regarding the nature and extent of impacted groundwater in the GOU.
- Section 5.0 deals with contaminant fate and transport of the impacted environmental media (groundwater) at the Site.
- Section 6.0 presents a groundwater exposure assessment for the Site.
- Section 7.0 provides a summary of the ERAs and other activities undertaken to date to mitigate adverse impacts at the Site.
- Section 8.0 presents a summary of findings and conclusions that are based upon the data collected during RI activities conducted at the Site.
- Section 9.0 contains a detailed list of references cited in this draft GOU RI Report.

2.0 PHYSICAL CHARACTERISTICS

The Site (Figure 1) comprises an area of approximately one square mile (approximately 640 acres) in portions of Section 12, Township 14 South, Range 14 East, and in Sections 7, 8, and 17, Township 14 South, Range 15 East, Pima County, Arizona, and is located within the municipal limits of the COT. The Site is approximately bounded on the east by Pantano Wash, on the south by Calle Madero (south of Broadway Boulevard), on the north by Speedway Boulevard, and on the west by Craycroft Road, or Kolb Avenue for the portion of the Site to the south of Broadway Boulevard (Figure 1).

2.1 LAND USE AND DEMOGRAPHICS

Land use in the vicinity of the Site is largely residential with some commercial development. Commercial development is generally located along the main streets passing through the area (Broadway and Speedway Boulevards, and Wilmot and Kolb Roads) and in the vicinity of St. Joseph's Hospital. The commercial development consists mainly of retail businesses and professional offices. Open undeveloped land is located at the BNL and BSL and to the east of the St. Joseph's Hospital complex. Refer to Appendix A for a detailed discussion of water use.

Multiple-tenant dwellings, a YMCA facility, and Gollob Park are present to the south of the estimated southern border of the BSL, and single-family homes are present to the west of the BSL across Prudence Road. A Hilton hotel has been constructed in the northeastern portion of the BSL, and a Culver's Restaurant has been constructed in the northwestern part of the BSL. The remainder of the BSL is undeveloped (Figure 4). An electrical substation is located to the northwest of the BNL, and a parking lot and entertainment center are located to the north of the BNL. The Pantano Wash runs along the eastern edge of the BNL and the eastern edge of the BSL. Single-family homes abut the southwestern perimeter of the BNL. A strip mall and parking lot sit on top of a portion of the southeastern landfilled area. Except for the strip mall, the BNL is undeveloped and has been fenced to preclude wildcat dumping and trespassing (Figure 3).

The Site is located within the boundaries of Zip Code 85710. The 2010 census data for the 85710 Zip Code reported that 54,439 people resided within the area. The population density for the area within the zip code is approximately 20,465 people per square mile. Potential human sensitive receptors (i.e., the young, the old, and/or infirm persons) residing within the area include students at Hudlow Elementary, Sewell Elementary, Saint Michael's Day Schools, and patients at St. Joseph's Hospital; as well as residents living directly adjacent to the southwestern boundary of the BNL and BSL, and trespassers on the surface of the closed landfill areas.

2.2 TOPOGRAPHY

The surface elevation of the Site ranges from approximately 2,530 to 2,580 feet above mean sea level (amsl). The surface topography is relatively flat and slopes to the northwest. Three ephemeral washes, each trending south to north and draining toward the north, are located in the vicinity of the Site. Pantano Wash is located at the east boundary of the Site, Rose Hill

Wash is located east of St. Joseph's Hospital, and Alamo Wash is located near the western boundary of the Site.

Except in areas of undeveloped land, surface runoff generally is directed toward the ephemeral washes. Infiltration of surface water in developed areas is reduced due to the presence of buildings, residences, and asphalt/concrete covered streets and parking areas. The main groundwater recharge areas are likely to be the ephemeral washes and undeveloped land areas. Previous investigations have noted that Pantano Wash, the largest of the three washes in the vicinity of the Site, is a poor source of stream channel recharge (URS, 2002a; Osterkamp, 1973; Alter, 2012). Due to current land use and the limited amount of precipitation in the area, significant recharge to the underlying aquifer from surface infiltration in the vicinity of the Site is likely to be minimal.

In general, based on visual observation of the BNL after heavy rainfall events, drainage from the thinly-capped landfilled areas appears to be adequate, particularly along the eastern perimeter, the southeastern portion, and the northwestern portion of the BNL adjacent to Gateway Center Circle. However, minor ponding occurs throughout the capped area, and sinkholes have developed in the central portion of the BNL (beside the SVE/AI treatment compound) and within the northern landfilled area of the BNL. Refer to Section 3.1.1 and Appendix B for further details on cover material thicknesses at the BNL.

2.3 CLIMATE

The Site is located in the Sonoran Desert and has a climate characteristic of the lower elevations of the southwestern U.S. The summers are long, lasting from April through October. Winters are dry and mild. Average monthly temperatures range from a low of 51.3 degrees Fahrenheit (°F) in January, to a high of 86.6°F in July, with an average of 26 sunny days per month, based upon data from the National Weather Service Forecast Office in Tucson, Arizona (National Weather Service, 2012).

According to National Weather Service (2012), the average monthly temperatures (which are the mean values for the monthly average high and average low temperatures) for the Tucson metropolitan area during 2011 ranged from a low of 48.9°F in December 2011, to a high of 89.3°F in August 2011. The highest monthly average high temperature was 103°F recorded in June, and the lowest monthly average low temperature was 36.2°F recorded in January. Daily temperature extremes ranged from 112°F (June 27, 2011) to 18°F (February 3rd and 4th, 2011).

National Weather Service (2012) also reports that 2011 is the 19th warmest year on record and the 38th wettest on record. The "monsoon" season of 2011 (which typically lasts from mid-July to mid-September) was the 10th warmest on record.

The normal yearly rainfall is 11.59 inches (based on annual precipitation data from 1981 to 2011). However, since 1994, the Tucson metropolitan area has experienced sustained drought conditions. From 1994 to 2011, the normal yearly rainfall was met or exceeded four times (in 1998, 2000, 2006, and 2011). The lowest rainfall recorded during this period was 5.67 inches in 2009 (National Weather Service, 2012).

Annual precipitation averaged 12 inches between 1961 and 1990, which is indicative of semi-desert conditions. Since 1895, the maximum annual precipitation recorded was 24.17 inches in 1905, and the minimum was 5.07 inches in 1924. In general, there are two periods of precipitation annually (Webb and Betancourt, 1992). In the winter, precipitation in the form of storm fronts moves into Arizona from the Pacific Ocean (U.S. Department of Agriculture [USDA], Soil Conservation Service, [SCS]; 1972). Fifty percent of the annual precipitation occurs during the "monsoon" season from mid-July through mid-September (USDA-SCS, 1972). This moisture comes from the Gulf of Mexico in the south.

2.4 SOILS

The primary soil classification for the Site and vicinity is the Mohave soils and Urban Land (USDA-SCS, 1972). These soils generally occur on 1 to 8 percent slopes that are broad, gently sloping, fan terraces, often dissected by shallow ephemeral drainage ways. The Mohave soils are formed in mixed alluvium and are very deep and well drained. The soils consist of sandy to sandy clay loam. The Mohave soils have a moderately slow permeability and high available water capacity. The Urban Land consists of soils altered by construction or obscured by structures and pavement, thus making identification difficult. In general, the underlying soil has many of the characteristics of the Mohave soil.

In an area trending north-south across the central portion of the GOU, the Cave soils are present. These soils are very shallow and calcareous throughout. Typically, the surface layer is gravelly fine sandy loam underlain by caliche at a depth of four to 20 inches. Permeability of the Cave soil is moderate with a very low available water capacity.

Immediately east of the BNL, and in proximity of the Pantano Wash, is a small area of Anthony fine sandy loam. The Anthony loam is a deep, well-drained soil that occurs on nearly level flood plains. It typically consists of gravelly sandy loams and has a moderately rapid permeability. All of the soils in the Site vicinity extend to an approximate depth of 60 inches bgs. The composition of these soils has little to no impact on investigation of the GOU.

2.5 GEOLOGIC SETTING

The following section describes the regional geology of the surrounding area of interest and the specific geology of the Site.

2.5.1 Regional Geologic Setting

The Site lies within the eastern portion of the Tucson Basin. The Tucson Basin is a broad northwest-trending structural basin filled with thousands of feet of consolidated to unconsolidated alluvial sediments derived by weathering from the surrounding mountain ranges (Anderson, 1987). The alluvial valley encompasses approximately 1,000 square miles and is bounded by mountain ranges on the northeast, east, and west margins.

The aquifer underlying the Tucson Basin consists of three primary water-bearing units. These units, in descending stratigraphic order, are the Quaternary-Age Fort Lowell Formation, the Tertiary-Age Tinaja beds, and the Tertiary-Age Pantano Formation. Quaternary (Holocene)-Age surficial alluvium overlies these formations. The alluvial deposits typically are gravels and gravelly sands with localized sands and sandy silts, and they range in thickness from a thin veneer to several tens of feet. The surficial deposits are not hydrologically significant because the water table is below these deposits throughout most of the Tucson Basin. The alluvium along some reaches of Rillito Creek and of smaller tributaries is saturated. The saturated alluvium receives and temporarily stores recharge from flood flows (Davidson, 1973).

The Quaternary-Age Fort Lowell Formation is composed of gravels near the basin margins and grades to silts near the center. The formation ranges in thickness from 300 to 400 feet, thinning toward the basin margins (Davidson, 1973). The Fort Lowell Formation is estimated to be 300 feet thick in the Broadway-Pantano GOU Area.

The Tertiary-Age Tinaja beds rest unconformably below the Fort Lowell Formation. They are composed of gravels and sands grading to a very thick sequence of gypsiferous clayey silts and mudstones toward the center of the Tucson Basin (Davidson, 1973). These beds were deposited in an internally draining basin, and they are estimated to be several thousand feet thick near the center (Davidson, 1973). The top of the Tinaja beds is encountered at an estimated depth of 300 to 320 feet bgs in the vicinity of the Site. The Tinaja beds are informally divided into the upper, middle, and lower Tinaja beds. The upper Tinaja beds consist predominantly of sands and clayey silts in the central Basin, whereas sands and gravels predominate near the mountain flanks. The middle Tinaja beds consist of gypsiferous and anhydritic clayey silts and mudstones, and the lower Tinaja beds consist of silty gravels and conglomerates. Based on lithologic logging and downhole geophysical logging, the lower portion of the upper Tinaja beds occurs at depths of approximately 470 to 540 feet bgs within and near the Site (Montgomery, 1992).

The Tertiary-Age Pantano Formation lies unconformably under the Tinaja beds, and it rests on pre-Tertiary crystalline and sedimentary bedrock. The Pantano Formation is composed of conglomerates, sandstones, mudstones, and gypsiferous mudstones. These sediments are moderately well lithified, and they are occasionally interbedded with volcanic flows and tuffs, and locally contain landslide debris and lenses of megabreccias. Sediments of the Pantano Formation are as much as several thousand feet thick (Anderson, 1987). Sediments of the Pantano crop out close to the edges of the Tucson Basin; a well log in the central part of the Basin indicates that the Pantano Formation is buried by more than 8,000 feet of younger rocks and sediments along the central axis of the Basin. However, between the central part of the Basin and the edges of the Basin, the depth of the contact between the Pantano Formation and younger rocks and sediments is uncertain. Only a few wells penetrate the Pantano Formation (Anderson, 1987).

2.5.2 Site Geology

Site-specific geologic conditions have been characterized through the logging and installation of 46 monitoring wells within, and adjacent to, the GOU. In addition, 15 TW production wells are present in the vicinity of and within the GOU, and three remedial wells have been installed at the BNL. The locations of these monitoring, production, and remedial wells are illustrated on Figure 2. Well boring logs for the SECOR-installed wells are presented in Appendix D. Refer also to Appendix C and E of CDM (1998) for BNL well borings and selected GOU water well borings, respectively, and to Appendix A of URS (2002a) for COT-installed monitor well borings.

Based on interpretation of these well logs, TW characterized the geology in the area of interest as consisting of thick homogenous sequences of sand and gravel which comprise the regional aquifer (TW, 1992). Based on lithologic logging of TW production wells in the vicinity of the GOU, sands and gravels extend to depths of 800 to 900 feet bgs. The degree of cementation increases with depth. TW also noted that a 20-foot-thick layer of alluvial veneer covered the surface of the study area (TW, 1992). This veneer consisted primarily of volcanic and gneissic sands with minor gravels and clays, and it typically supported the formation of soils and the development of caliche. Adjacent to the Pantano Wash, the alluvium may be as a much as 45 feet thick.

In 1996 and 1997, three monitoring wells (WR-273A, WR-274A, and WR-275A) were installed on the west side of the BNL. The lithologic logs of the well borings indicated the presence of a 20-foot-thick layer of landfill material at the BNL, underlain by up to 75 feet of poorly graded sands. Underlying these sands, to a depth of approximately 275 feet bgs, were predominantly well graded sands interbedded with clayey sands and sandy clays. The clayey sand layers may be as much as 50 feet thick. At a depth of approximately 275 feet bgs, granitic gravels were encountered; the water table was found within these gravels. The well borings were drilled to a maximum depth of 360 feet bgs (CDM, 1998).

In 1998, three monitoring wells (SJ-001, SJ-002, and SE-001) were installed by ADEQ. Wells SJ-001 and SJ-002 were installed about 0.75 mile west of the BNL, and well SE-001 was installed about 1.75 miles west of the BNL. The lithologic logs for well borings SE-001, SJ-001, and SJ-002 indicated that subsurface deposits consisted predominantly of gravelly sands and sandy gravels with varying silt contents, with 2- to 5-foot-thick interbedded layers of gravels or gravels with cobbles. The total borehole depths for SJ-001, SJ-002, and SE-001 were 396 feet, 398 feet, and 375 feet, respectively (Weston, 1999).

In 1999, four deep monitoring wells (WR-352A, WR353A, WR-354A, and WR-358A) were installed by COT (URS, 2000). Review of the lithologic logs for these well borings indicated thick sequences of clean sands (both poorly graded and well graded) interbedded with thinner silty sands or silts from the surface to approximately 275 feet bgs. Fine and coarse gravel deposits, some as much as 20 feet thick, were encountered from approximately 275 feet bgs to total depth of exploration (465 feet bgs). The gravel deposits were interbedded with sands and silty sands.

There have been no reported findings of perched water or perching conditions in the area. In addition, none of the reviewed historical investigations (see Section 3.2) have reported the presence of faults or other structural features downgradient of the LOU that may impact the migration of contaminants.

Using soil boring logs from previous BNL investigations (CDM, 1998; and Hydro Geo Chem, Inc. [HGC], 2000a), SECOR constructed five stratigraphic cross-sections in the vicinity of the BNL. The locations of the stratigraphic cross-sections are shown on Figure 9. Cross sections A-A’, B-B’, C-C’, D-D’, and E-E’ are presented on Figure 10 through Figure 14, respectively. Sediments encountered in the vicinity of the BNL consist of discontinuous horizons of clayey sands and silty sands within thick deposits of well-graded to poorly-graded sands in the upper 250 to 300 feet. Granitic gravels dominate the stratigraphy from approximately 250 to 350 feet bgs, underlain by sands and silty sands interbedded with gravel to the total depth of exploration (368 feet bgs).

A stratigraphic cross-section (cross-section F-F') running north-south through the center of the BSL and Prudence Landfills is shown on Figure 15, and the location of the cross-section is shown on Figure 16. Sediments encountered at the BSL and Prudence Landfills primarily consist of discontinuous horizons of clayey sands, silty sands and gravels within thick deposits of well-graded to poorly-graded sands in the upper 300 to 400 feet. Granitic gravels dominate the stratigraphy from approximately 400 feet (at BSL) and 300 feet (at Prudence Landfill) to the total depth of exploration (458 feet bgs at BSL, 405 feet bgs at Prudence Landfill).

A stratigraphic cross-section (cross-section G-G') running west to east across the GOU is shown in Figure 17, and the location of the cross-section is shown on Figure 7. Sediments encountered in the GOU primarily consist of thick sequences of well-graded to poorly-graded sands with discontinuous lenses of clayey sands, silty sands, and gravels. Clayey sand sequences are several hundred feet thick near boring BP-21, and thick gravel deposits are present from 350 feet bgs to at least 470 feet (total depth of exploration) in the western one-third of the GOU.

2.6 SURFACE WATER HYDROLOGY

The GOU area is well developed with residential developments, paved roads, and commercial facilities with paved parking areas. Most of the excess surface water drains along paved roadways into Pima County storm drains and into the adjacent natural washes. The washes present in the Site vicinity include the Pantano Wash on the eastern GOU boundary, the Rose Hill Wash near the center of the GOU, and the Alamo Wash near the western edge of the GOU. Each of these washes drains to the north into the Rillito River.

Because of its proximity to the BNL and BSL, Pantano Wash would be the surface water feature most likely to influence groundwater gradient, direction of flow, and quality in the GOU (Figure 1). Flow in Pantano Wash is ephemeral and occurs in response to runoff from precipitation events (chiefly during summer monsoon storms). The greatest average monthly precipitation occurs in the summer months (July through September), and 50 percent of the total annual precipitation occurs during these summer months in response to convective thunderstorms that precipitate moisture from the Gulf of Mexico (the aforementioned "monsoons"). Summer precipitation is localized and moderate on a daily basis, but it may be intense on an hourly basis. Occasional tropical storms from the Gulf of California and the Pacific Ocean precipitate large amounts of rainfall over much of the state, most frequently in late August and September. Winter precipitation, chiefly from cyclonic storms that originate to the northwest and move eastward across the Tucson Basin, is widespread and light to moderate in intensity (Davidson, 1973).

Flow in Pantano Wash is measured at a United States Geological Survey (USGS) stream gauging station near Vail, Arizona. The Site is located approximately 17 miles downstream from the Vail gauging station, along a reach that receives ungauged flow from Rincon Creek. The drainage area upstream of the Vail gauging station is about 457 square miles. Stream flow was recorded for the period of record from 1959 until 1973, when the gauging station was converted to a crest stage, partial record station. Maximum annual flow is about 8,800 acre-feet; minimum annual flow is about 1,490 acre-feet; and average annual flow is about 4,850 acre-feet. Peak flow for the period of record was 12,000 cubic feet per second (cfs). Pantano Wash at the Site drains a larger area than is drained by Pantano Wash at the Vail gaging station. Additionally, the area that the Pantano Wash drains at the Site has more commercial and residential development than does the area that the Pantano Wash drains at the Vail gaging station. Therefore, flow at the Site is probably higher than flow at the Vail gaging station when Pantano Wash is in flood (URS, 2002a).

Pantano Wash has been identified in previous studies as a poor source of stream channel recharge, relative to other stream channels in the Tucson Basin (Hanson and Benedict, 1994). Estimates for annual stream channel recharge for Pantano Wash range from 50 to 100 acre-feet per mile, or acre-feet/mile (Osterkamp, 1973), up to 240 acre-feet/mile (Anderson, 1987).

2.7 HYDROGEOLOGIC SETTING

The following sections describe the hydrogeologic setting of the Site and vicinity. The Site-specific hydrogeology of the GOU was evaluated through review of historical groundwater data, boring logs from wells located within the GOU, a groundwater flow model developed for the Site by COT, and previous remedial investigations completed for the BNL.

2.7.1 Regional Hydrogeology

The term “basin fill” refers to the assemblage of sedimentary units that form a regional, stratified, unconfined aquifer system that is underlain and bounded on the north and east by relatively impermeable bedrock. The regional aquifer consists of alluvium that is divided into Upper, Middle, and Lower Basin Fill hydrostratigraphic units in the manner suggested by Rogers (1987). This categorization is based upon regional (i.e., Basin-wide) hydrogeologic characteristics as presented in Anderson (1987) and Rogers (1987). Table 3 presents hydrogeologic parameter estimates for the regional aquifer in the Tucson Basin, and it provides a summary of the general relationships between the geologic units presented in Section 2.5 and the suggested hydrostratigraphic units described above. This table is adapted from Table 2-1 of URS’s 2002 GOU RI Report (URS, 2002a).

The Upper Basin Fill generally is equivalent to the Recent Alluvium, the Fort Lowell Formation, and the uppermost of the upper Tinaja beds. The Middle Basin Fill generally is equivalent to the lowermost of the upper Tinaja beds. The Lower Basin Fill is equivalent to the Pantano Formation, the lower Tinaja beds, and the middle Tinaja beds. In general, sediments of the Lower Basin Fill are less transmissive than sediments of the Upper Basin Fill. However, the Lower Basin Fill can store a greater volume of water than can the Upper Basin Fill, because it is thicker (Hanson and Benedict, 1994). The Precambrian intrusive and metamorphic rocks act as a lower confining unit (or aquiclude) for the Tucson Basin. Groundwater flow within the Tucson Basin generally is to the north-northwest, and the aquifer generally is unconfined to depths of 1,500 feet.

Inflows to the regional aquifer occur as: (1) groundwater underflow from the northeast, south, and southeast; (2) mountain-front recharge; and (3) natural infiltration along stream channels. Davidson (1973) reported that average annual inflow into the entire Tucson Basin was about 100,000 acre-feet; that underflow to the basin was about 17,800 acre-feet; that mountain front recharge was about 31,000 acre-feet; and that stream channel infiltration was about 51,000 acre-feet.

Outflows from the Tucson Basin occur as well pumpage, evapotranspiration, and groundwater underflow to the northwest. Groundwater withdrawals for industrial, irrigation, and municipal supply in the Tucson Basin have increased from the 1930s to present; since the 1940s, total withdrawals have exceeded natural recharge and underflow into the basin. As a result, significant groundwater level declines have been observed within the Tucson Basin. For example, TW reported declines for the CWF of up to 200 feet between 1950 and 1995, with declines in some areas averaging up to 4 to 5 feet per year (ADWR, 1999). Since 2001, however, groundwater levels in the GOU area have been rising (Stantec, 2012).

Movement and storage of groundwater are controlled by the distribution of hydraulic heads and by the transmissive and storage properties of the regional aquifer. Hydraulic properties in the basin vary laterally and vertically, depending on lithologic factors, such as grain size, sorting, and degree of cementation (Hanson and Benedict, 1994).

2.7.2 Site Hydrostratigraphy

The water table occurs at an elevation of approximately 2,279 feet amsl east in the vicinity of the Prudence Landfill and Pantano Wash, and it declines to 2222 feet amsl near the western edge of the GOU near Craycroft Road (September 2011) (Table 1). The groundwater gradient ranged from approximately 0.002 to 0.003 vertical feet per horizontal foot (ft/ft) across the GOU and the average depth to groundwater was approximately 325 feet bgs during the September 2011 monitoring event (Stantec, 2012). The natural groundwater gradient in the Tucson Basin generally is toward the northwest. In the east-central part of the Basin, where the GOU is located, groundwater flows from areas of mountain front recharge to the north, east, and south towards CWF pumping wells in the center of the Basin and towards the basin outflow to the northwest. In the immediate vicinity of the GOU, the groundwater flow directions are perpendicular to the groundwater elevation contour lines shown on Figure 5 and all other groundwater elevation contour maps.

Temporal changes in direction and magnitude of hydraulic gradients may occur in response to pumping of large-capacity production wells. According to Johnson (1993), there is a low hydraulic conductivity zone called the Pantano Feature east of the GOU; the zone trends from the southeast to the northwest. Steep hydraulic gradients east of the GOU are attributed to the Pantano Feature (Johnson, 1993).

A well search by City of Tucson Environmental Management (COTEM) and the PAG completed in 1999 (COTEM and PAG, Draft, 1999) identified eight active private wells, three ADEQ monitor wells, and 36 COT and TW CWF monitor or production wells in a 5-square-mile area including the GOU. These groundwater wells generally are screened in the Upper Basin Fill unit, which is comprised of the Fort Lowell Formation and the uppermost upper Tinaja beds. Most of the production wells at the Site and in the Site vicinity (including those in the CWF) are completed in the highly-transmissive Upper Basin Fill unit.

Typical horizontal hydraulic conductivity (K_H), which were estimated from 24- and 48-hour pumping tests at six TW production wells located in or near the Site GOU, ranged from approximately 54 to 118 feet per day (feet/day) (URS, 2002a), which converts to 404 to 883 gallons per day per square foot (gpd/ft^2). Vertical hydraulic conductivity (K_V) was measured at well C-026B (Errol L. Montgomery and Associates, 1992). The ratio of K_H/K_V was about 15:1, with a K_H of 280 gpd/ft^2 and a K_V value of 19 gpd/ft^2.

Based on water level measurements since 2001, groundwater flow at the Site is from the east toward the west-northwest and west across the GOU, as illustrated in Figure 5 (for September 2011). Figure 18 depicts the groundwater elevation contour map for March 2003 for the GOU just prior to the startup of the WCS. The average linear velocity for groundwater is 0.96 feet per day, based on a K_H of 75 feet/day (Dames & Moore, 2000), a specific yield of 0.25, and a hydraulic gradient of 0.003 ft/ft. Table 3, which is taken in part from Table 2-1 of URS (2002a), provides a summary of hydrogeologic parameter estimates for hydrostratigraphic units in and near the GOU.

According to Marra (1992) and Errol L. Montgomery and Associates (1992), there is a pronounced decrease in transmissivity values at the transitional contact between the uppermost upper Tinaja beds and the lowermost upper Tinaja beds. This contact generally occurs at depths ranging from approximately 470 to 540 feet bgs across the Site. This contact marks the depth at which moderately well-cemented unconsolidated sediments near the base of the Upper Basin Fill Unit become moderately well lithified.

In March 2003, prior to initiation of WCS operation, groundwater elevations in the vicinity of the Site ranged from 2207.87 to 2245.52 feet amsl. In September 2011, the groundwater elevations in the vicinity of the Site ranged from 2,222 to 2,279 feet amsl (Table 1). Groundwater flow in March 2003 through September 2011 was toward the west-northwest, at a gradient of approximately 0.003 ft/ft (Figure 18 and Figure 5, respectively).

According to URS (2002a), the groundwater in and near the GOU is a calcium bicarbonate type, and ambient inorganic groundwater quality is good. URS (2002a) stated that total dissolved solids (TDS) content ranged from about 200 to 250 milligrams per liter (mg/L) [except in the vicinity of the BSL and BNL where the TDS content ranged from 277 to 540 mg/L] and that nitrate concentrations in the GOU water-bearing zones ranged from about 2.5 to 8.8 mg/L.

2.8 PRESENT AND FUTURE GROUNDWATER USES

TW currently relies on water supply production from five well fields within the Tucson Basin and Avra Valley to meet current municipal demand (TW, 2004). The most significant renewable source of potable supply is the Central Avra Valley Storage and Recovery Project (CAVSARP) Well Field located in Avra Valley, while the CWF is TW's largest groundwater supply source (TW, 2004). The CWF is located in the Tucson Basin and encompasses much of the urbanized footprint of the COT. The GOU is situated within the CWF (TW, 2007).

TW has numerous water supply wells in the vicinity of the GOU (Figure 2). Four wells (C-021A, C-026B, D-021A, and D-022A) have been removed from operation since the late 1980s and early 1990s due to the presence of VOCs. A fifth well, C-022A, was contaminated after it was removed from service in October 1975. In 1994, TW designated five active water supply wells (C-020B, C-026B, C-056B, C-058B, and C-114A) as restricted-use status ("last on/first off", or LOFO) because of their proximity to the GOU. LOFO wells are among the last wells to be brought into service and the first wells to be taken out of service when a period of increased water supply need arises. In 1998, C-026B was removed from operation because of PCE contamination. In 1999, TW voluntarily has placed two other wells (wells C-025B and D-018A), both situated immediately south of the GOU, on restricted use to limit the potential for the GOU groundwater contamination to migrate toward these wells and to ensure the availability of these wells for supply should a need arise (URS, 2002a). All of these six LOFO wells were pumped in 2006 to assess the viability of the well infrastructure to meet system demand. TW is continuing to maintain and sample these wells so that they will be available to meet system demand as may be required (TW, 2007). Table 4 provides a summary of annual production (in millions of gallons) of TW CWF water supply wells located within the vicinity of the GOU. The table presents full production data for 1957 through 2010.

TW currently has a policy to take wells out of service that have VOC concentrations that exceed half of the potable drinking water standards for any regulated VOC compound (i.e., EPA Maximum Contaminant Levels [MCLs] or ADEQ AWQSs). The six municipal wells in the immediate vicinity of the GOU are being monitored for VOCs at least semi-annually, and at least monthly during those times when the wells are brought into service for more than seven days. This policy ensures the quality of potable water supplies drawn from this area (TW, 2007).

According to TW, the CWF has historically been, and will remain, an essential component of TW's water supply infrastructure. Current TW plans include continuing the recharge and recovery of Central Arizona Project (CAP) water at CAVSARP, an operating storage and recovery facility in the Avra Valley. Potable use of the recovered blend of CAP water and Avra Valley groundwater began in May 2001 and continues to the present. TW has expanded the recharge capacity of CAVSARP up to 80,000 acre-feet per year. TW is also currently in the process of developing a project similar to CAVSARP several miles to the south; this facility is called the Southern Avra Valley Storage and Recovery Project (SAVSARP), and it will provide an additional source of renewable supply. The recharge component of the SAVSARP facility, which is permitted to recharge up to 60,000 acre-feet per year, became operational in October 2008; the recovery component of the project is expected to become operational in late 2012 (TW, 2007; Prior, 2012a).

TW anticipates that use of both CAVSARP and SAVSARP facilities will further reduce its reliance on groundwater pumping in the CWF during most of each year; however, TW will continue to need the CWF and particularly the six LOFO wells in the near-term (5-10 years), mid-term (approximately 1 to 2 decades), and long-term (indefinitely) for the following reasons:

- To help meet peak water demand during the hottest months;
- To meet projected annual potable demand when it exceeds the TW’s current annual CAP allocation—anticipated to occur within the next few years;
- To meet demand during partial system outages associated with lengthy planned maintenance activities;
- To provide emergency backup supply should there be a disruption in CAP supply due to problems with the CAP infrastructure or due to supply disruptions caused by system outages on TW’s own system; and
- To provide potentially long-term backup potable supply should a shortage be declared on the Colorado River—the Secretary of Interior may make such a declaration within the next five years and it could be in place for an indeterminate period of time.

Therefore, TW places a high priority on maintaining its operational use of all CWF wells, including LOFO wells, as well as other available supply sources (TW, 2007; Marra, 2008).

According to TW, the six LOFO wells have not been pumped for water supply since 2006. TW's pumpage data for the six LOFO wells for 2006 (Table 4) indicates that the pumpage rates (in millions of gallons) ranged from 4.1 (for well D-018A) to 25.5 (for well C-114A) and totaled 90.7 for all six wells. By contrast, during 1992, these same six wells were pumped at rates (in millions of gallons) ranging from 128.9 (for well D-018A) to 221.8 (for well C-056B), and the total pumpage was 1022.8 (or approximately 1 billion gallons). According to TW, although they have been able to temporarily reduce reliance on CWF wells in recent years, the AVRA Valley 26-inch main break in November 2006 resulted in the need to turn on CWF wells and the LOFO wells for two months, and emphasized the need to contain the western migration of the Broadway-Pantano plume (TW, 2007).

The vast majority of Tucson residences and businesses receive their water from TW, but there are some private water supply wells in the vicinity of the Site. "Vicinity" is defined as approximately one mile downgradient of and approximately one-half mile cross-gradient of the GOU plume as mapped in 2004-2006 (Figure 1 in Appendix A). The only water supply wells within the GOU groundwater plume are the previously shut-down TW production wells and the St. Joseph's Hospital well which is receiving wellhead treatment that removes the VOCs, including PCE and TCE (Section 1.4). In the vicinity of the GOU, there is one small municipal water provider—Catalina Village—which provides water to its assisted living residents. Also, there are two non-exempt (more than 35 gallon per minute [gpm] capacity well pump) wells that are used solely for irrigation and a non-exempt well used by a commercial car wash. There are also five private exempt (less than 35 gpm well pump) domestic/potable supply wells and one private exempt commercial well used for irrigation/potable supply. For more information on groundwater users at the Site, see the Water Use Study Report in Appendix A.

3.0 REMEDIAL INVESTIGATIVE ACTIVITIES

The major purpose of the GOU RI is to characterize the nature and extent of groundwater impacted by hazardous constituents at the Site. As noted in the introductory paragraphs to Section 1.0, the source of the GOU groundwater plume originally was believed to be only the BNL. A focused investigation (discussed below in Section 3.1.4), which was conducted from July 2001 through March 2002, did not find evidence for commingling of the BNL and BSL groundwater plumes. Until 2005, the LOU encompassed only the BNL. In 2005, on the basis of additional groundwater sampling, ADEQ determined that the BSL groundwater plume had commingled with the BNL groundwater plume. The BSL was added to the LOU, and investigations of the BSL commenced in 2006. Most of the work completed between 2001 and 2005 concentrated on the GOU and the BNL portion of the LOU.

The objectives of the remedial investigative activities included in this Report have been to assess:

1. Sources of the groundwater contamination;
2. Physical characteristics of the Site, including the geology, surface water hydrology, and hydrogeology;
3. Nature and extent of contamination in the groundwater;
4. Fate and transport of the contaminants in the groundwater; and
5. Potential risk to public health from exposure to contaminants identified in the GOU.

Along with the Water Use Study for the Site (Appendix A), this RI report will be used to establish the GOU Remedial Objectives (ROs) for the Site (Appendix H).

To accomplish these objectives, a number of tasks were completed during the RI, including: installing additional groundwater monitoring wells, collecting groundwater samples for laboratory analysis, reviewing historical reports and aerial photographs, and reviewing various federal and state databases. The following sections present summaries of the various remedial investigative activities conducted during this RI.

3.1 SOURCES OF CONTAMINATION

Potential source areas for VOCs in groundwater were identified at the Site through historical records research, interviews, subsurface soil gas data, and primarily through analysis of groundwater quality data. Potential groundwater contamination source areas in the Site which were investigated or evaluated during the RI include: (1) landfilled areas of the BNL; (2) landfilled areas of the BSL; (3) former sand and gravel mining operations along Pantano Wash in the BNL and BSL; and (4) commercial operations located within or near the GOU that have documented or possible use and/or releases of solvents or cleaning fluids containing VOCs.

3.1.1 Broadway North Landfill

The BNL was operated as a municipal landfill from approximately 1959 to 1972. BNL was one of the major landfill operations in the Tucson area. It was open at all times with no charge imposed for disposal of any type of waste, including residential, commercial, and industrial wastes, and there were no restrictions on the kinds of refuse that were deposited at the BNL (HGL, 2012). Placement rates at the BNL ranged from a few tons per day at inception, to more than 300 tons per day during peak operations (PAG, 1997). Waste solvents and other chemicals from industrial, aeronautical, semiconductor, governmental, retail, educational, and military organizations were disposed of at the BNL by solvent collectors and recyclers as well as by municipal and private waste haulers. Research indicates that the above-mentioned industrial operations generated TCE, PCE, and MeCl waste (HGL, 2012).

According to HGL (2012), Sanitary District No. 1 of Pima County operated the BNL south of the Fifth Street alignment from approximately 1959 until 1968, when Sanitary District No. 1 of Pima County was dissolved and operation of the landfill was transferred to Pima County. The portion of the BNL north of the Fifth Street alignment was used by the COT to operate a landfill from 1965 to approximately 1970. After closure, the BNL property was covered with soil, and, with the exception of a strip mall and parking lot constructed at its southeastern edge, the BNL property has been left undeveloped (Aplomado, 2001; HGL, 2012). The estimated lateral extent and thickness of the waste in the BNL is shown in Figure 19 and the estimated cover thickness is shown in Figure 20. Estimated waste thickness ranges from zero to a maximum reported depth of 35.3 feet (HGL, 2012); however, most of the borehole data indicate that the waste thickness generally falls within the range of 10 to 25 feet. The thickest part of the waste appears to be in the northern section, and the thinnest part of the waste appears to be in the southeastern section. Estimated cover thickness ranges from almost no cover to 14 feet; however, most of the borehole data indicate that the cover thickness is usually 1 foot to 4 feet. These estimates are based on previous BNL borehole data from numerous investigations and review of historical aerial photographs of the BNL. For a detailed presentation of this data and the evaluation, refer to Appendix B.

Strong support for the BNL being the major source of the groundwater contamination is that, with the exception of upgradient well WR-181A, none of the groundwater samples from the upgradient wells 414-P (Far Horizons East; City of Tucson Environmental Services, 2007b), 417-P (Martin; City of Tucson Environmental Services, 2007c), WR-207A and WR-207B (Figure 2) have contained detectable concentrations of the Site COCs whereas many monitor wells situated beneath and downgradient of the BNL do. In over 20 years, only one sampling event for WR-181A showed either PCE or TCE detections above the AWQS (Table 5; URS, 2002a). Furthermore, the highest groundwater VOC concentrations historically have been detected in monitor wells located within the BNL (Table 5). The results of previous RIs performed by CDM for the BNL in 1996-1998 (CDM, 1998) and URS for the GOU in 1999-2000 (URS, 2002a) identified the BNL as the source of soil gas VOC contamination that has impacted groundwater.

Shallow and deep VOC soil gas testing results from previous investigations also indicate that the BNL is a source of the VOCs in groundwater.

- In 1996 (for COT), CDM tested soil gas at 64 locations scattered through the BNL at depths of 10 and/or 20 feet bgs and found PCE detections in almost 60% of the samples (Appendix C, Figure C-4 for sample locations and results), with most of the sample concentrations being between 1.0 µg/L and 3.0 µg/L (CDM, 1998).

- In 1996 (for COT), CDM installed three deep soil gas monitoring wells (DP-1, DP-2, and DP-3), each with four nested vapor probes set between 45 and 193 feet bgs, in the southern, central, and northern interior of the BNL. Between 1996 and 1997, CDM also installed three deep soil gas/shallow groundwater monitoring wells (WR-273A, WR-274A, and WR-275A), each with four nested vapor probes set between 45 and 300 feet bgs, along the western edge of the BNL. Laboratory testing results of samples collected from the deep interior soil gas monitor wells in 1997 showed PCE detections in all but one probe, with concentrations ranging from 11 to 38 µg/L; and TCE detections in 7 out of 12 probes, with concentrations ranging from 6.8 to 13 µg/L. Laboratory testing of samples from the deep western perimeter wells showed PCE in half of the probes, with concentrations ranging from 5 to 16 µg/L, and TCE in only one of the probes, at 5.3 µg/L (CDM, 1998) (Appendix C, Figure C-7).

- In 2000, Hydro Geo Chem (for COT and Pima County) installed a SVE/AI system consisting of six extraction wells (R-070A – R-075A) and two injection wells (R-068A and R-069A/R-069B) at the BNL. The extraction wells each contain nested soil gas probes set at 5-foot screened intervals at 50’ and 100’ bgs, and the injection wells each contain nested soil gas probes set at 5-foot screened intervals at 50’, 100’, 150’, and 200’ bgs. These SVE/AI probes, and the probes from the WR-273A, WR-274A, WR-275A, DP-1, DP-2, and DP-3, were sampled prior to start-up of the SVE/AI system (HGC, 2001). PCE was detected in almost all of the probes, with concentrations ranging from 1.3 to 160 µg/L; TCE was detected in approximately 80% of the probes, with concentrations ranging from 0.21 to 45 µg/L. It is noteworthy that PCE and TCE concentrations tended to increase, going from the shallower to the deeper probes, within each well (Figure C-8 in Appendix C).

Additionally, the removal of approximately 5,329 pounds of total VOCs, including approximately 2,266 pounds of non-Freon VOCs; 1,259 pounds of PCE; 274 pounds of TCE; 354 pounds of cis-1,2-DCE; and 41 pounds of vinyl chloride from the BNL vadose zone by the SVE/AI indicates that the BNL is a significant source of the groundwater contamination (SECOR, 2003c). For a more detailed presentation of the BNL soil gas investigations and results, refer to Appendix C.

3.1.2 Sand and Gravel Mining Operations

SECOR (2001a) determined, from a review of historical aerial photographs (dating from 1936 through 1998), that sand and gravel mining operations occurred in the vicinity of the BNL and BSL between the early 1940s and the early 1970s. The mined areas appeared to extend south from Speedway Boulevard, along the west bank of Pantano Wash, to Broadway Boulevard and further south to Kenyon Street. Support facilities for the mining operations (including numerous buildings, vehicles, and equipment) were located north of the BNL. Appendix B, Figures B-10, B-12, B-14, B-16, B-18, B-20, and B-22 depict site conditions at the BNL based on interpretation of aerial photographs for 1953 (Figure B-9), 1960 (Figure B-11), 1962 (Figure B-13), 1964 (Figure B-15), 1967 (Figure B-17), 1969 (Figure B-19) , and 1971 (Figure B-21), respectively. Detailed discussions of the individual historical aerial photograph reviews are provided in Appendix B. Owners of the BSL property leased the land for sand and gravel quarrying prior to 1953 (HGL, 2012). Sand and gravel mining operations occurred in the BSL area in the mid-1950s. Both the BSL and BNL properties were used as illegal dumping grounds or “wildcat” dumps during the sand and gravel operations as well as before the properties were used as municipal landfills. Illegal dumping continued at the BSL and BNL properties after landfill operations ceased (Scharman, 2006; HGL, 2008; HGL, 2012). Waste solvents and other chemicals from industrial, aeronautical, semiconductor, governmental, retail, educational, and military organizations were disposed of at the “wildcat dumps” by self-employed salvagers. Research indicates that these industrial operations generated TCE, PCE, and MeCl waste (Arizona Attorney General’s Office, 2009; Blankinship, 2006a; Blankinship, 2006b; HGL, 2012).

3.1.3 Other Potential Sources of Groundwater Contamination

Records Search

Prior to conducting this RI, SECOR (2001a) completed a review of regulatory agency databases and available historical records to identify facilities within or near the GOU which (1) used chlorinated solvents (and particularly PCE and TCE) in their commercial or industrial processes, and (2) had releases of chlorinated solvents at their facilities, and thus could have contributed to the Site groundwater contamination. The area covered by this review extends from East 22nd Street on the south, to East Pima Street on the north, and from Wilmot Road on the west, to Pantano Road on the east (Figure 21).

SECOR reviewed the following state and federal databases and available historical records:

- EPA’s National Priority List (NPL);
- EPA’s Comprehensive Environmental Response Compensation and Liability Information System;
- ADEQ’s WQARF Responsiveness Summary for the Registry Report;
- Arizona Alternative Resource Conservation and Recovery Act (RCRA) Information for States;
- EPA’s Corrective Action Sites;
- ADEQ’s Hazardous Waste Treatment, Storage, and Disposal Facilities;
- ADEQ’s RCRA Compliance Log;
- Superfund Amendment and Reauthorization (SARA) Title III, Section 313, Form R/Toxic Release Inventory reports;

- ADEQ's Arizona CERCLA [Comprehensive Environmental Response Compensation and Liability Act] Information Database System;
- ADEQ's Registered Drywells;
- EPA's Emergency Response Notification System (ERNS);
- ADEQ's Hazardous Material Incidents Logbook;
- ADEQ's Aquifer Protection Permit;
- ADEQ's Solid Waste/Landfill (Active, Inactive and Closed) Databases;
- Aerial photographs dating from 1936 through 1998;
- City directories;
- Sanborn Fire Insurance maps;
- Topographic maps; and
- Technical Memorandum No. 1, Broadway North Landfill (CDM, 1996).

Based on the results of the database and available historical records review, SECOR (2001a) concluded:

Other than the sand and gravel operations at the BNL and BSL, the area was principally native desert until the 1950s, when single-family residential development began to occur as COT grew eastward. Commercial development appears in the area in the early 1960s, along Broadway Boulevard and Wilmot Road. Increased development has occurred in the area up to the present date. The nature of the development has been generally residential, with commercial land use primarily located along the Speedway Boulevard, Broadway Boulevard, East 22nd Street, and Wilmot Road corridors. No significant industrial development was noted.

A review of the various regulatory databases identified the Site, two CERCLIS facilities, 41 Resource Conservation and Recovery Act (RCRA) generators, three facilities with permitted drywells, one hazardous material incident, two closed solid waste landfill facilities, two inactive municipal landfill facilities, one active construction debris landfill, two ERNS facilities, and two APP facilities. No other listings were noted, thereby confirming general land use within the area as residential/light commercial. With the exception of the Site, no ongoing regulatory compliance action was found within the study area. The data review did not identify any likely current or historical users of solvents or cleaning fluids containing VOCs (including dry cleaners and automotive repair facilities) whose facilities are (or were) located within the 2000 GOU boundaries (Figure 6). SECOR determined (Table 1 of SECOR, 2001a) that all 12 identified historical cleaners were located outside the GOU boundaries. Furthermore, SECOR (2001a) identified nine historical automotive repair facilities which were generators of used oils; none of them were located within the 2000 GOU boundaries. Finally, SECOR (2001a) identified eight historical automotive service stations which could have had service bays for automotive repair activities; however, none were located within the 2000 GOU boundaries. The only RCRIS generators of hazardous waste that lie within the 2000 GOU boundaries are Wilmot Medical Center and its adjunct medical facilities (Figures 5 through 8 of SECOR, 2001a). It should be noted that the Wilmot Medical Center is located near the toe of the 2000 GOU plume; therefore, it cannot be considered a likely source for the PCE groundwater plume.

At the request of ADEQ, SECOR conducted additional database and historical records research in 2001 along the portion of Broadway Boulevard, extending eastward from COT monitor well WR-179A to Pantano Wash (Figure 6). This section of Broadway Boulevard is dominated by commercial development, including strip malls and retail gasoline facilities. As part of this investigation, SECOR completed the following:

- Reviewed the current ADEQ Underground Storage Tank (UST) and Leaking Underground Storage Tank (LUST) databases;
- Contacted COT Fire Department regarding recorded incidents and UST data for specific addresses between 6899 and 7600 East Broadway Boulevard;
- Reviewed information regarding dates of operation, business licenses, and UST data tabulated by Mr. Jim Rossi (COT, 1995); and
- Conducted a site walk over the referenced area.

The purpose of this review and site walk was to identify likely users (historical and current) of solvents or cleaning fluids containing VOCs (including drycleaners, lube shops, automobile repair facilities, metal fabricating facilities, and medical centers). Facilities with currently operating USTs, facilities where USTs have been removed, UST sites with reported LUSTs, and locations (if any) of non-registered dry wells were reviewed. It should be noted that SECOR did not collect any soil, soil gas, or groundwater samples during this records review and site walk. No obvious stained areas were noted by the field investigators. With the exception of the aforementioned Wilmot Medical Center and its adjunct medical facilities, none of the suspected solvent-using facilities listed below were situated within the 2000 GOU boundaries (SECOR, 2001a).

- Six current and former establishments were identified as possibly having on-site dry-cleaning operations.
- A total of seven current and former automobile repair facilities were identified.
- ADEQ UST database and historical records identify 12 locations with active or removed USTs.
- Six LUST sites were identified. Five of the LUST sites have been closed by ADEQ. According to ADEQ records, the open LUST site does not pose a significant threat to impact groundwater.
- COT Fire Department does not have any incident reports on file for addresses between 6899 and 7600 East Broadway Boulevard.

No dry wells were observed during the site walk.

SECOR noted that commercial development in the vicinity of the GOU has been restricted to the major east-west thoroughfares (Broadway Boulevard and Speedway Boulevard) and one major north-south thoroughfare (Wilmot Road).

3.1.4 Broadway South Landfill

The BSL was operated as a municipal landfill from approximately 1953 to 1962. The BSL was the largest landfill operation in Pima County during the late 1950s. There were no restrictions on the type of waste deposited at the landfill (HGL, 2012). Placement rate at the BSL during peak operation was more than 200 tons per day (PAG, 1997; HGL, 2012). Waste solvents and other chemicals from industrial, aeronautical, semiconductor, governmental, retail, educational, and military organizations were disposed of at the BSL by solvent collectors and recyclers as well as municipal and private waste haulers. Research indicates that the industrial operations generated TCE, PCE, and MeCl waste (HGL, 2012).

Pima County began landfilling operations at the north end of the BSL, along East Broadway Boulevard, in 1953. Sanitary District No. 1 of Pima County took over operations of the BSL in 1956 and operations progressed southward, ending in 1961 or 1962. Since closure, BSL has remained undeveloped, except in the northeastern portion, where a Hilton Hotel property was developed, and the northwestern portion, where a Culvers Restaurant was developed. The YMCA, Stephan Gollob Park, and Broadway Property Retirement Community are located just southwest of the former BSL boundaries (HGL, 2012).

The groundwater contamination at the BSL was not discovered until 2000, when TW installed the first BSL groundwater monitoring well, WR-367A, near the northwestern edge of the landfill and 5.4 µg/L PCE was detected during its initial sampling (URS, 2002a).

ADEQ conducted a focused investigation, from July 2001 through March 2002, to evaluate the need for an ERA to protect or provide for use of the water from the TW water supply wells C-025B and D-018A (SECOR, 2002a). These wells are located south of Broadway Boulevard and west of the closed BSL (Figure 2). This investigation involved the installation of new groundwater monitor wells and the sampling/gauging of existing water wells in the vicinity of the BSL.

Key elements of the focused investigation included: (1) video logging of 16 water wells (particularly, investigation wells WR-179A, D-040A, and D-039A, which were the three wells closest to C-025B and D-018A); (2) discrete-depth groundwater sampling, during July/August 2001 and November 2001, of wells in the study area; and (3) installation of three monitoring wells (BP-9, BP-11, and BP-15) in the vicinity of the target wells.

The data generated during this investigation did not support implementation of an ERA for either well C-025B or well D-018A, since these data indicated that the BSL PCE plume was flowing to the northwest (not westward towards these water supply wells). However, TW did not pump either C-025B or D-018A during this investigation, so no determination could be made as to whether pumping of these wells would be likely to draw the BSL PCE plume towards these wells. VOC water quality results confirmed that the BSL groundwater plume was absent near, and upgradient of, these water supply wells (SECOR, 2002a).

These data also did not indicate that the BSL groundwater PCE plume was commingling with the BNL GOU groundwater plume(s) [which are north of Broadway Boulevard]—at least not during the time of this investigation. Groundwater monitoring wells BP-10 and BP-8 were also installed downgradient of the WR-367A well (Figure 2) during the focused investigation. PCE was detected in the BP-10 well (which lies between WR-367A and BP-8), but not in the BP-8 well. Thereafter, the BSL site was referred to ADEQ's Site Assessment Unit for further evaluation as a separate site.

ADEQ included the newly-installed wells in the BSL vicinity in the regular groundwater monitoring program for the Broadway-Pantano Site, since there was the possibility that the BSL PCE plume could either commingle with the Site plume and/or impact D-018A or C-025B if these wells were activated for water supply. The results from the sampling events performed in 2002 through the middle of 2004 continued to indicate that the BSL plume was not commingled with the Broadway-Pantano Site plume. However, PCE was detected in well BP-8 (and BP-7) in November 2004 and most of the sampling events between November 2004 and August 2007 (Table 5). ADEQ determined in 2005, on the basis of subsequent groundwater sampling, that the BSL plume was commingling with the BNL GOU groundwater plume; subsequently, the Broadway-Pantano Site boundary and RI were expanded to include the BSL groundwater plume. ADEQ's investigation of the lateral and vertical extent of the BSL refuse and BSL vadose zone soil gas is ongoing and will be reported in the future LOU RI for this Site.

It should be noted that groundwater data and figures for the Prudence Landfill (PL), located to the south of the BSL, were reviewed to evaluate whether the PCE release at PL could be contributing to the groundwater contaminant plume emanating from the BSL. COT has two groundwater monitor wells (R-124A and R-125A) located on the PL, and one groundwater monitor well (WR-435A) located immediately downgradient of the PL (Figure 2). PCE and all other groundwater COCs (for the Broadway-Pantano Site) levels in these three wells have been either non-detect or well below the AWQS since their installation (COT, 2012). Also, there are two BSL groundwater monitor wells (BP-11 and BP-22) located between these three PL wells and the BSL plume to the north, and PCE levels in monitoring wells BP-11 and BP-22 have rarely exceeded the AWQS. Therefore, the PCE release at the PL does not appear to be contributing to the BSL plume.

3.1.5 Conclusions Regarding Sources of Groundwater Contamination

Based on the preceding information, the BNL is considered to be the primary source of VOC groundwater contamination in the GOU, and the BSL is considered to be a secondary source of VOC groundwater contamination in the GOU. The former sand and gravel mining operations used as “wildcat” dumping sites is considered to be a third source of groundwater contamination in the GOU. The VOC plume emerging from the BNL is much larger and has much higher VOC concentrations than the VOC plume emerging from the BSL.

3.2 PREVIOUS GROUNDWATER INVESTIGATIONS BY COT AND TW

Numerous studies and investigations have been conducted in the vicinity of the GOU. Past investigations have typically involved invasive procedures (including drilling and monitor well installation) to collect groundwater samples for laboratory analysis. The collected data were compiled into summary reports.

Although SECOR personnel reviewed the majority of the available historical studies and investigation reports, not all of the data were considered appropriate for inclusion in this RI Report. Laboratory analytical data associated with historical investigations have been used to augment this RI; however, it should be noted that portions of this historical data set have not been verified or validated due to the absence of laboratory reports. Table 6 includes the historical groundwater studies and investigations reviewed by SECOR personnel. Historical materials cited in this RI Report are noted in the text and included in Section 9.0.

In chronological order, the investigations have been as follows:

- TW, 1992;
- Camp Dresser & McKee (for COT), 1998;
- HGC (for COT/Pima County), 2000;
- COT (for COT), 2000;
- COT (for COT), 2001;
- URS (for COT), 2002; and
- URS (for COT), 2005.

<u>Tucson Water (for TW, Planning and Technical Services Division), 1992</u>

The first published study regarding groundwater contamination in the vicinity of the Site was completed by COT in May 1992. The groundwater investigation was undertaken as a result of VOC concentrations detected in CWF production wells C-022A, D-021A, and D-022A, located downgradient (i.e., toward the west) of the BNL , Table 7). Activities conducted during Tucson Water (1992) investigation included installation of seven groundwater monitor wells (WR-177A, WR-178A, WR-179A, WR-180A, WR-181A, WR-186A, and WR-207A), water level measurements, and collection of groundwater samples for laboratory analysis. The wells generally were screened from above the water table (AWT) to approximately 100 feet below the water table (BWT). Locations of the groundwater monitor wells installed during this investigation are shown on Figure 22.

<u>Camp Dresser & McKee (for COT), 1998</u>

From 1996 to 1998, CDM conducted field investigations and prepared a BNL RI Report for COT and Pima County (CDM, 1998). This investigation followed a phase approach to include sampling and laboratory analysis of: (1) soil gas from existing, temporary, and newly installed monitoring probes; (2) subsurface soil; and (3) groundwater from existing and newly installed groundwater monitor wells.

In October and November 1996, CDM collected wellhead groundwater samples using the existing dedicated submersible pump and micro purge groundwater samples at discrete-depth intervals in groundwater monitor wells D-021A, D-022A, and WR-178A (Figure 6). The discrete-depth interval samples were collected from the upper, middle, and lower portions of the saturated interval of the well using a pneumatic low flow (100 milliliters per minute) bladder pump. A total of 12 groundwater samples, and one duplicate groundwater sample, were collected from each well and analyzed for VOCs and alkalinity. The shallow and deep discrete-depth interval samples and the wellhead samples also were analyzed for typical leachate indicators [including chloride, chemical oxygen demand, fluoride, nitrate, sulfate, calcium, potassium, sodium, TDS, total suspended solids (TSS), total organic carbon (TOC), methane, ethane, and ethene]. Based on the laboratory analytical results, CDM (1998) concluded that there was no evidence of vertical variations in contaminant concentrations in these wells. See also Section 3.5.3.2 under "Historical Vertical Dispersion Monitoring Results" for further discussion of these findings.

During the time period from December 1996 through February 1997, CDM installed three groundwater monitor wells (each with four nested soil gas monitor probes) along the western side of the BNL. Groundwater and soil gas samples were collected from the newly installed wells and probes. The groundwater monitor wells (designated MW-1, MW-2, and MW-3 by CDM; re-designated by COT as WR-273A, WR-274A, and WR-275A, respectively) were installed to total depths ranging from 347 to 360 feet bgs. Wells WR-273A through WR-275A were screened from 298 to 338, 306 to 346, and 317 to 358 feet bgs, respectively. The nested soil gas monitoring probes were screened at 45 to 50, 130 to 135, 215 to 220, and 295 to 300 feet bgs in wells WR-273A and WR-275A. Soil gas monitoring probes in well WR-274A were screened at 45 to 50, 95 to 100, 215 to 220, and 295 to 300 feet bgs. The locations of the groundwater monitor wells with nested soil gas monitoring probes (WR-273A, WR-274A, and WR-275A) are shown on Figure 6.

HGC (for COT/Pima County), 2000

Included with the installation of the BNL SVE/AI system in 2000 by HGC was the addition of two interior groundwater sampling locations (whereas previously there were none). The screens of AI wells R-068A and R-069B were extended approximately 30 and 40 feet BWT, respectively (HGC, 2000a). The initial sampling of these wells showed PCE concentrations of 200 µg/L in the R-068A sample and 35 µg/L in the R-069B sample (HGC, 2000b).

COT (for COT), 2000

In 2000, COT installed the WR-367A groundwater monitoring well in the northwest corner near the edge of the BSL (Figure 2, Table 7). This well is screened from 312 to 407 feet bgs, so that the screen extends to approximately 50 feet BWT (Table 1). PCE was detected at 5.4 µg/L during the initial post-purge sampling (COTEM, 2000a). This result was confirmed upon three subsequent post-purge samplings conducted by COT in 2000.

COT (for COT), 2001

In 2001, COT installed groundwater monitoring well WR-435A, located to the west of Gollob Park (Figure 2, Table 7). This well location is downgradient of the Prudence Landfill. This well is screened from 330 to 420 feet bgs, so that the screen initially extended to approximately 50 feet BWT; as of 2011, the screen extends to approximately 60 feet BWT (Table 1). Initial sampling of this well by COT using a bailer found 2.4 µg/L PCE (URS, 2001).

URS (for COT), 2002

During late 1999, URS conducted field investigations for the GOU at the Site. URS collected discrete-depth groundwater samples, using Hydropunch™ sampling techniques, during the advancement of four deep well borings. Each well boring was completed as a 5-inch-diameter schedule 80 polyvinyl chloride (PVC) groundwater monitor well with 40-foot screened intervals, typically 75 to 115 feet BWT. URS also installed one 200-foot-deep, 1.5-inch-diameter schedule 40 PVC piezometer in one of the well borings (WR-352A). Following well development, each of the groundwater monitor wells (WR-352A, WR-353A, WR-354A, and WR-358A) was equipped with a dedicated 4-inch-diameter submersible pump. Screen intervals and other well construction information is shown in Table 7. Figure 6 depicts the locations of monitoring wells used during the GOU RI.

Between late 1999 and late 2000, COT and Pima Country performed five groundwater sampling events (during September 1999, December 1999, February/March 2000, June 2000, and September 2000). The groundwater samples were analyzed for VOCs by EPA Method 8260B. Additionally, groundwater samples collected during the two semi-annual sampling rounds (i.e., February/March 2000 and September 2000) were analyzed for general chemistry (including major cations and anions, TOC, TDS, and TSS).

URS (2002a) presented a conceptual site model (CSM) of contaminant fate and transport in the GOU. URS indicated that the groundwater plume emanates primarily from the southern portion of the BNL and flows toward the southwest (for approximately one mile) and then shifts toward the northwest. Other source release areas include the central and northern portions of the BNL. The groundwater contaminant plumes are undergoing anaerobic reductive dechlorination near their “heads” at the BNL. Beyond the boundaries of the landfilled areas, the groundwater plume biodegrades aerobically in the absence of anthropogenic carbon or native carbon. According to URS, groundwater withdrawals from CWF production wells, as well as degradation processes, exert control over contaminant fate and transport in the GOU.

URS (2002a) concluded that a groundwater contaminant plume emanated from various portions of the BNL and extended from the BNL westward for approximately two miles. The COCs were the following four VOCs: PCE, TCE, MeCl, and vinyl chloride. Based on the analytical results from discrete-depth groundwater sampling conducted at wells WR352A and WR-353A (screened from 420 to 460 feet bgs and 410 to 450 feet bgs, respectively), URS (2002a) further concluded that the VOC plume was isolated to hydrologic units within the uppermost portion of regional aquifer at a depth of approximately 373 feet bgs.

URS (for COT), 2005

In August 2005, COT contracted URS to install two groundwater monitor wells (BP-20 and BP-21) downgradient of well BP-1 and BP-2 (Figure 5; Table 7) to help delineate the toe of the plume. Both wells BP-20 and BP-21 are screened from 280 to 430 feet bgs. The initial concentrations of PCE from post-purge groundwater samples were less than 0.50 µg/L for samples collected from well BP-20 and equal to 4.5 µg/L for samples collected from well BP-21 (URS, 2005).

COT (for COT), 2009

In January 2009, three groundwater monitoring wells (WR-702A, WR-703A, and WR-704A) were installed downgradient of wells B-20 and B-21 to help further delineate the toe of the plume (Figure 5; Table 7). (These wells were installed by COT with funding from ADEQ under the COT/ADEQ work share agreement.)These wells were originally named BP-27, BP-28, BP-29; however, the well names (as documented in ADEQ files) were changed to WR-702A, WR-703A, and WR-704A, respectively to conform to the naming convention of monitoring wells owned by the COT. Henceforth, the three monitoring wells will only be referred to by their COT well names. Well WR-702A is screened from 292 to 392 feet bgs, well WR-703A is screened from 294 to 394 feet bgs, and WR-704A is screened from 290 to 350 feet bgs. In February 2009, COT collected groundwater samples from approximately the upper three feet of the aquifer by using a bailer. Groundwater samples collected from WR-702A contained 8.2 µg/L PCE; PCE was not detected (less than 0.5 µg/L) in samples collected from wells WR-703A and WR-704A (COT, 2009).

3.3 MONITOR WELL INSTALLATION

There are numerous groundwater production and monitor wells located on, and adjacent to, the Site (Figure 2 and Table 7). These consist of the following:

- Active and inactive TW production wells (denoted on figures, tables, and in the text by the prefix “C” or “D,” followed by a number and the suffix “A” or “B”);

- Privately owned supply wells (denoted on figures, tables, and in the text using a number with a “P” suffix or the well owner’s name);

- Monitor wells installed by COT (denoted on figures, tables, and in the text with a prefix “WR,” followed by a number and the suffix “A” or “B”) between 1989 and 2009;

- The AI wells, R-068A and R-069B, installed by COT and Pima County in 2000 as part of the SVE/AI system at the BNL. The AI wells are located in the central portion of the BNL. Groundwater samples are collected from these wells on a periodic basis for laboratory analysis.

- Monitor wells installed by ADEQ prior to July 2001 (denoted on figures, tables, and in the text with a prefix “SE” or “SJ,” followed by a number);

- The WCS extraction well (R-092A) and injection wells (R-019A and R-090A) installed by COT/ADEQ; and
- Monitor wells installed by ADEQ (or COT, for wells BP-20 and BP-21) after July 2001 (denoted on figures, tables, and in text with the prefix “BP,” followed by a number).

3.3.1 Well Installation/Survey--Site-Wide (2001-2003)

Between July 2001 and February 2003, SECOR supervised the drilling and installation of 13 groundwater monitor wells (BP-1 through BP-5, BP-7 through BP-11, BP-15, BP-16, and BP-19) in the GOU. Prior to initiating well installation activities, ADEQ and SECOR, with input from COT, developed a list of 31 potential monitor well locations (SECOR, 2001b). The rationale used to develop the list of locations was to close data gaps in previous investigations that were identified by SECOR during analysis and interpretation of the results of the previous investigations. As monitor wells were installed and groundwater quality data was collected, it became apparent that some of the original locations would not be needed (BP-6, BP-12, BP-13, BP-14, BP-17, and BP-18) or should be moved from the originally selected Site (BP-3 and BP-16). During the course of well installation and sampling of existing and newly installed wells, it was determined that a groundwater monitor well (BP-19) was needed at a location not previously identified.

3.3.1.1 Well Drilling

The wells were drilled using air rotary casing hammer drilling techniques. This technique involves the advancement of 9.625-inch steel casing behind an air rotary drill stem, utilizing a casing hammer. SECOR subcontracted two drilling companies for the installation of the wells. Wells BP-1 through BP-10, BP-15, BP-16, and BP-19 were drilled and installed by WDC Exploration; and well BP-11 was drilled and installed by THF Drilling. Locations of the groundwater monitoring wells installed by SECOR and COT are shown on Figure 23; the edited well boring logs for these wells are provided in Appendix D.

3.3.1.2 Well Construction and Development

Groundwater monitor wells were drilled to depths between 443 and 501.5 feet bgs. With the exception of BP-11, each well is equipped with 175 feet of screened casing (5-inch-diameter, schedule 80 PVC, mill-cut 0.02-inch slots) installed from approximately 75 feet AWT to approximately 100 feet BWT. A 20-foot blank section was installed at the base to serve as a sediment trap. The long screen interval AWT table was installed to account for fluctuations in groundwater elevations. The approximately 100 feet of saturated screen interval was installed for collecting groundwater samples at multiple discrete zones within each well. Given the large number of groundwater data gaps for both lateral and vertical delineation of the plume, ADEQ viewed use of the single long-screened wells as a cost-effective alternative to installing multi-depth wells at each data gap location. Due to its location on the closed BSL, well BP-11 was installed with only 100 feet of submerged screen interval to inhibit the possibility of creating of a soil vapor migration pathway to groundwater. A brief summary of well construction details and well development are provided in the following inset table. Well construction diagrams are provided in Appendix E, and Table 7 summarizes well construction information.

Well No	Total Depth (feet bgs)	Screened Interval (feet bgs)	Development Completion Date
BP-1	456	261-436	01/22/02
BP-2	460	265-440	01/03/02
BP-3	450	255-430	07/03/02
BP-4	460	260-435	01/04/02
BP-5	477	280-455	01/21/02
BP-7	488	281-456	01/03/02
BP-8	492	297-472	07/16/01
BP-9	478	280.5-455.5	01/02/02
BP-10	487	285-460	12/04/01
BP-11	498	378-478	03/04/01
BP-15	488.5	293.5-468.5	12/04/01
BP-16	501.5	295-470	07/02/02
BP-19	440	245-420	02/14/03

3.3.1.3 Initial Groundwater Sampling

Initial sampling of the newly-installed groundwater monitor wells was conducted by SECOR approximately one week following development. The wells were not purged prior to sampling. Groundwater samples were collected using a Solinst Model 425 Discrete Interval Sampler (DIS). Groundwater samples were collected at three discrete intervals in each well. The inset table below provides the actual sampling depths. Generally, groundwater samples were collected at depths of 5, 50 and 100 ($\pm$10) feet BWT. The sole exception was well BP-11, where the groundwater samples were collected at 18, 63, and 100 feet BWT.

All samples were submitted to Turner Laboratories, Inc. (Turner) for VOC analysis using EPA Method 8260B. A summary of groundwater analytical data is presented in Table 5.

Well No	Sampling Date	Discrete Sampling Depths (feet BWT)
BP-1	01/28/02	5, 50, 104
BP-2	01/11/02	5, 50, 100
BP-3	07/10/02	5, 50, 98
BP-4	01/11/02	5, 50, 100
BP-5	01/28/01	5, 50, 100
BP-7	01/11/02	5, 50, 100
BP-8	07/25/01	5, 50, 100
BP-9	01/11/02	5, 50, 100
BP-10	12/12/01	5, 50, 100
BP-11	09/13/01	18, 63, 110
BP-15	12/12/01	5, 55, 100
BP-16	07/10/02	5, 50, 100
BP-19	02/24/03	5, 50, 101

3.3.1.4 Monitor Well Survey

SECOR subcontracted Lemme Engineering, Inc. an Arizona Licensed Land Surveyor, to determine the latitude, longitude, and top of casing elevation (using North American Datum 1988) for each of the newly installed and existing groundwater monitor wells. The wells were surveyed on November 8-10, 2004, and some of the wells were resurveyed by Lemme Engineering in October 2005 to verify previous surveys. Top of casing elevations and coordinates for the surveyed wells, using the Lemme Engineering survey data, is provided in Table 8.

3.3.2 Well Installation/Survey—Broadway South Landfill (2006)

3.3.2.1 Well Drilling

Between April 2006 and May 2006, SECOR supervised the drilling and installation of two nested groundwater and soil vapor monitoring wells (BP-22 and BP-23) and four nested soil vapor monitoring wells (BSDP-1, BSDP-2, BSDP-3, and BSDP-4). The wells were located on the northern portion of the BSL (Figures 16 and 23) in areas where historical records indicated that refuse was present. The southern portion of the landfill was not investigated.

The wells were drilled using the casing advance method with a Model AP-1000 reverse-circulation, dual-walled, air-percussion hammer drilling rig, which is also known as a Becker hammer rig. The casing advance drilling method utilizes a diesel fuel-powered hammer that drives a dual-walled casing into the ground without rotation, and the cuttings are lifted to the surface through the inner casing using compressed air. A 10 ¾ -inch outside diameter (OD) drill casing was used to drill wells BP-22, BP-23, BSDP-1, and BSDP-2. Wells BSDP-3 and BSDP-4 were drilled using a 9-inch OD drill casing. SECOR subcontracted Layne Christensen Company for the installation of the wells. The edited well boring logs for the groundwater wells are provided in Appendix D and the well construction diagrams for the groundwater wells are provided in Appendix E.

3.3.2.2 Well Construction and Development

Six nested groundwater monitor wells and soil vapor monitoring wells were drilled to depths between 150 and 445 feet bgs. Four-inch-diameter schedule 80 PVC was used for construction of the groundwater monitoring wells, and 1-inch-diameter schedule 80 PVC was used for construction of the soil vapor monitoring wells. Mill-cut 0.02-inch slotted schedule 80 PVC well screen was used for both the groundwater monitoring wells and the soil vapor monitor wells. Wells BP-22 and BP-23 were equipped with a 5-foot-long blank section of casing to act as a sediment trap, and the approximate 80-foot saturated screen interval was installed for collecting groundwater samples at multiple discrete zones within each well. A brief summary of well construction details and well development are provided in the following inset table. Boring logs are provided in Appendix D and well construction diagrams are provided in Appendix E. Table 7 summarizes well construction information.

Well No	Total Depth (feet bgs)	Screened Interval (feet bgs)	Development Completion Date
BP-22	458	358-438	05/17/06
BP-23	455	350-440	05/18/06

3.3.2.3 Initial Groundwater Sampling

Initial sampling of the newly-installed groundwater monitor wells was conducted by SECOR on May 24, 2006 (approximately one week following development). The wells were not purged prior to sampling. Water levels were measured prior to sampling, and groundwater samples were collected using a Solinst Model 425 DIS. Groundwater samples were collected at four discrete intervals in each well. The table below provides the actual sampling depths.

Well No	Sampling Date	Discrete Sampling Depths (feet BWT)	Depth to Water (feet bgs)
BP-22	5/24/06	5, 25, 50, 75	360.76
BP-23	5/24/06	5, 25, 50, 75	358.53

All samples were submitted to Environmental Science Corporation for VOC analysis using EPA Method 8260B. A summary of groundwater analytical data is presented in Table 5.

3.3.3 Well Installation/Survey—Broadway North Landfill (2007-2008)

3.3.3.1 Well Drilling

In November and December 2007, Stantec supervised the drilling and installation of three clustered discretely-screened groundwater monitoring wells (BP-24A, BP-24B, and BP-24C). This well cluster was installed to investigate the depth of the PCE plume near the BNL (Figure 2). Stantec subcontracted WDC Exploration & Wells (WDC) for drilling and installation of the well cluster. The BP-24 wells were installed using air rotary casing hammer techniques with a Speedstar 30K truck-mounted drilling rig.

In April and May 2008, Stantec supervised the drilling and installation of one single completion groundwater monitoring well (BP-25); this well was installed to investigate the northward extent of the PCE plume near the BNL (Figure 2). Well BP-25 was drilled by Yellow Jacket Drilling using air rotary casing hammer techniques with a Speedstar 50K truck-mounted drilling rig. The boring logs for wells BP-24 (A-C) and BP-25 are provided in Appendix D.

3.3.3.2 Well Construction and Development

Wells BP-24A, BP-24B, BP-24C, and BP-25 were each constructed using one string of five-inch diameter, schedule 80 polyvinylchloride (PVC) riser and 0.020-inch machine slotted well casing. Well BP-24A was drilled to a total depth of 358 feet bgs; this well was screened from 325 to

355 feet bgs. Well BP-24B was drilled to a total depth of 414 feet bgs; this well was screened from 385 to 405 feet bgs. Well BP-24C was drilled to a depth of 462 feet bgs; this well was screened from 440 to 460 feet bgs. Well BP-25 was drilled to a total depth of 380 feet bgs; this well was screened from 300 to 375 feet bgs. A brief summary of well construction details and well development are provided in the following inset table. Well construction diagrams are provided in Appendix E. Table 7 summarizes well construction information.

Well No	Total Depth (feet bgs)	Screened Interval (feet bgs)	Development Completion Date
BP-24A	358	325-355	12/21/07
BP-24B	414	385-405	12/21/07
BP-24C	462	440-460	12/21/07
BP-25	380	300-375	05/12/08

3.3.3.3 Initial Groundwater Sampling

Baseline groundwater samples were collected from wells BP-24A, BP-24B, and BP-24C on January 21, 2008 using a Solinst Model 425 DIS. Groundwater samples were collected for VOC analysis at two depths in each well, near the top of the screen and the bottom of the screen in BP-24B and BP-24C (submerged screen intervals) and 5 feet below the water surface and the bottom of the screen in BP-24A. Groundwater was also collected from wells BP-24A, BP-24B, and BP-24C for monitored natural attenuation (MNA) parameters from approximately the middle of the screen (or between the groundwater table and bottom of the screen for BP-24A).

Groundwater samples were collected from well BP-25 on June 2, 2008 using a Solinst Model 425 DIS. Samples were collected for VOC analysis at three depths (shallow, intermediate, and deep) corresponding to 5 feet BWT, 30 feet BWT, and 55 feet BWT.

The table below provides the actual sampling depths.

Well No	Sampling Date	Discrete Sampling Depths (feet bgs)	Discrete Sampling Depths (feet BWT)	Depth to Water (feet bgs)
BP-24A	01/21/08	341, 355, 345*	6, 20, 10*	335.14
BP-24B	01/21/08	385, 405, 395*	51, 71, 61*	333.87
BP-24C	01/21/08	440, 460, 450*	106, 126, 116*	333.84
BP-25	06/02/08	316, 341, 366	5, 30, 55	310.73

Note:
* Samples analyzed for monitored natural attenuation parameters.

All samples were submitted to Environmental Science Corporation for laboratory analysis. Groundwater samples collected for VOC analysis were analyzed using EPA Method 8260B. A summary of the analytical results is presented in Table 5.

The groundwater samples collected from the approximate mid-point of the screened interval, were analyzed for total alkalinity by EPA Method 310.1; sulfate, chloride, nitrate-nitrogen, and nitrite-nitrogen by EPA Method 300.0; sulfide by EPA Method 376.0; methane, ethane, and ethane by EPA Method SW3810; and Dissolved Organic Carbon (DOC) by EPA Method 9060A (Stantec, 2008).

3.3.3.4 Monitoring Well Survey

Stantec subcontracted Lemme Engineering, Inc. an Arizona Licensed Land Surveyor, to determine the latitude, longitude, and top of casing elevation (using North American Datum 1988) for each of the newly installed groundwater monitor wells. Wells BP-24A, BP-24B, and BP-24C were surveyed on December 18, 2007; well BP-25 was surveyed on May 22, 2008. Top of casing elevations and coordinates for the surveyed wells, using the Lemme Engineering survey data, is provided in Table 8.

3.4 GROUNDWATER MONITORING AND SAMPLING

During this RI, SECOR measured fluid levels and collected groundwater samples from existing and newly installed groundwater monitor wells on 38 occasions. Table 9 provides a summary of the RI groundwater sampling program, including general details regarding each of the groundwater monitoring and sampling events conducted by SECOR during this RI. Wells in the vicinity of the BSL continued to be included in the monitoring program (even after the focused investigation data indicated that the BSL PCE plume was not contributing to the Site PCE plume at that time) because the BSL PCE plume in the future could commingle with the Site plume or, if either of the two TW water supply wells to the west were activated, the BSL PCE plume could impact one or both of those wells. See also Section 3.1.4 for further discussion. Table 10 lists the wells, by sampling date, that were included in each groundwater sampling event. With the exception of the July/August 2001 monitoring and sampling event (SECOR, 2001c), groundwater samples were collected during each sampling event without purging the wells prior to sampling (i.e., no purge sampling). Groundwater samples from specific depth intervals within the well (typically 5, 50, and greater than 90 feet BWT, depending on the construction of the well) were collected using a Solinst Model 425 DIS (SECOR, 2001b). In general, the groundwater samples were analyzed for VOCs utilizing EPA Method 8260B and bicarbonate alkalinity (as calcium carbonate or $CaCO_3$) utilizing Standard Method (SM) 2320B. Laboratory analysis was conducted by Turner, located in Tucson, Arizona. During the initial monitoring and sampling event (i.e., the July/August 2001 sampling event), groundwater samples from monitor wells located in proximity to the BNL and the closed BSL were analyzed by Turner for RCRA 8 Metals (RCRA 8) total metals utilizing EPA Method 200.7 (for barium, cadmium, chromium, and silver), EPA Method 200.9 (for arsenic, lead, and selenium), and EPA Method 245.1 (for mercury). Laboratory analytical results for selected VOC constituents (VOC constituents that have been detected in samples from one or more water wells during the RI groundwater sampling program) are presented in Table 5. Laboratory analytical results for RCRA 8 total metals are presented in Table 11.

In conjunction with the startup and initial operation of the WCS, SECOR measured fluid levels and collected groundwater samples from a subset of the network of groundwater monitor wells in November 2002 and May 2003 (Table 9). SECOR measured fluid levels on a weekly basis for eight weeks (April 15 through June 3, 2003) after the WCS was put into permanent operational mode (SECOR, 2003b). The subset of wells associated with the startup and initial operation of the WCS included two private supply wells (411-P and 416-P; Figure 2). Due to well construction constraints, fluid levels are not measured in private supply well 416-P. Laboratory analytical results for groundwater samples collected from the two private supply wells in November 2002 and May 2003 are presented in Table 5. During the November 2002 sampling event, two wells (WR-178A and BP-2) were analyzed for all metals, inorganic compounds, and organic compounds (both VOCs and semi-volatile organic compounds) that had an EPA MCL or established AWQS threshold. The results are summarized in Table 12. The purpose of this testing was to confirm that the groundwater in the vicinity of the WCS extraction wells did not exceed regulatory limits for constituents other than the Site COCs. The only exceedance of an MCL or AWQS was 10.0 µg/L PCE in the sample collected from well BP-2.

Table 9 provides details on how many wells were sampled during each sampling event, when wells were added or dropped from the network of groundwater monitor wells for each event, and special analytical testing (other than the standard VOCs and bicarbonate alkalinity testing). Table 10 lists the wells which were included in each groundwater sampling event. Table 13 provides a historical summary of selected VOC groundwater sampling results for WCS wells C-026B, R-090A, R-091A, and R-092A. Although Table 5 provides a historical summary of selected VOC sampling results for scheduled RI groundwater sampling events, Table 13 provides additional groundwater sampling results collected during various aquifer pumping tests or during well development by URS (URS, 2002a).

3.4.1 AWQS Exceedances

During the various groundwater sampling events described above, five VOC constituents (PCE, TCE, cis-1,2-DCE, vinyl chloride, and MeCl) and two RCRA 8 metals (lead and mercury) have equaled, or exceeded, their respective AWQS in one or more depth-specific samples collected from one or more groundwater monitor wells. There have been 38 groundwater sampling events completed during the RI, covering the periods from July/August 2001 to September 2011. Twenty six events involved more than 15 wells. Eleven events involved only one to three wells. As shown in the inset table below, exceedances of the PCE and TCE AWQSs have been documented during every sampling event. Exceedances have also been documented for multiple sampling events for vinyl chloride, MeCl, cis-1,2-DCE, nitrate, and lead. Mercury has been exceeded in one sampling event. Details are provided in the table inset below.

Sampling Event	PCE	TCE	cis-1,2-DCE	Vinyl Chloride	MeCl	Lead	Mercury
July/August 2001	14	4	0	1	0	2	0
November 2001	6	3	0	0	0	NA	NA
February2002	12	6	1	2	1	NA	NA
May 2002	11	6	1	2	2	NA	NA

Sampling Event	PCE	TCE	cis-1,2-DCE	Vinyl Chloride	MeCl	Lead	Mercury
August 2002	13	6	1	2	1	1	1
November 2002	6	0	0	0	0	NA	NA
March 2003	13	6	1	1	0	0	0
May 2003	3	0	0	0	0	NA	NA
December 2003	12	8	0	2	1	0	0
March 2004	3	0	0	0	0	NA	NA
May 2004	11	7	0	2	0	0	0
July 2004	0	0	0	0	0	NA	NA
August 2004	2	0	0	0	0	NA	NA
September 2004	0	0	0	0	0	NA	NA
November 2004	14	7	0	2	1	0	0
January 2005	1	0	0	0	0	NA	NA
February 2005	2	0	0	0	0	NA	NA
March 2005	1	0	0	0	0	NA	NA
April 2005	2	0	0	0	0	NA	NA
May 2005	12	7	0	2	0	0	0
September 2005	6	1	0	0	0	NA	NA
November 2005	10	7	1	2	0	0	0
January 2006	5	4	0	1	0	NA	NA
February 2006	1	0	0	0	0	NA	NA
March 2006	1	0	0	0	0	NA	NA
April 2006	11	8	0	2	0	0	0
May 2006	1	0	0	0	0	NA	NA
September 2006	2	0	0	0	0	NA	NA
November 2006	13	7	0	1	0	0	0
February 2007	3	0	0	0	0	NA	NA
April 2007	13	6	0	1	0	0	0
August 2007	4	1	0	0	0	NA	NA
November 2007	12	5	0	1	0	0	0
January 2008	2	1	0	0	0	NA	NA
April 2008	15	6	0	1	0	0	0
June 2008	1	0	0	0	0	NA	NA
February 2009	1	0	0	0	0	NA	NA
September 2011	15	4	0	1	0	0	0

3.4.2 Groundwater Monitoring

Static water level gauging of the networks of groundwater monitor wells was conducted prior to each groundwater sampling event. The static water level elevation data were used to generate groundwater surface contour maps. Water table surface maps have been prepared for each groundwater monitoring event. Selected water table surface maps are depicted on Figure 24 through Figure 31 for the November 2001, May 2002, December 2003, May 2004, May 2005, April 2006, April 2007 and October/November 2008 monitoring events. Figure 8 and Figure 5 and depict the water table surface maps for the September 2003 (WCS capture area) and September 2011 (site-wide) monitoring events, respectively.

Based on the above-referenced groundwater surface contour maps, groundwater within the GOU (with several exceptions) flows toward the west at a hydraulic gradient of approximately 0.003 ft/ft. The notable exceptions are the BSL vicinity and localized perturbations in the WCS area (caused by sustained pumpage of the two WCS extraction wells and continual reinjection of treated water into two WCS injection wells). In the BSL vicinity, the groundwater flow direction is toward the northwest. Prior to start-up of the WCS (i.e., November 2002 gauging event), groundwater in the WCS area also flowed toward the west at an approximate hydraulic gradient of 0.003 ft/ft.

3.5 EVALUATION OF VERTICAL FLOW IN SELECTED WELLS

The groundwater monitor wells installed from 2001 through 2003 were installed with long saturated screens to provide a means of obtaining a vertical profile of the groundwater contamination at the Site by means of depth-discrete sampling (Section 3.4). However, it was observed in some of the old and new long-screened wells that the PCE concentrations would be similar at all depths tested during any one sampling event (Table 5). This pattern was seen in wells C-026A, D-022A, BP-10, and WR-181A. For example, the sample results collected on November 7, 2001, from C-026A were as follows: at 5 feet BWT, 5.7 µg/L PCE; at 50 feet BWT, 5.6 µg/L PCE (duplicate was 5.2 µg/L PCE); and at 95 feet BWT, 5.2 µg/L PCE (Table 5) [NOTE: The C-026B well was inactive at this point in time]. Another example is the sampling results for well D-022A on August 8, 2002. The sample results were as follows: at 5 feet BWT, 120.0 µg/L PCE; at 50 feet BWT, 120.0 µg/L PCE; and at 100 feet BWT, 110.0 µg/L PCE. Given that it would not be likely for the aquifer to have the same PCE concentration from 5 feet BWT to 100 feet BWT, it was determined that these wells, and some others at the Site, would be tested for the existence of vertical gradients within the boreholes. It should be noted that the pattern in well D-022A has persisted to the present. In September 2011, samples collected within D-022A at a depth of 5 feet BWT and 100 feet BWT contained PCE concentrations of 50 µg/L and 51 µg/L, respectively.

To identify vertical flow conditions within the casings of groundwater monitor wells located in the area of the Site, SECOR subcontracted Welenco, Inc. (Welenco) of Bakersfield, California in May 2003 to conduct temperature and FloVision™ surveys in select wells. The objective of the surveys was to determine whether vertical flow is occurring within the well casings. Seven groundwater monitor wells (BP-2, BP-4, BP-10, C-026A, D-022A, WR-178A, and WR-181A) were surveyed on May 13 and 14, 2003. The locations of the surveyed wells are shown on Figure 52. Monitor wells BP-2 and C-026A are located proximal to WCS extraction well C-026B. Monitor well BP-4 is located to the north of WCS injection wells R-090A and R-091A. Monitor well WR-178A is located to the northeast of WCS extraction well R-092A. Monitor wells D-022A and BP-10 are located downgradient of the BNL and BSL, respectively. Monitor well WR-181A is located to the north and upgradient of the BNL.

3.5.1 Temperature Surveys

Temperature surveys record the relative change in temperature versus depth of groundwater located within the saturated screen interval of the well. The temperature recording device is lowered into the well on a depth calibrated coaxial cable. A relatively constant temperature with increasing depth indicates vertical flow may be occurring within the well casing. Rising temperatures with depth suggest significant vertical flow is not occurring within the well casing. Temperature surveys are typically used to determine if vertical flow is occurring in the well casing; however, the surveys cannot be used to accurately quantify the rate or direction of vertical flow. The temperature survey logs are contained in Appendix C of SECOR (2004b).

Table 14 presents a summary of the temperature surveys, groundwater elevations on the day of the survey, and the distances between the surveyed monitor well and the closest WCS injection and extraction well. The temperature survey locations are shown on Figure 52.

The temperature surveys indicate vertical flow is occurring in some portion of the well casing in all of the groundwater monitor wells surveyed, except WR-181A. The temperature survey of monitor well WR-181A indicates a steady temperature increase over the entire saturated interval (312 to 440 feet bgs) of the well casing.

3.5.2 FloVision™ Surveys

FloVision™ surveys employ a downhole camera and a sensitive flapper device supported on nearly frictionless bearings mounted in a metal collar, attached to a calibrated coaxial cable. To prevent water movement around the outside of the metal collar (thus avoiding the flapper), a daisy-petal-like flexible plastic collar (skirt) is attached to the metal collar. The flexible skirt is in contact with the inside diameter of the casing and serves to direct water flow across the flapper. As the FloVision™ device is lowered slowly through the saturated screen interval of the well, it is stopped and held in position at various depths to allow observation, through the camera, of the relative motion, if any, of the flapper. If the flapper remains in a horizontal (neutral) position, significant vertical flow is not occurring at that particular depth. If the flapper rotates downward or upward while being held stationary, vertical flow in the direction of the flapper rotation is indicated. By moving the FloVision™ device through a known vertical distance and recording the time interval to traverse the distance, while keeping the flapper in a neutral position, the vertical flow velocity (either upward or downward) can be calculated. Using the vertical flow velocity and the cross-sectional area of the well casing, the volume of vertical flow in gpm can be determined. Welenco (2003) estimates vertical flow rates as low as approximately 0.25 feet per minute (ft/min) can be measured with a high degree of confidence. The FloVision™ Interpretation Package reports, prepared by Welenco, are included in Appendix A of SECOR (2004b).

Table 14 presents a summary of the FloVision™ surveys, groundwater elevations on the day of the survey, and the distances between the surveyed monitor well and the closest WCS injection and extraction well. Figure 52 shows the locations of the FloVision™ surveys.

Quantifiable vertical flow in a downward direction was observed in two groundwater monitor wells: (1) well C-026A at 360 feet bgs, or 28 feet BWT, with maximum velocity of 0.75 feet per second (ft/sec) and maximum flow rate of 3.06 gpm; and (2) well BP-2 at 390 feet bgs, or 60 feet BWT, with maximum velocity of 2.50 ft/sec and maximum flow rate of 2.30 gpm. It should be noted that WCS extraction well C-026B was pumping at a constant rate of 400 gpm during the period these wells were being surveyed. Groundwater monitor wells C-026A and BP-2 are located 32 feet and 250 feet distant, respectively, from extraction well C-026B.

Fluid level monitoring data collected prior to and after the startup of the WCS indicated that groundwater elevations in these wells had been lowered by approximately 4.2 and 1.6 feet, respectively, since the WCS system was started (SECOR, 2003b). It is apparent that pumping from WCS extraction well C-026B affects the groundwater elevations in nearby water wells. SECOR attributes the measurable downward vertical flows in wells BP-2 and C-026A to groundwater withdrawals from well C-026B.

Downward non-quantifiable vertical flow was observed in groundwater monitor well BP-4 in two discrete-depth intervals: 338 to 343 feet bgs (10 to 15 feet BWT), and 380 to 410 feet bgs (52 to 72 feet BWT). Welenco (2003) estimated the velocity and flow rate in these intervals to be approximately 0.25 ft/min and 0.23 gpm, respectively. Groundwater monitor well BP-4 is located approximately 425 feet north, and slightly west, of WCS injection well R-090A. Fluid level monitoring data collected prior to and after startup of the WCS indicated a rise in groundwater elevations of approximately six feet in well BP-4 since startup (SECOR, 2003b). It appeared likely that the reinjection of treated water into WCS injection wells R-090A and R-091A was causing a groundwater mounding effect in the vicinity of these wells.

Downward non-quantifiable vertical flow also was observed in groundwater monitor well BP-10. Welenco (2003) estimated a downward flow velocity of approximately 0.30 ft/sec, and a flow rate of approximately 0.28 gpm at a depth of 370 feet bgs (13 feet BWT) in this well. It should be noted that WCS extraction well R-092A was shut off after the temperature survey was completed in monitor well BP-10, but before the FloVision™ was performed. Two or three hours of shutdown had elapsed before the FloVision™ survey was conducted. Welenco (2003) speculated that the FloVision™ survey would show higher flow rates if WCS extraction well R-092A were operating. It should be noted that groundwater monitor well BP-10 is situated approximately 7,275 foot distant from WCS extraction well R-092A (Figure 52 and Table 14). Fluid levels are not monitored in monitor well BP-10 as part of the WCS performance monitoring program. However, based on the calculated groundwater elevations during the March 2003 (pre-startup of the WCS) Site-wide groundwater monitoring and sampling event (Table 1) and the calculated groundwater elevations on the date of the temperature and FloVision™ surveys (Table 14), the change in the groundwater elevation (+0.15 feet) is consistent with the historic groundwater elevation fluctuations in groundwater well BP-10 (Table 1) and thus does not appear to be impacted by the WCS pumping.

The FloVision™ surveys conducted in monitor wells D-022A and WR-181A (Figure 52) indicated that vertical flow was not occurring in these wells. Monitor wells D-022A and WR-181A are located significant distances (i.e., 6,150 feet and 7,425 feet, respectively) from the nearest WCS extraction well (R-092A). Fluid levels are not monitored in wells D-022A and WR-181A as part of the WCS performance monitoring program. However, based on the calculated groundwater elevations during the March 2003 (pre-startup of the WCS) Site-wide groundwater monitoring and sampling event (Table 1) and the calculated groundwater elevations on the date of the temperature and FloVision™ surveys (Table 14), the changes in groundwater elevations (+0.20 feet and -0.21 feet, respectively) are consistent with the historic elevation fluctuations in these wells (Table 1) and thus do not appear to be impacted by the WCS pumping.

Groundwater monitor well WR-178A is located approximately 425 feet northeast of WCS extraction well R-092A. The FloVision™ survey conducted in groundwater monitor well

WR-178A (Figure 52) on May 13, 2003 was interpreted by Welenco (2003) as having no vertical flow. Fluid level monitoring data collected prior to and after startup of the WCS indicated that groundwater elevations had declined approximately 4.9 feet since the WCS system began full-scale operations (SECOR, 2003b). The absence of vertical flow in well WR-178A was unexpected, and may indicate that the FloVision™ surveys could not reliably measure vertical flow that was occurring in this and other wells.

3.5.3 Vertical Groundwater Plume Extent

One of the objectives of this RI was to determine, to the degree possible, the vertical extent of contamination within the aquifer. To achieve this objective, groundwater monitor wells installed during this RI were designed with the intent to have a minimum of 100 feet of saturated screen interval (Section 3.3.1 through 3.3.3), and a discrete-depth sampling program was initiated for existing and newly installed wells (SECOR, 2001b). The sampling program consisted of collecting groundwater samples at three depths (5 feet BWT, 50 feet BWT, and approximately 5 feet above the base of the screen interval) from the existing groundwater monitor wells, newly installed groundwater monitor wells, and inactive CWF production wells.

A total of 38 groundwater monitor and/or inactive CWF production wells in the current monitoring well network for the GOU have saturated screen intervals greater than 100 feet (Table 1). The remaining monitoring, AI, and inactive production wells in the current monitoring network for the GOU have saturated screen intervals ranging from 14 to 95 feet BWT (Table 1).

The discrete-depth VOC sampling results for groundwater sampling events between July/August 2001 and September 2011 indicate that the vertical extent of the VOC groundwater plume is approximately 100 feet BWT near the head (primary portion) of the BNL plume. The vertical extent is defined as that depth at which all VOC constituents are less than, or equal to, their respective AWQSs. Wells WR353A, BP-24A, BP-24B, and BP-24C are located within the primary portion of the BNL plume and are wells in which deep discrete-depth groundwater samples have been collected (these wells have 20 to 40 feet of saturated screen).

Groundwater samples collected from well WR-353A at 103, 130, and 131 feet BWT (approximately 406 and 449 feet bgs) have not contained detectable concentrations of VOCs. Groundwater samples collected from wells BP-24A and/or BP-24B at 5, 15, 20, 50, 60, 70, and 80 feet BWT have contained PCE and/or TCE concentrations in exceedance of AWQSs. However, groundwater samples collected from well BP-24C at 105, 115, 125, and 135 feet BWT (between approximately 440 and 460 feet bgs) have not contained detectable concentrations of PCE or TCE. Based on this data, VOCs in this area (primary portion of the BNL plume) appear to extend to a minimum of 80 feet BWT and a maximum of 105 feet BWT (440 feet bgs).

Groundwater samples collected from well WR-178A, downgradient of the primary BNL plume, contained PCE concentrations in exceedance of the AWQS at 5 and 50 feet BWT (345 and 390 feet bgs). Groundwater samples collected from nearby well WR-352A between 86 and 121 feet BWT (427 to 459 feet bgs) did not contain detectable concentrations of VOCs. VOCs in this area appear to extend to a minimum of 50 feet BWT (390 feet bgs) and maximum of 86 feet BWT (427 feet bgs).

The vertical extent of the groundwater plume near extraction wells R-092A and C-026B is approximately 150 feet BWT based on one groundwater sample collected at 142 feet BWT (485 feet bgs) in R-092A that contained PCE in concentrations greater than the AWQSs. Groundwater samples from C-026B are generally collected at the wellhead. Groundwater samples are collected from nearby well C-026A, and include the deepest groundwater samples in the monitoring well network. Groundwater samples collected from C-026A at 153 feet BWT contained PCE concentrations in exceedance of the AWQSs; PCE was not detected in exceedance of the AWQSs from 160 to 202 feet BWT (485 to 532 feet bgs).

It is likely that the vertical extent of the plume is no more than approximately 100 feet BWT across the Site and that VOC contaminants are found at greater depths in some wells due to vertical wellbore mixing or proximity to pumping wells (as in the case at well C-026A). Depth-specific concentrations of PCE, TCE, and vinyl chloride groundwater concentrations are depicted on Figure 32 through Figure 51 for the November 2001, May 2002, March 2003, December 2003, May 2004, May 2005, April 2006, April 2007, October/November 2008, and September 2011 groundwater sampling events, respectively (depth-specific concentrations of TCE and vinyl chloride are not shown for all sampling events).

3.5.3.1 Discrete-Depth Sampling Program

Non-purge, discrete-depth groundwater sampling was conducted using the available water wells (those wells that were completed and developed prior to the sampling event) on 38 occasions during this RI (Section 3.4). On ten occasions between November 2002 and September 2011, 15 to as many as 29 wells were sampled as part of the performance monitoring of the WCS (Section 3.4). Laboratory analytical results from groundwater samples collected near the bottom of the saturated screen interval from wells with more than 100 feet of saturated screen length suggest the presence of concentrations of PCE and TCE in excess of their respective AWQS (5.0 µg/L). Examples include:

- inactive production well D-022A, near the BNL, at depths of at least 104 feet BWT (Table 5 and Figure 2);
- inactive production well C-026A, near the northwest boundary of the GOU, with PCE concentrations in excess of the AWQS at depths of at least 153 feet BWT (Table 5 and Figure 2); and
- WCS extraction well R-092A near St. Joseph's Hospital, at depths of up to 142 feet BWT (Table 5 and Figure 2).

Appendix F provides graphs of concentration trends from 2001 to 2011 for selected COCs (particularly PCE and TCE) at various discrete-depth sampling intervals in wells covering the GOU: 411-P, BP-2, BP-3, BP-4, BP-7, BP-8, BP-9, BP-10, BP-11, BP-16, BP-21, C-022A, C-026A, C-026B, D-022A, R-068A, R-069B, R-092A, SJ-001, SJ-002, WR-178A, WR-179A, WR-181A, WR-273A, WR-274A, WR-275A, WR-358A, WR-367A, and WR-435A. These time series graphs are used for analysis of data trends.

3.5.3.2 Validity of Discrete-Depth Sampling Data

The validity of discrete-depth water quality data collected from water wells with long saturated screen intervals is subject to debate. Peer-reviewed literature (Church and Granato, 1995; Collar and Mock, 1997; and Gossell and others, 1999) suggests vertical flow components may cause a mixing effect of contaminants in the casing of wells with long saturated screen intervals. In addition to the presence of vertical flow within the well casing, the sample collection methodology and equipment may introduce some level of error in the resulting data. The following presents a discussion of the overall validity (both pros and cons) of the depth-specific water quality data collected during this RI.

Use of Minimally-Intrusive Discrete-Depth Sampling Device:

During this RI, all discrete-depth groundwater samples were collected using a Solinst Model 425 DIS, which is a 1.66-inch-diameter sampling device. The DIS utilizes positive pressure while the stainless steel device is being lowered and raised within the well to achieve discrete level sampling. In a study conducted for U.S. Army Corps of Engineers (2002), the Solinst Model 425 DIS was found to be easy to use and did not disturb (i.e., by dragging contaminants from the upper portion to lower portions of the test well while lowering the sampler through standing water in the casing) or increase the turbidity of the standing water in the test well casing. Differences in the concentrations of VOCs in the samples taken with the Solinst sampler versus the control samples were generally small. Based on the overall consistency of the laboratory analytical results (Table 5), and given that the sampling equipment was the same type for each sampling event (errors, if any, introduced by the sampling equipment would have been equivalent for each event), the discrete-depth water quality sampling method does not appear to be affecting the groundwater results.

Vertical Flow Monitoring Results:

Temperature and FloVision™ surveys were conducted on wells BP-2, BP-4, BP-10, C-026A, D-022A, WR-178A, WR-181A (Section 3.5.1 and 3.5.2; Table 14). With the exception of monitor well BP-10, the WCS was pumping while the subject wells were being surveyed. The results of the temperature and FloVision™ surveys conducted on these wells are somewhat contradictory. The temperature surveys suggest that evidence of vertical flow was apparent in six out of seven tested wells (BP-2, BP-4, BP-10, C-026A, D-022A, and WR-178A). By contrast, the FloVision™ surveys suggest that measurable vertical flow was apparent in four of the seven tested wells (BP-2, BP-4, BP-10, and C-026A); however, the velocity of the flow was quantifiable in only two wells (BP-2 and C-026A located near pumping well C-026B). The results from other wells surveyed using FloVision™ (D-022A, WR-178A, and WR-181A) suggest there was no vertical flow (estimated or quantifiable) in these wells (Table 14). The temperature surveys for wells D-022A and WR-178 suggest that there may be vertical flow in these wells; however, the gradient may be negligible.

Consistent and Repeatable Concentration Gradients:

Discrete-depth sampling results from some wells with saturated screen intervals exceeding 100 feet have shown a consistency of contaminant concentrations at each of the levels sampled during a specific event. This concentration gradient pattern (Table 5; Figure 32 through

Figure 51) is evident at two inactive production wells (C-026A and D-022A) and four groundwater monitor wells (WR-178A, WR-181A, BP-10, and BP-23). This phenomenon suggests that the vertical distribution of contaminants in the saturated zone is either remarkably consistent, or that vertical flow is causing a mixing effect within the well casing. Discrete-depth sampling results from other long saturated screen wells in the monitoring network (specifically monitor wells BP-2, BP-4, and BP-8) indicate a small, but significant, difference in contaminant concentrations at specific depths. Water quality data collected from monitor wells BP-2, and to a lesser extent from monitoring wells BP-4 and BP-8, suggest vertical flow is not causing a mixing effect within the well casing.

Prior Site-Specific Discrete-Depth Sampling Results:

There are three sets of paired wells that offer some insight to the effectiveness of discrete-depth sampling results. These well pairs are WR-178A and WR-352A, WR-273A and WR-353A, and BP-24A, BP-24B, and BP-24C. Discrete-depth sampling results of each well pair are presented below.

Well Pair WR-178A and WR-352A. Monitor well WR-178A is screened from 312 to 454 feet bgs (approximately 28 feet AWT to 128 feet BWT based on September 2011 water level data). Monitor well WR-352A, located approximately 50 feet south of monitor well WR-178A, is screened from 424 to 463 feet bgs (approximately 85 to 125 feet BWT based on September 2011 water level data) (Table 1; Figure 2). During this RI, discrete-depth groundwater samples were collected from well WR-178A on 24 occasions at depths ranging from 5 to 112 feet BWT. PCE was detected in concentrations greater than the AWQS at 5 feet (9.1 µg/L) and 50 feet (7.8 µg/L) BWT and at a concentration less than the AWQS (4.3 µg/L) at 112 feet BWT in August 2001. PCE has not been detected in concentrations greater than the AWQS during subsequent sampling events (Table 5). Discrete-depth groundwater samples were collected from well WR-352A at depths ranging from 86 to 121 feet BWT on 26 occasions. PCE was not detected in concentrations greater than the laboratory reporting limit in any of the samples collected (Table 5). Based on this data, the vertical extent of the plume in this area in this area appears to be limited to a minimum of 50 feet BWT and a maximum of 86 feet BWT. Since August 2001, however, the plume has not been present in this area which is within the capture area of WCS extraction well R-092A.

Well Pair WR-273A and WR-353A. The second set of paired groundwater monitor wells is located on the western boundary of the northern portion of the BNL (Figure 2). Well WR-353A is located approximately 50 feet west (hydraulically downgradient) of well WR-273A. Well WR-273A is screened from 298 to 338 feet bgs (approximately 5 feet AWT to 20 feet BWT based on September 2011 water level data). Well WR-353A is screened from 410-450 feet bgs (approximately 100 to 135 feet BWT based on September 2011 water level data) (Table 1). Discrete-depth groundwater samples were collected from well WR-273A at a depth of 5 feet BWT on 17 occasions during this RI. PCE (8.7 µg/L to 130.0 µg/L), TCE (12 µg/L to 28.0 µg/L), vinyl chloride (2.4 µg/L to 12 µg/L), and MeCl (1.2 µg/L to 6.4 µg/L) were detected during these sampling events at concentrations that exceeded the respective AWQSs. Cis-1,2-DCE (2.3 µg/L to 14 µg/L) was also detected; however, the concentrations did not exceed the AWQS. Discrete-depth groundwater samples were collected from well WR-353A at a depth of 103 to 131 feet BWT on 17 occasions during this RI. PCE, TCE, vinyl chloride, MeCl and cis-1,2-DCE were not detected in concentrations greater that the laboratory reporting limit any of the samples collected (Table 5). Since there is 72 feet between the bottom the screened interval in well WR-273A and the top of the screened interval in well WR-353A, it is difficult to estimate the vertical extent of the plume in this this area; however, based on this analytical data the vertical extent of the plume in this area is less than 100 feet BWT (the top of the screened interval at well WR-353A).

Well Cluster BP-24A, BP-24B, and BP-24C. Wells BP-24A, BP-24B, and BP-24C were installed to investigate the vertical extent of contamination near the BNL (Figure 2). The wells are screened from 325 to 355 feet bgs (BP-24A), 385 to 405 feet bgs (BP-24B) and 440 to 460 feet bgs (BP-24C). The screened intervals correlate to 2 feet AWT to 12 feet BWT (BP-24A), 63 to 83 feet BWT (BP-24B), and 118 to 138 feet BWT (BP-24C) based on September 2011 water level data. Discrete-depth groundwater samples were collected from each well on at least 4 occasions during this RI. Groundwater samples collected at 5, 15, and 20 feet BWT from well BP-24A have contained up to 34 µg/L PCE and 5.2 µg/L TCE. Groundwater samples collected at 50, 60, 70, and 80 feet BWT from well BP-24B have contained up to 24 µg/L PCE and 6.2 µg/L TCE. Cis-1,2-DCE was also detected in samples collected from well BP-24B; however, the concentrations were below the AWQS Concentrations of PCE, TCE, and cis-1,2-DCE have not been detected above the laboratory reporting limits in the groundwater samples collected from BP-24C at 105, 115, 125, and 135 feet BWT (Table 5). Based on this data, the vertical extent of the plume in this area appears to be a minimum of 80 feet BWT and maximum of 105 feet BWT.

Thickness of Groundwater Contaminant Plume in the GOU

Groundwater monitor well WR-358A is located approximately 900 feet west and 225 feet north of paired groundwater monitor wells WR-273A and WR-353A (Figure 2). Monitor well WR-358A is screened from 321 to 371 feet bgs (approximately 5 feet AWT to 55 feet BWT based on September 2011 water level data) (Table 1). During this RI, discrete-depth groundwater samples were collected from well WR-358A at a depth of 50 feet BWT on three occasions. PCE (17.0 µg/L to 23.0 µg/L), TCE (2.7 µg/L to 3.5 µg/L), vinyl chloride (0.7 µg/L to 1.0 µg/L), and cis-1,2-DCE (1.5 µg/L to 2.1 µg/L) were detected on all three occasions; MeCl was detected on one occasion at a concentration of 1.7 µg/L (Table 5). The analytical data for WR-358A indicates that COCs in this area appear to extend to a minimum of 50 feet BWT. Based on the groundwater data from well cluster BP-24 (discussed above), the plume in this area appear to extend to a minimum of approximately 80 feet BWT and a maximum of 105 feet BWT.

Historical Vertical Dispersion Monitoring Results

While conducting the RI for the BNL, CDM collected one wellhead and three depth- samples for laboratory analysis using micro-purge techniques from inactive production wells D-021A and D-022A, and monitor well WR-178A. CDM (1998) concluded that there was no trend indicating the upper portions of the water column are more contaminated than lower portions. CDM (1998) also noted that micro-purge sampling methods were developed for small diameter monitor wells. The casing diameters of inactive production wells D-021A and D-022A, and monitor well WR-178A are 12-, 10-, and 6-inches, respectively. URS (2002a) reviewed the inorganic water chemistry and PCE concentrations of the wellhead and micro-purged groundwater samples collected by CDM at depths 331, 390, and 448 feet bgs. (Note: CDM did not provide a depth to water in monitor well WR-178A on the day the micro-purge groundwater samples were collected. To be consistent with the nomenclature used in the RI Report, SECOR has estimated that the groundwater samples were collected by CDM at, or near, the top of the water table, and at depths of approximately 60 and 115 feet BWT, respectively.) URS (2002a) concluded that there was a difference in the inorganic water chemistry and a smaller concentration of PCE (6.0 µg/L) in the uppermost micro-purge groundwater sample, compared to the inorganic water chemistry and the PCE concentration (25 µg/L) found in the lower micro-purge groundwater samples. URS (2002a) also stated that the PCE concentration in the wellhead sample (21 µg/L) corroborated the finding of mixing of larger PCE concentrations at depth with smaller PCE concentrations in the upper portions of the well water column when collecting wellhead samples. Therefore, CDM's micro-purge sampling suggests that there may be some component of vertical dispersion in the aquifer.

<u>Historical Hydropunch™ Discrete-Depth Sampling Results</u>

During the installation of groundwater monitor wells WR-352A and WR-353A (Figure 2), URS (2002a) collected depth-specific groundwater samples using a Hydropunch® and/or bailer. Groundwater samples collected at approximately 60, 90, and 148 feet BWT from monitor well WR-353A (located near the BNL) did not contain laboratory detectable concentrations of PCE. Groundwater samples collected at depths of approximately 19, 67, and 119 feet BWT from groundwater monitor well WR-178A (located approximately 1.5 miles west of the BNL) did not contain laboratory detectable concentrations of PCE. The groundwater sample collected from approximately 37 feet BWT (373 feet bgs) while installing monitoring well WR-178A contained a PCE concentration of 8 µg/L.

According to URS (2002a):

> "Analytical results collected during the installation of WR-352A indicated that there is a slight vertical component to the dispersion of the contaminant plume, as evidenced by the presence of PCE in the sample collected from 373-feet bgs and that WR-353A had no PCE at this depth. Also present in this sample were many of the same aldehydes identified in the samples collected during the installation of WR-353A (located at the northwest edge of the BNL). No detectable concentrations of the VOCs tested for were present in the samples collected below 373-feet bgs.
>
> Analytical results collected during the March and September 2000 sampling events indicated that detectable concentrations of VOCs were not present in the samples collected from WR-352A and WR-353A. These wells are screened from 420 to 460 feet bgs and 410 to 450 feet bgs, respectively. The VOC plume appears to be isolated to hydrologic units within the uppermost portion of the regional aquifer (to approximately 373-bgs), based upon analytical results from the depth-specific sampling and subsequent groundwater sampling events. This data is consistent with the vapor transport mechanism for groundwater contamination."

The data collected during the GOU RI suggest that the VOC plume is generally less than 100 feet thick across the Site.

3.5.4 Summary of Vertical Flow Monitoring Results

The following summary is based on the Welenco (2003) interpretations of temperature and FloVision™ surveys, historic groundwater elevations, radial distances between the surveyed monitor wells and the closest WCS extraction/injection well, pumping/injection rates of the extraction/injection wells on the date of the surveys, and the date the surveys were completed.

- Temperature logs (Section 3.5.1) appear to reflect actual vertical flow conditions within the well casing. The temperature logs, which showed evidence of vertical flow in each well, may have been more sensitive than the FloVision™ logs.

- Measurable (quantifiable) downward vertical flow (Section 3.5.2) was observed in groundwater monitor wells BP-2 at 390 feet bgs (60 feet BWT) and C-026A at 360 feet bgs (28 feet BWT). Based on the horizontal distance between the monitor wells and WCS extraction well C-026B, and the pumping rate of the well (C-026B), it is reasonable to expect some component of vertical flow within the well casing of the monitor wells.

- Based on the pumping and injection rates at the closest WCS extraction/injection wells, the observations of no vertical flow in monitor well WR-178A, and non-quantifiable downward vertical flow in monitor well BP-4 were not expected. No explanation for these observations is being put forth at this time.

- Historic groundwater elevation data and calculated groundwater elevations for three groundwater monitor wells located east of the WCS (BP-10, D-022A, and WR-181A) indicate that water level changes recorded prior to, and after, startup of the WCS have not been affected by operation of the system. Although vertical gradients were not necessarily quantifiable in all of the wells surveyed (including wells located outside of the area influenced by the WCS) small or negligible vertical gradients could cause mixing within the well bore that would result in the similar concentrations of COCs throughout the water column.

Because temperature and/or FloVision™ surveys were not conducted prior to startup of the WCS, it is not possible to determine the presence, or quantify the effect of, any observed vertical flow in monitor wells prior to startup of the system. However, it appears that vertical mixing is occurring in a number of the groundwater monitor wells in the GOU and that the temperature surveys may have been more sensitive than the FloVision™ surveys in measuring vertical flow in the well casings.

4.0 NATURE AND EXTENT OF CONTAMINATION

The purposes of this section are to review the results of laboratory analytical data to identify chemical compounds and RCRA 8 metals in groundwater that exceed established regulatory thresholds; and to define, to the degree possible, the lateral and vertical extent of the groundwater containing these contaminants above regulatory thresholds. The nature and extent of impacted groundwater were assessed utilizing results from historical investigations and data collected during this RI. Contaminants which have been detected in groundwater above regulatory levels define the Site GOU and are called contaminants of concern (COCs). Also, for a contaminant to be considered a groundwater COC, it must be found with some consistency within the Site.

To determine the degree to which the groundwater has been impacted, SECOR used ADEQ-established regulatory criteria. To determine chemical compounds and metals of concern in groundwater, and to delineate the extent of impacted groundwater, laboratory analytical results for samples collected during this RI (July/August 2001 through September 2011, Table 5 and Table 11) were compared to the AWQSs (published in Sections R18-11-406 (B), (C), and (D) of the Arizona Administrative Code [A.A.C.]).

The following sections discuss laboratory analytical results, findings, and conclusions regarding impacted groundwater in the vicinity of the BNL and BSL.

4.1 SOURCES

The BNL and BSL landfilled areas are the primary and secondary sources, respectively, of the VOC impacts to groundwater within the GOU. Additionally, the sand and gravel mining operations used as “wildcat” dumping sites are considered to be a third source of groundwater contamination in the GOU. Historical soil gas sampling (refer to Section 3.1.1 and Appendix C on BNL soil gas) has demonstrated that VOCs have migrated down to the water table and dissolved into groundwater. The distribution of COCs in soil gas is summarized in SECOR (2008).

4.2 GROUNDWATER

The monitoring well network for this RI includes 68 wells (Table 1 and 5; Figure 2). During this RI, each of the wells in the network were sampled on multiple occasions. Groundwater samples collected from the well network were typically analyzed for VOCs. Selected groundwater samples were also analyzed for one or more of the following: RCRA 8 Metals (arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver); bicarbonate alkalinity; nitrate; nitrite; 1,4-dioxane; and polychlorinated biphenyls (PCBs). Groundwater COCs are those VOCs which have had consistent exceedances for AWQSs during this RI.

The COCs, lateral extent, and vertical extent of groundwater contamination described in the following subsections are based primarily on data gathered during this RI.

4.2.1 Contaminants of Concern and Contaminants of Potential Concern

4.2.1.1 VOCs

PCE: Thirty one of the wells sampled during this RI contained concentrations of PCE in excess of the ADEQ AWQS for PCE (5.0 µg/L). PCE is a VOC constituent historically used as a solvent in dry-cleaning fluid and metal degreasing. The maximum concentration of PCE (290.0 µg/L) detected during this RI was in the groundwater sample collected from AI well R-068A on February 14, 2002 (Table 5). Well R-068A is located on the southern portion of the closed BNL (Figure 2).

TCE: TCE was detected at concentrations greater than the ADEQ AWQS for TCE (5.0 µg/L) in 11 wells during this RI; however, the one-time occurrence of TCE detected in WR-179A appears erroneous and is attributed to laboratory error. TCE has been used historically as a solvent in dry-cleaning and metal degreasing. TCE is also a degradation product of PCE. The maximum detected concentration of TCE (68.0 µg/L) was found in the groundwater sample collected from AI well R-068A on February 14, 2002 (Table 5, Figure 2).

Vinyl Chloride: Vinyl chloride was detected at concentrations above the ADEQ AWQS (2.0 µg/L) in three wells (AI well R-069B and groundwater monitor wells WR-273A and WR-358A) during this RI. The maximum concentration of vinyl chloride (12 µg/L) detected during this RI was in the groundwater sample collected from monitor well WR-273A on December 03, 2003 (Table 5). Well WR-273A is located hydraulically downgradient, and in close proximity, to the western boundary of the northern portion of BNL (Figure 2). Vinyl chloride has been used historically for manufacturing PVC. Vinyl chloride can also be an end product resulting from biodegradation of chlorinated ethenes, such as PCE and TCE.

Cis-1,2-DCE: One of the wells in the monitoring network sampled during this RI contained concentrations of cis-1,2-DCE in excess of the established ADEQ AWQS (70 µg/L). The groundwater sample collected from AI well R-068A on May 9, 2002, contained a concentration of 81.0 µg/L cis-1,2-DCE. This was the maximum concentration of cis-1,2-DCE detected in groundwater samples collected during this RI (Table 5, Figure 2). Cis-1,2-DCE is used in solvent mixtures and is a degradation product of chlorinated ethenes, such as PCE and TCE. Cis-1,2-DCE has not been detected in concentrations greater than the AWQS in a Site well since the November 2005 sampling event; if this trend continues, cis-1,2-DCE may be re-designated as a COPC.

MeCl: Groundwater samples collected from two of the wells (AI well R-069B and groundwater monitor well WR-273A) contained concentrations of MeCl above the ADEQ AWQS (5.0 µg/L). The maximum concentration of MeCl (7.1 µg/L) was detected in the groundwater sample collected from AI well R-069B on August 8, 2002 (Table 5). AI well R-069B is located in the northern portion of the BNL (Figure 2). MeCl is a volatile solvent used in a wide range of commercial and industrial processes. MeCl has not been detected at concentrations greater than the AWQS in a Site well since the November 2005 sampling event; if this trend continues, MeCl may be re-designated as a COPC.

4.2.1.2 RCRA 8 Metals – Contaminants of Potential Concern

Lead: Lead was detected in groundwater samples collected from three wells in the monitoring network at concentrations exceeding the ADEQ AWQS (50 µg/L). The maximum concentration of lead (130 µg/L) was detected in the groundwater sample collected from groundwater monitor well WR-353A on August 7, 2002 (Table 11). Well WR-353A is located hydraulically downgradient, and in close proximity, to the western boundary of the northern portion of the BNL (Figure 2). From 2001 to 2011, in the groundwater monitor wells at the BNL and BSL, lead detections have been rare and usually below the AWQS; thus, lead is a COPC and not a COC.

Mercury: Mercury was detected at a concentration exceeding the ADEQ AWQS (2 µg/L) in one groundwater monitor well (WR-273A) on one occasion. The laboratory detected concentration of mercury in the groundwater sample collected on August 8, 2002 was 2.3 µg/L (Table 11). Well WR-273A is located hydraulically downgradient, and in close proximity, to the western boundary of the northern portion of the BNL (Figure 2). From 2001 to 2011, in the groundwater monitor wells at the BNL and BSL, mercury detections have been rare and usually below the AWQS; thus, mercury is a COPC and not a COC.

4.2.2 Lateral Extent

As with any dynamic system, the lateral extent of the PCE groundwater plume originating from the BNL and BSL has fluctuated over time. Four wells located downgradient of the BNL (abandoned production well C-021A, inactive production wells C-022A and D-021A, and groundwater monitor well WR-178A; Figure 2) have recorded exceedances of the AWQS for PCE (URS, 2002a) between August 1988 (abandoned production well C-021A) and August 2001 (monitor well WR-178A). Historical data compiled by URS (2002a) indicates that the maximum concentration of PCE in these wells was reported to be 8.4 µg/L (abandoned production well C-021A on April 5, 1989), 37.9 µg/L (inactive production well C-022A on November 22, 1988), 23.2 µg/L (inactive production well D-021A on August 31, 1991), and 23.8 µg/L (well WR-178A on December 17, 1996). Changes in the shape and lateral extent of the plume are likely due to several factors. These factors may include: (1) the number of data points (in this case, groundwater monitor wells and private water supply wells sampled during an event); (2) groundwater elevation changes; (3) fluctuation in the magnitude (gradient) and flow direction associated with pumping of CWF production wells; and (4) naturally occurring degradation of contaminants (URS, 2002a; Clear Creek Associates, 2000; and COT, 2000b).

During the August 2002 sampling event (SECOR, 2002c), the groundwater samples collected at 5, 50, and 123 feet BWT from groundwater monitor well WR-181A were found to contain 5.5 µg/L, 5.1 µg/L, and 4.8 µg/L PCE, respectively (Table 5). At the request of ADEQ, monitor well WR-181A was resampled on November 26, 2002; at sample depths of 5, 50, and 123 feet BWT, laboratory analysis revealed PCE concentrations of 3.9 µg/L, 3.0 µg/L, and 3.4 µg/L, respectively (Table 5). As part of the Site-wide semi-annual sampling event, groundwater monitor well WR-181A was sampled on March 19, 2003 (SECOR, 2003b); at sample depths of 5, 50, and 123 feet BWT, laboratory analysis reported the presence of PCE concentrations of 2.2 µg/L, 2.1, µg/L, and 2.1 µg/L, respectively (Table 5). As detailed in Table 5, with the exception of the August 2002 sampling event, the laboratory results for the groundwater samples collected between November 26, 2002, and September 21, 2011, are below AWQSs and in the range of samples collected previous to the August 2002 event. Based on the historical (URS, 2002a) and current laboratory analytical data (Table 5), monitor well WR-181A should not be included in the Site GOU.

PCE: Given the widespread occurrence of PCE in groundwater, ADEQ utilizes concentrations of PCE exceeding the AWQS to define the lateral extent of the GOU. The most recent fluid level monitoring and groundwater sampling event to encompass the majority of wells in the monitoring well network occurred in September 2011. During the September 2011 event, groundwater samples were collected from 54 groundwater monitoring wells, groundwater remediation wells, TW water production wells, and two private supply wells (Catalina Village and 416-P) for VOCs, and in select cases, other inorganic compounds. Fifteen of the 54 wells sampled contained concentrations of PCE above the ADEQ AWQS of 5.0 µg/L (Table 5). Figures 5 and 49 illustrate the approximate extent of the GOU based on laboratory results of groundwater samples collected during the September 2011 sampling event.

Based on monitoring events conducted during this RI, the GOU consists of two distinct plumes, one emanating from the BNL and one emanating from the BSL (Figure 5 and Figure 49). At times the BNL and BSL plumes have been commingled. The BSL plume extends northwest from the BSL. The BNL plume extends westerly from the BNL and consists of discontinuous areas where PCE exceeds the AWQS (5 ug/L). The PCE concentrations in wells 411-P, C-022A, and SJ-002 fluctuate above and below the AWQS, and thus the shape of the downgradient portions of the BNL plume changes over time. PCE in exceedance of AWQSs is also present in the vicinity of monitor wells BP-21, WR-702A, and WR-704A; this impact is interpreted to be part of the primary plume that migrated through the area before operation of the WCS began in March 2003 (PCE in concentrations greater than 5 ug/L has not been detected in well BP-21 since May 2010).

Concentrations of PCE typically are higher in the southern (AI well R-068A and monitor wells D-022A and WR-274A) and northwestern (monitor well WR-273A) portions of the BNL (URS, 2002a; and Figure 5 and Figure 49). Concentrations appear to attenuate as impacted groundwater flows toward the west.

The sampling data obtained thus far from the groundwater wells at the BSL indicate that the groundwater contamination exceeding the PCE AWQS is primarily in the northern part of the landfill (Figure 5 and Figure 49). Well BP-11, located at the western edge of the central part of the BSL, has exceeded the PCE AWQS only once (5.5 µg/L in 2004); all other results from 2001 to 2011 have been less than 1.0 µg/L. With the exception of the September 2011 sampling event, PCE is generally not detected in Well BP-22, located southeast/upgradient of BP-11. Well WR-435A, located south of BP-22 and downgradient of the northern part of the Prudence Landfill, has never had an exceedance of the PCE AWQS. Therefore, the BSL plume appears to be relatively well defined and localized in the vicinity of well WR-367A, which has had PCE AWQS exceedances during every sampling event since its installation in 2001, and by well BP-23, which was installed to the southeast/upgradient of well WR-367A, and has had PCE exceedances during every sampling event since its installation in May 2006 (Table 5).

The maximum downgradient extent of the PCE groundwater contamination, based on data collected during this RI, is illustrated on Figure 5 and Figure 49 of this report. Based on historical and current (this RI) laboratory analytical results, the widest lateral extent of the GOU is defined on the south by eight wells (WR-435A, BP-11, WR-177A, BP-16, WR-179A, WR-354A, SE-001, and C-058A); on the west by private well Catalina Village; on the north by seven groundwater monitor wells (WR-703A, BP-20, BP-1, BP-5, WR-180A, BP-19, and WR-181A); and on the east by two groundwater monitor wells (WR-181A and WR-207B). The current (September 2011) spatial extent of the PCE groundwater plume is depicted on Figure 5 and Figure 49. With the exception of monitor well BP-11 (5.5 µg/L in 2004) and WR-181A (5.5 µg/L in 2002), groundwater samples collected from the aforementioned monitor wells have not been found to contain concentrations of PCE greater than 5.0 µg/L.

The C-026B extraction well was operated as a last-on/first-off TW water supply well from 1994 until spring 1998, when it was shut down because of PCE contamination (URS, 2002a). From 1999 until the WCS came on line in late March 2003 (Section 7.4), C-026A monitor well and C-026B extraction well had PCE concentrations slightly below, or slightly above, the AWQS of 5.0 µg/L (from 2001 through March 2003, PCE concentrations were between 3.4 µg/L and 5.4 µg/L) (Table 5 and URS, 2002a). Up until 2002, there were no groundwater monitor wells downgradient of C-026A/C-026B – only the TW production wells, located almost one mile away (Figure 6). Monitor well BP-2 was installed in 2002 approximately 400 feet west of C-026B (Figure 2; Table 7); PCE concentrations were detected in the BP-2 samples upon the initial groundwater sampling event. Between 2002 and mid-2005, the highest PCE concentrations detected in this well were in samples collected from 50 feet BWT; these concentrations ranged from 7.6 µg/L to 20.0 µg/L during this time (Table 5). In March 2003, the WCS was turned on, and the western edge of the WCS capture zone was estimated from the well water elevation data to lie in the vicinity of BP-2 (Figure 8) or slightly to the west of BP-2. In 2005, groundwater monitor wells BP-20 and BP-21 were installed downgradient of BP-1 and BP-2 to help delineate the toe of the plume (URS, 2005). Figure 54, which depicts the WCS potentiometric surface map and PCE plumes for September 19, 2005, shows that a PCE plume is centered on BP-21. The WCS potentiometric surface map indicates that wells BP-20 and BP-21 are outside the WCS capture zone (Figure 54). PCE concentrations in BP-20 samples have all been less than 1.0 µg/L; PCE concentrations in samples collected at 5', 25', and 50' BWT from BP-21 have ranged between 1.6 µg/L and 9.8 µg/L (Table 5). In January 2007, wells WR-702A, WR-703A, and WR-704A were installed downgradient of BP-20 and BP-21 to help further delineate the toe of the plume. PCE concentrations in well WR-702A have ranged between 6.7 µg/L and 10.1 µg/L and PCE concentrations in well WR-704A have ranged between <0.5 µg/L and 12 µg/L. The September 2011 groundwater sampling event included private well Catalina Village, west of well WR-704A; VOCs were not detected in groundwater samples collected from this well.

Based on historical and current groundwater sampling results, the lateral extent of PCE in the GOU appears to be adequately characterized.

<u>TCE</u>: TCE has been detected at concentrations above the AWQS (5.0 µg/L) in the central portion [AI wells R-068A and R-069B (except 2006-2011)] and along the western perimeter [inactive production well D-022A and monitoring wells WR-273A, WR-274A, and WR-275A (except 2008-2011)] of the BNL on a consistent basis, both historically (URS, 2002a) and during this RI (Table 5). TCE has also been consistently detected at concentrations above the AWQS in two wells downgradient from the central and northern portions of the BNL (wells BP-24B and WR-358A). Groundwater samples collected from three groundwater monitor and/or inactive production wells located downgradient of the western margin of the BNL (WR-353A, C-022A, and D-021A) have not had any historical (URS, 2002a) or current exceedances of the AWQS for TCE (Table 5). Groundwater samples collected from groundwater monitor well WR-177A (located on the southwestern corner of the BNL) have not had a historical or current exceedance of the AWQS for TCE. The groundwater sample collected from well WR-179A on April 4, 2006 reportedly contained 12.0 µg/L TCE, but all of the other samples collected from this well between July 31, 2001 and September 20, 2011, contained non-detectable concentrations of TCE (less than 0.50 or 1.0 µg/L). The April 2006 TCE sample concentration appears to be erroneous, and is attributed to laboratory error. Based on the available groundwater analytical data, the lateral extent of TCE greater than the AWQS is confined to the BNL and areas within one-third of a mile of the BNL (Figure 50). The lateral extent of TCE appears to be adequately characterized.

Vinyl Chloride: Vinyl chloride has been detected at concentrations above the AWQS (2.0 µg/L) in the north central portion (AI well R-069B) and on the northwestern perimeter (monitoring well WR-273A) of the BNL both historically (URS, 2002a) and during this RI (Table 5). However, vinyl chloride has not been detected in AI well R-069B since 2004 or in well WR-273A since 2008. Vinyl chloride has been detected on a consistent basis in the 25 feet BWT samples from well WR-358A, located downgradient of well WR-273A. Groundwater samples collected from five groundwater monitor wells and/or inactive production wells located downgradient and along the western margin of the BNL (WR-353A, WR-274A, D-022A, WR-275A, and WR-177A) have not had any historical (URS, 2002a) or current exceedances of the AWQS for vinyl chloride (Table 5). Based on the available groundwater analytical data, the lateral extent of vinyl chloride greater than the AWQS has been confined to the area within one-third of a mile of the BNL downgradient of groundwater monitor well WR-273A since 2008 (Figure 51). The lateral extent of vinyl chloride appears to be adequately characterized.

Cis-1,2-DCE: Cis-1,2-DCE has been detected at concentrations above the AWQS (70.0 µg/L) in the south central portion (AI well R-068A) of the BNL both historically (URS, 2002a) and during this RI (Table 5). Groundwater samples collected from seven groundwater monitor wells and/or inactive production wells located downgradient and along the western margin of the BNL (WR-273A, WR-353A, WR-358A, WR-274A, D-022A, WR-275A, and WR-177A) have not had any historical (URS, 2002a) or current exceedances of the AWQS for cis-1,2-DCE (Table 5). Based on the available historical groundwater analytical data, the lateral extent of cis-1,2-DCE greater than the AWQS has been confined to AI well R-068A; since 2005, the cis-1,2-DCE concentration in the R-068A sample has dropped significantly below the AWQS. The lateral extent of cis-1,2-DCE appears to be adequately characterized.

MeCl: MeCl has been detected at concentrations above the AWQS (5.0 µg/L) in the northern portion (AI well R-069B) of the BNL and on the western margin of the BNL (groundwater monitor well WR-273A) both historically (URS, 2002a) and during this RI (Table 5). Groundwater samples collected from five groundwater monitor wells and/or inactive production wells located downgradient and along the western margin of the BNL (WR-353A, WR-358A, WR-274A, D-022A, and WR-177A) have not had any historical or current exceedances of the AWQS for MeCl. Historical groundwater quality data (URS, 2002a) indicates two exceedances of the MeCl AWQS were detected in groundwater samples collected from monitor well WR-275 on June 28, 1997 (5.1 µg/L) and September 23, 1997 (5.4 µg/L). Based on the available historical groundwater analytical data, the lateral extent of MeCl greater than the AWQS has been confined to the northern portion of the BNL. MeCl has not been detected in R-069B in concentrations greater than the AWQS since 2003 or in WR-273A since 2005. The lateral extent of MeCl appears to be adequately characterized.

Lead: During this RI, lead was detected at concentrations above the AWQS (50 µg/L) in groundwater samples collected from three water wells. These wells are groundwater monitor wells WR-207A, WR-177A, and WR-353A (Figure 2). The lead detections are discussed in the following paragraphs.

Well WR-207A. One of the wells (abandoned groundwater monitor well WR-207A), located upgradient of the BNL, contained lead at a concentration of 78 µg/L in the non-purge depth-specific sample collected at a depth of 102 feet BWT on July 25, 2001; however, non-purge depth-specific groundwater samples collected at 5 and 50 feet BWT did not contain concentrations of lead above the AWQS. During the sampling event conducted in August 2002, non-purge depth-specific groundwater samples were collected from well WR-207A at 5, 50, and 101 feet BWT; lead was not detected at concentrations above the laboratory MRL (5.0 µg/L) in any of the three samples (Table 11).

Well WR-177A. Well WR-177A is located at the southwestern corner of the BNL. Lead was detected at concentrations above the AWQS in the pre-purge (81 µg/L) and post-purge (51 µg/L) depth-specific groundwater samples collected at a depth of 112 feet BWT on July 31, 2001 and August 1, 2001, respectively. Pre- and post-purge depth-specific groundwater samples collected at 5 and 50 feet BWT did not contain concentrations of lead above the laboratory MRL (5.0 µg/L). During the sampling event conducted in August 2002, non-purge depth-specific samples were collected at depths of 5, 50, and 111 feet BWT from well WR-177A (SECOR, 2002c). Lead was not detected at concentrations above the laboratory MRL (5.0 µg/L) in any of the three samples (Table 11).

Well WR-353A. Groundwater monitor well WR-353A is located on the west margin of the northern portion of the BNL. The non-purge depth-specific groundwater sample collected at 130 feet BWT on August 7, 2002 (SECOR, 2002c) contained lead at a concentration of 130 µg/L. The non-purge depth-specific groundwater sample collected at a depth of 131 BWT from well WR-353A on July 25, 2001contained concentrations of lead less than the laboratory MRL (5.0 µg/L) (Table 11).

Based on the sampling results obtained during this RI, lead concentrations greater than the AWQS have been found at depths of greater than 100 feet BWT, relatively upgradient and downgradient of the BNL, and do not appear to occur on a consistent basis. The lateral extent of lead detected during this RI is confined to the area around groundwater monitor wells WR-353A and WR177A and abandoned groundwater monitor well WR-207A. Based on the limited degree of impact and the inconsistent detection of lead, for purposes of this RI, the lateral extent of lead appears to be adequately characterized. The spatial orientation and depth of lead-impacted groundwater suggests that the source of lead may not be the BNL. Lead is not considered to be a COC at this time.

Mercury: Mercury was detected above the AWQS (2.0 µg/L) in groundwater monitor well WR-273A during the August 2002 sampling event. This was the only detection of mercury above the AWQS during this RI. The non-purge depth-specific groundwater sample collected at 5 feet BWT on August 8, 2002 contained mercury at a concentration of 2.3 µg/L. Mercury has been detected in well WR-274A at a maximum concentration of 1.4 µg/L (below the AWQS). Mercury has not been detected above laboratory reporting limits in groundwater samples from any other wells (Table 11). Laboratory analysis of groundwater samples collected during this RI suggests mercury does not occur on a consistent basis and has been confined to wells along the western margin of the BNL (monitor well WR-273A and WR-274A). For purposes of this RI, the lateral extent of mercury appears to be adequately characterized and is not considered to be a COC at this time.

4.2.3 Vertical Extent

Based on the groundwater quality results collected during this and two previous (CDM, 1998; and URS, 2002a) RIs conducted at the Site, the vertical extent of impacted groundwater has been fairly well characterized. Well cluster BP-24A (screened 325 to 355 feet bgs), BP-24B (screened 385 to 405 feet bgs), and BP-24C (screened 440 to 460 feet bgs) was specifically installed to investigate the vertical extent of contamination near the BNL in 2007. Depth-specific groundwater samples were collected from each well on at least 4 occasions during this RI.

PCE: The discrete-depth VOC sampling results for groundwater sampling events between July/August 2001 and September 2011 indicate that the vertical extent of the VOC groundwater plume is approximately 100 feet BWT near the head (primary portion) of the BNL plume (BP-24 well cluster) and approximately of 86 feet BWT (427 feet bgs) further downgradient (WR-178A). The vertical extent of the PCE plume is further discussed in Section 3.5.3.

TCE: Concentrations of TCE exceeded the AWQS in eleven monitoring wells during this RI; however, the one-time occurrence of TCE detected in WR-179A appears erroneous and is attributed to laboratory error. The maximum concentration of TCE (68.0 µg/L) was detected in the groundwater sample collected from AI well R-068A, located on the southern portion of the closed BNL. Groundwater samples from well R-068A are collected at 5 feet BWT. Groundwater samples collected from well BP-24A at 5, 15, and 20 feet BWT contained a maximum of 5.2 µg/L TCE (Table 5). Groundwater samples collected from well BP-24B at 50, 60, 70, and 80 feet BWT contained a maximum of 6.2 µg/L TCE. Groundwater samples collected from BP-24C at 105, 115, 125, and 135 feet BWT (between approximately 440 and 460 feet bgs) have had no detectable concentrations of TCE. This groundwater monitoring data suggests that the vertical extent of the TCE plume is similar to the PCE plume, where TCE in the vicinity of the BNL appears to extend to a minimum of 80 feet BWT and a maximum of 105 feet BWT (440 feet bgs).

Vinyl Chloride: Vinyl chloride exceeded the AWQS in three wells (R-069B, WR-273A, and WR-358A) during this RI, with the maximum concentration of 7.4 µg/L occurring in well WR-273A. Groundwater samples are collected from R-069B at 5 feet BWT, from WR-273A at 5 feet BWT, and from WR-358A at 5, 25, and 50 feet BWT (Table 5). Vinyl chloride has not been detected in well R-069B since 2003 and has not been detected in well WR-273A since 2006. Groundwater samples collected from well WR-358A at 5 and 25 feet BWT have contained vinyl chloride concentrations in exceedance of AWQSs. Vinyl chloride has exceeded laboratory reporting limits in well WR-358A at a depth of 50 feet BWT, but has not exceeded AWQS at this depth. Based on these data, the vertical extent of vinyl chloride exceeding AWQSs is less than 50 feet thick.

Cis-1,2-DCE and MeCl: One of the wells (R-068A) sampled during this RI contained concentrations of cis-1,2-DCE in excess of the AWQS. Two wells (R-069B and WR-273A) have contained MeCl in excess of the AWQS. Groundwater samples from these three wells are collected at 5 feet BWT. Groundwater samples collected from well WR-353A (near well WR-273A and within 1,500 feet of wells R-068A and R-069B) between 103 and 131 feet BWT have not had detectable concentrations of VOC constituents. This data suggests that the vertical extent of cis-1,2-DCE and MeCl is similar to the other COCs and is likely no more than 100 feet BWT. Additionally, cis-1,2-DCE and MeCl have not been detected in exceedance of AWQSs since 2005.

5.0 CONTAMINANT TRANSPORT AND FATE/POTENTIAL RECEPTORS

This section summarizes the fate and transport of COCs identified in groundwater (Section 4.0) at the GOU. This section discusses contaminant fate and transport mechanisms present and potential pathways of contaminant transport, contaminant persistence, and contaminant migration in groundwater at the Site. The subsections are intended for use in developing a CSM for the Site, which is summarized in this section.

5.1 STUDY AREA LIMITS

The limits of the Site are described in Section 1.3.

5.2 PROPERTIES OF THE CONTAMINANTS OF CONCERN

This section will address the fate and transport of the GOU COCs identified in Section 4.2.1. COCs identified in shallow groundwater (less than 50 feet BWT) in the GOU during this RI include PCE, TCE, cis-1,2-DCE, vinyl chloride, and MeCl. At greater depths, the only COCs identified during this RI are PCE and TCE.

The fate and transport of the COCs through groundwater can be evaluated by considering the properties of the chemicals that influence their mobility and persistence in the environment. The mobility and persistence of the COCs were evaluated by comparing their chemical properties to published criteria. Information on the properties of the COCs was obtained from numerous sources, including Technical Fact Sheets published by EPA and Lewis (1993a; 1993b).

Table 15 lists the primary mobility and persistence factors that are considered important for this evaluation. The mobility and persistence factors include the following.

- Water Solubility. Water solubility determines the affinity a chemical has for water and determines the maximum concentration that can be present in water.

- Octanol-Water Coefficient (log K_{ow}). Log K_{ow} is the equilibrium partitioning coefficient between octanol and water, and indicates the affinity of organic chemicals for sorption onto organic matter present in the soil. A high log K_{ow} indicates that the chemical will have a high affinity for organic carbon in soil, which will tend to retard the mobility of the chemical in the soil system and in the aquifer.

- Organic Carbon Coefficient (log K_{oc}). Log K_{oc} is the equilibrium partitioning coefficient between organic carbon and water, and indicates the potential for sorption onto aquifer materials when the percent of organic matter is known or estimated. Similar to the log K_{ow} values, relatively high values of log K_{oc} will tend to retard the movement of the chemical through the groundwater system.

- Vapor Pressure. Vapor pressure is the pressure at which equilibrium exists between a pure liquid chemical and air. A high vapor pressure is indicative of a chemical that readily partitions from the liquid phase to the vapor phase.

- Henry's Law Coefficient. The Henry's law coefficient is the ratio of solute vapor pressure to aqueous solubility and is a measure of the vaporization potential of dissolved organic chemicals from water. The greater the Henry's law coefficient, the more volatile the chemical.

- Water Half-Life. The water half-life is a measure of the persistence of a compound, and is defined as the amount of time (usually in days) it takes a chemical to be degraded by chemical (i.e., hydrolysis) and/or biotic processes to one-half its original concentration. Persistence is inversely proportional to the degradation potential of a compound (i.e., the more persistent a compound, the less the compound is expected to undergo degradation).

Table 15 presents a method for classifying the COCs into low, medium, and high classes for the various mobility and persistence factors described above. Solubility, log K_{ow} and water half-life classes are from Ney (1990). K_{ow} values and vapor pressure classes are from Dragun (1988). Henry's Law Coefficient classes are from Lyman and others (1992).

Table 16 lists, for each of the COCs, published values for the mobility and persistence properties described above. The values presented in Table 16 are taken from various published sources.

Each COC was ranked low, medium, or high in groundwater mobility, volatilization potential and persistence. The results of this analysis are provided on Table 16 and indicate the following.

- Vinyl chloride and MeCl have a high mobility ranking; cis-1,2-DCE and TCE have a medium to high mobility ranking; and PCE has a low to medium mobility ranking.

- All of the COCs have a high volatilization ranking.

- Vinyl chloride has a low persistence ranking; MeCl and cis-1,2-DCE have a medium to high persistence ranking; and PCE and TCE have high persistence rankings.

5.3 DISTRIBUTION OF CONTAMINANTS OF CONCERN IN GROUNDWATER

This section presents a summary evaluation of the distribution of COCs in groundwater at the Site.

Five chlorinated solvent VOCs (PCE, TCE, cis-1,2-DCE, vinyl chloride, and MeCl) are COCs in groundwater in the GOU of the Site (Section 4.2.1). The lateral extent has been relatively well defined by recent RI groundwater sampling events. Figure 49 depicts the areal extent of the PCE groundwater contaminant plume interpreted from the results of the September 2011 groundwater sampling event of the current 54-well monitoring well network (Table 5). All of the COCs are present in shallow groundwater to depths of approximately 100 feet BWT

(Section 4.2.3). Time series graphs of COC concentrations for selected wells are included in Appendix F.

5.4 MIGRATION PATHWAYS

This subsection describes the chemical fate and transport processes of the COCs within the GOU. The discussions include data analysis and interpretation of the collected groundwater data to identify which of the fate and transport processes are exerting the most effect on the groundwater plume and its evolution. The vertical extent of groundwater contamination is evaluated in Section 5.4.3.3

5.4.1 Conceptual Hydrogeologic Model

The following discussion is taken in part from Section 5.4 of URS (2002a). It describes the conceptual hydrogeologic model for the GOU based on then-available data. The BSL groundwater plume was not included in the GOU when URS completed its RI. The conceptual hydrogeologic model has been amended to incorporate more current data. The conceptual hydrogeologic model will be updated as needed as more data are collected for the LOU RI and the subsequent Feasibility Study (FS).

Based on monitoring events conducted during this RI, the GOU consists of two distinct plumes, one emanating from the BNL and one emanating for the BSL (Figures 49). At times the BNL and BSL plumes have been commingled. The BSL plume extends northwest from the BSL. The BNL plume extends westerly from the BNL and consists of discontinuous areas where PCE exceeds the AWQS. The PCE concentrations in wells 411-P, C-022A, and SJ-002 fluctuate above and below the AWQS, and thus the shape of the downgradient portions of the BNL plume changes over time. PCE in exceedance of AWQSs is also present in the vicinity of monitor wells BP-21, WR-702A, and WR-704A; this impact is interpreted to be part of the primary plume that migrated through the area before operation of the WCS began in March 2003 (PCE in concentrations greater than 5 ug/L has not been detected in well BP-21 since May 2010). The COCs found in the plume emanating from the northern portion of the BNL differ slightly from the southern portion of the BNL and northern portion of the BSL. The presence of vinyl chloride and MeCl is documented only in the northern portion of the BNL plume.

In the northeastern corner of the GOU, the groundwater contaminant plume appears to be undergoing reductive dechlorination, and predominately exhibits Type 1 Behavior near the "head" of the plume at the BNL. Type 1 Behavior, as described in EPA (1998), occurs where the primary substrate is carbon and the substrate drives the reductive dechlorination process under anaerobic conditions. This is based upon the presence of PCE daughter products TCE, cis-1,2-DCE, and vinyl chloride in the GOU (or the presence of TCE daughter products cis-1,2-DCE and vinyl chloride) and the availability of anthropogenic volatile fatty acids, which provide carbon and hydrogen, emanating from the landfill. The carbon and hydrogen are important compounds used by microbes in the sequential dehalogenation of PCE through TCE, cis-1,2-DCE, to vinyl chloride. With the exception of the northeast corner of the GOU, the remainder of the contaminant plume exhibits Type 3 Behavior, based upon the absence of vinyl chloride and the presence of TCE and cis1,2-DCE. Type 3 Behavior, again, as described in EPA's protocol for assessing biological degradation of chlorinated solvents (EPA, 1998), occurs in aerobic environments downgradient from reducing zones where the rate of vinyl chloride oxidation exceeds the rate of production because groundwater tends to be depleted in carbon (native or anthropogenic).

From the estimated retarded velocities of the Site contaminants described in URS (2002a), vinyl chloride should have migrated farther than the PCE; however, the processes which degrade PCE into TCE, cis-1,2-DCE, and vinyl chloride (or TCE into cis-1,2-DCE and vinyl chloride) primarily are reductive, and they are highly limited by the availability of hydrogen gas. The presence of PCE and TCE daughter products in the vicinity of the BNL may indicate the presence of sufficient hydrogen gas to drive the reductive dechlorination process to the point where vinyl chloride is generated. However, these processes are unlikely to be occurring to the same extent at other areas within the GOU that exhibit more aerobic conditions. Well WR-358A, located approximately 900 feet from BNL perimeter well WR-353A, is the most downgradient well where vinyl chloride has been detected.

The groundwater contaminant plume will continue to evolve until additional contaminants cease to enter the system or the biodegradation rate of the contaminants exceeds the flux of new contaminants into the aquifer. The discontinuity of the groundwater contaminant plume beyond about one-third mile from the LOU (Figure 5) suggests that source additions and/or biodegradation rates may be sporadic rather than continuous. Further migration beyond the present contaminant plume boundaries could potentially occur if the contaminant flux from the landfill sources, and/or groundwater flow conditions are altered.

5.4.2 Hydrologic Processes

The primary hydrologic processes at the GOU of the Site include the following:

- Downward percolation (infiltration) of surface water runoff that collects in low-lying areas.
- Surface drainage (runoff) of precipitation during large storm events in excess of that which can percolate into the soil.
- Stream channel recharge along Pantano Wash, particularly during, and shortly after, times of flood; however the Pantano Wash is, in general, a poor source of stream channel recharge. During infrequent, extreme, long duration events, the Pantano Wash may be a more significant source of recharge.
- Advective flow of groundwater. Groundwater in the regional aquifer generally flows from areas of mountain front recharge to the north, east, and south toward pumping wells in the center of the Tucson Basin and toward basin outflows to the northwest. In the GOU, groundwater flows toward the west-northwest.
- Groundwater withdrawals from large-capacity TW production wells in the CWF.
- Groundwater interception, extraction, and reinjection at the WCS (localized in extent, near the leading edge of the VOC-impacted groundwater plume).

- Recharge of shallow groundwater from upgradient upland areas. Recharge of groundwater is primarily due to precipitation that falls in the mountain ranges surrounding the Tucson Basin.

5.4.3 Groundwater Pathway

The discussion of chemical transport in groundwater is focused on the regional aquifer that underlies the LOU and is within the GOU. This aquifer has been impacted by COCs and is the subject of an ongoing groundwater remediation using the downgradient WCS. Refer to Section 7.4 for more details on this ERA. Potential chemical migration of COCs in the regional aquifer has been determined during the RI to be approximately within 100 feet BWT. However, as DNAPL migration has not been documented in the BNL and BSL, the primary fate and transport mechanisms for the groundwater COCs appear to be advection, vertical hydrodynamic dispersion, biodegradation, and likely, sorption. These are discussed below in Section 5.4.3.2.

5.4.3.1 Aquifer Characteristics Summary

Immediately downgradient of the landfilled areas, the unconfined aquifer is estimated to be 1,500 feet thick (Section 2.7.1). The aquifer media consists of thick homogenous sequences of sand and gravel to depths of 800 to 900 feet bgs (Section 2.5.2). The degree of cementation increases with depth. The top of the Middle Basin Fill hydrostratigraphic unit (which is the lowermost Upper Tinaja beds) generally represents the contact between poorly cemented and well cemented unconsolidated deposits. The depth at which thick (i.e., typically as much as 20-feet thick) fine to coarse gravel deposits are first encountered is approximately 275 feet bgs in the GOU. These gravel deposits are interbedded with lenses and layers of sand and silty sand to the total exploration depth (498 feet bgs).

The average hydraulic conductivity (K_H) of the regional unconfined aquifer immediately downgradient of the closed BNL is approximately 75 feet/day (Dames & Moore, 2000). RI-derived groundwater flow data and the hydrogeologic parameter estimates for Tucson Basin hydrostratigraphic units (Table 3) are summarized below.

- For the Upper Basin Fill Unit, K_H ranges from 1 to 350 feet/day in the GOU and CWF portions of the Tucson Basin.

- For the Middle Basin Fill Unit, K_H ranges from 5 to 10 feet/day.

- The wetted thickness, b, is assumed to be 1,500 feet in the GOU.

- The average hydraulic gradient during the RI has been approximately 0.003 ft/ft.

- The specific yield of the uppermost Upper Tinaja bed is 0.25; whereas the storage coefficient of the lowermost Upper Tinaja beds and the Middle Tinaja beds is 0.0001.

- The transmissivity, $T=K_Hb$, for the COC-impacted water-bearing zones are calculated to be 1,500 to 525,000 square feet per day (ft^2/day) for the Upper Basin Unit and 7,500 to 15,000 ft^2/day for the Middle Basin Unit.

- The average linear velocity for groundwater in the GOU near the BNL is approximately 1.0 foot/day.

5.4.3.2 Groundwater Fate and Transport Processes

The fate and transport of the identified groundwater COCs is controlled and driven by several destructive, as well as non-destructive, processes. These processes are dependent on the physical characteristics of the aquifer material and groundwater, the chemical and physical properties of the COCs, the availability of anaerobic and aerobic microbiological organisms, and the availability of hydrogen gas (H_2). Non-destructive processes typically result in a decrease in the concentration of the COCs, but do not decrease the total mass of COCs. Non-destructive processes include: advection, dispersion, diffusion, sorption, dilution, and volatilization. Destructive processes result in a reduction of the mass of COCs. Biodegradation is typically the dominant destructive process acting on the contaminant mass. Abiotic (non-biological) degradation of chlorinated solvents has been demonstrated to occur at other sites, but the rate of contaminant mass reduction is relatively minor when compared to those for the biodegradation processes (URS, 2002a).

Advective Flow with Groundwater. Advective flow is the movement of a liquid through a porous medium in response to a hydraulic gradient. Advective flow is from areas of high hydraulic head to areas of low hydraulic head. For an unconfined aquifer, as seen at this Site, groundwater flows from higher water table elevation to lower water table elevation. However, the COCs typically will not move at the same rate as groundwater because of adsorption onto aquifer solids, diffusion, dispersion, and degradation. The retardation factor, R, expresses the velocity of the dissolved COC relative to the velocity of groundwater. The larger the R value, the less mobile (or more retarded) the COC.

Advection transports the COCs by the bulk movement (flow) of groundwater in the GOU. The rate of movement is primarily dependent on the hydraulic conductivity, hydraulic gradient, and homogeneity of the aquifer. In a homogeneous aquifer, excluding all other fate and transport processes except advection, the COCs would be distributed uniformly. In non-homogeneous aquifers, preferential flow within differing hydraulic conductivity layers will occur, thus altering the uniformity of contaminant distribution. However, the aquifer at the Site is relatively homogeneous, based on review of cross-section G-G' (Figure 17), which is oriented in a west-to-east direction (Figure 7) (i.e., along the flow path for the central portion of the GOU plume). Using generally accepted values for the unconsolidated zone aquifer (such as hydraulic conductivity of 75 feet/day; hydraulic gradient of 0.004 ft/ft, and effective porosity of 0.25), URS (2002a) calculated an average linear groundwater velocity of 0.96 feet/day. Using the calculated average groundwater linear velocity and a centerline of the contaminant plume of 10,800 feet, URS (2002a) postulated that the plume originated at the closed BNL in approximately 1970 (approximately 10 years after the landfill began accepting refuse). At the estimated time the plume originated, the approximate depth to water and groundwater elevation in active production well D-022A (located on the western boundary of the BNL) was 217 feet bgs and 2,358 feet amsl, respectively. This data was not independently verified by Stantec.

The primary "external" factor affecting advective transport at the GOU is the operation of high-capacity production wells. Although the operation of TW production wells in the vicinity of the GOU has ceased, the spatial pattern and migration velocity of the contaminant plume appear to have been affected by the operation of the WCS. The PCE plume in the WCS area, evident on Figure 8 (September 2003) and Figure 5 (September 2011), has shrunk considerably, based on September 2011 sampling event results. Based on the current and historical shape of the plume and the likely effect of historical and current production well pumping, advection appears to be the primary contaminant transport mechanism at the Site.

Advective Transport Due to Vertical Hydraulic Gradients. Vertical groundwater flow, particularly where steep hydraulic gradients are present, is a possible transport mechanism to account for the apparent presence of groundwater VOCs at depths below the water table as great as 100+ feet. The results of FloVision™ vertical flow monitoring conducted during this RI (Section 3.5.2) found almost no vertical flow in the tested groundwater monitoring wells located significantly away from the operating WCS extraction and injection wells. These include wells BP-10, WR-181A, and D-022A. However, the temperature survey results (Section 3.5.1) showed that some downward vertical flow was occurring in some portions of the well casings in all of the tested wells except WR-181A. Overall, the FloVision™ vertical flow monitoring and temperature data suggest that mixing is likely occurring within the wellbores that could account for the observed consistency of PCE concentrations with depth in such wells as D-022A, C-026A, WR-178A, WR-181A, BP-10, BP-21, and BP-23 (Section 3.5.3.2; Table 5). Vertical advective transport does not, however, appear to be a significant mechanism within the aquifer.

Hydrodynamic Dispersion. Hydrodynamic dispersion is the “spreading” of chemicals in groundwater due to differences in groundwater velocity caused by the tortuous path the water takes. Higher velocities of groundwater flow result in higher rates of hydrodynamic dispersion.

Dispersion is a transport process that causes mixing of impacted and non-impacted groundwater within the aquifer. The dispersion process is primarily due to various irregularities (hydraulic conductivity, pore size, friction, and flow path length) in an aquifer material. The dispersion transport mechanism is likely responsible for the occurrence of contaminants generally within the top 100 feet BWT (Section 3.5.3) in the GOU.

Diffusion. Diffusion is the movement of a dissolved chemical through the water-bearing zone in response to a concentration gradient. The movement of chemicals via diffusion is greatest when large differences in chemical concentrations exist.

Since the COCs are present at low, part per billion, concentrations in groundwater, the effect of diffusion on chemical transport in the water-bearing zone will be minimal.

Dilution. Dilution is the process by which concentrations of COCs within the groundwater plume are decreased by mixing with less contaminated groundwater. Contaminant-free groundwater is typically added to the impacted groundwater by recharge or reinjecting treated groundwater. Based on the Hydrologic Evaluation of Landfill Performance (a.k.a. HELP) modeling results (CDM, 1998), dilution due to stormwater recharge is not considered to be a major contaminant fate and transport mechanism at the Site. In the vicinity of WCS injection wells R-090A and R-091A (Figure 5 and Figure 54), treated groundwater is being reinjected into the aquifer at rates up to 800 gpm (or roughly 1.1 million gallons per day). Dilution in the vicinity of the WCS injection and extraction wells is likely a significant fate and transport mechanism. Dilution near the edges of the plume is also likely occurring as less contaminated water disperses into areas of higher concentration.

DNAPL Dissolution. When DNAPL is in contact with groundwater, a minor fraction will dissolve and partition into the groundwater. The degree of dissolution is determined by the water solubility of the individual constituents (Section 5.2). DNAPLs have not been identified in the thick vadose zone at the BNL or BSL. The relatively low concentrations of COCs found at the BNL and BSL are indicative that DNAPLs are not present near any of the sampled areas.

Sorption. Sorption is the process by which contaminants are temporarily partitioned onto organic carbon and clay mineral particles found in the aquifer material. The effect of sorption and desorption is to decrease groundwater COC concentrations as contaminants are sorbed and to increase groundwater COC concentrations as contaminants are desorbed. Overall, sorption acts as a retardant to groundwater contaminant plume migration. Factors affecting the sorption and desorption rate are the availability of organic carbon and clay mineral particles. Based on the average dissolved organic carbon contents observed in the area of the GOU (380 µg/L or 0.000038 percent), URS (2002a) concluded that sorption was not a major mechanism of fate and transport of COCs in the GOU. However, TOC content in soil samples were not collected. A major characteristic of the Site groundwater plume is that PCE and TCE concentrations beneath the landfilled areas are high, relative to those downgradient of the LOU and that the PCE and TCE concentrations attenuate quickly with distance away from the LOU. One of the likeliest fate and transport processes that could achieve this attenuation of the dissolved PCE and TCE concentrations in the groundwater plume is sorption; another is biodegradation, which is discussed below. If only biodegradation was operating, then the concentrations of the PCE and TCE daughter degradation products should be increasing while the PCE and TCE groundwater concentrations would be decreasing at any given location away (downgradient) from the landfilled areas. Since all of the VOC concentrations are decreasing, sorption could be playing a significant role within the groundwater plume.

Chemical Partitioning. Chemical partitioning is the movement of chemicals from one phase (i.e., water, adsorbed, gas or liquid) to another. The partitioning of a chemical between the liquid and the gas phase (off-gassing of VOCs from the groundwater surface) is defined by Henry's Law Constant, which is the ratio of the chemical concentration in air to the chemical concentration in water (see Section 5.2). The partitioning of a chemical between the water and adsorbed phase is defined by the soil-water partition coefficient (K_d).

Volatilization is the partitioning of groundwater COCs from the water into the overlying vadose zone. With the exception of vinyl chloride, the identified groundwater COCs have low Henry's Law Constants (Table 16), preventing them from easily volatilizing into the vadose zone. Volatilization of groundwater COCs is not considered to be a significant fate and transport mechanism at the Site. In fact, it is thought that transport from the soil gas below the BNL and BSL landfills into the groundwater is the dominant chemical partitioning mechanism that occurs at the Site.

Degradation. Degradation of chemicals in groundwater also plays a role in the fate and transport of COCs in groundwater. As discussed above, organic chemicals are degraded either by chemical or biotic processes. The ability of a chemical to be readily degraded is dependent on a number of factors, including the properties of the chemical and the characteristics of the aquifer.

Biodegradation is the destructive mechanism in which highly chlorinated ethenes (such as PCE and TCE) are degraded in a process known as reductive dechlorination. Through a series of oxidation-reduction reactions, reductive dechlorination results in the formation of less chlorinated compounds (such as cis-1,2-DCE and vinyl chloride). When concentrations of dissolved O_2 are greater than 1,000 µg/L, reductive dechlorination is not likely (EPA, 1998). Evidence (particularly the presence of cis-1,2-DCE and vinyl chloride in monitoring wells WR-273A and WR-275A) presented by URS (2002a) suggests that hydrogen gas is being produced near the BNL from anaerobic microbial biodegradation of volatile fatty acids (a common component of landfill gas). This is then directly substituted for a chlorine atom during the reductive chlorination reaction. Based on the lack of cis-1,2-DCE and vinyl chloride at the far reaches of the GOU (Table 5), reductive dechlorination does not appear to be taking place more than one-third of a mile outside of the BNL area. Concentrations of groundwater COCs at, and near, the western boundary of the BNL suggest that anaerobic biodegradation is significant in limiting the fate and transport of PCE and TCE and their daughter products in that area. Biodegradation does not appear to limit the fate and transport of COCs in the portions of the GOU located west of Kolb Road (Figure 5).

The COCs vary in their persistence ranking from low to high (Table 16). Vinyl chloride has a low persistence ranking based on its ability to be biologically degraded under aerobic conditions (this is not the case under weakly reducing conditions where complete dechlorination is unlikely to occur). Other COCs (MeCl and cis-1,2-DCE) have a moderate to high persistence ranking (cis-1,2-DCE under strongly reducing conditions in the presence of dechlorinating bacteria will not persist). These chemicals will not be as readily biodegraded under aerobic conditions as benzene and vinyl chloride. PCE and TCE have a high persistence ranking, particularly under aerobic conditions. Anaerobic reductive dechlorination rates for PCE and TCE are significantly higher than their degradation rates under aerobic conditions. However, over time, it is expected that degradation of these COCs (by such processes as reductive dechlorination and methanogenesis) will result in a decrease in chemical concentrations.

While no specific investigation has been conducted to assess the degree to which these processes are operative at the Site, such processes commonly are observed to be operative at similar chlorinated solvent-impacted sites. Azadpour-Keeley and others (2001) provides a thorough discussion of monitored natural attenuation (MNA) of contaminants in the subsurface, including chlorinated solvents, such as PCE and TCE. The authors note that biodegradation of organic chemicals commonly progresses from aerobic to anaerobic conditions, and that chlorinated solvents such as PCE and TCE biodegrade much faster under anaerobic than aerobic conditions. Bouwer (1994) discusses the process of reductive dechlorination, which is the anaerobic process for the biodegradation of halocarbon compounds by the removal of successive chlorine atoms. Samprini and others (1991) and Yare and others (1989) both present the results of pilot-scale field studies of in-situ biodegradation of halocarbon compounds. The Samprini paper assesses reductive dechlorination of chlorinated ethenes (such as PCE and TCE), under anaerobic conditions, at the Moffett Naval Air Station in Mountain View, California. The Yare paper assesses reductive dechlorination of chlorinated ethanes (such as 1,2-dichloroethane and 1,1,2-trichloroethane at the Brio Refining Superfund site in Harris County, Texas.

5.4.3.3 Vertical Extent of Groundwater Contamination

The collection of depth-specific VOC groundwater samples during this RI revealed that there were a number of groundwater monitoring wells that had consistent PCE concentrations with depth (to as much as 100+ feet BWT), which could suggest that the groundwater plume was at least 100 feet thick. URS (2002a), in a previous GOU RI Report, found that the PCE groundwater plume was approximately 50 feet thick in the vicinity of wells WR-353A and WR-352A. As discussed above in Section 5.4.3.2, however, vertical advective transport does not appear to be a significant mechanism within the aquifer. Vertical mixing within the wellbore of groundwater monitoring wells that have long saturated screened lengths, however, is a mechanism that could make a 50-foot-thick groundwater plume in the GOU appear to be much thicker than it actually is. Vertical mixing within the wellbore of several groundwater monitoring wells, even in the absence of steep hydraulic gradients, can account for the observed consistency of PCE concentrations with depth in such wells as D-022A, C-026A, WR-178A, WR-181A, BP-10, BP-21, and BP-23 (Section 4.2.3; Table 5).

Discrete-depth sampling at paired wells WR-178A/WR-352A (screened from 309 to 460 feet bgs and 420 to 460 feet bgs, respectively) and WR-273A/WR-353A (screened from 298 to 338 feet bgs and 410 to 450 feet bgs, respectively), and well cluster BP-24A, PB-24B, and BP-24C (screened from 325 to 355 feet bgs, 385 to 405 feet bgs, and 440 to 460 feet bgs, respectively) indicates that the thickness of the plume is approximately 100 feet BWT near wells WR-273A/WR-353A and 105 feet BWT feet near well cluster BP-24A, BP-24B, and BP-24C as discussed in Section 3.5.3.2. The thickness of the plume near wells WR-178A/WR-352A historically was approximately 50 to 86 feet BWT**.** Wells WR-178A and WR-352A are within the capture area of WCS extraction well R-092A and although PCE has historically been present in samples collected from well WR-178A, it has not been detected in concentrations greater than the AWQS since August 2001. Based on this data, the vertical extent of the plume in this area appears to be a minimum of 80 feet BWT and maximum of 105 feet BWT

<u>Summary:</u> In summary, chemical migration has occurred in the groundwater, as evidenced by the distribution of the COCs in groundwater presented in Section 5.3. However, the WCS, located downgradient of the BNL and BSL, appears to be capturing all of the Site groundwater COC contamination except for the contamination that had already passed by the downgradient extent of the WCS capture zone when the WCS came on line in 2003 (Figure 8).

To some degree, all of the aforementioned fate and transport processes affect the movement and concentration of identified groundwater COCs at the Site GOU. However, it is evident that advection, hydrodynamic dispersion, sorption, and biodegradation (the latter two processes especially operative in the vicinity of the BNL and BSL), are the primary fate and transport mechanisms in the GOU. It is likely that the COC concentrations that are seen in certain wells in the deeper portion of the saturated screened interval have resulted from vertical mixing within the wellbores themselves.

5.5 IDENTIFICATION OF POTENTIAL RECEPTORS

ADEQ (1997) and ASTM (1995) both require that the population potentially at risk should be identified during the development of a CSM. The GOU groundwater exposure pathway is presently closed, but potentially complete. It should be noted that TW's current LOFO policy with regard to usage of CWF production wells that could intercept the groundwater plume is subject to change, and CWF production wells currently shut down may be placed back in service. Potential human sensitive receptors (e.g., young, old, and/or infirm) in the GOU include students at Hudlow Elementary, Sewell Elementary, Saint Michael's Day Schools, and patients at St. Joseph's Hospital. Potential human receptors include those persons who come into contact with and ingest impacted groundwater or inhale vapor during bathing or washing. See Section 7 for further discussions of ERAs and ERA-type activities to prevent or reduce the likelihood of human exposure to COCs. .

5.6 CONCEPTUAL SITE MODEL SUMMARY

ADEQ (1997) describes a CSM as follows: "The CSM is a representation of the connection between contaminant sources, release mechanisms, exposure pathways, and receptors." The American Society for Testing and Materials (ASTM; 1995) expands this description by listing the following six basic activities associated with developing a CSM:

1. Identification of potential contaminants of concern;
2. Identification and characterization of the source(s) of potential contaminants of concern;
3. Delineation of potential migration pathways through environmental media, such as groundwater, surface water, soils, sediment, biota, and air;
4. Establishment of background concentrations of contaminants for each contaminated medium;
5. Identification and characterization of potential environmental receptors (human and ecological); and
6. Determination of the limits of the study area or system boundaries.

5.6.1 Contaminants of Concern

COCs for groundwater and the rationale for their selection are detailed in Section 4.2.1. Based on the data available at the time this report was prepared, the COCs identified in groundwater are PCE, TCE, vinyl chloride, cis-1,2-DCE, and MeCl. Toxicity information about each COC is provided in Appendix G.

5.6.2 Potential Sources of Contaminants

On the basis of historical investigations (CDM, 1998; McLaren/Hart, 1998; and URS, 2002a) and this RI, the only known source areas for COCs at the Site GOU are the BNL, the northern part of the BSL, and the former sand and gravel pits.

5.6.3 Delineation of Potential Migration Pathways

The groundwater pathway is through the regional aquifer from beneath the LOU toward TW production wells and private water supply wells. The direction of groundwater flow is generally from the LOU to the west and northwest (Figure 5). Investigation of the LOU is ongoing and will be presented in the LOU RI to be prepared at a later date.

5.6.4 Establishment of Background Concentrations

Identification of background concentrations of COCs for the Site GOU can be accomplished by evaluating groundwater that is not potentially affected by landfilling activities. Groundwater samples collected from wells upgradient of the BNL LOU (414-P, 417-P, WR-181A, WR-207A, and WR-207B; Figure 2) do not consistently contain concentrations of identified groundwater COCs at, or above, the respective laboratory reporting limits. PCE has been found in samples from well WR-181A, with a maximum concentration of 5.5 µg/L in August 2002. This is the only sampling date on which PCE concentrations exceeded the AWQS. It should be noted that none of the COCs occur naturally, so the background concentrations should be the respective laboratory MDLs.

5.6.5 Identification of Potential Receptors

Potential receptors to identified groundwater COCs at the Site would include persons coming into contact with and ingesting groundwater and/or inhaling vapor during bathing or washing (if the exposure pathway were complete).

5.6.6 Determination of the Limits of the Study Area or System Boundaries

The limits of the Site are described in Section 1.3.

6.0 EXPOSURE ASSESSMENT

Several typical elements of a Risk Assessment, particularly the Exposure Assessment, are provided in this section of the RI Report. The following discussions do not include numerical evaluations of the risks of exposure to the identified potential receptors (Section 5.6.5), because presently there is no known exposed population.

The Exposure Assessment that follows uses the COCs listed in Section 5.6.1, which are PCE, TCE, cis-1,2-DCE, vinyl chloride, and MeCl.

The following sections are taken in part from Section 7 -- Risk Assessment Summary, in CDM (1998). The text has been updated with new data derived from the 2001-2006 Site-Wide RI.

6.1 EXPOSURE PATHWAYS

The basic assessment strategy is developed in the following sections. An exposure pathway consists of four elements, listed below:

1. A source and mechanism of release of chemicals to the environment;
2. A transport medium for the released chemical;
3. An exposure point (the point of potential contact between receptor and medium); and
4. An exposure route (such as inhalation or ingestion).

If one or more of these elements are absent, no exposure is possible, and an exposure pathway is defined as incomplete. Furthermore, even when exposure pathways are complete, potential exposures may be too small to present a human health risk. For any Risk Assessment, theoretically possible exposure pathways are evaluated to identify those which are incomplete so that the assessment can focus on those pathways that present the greatest potential for significant human health impacts.

Receptor groups and possible exposure pathways for the Site groundwater contamination are presented and summarized in the following inset table [adapted from CDM (1998)].

Summary of Exposure Pathways Analysis and Exposure Scenarios Site		
Exposure Pathway	Exposure Scenarios	Comments
Ingestion of, Dermal Contact with, and Inhalation of Vapors from Contaminated Groundwater	Current and Future Near-Site Resident/Visitor	Monitoring of public water supply and institutional controls make this pathway incomplete, currently and for the foreseeable future.

(Pathways for potential human exposure to contaminants from the LOU will be evaluated at a later time in the LOU RI.)

6.2 GROUNDWATER EXPOSURE PATHWAYS

Because of the implementation of TW's well water use policies and wellhead treatment for private supply well 411-P (Sections 7.1 and 7.2), there currently are no complete pathways for users of the CWF potable water supply to be exposed to the GOU groundwater plume. However, the groundwater exposure pathway could potentially become complete if the TW's well water use policies change or if wellhead treatment at private well 411-P ceases. For the purpose of this RI, ADEQ assumes that the potentially exposed population includes persons coming into contact with and ingesting groundwater and/or inhaling vapor during bathing or washing.

6.3 REMEDIAL OBJECTIVES

A Groundwater Remedial Objectives Report (RO) was prepared by ADEQ in 2008 utilizing information from the Draft GOU RI Report, the Water Use Report, and input from stakeholders and interested parties. The RO Report is in Appendix H of this GOU RI Report. Included as appendices in the RO Report are the following: (1) public input prior to draft RO Report issuance, (2) public comment following draft RO Report issuance, and (3) ADEQ's response to the public input and comments. The ROs for groundwater at the Broadway-Pantano WQARF Site for potable and non-potable uses are as follows:

> "The proposed groundwater RO 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 vinyl chloride contamination emanating from the WQARF Site. ["Potable" is defined here as water which meets state and federal primary drinking water standards (a.k.a. Maximum Contaminant Levels) and Arizona Aquifer Water Quality Standards.] This action is needed for as long as the level of contamination in the groundwater resource prohibits its use as a potable water supply."

> "The proposed groundwater RO will be to protect for the future non-potable use of the regional aquifer threatened by PCE, TCE, and vinyl chloride 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. Maximum Contaminant Levels) and Arizona Aquifer Water Quality Standards.] 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."

7.0 EARLY RESPONSE ACTIONS

ERAs are defined in A.A.C., Section R18-16-405(A), as remedial actions performed prior to selection of a remedy at a site under A.A.C. Section R18-16-410 and which are necessary to accomplish one of the following:

1. Address current risk to public health, welfare, and the environment;
2. Protect or provide a supply of water;
3. Address sources of contamination; or
4. Control or contain contamination where such actions are expected to reduce the scope or cost of the remedy needed at the Site.

To date there have been two ERAs implemented at the Site to affect the groundwater VOC plume and prevent human exposure:

- Installation and operation of a SVE/AI system at the BNL portion of the LOU; and
- Installation and operation of the WCS.

There have also been two other remedial activities performed by the City of Tucson to affect the groundwater VOC plume and prevent human exposure which are not defined herein as ERAs because they have not been formally reviewed and approved by ADEQ:

- Development of operating guidelines restricting use of TW production wells located in the vicinity of the GOU; and
- Installation and maintenance of a wellhead treatment system at private supply well 411-P (St. Joseph's Hospital).

These remedial activities will be discussed in chronological order of implementation.

These actions, summarized in the following sections, have been undertaken by TW, COT, Pima County, and ADEQ, individually or cooperatively.

7.1 PRODUCTION WELL OPERATING GUIDELINES

Since the late 1980s, the TW has removed four CWF production wells (C-021A, C-026B, D-022A, and D-021A; Figure 2) from operation because of the presence of VOCs. TW has maintained a policy since 1993 to remove from service any production wells that have concentrations of VOCs that exceed one-half of the EPA MCL published thresholds (URS, 2002a).

In 1994, TW voluntarily placed five CWF production wells (C-020B, C-056B, C-058B, C-114A, and C-026B; Figure 2) on restricted-use (last-on/first-off, or LOFO) because of their proximity to the GOU (URS, 2002a). (In 1998, TW shut down the C-026B well because it had detections of PCE exceeding one-half the EPA MCL.) These wells have been needed to supplement production during peak use periods (May to October); however, they are the last wells to be brought into service and the first wells to be shutdown after the peak demand has been satisfied. TW's CWF production wells C-025B and D-018A (Figure 2) were voluntarily placed in a restricted supply use category in August 1999. During the past ten years, these wells have been used twice, once in the fall of 2006, to meet system demand when a water main broke in Avra Valley (Table 4; Prior 2012b) and all of the six LOFO wells were also pumped in the summer of 2006 to assess the viability of the well infrastructure to meet system demand. TW is continuing to maintain and sample these wells so that they will be available to meet system demand as may be required (TW, 2007).

The overall effect of the voluntary use restriction implemented by TW is to reduce the potential of drawing the VOC impacted groundwater plume toward the CWF production wells and, thereby, imposing a potential health risk to the public. Also, since 1993, it has been TW's policy to take out of service any well containing a VOC exceeding one-half the MCL for any regulated compound. TW samples the LOFO wells at least semi-annually and, when a LOFO well is operating for more than 7 days, the LOFO well is sampled at least monthly (TW, 2007). Well C-051B (located immediately downgradient of the toe of the plume) is sampled quarterly for VOCs (Prior, 2012c).

7.2 WELLHEAD TREATMENT AT PRIVATE SUPPLY WELL 411-P

COT began collecting and analyzing groundwater samples on a periodic basis from the St. Joseph's Hospital private water supply well 411-P (Figure 2) in April 1994. Laboratory analytical results indicated a general increase in concentrations of PCE in samples collected between April 1994 (1.1 µg/L) and October 1995 (5.3 µg/L). TCE was also detected (0.5 µg/L and 1.0 µg/L) in April and October 1995. Because of the increasing concentrations of PCE observed in the groundwater samples, private supply well 411-P was taken out of service by the well owner and the hospital switched to City water in September 1995.

During the winter of 1996-1997, COT installed an ADEQ-approved wellhead treatment system at the private supply well 411-P. The treatment system consists of two 6,000-gallon granular activated carbon (GAC) treatment vessels. The private supply well was put back in service in May 1997 (URS, 2002a). Laboratory analyses of groundwater samples collected prior to the wellhead treatment system indicate influent concentrations of PCE ranging from 12.6 µg/L (May 7, 1997; URS, 2002a) to less than 0.50 µg/L (May 21, 2003; URS, 2002a). VOCs are not present above the laboratory MDL in water samples collected after passing through the GAC treatment system (COT, 2000b).

In 2009, St. Joseph's Hospital shut down the 411-P well because of problems with the well itself and the hospital switched its water source to Tucson Water. As of June 2012, the well was still shut down.

7.3 SOIL VAPOR EXTRACTION/AIR INJECTION SYSTEM

To control the only source of groundwater contamination documented as of 2000, COT and Pima County installed a SVE/AI system at the BNL portion of the LOU. The system, which became operational in June 2000 (URS, 2002a), consisted of six SVE wells (R-070A through R-075A), located around the perimeter of the BNL, and two AI wells (R-068A and R-069B), located along the north-south axis of the BNL. Soil gas recovered from the vadose zone was treated utilizing GAC. The SVE/AI system operated on a continuous basis for 27 months (June 2000 until September 2002) and removed an estimated 5,329 pounds of total VOC constituents that included approximately 1,259 pounds of PCE; 274 pounds of TCE; 354 pounds of cis-1,2-DCE; 41 pounds of vinyl chloride; and 2,266 pounds of non-Freon VOCs (SECOR, 2003c). The system was shut down in 2002 because of low recovery. Since the system shutdown, rebound testing has been conducted five times, with the most recent testing being conducted in 2008 (SECOR, 2008). As can be seen in Figure 53, very little PCE rebound has occurred over the past ten years.

During this RI (which overlaps the operation of the SVE/AI system), concentrations of identified COCs in groundwater (Section 4.2.1) collected from wells at and near the BNL appear to have been affected by operation of the SVE/AI system. In five of the six groundwater monitoring wells located at and near the western edge of the BNL, concentrations of COCs have dropped significantly during the past ten years (Table 5). The COC concentrations in these wells at the beginning (2001) and end (2011) of the RI are summarized in the table inset below.

Well	Year	PCE (µg/l)	TCE (ug/l)	VC (µg/l)
D-022A (5' BWT)	August 2001	120.0	18.0	<0.5
	September 2011	50.0	13.0	<1.0
R-068A (5' BWT)	February 2002	290.0	68.0	<0.5
	September 2011	36.0	7.4	<1.0
R-069B (5' BWT)	February 2002	58.0	18.0	3.1
	September 2011	1.8	<1.0	<1.0
WR-273A (5' BWT)	July 2001	71.0	14.0	5.0
	September 2011	8.7	2.8	<1.0
WR-274A (5' BWT)	July 2001	57.0	9.9	<0.5
	September 2011	190.0	50.0	<1.0
WR-275A (5' BWT)	July 2001	79.0	16.0	<0.5
	September 2011	<1.0	<1.0	<1.0

The SVE system and its impact on the Site will be discussed in detail in the future LOU RI.

7.4 WESTERN CONTAINMENT SYSTEM

The WCS was designed and installed by COT with oversight and funding by ADEQ. The system consists of two groundwater extraction wells (C-026B and R-092A), a GAC treatment compound, and two injection wells (R-090A and R-091A). The locations of the injection and extraction wells are shown on Figure 2, and a detail of the WCS well field is shown on Figure 8 and Figure 54. The treatment compound is located at extraction well R-092A. Full scale operation of the WCS began on March 24, 2003 (URS, 2002b; SECOR, 2003b).

The purpose of the WCS is to limit, to the extent possible, the migration of VOC-impacted groundwater that exceeds the AWQS beyond the current boundaries of the GOU. The system was designed to provide hydraulic containment of the leading edge of the VOC-contaminated plume and prevent further migration of VOCs toward TW's uncontaminated wells. To achieve this goal, the two extraction wells would intercept the groundwater plume and create localized "cones of depression" that would divert the groundwater flow directions toward the extraction wells. The extracted groundwater would then be treated to below MCLs (AWQS) and then injected downgradient and cross-gradient of the plume to create a mounding effect to further divert the direction of groundwater flow toward the extraction wells. Based on the results of weekly fluid level monitoring events conducted between April 13 and September 23, 2003, operation of the WCS did create groundwater depressions in the vicinity of extraction wells C-026B and R-092A, and groundwater mounding in the vicinity of injection wells R-090A and R-091A (SECOR, 2003b; 2004a). Figure 18 illustrates the groundwater elevations for March 2003 (Table 1) as mapped prior to full-scale operation of the WCS. Figure 57 illustrates the change in groundwater elevation between the baseline monitoring event (March 17 and 18, 2003) and the December 1, 2003 monitoring event. These figures illustrate that the WCS had been effective in providing hydraulic containment of the plume. Water levels in the GOU have risen since the WCS began operation in 2003; however, the water level rise has not significantly changed the geometry of the WCS capture area. Figure 58 illustrates the change in groundwater elevation between the baseline monitoring event (March 17 and 18, 2003) and the September 2011 monitoring event.

As indicated for PCE in Section 4.2.2, with the 2005 installation and sampling of well BP-21 (Figure 54) and the 2009 installation and sampling of WR-702A, WR-703A, and WR-704A (Figure 49), it was confirmed that the GOU extended somewhat beyond the WCS capture zone. ADEQ had a WCS effectiveness evaluation performed. The evaluation included use of historical water quality and well water elevation data, including transducer data; lithologic, well construction, and well video logs; vertical gradient measurement data; groundwater modeling data; and particle tracking analysis. The results of the evaluation (Stantec, 2009) were as follows: 1) the WCS capture area was consistent with the model-predicted capture area (Clear Creek Associates, 2000) and 2) groundwater between the C-026B extraction well and the R-090A/R-091A injection well pair is being effectively intercepted by the C-026B extraction well. This analysis assumed no sustained pumping of TW LOFO wells. Since the WCS was turned on in 2003, PCE concentrations in the C-026B extraction well downgradient of the R-092A extraction well (and the adjacent C-026A groundwater monitor well) have continued to decline and most sample results have been below the AWQS (Table 5; Table 4, URS, 2012). Since September 2005 (Figure 54), the PCE concentrations in groundwater samples from BP-2 have also consistently been below the AWQS. TCE and cis-1,2-DCE have been detected in BP-2; however, the concentrations have been consistently below the AWQS and have not been detected since May 2005 (Table 5). These data demonstrate the effectiveness of the WCS in containing and cleaning up the VOC groundwater plume in the WCS area. Current PCE distribution (as of September 2011) is depicted on Figure 49. Comparison of Figure 49 to Figure 8 (the WCS PCE plume extent for September 2003) shows that the PCE plume in the WCS area has shrunken considerably.

8.0 SUMMARY AND CONCLUSIONS

This GOU RI report summarizes field investigations conducted by ADEQ and other parties to identify and assess groundwater contamination at the Site. The RI has adequately identified the contaminants, the nature and approximate extent of contamination in groundwater, contaminant sources, fate and transport of contaminants, and associated potential public health risks resulting from groundwater contamination.

The conclusions presented below are based on the following: findings presented in historical investigations conducted at, and in the vicinity of, the BNL and BSL and GOU; review of historical aerial photographs; investigations conducted during this RI; and the professional experience and opinions of SECOR and Stantec personnel who conducted the investigation activities and who prepared this GOU RI Report.

- The BNL landfilled areas, the northern portion of the BSL landfilled area, and the former sand and gravel mining operations on both the BNL and BSL properties are the source areas.

- PCE, TCE, vinyl chloride, cis-1,2-DCE, and MeCl have been identified as COCs in groundwater; however, cis-1,2-DCE and MeCl have not been detected above the AWQS since 2005.

- Lead and mercury have been detected sporadically in groundwater in the vicinity of the BNL; however, these metals are not COCs as detections above the AWQSs have not been seen since 2002.

- Nitrate has been detected in many of the wells sampled at the Site, though detections above the AWQS have been found only in the 416-P car wash production well (outside the Site GOU); therefore, it is not a Site COC.

- The vertical extent of groundwater contamination (defined by exceedances of the respective AWQSs for the COCs) appears to be approximately 100 feet BWT based on the data collected during this RI.

- The toe of the plume extends to at least the vicinity of well WR-704A. As of September 2011, VOCs (including PCE), have not been detected in downgradient water supply wells C-048B, C-051B, or Catalina Village.

- Advection, hydrodynamic dispersion, biodegradation, and sorption (biodegradation being especially operative in the vicinity of the BNL and BSL LOU), are the primary fate and transport mechanisms in the GOU. Reductive dechlorination of PCE and TCE results in the generation of cis-1,2-DCE, and vinyl chloride (the latter confined to the northern portion of the BNL and extending downgradient to approximately one-third of a mile [well WR-358A]).

- For purposes of this RI, the future FS, and the future remedial action plan (RAP), the horizontal extent of groundwater impacted by the identified COCs has been adequately characterized.

- There is a potentially complete exposure pathway for human receptors to be impacted by the GOU groundwater plume, should TW resume operation of the restricted-status/LOFO CWF production wells that are currently on standby. However, there are currently no complete exposure pathways for human receptors to be impacted by the GOU groundwater plume as a result of the ERAs and ERA-type activities undertaken by TW, COT, Pima County, and ADEQ. The primary potential exposure routes to human receptors of identified COCs in groundwater are ingestion of impacted groundwater or inhalation of vapors while bathing or washing.

- Based on the currently available data, the two ERAs undertaken at the Site have performed as designed and have been consistent with the intent of A.A.C. Section R18-16-405(A).

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APPENDIX A
WATER USE STUDY
REMEDIAL INVESTIGATION REPORT
GROUNDWATER OPERABLE UNIT
Arizona Department of Environmental Quality
Broadway-Pantano Water Quality Assurance Revolving Fund Site
June 1, 2012

APPENDIX B
VERTICAL AND HORIZONTAL EXTENT OF REFUSE, BROADWAY NORTH LANDFILL
REMEDIAL INVESTIGATION REPORT
GROUNDWATER OPERABLE UNIT
Arizona Department of Environmental Quality
Broadway-Pantano Water Quality Assurance Revolving Fund Site
June 1, 2012

APPENDIX C
PRE-EARLY RESPONSE ACTION, VOLATILE ORGANIC COMPOUNDS IN SOIL GAS, BROADWAY NORTH LANDFILL

REMEDIAL INVESTIGATION REPORT
GROUNDWATER OPERABLE UNIT

Arizona Department of Environmental Quality

Broadway-Pantano Water Quality Assurance Revolving Fund Site

June 1, 2012

APPENDIX D
BP-SERIES WELL BORING LOGS
REMEDIAL INVESTIGATION REPORT
GROUNDWATER OPERABLE UNIT
Arizona Department of Environmental Quality
Broadway-Pantano Water Quality Assurance Revolving Fund Site
June 1, 2012

APPENDIX E
BP-SERIES WELL CONSTRUCTION DIAGRAMS
REMEDIAL INVESTIGATION REPORT
GROUNDWATER OPERABLE UNIT
Arizona Department of Environmental Quality
Broadway-Pantano Water Quality Assurance Revolving Fund Site
June 1, 2012

APPENDIX F
DISSOLVED VOC CONCENTRATION TREND GRAPHS
REMEDIAL INVESTIGATION REPORT
GROUNDWATER OPERABLE UNIT

Arizona Department of Environmental Quality

Broadway-Pantano Water Quality Assurance Revolving Fund Site

June 1, 2012

APPENDIX G
U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES, AGENCY FOR TOXIC SUBSTANCES AND DISEASE REGISTRY ToxFAQs

REMEDIAL INVESTIGATION REPORT
GROUNDWATER OPERABLE UNIT

Arizona Department of Environmental Quality

Broadway-Pantano Water Quality Assurance Revolving Fund Site

June 1, 2012

APPENDIX H
GROUNDWATER REMEDIAL OBJECTIVES REPORT
(INCLUDING RESPONSIVENESS SUMMARY)
REMEDIAL INVESTIGATION REPORT
GROUNDWATER OPERABLE UNIT

Arizona Department of Environmental Quality

Broadway-Pantano Water Quality Assurance Revolving Fund Site

June 1, 2012

APPENDIX I
GROUNDWATER OPERABLE UNIT REMEDIAL INVESTIGATION REPORT—WRITTEN PUBLIC COMMENTS AND RESPONSIVENESS SUMMARY

REMEDIAL INVESTIGATION REPORT
GROUNDWATER OPERABLE UNIT

Arizona Department of Environmental Quality

Broadway-Pantano Water Quality Assurance Revolving Fund Site

June 1, 2012

TABLES

GROUNDWATER OPERABLE UNIT REMEDIAL INVESTIGATION REPORT—WRITTEN PUBLIC COMMENTS AND RESPONSIVENESS SUMMARY

REMEDIAL INVESTIGATION REPORT
GROUNDWATER OPERABLE UNIT

Arizona Department of Environmental Quality

Broadway-Pantano Water Quality Assurance Revolving Fund Site

June 1, 2012

FIGURES
GROUNDWATER OPERABLE UNIT REMEDIAL INVESTIGATION REPORT—WRITTEN PUBLIC COMMENTS AND RESPONSIVENESS SUMMARY
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