

FINAL REMEDIAL INVESTIGATION REPORT

Broadway-Pantano WQARF Site
Landfill Operable Unit
Tucson, Arizona



Prepared for:

Arizona Department of Environmental Quality
400 West Congress Street, Suite 433
Tucson, Arizona 85701

Prepared by:

Clear Creek Associates, P.L.C.
221 N. Court Avenue, Suite 101
Tucson, Arizona 85701

February 27, 2015



Expires 6/30/2015

TABLE OF CONTENTS

LIST OF ABBREVIATIONS.....	vii
EXECUTIVE SUMMARY	xi
1.0 INTRODUCTION.....	1
1.1 OBJECTIVES.....	2
1.2 SCOPE OF WORK	2
1.3 SITE BACKGROUND.....	3
1.4 SITE HISTORY	4
1.4.1 BSL Operations	4
1.4.2 BNL Operations	5
1.4.3 Early Evidence of Releases	6
1.5 REPORT ORGANIZATION	6
2.0 SITE CHARACTERISTICS	8
2.1 PHYSIOGRAPHIC SETTING.....	8
2.2 LAND USE AND DEMOGRAPHICS	8
2.3 TOPOGRAPHY	9
2.4 CLIMATE	10
2.5 GEOLOGY.....	10
2.5.1 Regional Geologic Setting	10
2.5.2 Site Geology	11
2.6 SURFACE WATER HYDROLOGY.....	12
2.7 HYDROGEOLOGY.....	13
2.7.1 Aquifer	14
2.7.2 Depths to Groundwater	14
2.7.3 Water Resources.....	15
3.0 INVESTIGATIONS AND REMEDIAL ACTIONS	17

3.1	PREVIOUS INVESTIGATIONS.....	17
3.1.1	Early (pre-1995) Investigations at BNL.....	17
3.1.2	Early (pre-1995) Investigations at BSL	18
3.1.3	BNL Preliminary Assessment/Site Investigation--1995	20
3.1.4	BSL Preliminary Assessment/Site Investigation--1995.....	20
3.1.5	CDM Remedial Investigation Report, BNL--1998.....	20
3.1.6	HydroGeoChem Soil Vapor Extraction/Air Injection Design--1998.....	22
3.1.7	Shallow Soil Gas Surveys at BSL--1990 and 2000	22
3.1.8	HydroGeoChem Remedial Closure Criteria--2001	23
3.1.9	SVE/AI Rebound Tests at BNL--2002-2008	25
3.1.10	URS Groundwater Operable Unit Remedial Investigation--2002	26
3.1.11	SECOR BNL Soil Sampling--2004.....	26
3.1.12	SECOR BNL Shallow Probe Testing—2006.....	26
3.1.13	SECOR BSL Investigation—2006.....	27
3.1.14	SECOR BSL Soil Gas Investigation-- 2007	28
3.1.15	Stantec BNL Human Health Risk Assessment—2010	28
3.1.16	HydroGeoLogic Site History Report--2012.....	29
3.2	EARLY RESPONSE ACTIONS AND REMEDIATION	29
3.2.1	Soil Vapor Extraction at BNL.....	30
3.2.2	Dross Site Soil Cover	31
3.2.3	Western Containment System	33
3.2.4	St. Joseph’s Hospital Wellhead Treatment	33
3.3	RECENT FIELD INVESTIGATIONS	33
3.3.1	Vapor Intrusion Data Collection--BSL	33
3.3.2	Onsite Risk Evaluation Data Collection—BNL and BSL	36
3.3.3	Deep Soil Gas Evaluation--BNL and BSL.....	37
3.3.4	Gollob Park Delineation of Landfill Waste.....	40
3.3.5	Shallow Soil Quality Evaluation at BSL.....	41
4.0	NATURE AND EXTENT OF CONTAMINATION	42
4.1	CONTAMINANTS OF CONCERN	42
4.1.1	COCs Adversely Affecting Groundwater Quality	42

4.1.2	COCs Exceeding SRLs	43
4.1.3	COCs Exceeding Risk-Based Standard.....	44
4.2	POTENTIAL SOURCES	44
4.3	LANDFILL REFUSE.....	47
4.3.1	BNL.....	47
4.3.2	BSL.....	48
4.4	SOIL CONTAMINATION	50
4.5	VOCS IN SOIL GAS	51
5.0	CONTAMINANT FATE AND TRANSPORT	54
5.1	PROPERTIES OF THE COCS	54
5.1.1	VOCs.....	54
5.1.2	Metals	57
5.2	MIGRATION PATHWAYS	57
5.2.1	VOC Transport Mechanisms in the LOU	57
5.2.2	Metals Transport Mechanisms in the LOU	59
5.2.3	Biodegradation	59
6.0	CONCEPTUAL SITE MODEL.....	61
6.1	SOURCES	61
6.2	RELEASE PROFILE	61
6.2.1	Active Release Phase	62
6.2.2	Post-SVE/AI Phase	63
6.3	EXPOSURE MEDIA	64
6.4	EXPOSURE PATHWAYS	64
6.5	RECEPTORS.....	65
7.0	RISK ASSESSMENT SUMMARY	66
7.1	VAPOR INTRUSION RISK ASSESSMENT (BNL).....	66
7.2	ONSITE (BNL AND BSL) AND VAPOR INTRUSION (BSL) RISK ASSESSMENT.....	67

7.3	SOIL RISK EVALUATION (BNL and BSL)	70
7.4	REMEDIAL OBJECTIVES	70
8.0	SUMMARY, DATA GAPS, AND CONCLUSIONS	72
9.0	REFERENCES.....	75

FIGURES

Figure 1	Site Location Map, Broadway-Pantano WQARF Site, Tucson, AZ
Figure 2	LOU Location Map, Broadway-Pantano WQARF Site, Tucson, AZ
Figure 3	Location of Stratigraphic Cross Sections, Broadway North Landfill
Figure 4	Cross Section A-A', Broadway North Landfill
Figure 5	Cross Section B-B', Broadway North Landfill
Figure 6	Cross Section C-C', Broadway North Landfill
Figure 7	Cross Section D-D', Broadway North Landfill
Figure 8	Cross Section E-E', Broadway North Landfill
Figure 9	Location of Stratigraphic Cross Section, Broadway South Landfill
Figure 10	Cross Section F-F', Broadway South Landfill
Figure 11	Groundwater Elevation Map, Broadway-Pantano WQARF Site
Figure 12	Surface Soil Sampling Locations, Broadway North Landfill
Figure 13	Shallow Soil Gas Monitoring Probes Used for Health Risk Assessment, Broadway North Landfill
Figure 14	Methane Probe Locations, Broadway South Landfill
Figure 15	Shallow Temporary Soil Gas Probe Locations, Broadway North Landfill
Figure 16	Shallow Temporary Soil Gas Probe Locations, Broadway South Landfill
Figure 17	Deep-Nested Soil Gas Probe Locations, Broadway North Landfill
Figure 18	Deep-Nested Soil Gas Probe Locations, Broadway South Landfill
Figure 19	Selected Soil Gas Monitoring Results, Deep-Nested Soil Gas Probes, Broadway North Landfill
Figure 20	Selected Soil Gas Monitoring Results, Deep-Nested Soil Gas Probes, Broadway South Landfill

Figure 21	Historical PCE Distribution in Soil Gas, Deep-Nested Soil Gas Probes, Broadway North Landfill
Figure 22	Historical PCE Distribution in Soil Gas, Deep-Nested Soil Gas Probes, Broadway South Landfill
Figure 23	Shallow Temporary Soil Gas Probe Locations, Gollob Park, Broadway South Landfill
Figure 24	Refuse Isopach Map, Broadway South Landfill
Figure 25	Landfill Cover Isopach Map, Broadway South Landfill
Figure 26	Shallow Soil Sampling Locations, Broadway South Landfill
Figure 27	Refuse Isopach Map, Broadway North Landfill
Figure 28	Landfill Cover Isopach Map, Broadway North Landfill
Figure 29	Conceptual Site Model, Broadway-Pantano WQARF Site, Landfill Operable Unit
Figure 30	WR-274A Groundwater Elevations versus PCE Groundwater Concentrations

TABLE

Table 1:	Chronology of Events, Broadway-Pantano WQARF Site, Tucson, Arizona
Table 2:	Summary of Perimeter Shallow Soil Gas Sampling Results 2002 and 2006, Broadway North Landfill
Table 3	Broadway North Landfill—Comparison of Predicted Indoor Air Concentrations to Regional Screening Levels

APPENDICES

Appendix A	Land Use Study Broadway-Pantano WQARF Site, Landfill Operable Unit, Tucson, Arizona
Appendix B	Well Construction Diagrams and Lithologic Logs
Appendix C	Methane Probe Monitoring Report, Broadway South Landfill, Broadway-Pantano WQARF Site, Landfill Operable Unit, Tucson, Arizona
Appendix D	Shallow Temporary Soil Gas Probe Installation and Sampling Report, Broadway North and Broadway South Landfills, Broadway-Pantano WQARF Site, Landfill Operable Unit, Tucson, Arizona
Appendix E	Deep-Nested Soil Gas Probe Monitoring Report, Broadway North and Broadway South Landfills, Broadway-Pantano WQARF Site, Landfill Operable Unit, Tucson, Arizona

- Appendix F Gollob Park Temporary Soil Gas Probe Installation and Sampling Report, Broadway South Landfill, Broadway-Pantano WQARF Site, Landfill Operable Unit, Tucson, Arizona
- Appendix G Shallow Soil Sampling Report, Broadway South Landfill, Broadway-Pantano WQARF Site, Landfill Operable Unit, Tucson, Arizona
- Appendix H Laboratory Reports
- Appendix I Data Validation Reports
- Appendix J Field Notes
- Appendix K Vertical and Horizontal Extent of Refuse, Broadway North Landfill, Remedial Investigation Report, Groundwater Operable Unit (Stantec, 2012b)
- Appendix L Health Risk Assessment, Broadway-Pantano WQARF Site, Landfill Operable Unit, Tucson, Arizona, November 15, 2013
- Appendix M Human Health Risk Assessment, Broadway North Landfill, Broadway-Pantano Water Quality Assurance Revolving Fund Site, dated July 6, 2010
- Appendix N Historical PCE Concentrations in Soil Gas and Groundwater for Wells Located at Broadway South Landfill, Broadway-Pantano WQARF Site, Tucson, Arizona.
- Appendix O Revised Draft Final Letter Report – Remedial Investigation, Broadway–Pantano WQARF Registry Site, dated April 4, 2012
- Appendix P Potential Historical Users of Tetrachloroethene and/or Trichloroethene, Broadway-Pantano WQARF Site, Tucson, Arizona, dated May 1, 2012
- Appendix Q Remedial Objectives Report—Broadway-Pantano WQARF Site--Landfill Operable Unit, (includes Responsiveness Summary)
- Appendix R Responsiveness Summary—Draft Remedial Investigation Report—Broadway-Pantano WQARF Site—Landfill Operable Unit
- Appendix S PCE/Freon-12 Ratios in Select Groundwater Monitoring Wells, Broadway South Landfill, Broadway-Pantano WQARF Site, Tucson, Arizona.

LIST OF ABBREVIATIONS

AAC	Arizona Administrative Code
ADEQ	Arizona Department of Environmental Quality
ADHS	Arizona Department of Health Services
ADWR	Arizona Department of Water Resources
AF	Attenuation Factor
AI	air injection
ASRAC	Arizona Superfund Remedial Action Contract
atm	atmosphere
AWQS	Aquifer Water Quality Standard
bls	below land surface
BNL	Broadway North Landfill
BSL	Broadway South Landfill
CAP	Central Arizona Project
CAVSARP	Central Avra Valley Storage and Recovery Project
CDM	Camp Dresser & McKee
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
CERCLIS	Comprehensive Environmental Response, Compensation, and Liability Information System
<i>Cis</i> -1,2-DCE	<i>cis</i> -1,2-dichloroethene also known as <i>cis</i> -1,2-dichloroethylene
cfs	cubic feet per second
COC	Contaminant of Concern (synonymous with Chemical of Concern)
COPC	Contaminant of Potential Concern (synonymous with Chemical of Potential Concern)
COT	City of Tucson
COT-ES	City of Tucson Environmental Services
CSM	Conceptual Site Model
CVOC	Chlorinated volatile organic compound
CWF	Central Well Field
$\delta^{13}\text{C}$	delta carbon 13
DU	Data usability
ECR	Excess Cancer Risk

EDD	Electronic data deliverable
EPC	Exposure Point Concentration
FEMA	Federal Emergency Management Agency
GOU	Groundwater Operable Unit
GPL	Groundwater Protection Level
GPS	Global Positioning System
GRC	Geo/Resources Consultants, Inc.
HASP	Health and Safety Plan
HDPE	High Density Polyethylene
HGC	HydroGeoChem
HGL	HydroGeoLogic, Inc.
HI	Non-cancer Hazard Index
H _o	Dimensionless Henry's Law coefficient
HRA	Health Risk Assessment
IDW	Investigation Derived Waste
ILCR	Incremental lifetime cancer risk
IUR	Inhalation Unit Risk
J&E	Johnson and Ettinger
K _{oc}	Soil organic carbon-water partitioning coefficient
LOU	Landfill Operable Unit
MCL	Maximum Contaminant Level
µg/L	Micrograms per liter
ml/min	Milliliters per minute
mg/kg	Milligrams per kilogram
mg/m ³	Milligrams per cubic meter
NAPL	Non-aqueous phase liquid
PA/SI	Preliminary Assessment/Site Inspection
PAD	Planned Area Development
PAG	Pima Association of Governments
PCB	Poly-chlorinated biphenyl
PCE	Tetrachloroethene also known as Tetrachloroethylene
PDEQ	Pima Department of Environmental Quality
QAPP	Quality Assurance Project Plan

QA/QC	Quality Assurance/Quality Control
RAO	Remedial Action Objective
RCRA	Resource Conservation and Recovery Act
RfC	Reference concentration
RfD	Reference dose
RI	Remedial Investigation
RI	Remedial Investigation
RME	Reasonable Maximum Exposure
RO	Remedial Objective
RSL	Regional Screening Level
S2BVEM	Stage 2B Validation Electronic and Manual
S4VEM	Stage 4 Validation Electronic and Manual
SAP	Sampling and Analysis Plan
SAVSARP	Southern Avra Valley Storage and Recovery Project
SD1PC	Sanitary District No. 1 of Pima County
SF	Slope factor
Site	Broadway-Pantano WQARF Site
SOW	Scope of work
SRL	Soil Remediation Level
SSGC	Shallow Soil Gas Concentration
SSL	Soil Screening Level
SVE	Soil Vapor Extraction
SVE/AI	Soil Vapor Extraction/Air Injection
SVOC	Semi-volatile Organic Compound
TCE	Trichloroethene also known as Trichloroethylene
TW	Tucson Water
URF	Unit Risk Factor
UCL	Upper confidence limit
USDA	U.S. Department of Agriculture
USEPA	U.S. Environmental Protection Agency
VC	Vinyl Chloride
VF	Volatization Factor
VOC	Volatile Organic Compound

WCS

Western Containment System

WQARF

Water Quality Assurance Revolving Fund

EXECUTIVE SUMMARY

The Broadway North Landfill (BNL) and Broadway South Landfill (BSL) are the major sources of the dissolved volatile organic compounds (VOCs) in groundwater at the Broadway-Pantano Water Quality Assurance Revolving Fund Site (Site); wastes containing VOCs were disposed in these landfills during their operation. The BSL operated from approximately 1953 to 1962 and BNL operated from approximately 1959 to 1972. The contaminants of concern (COCs)¹ in groundwater are tetrachloroethene (PCE); trichloroethene (TCE); vinyl chloride (VC); *cis*-1,2 dichloroethene; and methylene chloride. The Site groundwater contamination extends approximately 2.5 miles west (downgradient) of the BNL and BSL. Impacts to the City of Tucson's (COT's) Central Well Field have resulted in a shutdown of four municipal water supply wells and alteration of COT's pumping operations.

The Arizona Department of Environmental Quality (ADEQ) has divided the Site into two operable units for the Remedial Investigation (RI): the Groundwater Operable Unit (GOU) and the Landfill Operable Unit (LOU). The latter includes the closed BNL, the closed BSL, and the vadose zone directly beneath and in close proximity to the BNL and BSL boundaries. The LOU RI and the GOU RI (Stantec, 2012b) will be used to support a combined LOU and GOU Feasibility Study and remedial action plan so that a final remedy can be implemented.

The LOU RI Report was prepared to meet the following objectives:

- Establish the nature and approximate extent of the contamination in the LOU and the sources thereof;
- Identify current and potential impacts to public health, welfare, and the environment;
- Identify current and reasonably foreseeable uses of land within the LOU;
- Present other information necessary for identification and comparison of remedial alternatives; and

¹ A COC, as defined by Arizona Administrative Code R18-16-401, "means a hazardous substance that results from a release and that has been identified by the Department as the subject of remedial action at a site." COCs are those contaminants that have been detected with some consistency in groundwater, soil or soil gas at concentrations above regulatory or risk-based levels.

- Establish the LOU Remedial Objectives (ROs) for the Site (Appendix Q).

To achieve these objectives, soil gas samples were collected and analyzed from existing methane probes around the perimeters of the BNL (SECOR, 2006a; Appendix M) and BSL (Appendix C) to evaluate vapor intrusion risk at adjacent properties; soil gas samples were collected and analyzed from onsite, temporary, shallow soil gas probes at the BNL and BSL to evaluate onsite risk (Appendices D and F); and samples from deep-nested soil gas probes were sampled to characterize further the VOCs in the LOU vadose zone and to evaluate rebound of VOCs at the BNL since a soil vapor extraction/air injection (SVE/AI) system was turned off in 2002 (Appendix E). Shallow soil samples from the BNL (SECOR, 2004) and the BSL (Appendix G) were also collected and analyzed for evaluation of risk of exposure to soil media. The extent and nature of dross at the southern part of the BNL was characterized in 2000-2001, and the associated health risks were evaluated (Aplomado, 2000). A Land Use Study (Appendix A) was prepared to identify current and reasonably foreseeable uses of land within the LOU.

Analyses of soil gas samples collected from deep-nested (i.e., 50 feet deep and greater) probes at BNL detected low concentrations of VOCs. These VOC soil gas concentrations were converted to “soil equivalent” concentrations (assuming that equilibrium partitioning of the VOCs). Soil equivalent concentrations were below Arizona Soil Remediation Levels (SRLs) and Groundwater Protection Levels² (GPLs). The deep soil gas data from BNL do not show an appreciable rebound of VOCs in the vadose zone since a SVE/AI system was turned off in September 2002 after 27 months of operation. The data from the deep-nested soil gas probes at BNL do not indicate that an ongoing source of VOCs exists below most of the BNL that could adversely affect groundwater quality; however, the recently increasing VOC concentrations in groundwater well WR-274A indicate a continuing release to groundwater upgradient of WR-274A.

² GPLs are the level of residual contaminant in soil that would be protective of groundwater at a point of compliance in the underlying aquifer. ADEQ has calculated minimum GPLs for a number of metals and VOCs (ADEQ, 1996). Minimum GPLs for VOCs were revised by ADEQ in 2008. Soil equivalent concentrations were compared to the most recent applicable minimum GPL calculated by ADEQ.

Recent VOC concentrations in soil gas from several depths and locations at BSL are higher than those measured during the previous monitoring event in 2006. However, there are fewer historical data at BSL for comparison, and discerning trends is therefore more difficult. PCE concentrations in groundwater have increased in wells BP-22 and BP-23, concurrent with the observed increase in soil gas concentrations. Recent PCE and TCE concentrations in soil gas are higher than recent concentrations at BNL, but lower than peak concentrations detected at BNL prior to SVE/AI. This is consistent with Stantec's (2012b) conclusion that the BSL is a lesser source of VOCs to the GOU.

A conceptual site model (CSM) is proposed that includes an "active release phase" in which VOCs from the vadose zone are transferred to groundwater, and a "post-SVE/AI phase" in which the vadose zone is no longer adversely impacting groundwater quality. Soil gas and groundwater analytical data indicate that BNL is in the post-SVE/AI phase, and BSL may be in the active release phase. Wastes generated by commercial and industrial businesses in the Tucson area, Phoenix area, and Southern Arizona were deposited at BNL and BSL and are the sources of VOCs found in groundwater. During the active release phase, the primary fate and transport mechanisms in the vadose zone are volatilization, vapor advection, vapor diffusion, adsorption, and biodegradation. Mass transfer from the vadose zone to the saturated zone occurs according to Henry's Law. Contaminants sorb to fine-grained layers and are slowly released by diffusion. In the post-SVE phase, according to the proposed CSM, advective transport and mass transfer across the water table are not significant transport mechanisms. Diffusion continues to occur, but at lower rates due to the decreased concentration gradient. Diffusion appears to be offset by biodegradation during this phase, so rebound of VOC concentrations in soil gas is not observed. Advective transport of aqueous phase VOCs in infiltrating soil water is not considered a significant transport mechanism during either phase.

Generally declining concentrations of VOCs in groundwater at BNL and low VOC concentrations in soil gas indicate that it is in the post-SVE/AI phase. For most of the BNL, it does not appear that the vadose zone is acting as a continuing source for VOCs in groundwater. (However, the BNL and BSL could still contain waste, possibly in containers, that could be released to the vadose zone in the future.) There appears to be a correlation between a rising groundwater level and increasing VOC concentrations in one monitoring well, WR-274A,

located at the downgradient (western) side of BNL. This relationship is interpreted to indicate that VOCs that are sorbed to fine-grained material in the lower part of the vadose zone and capillary fringe are being re-mobilized in groundwater as the sediments become re-submerged due to the rising water table. This mechanism is considered to be limited to the area upgradient of WR-274A; this phenomenon is not observed at other monitoring wells that are immediately downgradient of the BNL.

At BSL, increasing VOC concentrations in soil gas and groundwater suggest that an ongoing source in the vadose zone may be present. BSL may therefore still be in the active release phase.

The results of the 2013 soil gas monitoring were used to assess the potential human health risks associated with soil gas present at the BNL (onsite risk), BSL, and four developed areas within or adjacent to the BSL. The following exposure areas and receptors were evaluated: BNL (current/future outdoor trespasser), BSL (current/future outdoor trespasser), Gollob Park (current/future outdoor worker), the YMCA (current/future indoor worker), Broadway Proper (current/future indoor resident), and Kenyon Terrace (current/future indoor resident).

The 2013 soil gas sampling results were used in the USEPA outdoor air model for the exposure assessment and risk characterization of the outdoor scenarios (BNL, BSL and the current/future worker at Gollob Park). The maximum soil gas concentration for each contaminant of potential concern (COPC) in the exposure area was used to characterize risk for the outdoor scenarios. The maximum incremental lifetime cancer risk (ILCR) and the maximum non-cancer hazard index (HI) are reported for each outdoor exposure area as shown in the summary table below.

The results of the 2013 soil gas sampling were used in the USEPA version of the Johnson & Ettinger (J & E) indoor air model for the current/future indoor air scenario for YMCA, Broadway Proper, and Kenyon Terrace. For these indoor scenarios the ILCR and HI were calculated for every soil gas data point using the J&E model; thus a range of cumulative risks were calculated and are shown in the summary table below.

Exposure Area	Receptor	ILCR ³	HI
BNL (current/future)	Trespasser	9 E-11	0.001
BSL (current/future)	Trespasser	2 E-11	0.0004
Gollob Park (current/future)	Outdoor worker	1 E-08	0.024
YMCA (current/future)	Indoor worker	2 E-08 to 2 E-07	0.00001 to 0.00008
Broadway Proper (current/future)	Indoor Resident	4 E-08 to 5 E-07	0.00001 to 0.0016
Kenyon Terrace (current/future)	Indoor Resident	6 E-09 to 1 E-07	0.0000009 to 0.00003

Indoor air concentrations were also evaluated using a default USEPA attenuation factor (AF) of 0.03 (USEPA, 2012) in conjunction with the measured soil gas concentrations for each COPC for BSL and for the maximum concentration for each contaminant for BNL. The AF relates the concentration of a chemical in soil gas to predicted potential indoor air concentration. The resulting predicted indoor air concentration was compared to the USEPA Region 9 residential and commercial Regional Screening Level (RSL) for ambient air⁴ (USEPA, 2013). For BSL, the predicted indoor air concentrations are less than the residential and commercial RSLs with the exception of benzene and chloroform at Broadway Proper and chloroform at Kenyon Terrace.

The results of 2002 and 2006 shallow soil gas sampling at the BNL by Stantec (previously called SECOR) were used to evaluate human health risks to current residents from exposure to VOCs from indoor vapor intrusion for the residences near the western and southwestern perimeter of the BNL. The Advanced Johnson & Ettinger (J&E) Model was used to estimate indoor air concentrations at the exposure points of interest, making the conservative assumption that the soil gas probes were next to the foundations of adjacent residences with concrete slab on grade. The predicted indoor health risk results using the 2006 data were less than an HI of 1 and reasonable maximum exposure (RME) excess cancer risk less than 1.0 E-06. Stantec concluded

³ A.C.C. R18-7-206(D) states, “A person conducting a remediation to a residential or non-residential site-specific remediation level shall remediate the contaminants in soil to a Hazard Index no greater than 1 and a cumulative excess lifetime cancer risk no greater than 1 x 10⁻⁶ to 1 x 10⁻⁴.”

⁴ The “new” RSL table using a target hazard quotient (TQH) = 0.1 was used to make screening more conservative to account for multiple contaminants.

that there are no potential health concerns associated with vapor intrusion at residences near the western and southwestern perimeter of the BNL.

ADEQ also used the AT of 0.03 and maximum VOC concentrations from the most recent BNL shallow soil gas sampling, (2006 data) (SECOR, 2006a; Appendix M) to predict indoor air concentrations in the residences adjacent to BNL. For BNL, the predicted indoor air concentrations were less than the RSL except for chloroform; 1,4-dichlorobenzene; 1,2-dichloropropane; naphthalene; and TCE.

In addition, potential health risks associated with chemicals detected in shallow soil at the BSL were evaluated; no unacceptable health risks associated with shallow soil at BSL were found. An evaluation of soil at BNL (SECOR, 2004) found no unacceptable health risks associated with shallow soil.

Current and future land uses at BNL and BSL are subject to COT's landfill ordinance. BNL is within the "Gateway Centre Planned Area Development" which was prepared by the COT Planning Department and passed by the Mayor and Council in 1983. The Planned Area Development (PAD) allows for a variety of commercial and residential uses, including those areas of the PAD within the LOU. The Broadway Star Plaza, located in the southernmost part of the BNL, is not in the PAD. The owner of this property indicated to ADEQ that commercial uses are expected to continue, and additional commercial space may be added at that location.

Future uses at the BSL will be guided by the Broadway Proper Redevelopment Plan that was adopted by the Mayor and Council in 1984. The plan has a mix of office, business, and multi-family uses. Since the plan was approved, development has taken place at BSL which is consistent with the plan. A Hilton Hotel, Culver's Restaurant, and the Broadway Proper retirement community are currently operating within the Broadway Proper Development. South of the Broadway Proper Development are a YMCA fitness center and COT-owned Gollob Park. The owners of these properties do not anticipate significant changes in use in the foreseeable future. Requirements regarding methane testing and mitigation in COT's Landfill Ordinance will also apply to redevelopment.

The results of the LOU RI, including the Land Use Study, were used by ADEQ to produce the ROs for remediation of the LOU part of this Site pursuant to A.C.C. R18-16-406(I). These ROs are as follows:

LOU Residential— The RO for existing and future residential use of LOU properties is to protect against exposure to Contaminants of Concern within or released from the LOU waste. This action is needed at the present time and for as long as the landfill and dross wastes remain at the property.

LOU Non-Residential— The RO for existing and future non-residential use of LOU properties is to protect against exposure to Contaminants of Concern within or released from the LOU waste. This action is needed at the present time and for as long as the landfill and dross wastes remain at the property.

1.0 INTRODUCTION

This Final Remedial Investigation (RI) Report for the Broadway-Pantano Water Quality Assurance Revolving Fund (WQARF) Registry Site (Site) Landfill Operable Unit (LOU) was prepared by Clear Creek Associates PLC (Clear Creek) for the Arizona Department of Environmental Quality (ADEQ). This work was completed in accordance with ADEQ Task Assignment 13-031176 under the Arizona Superfund Remedial Action Contract (ASRAC).

The Broadway North Landfill (BNL) and Broadway South Landfill (BSL) are the major sources of a groundwater plume of dissolved volatile organic compounds (VOCs) that extends approximately 2.5 miles west (downgradient) from the BNL and BSL. Contamination at the BNL and BSL originated from waste generated by commercial and industrial businesses in the Tucson area, Phoenix area, and Southern Arizona. Former municipal waste haulers, private waste haulers, and solvent collectors and recyclers recalled collecting waste that included the Site contaminants of concern (COCs) from commercial and industrial businesses in those areas and disposing of the waste at the BNL and BSL (Appendix O). Concentrations of tetrachloroethene (PCE), trichloroethene (TCE), and vinyl chloride (VC) above Arizona Aquifer Water Quality Standards (AWQSs) have been detected in groundwater at the Site. Impacts to the City of Tucson's (COT's) Central Well Field have resulted in a shutdown of four municipal water supply wells and alteration of COT's pumping operations.

ADEQ divided the Site into two operable units for the RI: the Groundwater Operable Unit (GOU), which includes the volume of the saturated zone containing VOCs exceeding AWQSs, and the LOU, which includes the closed BNL, the closed BSL, and the vadose zone directly beneath and in close proximity to the BNL and BSL boundaries. The RI Report for the GOU was prepared by Stantec Consulting Services, Inc. (Stantec) and finalized by ADEQ on June 1, 2012 (Stantec, 2012b).

The Draft LOU RI Report was made available for public review and comment between November 29, 2013 and February 26, 2014. ADEQ prepared a Responsiveness Summary to address the written comments received regarding the Draft LOU RI Report. ADEQ's responses to those comments can be found in Appendix R of this Final LOU RI Report.

This Final LOU RI Report presents the findings, conclusions, and recommendations resulting from investigations conducted by Clear Creek and previous investigators under the direction or oversight of ADEQ through March 2013. The Final LOU RI and GOU RI Reports will be used to support a single Feasibility Study (including both the LOU and GOU) and remedial action plan so that a final remedy can be implemented for this Site.

1.1 OBJECTIVES

The objectives of this RI, in accordance with Arizona Administrative Code (A.A.C.) R-18-16-406, are as follows:

- Establish the nature and extent of the contamination in the LOU and the sources thereof;
- Identify current and potential impacts to public health, welfare, and the environment;
- Identify current and reasonably foreseeable uses of land within the LOU;
- Obtain and evaluate other information necessary for identification and comparison of remedial alternatives; and
- Establish the LOU Remedial Objectives (ROs) for the Site (Appendix Q).

1.2 SCOPE OF WORK

The scope of work conducted for this LOU RI includes the following tasks:

- Provide a summary of LOU investigations performed through March 2013;
- Collect shallow soil gas samples throughout the LOU and shallow soil samples at the BSL to allow for an evaluation of health risks;
- Collect deep soil gas samples throughout the LOU to evaluate extent of VOCs in the vadose zone;
- Evaluate the extent of landfill waste⁵ at Gollob Park;
- Evaluate data and perform risk assessments to determine COCs;

⁵ For the purposes of this RI, the term “landfill waste” refers to any material that was deposited in the landfill, including demolition/construction debris. The terms “refuse” and “waste” are used interchangeably with the term “landfill waste”.

- Formulate a conceptual site model for the LOU; and
- Present the findings, conclusions and recommendations resulting from studies at the LOU to meet the objectives listed in Section 1.1.

The Site has been under investigation since the 1980s. Substantial amounts of data have been generated over the years. In the interest of efficiency, and at the recommendation of ADEQ, previous reports prepared by others are frequently referenced in this RI. For example, this Draft RI Report cites the HydroGeoLogic (HGL) Site history report (2012) and the Stantec Site GOU RI Report (2012b), which were prepared for ADEQ.

1.3 SITE BACKGROUND

The Site is located in east-central Tucson. Approximate boundaries of the WQARF Site are Speedway Boulevard to the north, Pantano Wash to the east, Calle Madero to the south, and Craycroft Road to the west (Figure 1). The LOU footprint (Figure 2) is smaller than the GOU footprint, and encompasses four discontinuous areas defined by the former landfilling operations that took place in the area. The LOU is located in parts of Sections 8 and 17 of Township 14 South, Range 15 East.

The closed BNL has been identified as the primary source of VOCs in the GOU. The closed BSL is considered to be a secondary source. Former sand and gravel mining operations on the west side of the Pantano Wash (in the vicinity of the BNL and BSL) that operated from the mid-1940s to the early 1970s and were used as “wildcat” dumping sites are considered a third source. The closed Prudence Landfill, located to the east and south of BSL, is not considered to be a source based on groundwater quality data from monitoring wells within and downgradient of the Prudence Landfill boundary (Appendix O).

The LOU consists of the closed approximately 100+ acre BNL, the 50+ acre BSL, and the unsaturated zone directly beneath and in close proximity to the closed landfills (Figure 2). Gollob Park has not been included within the LOU boundary in past reports (Stantec, 2012b) because of the previous unavailability of confirmatory borehole logs within Gollob Park. The LOU boundary has been revised for this RI, and a portion of Gollob Park is now included in the LOU at the southern end of the BSL.

1.4 SITE HISTORY

HGL (Appendix O) conducted an investigation of the Site history for ADEQ as part of the GOU RI. The comprehensive summary includes information regarding operational history, management, closure, waste streams, and haulers for both the BNL and BSL. Source documents, including newspaper clippings, transcribed depositions, and legal agreements, are provided for reference. This section relies on information provided in the HGL document.

1.4.1 BSL Operations

Prior to 1953, the BSL property was used for agriculture and then leased for sand and gravel operations. Precise dates of these operations are not known. The landfill at the BSL was operated by Pima County from 1953 to 1956, and by Sanitary District No. 1 of Pima County (SD1PC) from 1956 to 1958 (Appendix O and URS, 2004)⁶. In 1958, Pima County and SD1PC agreed to share undivided interest in the landfill, which they did until the landfill closed in 1962.

Landfilling at BSL progressed from north to south. The owners, Stefan and Magdalena Gollob, leased the land to the landfill operators under a series of agreements as the landfill grew southwards. No records were found to indicate that a liner was used beneath the landfill waste. Lining of landfills was not the customary practice at the time. According to Pima Association of Governments (PAG) (1997), approximately 200 tons of garbage and trash were deposited in the landfill per day. Green waste and debris were separated from garbage and trash.

Aerial photographs (URS, 2004) show that most of the pits at BSL were filled and graded by 1958, but that the final cover had not been completed. A 1962 aerial photo shows the area as smoothed and graded. SD1PC placed warning signs at the BSL in response to wildcat dumping, a practice that apparently continued after closure (Appendix O).

⁶ *COT Resolution Nos. 4172, 4463, and 4861 demonstrate that COT paid a percentage of the cost of operating Sanitary District No. 1 of Pima County's landfills during fiscal years 1959 to 1960, 1960 to 1961, and 1961 to 1962. Sanitary District No. 1 of Pima County meeting minutes from 1959 to 1962 also show discussions of agreements with COT and payment with regard to landfill operations (quotes from Appendix O).*

1.4.2 BNL Operations

Sand and gravel mining operations began at BNL in the mid-1940s. In 1959, formal landfilling operations began at BNL and continued to 1972, but the area was known to have been used as a “wildcat” dump prior to 1959. In 1959 and 1961, the owners of the property, Stefan and Magdalena Gollob, granted easements to the SD1PC for eight parcels south of the 5th Street alignment. SD1PC operated this portion of the BNL until 1968, when the SD1PC was dissolved. Operations were transferred to Pima County Department of Sanitation, which agreed to assume the duties and responsibilities regarding the District’s contracts (Appendix O)⁷.

In 1965 and in 1968, COT executed agreements with Tucson Rock and Sand Co., Inc. and the Martin family to operate a landfill north of the 5th Street alignment. COT had previously been involved in SD1PC’s landfilling operations at the southern part of the BNL to the extent that COT paid a percentage of the operating costs. COT was allowed to dispose of trash, refuse, garbage, tree trimmings, dirt, debris, and other waste material until the sand and gravel excavations were filled in (Appendix O). HGL indicates that the BNL was closed in “approximately 1972”; HGL found conflicting data and discrepancies regarding the closure date(s), but it appears that the COT-operated portion was closed, graded, and covered with soil by approximately 1971 and the Pima County-operated portion was closed, graded, and covered with soil by approximately 1973. Wildcat dumping continued after closure. Pima County ended its lease in 1974, and the property reverted back to the landowners.

As was the case at BSL, there were no restrictions to the wastes that were permitted to be placed in the landfill (ADEQ, 1995a and Appendix O). Employees were present for nine hours per day, even though the landfill was open 24 hours per day (Appendix O). No records were found in HGL’s document review (Appendix O) to indicate that a liner was used beneath the landfill waste. Lining of landfills was not the customary practice at the time.

⁷ *COT Resolution Nos. 4172, 4463, and 4861 demonstrate that COT paid a percentage of the cost of operating Sanitary District No. 1 of Pima County’s landfills during fiscal years 1959 to 1960, 1960 to 1961, and 1961 to 1962. Sanitary District No. 1 of Pima County meeting minutes from 1959 to 1962 also show discussions of agreements with COT and payment with regard to landfill operation (quotes from Appendix O).*

1.4.3 Early Evidence of Releases

The first evidence of VOCs in groundwater beneath the LOU was in the D-022A well at the BNL in 1983, (CDM, 1988 and ADEQ, 1995a). Between 1987 and 1991, Tucson Water (TW) took production wells D-022A, C-021A, and D-021A out of service due to laboratory-detected concentrations of PCE in groundwater samples collected from these wells. The Broadway-Pantano Site was placed on the WQARF priority list on September 14, 1990 (Appendix O).

ADEQ conducted Preliminary Assessment/Site Inspections (PA/SIs) at the BNL and BSL in 1995. ADEQ concluded that both landfills were considered potential sources of groundwater contamination because PCE and TCE were detected in soil gas at both landfills (ADEQ, 1995a and 1995b). CDM, under contract with the COT and Pima County, completed a Draft RI of the BNL in 1998. In 2000, USEPA designated the Site as a “State Lead” site. In 2000, as an Early Response Action (ERA), COT and Pima County had a soil vapor extraction/air injection (SVE/AI) system installed at BNL to remove VOCs from the vadose zone; the system operated for 27 months. In 2005, the BSL became part of the Broadway-Pantano WQARF Site after it was determined that the BSL plume was co-mingling with the BNL groundwater plume.

1.5 REPORT ORGANIZATION

This report was prepared based on the USEPA *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* (USEPA, 1988). The remainder of this report is organized as follows:

- Section 2 describes the physical characteristics of the LOU, including the physiographic setting, land use and demographics, topography, climate, geology, surface water hydrology, and hydrogeology.
- Section 3 provides information regarding previous investigations pertinent to the BNL and BSL sections of the LOU, early response actions, and the recent field investigations conducted for this RI.
- Section 4 describes the nature and extent of contamination. Descriptions of the extents of refuse and extents of contamination in soil and soil gas are provided.
- Section 5 describes the contaminant fate and transport. Migration pathways, exposure media and receptors are described.

- Section 6 presents the conceptual site model for the LOU.
- Section 7 presents a summary of the Health Risk Assessment (HRA) for the BSL LOU. An HRA for the BNL was previously conducted by Stantec in 2010. The complete risk assessment report for BSL is in Appendix L of this RI report.
- Section 8 summarizes the LOU RI and presents conclusions.
- Section 9 cites references used in the preparation of this RI.

2.0 SITE CHARACTERISTICS

Site characteristics have been described in a number of previous investigations, including the Draft RI report by CDM (1998), PA/SI investigations by ADEQ (1995a and 1995b), and the GOU RI by Stantec (2012b). This section relies on these references and others, as noted.

2.1 PHYSIOGRAPHIC SETTING

The BNL and BSL landfills are located in the City of Tucson. The City is located in the Tucson Basin subarea of the Upper Santa Cruz Groundwater Basin in the Sonoran Desert section of the Basin and Range physiographic province. The northwest-trending Tucson Basin is a broad alluvial valley bounded by the Tortolita and Santa Catalina Mountains to the north; the Tanque Verde, Rincon, Empire, and Santa Rita Mountains to the east and southeast; and the Sierrita, Black, and Tucson Mountains to the east.

2.2 LAND USE AND DEMOGRAPHICS

The Broadway-Pantano LOU falls within the 85710 zip code, which measures approximately 4 miles by 3 miles (total area of 12.5 square miles). The zip code's eastern boundary is roughly at Harrison Road, the western boundary is Wilmot Road, the north boundary generally coincides with Speedway Boulevard, and the southern boundary coincides with Golf Links Road. According to the 2010 U.S. census, 54,439 people reside within the zip code⁸. There are 24,849 households, for an average of 2.19 persons per household. The average population density in the zip code is 4,189 persons per square mile. The median age of the residents is 41.2 years.

Broadway Boulevard, a major east-west thoroughfare, runs between the BNL and BSL (Figure 2). Properties along Broadway Boulevard, including those in the LOU, are used primarily for commercial purposes, including retail goods and services, restaurants, and hotels. Residences, both single family and multi-family, are located behind the commercial properties along Broadway Boulevard. The Pantano Wash runs along the east side of the BNL and BSL.

⁸source: <http://www.zip-codes.com/zip-code/85710/zip-code-85710-2010-census.asp>

At the BSL, uses include undeveloped land, a Hilton Hotel at the northeast corner, a Culver's restaurant at the northwest corner, the Broadway Proper Retirement community to the southwest, and Gollob Park at the south end of the BSL. The YMCA is located west of Gollob Park and is not considered to be in the LOU. Kenyon Terrace, a townhome development, is located immediately south of the YMCA and Gollob Park and is also outside the LOU boundary. Adjacent property uses are single family homes on the west side of the LOU across Prudence Road, and multi-family homes across the Pantano Wash on the east side of the LOU and south of the LOU.

The BNL portion of the LOU is mostly unoccupied. There are no permanent residents or full-time workers at the site. The BNL is vacant, except for the Broadway Star Plaza, a 23,600 square foot strip mall with six tenants, located just north of Broadway Boulevard. The tenants are retailers of goods and services; there is currently no manufacturing at the property. Land use varies in the area around the BNL. Land uses east of the BNL (across Pantano Wash) include single family residences, multi-family residences, and commercial properties, the nearest one being a Home Depot store. Single family housing is the primary land use southwest of the BNL. Land uses northwest of the BNL include offices, a medical center, and an electrical substation, owned by Tucson Electric Power (TEP).

The Land Use Study, provided in Appendix A, provides more information on current uses and permitted future uses in and around the LOU.

2.3 TOPOGRAPHY

The LOU is included on the U.S. Geological Survey's Tucson East Topographic quadrangle (scale 1:24,000). According to the 2011 version of this map, topography at the LOU slopes down to the north and east. The highest elevation within the combined LOU (including BNL and BSL) is at the southeast corner of the Broadway Proper parcel, which has an elevation of 2,620 feet above mean sea level (amsl). The lowest elevation in the combined LOU is 2,530 feet amsl in an excavated area (a former gravel pit) at the northwest corner of BNL. Slopes are gradual over most of the LOU except at the previously-mentioned pit and along the eastern boundaries of the landfills along the Pantano Wash where a steep embankment (over ten feet high) borders the wash.

2.4 CLIMATE

The Site is located in the Sonoran Desert, and has long, hot summers and mild winters. The Western Region Climate Center at the University of Arizona maintains detailed records of Tucson's climate at <http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?aztucs>. Average monthly temperatures range from 87.3°F in July to 52.6°F in December, and average monthly high temperatures range from 99.1°F in June to 64.4°F in December, based on data from 1981 through 2010. Average monthly lows ranged from 40.8°F in December to 75.7°F in July for the same 30-year period. According to the National Weather Service, 2012 was the second warmest year on record, with an average temperature of 71.3°F. The warmest year was 1989 with an average temperature of 71.4°F (<http://www.wrh.noaa.gov/twc/climate/monthly/2012.php>).

The area has two rainy seasons: a winter season in which storms generally originate in the Pacific Ocean, and a summer monsoon in which storms originate in the Gulf of Mexico. Annual precipitation averaged 11.62 inches from 1981 through 2010, with approximately half of the precipitation falling during the summer monsoon. The driest month, May, averaged 0.21 inches of precipitation from 1981 through 2010. Rainfall in 2012 was below average at the Tucson International Airport (7.91 inches, according to the National Weather Service). The Tucson area has experienced sustained drought conditions since 1994 (Stantec, 2012b).

2.5 GEOLOGY

2.5.1 Regional Geologic Setting

The mountains surrounding the Tucson basin are formed of igneous, metamorphic, and sedimentary rocks ranging from Precambrian to Tertiary in age (ADEQ, 1995a). The mountains and valley were formed during a mid-Tertiary orogeny (12 to 36 million years ago), and Basin and Range extension (1-12 million years ago). The mid-Tertiary orogeny deformed and uplifted the Tortolita, Santa Catalina, Tanque Verde, and Rincon Mountains. As these mountains eroded, the resulting sediments were deposited with volcanic deposits from the mountain-building events. During the extensional phase, normal faulting resulted in the current landscape where elongate mountain ranges are separated by alluvium-filled basins. The more recent sedimentary deposits consist of relatively undeformed alluvial fan, alluvial plain, and playa deposits (Houser et al., 2004). Deeper (older) sedimentary deposits consist of more consolidated and faulted basin

fill. The Tucson basin is estimated to contain over 11,000 feet of sediments at its deepest location (Richard et al, 2007).

2.5.2 Site Geology

Due to gravel mining and landfilling activities at the LOU, there are no undisturbed surficial deposits that can be sampled and described. Most of the LOU has been mapped by the U.S. Department of Agriculture (USDA) as “pits/dumps”⁹. A portion of the Broadway Proper site (at the southwest corner of the BSL) is classified as Mohave soils/urban land with a 1-8% slope. A portion of Gollob Park is classified as Pinaleno-Stagecoach-Palos Verdes soil type with a 10-35% slope.

Due to the LOU’s location adjacent to the Pantano Wash, it is reasonable to conclude that native surficial deposits consisted of Quaternary (Holocene)-Age alluvium deposited as stream channel and flood plain deposits. The alluvial deposits typically consist of gravels and gravelly sands with localized sands and sandy silts. The thickness of these alluvial deposits can be highly variable, from a thin veneer to several tens of feet along major surface drainages. The sand and gravel components of the alluvium make it attractive for quarrying operations, such as those that operated at the BNL and BSL prior to the landfilling operations. These deposits make up much of the vadose zone that underlies the LOU.

Five geologic cross sections of the BNL using information from previous investigations (CDM, 1998 and HydroGeoChem, 2000) were prepared by SECOR and included in the GOU RI by Stantec (2012b). For the BNL, SECOR constructed one north-south cross section and four east-west cross sections (Figure 3). The cross sections are provided on Figures 4-8. Depths to water measured by Clear Creek in February 2013 and PCE concentrations in soil gas have been added to the cross sections and will be discussed later. The cross sections are constrained by the depths of the wells, but many of the wells penetrate the vadose zone to groundwater and the deepest well (R-068A) reaches a depth of 368 feet below land surface (bls). At BNL, cross sections show

⁹USDA soil maps are available on COT mapping site <http://maps.tucsonaz.gov/realestate/index.html>.

well-graded sands with discontinuous lenses of clayey and silty sands in the upper 250 to 300 feet. Gravel horizons are present within this interval but are not as common. Below 250 to 300 feet, granitic gravels are dominant, as shown in cross section A-A' (Figure 4). Stantec also noted, based on lithologic logs from WR-273A, WR-274A, and WR-275A, that the “clayey sand layers can be as much as 50 feet thick.”

Stantec (2012b) prepared a north-south cross section through the BSL and Prudence Landfills (cross section location is plotted on Figure 9), shown as cross section F-F' (Figure 10). The cross section extends to a depth of 458 feet bls at BSL (at wells BP-22 and BP-23) and to 405 feet bls at Prudence Landfill (at well R-124A). Sediments consist of discontinuous horizons of clayey sands, silty sands and gravels within thick deposits of well-graded to poorly-sorted sands in the upper 300 to 400 feet. The borings at the adjacent Prudence Landfill had greater amounts of gravel than those at BSL. Granitic gravels are predominant below depths of 400 feet at BSL and 300 feet at Prudence (Stantec, 2012b).

2.6 SURFACE WATER HYDROLOGY

With the exception of the developed parcels (the Hilton Hotel, Culver's, and Broadway Proper at BSL and the Broadway Star Plaza at BNL), the BNL and BSL are unpaved.

The Pantano Wash flows from south to north along the east side of BNL and BSL. Clear Creek's observations indicate that the banks (but not the bottom) are armored with soil cement to prevent erosion during flow events. It is zoned “AE” and is a floodway, according to the Flood Insurance Rate Maps by the Federal Emergency Management Agency (FEMA, 2011). The BNL and BSL are in the “X” zone, which is determined to be outside the 0.2% annual chance floodplain. Flow is ephemeral and occurs in response to runoff from precipitation events, primarily during summer monsoon storms. Summer monsoon precipitation events are localized, and moderate on a daily basis, but they can be intense on an hourly basis. Winter precipitation events are more widespread and light to moderate in intensity.

In 1998, Cella-Barr Associates channelized stormwater flows in the southern portion of the BNL to redirect stormwater from residential areas away from the landfill and toward Pantano Wash (CDM, 1998). According to Tucson Department of Transportation mapping¹⁰, there is one stormwater drainage channel at BNL. Stormwater flows northward along Prudence Road from Broadway Boulevard. Stormwater flows in a channel onto the BNL at the northern end of Prudence Road and continues about 400 feet north. The channel turns to the northeast and runs about 600 feet to the Pantano Wash. Stantec (2012b) observed generally adequate drainage at BNL after heavy rainfall events. However, minor ponding was observed in the soil-covered area and sinkholes were observed in the central portion of the BNL and within the northern landfilled areas of the BNL.

There is no channelized surface water flow at the BSL according to Tucson Department of Transportation mapping. Cella-Barr conducted a hydrologic study of the BSL in 1985, which documented run-on to the BSL from properties to the west. In addition, the study said that the site was within the 100-year floodplain (Cella-Barr, 1985). It appears that bank protection measures and other site development work that was conducted after Cella-Barr's study have addressed issues raised by Cella-Barr in the 1985 report, because current maps show the BSL outside the 0.2% annual chance floodplain (FEMA, 2011).

2.7 HYDROGEOLOGY

The regional hydrogeologic setting was described in Section 2.7.1 of the GOU RI Report by Stantec (2012b), and the site hydrostratigraphy (in the GOU) was described in Section 2.7.2. The aquifer below the LOU is unconfined, and facies changes during the deposition of sediments in the alluvial basin have resulted in varying lithologies, ranging from clayey lenses, generally of limited thickness and extent, to more extensive, hydraulically conductive sandy gravels (as shown on cross sections on Figures 4-8 and 10). Perched groundwater has not been observed in the area, according to the GOU RI (Stantec, 2012b).

¹⁰ <http://maps.tucsonaz.gov/tdot/>

2.7.1 Aquifer

The geology of the east-central Tucson basin is characterized by a thick (greater than 1,000 foot) sequence of alluvial fan deposits that are likely derived from the Santa Catalina Mountains to the north. Clear Creek reviewed lithologic and geophysical logs from COT supply wells and other supply well and monitoring well boreholes in and around the WQARF Site for the Groundwater Flow Model Documentation Report (Clear Creek, 2010). The lithologic logs did not indicate the existence of a laterally extensive stratigraphic contact to at least 1,000 feet in depth within the model area, which included the LOU.

The lithologic logs examined by Clear Creek generally indicated similar grain size (sands and gravels) and clast composition (granitic gneiss) from the land surface to total drilled depths. Likewise, the geophysical logs that were reviewed indicated relatively similar geologic conditions (e.g., grain size, density) throughout the total drilled depth. Thin discontinuous clayey beds were noted in some lithologic logs, but do not appear laterally extensive or thick enough to warrant separate hydrostratigraphic designations in the groundwater flow model. An increase in cementation and/or consolidation was suggested by subtle shifts on geophysical logs, particularly the sonic and electric logs. Clear Creek concluded that, in general, the lithology of saturated sediments within the study area appeared to be relatively uniform and homogeneous to depths of at least 1,000 feet. The lithologic and geophysical logs did not indicate any mappable geologic contacts within this depth interval (Clear Creek, 2010).

2.7.2 Depths to Groundwater

In February 2013, Clear Creek measured groundwater levels throughout the GOU. Depths to groundwater within the LOU ranged from approximately 297 to 332 feet bls at BNL and from 320 to 356 feet bls at BSL. The water table elevation below the LOU ranges from a high elevation of approximately 2,266 feet amsl at Gollob Park to approximately 2,253 feet amsl at BP-25 at the northwest side of BNL. Groundwater below the BSL flows in a north-northwesterly direction and then turns more westerly toward the north end of the BSL. The approximate horizontal gradient at BSL is 0.005. Groundwater below the BNL flows generally west-northwest at a gradient of 0.002 (Figure 11).

Groundwater levels have increased throughout the GOU since Tucson Water began turning off or significantly curtailing pumping of its Central Well Field (CWF) wells over a decade ago (discussed in Section 2.7.3). In general, water levels beneath the LOU have risen about 14-16 feet since 2007, according to groundwater level data provided in the GOU RI (Stantec, 2012b).

Aquifer recharge sources in the area investigated by Clear Creek for the Groundwater Flow Model Documentation Report include Pantano Wash, Rillito Creek, and Tanque Verde Creek, which are ephemeral streams that flow in response to storm events. As such, aquifer recharge varies seasonally and annually (Clear Creek, 2010).

2.7.3 Water Resources

The aquifer system in the Tucson Basin is an important source of water for municipal and private water supply. Until 1993, groundwater was the sole water supply in Tucson. In 1993, Tucson Water significantly reduced municipal supply well pumping when Central Arizona Project (CAP) water was directly delivered to customers. Full-scale groundwater pumping resumed in 1994 while recharge basins for CAP water were constructed in Avra Valley. Pumping in the CWF was reduced again in 2001, after Tucson Water began importing recharged CAP/native groundwater “blend” water from the Central Avra Valley Storage and Recovery Project (CAVSARP) and serving it to customers who previously had received groundwater mainly from the CWF. Importation of this “blend” water has allowed Tucson Water to turn off or significantly curtail pumping of its CWF wells. As of 2011 the CAP “blend” percentage of Tucson Water potable water supply reached 70% (Prior, 2013)¹¹.

The Broadway-Pantano WQARF Site is within the CWF. Tucson Water anticipates that use of CAP water from CAVSARP and Southern Avra Valley Storage and Recovery Project (SAVSARP) will reduce pumping in the CWF for most of the year. However, Tucson Water

¹¹ For more information, see <http://cms3.tucsonaz.gov/files/water/docs/cw-2001.pdf>

intends to maintain the CWF as an essential component of Tucson Water's water supply infrastructure. Six "last-on first-off" wells around the Broadway-Pantano Site will continue to be used for the following reasons:

- To meet peak water demands;
- To meet projected annual demand when that demand exceeds the current CAP allocation;
- To meet demand during partial system outages during maintenance activities;
- To provide emergency backup when unforeseen CAP or Tucson Water system outages occur; and
- To provide potentially long-term supply should shortages on the Colorado River reduce Tucson's CAP allocation (Stantec, 2012b).

Four municipal water supply wells within the GOU have been shut down but three are still used for periodic groundwater monitoring (D-022A, D-021A, and C-026B)¹². The St. Joseph's Hospital supply well (411-P) is also within the GOU. It is currently not operating because of the poor condition of the well, but, during operation, water was treated at the wellhead with granular activated carbon (as discussed in Section 3.2.4).

Further discussion of the present and future uses of groundwater in the area of the Site can be found in the Section 2.8 and Appendix A of the GOU RI Report (Stantec, 2012b).

¹² C-021A has been abandoned since shutdown. A fifth municipal supply well, C-022B, was removed from service by Tucson Water before VOCs were detected in the well. It is currently used for groundwater monitoring purposes. C-026B is used as one of two extraction wells for the Western Containment System, which is discussed in Section 3.2.3.

3.0 INVESTIGATIONS AND REMEDIAL ACTIONS

The sections below summarize previous investigation activities at the LOU. Groundwater data and GOU investigations are included if they are of particular relevance to the LOU.

3.1 PREVIOUS INVESTIGATIONS

3.1.1 Early (pre-1995) Investigations at BNL

The following is a timeline of investigation activities conducted prior to the 1995 BNL PA/SI which is extracted from Section 2.3 of the RI report by CDM (1998).

- Numerous geotechnical studies were conducted for Cienega Limited (the owner of BNL) between 1979 and 1987. Some of these studies included a characterization of the thickness of waste in the BNL. The studies documented a variable thickness from zero to 35.3 feet, with the possibility of pockets of waste up to 50 feet thick.
- Cella-Barr Associates was retained by Cienega Limited in 1982-83 to evaluate stormwater drainage and design and construct mitigation measures to direct stormwater flow away from residential developments and into Pantano Wash.
- After a request from the Arizona Department of Health Services (ADHS) in 1980, Cienega hired G.A. Nicholl & Associates, Inc., Geo/Resources Consultants, Inc. (GRC), and EMCON to conduct evaluations of methane production and migration.
- G.A. Nicholl and Associates, Inc. (1980) installed 80 soil gas probes in the southern and western boundary of the BNL. They concluded that methane concentrations were highest along the western boundary where probes were installed in the refuse layer.
- GRC and their subcontractor, EMCON, conducted a methane gas control study in 1982. They installed 20 borings and installed a trench to evaluate the effectiveness of a trench landfill gas (LFG) withdrawal system. The study concluded that the waste thickness on the western side of the BNL ranged from 15 to 25 feet and that the trench system was feasible.
- EMCON designed and constructed a methane mitigation system in 1983-1984. The system consists of a passive vent/barrier trench installed along limited areas of the west and south perimeters of the BNL. A blower was installed as a contingency backup (CDM,

1998). This system was dismantled by the time ADEQ conducted the PA/SI in 1995 (ADEQ, 1995a).

- In 1988, Tracer Research Corporation (Tracer), as a subcontractor to Woodward-Clyde, performed a site assessment and conducted a soil gas survey at 40 sampling points to depths of 14 feet or less. PCE and TCE were detected in soil gas in four areas of the site. Tracer's site reconnaissance identified building remnants of the O'Reilly New Car Prep facility.
- In 1989, Ensco Environmental Services placed five borings in the four areas of interest identified by Tracer in 1988. PCE and TCE were detected in soil from the borings. Three of the borings were completed as 60-foot deep soil gas probes; no soil gas data were included in the report.
- GRC conducted Phase I and Phase II Environmental Assessments (specifically Block 1, lots 2 through 5 of Gateway Centre just north of the BNL) in 1989 and 1990 to investigate subsurface conditions in areas thought to be sources of the PCE and TCE in soil gas that were identified by Ensco and Tracer. Four borings were drilled and completed as soil gas sampling points. Soil gas concentrations were analyzed using Draeger tubes and were reported as non-detect for PCE and TCE. Evidence of petroleum hydrocarbons was found and attributed to waste oil used for dust control at the former sand and gravel operations and to a former UST or pit for storage of tar or waste oil.
- In 1990, Water Resources Associates, Inc. conducted a Phase II investigation at the same parcels investigated by GRC in 1989-90. They also found petroleum hydrocarbons in soil and attributed them to the sand and gravel operations. Anecdotal information regarding a truck wash and vehicle maintenance activities at the sand and gravel operations were also cited as possible sources.

3.1.2 Early (pre-1995) Investigations at BSL

The following is a timeline of early (pre-1995) investigation activities conducted at the BSL, as reported by PAG (1997).

- A 1971 letter from Cella, Barr, Evans and Associates refers to borings drilled at 25-foot intervals around the perimeter of the landfill in 1969 by Marco Engineers. Unfortunately, PAG was unable to locate the original document.
- In 1984, GRC excavated 29 test pits and drilled 25 exploratory borings to delineate the extent of landfilled materials. Most of the test pits and all but eight of the borings were located along the edge of the landfill. GRC noted soil characteristics, stratigraphy, and presence or absence of refuse. A refuse isopach map was prepared (GRC, 1984)¹³.
- In 1984, EMCON Associates prepared a Master Methane Control Plan for the Broadway Proper Development.
- In 1984, GRC installed 19 LFG monitoring probes at BSL. The probes were installed at 200 foot intervals along the western and southern edges of the property, and at 100 foot intervals along Broadway Boulevard. The probes were monitored for three days to assess methane migration from the site. Methane concentrations above the lower explosive limit were detected in nine probes.
- PAG (1997) cites a 1985 report titled “Groundwater Conditions in the Vicinity of the Broadway Proper Project” by K. Schmidt which includes information regarding subsurface geology, information on nearby active public water supply wells, water level and water quality data for these wells, and aquifer characteristics.
- In March 1985, nine exploratory borings were drilled near the Hilton Hotel site by GRC under contract with Woodward-Clyde Consultants. Woodward-Clyde determined that the sandy fill at the surface was underlain by a mixture of landfill waste and sandy soil that ranged from a few inches thick to 26 feet thick in the area of the hotel. The native material underneath the landfill waste was determined to be very dense.
- In 1986 EMCON constructed the LFG migration control system along the perimeter of the BSL. It consisted of 37 wells, a collection header located near the perimeter of the refuse, and a series of gas monitoring probes along Prudence Road, Broadway Boulevard, under the Hilton Hotel, and around the Broadway Proper Retirement Community facility.

¹³ A copy of the map is available, but the full report is not available.

Both the Hilton and the Broadway Proper buildings are equipped with methane sensor/alarm devices.

- In 1990, Tracer Research Corporation, under contract to SCS Engineers, collected and analyzed 21 shallow soil gas samples at BSL. The samples were analyzed for methane and VOCs including PCE and TCE. The highest concentrations of TCE and PCE in soil gas were detected near the west central part of the landfill.

3.1.3 BNL Preliminary Assessment/Site Investigation--1995

In 1995, USEPA directed ADEQ to conduct a PA/SI of the BNL under the authority of the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA). The assessment included a review of previous studies, shallow soil sampling, soil gas sampling, and groundwater sampling. The study confirmed the presence of dissolved chlorinated solvents in groundwater west (downgradient) of the landfill (in well WR-178A) and in soil gas at the site. Seventy-four public or “semi-public” water supply wells serving 215,421 persons were identified within a four-mile radius of the site. ADEQ concluded that there was sufficient evidence of a release to groundwater under CERCLA guidelines. USEPA determined that further assessment was needed, and recommended an expanded site inspection to address data gaps (primarily to collect soil samples beneath the landfill to evaluate presence of PCE in the unsaturated zone and the landfill as the source of groundwater contamination) (CDM, 1998).

3.1.4 BSL Preliminary Assessment/Site Investigation--1995

ADEQ also conducted a PA/SI at the BSL under the authority of CERCLA in 1995. ADEQ collected samples of soil, soil gas, and groundwater from existing COT wells. Based on detection of VOCs in soil gas from the center of the landfill and on the detection of PCE in some COT wells, ADEQ concluded that, “a release of tetrachloroethene (PCE) can be established.” However, further investigation was needed to establish whether the landfill was the source of groundwater contamination (ADEQ, 1995b).

3.1.5 CDM Remedial Investigation Report, BNL--1998

CDM conducted an RI at BNL for COT and Pima County (CDM, 1998). The draft report is dated March 1998 and it does not appear that the report was ever finalized. CDM reviewed

previously-generated data and conducted a limited field investigation followed by a more extensive phased field investigation. CDM's investigation included performing a soil gas survey and installation of permanent soil gas monitoring wells ranging from 60 feet to approximately 193 feet deep. A preliminary HRA was also conducted.

CDM's records review identified several potential source areas of the groundwater contamination that had been observed by that date; however the BNL was the focus of the RI. CDM's conclusions included:

- Landfill gas and VOCs were detected in shallow soil gas. The distribution of PCE in soil gas was not evenly distributed throughout the site; five areas of the BNL had relatively higher concentrations of PCE. These were in the south central, southeast, northeast, northwest, and west central portions of the BNL.
- Soil samples from borings for monitoring wells MW-1, MW-2, and MW-3 (now referred to as WR-273A, WR-274A, and WR-275A, respectively) were analyzed for VOCs. CDM found that "no significant inorganic leachate indicators or organic compounds were detected in any of the soil samples collected and submitted for laboratory analysis."
- Methane was detected throughout the vadose zone to a depth of 300 feet. PCE and TCE were not detected at these depths, but CDM thought the design of the probes may have resulted in dilution of the soil gas samples with surface air.
- Leachate was determined not to be a significant transport mechanism for VOCs from soil to groundwater.
- Gas migration from the landfill to the groundwater was determined to be the primary migration pathway of VOCs. This conclusion was based on several lines of evidence, including chemical and isotopic data and partitioning calculations based on Henry's Law. The presence of PCE; TCE; *cis*-1,2-dichloroethene (*cis*-1,2-DCE); and Freon 12 in shallow soil gas and groundwater in monitoring wells at the western (downgradient) boundary of the landfill suggested a similar source and supported a gas migration transport mechanism. Furthermore, increased bicarbonate in groundwater in downgradient monitoring wells suggested that carbon dioxide from the landfill may be a source of carbon.

- Long-term risks of chronic exposure to vapors migrating to indoor air were calculated. The only significant complete exposure pathway was determined to be the migration of landfill gases into adjacent residences. The only potential cancer risk identified for the indoor air pathway that exceeded EPA's risk range was the estimated potential cancer risk due to exposure to vinyl chloride, while non-cancer health effects were deemed possible due to vapor intrusion of *cis*-1,2-DCE; Freon 12; PCE; and TCE. However, CDM stated that "all estimates of the risks associated with vapor migrating to indoor air spaces are exaggerated by conservative assumptions in the modeling." CDM also found the risk of exposure resulting from onsite excavation or construction "does not appear to be potentially significant."

3.1.6 HydroGeoChem Soil Vapor Extraction/Air Injection Design--1998

Under contract with COT, HydroGeoChem (HGC) used data generated by CDM (1998) to design a soil vapor extraction/air injection (SVE/AI) system to remove VOCs from the vadose zone at BNL. The objective of the system was to prevent further impacts to groundwater. HGC's model predicted that air injection would sweep VOCs radially out toward the extraction wells, and reduce PCE concentrations above the water table by an order of magnitude within 300 feet of the injection well within three months and within 500 feet of the injection well within six months (HydroGeoChem, 1998).

In 2000, COT and Pima County installed the SVE/AI system at BNL as an Early Response Action. It operated from June 26, 2000 until September 10, 2002. At the time the system was shut down, it had removed 2,200 pounds of non-Freon VOCs, including 1,260 pounds of PCE (Stantec, 2008a).

3.1.7 Shallow Soil Gas Surveys at BSL--1990 and 2000

Tracer conducted a shallow soil gas investigation at BSL in 1990 under contract with SCS Engineers. Twenty-one soil gas samples were collected and analyzed for PCE; TCE; methane; 1,1,1-trichloroethane; benzene; toluene; ethylbenzene; xylenes; and total petroleum hydrocarbons. Tracer concluded that "significant" concentrations of chlorinated solvents, total petroleum hydrocarbons, and methane were present in soil gas at the BSL. Although significant,

the concentrations were still considered to be “at very low levels”. The highest TCE and PCE concentrations detected was 0.3 µg/L for both compounds (Tracer, 1990).

Tracer conducted a second shallow soil gas survey at BSL for Quarles and Brady in 2000. The goal was to “determine the extent of soil and/or groundwater contamination by screening shallow soil gas.” Samples were collected from 77 locations from a depth of 15 feet. Samples were analyzed for hydrocarbons (methane, benzene, toluene, ethylbenzene, xylenes, and total volatile hydrocarbons) and for 1,1-dichloroethene; 1,1,1-trichloroethane; TCE; and PCE. TCE and PCE were detected in 50 and 77 of the samples, respectively. Methane was detected in 53 samples. Except for methane, Tracer said that concentrations were “very low” and concluded that “no further studies are warranted for the area” (Tracer Research Corporation, 2000).

3.1.8 HydroGeoChem Remedial Closure Criteria--2001

HGC prepared the “Draft Development of Remedial Closure Criteria for COT Landfills Undergoing Vadose Zone Remediation” which provided remedial action objectives (RAOs) for VOCs in the vadose zone at BNL (HGC, 2001). A screening level model was used to compute the RAOs. The model considered the transport of VOCs from the base of the vadose zone into the saturated zone by infiltrating or draining water, molecular diffusion, and mechanical dispersion. A soil gas RAO was calculated to be the gas concentration at the base of the vadose zone that would not result in a groundwater concentration exceeding the AWQS in samples from a monitoring well located at the downgradient boundary of the landfill. RAOs for PCE (14 micrograms per liter [µg/L]); TCE (6 µg/L); *cis*-1,2-DCE (67 µg/L); methylene chloride (2 µg/L); and VC (176 µg/L), were determined for BNL. The soil equivalent concentrations of the RAOs are below the most stringent Arizona Soil Remediation Levels (SRLs) and the GPLs.

Important points regarding sources and transport processes that were made in this report include:

- Chlorinated VOCs are present in the vadose zone beneath the landfill but are very low within the landfill, based on a shallow soil gas investigation at 64 monitoring points by CDM in June, 1996. At that time, the maximum PCE concentration in the landfill was 7 µg/L and the maximum TCE concentration was 16 µg/L. Low VOC concentrations were explained by their having been “expelled from the refuse by landfill gas (LFG)

generation within the refuse. Chlorinated VOCs may also have been anaerobically biodegraded in the refuse.”

- In the vadose zone, chlorinated VOCs exist in the vapor phase, dissolved phase (in soil water), and adsorbed onto soil solids (primarily organic carbon). Soil gas concentrations reported from BNL are not indicative of the presence of non-aqueous phase liquids (NAPL) beneath the landfill. However, the possibility that containerized NAPL in the waste and/or isolated pockets of NAPL in the vadose zone are present cannot be ruled out.
- Chlorinated VOCs are transported within the vadose zone by (1) aqueous-phase advection in infiltrating soil water (including leachate, if present), (2) vapor-phase advective transport, which can be influenced by barometric pumping and LFG generation, and (3) vapor-phase molecular diffusion. Based on soil moisture measurements, leachate infiltration is not thought to play a significant role at BNL.
- Contaminants move from the vadose zone into the saturated zone by direct dissolution from the gas phase into the groundwater or by dissolving into soil water infiltrating through the vadose zone to the capillary fringe. The model assumes that the soil gas and pore water in the capillary fringe are in equilibrium, and thus can be described by Henry’s Law.

HGC noted that concentrations of PCE in groundwater and soil in the southern part of the BNL were not consistent with one another—specifically, soil gas concentrations were much lower than what would be expected if they were to be in equilibrium with groundwater. HGC stated, “If the PCE originates from the vadose zone, whether by vapor-phase or liquid-phase transport, the groundwater concentration should be less than the vadose zone gas concentrations due to non-equilibrium partitioning between the groundwater and soil gas, and dilution and dispersion processes within the aquifer.”

In 2005, SECOR prepared a “vadose zone cleanup evaluation” for ADEQ (SECOR, 2005). In this document, they stated that the RAOs as determined by HGC were reasonable, and that using RAOs was preferable to comparing with Groundwater Protection Levels (GPLs) (ADEQ, 1996, revised 2008), based on the inherent difficulties in collecting representative soil samples.

SECOR noted that based on the first two rebound tests (discussed in Section 3.1.9), the RAOs had been met¹⁴.

3.1.9 SVE/AI Rebound Tests at BNL--2002-2008

After the shutdown of the SVE/AI system at BNL, SECOR (and later Stantec) conducted five rebound tests for ADEQ to assess whether adsorbed phase VOCs had been left in place in the subsurface or if ongoing vapor releases were occurring at the site from the landfill waste. The rebound tests were conducted on December 17-19, 2002; May 29, 2003; June 17-18, 2004; May 8-12, 2006; and January 22-23, 2008 (Stantec, 2008a). Key findings of the 2008 rebound test are:

- PCE was detected in 59 of 74 soil gas samples. The soil equivalent concentrations did not exceed the most stringent SRL or the GPL. Average PCE concentrations in 2008 were slightly higher (0.9 µg/L versus 0.649 µg/L) than the 2006 rebound test.
- *Cis*-1,2-DCE was detected in 32 of the 74 soil gas samples in 2008. The soil equivalent concentrations did not exceed the most stringent SRL or the GPL. On average, *cis*-1,2-DCE concentrations in soil gas declined from 2006 to 2008.
- TCE was detected in 40 of the 74 soil gas samples during the 2008 rebound test. The soil equivalent concentrations did not exceed the most stringent SRL or the GPL. On average, concentrations of TCE in soil gas declined from 2006 to 2008.
- Methylene chloride was detected in 21 of the 74 samples during the 2008 rebound test. The soil equivalent concentrations did not exceed the most stringent SRL or the GPL. The average concentration of methylene chloride declined from 2006 to 2008.
- VC was detected in 19 of the 74 samples during the 2008 rebound test. The soil equivalent concentrations did not exceed the most stringent SRL or the GPL. The average concentration of VC declined from 2006 to 2008.

¹⁴ Use of soil equivalent concentrations calculated from soil gas data to evaluate compliance with ADEQ's soil rule (A.C.C. Title 18, Chapter 7, Article 2, Soil Remediation Standards") was allowed when the soil rules were revised in 2007.

3.1.10 URS Groundwater Operable Unit Remedial Investigation--2002

URS prepared an RI report for the GOU that covered the period from the mid-1980s through 2000 (URS, 2002). At the time this RI was conducted, the BNL was considered the only source. (The BSL had not yet been incorporated in the GOU of the Site.) Much of the content of the URS RI report was eventually incorporated into the Stantec GOU RI Report (2012b). URS's RI report was, in general, strictly confined to the GOU, and there was no evaluation of potential sources or the fate and transport of contaminants from the vadose zone into the saturated zone.

URS characterized groundwater chemistry in the GOU. They found that the water was predominantly the calcium bicarbonate type. It was demonstrated that carbonate species increased downgradient of the landfill, as did magnesium. The water quality data showed that contaminants from the BNL were impacting the quality of groundwater downgradient of the landfill down to a depth of 373 feet bls, based on samples collected during drilling of WR-353A.

3.1.11 SECOR BNL Soil Sampling--2004

In April 2003, SECOR collected 54 shallow (0-3 inches or 0-6 inches bls) soil samples (including five field duplicates) at the BNL (Figure 12) (SECOR, 2004). The sample locations were selected based on SECOR's observations of "suspected environmental conditions and/or topography." Fourteen of the samples were collected around the perimeter of the dross site. The samples were analyzed for Resource Conservation and Recovery Act (RCRA) metals (barium, cadmium, chromium, lead, silver, arsenic, mercury and selenium), pesticides, poly-chlorinated biphenyls (PCBs), and semi-volatile organic compounds (SVOCs). Analytical results showed that no analyte was detected at or above the Arizona residential SRLs (ADEQ, 2007). A recent review of the data found that there were also no detections above GPLs.

3.1.12 SECOR BNL Shallow Probe Testing—2006

In April-May 2006, SECOR conducted shallow soil gas sampling and testing at the BNL "to (1) determine the presence and degree of vapor phase volatile organic compounds residing near the surface of BNL; and (2) compare current VOC soil gas concentrations to those collected in December 2002 from the same set of shallow gas probes." The data were used by ADEQ to evaluate the exposure pathways of shallow VOC vapor migration to determine risk to individuals

living near the landfill. Sample locations are shown on Figure 13, and a summary of the results is provided in Table 2. SECOR found that most VOCs had lower concentrations compared to the 2002 results, but the maximum PCE concentration had increased (SECOR, 2006a). Based on the 2002 results, ADEQ identified the following VOCs as contaminants of potential concern (COPCs¹⁵) from a health risk standpoint: benzene, chloroform, ethylbenzene, Freon 12, TCE, and VC. Based on the 2006 results, the COPCs were identified as chloroform, PCE, and TCE. (SECOR, 2006a). The data were later used to conduct an assessment of risk to human health, as discussed in Section 3.1.15.

3.1.13 SECOR BSL Investigation—2006

In 2006, SECOR prepared a report titled “Soil Vapor/Groundwater Monitoring Well Installation Activities, April and May 2006.” The report documents the installation and monitoring of two nested soil gas/groundwater monitoring wells (BP-22 and BP-23) and four nested vapor monitoring wells (BSDP-1, BSDP-2, BSDP-3, and BSDP-4). These wells are located within the BSL footprint (Figure 18). Well construction diagrams are provided in Appendix B. Soil gas samples were collected from each of the probes and the groundwater monitoring wells, which are partially screened in the unsaturated zone.

Compounds detected in soil gas included: PCE, TCE, 1,2,4-trimethylbenzene; 4-ethyltoluene; carbon disulfide; chlorobenzene; chloroform; chloromethane; *cis*-1,2-DCE; *cis*-1,3-dichloropropene; cyclohexane; ethanol; ethylbenzene; Freon 11; Freon 114; Freon 12; methylene chloride; n-hexane; naphthalene; toluene; *trans*-1,2-dichloroethene; 1,1-dichloroethane; 1,1-dichloroethene; 1,2-dichloropropane; 1,4-dichlorobenzene; 2-propanol; benzene; *o*-xylene, *m*- & *p*-xylene; and VC. The highest PCE concentration was from the BSDP-3 probe at a depth of 150 feet (SECOR, 2006b). The soil concentration calculated using ADEQ’s conversion methodology (ADEQ, 2011) was below the most stringent SRL for PCE (residential 10-6 risk) and the revised GPL (ADEQ, 1996, revised 2008).

¹⁵ The terminology “Chemicals of Potential Concern” (COPCs) is a risk assessment term. For the purposes of this RI, the more general term COC will be used, except when quoting or paraphrasing from health risk assessment documents.

3.1.14 SECOR BSL Soil Gas Investigation-- 2007

SECOR conducted a second round of soil gas testing at the BSL in October 2006 to evaluate vapor phase VOCs in the vadose zone beneath the BSL. They collected samples from two nested soil gas/groundwater monitoring wells, BP-22 and BP-23, and four nested vapor monitoring wells (BSDP-1, BSDP-2, BSDP-3, and BSDP-4). VOCs detected included benzene; 1,4-dichlorobenzene; 1,2,4-trimethylbenzene; 1,3,5-trimethylbenzene; TCE; and PCE. The highest PCE concentration was 1,200 parts per billion volume (ppbv) or 8.14 µg/L (detected in BSDP-2 from a depth of 100 feet) (SECOR, 2007). This soil gas concentration, when converted to a soil concentration using ADEQ's methodology¹⁶, is equivalent to 0.013 milligram per kilogram (mg/kg). This concentration is an order of magnitude below the most stringent SRL for PCE of 0.51 mg/kg (residential 10-6 risk) and the GPL.

3.1.15 Stantec BNL Human Health Risk Assessment—2010

Stantec prepared a report titled "Human Health Risk Assessment, Broadway North Landfill" dated July 6, 2010. The human HRA used shallow soil gas data collected by SECOR in December 2002 and April-May 2006 (as discussed in Section 3.1.12 of this report) near the western and southwestern perimeter of the BNL (Figure 13) to estimate potential human health risks to residents on properties adjacent to the landfill. Thirty-six analytes that were detected during the 2002 and 2006 sampling events were included as COPCs. The indoor inhalation exposure pathway of COPCs for residents at properties adjacent to the landfill was evaluated. The outdoor inhalation pathway in ambient air was not evaluated because indoor VOC concentrations are always higher than VOC levels in outdoor air, and thus, the indoor inhalation exposure pathway would provide a worst-case scenario. The maximum calculated indoor air concentrations (using the advanced Johnson and Ettinger model and the 2006 soil gas data) were

¹⁶ Use of soil equivalent concentrations calculated from soil gas data to evaluate compliance with ADEQ's soil rule (A.C.C. Title 18, Chapter 7, Article 2, Soil Remediation Standards") was allowed when the soil rules were revised in 2007. Section 6 of ADEQ's Soil Vapor Sampling Guidance (ADEQ, 2011) provides the methodology for calculation of total soil concentrations based on soil gas concentrations. Default values provided in the guidance are conservative so as to be protective of public health and the environment.

below background levels reported in the literature for existing residences and office buildings, except for 4-ethyltoluene, which is a non-carcinogen that does not pose a significant noncarcinogenic health risk. Furthermore, reasonable maximum exposures (RMEs) calculated from the 2006 data were several orders of magnitude below background concentrations reported in the literature. The 2006 RME excess cancer risks were less than the lower end of the acceptable range of 1E-06, indicating no unacceptable health effects to current adjacent residents. It was concluded that, “even if no remediation takes place at the Site, these residents should not incur any unacceptable health risks from exposure to detected VOCs in the shallow soil gas” (Appendix M¹⁷).

Table 2 summarizes maximum soil gas concentrations from 2002 and 2006 that were used by Stantec for the HRA. The maximum concentrations were converted to soil equivalent concentrations for comparison to SRLs and GPLs. There were no analytes that had soil equivalent concentrations exceeding either of these levels.

3.1.16 HydroGeoLogic Site History Report--2012

ADEQ contracted with HydroGeoLogic, Inc. to conduct an investigation of the site history, including the history of landfill ownership and operations, and waste streams (Appendix O) in support of the RI for the GOU. Information regarding the Site history taken from the HGL report is presented in Section 1.4 of this report.

3.2 EARLY RESPONSE ACTIONS AND REMEDIATION

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

- Address current risk to public health, welfare, and the environment;

¹⁷ Further information regarding risks due to vapor intrusion at the west and southwest perimeter of the BNL are explained in the Stantec HRA on pages 24-25 and on tables 10-12.

- Protect or provide a supply of water;
- Address sources of contamination; or
- Control or contain contamination where such actions are expected to reduce the scope or cost of the remedy needed at the site.

There has been one ERA conducted within the LOU that was reviewed and approved by ADEQ; it is discussed in Section 3.2.1 below.

A remedial action conducted at a dross disposal site was not conducted under ADEQ oversight. It is discussed in Section 3.2.2.

ERAs conducted within the GOU are noted in Sections 3.2.3 and 3.2.4 for completeness.

3.2.1 Soil Vapor Extraction at BNL

In 2000, COT and Pima County installed the SVE/AI system at BNL as an ERA. The system was designed to remove soil gas beneath the landfill. It consisted of six soil vapor extraction (SVE) wells (R-70A through R-075A) installed around the perimeter of the BNL, and two air injection (AI) wells (R-068A and R-069B) installed in the center of the northern and southern parts of the BNL. Extracted soil gas was treated using granular activated carbon to remove VOCs prior to discharge.

The SVE/AI system began operating June 26, 2000 and operated until September 10, 2002. At the time the system was shut down, it had removed an estimated 5,329 pounds of total VOCs, including 1,259 pounds of PCE, 274 pounds of TCE, 354 pounds of *cis*-1,2-DCE, 41 pounds of VC, and 2,266 pounds of non-Freon VOCs (Stantec, 2012b).

Since shutdown, six rebound tests, including one in 2013 for this RI, (Section 3.1.9 and Appendix E) have been conducted. These tests do not indicate that there has been appreciable rebound in VOC concentrations in the vadose zone since 2002 when SVE/AI operations were discontinued.

As noted by Stantec (2012b), SVE/AI appears to have resulted in declining VOC concentrations in groundwater in five of six monitoring wells located at and near the downgradient (western) edge of the BNL (Figure 11). From August 2001 to September 2011, PCE concentrations

declined in D-022A (from 120 to 50 µg/L), R-068A (290 to 36 µg/L), R-069B (58 to 1.8 µg/L), WR-273A (71 to 8.7 µg/L), and WR-275A (79 to <1.0 µg/L). The exception is WR-274A, which yielded PCE concentration increases from 57 to 190 µg/L during the same period.

3.2.2 Dross Site Soil Cover

The southernmost waste cell at the BNL is identified as a “construction debris waste site” in the GOU RI (Stantec, 2012b) (Figure 2). In a portion of this cell with an estimated areal extent of one to two acres, buried dross (a waste product related to molten metal) was identified in the mid-1990s. The information below is derived from a report by Aplomado Environmental LLC (2000) titled *Final Broadway Store Re-Location Risk Evaluation of Remedial Alternatives*.

In the mid-1990s, Home Depot, Inc. was considering construction of a new store just to the north of the Broadway Star Plaza. Geraghty and Miller, Inc. conducted a Phase I Environmental Site Investigation for Home Depot in 1997, and Speedie and Associates conducted a Geotechnical Investigation in 1996. Copies of these reports were not available for this RI, but they are referenced in the Aplomado report (2000).

Based on the identification of waste beneath the area where they planned to construct a building, Home Depot wrote a letter to ADEQ identifying possible options for the site. ADEQ responded that they must submit a closure plan for review and approval before they could build. In 1998, McLaren Hart, Inc. submitted a Final Solid Waste Closure Plan on behalf of Home Depot in which they identified elevated levels of cadmium and copper in soil. These concentrations exceed the 2007 residential SRLs. The laboratory reports were not included in this report to document these results (McLaren Hart, 1998). In 2000, a site-specific Sampling and Analysis Plan (SAP) by Aplomado was prepared based on the assumptions and procedures outlined in the closure plan. It was a guidance document for conducting waste determinations before and during waste removal activities at the site, and it included a characterization plan for the dross.

Aplomado found that dross had concentrations of cadmium and lead above the RCRA threshold for hazardous waste. Metals that were detected above the residential and non-residential SRLs (as revised in 2007) were arsenic (in 13 out of 27 samples), and lead (above the residential SRL in 17 out of 27 samples). Cadmium was detected above the residential SRL (in 17 out of 27 samples). Chromium was not speciated, so concentrations cannot be evaluated against SRLs.

Cadmium, chromium and lead exceeded their GPLs. Volatile organic compounds and PCBs were not detected or detected at very low concentrations below SRLs and GPLs. Metals were not detected in soil above SRLs or GPLs in two additional areas, referred to as PADs A and B, on the south side of the Broadway Star Plaza.

Based on these occurrences, four remedial alternatives for the dross area were evaluated by Aplomado:

1. Excavate, load, and transport the materials to an off-site disposal facility;
2. Excavate and treat the materials using soil stabilization, then transport to an offsite disposal facility;
3. Excavate and treat the materials using soil stabilization, then dispose on-site; and,
4. Cap the materials using a geosynthetic clay liner.

A risk evaluation determined that each of the four options offered overall protection for human health and the environment. Capping (alternative 4) was determined to be the most cost-effective and implementable alternative while providing a moderate to high level of long-term and short-term protectiveness.

According to Homer Hansen of Aplomado (Homer Hansen, personal communication, 2013), soil cover (not a geosynthetic clay liner) was placed over the dross on December 16-17, 2000 and a temporary fence was installed by Home Depot on December 19-20, 2000. The soil cover placed was not intended to be a permanent, engineered cap, because Home Depot did not own the property. The cover placed by Home Depot was intended to (1) cover any dross that had been exposed during the investigative field activities (for example, where dross was near the surface, the dross would be exposed where the backhoe would place its pads, etc.), (2) to improve the site conditions by covering any dross that was identified near the surface; and (3) to attempt to minimize the potential for exposure from anyone (transients) that might traverse the area. Mr. Hanson observed that the thickness of the cover varied because the depth of the dross varied significantly, from a few inches to a few feet. Covering of the dross disposal area is not defined herein as an ERA because it was not reviewed by ADEQ.

Home Depot did not construct a store at the property, and it remains undeveloped. A permanent fence with warning signs was installed by ADEQ to further reduce exposure to the public. The

soil cover is inspected periodically by ADEQ and its contractors. Two inspections by Clear Creek in 2013 indicate that burrowing animals are bringing dross material to the surface (Clear Creek, 2013b and 2013c).

3.2.3 Western Containment System

In 2001, the Western Containment System (WCS) was installed in the GOU as an ERA to contain the PCE plume. The system consisted of two extraction wells and two injection wells. The WCS was shut down on October 12, 2012 due to continuing very low influent concentrations of PCE, well below the AWQS. Additional information regarding the WCS is provided in Section 7.4 of the GOU RI Report (Stantec, 2012b).

3.2.4 St. Joseph's Hospital Wellhead Treatment

COT selected, designed, constructed, and funded a wellhead treatment system for the St. Joseph's Hospital well (URS, 2002). COT monitored the system on a monthly schedule during the time that the well was in operation. The well has been out of service since 2009 due to well corrosion and sanding problems. Additional information regarding this ERA is provided in Section 7.2 of the GOU RI (Stantec, 2012b).

3.3 RECENT FIELD INVESTIGATIONS

In February and March 2013, Clear Creek conducted field investigations in support of this RI to achieve a variety of objectives. These investigations are summarized in Sections 3.3.1 through 3.3.5. Reports for these investigations are provided in Appendices C through G. Laboratory reports, data validation reports, and field notes for these investigations are in Appendices H, I, and J, respectively.

The field work for these investigations was conducted according to the RI Work Plan (Clear Creek, 2013a).

3.3.1 Vapor Intrusion Data Collection--BSL

Soil gas samples were collected from existing shallow methane probes at BSL to evaluate vapor intrusion risk. Vapor intrusion risks at BNL were previously evaluated by Stantec (Appendix M),

as discussed in Section 3.1.15. The methodology and results of the BSL data collection are provided in Clear Creek's task-specific report provided in Appendix C.

Twenty-two soil gas samples, including one field duplicate, were collected from the following methane monitoring probes at BSL:

- MW-5 at 14.6 feet bls¹⁸
- MW-6 (depth unknown)
- MW-7 at 18.5 feet bls¹⁸
- MW-8 at 18.5 feet bls¹⁸
- MW-9 at 19.4 feet bls¹⁸
- PRUD-1 (depth unknown)
- PRUD-2 (depth unknown)
- PRUD-3 (depth unknown)
- PRUD-4 at 9.8 feet bls¹⁸
- PRUD-5 at 30.5 feet bls¹⁸
- PRUD-6 at 29.7 feet bls¹⁸
- PRUD-16 at 15 and 25 feet bls
- PRUD-17 at 10 and 25 feet bls
- PRUD-18 at 10 and 25 feet bls
- PRUD-19 at 10 and 25 feet bls
- PRUD-20 at 10 and 25 feet bls

The locations of these probes are shown on Figure 14. Construction information, if known, is provided in Appendix B of this RI report.

Methane concentrations measured in the field during purging ranged from 0.0% to 7.4%. Carbon dioxide concentrations ranged from 0.9% to 15.5%. The highest concentrations of methane and

¹⁸ Depth was measured on May 10, 2013 by Clear Creek and ADEQ. Possible obstructions may have been present, causing inaccurate measurements (Appendix E, Attachment E5).

carbon dioxide, and the lowest concentration of oxygen were measured from the same probe, MW-5, located east of the Broadway Proper retirement community.

PCE was detected in 14 of the 22 methane probe samples at concentrations above the laboratory reporting limits. The highest soil gas PCE concentration was 0.05 milligrams per cubic meter (mg/m^3 or micrograms per liter [$\mu\text{g}/\text{L}$]) in PRUD-16 from a depth of 15 feet bls. Using the conversion methodology in the ADEQ Soil Vapor Sampling Guidance (ADEQ, 2011), the soil equivalent concentration of the highest soil gas PCE concentration is 0.000078 milligrams per kilogram (mg/kg). This soil equivalent concentration is lower than the most stringent SRL of 0.51 mg/kg and the minimum GPL of 0.80 mg/kg .

TCE was detected in one of the 22 methane probe samples at concentrations above the laboratory reporting limits. The detected concentration of soil gas TCE ($0.0024 \text{ mg}/\text{m}^3$ or $\mu\text{g}/\text{L}$) was from methane probe PRUD-19 at a depth of 25 feet bls. The soil equivalent concentration of the detected soil gas TCE concentration is 0.000007 mg/kg . This is below the most stringent SRL of 3.0 mg/kg and minimum GPL of 0.76 mg/kg .

VC was not detected at concentrations above the laboratory reporting limits in the 22 samples collected from the methane probes.

The data were used to evaluate vapor intrusion risks at the Broadway Proper Retirement Community, the YMCA, and Kenyon Terrace (Appendix L). COPCs for soil gas were selected for each exposure area by comparing the maximum concentration of each detected VOC to the screening USEPA “Target Shallow Soil Gas Concentration” (SSGC) protective of residential indoor air (USEPA, 2002a). Any VOC exceeding the SSGC was retained as a COPC in the HRA. COPCs at each exposure area are:

- Broadway Proper Exposure Area: benzene, chloroform, chloromethane, and PCE.
- Kenyon Terrace Exposure Area: chloroform and PCE.
- YMCA Exposure Area: chloroform, PCE, and TCE.

Results of the HRA are summarized in Section 7 of this RI. The HRA report is provided in Appendix L.

3.3.2 Onsite Risk Evaluation Data Collection—BNL and BSL

Soil gas samples were collected from 20 temporary, five-foot deep probes to evaluate onsite health risks at BNL and BSL. Fifteen probes were installed at BNL (Figure 15) and five were installed at BSL (Figure 16) using direct push methods. The methodology and results are provided in a task-specific report in Appendix D.

At BNL, 15 soil gas samples, including one field duplicate, were collected from 14 probes. Oxygen concentrations in the temporary soil gas probes ranged from 14.6% to 21.0%. Methane concentrations ranged from 0.0% to 4.6%. The highest concentration of methane was measured in BNL-2013-11. Carbon dioxide concentrations ranged for 0.5% to 6.0%, with the highest concentration of carbon dioxide in BNL-2013-20. PCE was detected in six of the 15 temporary soil gas probe samples in the BNL at concentrations above the laboratory reporting limits. The highest soil gas PCE concentration was 0.19 mg/m³ in BNL-2013-08. TCE was detected in three of the 15 BNL soil gas probe samples at concentrations above the laboratory reporting limits. The highest TCE concentration was 0.064 mg/m³ in BNL-2013-08. VC was detected in four of the 15 BNL soil gas probe samples at concentrations above the laboratory reporting limits. The highest VC concentration was 0.028 mg/m³ in BNL-2013-14.

At BSL, eight soil gas samples, including three field duplicates, were collected from five probes. Oxygen concentrations in the five shallow temporary soil gas probes ranged from 17.4% to 21.9%. The lowest concentration of oxygen was measured in BSL-2013-01. Methane concentrations ranged from 0.0% to 0.4%. The highest concentration of methane was measured in BSL-2013-03. The carbon dioxide concentrations ranged from 0.1% to 3.4%, with the highest concentration of carbon dioxide in BSL-2013-01. PCE was detected in three samples from two probes at concentrations above the laboratory reporting limits: BSL-2013-04, BSL-2013-05, and the duplicate for BSL-2013-05. The highest soil gas PCE concentration was 0.024 mg/m³ in BSL-2013-04. TCE was not detected in the eight BSL soil gas samples at concentrations above the laboratory reporting limits. VC was detected in two samples from one of the BSL probes—BSL-2013-03 and its duplicate—at a concentration of 0.0066 mg/m³.

The VOC concentrations in soil gas for the BNL and BSL samples were converted to soil equivalent concentrations according to ADEQ guidance (ADEQ, 2011). The soil equivalent concentrations did not exceed the most stringent applicable SRLs or GPLs.

COPCs for soil gas were selected for BNL and BSL by comparing the maximum concentration of each detected VOC to the screening SSGC protective of residential indoor air (USEPA, 2002a). Any VOC exceeding the SSGC was retained as a COPC in the HRA. The following compounds were identified in the HRA (Appendix L) as COPCs at BNL: 1,2,4-trimethylbenzene; 1,2-dichloroethane; 1,3,5-trimethylbenzene; benzene; chloroform; Freon 12; ethylbenzene; PCE; TCE; and VC. The following compounds were identified in the HRA as COPCs at BSL: benzene, ethylbenzene, PCE, and VC. Results of the HRA are summarized in Section 7 of this RI. The HRA report is provided in Appendix L.

3.3.3 Deep Soil Gas Evaluation--BNL and BSL

An investigation of VOCs in the deeper vadose zone (at depths of 50 feet and greater) was conducted to evaluate whether there had been rebound of VOC concentrations at BNL since SVE/AI was discontinued and to evaluate whether the landfill wastes and vadose zone soils are acting as an ongoing source of VOCs to groundwater at BNL and BSL. The methodology and results of the deep soil gas evaluation are provided in a task-specific report in Appendix E.

Soil gas samples were collected from the following deep-nested probes at BNL¹⁹:

- DP-1 vapor monitoring probes at 50, 125, 150, and 193 feet bls

¹⁹ On April 22-23, 2014, at the recommendation of the City of Tucson, ADEQ had Clear Creek Associates measure the total depth of each deep soil gas probe at BNL and BSL. The results of this gauging are as follows: (1) DP-2 and DP-3 have blockages at approximately 6' bls and 20' bls, respectively. This structural damage calls into question the validity of the probe data. Therefore, ADEQ did not use the DP-2 or DP-3 data in drawing conclusions for the Final LOU RI Report and these data have been flagged accordingly in the tables and figures. (2) The measured depths for the DP-1-150' and DP-1-193' soil gas probes were 191.45' bls and 153.95' bls; ADEQ is surmising that the probes were mislabeled from the beginning and ADEQ has revised the LOU RI Report tables and figures accordingly. (3) Excluding the measurements from DP-2 and DP-3, the average deviation from the "nominal" probe depth was approximately $\pm 2'$; therefore, the probe depths listed below, e.g., "50, 125, 150, and 195" should be viewed as approximate. (Appendix E, Attachment E5).

- DP-2 vapor monitoring probes at 50,100, 150, and 195 feet bls
- DP-3 vapor monitoring probes at 50,100, 150, and 190 feet bls
- DP-4 vapor monitoring probes at 50, 100, 150, 200, 250, and 300 feet bls
- DP-5 vapor monitoring probes at 50, 100, 150, 200, 250, and 300 feet bls
- DP-7 vapor monitoring probes at 50, 100, 150, 200, 250, and 300 feet bls
- R-068A injection well with vapor probes at 50, 100, 150, and 200 feet bls
- R-069A injection well with vapor probes at 50, 100, 150, and 200 feet bls
- R-070A extraction well nested probes at 50, 100, and the wellhead screened interval from 158-225 feet bls
- R-071A extraction well nested probes at 50, 100, and the wellhead screened interval from 158-228 feet bls
- R-072A extraction well nested probes at 50, 100, and the wellhead screened interval from 157-227 feet bls
- R-073A extraction well nested probes at 50, 100, and the wellhead screened interval from 158-228 feet bls
- R-074A extraction well nested probes at 50, 100, and the wellhead screened interval from 156-225 feet bls
- R-075A extraction well nested probes at 50, 100, and the wellhead screened interval from 157-225 feet bls
- WR-273A vapor monitoring probes at 50, 130, 220, and 300 feet bls
- WR-274A vapor monitoring probes at 50, 130, 220, and 300 feet bls
- WR-275A vapor monitoring probes at 50, 130, 220, and 300 feet bls

Soil gas samples were collected from the following deep-nested probes at BSL:

- WR-434A monitoring probes at 50, 150, 250 and 350 feet bls
- BP-22 vapor monitoring probes at 200, 250, and 300 feet bls
- BP-23 vapor monitoring probes at 200, 250, 300 feet bls
- BSDP-1 vapor monitoring probes at 100, 150, 200, 250 feet bls
- BSDP-2 vapor monitoring probes at 100, 150, 200, 250, 300 feet bls
- BSDP-3 vapor monitoring probes at 50, 100, 150 feet bls

- BSDP-4 vapor monitoring probes at 50, 100, 150 feet bls

The locations of these probes are shown on Figures 17 and 18. Construction information is provided in Appendix B of this RI report.

Results of the soil gas monitoring at BNL and BSL are provided in Appendix E and plotted on Figures 19 and 20. Soil gas concentrations were converted to soil equivalent concentrations according to ADEQ guidance (2011). Soil equivalent concentrations did not exceed SRLs or GPLs.

Soil gas concentrations at BNL showed no indication of rebounding VOC concentrations in the vadose zone since SVE/AI operations were discontinued in 2002 (Figure 21). Tables of historical soil vapor concentrations and plots of soil vapor concentrations versus time at BNL are provided in Attachment E4 in Appendix E and on Figure 21. The highest PCE concentration detected in soil gas at BNL was 2.2 mg/m³ in WR-273A from a depth of 220 feet bls; this concentration is lower than the 2008 maximum PCE concentration of 15 mg/m³ that was detected from the same probe (Stantec, 2008a).

In general, at a given multi-level probe location at BNL, the highest PCE concentrations were neither shallow (just below the refuse) nor deep (just above the groundwater table). Highest PCE concentrations tended to occupy an intermediate depth in the vadose zone, roughly between 150 and 250 feet bls, as shown on the cross sections (Figures 4-8). It is difficult to draw definitive conclusions, however, about the vertical distribution of VOCs in the vadose zone, because not all of the probes extend to the groundwater table.

Recent VOC concentrations in soil gas from several depths and locations at BSL are higher than those measured during the previous monitoring event in 2006 (Figure 22 and Attachment E4.3 in Appendix E). However, there are fewer historical data at BSL for comparison, and discerning trends is therefore more difficult. Recent PCE and TCE concentrations in soil gas are higher than recent concentrations at BNL, but lower than peak concentrations detected at BNL prior to SVE/AI. This is consistent with Stantec's (2012b) conclusion that the BSL is a lesser source of VOCs to the GOU.

3.3.4 Gollob Park Delineation of Landfill Waste

Four direct push borings were installed at Gollob Park and temporary soil gas probes were installed. These borings were installed to evaluate VOCs in soil gas for HRA and to delineate the extent of landfill waste. The methodology and results of the investigation are provided in a task-specific report in Appendix F.

The borings were designated as GOLLOB-2013-1, GOLLOB-2013-2, GOLLOB-2013-3, and GOLLOB-2013-4 (Figure 23). Waste was encountered in three (GOLLOB-2013-1, GOLLOB-2013-3, and GOLLOB-2013-4) of the four borings. Landfilled material was observed to be 8.5 feet thick in Gollob-2013-1, 1-foot thick in GOLLOB-2013-3, and 8.5 feet thick in GOLLOB-2013-4. No landfilled material was observed in GOLLOB-2013-2, though an oily sand layer less than a 1/2-foot thick was observed. The extent of landfill waste is discussed further in Section 4.3.2 of this RI report. The extent of BSL landfill waste and the thickness of cover are mapped in Figures 24 and 25.

Soil gas samples were collected from the four Gollob Park temporary probes. The probes had different sampling depths. The boreholes were drilled until the borehole was five feet below the bottom of landfill waste or until the drill string could no longer advance (refusal). GOLLOB-2013-1 had a sample depth of 18 feet bls, GOLLOB-2013-2 had a sample depth of 10 feet bls, GOLLOB-2013-3 had a sample depth of 8.7 feet bls, and GOLLOB-2013-4 had a sample depth of 22.5 feet bls.

COPCs for soil gas were selected for by comparing the maximum concentration of each detected VOC to the screening SSGC protective of residential indoor air (USEPA, 2002a). Any VOC exceeding the SSGC was retained as a COPC in the HRA. The COPCs identified for soil gas at Gollob Park were: 1,2-dichloropropane; benzene; chloroform; *cis*-1,2-dichloroethene; Freon 12; ethylbenzene; methylene chloride; PCE; TCE; and VC. Results of the HRA are summarized in Section 7 of this RI. The HRA report is provided in Appendix L.

3.3.5 Shallow Soil Quality Evaluation at BSL

Ten shallow soil samples were collected at BSL on March 4, 2013 to evaluate human health risks of direct exposure to soil (Figure 26). A task-specific report documenting the sample collection is included in Appendix G.

The soil samples were analyzed for total RCRA metals (barium, cadmium, chromium, lead, silver, arsenic, mercury and selenium), pesticides, PCBs and SVOCs.

Pesticides, PCBs, and SVOCs were not detected. Each of the metals, with the exception of selenium, was detected in at least one sample. Because metals concentrations were below the SRLs and GPLs, it was not necessary to evaluate risk of exposure to soil media in the HRA.

4.0 NATURE AND EXTENT OF CONTAMINATION

4.1 CONTAMINANTS OF CONCERN

A contaminant of concern (COC), as defined by R18-16-401, “means a hazardous substance that results from a release and that has been identified by the Department as the subject of remedial action at a site.” COCs are those contaminants that have been detected with some consistency in groundwater or soil at concentrations above regulatory levels or a risk-based level. For the LOU, a contaminant is considered a COC if it meets any one of the following criteria:

1. The contaminant is adversely affecting groundwater quality, or has the potential to adversely affect groundwater quality. A contaminant is considered to be adversely affecting groundwater quality if it is present in groundwater at concentrations exceeding the AWQS. If a contaminant is present in soil at concentrations above its GPL, it is considered to have the potential to adversely affect groundwater quality (and thus it is considered a COC under this criterion.)
2. The contaminant concentrations in soil (or soil gas converted to a soil equivalent) exceed the Arizona SRL.
3. The contaminant is detected in soil or soil gas above the risk-based standard, as determined in the HRA.

These three criteria are discussed in the sections below.

4.1.1 COCs Adversely Affecting Groundwater Quality

Chemicals that adversely affect groundwater quality are COCs in the LOU. A chemical can adversely affect groundwater quality if (1) it is present in soil at concentrations above the GPL, and/or (2) it is detected in groundwater at concentrations above AWQS.

Chemicals known to be (or to have been previously) adversely impacting groundwater are: PCE; TCE; VC; *cis*-1,2-DCE; and methylene chloride (Stantec, 2012b). These chemicals have been detected in groundwater below the LOU at concentrations exceeding their AWQSs. Therefore, these chemicals are considered COCs in the LOU, based on Criterion 1 above. *Cis*-1,2-DCE and methylene chloride have exceeded AWQSs in the past, but they have not exceeded the AWQS

since November 2005. Thus, ADEQ may elect to re-designate these two contaminants (*cis*-1,2-DCE and methylene chloride) as COPCs.

At the dross site, cadmium, chromium, and lead were detected in soil at concentrations greater than their GPLs in dross samples collected (Aplomado, 2000); therefore, even though groundwater analytical data collected over the past decade do not indicate that these metals are adversely affecting groundwater, these three metals are considered COCs under COC Criterion 1 because the potential for impact exists.

4.1.2 COCs Exceeding SRLs

At the dross disposal area (Section 3.2.2), arsenic and lead were detected above the residential and non-residential SRLs (as revised in 2007) in dross. Cadmium was detected at concentrations exceeding the residential SRL. These three metals can thus be considered COCs, based on COC Criterion 2.

Outside of the dross disposal area, no COCs have been identified as a result of its concentration exceeding an SRL. The following lines of evidence indicate that there are no COCs (outside of the dross disposal area) based on this criterion:

- Clear Creek sampled soil gas at BNL and BSL during February and March 2013. Samples were collected from methane monitoring probes (Figures 14), shallow temporary probes (Figures 15, 16, and 23) and deep-nested soil gas monitoring probes (Figures 17 and 18). Analytical results are provided in Appendices C, D, E, and F. Soil gas concentrations were converted to soil equivalent concentrations according to ADEQ's guidance (ADEQ, 2011). No analyte was detected at levels that would result in a soil equivalent concentration at or above the applicable Arizona SRL.
- Ten shallow soil samples were collected from BSL on March 4, 2013 (Figure 26). The report documenting the sample collection and analytical results is provided in Appendix G. The samples were analyzed for eight RCRA metals (barium, cadmium, chromium, lead, selenium, and silver), pesticides, PCBs, and SVOCs. No analyte was detected at levels at or above the Arizona SRLs.

- In April 2004, SECOR collected 54 soil samples, including five duplicate samples, at the BNL (SECOR, 2004), as discussed in Section 3.1.11. No analyte was detected at levels at or above the Arizona SRLs.

4.1.3 COCs Exceeding Risk-Based Standard

The HRAs performed for this LOU identified COPCs but no risk-based COCs. The incremental lifetime cancer risks (ILCRs) for the COPCs for each exposure scenario were below 1E-06 and thus there are no risk-based standard COCs identified in the BSL (or for the BNL onsite). Results of the HRA are discussed in Section 7.

The vapor intrusion/indoor air HRA conducted at BNL by Stantec (Appendix M) did not identify any risk-based COCs, as discussed in Section 3.1.15 of this RI Report.

4.2 POTENTIAL SOURCES

Stantec (2012a) investigated potential sources of VOCs in groundwater through historical records research, interviews, subsurface soil gas data, and through chemical analyses of groundwater quality. The following potential sources were considered:

- Landfilled areas of the BNL,
- Landfilled areas of the BSL,
- Former sand and gravel mining operations along Pantano Wash in the BNL and BSL,
- Commercial operations located within or near the GOU that have documented or possible use and/or releases of materials containing VOCs.

Several lines of evidence indicate that the BNL is a source of contaminants detected in groundwater:

- Wells upgradient of BNL do not contain detectable levels of VOCs (with the one-time exception of WR-181A in 2002).
- Wells beneath and downgradient of the BNL contain VOCs above the AWQSs.
- Highest VOC concentrations have generally occurred in monitoring wells screened beneath and immediately downgradient of the BNL.

- Shallow and deep soil gas sampling have indicated that VOCs were/are present in the vadose zone under the BNL.

Similar lines of evidence indicate that the BSL is a source of contaminants detected in groundwater:

- Wells upgradient of BSL do not contain VOCs above the AWQs. PCE and other COCs in two monitoring wells at the upgradient Prudence Landfill (R-124A and R-125A) have not been detected or were well below the AWQs since these wells were installed (Stantec, 2012b).
- Wells screened beneath and downgradient of the BSL contain VOCs above the AWQs.
- Shallow and deep soil gas sampling have indicated that VOCs were/are present in the vadose zone under the BSL.

HGL (Appendix O) conducted historical records reviews and interviews and obtained information on disposal of “spent solvents” and other chemicals at the BNL and BSL sites. Neither landfill had restrictions on the type of wastes that could be disposed. Private waste haulers (Arizona Transport Agency and Garbage Service Company of Tucson, Arizona, Inc.) collected waste in COT and in Pima County from domestic and commercial customers. The recycler collected spent solvent and other chemicals from the Tucson, Phoenix, southeastern Arizona, and San Diego areas. After filtering the spent solvent, the still bottoms and other residues were disposed of in the BNL and BSL. If the solvents could not be recycled because they were too contaminated, the solvents were put directly into the landfills. The solvent recycler favored the BNL and BSL because they were open to the public and there were no gate fees.

The possibility that contaminants were released from the BNL and BSL site during its use as sand and gravel operations cannot be eliminated. Dumping activities were not restricted to the operational periods of the landfills. Illegal “wildcat” dumping at the BNL and BSL locations during the sand and gravel operations was known to occur, and, in fact, it continued to occur during the landfilling operations and after landfilling ceased. As stated by HGL (Appendix O), “According to a June 25, 2009 amended petition for the perpetuation of testimony of a solvent collector and recycler, waste solvents and other chemicals from industrial, aeronautical,

semiconductor, governmental, retail, educational, and military organizations were disposed of at the ‘Broadway-Pantano Landfills’ before, during and after their operational periods.”

Based on the preceding information, Stantec’s (2012b) conclusions regarding the sources of groundwater contamination at the Broadway-Pantano WQARF site are consistent with groundwater quality and soil gas data. Stantec stated, “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 . . . has demonstrated that VOCs have migrated down to the water table and dissolved into groundwater.”

Based on the discussion above, the BNL and BSL can also be considered the sources of the VOCs in soil gas that have been measured beneath and directly adjacent to the BNL and BSL.

In 2012, ADEQ’s contractor, Stantec, updated and expanded (to include BSL) SECOR’s 2001 Regulatory Agency and Historical Records Review for the Site. This expanded review of facilities which could have used (or are using) tetrachloroethene and trichloroethene was performed so that ADEQ could determine whether existing information justified field investigation of facilities other than the Broadway North and South Landfills as potential contributors to the Site groundwater contamination. ADEQ evaluated the following:

- Environmental and other records of facilities located at and near the Site that potentially could be (or could have been) users of PCE and TCE were reviewed to see if PCE or TCE use and release were documented for those facilities at the indicated locations. If there was a PCE or TCE release at the facility, ADEQ evaluated the available information on the release (e.g., date of spill, volume, physical state, clean-up response, etc.). [Is there enough evidence of a significant PCE or TCE release for one to suspect possible groundwater impact?]
- The locations of these facilities in relation to the Site groundwater contamination and flow direction. [Is the release location within or upgradient of the existing plume (without a “clean” well between the location and the plume?)]

- Groundwater plume anomalies or other groundwater data supporting the existence of another source (Appendix S).

Fifty-nine facilities were reviewed and no justification was found for performing field investigations of any of them. Details of this records review can be found in the referenced report (SECOR, 2001; Appendix P).

4.3 LANDFILL REFUSE

4.3.1 BNL

Appendix B of the GOU RI (Stantec, 2012b) provides an evaluation of the extent of refuse at BNL. The evaluation is based on eight previous studies conducted from 1977 to 2004. Boring and test pit logs from these studies were reviewed, and the thickness of the landfill cover and refuse were plotted on a base map (Figures 27 and 28). In addition, historical aerial photographs from 1953, 1960, 1962, 1964, 1967, 1969, 1971, and 1976 were also reviewed and interpreted. Clear Creek reviewed Stantec's evaluation and found it to be a satisfactory assessment of the extent of waste and cover thickness at BNL. A copy of this evaluation by Stantec is provided in Appendix K of this RI report.

Three separate areas of landfill wastes are present at BNL (Figure 2). The northernmost area is situated north of the 5th Street Alignment; a larger landfill area is situated south of the 5th Street alignment. These areas were used for landfilling municipal waste (Stantec, 2012b). A small area (located south of the two aforementioned areas) to the northeast of Broadway Boulevard and Prudence Rd. was a construction debris landfill; it is in this area where dross was identified by Aplomado (2000) (Figure 2). The dross disposal area is discussed further in Section 3.2.2 of this RI report. Figure 27, based on Stantec's evaluation, shows that the maximum refuse thicknesses at BNL are located in three areas: (1) north of the 5th Street alignment and west of the north-trending TEP electrical transmission line poles (thickness greater than 30 feet); (2) between Pantano Wash and the north-trending electrical transmission line poles (thickness greater than 20 feet); and (3) immediately east of the residences that are located on the east side of Flamenco Drive (thickness greater than 20 feet).

4.3.2 BSL

Studies that have been conducted regarding the extent of refuse at BSL include:

1. Induced Polarization (IP) and Resistivity Survey at Gollob Park, Kenyon Terrace, and Prudence Landfill (Zonge, 2002),
2. Historical Summary Report of the Prudence Landfill/Gollob Park Area by URS (2004),
3. Isopach map prepared by GRC (1984). This map, which predates the permanent wells and soil gas probes that were installed within the landfill, was prepared using geotechnical soil boring data and test pit observations. GRC included isopach contours of the refuse. The text of the report was not available to Clear Creek, but the isopach map was available.
4. Logging of monitoring wells and soil gas wells (SECOR, 2006b).
5. Drilling and installation of 67 belled, end-bearing caissons to a minimum of six feet into dense, undisturbed natural soil to serve as a foundation for the Hilton Hotel in 1985. The caissons reached depths of 24 to 31 feet, indicating that native soil was encountered at no deeper than 18 to 25 feet bls (GRC, 1986). These depths can be interpreted as the maximum depths of refuse under the Hilton Hotel. (The map in the copy of the report available to ADEQ did not show caisson locations.)
6. An interpretation of BSL landfilled areas by Stantec (2008b) based on borings, test pit data, geotechnical investigations, installation of soil gas probes, LFG probes, and groundwater monitoring wells, historical aerial photographs, and the aforementioned report by Zonge.
7. Data collected by Clear Creek from four soil borings at Gollob Park in February 2013 for this RI (Appendix F).

A review of these studies indicates that they are consistent with one another, and the areal extent of waste is well-constrained. The southern extent of the BSL landfill is interpreted to be near the southern boundary of the Gollob Park property. The following lines of evidence support the possibility of isolated waste pockets at Kenyon Terrace, which is located immediately south of Gollob Park:

- Zonge (2002) noted anecdotal information that waste was encountered during digging of the pool at Kenyon Terrace.
- Zonge (2002) identified an IP anomaly in the pool area that could be indicative of deeper waste that was left in place.
- The aerial photograph from 1960 (CDM, 2004) show a deep pit located near the pool anomaly identified by Zonge (2002).
- In 1987, 11 borings were drilled at Kenyon Terrace (GRC, 1987). Landfill refuse was not found, indicating that if landfill refuse is present at Kenyon Terrace, it is present only in isolated pockets. Minor amounts of construction debris were encountered, and measurable levels of methane were encountered in about half of the borings. Methane may have been indicative of nearby landfill refuse.
- In a letter to ADEQ dated January 15, 2004, Tanis A. Duncan, attorney for the Kenyon Terrace Homeowners' Association, reported damage to a wall at Kenyon Terrace due to settling related to the landfill (Duncan, 2004).

Figures 24 and 25 incorporate the sources of information referenced above to delineate the areal extent of refuse at BSL, not including any isolated pockets that might exist at Kenyon Terrace, and the cover thickness. The data sources are cited in the map legend. Most of the data used to compile this map pre-date construction of the Hilton Hotel and the Broadway Proper retirement community, so the data do not reflect the removal of refuse from the Hilton pool and canopy areas (GRC, 1986) and from the Broadway Proper site (Brinsko, 1989) that took place prior to the construction of these facilities. Documentation of the extent to which refuse was removed was not available. The estimated area of landfill material removal from Broadway Proper is shown on Figure 23; this estimation is based on a memo by Brinsko (1989) which says that the retirement community was built on an earth foundation following the removal of landfill material.

The isopach map by GRC (1984) provides information regarding the boundary of the landfilled area. GRC's isopach contour lines within this boundary are not in agreement with boring data generated at a later date, and thus, the isopach contour lines on Figure 24 and 25, which were drawn by Clear Creek, differ from those of the 1984 GRC map. Based on currently-available data, the following conclusions regarding the thicknesses of cover and refuse can be drawn:

- Thicknesses of refuse have been observed as great as 30 feet (as logged in BSDP-3 and BSDP-4), with thinner layers of refuse towards the edges of the landfilled area.
- An average thickness of 20 feet of refuse at BSL is a reasonable estimate, based on refuse thicknesses documented by SECOR (2006b), Stantec (2008b), and Zonge (2002).
- The thickness of cover material ranges from less than a foot at test pits along the perimeter of the landfill (Stantec, 2008b), to approximately 4-5 feet (at Gollob Park) (Zonge, 2002) to 15 feet (at BSDP-1 and BSDP-2). The average thickness of soil cover over the landfill is approximately 5 feet (Figure 25).

4.4 SOIL CONTAMINATION

Direct characterization of soil at the LOU to date has been limited. The extent of soil impacts within and under the landfills has not been directly investigated by collection and analysis of soil samples. Furthermore, the soil gas concentration data (which are used to calculate soil equivalent concentrations) are limited by the number of soil gas probes. Nevertheless, available soil and soil gas analytical data do not indicate the current presence of soil contamination that would serve as an ongoing source for groundwater contamination assuming equilibrium conditions between soil and soil gas. This is based on the three following lines of evidence:

1. Concentrations of metals, SVOCs, pesticides, and PCBs were found to be below SRLs and GPLs in shallow soil samples at BSL (see Appendix G and Section 3.3.5). Similarly, concentrations of metals, SVOCs, pesticides, and PCBs were below SRLs and GPLs in shallow samples at BNL (SECOR, 2004) as discussed in Section 3.1.11.
2. Soil equivalent concentrations from the soil gas concentrations for samples collected at BNL and BSL during February and March 2013 do not exceed SRLs or GPLs.
3. Absence of measurable rebound of VOC concentrations in soil gas from probes below the BNL indicates that sorbed phase VOCs do not appear to be a significant source of vapor phase VOCs at BNL.

Only the first of these lines of evidence is based on direct analysis of soils, and it is limited to shallow soil only. The other lines of evidence are based on soil equivalent concentrations and they assume equilibrium conditions between soil and soil gas. This is discussed further in Section 5.1.

4.5 VOCS IN SOIL GAS

The distribution of VOCs in soil gas cannot consistently be correlated to a single factor such as depth, lithology, location, or physical properties of the COC. Rather, it appears that VOC concentrations in soil gas are affected by many factors, including some that cannot be characterized, such as the location(s) of the release(s), and the possible presence of residual NAPL. Nevertheless, some conclusions can be drawn based on the 2013 soil gas data, including:

- Soil gas samples from deep-nested soil gas probes at BSL had higher concentrations of VOCs than those collected from deep-nested probes at BNL. The highest PCE concentrations at BSL were 18 mg/m³ (BP-23 from 250 feet bls), 12 mg/m³ (BSDP-2 from 250 feet bls) and 8.8 mg/m³ (BSDP-2 from 300 feet bls). These are higher than the highest PCE concentration in soil vapor detected at BNL of 2.2 mg/m³ from WR-273A at 220 feet bls. The highest TCE concentrations were also detected in samples from BSL. The highest TCE concentrations at BSL were 3.6 mg/m³ (Gollob-2013-2 from 18 feet bls) and 2.4 mg/m³ (BSDP-1 from 150 feet bls). These concentrations exceed the highest TCE concentration in soil vapor detected at BNL of 0.75 mg/m³ from DP-7 at 300 feet bls.
- Recent VOC concentrations in soil gas from several depths and locations at BSL are higher than those measured during the previous monitoring event in 2006 (Figure 22 and Attachment E4.3 in Appendix E). PCE concentrations in groundwater have increased in wells BP-22 and BP-23, concurrent with the observed increase in soil gas concentrations. Soil equivalent concentrations were below SRLs and GPLs. However, an ongoing source may be present in the vadose zone at BSL that is not being detected with the current monitoring network.
- VOC concentrations in soil gas at BNL did not show evidence of appreciable rebound since SVE/AI operations stopped in 2002²⁰, suggesting that there currently is no

²⁰At the time the system was shut down, it had removed an estimated 5,329 pounds of total VOCs, including 1,259 pounds of PCE, 274 pounds of TCE, 354 pounds of *cis*-1,2-DCE, 41 pounds of VC, and 2,266 pounds of non-Freon VOCs (Stantec, 2012b).

significant ongoing source of VOCs in the vadose zone below BNL that would adversely affect groundwater quality. This is supported by generally declining VOC concentrations in groundwater below the BNL.

- TCE concentrations were lower than the corresponding PCE concentrations from the same sample at BNL. At BSL, this was usually the case. A notable exception is BSDP-1 where TCE was higher than PCE in both samples (from 200 and 250 feet bls).
- VOC detections were vertically distributed in soil gas from the refuse layer at and near the surface to the deepest levels of the vadose zone that were investigated. It is notable, however, that the non-detect results for PCE were usually, but not always, shallow methane monitoring probes or temporary probes that were installed in or adjacent to the waste layer. This is consistent with the observations of Walter et al (2003), who noted that higher VOC concentrations may occur below the waste, rather than in the waste, due to the expulsion of VOCs from the refuse by LFG generation in the refuse. The same observation is true for TCE.
- PCE concentrations are plotted on the cross sections (Figures 4-8 and Figure 10). The distribution of highest PCE concentrations in soil gas in each borehole generally occurred between 100 feet and 250 feet bls. At BNL, in borings where deep soil gas samples were collected near the water table (WR-273A, WR-274A, WR-275A), the soil gas concentration near the water table was lower than the shallower samples from the same boring.
- In some cases, the highest PCE concentration in soil gas from a given well was from a probe screened at or near a fine-grained layer (R-069B, R-075A, and R-068A). It is possible that PCE is diffusing from the fine-grained layer, resulting in the higher concentration. In other cases, however, the highest concentrations show no correlation with lithology (BP-23, R-073A, and WR-273A).
- The compound detected in soil gas with the most frequency was Freon 12 (dichlorodifluoromethane). This compound was detected in 52 of 59 samples analyzed from the BSL (including duplicates) and in 89 of 91 samples analyzed from the BNL (including duplicates). The maximum concentration detected at BNL was 3.9 mg/m³ (DP-2 from 200 feet bls) and the maximum concentration detected at BSL was 39 mg/m³ (BP-23 from 250 feet bls). As was the case with PCE and TCE, higher concentrations

were detected at BSL. This compound is not considered a COC for groundwater because there is no AWQS²¹.

²¹EPA's regional screening level for soil, (residential, non-cancer exposure) for Freon 12 is 9.4 mg/kg (USEPA, 2013). EPA's risk-based soil screening level for protection of groundwater is 0.30 mg/kg. Soil equivalent concentrations measured at BNL and BSL in 2013 did not exceed either of these screening levels. EPA's regional screening levels are available for review and/or download at: <http://www.epa.gov/region9/superfund/prg/>. EPA Region 9's regional screening level for residential tap water for Freon 12 is 190 µg/L. Freon-12 concentrations in most Site groundwater monitor wells ranges between below detectable levels and approximately 20 µg/L, and the highest level found in Site groundwater was 90 µg/L in 2007 in a monitor well near the BNL (Table 5 in Stantec, 2012b).

5.0 CONTAMINANT FATE AND TRANSPORT

This discussion of the fate and transport of the COCs at the LOU references several key documents including:

1. CDM's 1998 Revised Draft Final Remedial Investigation Report of the Broadway North Landfill, prepared for COT and Pima County;
2. HydroGeoChem's 2001 Draft Development of Remedial Closure Criteria for COT Landfills Undergoing Vadose Zone Remediation;
3. Walter et al, 2003, Vapor Phase Transport as a Groundwater Contamination Process at Arid Landfill Sites; and
4. EPA, 1993, Behavior and Determination of Volatile Organic Compounds in Soil: A Literature Review, USEPA 600/R-93/140.

5.1 PROPERTIES OF THE COCS

5.1.1 VOCs

The degree to which transport processes play a role in the fate and transport of COCs depends on their physical properties. Physical properties of COCs in soil gas (as identified in Section 4.1) are summarized in the table below:

Compound	Vapor Pressure (mm Hg) (Sax, 1968)	Dimensionless Henry's Law Constant (ADEQ, 2011)	Vapor Density (air = 1) (Sax, 1968)	K _{oc} (ADEQ, 2011)
PCE	15.8 @ 22°C	0.74	5.83	155
TCE	100 @ 32°C	0.42	4.53	166
VC	2600 @ 25°C	1.1	2.15	18.6
<i>Cis</i> -1,2-DCE	400 @ 41°C	0.167	3.34	355
Methylene chloride	380 @ 22°C	0.0898	2.93	12

The COCs have high vapor pressures, allowing them to move from the liquid phase to the vapor phase readily. High vapor densities indicate that the vapor phases of the COCs are heavier than air, which has a vapor density of 1. The degree of partitioning of a chemical between the vapor and aqueous phases is determined by the dimensionless Henry's Law Coefficient. This constant

(H_o) is a ratio of the concentration in air to the concentration in water under equilibrium conditions.

Depending on temperature and pressure conditions, COCs can be present in the following phases: (1) non-aqueous phase liquid (NAPL), (2) soil gas (also referred to as soil vapor), (3) aqueous (dissolved in soil moisture in the vadose zone or in groundwater in the saturated zone, and (4) sorbed to soil and organic carbon. NAPL has not been observed in excavations, soil borings, or groundwater monitoring wells at the Broadway-Pantano WQARF site. However, based on the site history, including information provided by customers at the landfills (Appendix O), it is reasonable to infer that it was present at one time and that residual NAPL may still be present in isolated pockets of waste or in containers within the waste. Shallow soil gas studies, including one by CDM for the 1998 RI Investigation, have not provided evidence of NAPL in the refuse.

COCs may change phases based on site conditions. After NAPL volatilizes, the resulting vapor phase may partition into the aqueous phase, or aqueous phase COCs may partition back into soil gas. COC concentrations in gas and aqueous phases are constantly seeking a state of equilibrium²², as governed by Henry's Law. When soil gas concentrations are elevated relative to concentrations in the aqueous phase, COCs will dissolve into the aqueous phase. Conversely, when soil gas concentrations are relatively low compared to concentrations in the aqueous phase (for example in response to SVE operations), COCs will come out of solution from the soil water or from the saturated zone and move into soil gas.

COCs in the vapor or aqueous phases can sorb to soil particles and organic carbon. Rapid sorption of VOCs by wet or moist soils is determined by the organic-carbon partitioning coefficient (K_{oc}) for the compound and from the soil organic carbon content. Higher K_{oc} values correlate to less mobile organic chemicals while lower K_{oc} values correlate to more mobile organic chemicals.

²² Equilibrium between phases will not occur in the presence of an ongoing source.

Equilibrium conditions between the phases are rarely achieved in nature. Therefore, the term “non-equilibrium” is used in the literature to refer to the concept that numerous physical and chemical factors preclude equilibrium in field environments. Non-equilibrium transport can result from secondary soil structures such as fractures or bedding. Slow sorption (also called “non-equilibrium sorption”) is believed to be controlled by diffusion within soil organic matter or by diffusion into soil micropores. With time, the soluble, volatile, and easily desorbed phases (i.e. the equilibrium fraction) dissipate, and the non-equilibrium (i.e. slowly-desorbed) fraction dominates (USEPA, 1993).

A comparison of VOC concentrations in deep soil gas and groundwater at BNL can be used to evaluate whether equilibrium or non-equilibrium conditions exist between the aqueous and vapor phases. These comparisons of aqueous and soil vapor concentrations are limited by the monitoring network. There are no instances at BNL or BSL where recent groundwater data and soil vapor data from depths just above the groundwater table (within 10 feet) are available. Perhaps the best location for comparison is WR-274A where the deepest soil gas probe is about 15 feet above the groundwater table. At WR-274A, soil gas concentrations are three to four orders of magnitude lower than what would be expected based on the groundwater concentration at WR-274A. On December 20, 2012 dissolved concentrations of PCE, TCE, and *cis*-1,2-DCE were detected in groundwater at 122 µg/L, 37.9 µg/L, and 41.7 µg/L, respectively. The soil gas concentrations collected from approximately 15 feet above the groundwater table two months later were 0.006 µg/L (mg/m³), <0.00214 µg/L, and 0.0019 µg/L for PCE, TCE, and *cis*-1,2-DCE respectively. Using dimensionless Henry’s constants of 0.74 for PCE, 0.442 for TCE and 0.167 for *cis*-1,2-DCE, and the December 20, 2012 groundwater concentrations, soil gas concentrations of 90.3 µg/L for PCE, 16.8 µg/L for TCE and 6.7 µg/L, for *cis*-1,2-DCE would be expected in soil gas. In fact, when comparing historic groundwater concentrations with soil gas concentrations at this location since 2000, the result is the same: soil gas concentrations are orders of magnitude lower than what would be expected based on the groundwater concentration approximately 15 feet below the probe.

According to USEPA (1993), “Equilibrium among the phases in the field is not presumed. Measurement of one phase, such as the vapor phase, does not generally provide estimates of the total VOC concentration in the soil. Both errors in measurement and erroneous assumptions of

equilibria contribute to poor predictions.” Though it is difficult to predict the concentration of a contaminant in a given phase based on its concentration in another, it is useful to compare general observations of COCs in each phase across the site. Soil gas concentrations at BNL have remained low since SVE/AI activities were completed in 2002. Over this time period, groundwater concentrations have generally been declining in the area beneath the BNL (WR-274A is the notable exception at BNL and is discussed further in Section 6.2). VOC concentrations in groundwater have increased recently in BSL wells BP-22 and BP-23. Recently measured deep soil gas concentrations from several depths and locations at BSL were higher than those measured during the previous sampling event in 2006. Spatially correlated historical soil gas and groundwater concentrations at BSL are presented in Appendix N. The potential implications of these observations are discussed in section 6.0.

5.1.2 Metals

As discussed in Section 3.2.2, arsenic, and lead were detected in dross above the non-residential SRLs and cadmium was detected above the residential SRL. Cadmium, chromium and lead were detected at concentrations above ADEQ’s minimum GPLs (ADEQ, 1996). Unlike VOCs, metals do not volatilize, nor are they biodegraded (although they can be taken up by plants). Metals may be present in a solid (e.g. as dross or naturally-occurring soil) or aqueous (dissolved in groundwater) phase. Unlike the VOCs of concern, metals occur naturally in soil. Their natural occurrences are usually related to the parent rock from which the sediment (or soil) was derived.

5.2 MIGRATION PATHWAYS

5.2.1 VOC Transport Mechanisms in the LOU

The transport processes that may distribute VOCs include:

1. Aqueous-phase advection in infiltrating soil water (including leachate, if present),
2. Vapor-phase advective transport due to LFG movement and barometric pumping, density driven flow of LFG during the early stages of LFG generation (Walter et al, 2003),
3. Vapor-phase density-driven advective transport due to the vapor density of VOCs (CDM, 1998), and
4. Vapor-phase molecular diffusion (Walter *et al*, 2003).

The first of these transport processes, advective transport of aqueous phase COCs in infiltrating soil water is not considered to be a significant source of COCs to groundwater based on low net infiltration rates and an apparent lack of leachate (Walter et al., 2003, and HydroGeoChem 2001). Lines of evidence that indicate that leachate is not generated in significant amounts include:

- Inorganic leachate indicators (sodium and chloride) in soil samples directly below the landfill and in shallow groundwater are not indicative of significant quantities of leachate (CDM, 1998).
- URS (2002) found little variance regarding groundwater types upgradient and downgradient of the landfill.
- Moisture content analyses do not indicate significant leachate generation. CDM (1998) documented low soil moisture content (from 1.6 to 7.8% from 40 feet to 310 feet bls. If leachate were a significant transport mechanism, near saturated conditions would be expected above the water table, at least periodically. Such conditions have not been observed.
- Soil gas concentrations are not high enough to suggest the presence of NAPL beneath the landfills (HGC, 2001).

The primary mechanism whereby the COCs migrate from the landfilled materials to soil gas is volatilization. The high vapor pressures of the COCs allow them to move readily from the liquid to vapor phase. Once in the vapor phase, the COCs are transported by advection or diffusion. Advection is flow resulting from pressure gradients, while diffusion is flow resulting from concentration gradients. Because the COCs are heavier than air (i.e. they have vapor densities >1) they will move downward through the vadose zone by advective flow. This density-driven transport may be assisted by the generation of LFG (e.g.. methane and carbon dioxide) in the refuse, displacing the COCs, and forcing them downward or by changes in barometric pressure (Walter et al, 2003).

Diffusion is the dominant transport mechanism of COCs into air above the landfill and in vapor intrusion (EPA, 1993). In the vapor phase, volatile chemicals may migrate to indoor and outdoor air via gaseous diffusion and, in the presence of a pressure gradient, via advection.

VOCs are transported into the saturated zone at the capillary fringe, as COCs in soil gas partition into groundwater. This transport mechanism is governed by Henry's Law as discussed in Section 5.1.

5.2.2 Metals Transport Mechanisms in the LOU

At the surface, the transport processes that may distribute non-volatile COCs (metals) include wind erosion and surface water erosion. These transport mechanisms are not significant in the transport of VOCs, which disperse in the vapor phase at the surface.

5.2.3 Biodegradation

In addition to the transport mechanisms discussed above, biodegradation processes play a role in the fate of the VOCs. Reductive dechlorination of PCE, primarily through biotic processes under anaerobic conditions, results in the following transformation:



In groundwater, reductive dechlorination is considered the primary mechanism of biodegradation of PCE. However, the presence of TCE; *cis*-1,2-DCE; and VC in soil gas suggests that the transformation also occurs in the vadose zone. In reductive dechlorination, the chlorinated hydrocarbon acts as an electron acceptor, so there must be an appropriate source of carbon in order for microbial growth to occur. The most rapid rates of PCE biodegradation occur under methanogenic conditions, rather than nitrate- and sulfate-reducing conditions.

CDM (1998) noted isotopic evidence of biodegradation in the vadose zone. Soil gas samples from a depth of 300 feet from MW-1 (now known as WR-273A) and MW-3 (now known as WR-275A) had carbon dioxide with lower delta carbon 13 ($\delta^{13}\text{C}$) values than what would be expected from carbon dioxide derived from arid climate plant respiration and decay²³. CDM postulated that the low $\delta^{13}\text{C}$ values in the vapor samples from these wells "may have been

²³ Stable isotope data are expressed in the conventional "delta" (δ) notation, which is the per mil (‰, parts per thousand) difference in the ratio of the less abundant isotope in a sample relative to the same ratio in a known standard)

derived from biodegradation, which tends to favor production of the lighter isotope (^{12}C),” as described by Hackley *et al* (1996). Further, CDM interpreted that the deep carbon dioxide gas resulting from biodegradation processes was likely in contact with the groundwater table, thereby contributing to the dissolved carbon dioxide and bicarbonate in the groundwater. This is consistent with URS’s (2002) observation of an increase in carbonate species in groundwater downgradient of the landfill.

6.0 CONCEPTUAL SITE MODEL

U.S. Army Corps of Engineers (2003) describes the conceptual site model (CSM) as “a description of a site and its environment that is based on existing knowledge.” It describes sources of the chemicals of concern; actual, potentially complete, or incomplete exposure pathways; current or reasonable proposed use of property; and potential receptors. Development of a CSM is an iterative process in that the CSM evolves over time as more data are collected and interpreted.

The CSM for the Broadway-Pantano LOU is based on previous sections of this report regarding the facility profile (e.g. site history, uses, management in Section 1.4), site characteristics (geology, climate/precipitation data, hydrology, topography in Section 2.0), properties of the volatile COCs and migration pathways (as discussed in Section 5.0), and land use and exposure profiles (see Land Use Study in Appendix A). Based on these data, the CSM, as illustrated in Figure 29 is proposed.

6.1 SOURCES

The BNL and BSL are the sources of VOCs that have been detected in soil gas in the LOU. Wastes containing VOCs were disposed in the BNL and BSL during the years of operation. BSL operated from approximately 1953 to 1962, and BNL operated from approximately 1959 to 1972. Additionally, wildcat dumping before and after the formal years of operation may be another source of VOC contamination at the Broadway-Pantano WQARF site.

6.2 RELEASE PROFILE

Figure 29 shows the CSM during an “active release phase” and the “post-SVE/AI phase”. The active release phase probably began as soon as the COCs were deposited in the landfills. At BNL, this phase appears to have ended with SVE/AI operations. At BSL, the active release phase may be continuing to this day, based on observations of increasing COC concentrations in soil gas and groundwater at some locations within the landfill.

6.2.1 Active Release Phase

During the active release phase, COCs in the waste move readily from liquid to vapor phase due to the high vapor pressures. Once in the vapor phase, COCs are transported within the vadose zone by the following mechanisms:

1. Vapor-phase advective transport due to LFG movement and barometric pumping, density driven flow of LFG during the early stages of LFG generation,
2. Vapor-phase density-driven advective transport due to the vapor density of VOCs, and
3. Vapor-phase molecular diffusion.

Advective transport of aqueous phase COCs in infiltrating soil water (i.e. leachate) is not considered to be a significant transport mechanism at the Site, for the reasons described in Section 5.2.

The vadose zone at the Site is generally sandy, with varying amounts of gravel; this lithology is conducive to vapor advection. During the active release phase, the density-driven advective transport may be assisted by the generation of LFG (methane and carbon dioxide) in the refuse, displacing the COCs and forcing them down through the vadose zone.

Fine-grained lenses of limited extent are present in the vadose zone. COCs diffuse into and sorb to fine-grained material during the active-release phase and can then be slowly released over long periods of time. Thus, fine-grained material may act as a continuing source after concentrations in the surrounding soil have decreased (e.g. following SVE/AI activities). Vapor diffusion is also the dominant transport mechanism of COCs into air above the landfill and in vapor intrusion. In the presence of a pressure gradient, vapor intrusion can also occur via advection.

At the capillary fringe during the active release phase, COCs are transported into the saturated zone, as COCs in soil gas partition into groundwater. This transport mechanism is governed by Henry's Law as discussed in Section 5.1. Theoretically, COCs can partition out of groundwater into soil gas to maintain equilibrium according to Henry's Law. However, it is likely that equilibrium conditions, which rarely occur in nature, are not present between the vapor and dissolved phases at the Site.

The active release phase at BNL appears to have ended with the removal of VOCs from the vadose zone by SVE/AI (with the possible exception of the area upgradient of WR-274A, which is discussed further in Section 6.2.2). Increasing concentrations of VOCs in groundwater at BSL indicate that it is likely still in the active release phase, and VOCs are migrating from the vadose zone to the saturated zone.

6.2.2 Post-SVE/AI Phase

During the post-SVE/AI phase, advective transport and mass transfer across the water table are interpreted to no longer be significant transport mechanisms, as suggested by declining COC concentrations in groundwater (with the exception of WR-274A which is addressed below). Diffusion from fine-grained deposits in the vadose zone may be occurring to a limited degree, based on the very low, but detectable VOC concentrations in soil gas. However the lack of “rebound” of VOCs in the vadose zone at BNL, as demonstrated by six rebound tests in 11 years, indicates that diffusion is offset by natural attenuation processes.

In the post-SVE/AI phase, vapor diffusion continues to be the primary transport mechanism of COCs into air above the landfill and in vapor intrusion. However, because of the lower VOC concentrations in the vadose zone and lower concentration gradients, the mass transfer rates by diffusion are lower than they were during the active release phase.

Water levels beneath the LOU have risen about 14-16 feet since 2007, according to groundwater level data provided in the GOU RI (Stantec, 2012b). As water levels rise, relatively immobile COCs sorbed onto soil particles and organic carbon in isolated fine-grained lenses may become submerged and re-mobilized by diffusing directly into groundwater. This mechanism is a likely explanation for the increasing PCE concentrations observed at WR-274A. A plot of dissolved PCE concentrations in WR-274A in groundwater mimics the groundwater elevation plot, suggesting that increasing PCE concentrations are related to rising groundwater levels in this well (Figure 30). The phenomenon of increasing PCE concentrations with rising groundwater levels is not occurring throughout the LOU. Groundwater quality data (Stantec, 2012b) for wells in the LOU show that as groundwater levels are rising, COC concentrations at most wells are declining. This suggests a source of limited extent, at a location upgradient of WR-274A, for the rising COC concentrations observed in WR-274A.

6.3 EXPOSURE MEDIA

Potential exposure media for the COCs include soil gas, soil, and groundwater. Groundwater was established as an exposure medium in the GOU RI and will not be discussed in this RI. Soil at the BNL was assessed in the Health Risk Assessment by Stantec (Appendix M) and soil at the BSL was later characterized (Section 3.3.5 and Appendix G). Concentrations of metals, SVOCs, PCBs, and pesticides in soil were found to be below SRLs. Therefore soil is not considered an exposure medium. Soil gas is the exposure medium of COCs at the LOU. Exposure to soil gas was assessed in the HRA (Section 7.0 and Appendix L).

Other potential exposure media include landfill waste and dross. Landfill waste is an exposure medium that remains uncharacterized. Exposure to landfill waste may occur whenever landfill cover is removed and waste is exposed at the surface. Due to the high variability of waste and the extent of landfill waste, exposure to this medium is considered unquantifiable.

Dross, which has been shown to contain arsenic, cadmium, chromium, and lead in excess of SRLs and/or GPLs, is present underneath the Broadway Star Plaza and its paved parking lot and in an unpaved, fenced area north of the Broadway Star Plaza (Figures 2 and 27). Cover material was placed over the dross in 2000, as discussed in Section 3.2.2.

6.4 EXPOSURE PATHWAYS

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

- Inhalation of indoor air via vapor intrusion of VOCs in soil gas through diffusion/advection.
- Inhalation of outdoor air via diffusion of soil gas from land surface at or near the landfills.

At BSL, the indoor exposure pathway at the Hilton is considered incomplete because the building's construction on caissons above grade prevents vapors from migrating directly from the soil into the building (Clear Creek Associates, 2013d). ADEQ determined that an evaluation of vapor intrusion at Culver's Restaurant was not necessary because: (1) the existence of a tested methane mitigation system (membrane under the building), (2) the building was not constructed over landfill waste, and (3) ADEQ has issued a no-further-action determination for soil with a Declaration of Environmental Use Restriction with Engineering Controls for this property (Wagenseller, 2013a; Wagenseller, 2013b; ADEQ, 2008).

Potentially complete pathways are the indoor air pathways at the YMCA, Kenyon Terrace, and Broadway Proper. Potentially complete outdoor exposure pathways exist at the BNL and BSL.

Aplomado (2000) identified direct exposure, ingestion, and inhalation as the exposure pathways for dross. These pathways were removed at the Broadway Star Plaza using cover material (i.e. the building and pavement). Soil cover over the remaining dross disposal area was considered to be an effective way to cut off the exposure pathway. However, it appears that burrowing animals are bringing dross to the surface. Although exposure to dross through direct contact, ingestion, and inhalation is likely reduced by the fence, exposure pathways continue to exist for trespassers who enter the fenced dross disposal area.

6.5 RECEPTORS

Receptors, based on the current and future potential uses, are:

- Outdoor trespasser (at BNL and BSL)
- Outdoor worker (Gollob Park)
- Indoor worker (YMCA)
- Resident (Broadway Proper and Kenyon Terrace)

7.0 RISK ASSESSMENT SUMMARY

Health risks associated with the Site are assessed in two separate Health Risk Assessment (HRA) reports: (1) “Human Health Risk Assessment, Broadway North Landfill” prepared by Stantec (Appendix M), and (2) “Health Risk Assessment, Broadway-Pantano WQARF Site, Landfill Operable Unit, Tucson, Arizona” prepared by Copeland & Associates using data generated for this RI (Appendix L).

7.1 VAPOR INTRUSION RISK ASSESSMENT (BNL)

ADEQ performed a conservative risk evaluation of indoor exposure scenarios for the residents adjacent to the BNL. The USEPA “generic value” attenuation factor of 0.03 was used (USEPA, 2012) in conjunction with the maximum measured soil gas concentrations (from the most recent shallow soil gas sampling event in 2006) for each contaminant to evaluate current and future indoor exposure scenarios. This attenuation factor relates the concentration of a chemical in soil gas to potential indoor air concentrations. The predicted indoor air concentrations were compared to the USEPA Region 9 residential Regional Screening Levels (RSLs) for ambient air (USEPA, 2013²⁴). The results of this analysis are provided in Table 3. For BNL, the predicted indoor air concentrations were less than the USEPA Region 9 RSL except the following: chloroform; 1,4-dichlorobenzene; 1,2-dichloropropane; naphthalene; and TCE.

As a more rigorous approach to assessing risk, Stantec used the Advanced Johnson & Ettinger (J&E) Model to evaluate risk of indoor exposure scenarios at the BNL. The Stantec HRA (Appendix M) was conducted to evaluate human health risks to current residents from exposure to VOCs from indoor vapor intrusion near the western and southwestern perimeter of the BNL. The results are presented in Section 3.1.15. The HRA used soil gas data collected by SECOR in 2002 and 2006. The J&E Model was used to estimate indoor air concentrations at the exposure points of interest, making the conservative assumption that the soil gas probes were next to the foundations of adjacent residences with concrete slab on grade. The maximum calculated indoor

²⁴ The “new” RSL table using a target hazard quotient (TQH) = 0.1 was used.

air concentrations using J&E model and the 2006 soil gas data were below background levels reported in the literature for existing residences and office buildings, with the exception of 4-ethyltoluene, which is not a carcinogen and which was determined to not pose any significant health risk. Stantec concluded that there are no potential health concerns associated with vapor intrusion at residences near the western and southwestern perimeter of the BNL. The Broadway Star Plaza is located on top of the southern half of the dross (mixed metal waste-soil)/construction debris site and also approximately 400 feet away from the southeastern tip of the municipal mixed-waste BNL. Shallow soil gas health risk evaluation was not performed for the Broadway Star Plaza, based on the dross analytical data previously obtained by Home Depot. In the latter 1990s, for a planned development, Home Depot performed extensive trenching and testing in the parcel located immediately to the north of the Broadway Star Plaza. The data indicate that landfill and soil samples collected at six lateral locations [at depths ranging from 3 feet bls to 15.5feet bls] contained no detectable VOCs, with the exception of one sample which contained 48 parts per billion of acetone (McLaren Hart, 1998). Home Depot performed additional trenching and dross testing—mainly for metals which were the COCs for the dross—but four of the collected samples were also tested for VOCs. The four samples were non-detect for VOCs, with the exception of one sample which contained TCE at a concentration of 0.180 milligrams per kilogram; this concentration is an order of magnitude lower than the residential SRL of 3.0 milligrams per kilogram and two orders of magnitude lower than the non-residential SRL of 65 milligrams per kilogram (Aplomado, 2000). Given the preceding site conditions, shallow soil gas health risk evaluation was not warranted for the BSP shopping center.

7.2 ONSITE (BNL AND BSL) AND VAPOR INTRUSION (BSL) RISK ASSESSMENT

Indoor exposure scenarios at YMCA, Broadway Proper, and Kenyon Terrace were evaluated using the conservative risk evaluation approach (using the assumed AF of 0.03) described in Section 7.1. The results of this analysis are provided in the table below:

Exposure Scenario (current/future)	Predicted Indoor Air Concentration* µg/m ³	USEPA RSL µg/m ³	Exceeds RSL?
YMCA			
Indoor Worker			
Chloroform	0.44	0.53	No
Tetrachloroethene	1.5	18	No
Trichloroethene	0.072	0.88	No
Broadway Proper			
Indoor Resident			
Benzene	0.52	0.31	Yes
Chloroform	0.78	0.11	Yes
Chloromethane	1.1	9.4	No
Tetrachloroethene	0.93	4.2	No
Kenyon Terrace			
Indoor Resident			
Chloroform	0.15	0.11	Yes
Tetrachloroethene	0.45	4.2	No

*Indoor air concentration is derived by multiplying the maximum concentration of each COPC in soil gas by the AF of 0.03.

The predicted indoor air concentrations are less than the RSL with the exception of benzene and chloroform at Broadway Proper and chloroform at Kenyon Terrace. A more rigorous assessment of risk associated with indoor air exposure was conducted as part of the HRA prepared by Copeland & Associates.

The objective of the HRA prepared by Copeland & Associates was to assess the potential human health risks associated with VOCs detected in soil gas at the BNL (onsite risk only), BSL, and four developed areas within or adjacent to the BSL (Kenyon Terrace, YMCA, Gollob Park, and Broadway Proper). In addition, health risks associated with chemicals detected in shallow soil at the BSL were evaluated. The HRA employed current ADEQ and USEPA guidance.

Based on the CSM, potential exposure to COPCs in soil gas was evaluated for the following HRA exposure areas and receptors:

- BNL (current/future outdoor trespasser)
- BSL (current/future outdoor trespasser)
- Gollob Park (current/future outdoor worker)
- YMCA (current/future indoor worker)

- Broadway Proper retirement community (current/future resident)
- Kenyon Terrace townhomes (current/future resident)

Additionally, human health risks associated with direct contact with chemicals detected in shallow soil was evaluated for the BSL area.

The soil gas and soil data were evaluated and determined to be useable for purposes of the HRA. COPCs for soil gas were selected for each of the six exposure areas by comparing the maximum concentration of each detected VOC to the screening USEPA target SSGC²⁵ protective of residential indoor air (USEPA, 2002a). Any VOC exceeding the SSGC was retained as a COPC in the HRA.

The results of the 2013 soil gas sampling were used in the USEPA outdoor air model (USEPA, 2002b) for the exposure assessment and risk characterization for BNL, BSL and the current outdoor worker at Gollob Park (there are no buildings at the park). The results of the 2013 soil gas sampling were used in the USEPA version of the Johnson & Ettinger (J&E) indoor air model for the exposure assessment and risk characterization for the current/future indoor air scenario for YMCA, Broadway Proper, and Kenyon Terrace. As discussed in the HRA (Appendix L), these models are very conservative and likely overestimate risk.

For the outdoor exposure scenarios, the maximum soil gas concentration for each COPC in the exposure area was used to characterize cumulative risk; therefore only the highest incremental lifetime cancer risk (ILCR) and non-cancer hazard index (HI) are reported for each outdoor exposure area. For the indoor exposure scenarios, ILCR and HI were calculated using the J&E model for each individual soil gas sample location within the exposure area, based on the default assumption that a building could be present over any soil gas sample location. (This means that the modeler conservatively assumed that the measured soil gas concentration would not be reduced by dispersion, biodegradation or adsorption if the soil gas were to migrate through the

²⁵ USEPA's current SSGCs are from 2002 and toxicity values for several chemicals have been updated since then. However, when the SSGCs are adjusted for these new toxicity values, it does not change the COPCs for this site.

soil towards the building.) The cumulative ILCR and HI for each receptor/area are summarized as follows:

Exposure Area	Receptor*	ILCR	HI
BNL	Trespasser	9 E-11	0.001
BSL	Trespasser	2 E-11	0.0004
Gollob Park (current)	Outdoor worker	1 E-08	0.024
YMCA	Indoor worker	2 E-08 to 2 E-07	0.00001 to 0.00008
Broadway Proper	Indoor Resident	4 E-08 to 5 E-07	0.00001 to 0.0016
Kenyon Terrace	Indoor Resident	6 E-09 to 1 E-07	0.0000009 to 0.00003

* Due to the low risks for the indoor air scenario for YMCA, Broadway Proper and Kenyon Terrace, the outdoor air exposure scenario was not quantitatively evaluated.

These ILCRs and HIs are within (or less than) the ADEQ and USEPA target risk range (1 E-06 to 1 E-04 and an HI of 1, respectively) for all scenarios.

USEPA advises that conservatism in the risk estimate be communicated and suggests the following statement be included in the HRA in regard to estimated incremental lifetime cancer risks (USEPA, 1989):

These values are upperbound estimates of excess cancer risk potentially arising from lifetime exposure to the chemical in question. A number of assumptions have been made in the derivation of these values, many of which are likely to overestimate exposure and toxicity. The actual incidence of cancer is likely to be lower than these estimates and may be zero."

7.3 SOIL RISK EVALUATION (BNL AND BSL)

Potential health risks associated with chemicals detected in shallow soil at the BSL were evaluated; no unacceptable health risks associated with shallow soil at BSL were found (Section 3.3.5). An evaluation of soil at BNL (SECOR, 2004) found no unacceptable health risks associated with shallow soil (Section 3.1.11).

7.4 REMEDIAL OBJECTIVES

The Proposed Remedial Objectives (ROs) Report for the LOU was prepared by ADEQ utilizing information from the November 15, 2013 Draft LOU RI Report, the Land Use Study Report and input from stakeholders and interested parties. The Proposed LOU RO Report was made available for public review and comment from March 5, 2014 through April 3, 2014. The RO

Report is in Appendix Q of this Final LOU RI Report. Included as appendices in the RO Report are the following; (1) public input prior to draft LOU RO Report issuance, (2) public comment following proposed RO report issuance, and (3) ADEQ's response to the public input and comments. The ROs for the LOU at the Broadway-Pantano WQARF site are as follows:

LOU Residential— The RO for existing and future residential use of LOU properties is to protect against exposure to contaminants of concern within or released from the LOU waste. This action is needed at the present time and for as long as the landfill and dross wastes remain at the property.

LOU Non-Residential— The RO for existing and future non-residential use of LOU properties is to protect against exposure to contaminants of concern within or released from the LOU waste. This action is needed at the present time and for as long as the landfill and dross wastes remain at the property.

A contaminant of concern (COC), as defined by R18-16-401, “means a hazardous substance that results from a release and that has been identified by the Department as the subject of remedial action at a site.” COCs are those contaminants that have been detected with some consistency in groundwater or soil at concentrations above regulatory levels or a risk-based level (see Section 4.1).

8.0 SUMMARY, DATA GAPS, AND CONCLUSIONS

This LOU RI report summarizes field investigations conducted by ADEQ and other parties to identify and assess contamination at the Site. The RI has identified the contaminants, contaminant sources, fate and transport of contaminants, and associated potential health risks resulting from exposures to soil and soil gas containing the COCs.

- The BNL and BSL are the sources of VOCs that have been detected in soil gas in the LOU. Wastes containing VOCs were disposed in the BNL and BSL during the years of operation. BSL operated from approximately 1953 to 1962, and BNL operated from approximately 1959 to 1972. Wildcat dumping, which occurred at the BNL and BSL locations before and after the landfills were operational, is another possible source.
- No evidence of NAPL has been observed at BNL or BSL. However, the possibility of the presence of residual NAPL in the vadose zone and/or below the water table cannot be eliminated.
- Chemicals known to be (or to have been previously) adversely impacting groundwater are: PCE; TCE; VC; *cis*-1,2-DCE; and methylene chloride (Stantec, 2012b). These chemicals have been detected in groundwater below the LOU at concentrations exceeding their AWQs; therefore, these chemicals are considered COCs in the LOU. *Cis*-1,2-DCE and methylene chloride have exceeded AWQs in the past, but they have not exceeded the AWQs since November 2005. Thus, ADEQ may elect to re-designate these two contaminants (*cis*-1,2-DCE and methylene chloride) as COPCs.
- No VOCs have been identified as COCs as a result of the chemical having a concentration in soil exceeding an SRL or a GPL. Soil equivalent concentrations calculated from soil gas concentrations, according to ADEQ's Soil Vapor Sampling Guidance (ADEQ, 2011), also do not exceed SRLs or GPLs.
- At the dross disposal area, arsenic and lead were detected above the residential and non-residential SRLs (as revised in 2007) in dross. Cadmium was detected at concentrations exceeding the residential SRL. Cadmium, chromium, and lead were detected above the minimum GPLs. Thus these metals are considered COCs. Outside of the dross disposal area, no COCs have been identified as a result of its concentration exceeding an SRL.

- An SVE/AI system operated at BNL from June 26, 2000 to September 10, 2002. The system was installed as an ERA under ADEQ supervision. At the time the system was shut down, it had removed over 2,200 pounds of non-Freon VOCs, including 1,260 pounds of PCE. Six rebound tests, including one conducted from February 19 to March 15, 2013 do not show evidence of rebounding VOC concentrations in the vadose zone. This is consistent with generally declining dissolved VOC concentrations in groundwater at and downgradient of the BNL.
- Recent VOC concentrations in soil gas from several depths and locations at BSL are higher than those measured during the previous monitoring event in 2006. PCE concentrations in groundwater have increased in wells BP-22 and BP-23, concurrent with the observed increase in soil gas concentrations. ADEQ plans to resample the deep nested soil gas monitor wells at BSL as part of the Feasibility Study.
- A CSM that includes an “active release phase” and a “post-SVE/AI phase” is proposed. During the active release phase, volatilization, vapor advection, vapor diffusion, sorption, and biodegradation are the primary fate and transport mechanisms in the vadose zone. COCs move into the saturated zone by mass transfer across the water table according to Henry’s Law. In the post-SVE/AI phase, advective transport and mass transfer across the water table cease to be significant transport mechanisms. Vapor diffusion may be occurring to a limited extent, but it appears to be offset by biodegradation processes. Based on the data collected for this RI, BNL is considered to be in the post-SVE/AI phase, while BSL may still be in the active release phase.
- Evaluating indoor scenarios using an attenuation factor of 0.03 applied to shallow soil gas concentrations indicated that the predicted indoor air concentrations for facilities/residences adjacent to the BSL were less than the USEPA Region 9 RSLs except benzene and chloroform at Broadway Proper and chloroform at Kenyon Terrace. Using this same evaluation method for residences adjacent to BNL with the most recent shallow soil gas data from the BNL (SECOR, 2006A; Stantec, Appendix M), chloroform; 1,4-dichlorobenzene; 1,2-dichloropropane; naphthalene; and TCE had indoor air concentrations exceeding RSLs.
- The results of the 2013 soil gas sampling were used in the indoor air model for the exposure assessment and risk characterization of current/future indoor air scenarios. For

the YMCA, Broadway Proper, and Kenyon Terrace and for the BNL adjacent residences, the ILCRs were equal or less than 1 E-07. The results of the 2006 soil gas sampling were used to evaluate risk for current and future indoor air scenarios for residences on the southwest side of BNL; excess cancer risks were found to be less than 1 E-06. ADEQ plans to perform another round of shallow soil gas sampling of the BSL methane monitoring probes and to re-evaluate, if needed, the shallow soil gas pathway from the BSL landfill waste to adjacent structures.

- This RI relied on soil gas as an indicator of VOC concentrations in soil; however, correlations between soil gas and soil VOC concentrations are affected by site-specific conditions. Equilibrium between vapor, sorbed, and groundwater concentrations cannot be assumed; non-equilibrium conditions are common in field environments. Groundwater quality data are a qualitative indicator of whether VOCs in the vadose zone are migrating into the saturated zone.
- Overall, VOC concentrations in groundwater have been declining at the BNL. WR-274A is a notable exception at BNL. In well WR-274A, PCE concentrations have increased as groundwater levels have increased, suggesting mobilization of sorbed VOCs by groundwater as they become submerged beneath the groundwater table.
- At the BSL, VOC concentrations are increasing in groundwater, suggesting that VOCs in the vadose zone are adversely affecting groundwater quality. It is also possible that rising groundwater levels are remobilizing VOCs sorbed to fine-grained material, similar to the scenario at WR-274A.
- Concentrations of metals in dross disposed at the southern portion of BNL have been found to exceed SRLs and GPLs. Arsenic and lead concentrations exceeded the residential and non-residential SRLs and cadmium exceeded the residential SRLs. Cadmium, chromium and lead exceeded GPLs. The dross was covered with soil and fenced to mitigate the potential for direct contact with the dross material. Recent inspections indicate that burrowing animals are bringing dross material to the surface.

9.0 REFERENCES

- Aplomado Environmental, LLC, 2000. Final Broadway Store Re-Location Risk Evaluation of Remedial Alternatives. Prepared for Home Depot USA, Inc. December 11.
- Arizona Department of Environmental Quality (ADEQ), 1995a. Preliminary Assessment/Site Inspection Report, Broadway North Landfill. June 30, 1995.
- Arizona Department of Environmental Quality (ADEQ), 1995b. Preliminary Assessment/Site Inspection Report, Broadway South Landfill. June 30, 1995.
- Arizona Department of Environmental Quality (ADEQ), 1996, revised 2008. A Screening Method to Determine Soil Concentrations Protective of Groundwater Quality, prepared by the Leachability Working Group of the Cleanup Standards/Policy Task Force. September.
- Arizona Department of Environmental Quality (ADEQ), 2007. Arizona Administrative Code (A.A.C.). Title 18 - Environmental Quality, Chapter 7 -Department of Environmental Quality Remedial Action, Article 2. Soil Remediation. http://www.azsos.gov/public_services/title_18/18-07.htm
- Arizona Department of Environmental Quality, 2008. Letter to Robert Caylor re: No Further Action Determination for Soil with a Declaration of Environmental Use Restriction with Engineering Controls, signed by Jennifer Barr. August 4.
- Arizona Department of Environmental Quality, 2011. Soil Vapor Sampling Guidance. July 10, 2008 (Revised May 19, 2011).
- Arizona Department of Environmental Quality, 2014. Summary of Results from Clear Creek Associates' April 22-23, 2014 Gauging of Broadway North Landfill and Broadway South Landfill Soil Gas Probes/Wells memorandum from Gretchen Wagenseller to the Broadway-Pantano Water Quality Assurance Revolving Fund Site Project File. June 18.
- Brinsko, G., 1989. Memorandum to Charles H. Huckleberry regarding the Broadway Proper Development. March 27.
- CDM, 1998. Revised Draft Final, Remedial Investigation Report, Broadway North Landfill, Tucson, Arizona. March.
- Cella-Barr Associates, 1985. Hydrologic Investigation for Broadway Proper, Revised January 31 and April 2.
- Clear Creek Associates, 2010. Groundwater Flow Model Documentation Report for Use in Conducting Feasibility Study, Broadway-Pantano Water Quality Assurance Revolving Fund Site, Tucson, Arizona, prepared for ADEQ. June 25.
- Clear Creek Associates, 2013a. Remedial Investigation Work Plan, Broadway-Pantano WQARF Site, Landfill Operable Unit. February 1.
- Clear Creek Associates, 2013b. Dross Site Inspection Report. January 25.
- Clear Creek Associates, 2013c. Dross Site Inspection Report. May 2.
- Clear Creek Associates, 2013d. Methane Mitigation System, Hilton Hotel, Broadway South Landfill, Technical Memorandum. May 17.

- Duncan, Tanis, A., 2004. Letter to ADEQ Southern Regional Office. January 15.
- Federal Emergency Management Agency, 2011. FIRM Map for Pima County Arizona, Panels 2302 and 2304 of 4750, Map numbers 04019C2302L and 04019C2304L. June 16, 2011 revisions.
- G.A. Nicholl and Associates, Inc. 1980. Methane Monitoring Investigation – Broadway Landfill Site, prepared for Cienega Limited. December.
- GRC Consultants, Inc., 1984. Soil borings, test pit profiles, and a refuse isopach map showing boring and test pit locations. Full report not available.
- GRC Consultants, Inc. 1986. Progress Report—Geotechnical Services During Construction—Broadway Proper Hilton Hotel, Tucson, Arizona, prepared for Decker Land Developers. January.
- GRC Consultants, Inc., 1987. Preliminary Geotechnical Investigation, Kenyon Terrace, East Side of Prudence Road Between Broadway Boulevard and 22nd Street, Tucson, Arizona. July.
- Hackley, K.C., C.L. Lui, D.D. Coleman, 1996. Environmental isotope characteristics of landfill leachates and gases, *Groundwater*, v. 34, no. 5, pp. 827-836.
- Hanson, Homer, 2013, personal email communications with Gretchen Wagenseller and Alison Jones. May 20 and June 3.
- HydroGeoChem, Inc., 1998. Phase I Field Tests and SVE Field Test Design at the Broadway North Landfill, prepared for City of Tucson Office of Environmental Management. August 17.
- HydroGeoChem, Inc., 2000. Operation and Maintenance Manual—Soil Vapor Extraction and Air Injection System at the Broadway North Landfill Site, prepared for Environmental Management City of Tucson. June 21.
- HydroGeoChem, Inc., 2001. Draft Development of Remedial Closure Criteria for City of Tucson Landfills Undergoing Vadose Zone Remediation, prepared for Environmental Management City of Tucson. December 28.
- Houser, Brenda B., Lisa Peters, Richard P. Esser, et al., 2004. Stratigraphy and Tectonic History of the Tucson Basin, Pima County, Arizona, Based on the Exxon State (32)-1 Well, Report No. 2004-5076, U.S. Geological Survey.
- McLaren Hart, Inc., 1998. Final Solid Waste Closure Plan—Proposed Home Depot Development Project prepared for The Home Depot. March 11.
- Pima Association of Governments (PAG). 1997. Broadway South Landfill Section of the LESP Preliminary Assessment of Fourteen County-Operated Landfills, Pima County, Arizona, Draft Report. February.
- Prior, B., 2013. Email re Tucson Water reduction of pumping of Central Well Field groundwater wells from Bruce Prior of Tucson Water, Planning and Engineering Division, Water Resources Management Section to Gretchen Wagenseller, ADEQ. June 24.

- Richard, Stephen M., Todd C. Shipman, Lizabeth C. Greene, Raymond C. Harris, 2007. Estimated Depth to Bedrock in Arizona, Arizona Geological Survey Digital Geologic Map Series DGM-52, ver. 1.
- Sax, N. Irving, 1968. Dangerous Properties of Industrial Materials, Reinhold Book Corporation, New York, 1251 pp.
- SECOR International Incorporated 2001. Regulatory Agency and Historical Records Review, Broadway-Pantano WQARF Site. March 24.
- SECOR International Incorporated 2004. Summary of Surface Soil Sampling Conducted at the Closed Broadway North Landfill, Broadway-Pantano WQARF Site, Technical Memorandum. October 5.
- SECOR International Incorporated 2005. Vadose Zone Cleanup Evaluation, Closed Broadway North Landfill, Broadway-Pantano WQARF Site, Tucson, Arizona, correspondence to Gretchen Wagenseller, ADEQ Project Manager. October 25.
- SECOR International Incorporated, 2006a. Summary of Shallow Probe Soil Gas Testing Conducted at the Closed Broadway North Landfill, Broadway-Pantano WQARF Site, Tucson, Arizona, prepared for the Arizona Department of Environmental Quality. July 3.
- SECOR International Incorporated, 2006b. Soil Vapor/Groundwater Monitoring Well Installation Activities, April and May 2006, Broadway South Landfill, Tucson, Arizona. prepared for the Arizona Department of Environmental Quality. November 15.
- SECOR International Incorporated, 2007. Summary of Soil Gas Testing Conducted at the Closed Broadway South Landfill, Broadway-Pantano WQARF Site, Tucson, Arizona, prepared for the Arizona Department of Environmental Quality. April 18.
- Stantec, 2008a, Fifth Rebound Test Report, Broadway North Landfill Operable Unit, Soil Vapor Extraction and Air Injection System, Broadway-Pantano Water Quality Assurance Revolving Fund Site, Tucson, Arizona. August 21.
- Stantec, 2008b. Reinterpretation of BSL Landfilled Areas, an email memo to Gretchen A. Wagenseller from Cliff Pollock. October 28.
- Stantec, 2012b. Remedial Investigation Report, Groundwater Operable Unit, Arizona Department of Environmental Quality, Broadway-Pantano Water Quality Assurance Revolving Fund Registry Site, Tucson, Arizona. June 1.
- Tracer Research Corp., 1990. Shallow Soil Gas Investigation, Broadway South Landfill, Tucson, Arizona, prepared for SCS Engineers. September 1990.
- Tracer Research Corp., 2000. Vapor Trace® Shallow Soil Gas Survey, Former Broadway South Landfill, Tucson, Arizona, prepared for Quarles and Brady. March.
- URS, 2002. Remedial Investigation Report – Broadway-Pantano WQARF Site Groundwater Operable Unit for mid 1980s through 2000, prepared for the City of Tucson Environmental Management. June 30.
- URS, 2004. Historical Summary Report, Prudence Landfill/Gollob Park Area, Tucson, Arizona, prepared for the City of Tucson Environmental Services. March 5.

- U.S. Army Corps of Engineers, 2003. Conceptual Site Models for Ordnance and Explosives (OE) and Hazardous, Toxic, and Radioactive Waste (HTRW) Projects, Engineer Manual 1110-1-1200. February 3.
- U.S. Environmental Protection Agency (USEPA), 1988. Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA. October USEPA/540/G-89/004.
- U.S. Environmental Protection Agency (USEPA), 1989. Risk Assessment Guidance for Superfund: Volume I—Human Health Evaluation Manual (Part A). Interim Final. Office of Emergency and Remedial Response, Washington, D.C. USEPA/540/1-89/002. December. <http://www.epa.gov/oswer/riskassessment/ragsa/index.htm>
- U.S. Environmental Protection Agency (USEPA), 1993. Behavior and Determination of Volatile Organic Compounds in Soil, A Literature Review, USEPA Office of Research and Development, USEPA/600/R-93/140, 104 pp.
- U.S. Environmental Protection Agency (USEPA). 2002a. OSWER Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils (Subsurface Vapor Intrusion Guidance). November. USEPA530-D-02-004. <http://www.epa.gov/osw/hazard/correctiveaction/eis/vapor/complete.pdf>
- U.S. Environmental Protection Agency (USEPA), 2002b. Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites. Office of Solid Waste and Emergency Response, December. <http://www.epa.gov/superfund/resources/soil/index.htm>
- U.S. Environmental Protection Agency (USEPA). 2012. EPA's Vapor Intrusion Database: Evaluation and Characterization of Attenuation Factors for Chlorinated Volatile Organic Compounds and Residential Buildings; EPA 530-R-10-002; March 16, 2012; http://www.epa.gov/oswer/vaporintrusion/documents/OSWER_2010_Database_Report_03-16-2012_Final_witherratum_508.pdf
- U.S. Environmental Protection Agency (USEPA). 2013. Regional Screening Levels, Region 9. Downloaded in September 2013 from <http://www.epa.gov/region9/superfund/prg/>.
- U.S. Geological Survey, 2011. Tucson East, Arizona Topographic Quadrangle (scale 1:24,000).
- Wagenseller, Gretchen, 2013a. Email to Alison Jones, Clear Creek Associates, Broadway-Pantano LOU RI Report—documentation of Culver's restaurant methane mitigation system + adjacent Caylor property environmental data—email 1 of 2. August 9.
- Wagenseller, Gretchen, 2013b. Email to Alison Jones, Clear Creek Associates, Broadway-Pantano LOU RI Report—documentation of Culver's restaurant methane mitigation system + adjacent Caylor property environmental data—email 2 of 2. August 9.
- Walter, G.R., A.M. Geddis, R. Murray and H.W. Bentley, 2003. Vapor Phase Transport as a Groundwater Contamination Process at Arid Landfill Sites, Presented at The 18th International Conference on Solid Waste Technology and Management.
- Woodward-Clyde Consultants (WCC), 1985. Geotechnical Engineering Study, Hilton Hotel, Broadway Proper Site, Tucson Arizona. June 13.
- Zonge Engineering & Research Organization, Inc., 2002. IP/Resistivity Survey, Broadway South (Southern Portion) and Prudence Landfills. December 30. Plates 8 and 10—IP Survey

Results at 20 Feet and 30 Feet depths, respectively; and Plate 13—IP Cross sections for Lines 9,20.5, 23, and 29.

FIGURES

TABLES

APPENDIX A

LAND USE STUDY

BROADWAY-PANTANO WQARF SITE, LANDFILL OPERABLE UNIT

TUCSON, ARIZONA

APPENDIX B

**WELL CONSTRUCTION DIAGRAMS AND LITHOLOGIC LOGS
BROADWAY-PANTANO WQARF SITE, LANDFILL OPERABLE UNIT
TUCSON, ARIZONA**

APPENDIX C

**METHANE PROBE MONITORING REPORT, BROADWAY SOUTH LANDFILL
BROADWAY-PANTANO WQARF SITE, LANDFILL OPERABLE UNIT
TUCSON, ARIZONA**

APPENDIX D

**SHALLOW TEMPORARY SOIL GAS PROBE INSTALLATION AND
SAMPLING REPORT, BROADWAY NORTH AND SOUTH LANDFILLS
BROADWAY-PANTANO WQARF SITE, LANDFILL OPERABLE UNIT
TUCSON, ARIZONA**

APPENDIX E

**DEEP-NESTED SOIL GAS PROBE MONITORING REPORT
BROADWAY NORTH AND SOUTH LANDFILLS
BROADWAY-PANTANO WQARF SITE, LANDFILL OPERABLE UNIT
TUCSON, ARIZONA**

APPENDIX F

**GOLLOB PARK TEMPORARY SOIL GAS PROBE INSTALLATION
AND SAMPLING REPORT, BROADWAY SOUTH LANDFILL
BROADWAY-PANTANO WQARF SITE, LANDFILL OPERABLE UNIT
TUCSON, ARIZONA**

APPENDIX G

**SHALLOW SOIL SAMPLING REPORT
BROADWAY SOUTH LANDFILL
BROADWAY-PANTANO WQARF SITE, LANDFILL OPERABLE UNIT
TUCSON, ARIZONA**

APPENDIX H

LABORATORY REPORTS

**BROADWAY-PANTANO WQARF SITE, LANDFILL OPERABLE UNIT
TUCSON, ARIZONA**

APPENDIX I

DATA VALIDATION REPORTS

**BROADWAY-PANTANO WQARF SITE, LANDFILL OPERABLE UNIT
TUCSON, ARIZONA**

APPENDIX J

FIELD NOTES

**BROADWAY-PANTANO WQARF SITE, LANDFILL OPERABLE UNIT
TUCSON, ARIZONA**

APPENDIX K

**VERTICAL AND HORIZONTAL EXTENT OF REFUSE
BROADWAY NORTH LANDFILL
REMEDIAL INVESTIGATION REPORT
GROUNDWATER OPERABLE UNIT (STANTEC 2012)**

APPENDIX L

HEALTH RISK ASSESSMENT

BROADWAY-PANTANO WQARF SITE, LANDFILL OPERABLE UNIT

TUCSON, ARIZONA

APPENDIX M

HUMAN HEALTH RISK ASSESSMENT

BROADWAY NORTH LANDFILL

BROADWAY-PANTANO WATER QUALITY ASSURANCE REVOLVING FUND SITE

JULY 6, 2010

APPENDIX N

**HISTORICAL PCE CONCENTRATIONS IN SOIL GAS AND
GROUNDWATER AT BROADWAY SOUTH LANDFILL, BROADWAY-
PANTANO WQARF SITE, TUCSON, ARIZONA**

APPENDIX O

**REVISED DRAFT FINAL LETTER REPORT—REMEDIAL
INVESTIGATION, BROADWAY-PANTANO WQARF REGISTRY SITE,
DATED APRIL 4, 2012**

APPENDIX P

**POTENTIAL HISTORICAL USERS OF TETRACHLOROETHENE
AND/OR TRICHLOROETHENE, BROADWAY-PANTANO WQARF
SITE, TUCSON, ARIZONA, DATED MAY 1, 2012**

APPENDIX Q

**REMEDIAL OBJECTIVES REPORT—BROADWAY-PANTANO WQARF
SITE—LANDFILL OPERABLE UNIT,
DATED NOVEMBER 15, 2014**

APPENDIX R

RESPONSIVENESS SUMMARIES

APPENDIX S

**PCE/FREON-12 RATIOS IN SELECT GROUNDWATER MONITORING
WELLS AT BROADWAY SOUTH LANDFILL, BROADWAY-PANTANO
WQARF SITE, TUCSON, ARIZONA**