REMEDIAL INVESTIGATION REPORT

7TH STREET AND ARIZONA AVENUE WQARF SITE
TUCSON, ARIZONA

March 21, 2014

Prepared for:

ARIZONA DEPARTMENT OF ENVIRONMENTAL QUALITY
SOUTHERN REGIONAL OFFICE
Superfund Programs Unit
400 West Congress, Suite 433
Tucson, Arizona 85701
(520) 628-6733

Contract EV09-0100AL | Task Assignment ADEQ12-011179

Prepared by:

HYDRO GEO CHEM, INC.
51 West Wetmore Road, Suite 101
Tucson, Arizona 85705-1678
(520) 293-1500

Project Number 2012016.10

HYDRO GEO CHEM, INC.
Environmental Science & Technology

REMEDIAL INVESTIGATION REPORT
7TH STREET AND ARIZONA AVENUE WQARF SITE
TUCSON, ARIZONA

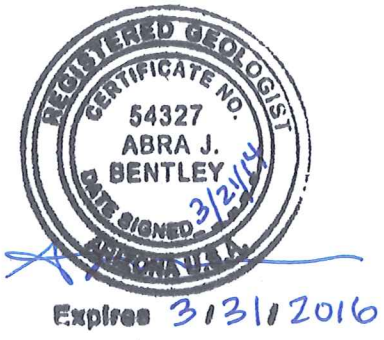
Prepared for:

ARIZONA DEPARTMENT OF ENVIRONMENTAL QUALITY
SOUTHERN REGIONAL OFFICE
Superfund Programs Unit
400 West Congress, Suite 433
Tucson, Arizona 85701
(520) 628-6733

Prepared by:

Michael J. Barden
Senior Hydrogeologist

Prepared and Reviewed by:



Abra J. Bentley, AZ R.G. No. 54327
Project Scientist

March 21, 2014

EXECUTIVE SUMMARY

This Remedial Investigation (RI) report summarizes the results of site characterization activities and Early Response Actions (ERAs) that occurred at the 7th Street and Arizona Avenue Water Quality Assurance Revolving Fund (WQARF) site (Site) from 1992 to present. The purpose of the RI was to investigate the nature and extent of contamination at the Site and evaluate whether the contamination posed unacceptable risks to human health or the environment. The RI addresses impacts to perched groundwater, and concerns over potential impacts to groundwater in the regional aquifer downgradient of the former Oliver's Laundry and Dry Cleaners Co. (Oliver's Cleaners) property. It also addresses impacts to soil and soil vapor at the former Oliver's Cleaners property. The RI Report details site characterization and investigation activities that have taken place at the Site and provides the Remedial Objectives (ROs), Land and Water Use Study, and baseline Human Health Risk Assessment (HHRA).

The RI was conducted pursuant to Arizona Administrative Code (AAC) R18-16-406. Specifically, the RI addresses the following, as required by AAC R18-16-406(A):

- Establishes the nature and extent of the contamination and the sources thereof,
- Identifies the current and potential impacts to public health, welfare, and the environment,
- Identifies current and reasonably foreseeable uses of land and water of the state, and
- Obtains and evaluates any other information necessary for identification and comparison of remedial actions.

The boundary for the 7th Street and Arizona Avenue WQARF site is based on tetrachloroethene (PCE) concentrations in perched groundwater that exceed the Arizona Aquifer Water Quality Standard (AWQS) of 5 micrograms per liter (µg/L). The source of the groundwater contamination was solvent releases from the former Oliver's Cleaners property. PCE has moved downward through the vadose zone and mixed with part of a light non-aqueous phase liquid (LNAPL) body consisting of diesel fuel that extends under the former Oliver's Cleaners property from the Union Pacific Railroad property to the south. The LNAPL body and associated chlorinated ethenes appear to be an ongoing source of contamination to perched groundwater and soil vapor. Residual dense non-aqueous phase liquid (DNAPL), predominantly PCE and trichloroethene (TCE), in the vadose zone likely also contributes to ongoing soil vapor contamination.

The PCE groundwater solute plume extends approximately 4,500 feet northwest from the former Oliver's Cleaners property. The center of mass of PCE in groundwater appears to have shifted downgradient to the northwest from the former Oliver's Cleaners property as evidenced by higher concentrations in this area. The extent of the PCE solute plume in the perched groundwater is reasonably well-defined, although there is uncertainty regarding its extent along the northwest margin due to the large gap between monitoring wells in this area.

The nature and extent of on-site contamination was investigated and evaluated. PCE, TCE, *cis*-1,2-dichloroethene (*cis*-DCE) and *trans*-1,2-dichloroethene (*trans*-DCE) have been detected in shallow soil gas samples beneath the asphalt of the former Oliver's Cleaners property at elevated concentrations. The highest concentrations, in all matrices, were detected at former Oliver's Cleaners property locations (wells 7AZP-2 and 7AZP-4; shallow soil gas investigation points) or directly to the west of the property (well MW-PD-14).

PCE in soil vapor and a TCE concentration above the AWQS in perched groundwater were also detected south of the Site (well MW-PD-6). Additional investigation is necessary to determine if contamination detected in this well is associated with the former Oliver's Cleaners facility.

An ERA conducted at the Site from June 2006 to June 2009, using soil vapor extraction (SVE) successfully removed a portion of the contaminants from the vadose zone. The mass of contaminants in the subsurface cannot be estimated and, based on the most recent evaluation, contamination still exists in LNAPL on the water table and possibly in soils beneath the former Oliver's Cleaners property.

The HHRA evaluated human health risks that result from current use of the Site. The HHRA concluded that Site-related human health risks associated with the perched groundwater solute plume and soil vapor downgradient of the former Oliver's Cleaners property appear to be minimal. However, elevated concentrations of PCE and TCE in shallow soil vapor were detected at the former Oliver's Cleaners property. Based on the concentrations detected, remediation to address soil vapor is warranted at the former Oliver's Cleaners property.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLES

TABLE OF CONTENTS (Continued)

FIGURES

TABLE OF CONTENTS (Continued)

APPENDICES

ACRONYMS

AAC	Arizona Administrative Code
ADEQ	Arizona Department of Environmental Quality
ARAR	Applicable or Relevant and Appropriate Requirement
AWQS	Aquifer Water Quality Standards
bgs	below ground surface
BTEX	benzene, toluene, ethyl-benzene and xylenes
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
COC	Contaminant of Concern
COPC	Chemical of Potential Concern
CSM	Conceptual Site Model
DCE	dichloroethene or dichloroethylene
DNAPL	Dense Nonaqueous Phase Liquid
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
EPA	United States Environmental Protection Agency
ERA	Early Response Action
FS	Feasibility Study
HGC	Hydro Geo Chem, Inc.
HHRA	Human Health Risk Assessment
HI	Hazard Index
HQ	Hazard Quotient
IDW	Investigation-Derived Waste
IRIS	Integrated Risk Information System
LNAPL	Light Nonaqueous Phase Liquid
MCL	Maximum Contaminant Level
MEK	methyl ethyl ketone or 2-butanone
mg/kg	milligrams per kilogram
µg/L	micrograms per liter
MNA	Monitored Natural Attenuation
NAPL	Nonaqueous Phase Liquid
ORP	Oxidation Reduction Potential
OSHA	Occupational Safety and Health Administration
PCE	tetrachloroethene or tetrachloroethylene
PEL	Permissible Exposure Limit
QA/QC	Quality Assurance/Quality Control
RI	Remedial Investigation
RO	Remedial Objective

ACRONYMS (Continued)

RSL	Regional Screening Level
SRL	Soil Remediation Levels
SVE	Soil Vapor Extraction
TCE	trichloroethene or trichloroethylene
TDS	Total Dissolved Solids
TPH	Total Petroleum Hydrocarbons
UPRR	Union Pacific Railroad
UST	Underground Storage Tank
VOC	Volatile Organic Compound
WQARF	Water Quality Assurance Revolving Fund

1. INTRODUCTION

This Remedial Investigation (RI) Report presents the information generated during implementation of the RI for the 7th Street and Arizona Avenue Water Quality Assurance Revolving Fund (WQARF) site (Site) in Tucson, Arizona (Figure 1). The purpose of the RI is to investigate the nature and extent of contamination at the Site and evaluate whether the contamination poses unacceptable risks to human health or the environment. It addresses impacts to perched groundwater and concerns over potential impacts to groundwater in the regional aquifer downgradient of the former Oliver's Cleaners property. It also addresses impacts to soil and soil vapor at the former Oliver's Cleaners property and within the Site boundary. This work is being conducted for Arizona Department of Environmental Quality (ADEQ) under ADEQ Task Assignment 12-011179. The RI was conducted pursuant to AAC R18-16-406. Specifically, this RI addresses the following as required by AAC R18-16-406(A):

1. Establish the nature and extent of the contamination and the sources thereof,
2. Identify the current and potential impacts to public health, welfare, and the environment,
3. Identify current and reasonably foreseeable uses of land and water of the state, and
4. Obtain and evaluate any other information necessary for identification and comparison of remedial actions.

This RI report compiles and integrates available data from previous investigations and work at the Site, in addition to work performed during the RI. It was developed in accordance with the Guidance for Conducting Remedial Investigations/Feasibility Studies under CERCLA (EPA, 1988). The RI report summarizes the following information and data pertaining to the Site:

- Boring logs and well construction diagrams;
- Data tables presenting the analytical results for the groundwater, soil vapor and soil samples, including comparisons to appropriate standards, criteria, and guidance [e.g., Arizona Soil and Groundwater Standards; EPA screening levels for soil vapor (Arizona does not have any soil vapor standards, criteria, or guidance values for concentrations of volatile chemicals in subsurface vapors)];
- Figures presenting concentrations of groundwater contaminants;
- A graphical conceptual model of the Site;
- A narrative that summarizes the results of the remedial investigation, including a discussion of the physical and analytical results;
- A Land and Water Use Study;
- A baseline human health risk assessment (HHRA); and

- Remedial Objectives (ROs).

1.1 Site Description

The former Oliver's Laundry and Dry Cleaners Co. is located at 300 E. 7th Street, Tucson, Arizona 85705 (NE-NW-SE-Sec 12-T14S-R13E, Tucson 7½' topographic quadrangle). The former Oliver's Cleaners property is bounded by 7th Street to the north, Herbert Avenue to the east and 5th Avenue to the west. The property currently consists of an asphalt-paved parking lot. Downtown Auto Center and Towing is located on the parcel to the south. The location of the Site, including the former Oliver's Cleaners property and the surrounding features, are shown on Figure 2.

The approximate Site boundaries are based on the extent of a plume of tetrachloroethene (PCE)-affected perched groundwater underlying the Site (Figure 2). The solute plume begins at the former Oliver's Cleaners property, and extends at least 4,500 feet to the northwest. A large body of light non-aqueous phase liquid (LNAPL) consisting of petroleum hydrocarbons (diesel fuel) floating on the perched water table, reportedly associated with releases from the Union Pacific Railroad (UPRR) Passenger Depot located approximately 1,000 feet to the south of the Site, exists at the southern, upgradient fringe of the PCE solute plume. Two leaking underground storage tank (UST) sites, the former Yellow Cab Company of Tucson and the former Bridgestone-Firestone Service Center facilities, are located northwest of the former Oliver's Cleaners location within the extent of the PCE solute plume.

Soil and perched groundwater have been impacted by volatile organic compounds (VOCs) associated with the former Oliver's Cleaners facility. Concentrations of PCE up to 17 milligrams per kilogram (mg/kg) were detected in soil samples from beneath the facility during the site investigation (Kleinfelder and HGC, 2003). PCE and its breakdown products, trichloroethene (TCE), *cis*-1,2-dichloroethene (*cis*-DCE), and *trans*-1,2-dichloroethene (*trans*-DCE), have been detected in samples from perched groundwater beneath and northwest of the facility.

The existing monitoring well and soil vapor probe network at the Site is shown in Figure 2. Details on monitoring well and vapor probe locations and configurations are summarized in Table 1 and Appendix C.

The main Site contaminants of concern (COCs) in soil vapor and in perched groundwater include PCE, TCE and *cis*-DCE. Other contaminants that have occurred frequently at the Site include *trans*-DCE, chloroform, 2-butanone, benzene, toluene, ethylbenzene, xylenes, 1,2,4-trimethylbenzene and 1,3,5-trimethylbenzene, but concentrations are generally below Aquifer

Water Quality Standards (AWQSs) for constituents with a standard or below levels that would constitute a health concern.

1.2 Site History

A review of the historical information available for the Site has been performed with the results summarized in a report prepared by Kleinfelder, Inc. and HGC titled "*Early Response Action Evaluation Report, 7th Street and Arizona Avenue, Water Quality Assurance Revolving Fund (WQARF) Site, Tucson, Arizona*" (Kleinfelder and HGC, 2003).

A building was constructed at the former Oliver's Cleaners property as early as 1928 and dry cleaning may have been performed since 1935, although this use cannot be currently verified. Dry cleaning was performed continuously on the property from 1957 until the buildings were destroyed by fire in 1989 (ADEQ, 1999). The property is currently a 40,000-square foot (ft^2) paved parking lot measuring approximately 200 feet on a side (Figure 3).

Seven USTs were removed from the property in 1991. These included one 10,000-gallon and four 1,000-gallon solvent tanks and two 500-gallon heating oil or waste oil tanks. Available information indicates that petroleum distillate solvents were used at the former Oliver's Cleaners property (Kleinfelder and HGC, 2003). Locations of the USTs are shown on Figure 4.

The former Oliver's Cleaners water supply well, located on the property (Figure 4), was abandoned on December 29, 1996. The Site was placed on the WQARF Registry in April 2000 with an eligibility and evaluation score of 40 out of a possible 120.

1.3 Summary of Previous Environmental Investigations and Actions

1.3.1 Former Oliver's Cleaners Property

Environmental studies at the former Oliver's Cleaners property were first initiated pursuant to UST regulations. In 1992, Zenitch was contracted by the property owner at that time to collect soil samples in the vicinity of the heating oil USTs (ADEQ, 1999). Total petroleum hydrocarbons (TPH) ranged from 28 to 120 mg/kg in the soil samples; benzene, toluene, ethylbenzene, xylene (BTEX) were not detected. Analysis of groundwater from the former Oliver's Cleaners water supply well, completed within the regional aquifer, detected PCE and TCE at 2.9 and 0.5 micrograms per liter (µg/L), respectively.

In 1997, ADEQ collected 26 soil and soil gas samples at the former Oliver's Cleaners property as part of a Preliminary Assessment/Site Inspection (PA/SI). The purpose of the investigation

was to estimate the extent of PCE contamination in the vadose zone. Ten soil samples were collected from 10 to 13 feet below ground surface (ft bgs), with vapor samples at 8.5 ft bgs, in the vicinity of the 1,000-gallon tanks and the fuel oil tanks. Three soil samples were collected from 14 to 17 ft bgs, with vapor samples at 13.5 ft bgs, in the vicinity of the 10,000-gallon UST. The samples collected along the western property boundary were considered background samples. According to the PA/SI report (ADEQ, 1999), the highest and most significant soil sampling result was found to be near the property's center 1,000-gallon UST. The second highest concentrations were found at the property's southeastern 1,000-gallon USTs. The contaminated area was estimated from the former center 1,000-gallon UST to the former southernmost 1,000-gallon UST, an area including the west end of the 10,000-gallon UST. Furthermore, the PA/SI report concludes that concentrations near the 10,000-gallon UST may be associated with a release from the 1,000-gallon UST.

A site investigation in support of an Early Response Action (ERA) evaluation at the Site was undertaken in 2002 (Kleinfelder and HGC, 2003). This investigation was conducted to define the nature, degree and extent of NAPLs and contaminants in soil, soil vapor and perched groundwater at the Site, and to investigate potential contamination of the regional aquifer.

Environmental investigations have also been conducted at several locations within the vicinity of the Site to evaluate petroleum hydrocarbon contamination associated with leaking underground storage tank (LUST) sites (Basin & Range Hydrogeologists, 1996a, 1996b, 1998, 2000; Woodward-Clyde, 1994; Geraghty & Miller, 1997a, 1997b; ARCADIS, 2000; Environmental Resources Management, 2000). These include the former Yellow Cab Company of Tucson, the former Bridgestone/Firestone Service Center and UPRR Passenger Depot sites. The locations of selected monitoring wells for these sites are shown on Figure 2, with designations of YC, BF and PD, respectively.

1.3.2 Union Pacific Railroad Passenger Depot

Historical releases associated with two fueling facilities at the UPRR Passenger Depot, located south of the Site (Figure 2), have impacted vadose zone soils and perched groundwater (ERM, 2000). The two facilities included fueling platforms, underground storage tanks and a #2 fuel oil pipeline. UPRR sold the southern portion of the property to the City of Tucson (COT) in November 1998 and Amtrak currently uses portions of the main passenger depot building.

Releases from the two facilities at the northwest and southeast ends of the Passenger Depot site have coalesced to form a contiguous body of diesel LNAPL that extends below the former Oliver's Cleaners property. LNAPL thicknesses of up to 8.23 feet are present below the

Passenger Depot property and the LNAPL body extends approximately 3,000 feet northwest to southeast and 2,750 feet northeast to southwest (CH2M-Hill, 2012; ADEQ, 2012).

Remedial actions to remove LNAPL have been ongoing since 1993 under ADEQ's LUST program (ADEQ, 2012). Collection of LNAPL by skimming was performed from 1993 to 1997. A multi-phase extraction system was employed from 1999 through 2011. The equivalent of 212,291 gallons of LNAPL was removed from the Site using liquid phase removal, vapor phase removal and biodegradation. LNAPL saturations are currently low in the area where multi-phase extraction was performed, with consequent low mobility that limits migration potential and product recovery (ADEQ, 2012). ADEQ's LUST program approved a monitored natural attenuation (MNA) remedy for the Site in 2012 and monitoring is ongoing (ADEQ, 2013).

1.3.3 Yellow Cab Company of Tucson

Historical releases of petroleum hydrocarbons, including benzene, toluene, ethylbenzene, xylenes (BTEX) and methyl *tert*-butyl ether (MTBE), associated with a fueling facility at the former Yellow Cab (YC) property, located immediately northwest of the former Oliver's Cleaners property (Figure 2), have impacted vadose zone soils and perched groundwater. A hole was found in a 12,000-gallon gasoline UST upon removal in March 1990 and free product in the excavation was noted, in addition to detection of BTEX in soil samples (Petro Enviro Tech, 1990).

A corrective action plan (CAP) and revised CAP, prepared in accordance with the requirements of a 1995 Consent Decree between ADEQ and YC, were completed in 1998. Several supplemental site investigation activities were performed, per the approved CAP, to 1) investigate whether further regional aquifer characterization was warranted; 2) evaluate whether soil conditions should be considered protective of groundwater quality; and 3) evaluate whether an active groundwater remedial method was warranted based on EPA's criteria of natural attenuation effectiveness. Further regional aquifer characterization was concluded to be unnecessary based on groundwater quality results from a monitoring well completed within the aquitard between the perched groundwater and regional aquifer. Soil concentrations from supplemental soil investigation results were less than proposed alternative Groundwater Protection Levels (GPLs), and therefore concluded to be protective of groundwater quality. The criteria established by EPA for site-specific natural attenuation were evaluated and found to be acceptable for this site, unless free product was discovered. As free product currently exists on the perched groundwater, remedial activities are required (B&R, 2000). VOCs associated with the former Oliver's Cleaners property have also been detected in monitoring wells at the YC property. There are no reports of any significant remedial activities completed at the YC site

prior to involvement by the ADEQ State Lead Unit in 2012. The State Lead Unit completed site characterization activities and installed replacement monitoring wells, as well as ozone sparge remediation wells in 2013. The ozone sparge remediation system was started up in December 2013.

1.3.4 Bridgestone/Firestone Service Center

The former Bridgestone/Firestone Service Center (BFSC), located to the northwest of the former Oliver's Cleaner's property (Figure 2), operated until 1986. Seven USTs of various sizes containing gasoline, fuel oil and/or used oil were removed from the property between 1970 and 1991. LUST files were opened by ADEQ in August 1988 and August 1994 following the discovery of releases associated with 8,000-gallon gasoline and 5,000-gallon gasoline USTs (BB&J, 2001).

Based on benzene data from soil sampling and the demonstrated fact that the BFSC site was not a source of chlorinated compounds, the groundwater contamination observed at the BFSC site was concluded to have resulted from offsite sources. A CAP was approved by ADEQ in June 1997 under condition that the remediation would be considered complete when benzene concentrations in soil within 30 feet of the groundwater table did not exceed the GPL of 0.71 mg/kg. In October 1998, a Soil Vapor Extraction (SVE) system was installed in accordance with the ADEQ-approved CAP. Verification soil sampling was conducted in September 2000 to characterize concentrations of post-remediation benzene remaining in vadose zone soils at the BFSC site. Benzene was detected above the GPL in soils at 40 ft bgs, but not in deeper soils. A passive free product removal apparatus in one of the monitoring wells collected no product after two months (BB&J, 2001).

Based on the soils results and absence of free product, ADEQ was petitioned to close the LUST files associated with the BFSC site in November 2000. ADEQ rejected the petition for closure as benzene concentrations in the soil within 30 feet of the groundwater table exceeded the applicable GPL. A Risk-Based Closure Report was submitted to ADEQ in January 2001 with a Site-Specific Alternative GPL (SSAGPL) of 11 mg/kg. ADEQ was petitioned again to close the LUST files based on the argument that remediation should be considered complete as benzene concentrations were below the SSAGPL within 30 feet of the groundwater table (BB&J, 2001). The LUST files were closed in March 2002, with releases at the BFSC site assumed not to have impacted groundwater quality.

1.4 Narrative Site Description

A groundwater solute plume predominated by the chlorinated VOCs PCE, TCE, *cis*-DCE extends northwest at least 4,500 feet from the former Oliver's Cleaners property in the perched groundwater. The areal extent of the solute plume is relatively well-defined. This solute plume begins on the northeastern fringe of an extensive body of LNAPL (Figure 2) consisting of petroleum hydrocarbons (diesel fuel) thought to be associated with the UPRR Passenger Depot which is located approximately 1,000 feet to the south. The YC and former BFSC LUST sites are located northwest of the dry cleaning facility within the PCE solute plume.

Although there was no documented release of PCE from the former dry cleaning establishment, such a release is apparent due to the widespread presence of PCE in the perched groundwater and soil vapor below the Site. PCE is a widely used dry cleaning solvent and is a dense non-aqueous phase liquid (DNAPL). No DNAPL has been identified from investigative soil borings or monitoring wells, and measured concentrations of PCE do not reflect the presence of a DNAPL in groundwater. A likely scenario is that the released PCE moved downward through the vadose zone as a DNAPL and encountered the LNAPL (diesel fuel) body that extends under the former dry cleaning facility. The PCE dissolved into the LNAPL and this admixture acts as an ongoing source of contamination to perched groundwater and soil vapor. Figure 5 presents a conceptual model of the Site which includes free-product PCE in the vadose zone thought to be contributing to soil vapor contamination, LNAPL at the water table, dissolved contaminants in perched groundwater, and the aquitard preventing contaminant migration into the regional aquifer.

The mobile LNAPL body ranges up to seven feet in apparent thickness in the vicinity of the Site and appears to be in a state of dynamic equilibrium. The LNAPL appears to consist of a somewhat weathered diesel fuel (HGC, 2006c). PCE concentrations in the LNAPL from the area of the Site range from <25 to 440 mg/kg and TCE concentrations range from <25 to 280 mg/kg. The DCE isomers are found at concentrations up to 130 mg/kg in the LNAPL. The LNAPL may be depleted in soluble hydrocarbons, as the extent of the hydrocarbon solute plume substantially mimics the extent of LNAPL and dissolved organic carbon concentrations are low.

Based on the lack of any identifiable source of TCE and DCE in the vicinity of the Site and the presence of petroleum hydrocarbons in the soil and perched groundwater, it is evident that reductive dechlorination of PCE is occurring at the Site. Reductive dechlorination involves the sequential replacement of chlorine atoms with hydrogen on the chlorinated hydrocarbon compound, typically through microbial mediation, producing the well-defined reaction sequence: PCE → TCE → DCE → vinyl chloride (Bradley, 2003). The lack of significant vinyl chloride in groundwater or soil vapor suggests that reductive dechlorination has "stalled" at DCE which

likely reflects the composition of the underlying microbial community and/or a change in downgradient groundwater geochemistry to more oxidized conditions.

Reductive dechlorination appears to be occurring in groundwater immediately associated with the LNAPL where petroleum hydrocarbons are dissolving and being biodegraded based on the presence of the daughter products TCE, *cis*-DCE and *trans*-DCE. However, the groundwater downgradient from the LNAPL is substantially aerobic and there is no evidence for conditions suitable for reductive dechlorination of PCE and TCE to occur in that area.

2. PHYSICAL SETTING

2.1 Geology

The Site is located in the west-central part of the Tucson basin, a relatively large late Cenozoic extensional basin developed in the upper plate of the Catalina detachment fault (Houser et al., 2005). The Tucson basin is a north- to northwest-trending structural depression in the southern Basin and Range Province of southeastern Arizona. The basin fill consists of Tertiary and Quaternary age deposits eroded from the surrounding uplifted fault blocks that attain a thickness of greater than 2,000 feet (Davidson, 1973). Basin-fill sediments unconformably overlie pre-Basin and Range sediments that consist of moderately to highly consolidated deposits that range from clay, silt and claystone to gravel and conglomerate (Anderson et al., 1992). Basin-fill sediments are divided into a lower and upper unit that is in turn overlain by stream alluvium. The lower basin-fill deposits generally are finer grained and more consolidated and deformed than the upper basin-fill deposits (Anderson et al., 1992).

The lower basin-fill deposits of the Tucson basin are comprised of the "Tinaja beds" which unconformably overlie the pre-Basin and Range Pantano Formation (Anderson et al., 1992; Anderson 1987; Davidson, 1973). The upper Tinaja bed is unconformably overlain by the Pleistocene-age Fort Lowell Formation (Anderson, 1987; Davidson, 1973) which constitutes the upper basin-fill deposit (Anderson et al., 1992). The Fort Lowell Formation represents sediments deposited during the transition from a closed basin to a through-flowing drainage basin and consists of weakly consolidated to unconsolidated, light to dark reddish brown silty sand and clayey silt (Anderson, 1987; Davidson, 1973). The Fort Lowell Formation is 300 to 400 feet thick throughout most of the basin (Anderson, 1987; Davidson, 1973).

The soil is highly variable in the subsurface. Soils in the vadose zone, above the perched groundwater, are described as artificial fill to depths of 5 to 10 feet, underlain by sands, silts, and clays. A few coarse gravel lenses at various depths are noted, but the sediments are predominantly fine-grained. A clay layer appears in most lithologic logs at depths ranging from 75 to 85 ft bgs. Geologic cross-sections for locations shown in Figure 6 are provided in Figures 7, 8 and 9.

The strata beneath the Site are predominantly fine-grained sands and silts interbedded with finer grained sediment (silts and clays) to approximately 80 ft bgs. The interbedded material is underlain by a clay aquitard that is approximately 12 to 14 feet thick. The aquitard separates the perched groundwater from underlying unsaturated sediments composed predominantly of well-graded sands to 130 ft bgs. Silty sands were observed to 165 ft bgs, where they become

interbedded with fine-grained material to 195 ft bgs. Lean clays were observed at 200 ft bgs. The regional aquifer becomes saturated at around 170 ft bgs.

2.2 Hydrogeology

The hydrogeologic setting of the Tucson Basin is described in detail elsewhere (Davidson, 1973; Anderson et al., 1992; Mason and Bota, 2006). Only the upper portion of the sediments in the Tucson Basin is relevant to this investigation. The Quaternary Fort Lowell Formation, consisting of unconsolidated clayey silts with interbedded sand and gravel, underlies the Site. In general, the basin sediments are hydraulically connected and form a single aquifer system; however, the Fort Lowell Formation generally has a greater transmissivity because it is generally coarser grained and less consolidated (Davidson, 1973).

The regional aquifer is a primary source of drinking water for Tucson and surrounding areas. Overdraft of the regional aquifer within the upper Santa Cruz sub-basin has resulted in a decrease in groundwater levels of 80 to 100 feet in the vicinity of the Site since the 1920s. The overdraft has resulted in the formation of remnant perched groundwater above low permeability clay layers (Hanson and Benedict, 1994).

Lithologic logs indicate that the perched groundwater is continuous beneath the Site and logs from boreholes 7AZP-2 and 7AZR-1 indicate an aquitard thickness of about 12 feet starting at 85 feet bgs, based on 5-foot sample intervals. Some soil borings south and southwest of the Site indicate that the aquitard is approximately 30 to 40 feet thick and consists of silty to sandy clay (B&R, 1998). Groundwater flow in the perched groundwater is consistently to the northwest and north (Figure 10) and the saturated thickness thins in this direction. Hydraulic gradients range from about 0.003 to 0.006 feet per foot (ft/ft). The response of the perched groundwater during the air sparging pilot test suggests that it may be, locally, under semi-confined conditions (HGC, 2008c).

Groundwater movement within the regional aquifer is generally to the north and northwest (Mason and Bota, 2006). Municipal withdrawals from the City of Tucson's central well field, located in T14S, R14E, had created a large cone of depression in the central part of the Upper Santa Cruz sub-basin under central Tucson in 1999 (Mason and Bota, 2006 – Fig 10), indicating that groundwater flow in the regional aquifer in the vicinity of the Site may have been to the northeast at that time. This is consistent with the evaluation from the ERA report (Kleinfelder and HGC, 2003).

Hydraulic conductivity and storage values for the Fort Lowell Formation vary widely and are dependent on the particle-size distribution and degree of cementation within the unit. Reported hydraulic conductivity values generally range from less than 5 to over 700 feet per day (ft/d), with transmissivity values ranging 1,500 to 40,000 ft^2 per day (Hanson and Benedict, 1994). A nonlinear decrease in mean hydraulic conductivity from 140 to 20 ft/d corresponding to a 40 percent increase in silt and clay for sediments in the Fort Lowell Formation (Anderson et al., 1992) is based on particle size data from well borings. Calibrated hydraulic conductivity values from the vicinity of the Site are on the order of 75 to 125 ft/d (Hanson and Benedict, 1994). Values for specific capacity range from 10 to 100 gallons per min per ft of drawdown and porosity ranges from 26 to 30 percent (Davidson, 1973). Estimates of specific yield range between 0.03 and 0.25 with an average value between 0.12 and 0.15 (Davidson, 1973; Anderson et al., 1992; Hanson and Benedict, 1994).

2.3 Climate

The climate of the area is arid with average annual precipitation for Tucson of 11.6 inches, based on the 1981-2010 climate normals (NCDC, 2011). Precipitation in the region is strongly influenced by the North American monsoon, characterized by a summer rainfall peak occurring from July through early September due to moist tropical air moving from the south or southeast that generates localized convective thunderstorms of high intensity and short duration. Winter precipitation is influenced by cyclonic storms that move from the west or southwest and is more widespread and generally of low intensity and long duration. Interannual variability in winter precipitation is typically related to El Niño-Southern Oscillation (ENSO) events that result from variation in sea-surface temperature of the eastern equatorial Pacific Ocean (Sheppard et al., 2002). Increased temperatures (El Niño) usually result in wet winters and decreased temperatures (La Niña) usually result in dry winters. Additionally, the Pacific Decadal Oscillation (PDO), a temporal variation in sea-surface temperatures for most of the Northern Pacific Ocean, can interact with ENSO. The effects of ENSO and PDO can amplify each other, resulting in increased interannual variability in precipitation over the Southwest (Sheppard et al., 2002).

Between 1981 and 2010, the average annual temperature for Tucson was 69.4 degrees Fahrenheit (°F) with average maximum and minimum temperatures of 83.1°F and 55.8°F, respectively (NCDC, 2011). Monthly average maximum temperatures range from 64.8 to 100.3°F and monthly average minimum temperatures range from 39.1 to 74.4°F (NCDC, 2011). Average annual standardized potential evapotranspiration is 1,732 mm (68.2 inches) (Brown, 2005).

3. REMEDIAL INVESTIGATION ACTIVITIES

The RI was designed to establish the Site characteristics, including the nature and extent of contamination in the various media. This section discusses the groundwater, soil and soil gas investigations and results. The field procedures associated with the investigations are described in Appendix M.

3.1 Groundwater Investigation

HGC has been collecting water level measurements and groundwater samples from Site wells since 2005. HGC conducted groundwater investigation activities in 2013 at the Site to evaluate the current degree and extent of VOC contamination and geochemical conditions in perched groundwater. The following were evaluated during groundwater sampling:

- Static water levels in the perched groundwater to evaluate the direction of groundwater movement and the hydraulic gradient;
- Concentrations and spatial distribution of VOCs in the perched groundwater;
- Concentrations and spatial distribution of geochemical parameters in the perched groundwater;
- The thickness and distribution of the LNAPL associated with the UPRR Passenger Depot;
- Trends in VOC concentrations to identify changes in the plume;
- Static water levels in the regional aquifer to evaluate the direction of groundwater movement and hydraulic gradient; and
- Water quality of the regional aquifer.

The RI/FS Work Plan (HGC, 2013) contains the field procedures and methods that were followed during implementation of the groundwater field investigation. These are also summarized in Appendix M.

3.1.1 Monitoring Wells

The locations of all wells that have been used for monitoring groundwater at the Site are shown in Figure 11. Four groundwater monitoring wells with associated vapor probe nests (7AZP-1 through 7AZP-4) were installed in the perched groundwater and an additional groundwater monitoring well (7AZR-1) was installed in the regional aquifer in 2002. Three monitoring wells (7AZP-5, 7AZP-6, 7AZP-7) were installed in the perched groundwater in February and March 2007 to evaluate the lateral extent of the solute plume (HGC, 2007a). Additionally, monitoring

well 7AZR-2, with one associated vapor probe in the vadose zone below the perched groundwater, was installed to evaluate potential contamination of the regional aquifer (HGC, 2007a). Two monitoring wells (7AZP-9, 7AZP-10) were installed in the perched groundwater in November 2007 to further define the downgradient and lateral extent of the solute plume (HGC, 2008b). Two additional perched groundwater monitoring wells (7AZP-11, 7AZP-12) and one additional regional aquifer well (7AZR-3) were installed in October and November 2012. The perched groundwater wells were intended to further delineate the downgradient extent of the solute plume in the perched groundwater. Well construction diagrams are provided in Appendix C. The remaining wells indicated on Figure 11 were installed as part of site investigation activities related to the UPRR Passenger Depot, Bridgestone/Firestone and Yellow Cab sites and have the designations PD, BF and YC, respectively. Table 1 contains a summary of well completion details for all wells associated with the Site.

Three of the Site monitoring wells in perched groundwater (MW-PD-2, MW-PD-14 and MW-PD-17), one regional aquifer monitor well (MW-PD-19), and one nested soil vapor well (7AZP-8), were abandoned by COT during a large drainage improvement and streetcar rail project at the end of 2011. Another perched well (MW-PD-16) was abandoned during COT/Pima County courthouse construction activities in late 2011, and well 7AZP-7 became obstructed and likely destroyed during University of Arizona off-campus housing development activities.

3.1.2 Groundwater Monitoring

The entire network of monitoring wells, some no longer existing, from which data have been collected at the Site is presented in Figure 11. Monitoring wells from other nearby sites have been included as part of the Site groundwater monitoring. These include the Yellow Cab, Bridgestone/Firestone and UPRR passenger depot sites.

Groundwater samples were collected from 12 monitoring wells from March 18 to March 21, 2013. The wells were selected as a subset of the full groundwater monitoring network in order to obtain representative samples to characterize geochemical conditions across the solute plume. In the absence of an upgradient well reflecting background water quality and based on historical measurements, samples from MW-PD-5 and 7AZP-10 were collected to represent background conditions for various parameters. Geochemical parameter sampling was performed in accordance with Appendix A.2 of the RI/FS Work Plan.

3.1.3 Groundwater Investigation Results

Results for groundwater monitoring events are detailed in groundwater monitoring reports (HGC, 2004a, 2004b, 2005a, 2005b, 2006c, 2006d, 2007b, 2008a, 2008d, 2012b, 2012c). Results for subsequent monitoring events in 2012 through 2013 are presented herein.

3.1.3.1 Fluid Level Results

Historical water elevation and LNAPL thickness data for wells associated with the Site are summarized in Table 2. The apparent LNAPL thickness in the well, groundwater elevation, and corrected groundwater elevation for those wells containing LNAPL are included; groundwater elevation corrections were based on the average specific gravity of 0.87 from previous LNAPL samples. Appendix H presents LNAPL thickness with water elevation hydrographs for all groundwater monitoring wells at the Site. LNAPL has appeared in monitoring wells 7AZP-2, 7AZP-3, 7AZP-4, MW-PD-2, MW-PD-4, MW-PD-6, MW-PD-7, MW-PD-12, MW-PD-14, MW-PD-15, MW-PD-16, YC-5 and YC-6 since 2002. LNAPL has been present in most of these wells since it was initially measured, except in wells 7AZP-3, 7AZP-4, MW-PD-7, MW-PD-14 and YC-5, where it appeared in May 2012, February 2005, February 2005, May 2007 and April 2007, respectively. LNAPL thickness has continued to increase from 2002 through 2013 at MW-PD-12, where the source is believed to have originated, but has not increased substantially in other wells across the Site.

Depth to perched groundwater in March 2013 ranged from approximately 59 to 84 ft bgs. Depth to water for the regional aquifer in March 2013 ranged from approximately 171 to 177 ft bgs.

Fluid level measurements are used to evaluate changes in groundwater direction and gradient in the perched groundwater. Groundwater elevation contours based on March 2013 water levels are presented in Figure 10. Figure 12 provides LNAPL thickness contours for the perched groundwater in the study area based on data collected during this monitoring event. The gradient in the perched groundwater between MW-PD-4 and MW-PD-30, which appears to approximate the contaminant flow path through the Site, is 0.0028 ft/ft to the northwest, shifting to 0.0064 ft/ft to the north-northwest from MW-PD-30 to 7AZP-11. The lack of groundwater in well 7AZP-12 indicated that the perched groundwater "pinches out" to the south of this location, limiting the extent of the solute plume in perched groundwater to the north.

3.1.3.2 Perched Groundwater Sampling Results

Historical data from sampling of the monitoring wells in perched groundwater are provided in Table 3 and stable purge parameters are summarized in Table 4. Concentration time series

prepared for selected monitoring wells in the perched groundwater that contain reported concentrations of VOCs showing trends in concentrations of PCE, TCE, *cis*-DCE, and *trans*-DCE are included as Appendix K. A concentration time series is not included for wells that were non-detect or nearly non-detect in these VOCs over time, or if there were an insufficient number of data points.

The May 2012 groundwater sampling results for the monitoring wells in perched groundwater were consistent with results for previous groundwater monitoring at the Site. Concentrations of PCE and TCE generally increased over 2008 levels in wells at the former Oliver's Cleaners property, while VOC concentrations in the central and proximal portions of the plume decreased. Concentrations of 1,2-DCE increased in well MW-PD-15, suggesting microbial degradation of TCE upgradient of that location.

Appendix D presents the groundwater sampling field forms for the May 2013 sampling event. Water quality indicator parameters collected during purging are included in Table 4. Table 3 includes the VOC analytical results for groundwater samples and field duplicates for the May 2013 sampling event. Groundwater sampling results allow for the evaluation of concentration and spatial distribution of VOCs in the perched groundwater, and trends in VOC concentrations to identify changes in the plume. Figures 13, 14, 15, and 16 show concentration distributions for PCE, TCE, *cis*-DCE and *trans*-DCE, respectively, in groundwater for the May 2013 sampling event. PCE concentrations in groundwater ranged from <0.5 µg/L to 39 µg/L, with the highest concentration occurring in well MW-PD-30. TCE concentrations in groundwater ranged from <0.5 µg/L to 12 µg/L, with the highest concentration occurring in well 7AZP-2. *Cis*-DCE and *trans*-DCE were detected at concentrations up to 16 and 2.1 µg/L, both in well BF-1. Chlorinated organic solute concentrations did not change significantly in the sampled wells since the May 2012 sampling event, although only a subset of monitoring wells was sampled in May 2013.

Table 5 summarizes the geochemical parameter results for groundwater samples for the March 2013 sampling event. Figures 17 through 26 provide posted purge parameter and geochemical parameter results.

Groundwater analytical reports for the November 2012 and March 2013 sampling events are provided as Appendix F.

3.1.3.3 Regional Groundwater Sampling Results

Historical data from sampling of the regional aquifer wells are included in Table 3. During the First Quarter 2002 and Second Quarter 2002 monitoring events, no detections were reported for

the groundwater from regional aquifer monitoring well MW-PD-19. PCE and TCE were reported at 3.5 and 2.1 µg/l, respectively, in regional well 7AZR-1 during June 2002. However, the results of a sampling event conducted on October 8, 2002 reported PCE and TCE concentrations at less than laboratory reporting limits in well 7AZR-1. Subsequent samples from 7AZR-1 and samples from 7AZR-2 and 7AZR-3 did not have detections of PCE or TCE above reporting limits. Acetone, 2-Butanone or methyl ethyl ketone (MEK), methylene chloride, and benzene have been detected sporadically at low concentrations in one or more of the wells since 2002. These constituents have occurred at concentrations less than the relevant AWQS or U.S. EPA Regional Screening Level (RSL) for tap water (EPA, 2012).

No chlorinated VOC concentrations were detected in samples from regional aquifer wells 7AZR-1 and 7AZR-2 for the most recent sampling in May 2012. Detectable concentrations of acetone (30 µg/L maximum) and 2-butanone (22 µg/L) were reported in these wells; however, neither compound was reported in any perched groundwater well nor were these compounds reported in previous sampling events, suggesting that the presence of these constituents in the regional aquifer was not related to the Site. Regional aquifer monitoring well MW-PD-19 had been abandoned by the COT prior to this event and was therefore not sampled.

3.1.4 LNAPL Sampling Results

A compilation of VOCs detected in LNAPL samples from select monitoring wells (seven in total) between March 2002 and November 2012 is provided in Table 6. The most frequently occurring VOCs are the trimethylbenzene isomers, naphthalene, propylbenzenes, butylbenzenes, 4-isopropyltoluene, and BTEX at concentrations ranging from a few tens to about 1,000 mg/kg. PCE is commonly reported at concentrations ranging from 2 to 1,100 mg/kg, as is TCE at concentrations ranging from 0.5 to 970 mg/kg. The DCE isomers are also present in several samples at concentrations up to 240 mg/kg. Additionally, 1,1,2,2-tetrachloroethane, 1,2,3-trichlorobenzene, 1,2,3-trichloropropane, 1,1-dichloroethene, chlorobenzene and chloroform have been reported in one or a few samples at concentrations less than a few hundred mg/kg.

3.2 Soil Sampling

Soil samples were collected from four well borings in 2002 and from a soil boring located in the southeast corner of the former Oliver's Cleaners property in 2005. Soil samples were collected for VOC analysis during drilling of monitoring wells 7AZP-2, 7AZP-3 and 7AZP-4 and regional aquifer monitoring well 7AZR-1 (Kleinfelder and HGC, 2003). Soil samples were collected for metals, petroleum hydrocarbon and polycyclic aromatic hydrocarbon analysis from boring OC-1

(HGC, 2006b), located within the underground storage tank bed in the southeast corner of the former Oliver's Cleaners Facility (Figure 27).

OC-1 borehole samples were collected in December 2005 to investigate the potential presence of Stoddard solvent or similar petroleum dry cleaning solvent from the former underground storage tank bed in the southeast corner of the former Oliver's Cleaners property (HGC, 2006b).

Table 7 tabulates the soil VOC results for 7AZP-2, 7AZP-3, and 7AZP-4 borings with depth. Soil samples collected from borings 7AZP-1 and 7AZR-1 (within the regional aquifer zone) showed no detections of VOCs, and these results are therefore not tabulated. PCE was detected in the 7AZP-2 boring at levels above the residential Soil Remediation Level (SRL) of 0.51 mg/kg at a depth of 15 feet bls and between depths of 30 and 65 feet bls (with a maximum of 17 mg/kg at 35 feet bls). PCE was detected at levels exceeding the residential SRL in the 7AZP-3 and 7AZP-4 borings at a depth of 5 feet bls. Other than detections of TCE at two depths in 7AZP-4 at concentrations below the residential SRL, detections were associated with petroleum hydrocarbons and were below residential SRLs. All constituents were below non-residential SRLs with the exception of PCE in boring 7AZP-2 at a depth of 35 feet bls.

Results for organic carbon contents for soil in 7AZP-2, 7AZP-3, 7AZP-4 and 7AZR-1 are presented in Table 8. Values for TOC are uniformly low, which is typical for subsoils.

Results for TPH, PAH and metals in boring OC-1 with depth are presented in Table 9. TPH and PAH were below the detection limit for every soil sample. Metals, collected from 45 and 55 feet bls in OC-1, were below residential and non-residential SRLs.

3.3 Soil Vapor Sampling

Soil vapor sampling at the Site has included a passive soil gas survey conducted in 2002, sampling from vapor probe nests, and a shallow soil gas investigation conducted in March 2013 to evaluate potential vapor intrusion issues.

3.3.1 Passive Soil Gas Survey

A passive soil gas screening survey on the former Oliver's Cleaners property was conducted between March 19 and April 1, 2002 (Kleinfelder and HGC, 2003).

A summary of the passive soil gas analytical results is provided in Table 10. Sample module SG-160-88, exhibited an anomalously low VOC concentration with respect to surrounding sample modules. PCE, TCE, *cis*-DCE, and chloroform were the most widely distributed constituents in

the passive soil gas samples. Based on elevated PCE, TCE and *cis*-DCE results within the vicinity of sample location SG-80-88, monitoring well 7AZP-4 was installed at that location. Elevated VOC results were also reported for samples collected along the southern edge of the property (Figure 28).

3.3.2 Vapor Probe Nests

Four vapor probe nests were installed on the former Oliver's Cleaners property associated with groundwater monitoring wells 7AZP-1 through 7AZP-4 in 2002. An additional vapor probe nest, 7AZP-8, also was installed in the vicinity of MW-PD-14, which typically had the highest concentrations of VOCs in samples from perched groundwater, to evaluate the vertical distribution of VOCs (HGC, 2007a). Probes were installed at depths of 15, 30, and 45 feet bgs to form a vapor probe nest. Details on probe installation are provided in Kleinfelder and HGC (2003) and HGC (2007a).

HGC conducted soil vapor sampling activities at the Site to evaluate the extent of VOC contamination in soil vapor, as well as the effectiveness of the ERA remedial system. Soil vapor samples have been collected from the 16 soil vapor probes (3 of which, from 7AZP-8, no longer exist) and 24 perched groundwater monitoring wells (2 of which, MW-PD-14 and MW-PD-16, have been abandoned) listed in Table 11 between 2002 and 2012. These soil vapor sample locations include accessible probes and monitoring wells that have been sampled based on water levels and screening location with respect to the water table, i.e. part of screened interval is in unsaturated soil so that a soil vapor sample can be collected (HGC, 2012a; 2012b).

3.3.2.1 Soil Vapor Sampling Results

Table 11 presents VOC analytical results for soil vapor sampling. Soil vapor sampling results allow for the evaluation of concentration and spatial distribution of VOCs in soils. PCE concentrations in soil vapor ranged from 10.2 micrograms per cubic meter ($\mu g/m^3$) to 14,000,000 $\mu g/m^3$, the latter in vapor probe 7AZP-2-45 (45 feet bgs) in June 2002. TCE concentrations in soil vapor ranged from 10.7 $\mu g/m^3$ to 4,360,000 $\mu g/m^3$, the latter in well 7AZP-4 (screened interval above water table) in March 2004, with a similar concentration in May 2002. *Cis*-DCE and *trans*-DCE were detected at concentrations of up to 874,000 $\mu g/m^3$ and 55,300 $\mu g/m^3$, both in well 7AZP-4 in March 2004 and September 2006, respectively. PCE and TCE soil vapor concentration trends in nested wells 7AZP-1, 7AZP-2, 7AZP-3 and 7AZP-4 are presented in Appendix I. PCE concentrations with depth for wells 7AZP-1, 7AZP-2, 7AZP3, 7AZP-4 and 7AZP-8 are also presented in Appendix I.

PCE, TCE, *cis*-DCE and *trans*-DCE soil vapor concentrations from November 2011 to November 2012 are posted on Figure 29. A soil vapor concentration contour map of PCE at the water table (i.e. soil vapor sampled from monitoring wells) in 2011 and 2012 is presented as Figure 30. Soil gas samples collected from seven wells (five with nested soil vapor probes) in October and November 2011 had PCE detections at concentrations up to 39,200 µg/m^3 (7AZP-4) and TCE at concentrations up to 203,000 µg/m^3 (7AZP-4-30). Additional soil gas samples collected from 17 perched groundwater wells screened across the water table in May 2012 contained mainly PCE, TCE, and 1,2-DCE. PCE was detected in soil gas samples at concentrations up to 51,700 µg/m^3 (MW-PD-6) and TCE was detected at concentrations up to 2,150 µg/m^3 (MW-PD-15). Additionally, 1,2,4-trimethylbenzene was detected at 4,770 µg/m^3 in well MW-PD-12. A 2012 soil gas sample from well 7AZP-12 contained detectable and relatively low concentrations of chlorinated organic compounds (PCE, TCE and chloroform).

Figures 31 through 34 present PCE, TCE, *cis*-DCE and *trans*-DCE concentrations with depth in the vapor probes and monitoring wells located in the vicinity of the former Oliver's Cleaners property. PCE concentrations show a heterogeneous distribution (Figure 31). The highest concentrations of TCE (Figure 32) are in well 7AZP-4 at a depth of 30 ft bls (203,000 µg/L) and at the water table (58,300 µg/L), and in well 7AZP-2 at the water table (88,100 µg/L). TCE concentrations at all wells (other than 7AZP-4) are below or just above the detection limit at 15 ft, 30 ft and 45 ft depths and slightly to somewhat elevated at the water table (other than 7AZP-4 and 7AZP-2 where they are more than an order of magnitude higher). The highest concentrations of *cis*-DCE and *trans*-DCE are in well MW-PD-14 at the water table (19,800 and 5,540 µg/L, respectively), with concentrations above the detection limit at the water table depth for at least one of the isomers in YC-5, 7AZP-1, 7AZP-2, 7AZP-3 and 7AZP-4. The DCE isomers are below the detection limit or near it at 15 ft, 30 ft and 45 ft bls depths near the former Oliver's Cleaners property.

3.3.3 Shallow Soil Gas Investigation

HGC conducted a soil gas investigation in May 2013 to collect shallow soil gas samples from beneath the asphalt of the former Oliver's Cleaners property for use in a vapor intrusion screening evaluation.

3.3.3.1 Soil Gas Investigation Results

Table 12 summarizes the results of the shallow soil gas investigation conducted at the former Oliver's Cleaners property in May 2013. Analytical reports are provided as Appendix G. PCE was detected in all eleven soil gas sampling locations, up to a maximum concentration of

499,000 µg/m^3 at location SG-6 at a depth of 5 ft bgs (Figure 35). TCE was detected in five of the shallow depth samples, up to a maximum concentration of 16,900 µg/m^3 at location SG-6-5', as well as in the 10-foot sample. *Cis*-DCE and a number of non-chlorinated organics, including BTEX, were detected at relatively low concentrations in soil gas. MEK was detected at location SG-6-5' at a relatively high concentration of 12,600 µg/m^3, but below the level of health concern based on the RSL for industrial air (EPA, 2012).

3.4 Early Response Action (ERA)

The Early Response Action for the Site included installation of an SVE system and a pilot test for air sparging. The SVE system was intended to address VOC contamination in the vadose zone below the former Oliver's Cleaners property. The air sparge pilot test was intended to evaluate potential vaporization of COCs from LNAPL below the property.

3.4.1 SVE System

The ERA at the Site included installing and testing of a SVE well and designing and construction of a SVE system to remove VOCs from the vadose zone (HGC, 2006a). Operation of the SVE system at the former Oliver's Cleaners property began June 13, 2006, with the system remaining in operation until June 23, 2009.

3.4.1.1 Design and Construction

The SVE system consisted of one SVE well, SVE-1, and was designed to operate at a nominal flow rate of 50 standard cubic feet per minute (scfm). Figure 27 shows the location of the SVE-1, near the center of the former Oliver's Cleaners property, and the SVE compound. Table 1 summarizes construction details for well SVE-1. The off-gas from the SVE system was passed through two 2,000-pound granular activated carbon vessels, considered lead and lag vessels, plumbed in series to remove VOCs from the air stream.

A SVE pilot test was conducted on the former Oliver's Cleaners property (HGC, 2006b) using pressure transducers to evaluate pneumatic parameters of the vadose zone. Pneumatic properties from this test are summarized in Table 13. Effective gas porosity estimates range from 0.08 to 0.23; the higher end of the range is generally consistent with the reported vadose zone volumetric moisture content of 0.12 (B&R, 1998). Horizontal effective gas permeability values range from 15.9 to 41 darcies and vertical effective gas permeability values range from 1 to 5.7 darcies.

A numerical model was used to evaluate and optimize the SVE system design. The details of the numerical gas flow and transport model used for the Site are described in the Draft Work Plan Addendum (HGC, 2006b).

3.4.1.2 Operating Parameters

SVE influent, between vessel, and effluent samples were collected approximately monthly through 2007, approximately bi-monthly in the first half of 2008, and then twice more (August 2008 and May 2009) for analysis of VOCs and hydrocarbons, prior to shutting off the SVE system. Table 14 presents these data. Soil vapor samples were collected from wells 7AZP-1, 7AZP-2, 7AZP-3, 7AZP-4, YC-5 and MW-PD-14 at the water table screened interval for laboratory analysis (Table 11), just prior to and during SVE operation to qualitatively evaluate remedial effectiveness. The rate of hydrocarbon removal varied considerably, but in general appeared to be on a declining trend (HGC, 2008e).

3.4.1.3 Results of Remedial Efforts

Over the three years of SVE system operation, approximately 780 pounds of VOCs and over 10,800 pounds of hydrocarbons were removed (Table 15). Concentrations of VOCs declined rapidly in the first six months of operation and more slowly after that time (HGC, 2008e). The rate of removal dropped from several pounds of VOCs per day in the first four months of operation to approximately 0.4 pounds per day at the end of the reporting period.

3.4.2 Air Sparge Pilot Test

A pilot test at the former Oliver's Cleaners property was conducted in November 2007 to evaluate the efficacy of air sparging to remove chlorinated VOCs from the LNAPL at the Site (HGC, 2008c). A sparge well (7AZAS-1) and two nests of vapor probes and piezometers (7AZV-1 and 7AZV-2) were installed to conduct and monitor the test. Figure 27 shows the locations of the well 7AZAS-1 and the vapor wells. Table 1 summarizes construction details for well 7AZAS-1 and associated vapor wells. Vented Level TROLL® 500 pressure transducers were installed in ten vapor monitoring locations at 7AZP-4, 7AZV-1, and 7AZV-2 and absolute pressure Level TROLL 500 transducers were installed in two piezometers 7AZV-1-70 and 7AZV-2-70 to monitor water levels near the sparge well. In addition to pressure transducer data, flow rate, pressure, water level, LNAPL thickness, field gas concentration, analytical vapor sample, dissolved oxygen (DO) and analytical LNAPL data were collected during the sparge test.

The test was conducted at flow rates of 2.4, 28, and 47 scfm on November 1, 2007 while the SVE system at the property was in continuous operation. The sparge well generated an area of influence approximately 35 feet in radius and caused significant static water level rises in surrounding monitoring wells. Sampling of influent flow to the SVE system demonstrated large increases in concentrations of target COCs, as well as petroleum hydrocarbons. PCE concentration in the LNAPL was reduced 48 percent and TCE and *cis*-DCE concentrations were reduced 80 and 74 percent, respectively (HGC, 2008c).

4. DATA EVALUATION

4.1 Hydrogeology

4.1.1 Groundwater Hydraulic and Pneumatic Properties

The porosity of the matrix of the Fort Lowell Formation ranges from 0.26 to 0.30 (Davidson, 1973) and porosity measurements for silty and clayey sand at the adjacent Yellow Cab site yielded values of 0.32 with associated bulk densities of 1.79 to 1.81 grams per cubic centimeter (g/cm^3) (B&R, 1998). Results of a slug test in monitoring well MW-PD-13 yielded a hydraulic conductivity estimate of 9.33×10^{-3} centimeters per second (cm/s) (ERM, 2000); equivalent to 26 ft/day. Laboratory measurements of vertical hydraulic conductivity for silty and clayey sand at the adjacent Yellow Cab site yielded values of 3×10^{-4} and 2×10^{-4} cm/s and the measurement for the clay aquitard is 3×10^{-7} cm/s (B&R, 1998). No data are presently available regarding the site-specific hydraulic properties of the regional aquifer.

Pneumatic properties from a SVE pilot test conducted on the former Oliver's Cleaners property property (HGC, 2006b) are summarized in Table 13. Effective gas porosity estimates range from 0.08 to 0.23; the higher end of the range is generally consistent with the reported vadose zone volumetric moisture content of 0.12 (B&R, 1998). Horizontal effective gas permeability values range from 15.9 to 41 darcies and vertical effective gas permeability values range from 1 to 5.7 darcies.

4.1.2 Depth to Groundwater

The average depth to perched groundwater in March 2013 was about 71 ft bgs. Water levels in the perched groundwater generally have declined by about 1.5 feet since 2008. The average depth to groundwater in the regional aquifer in March 2013 was about 174 ft bgs. Water levels in the regional aquifer declined significantly between 2002 and 2005 and subsequently have been relatively stable, varying over a range of about two feet.

4.1.3 Groundwater Flow and Gradients

4.1.3.1 Perched Groundwater

Perched groundwater flows in a northwesterly direction at an average gradient (March 2013) of 0.0028 ft/ft in the southern portion of the Site and 0.0064 ft/ft in the northern portion of the Site (Figure 10), where the saturated interval thins.

The groundwater flow direction has been consistent over the period of observation (2002 – 2013) and hydraulic gradients have been relatively uniform.

The average linear velocity (v) of groundwater flow is calculated as:

$$v = \frac{KI}{n_e}$$

Where:

K	is the hydraulic conductivity (ft/day),
I	is the hydraulic gradient (ft/ft), and
n_e	is the effective porosity (cm^3/cm^3).

Based on the hydraulic conductivity estimate of 26 ft/day and an assumed effective porosity of 0.25, the observed gradients yield an average linear velocity of groundwater flow ranging from 0.29 ft/day in the proximal part of the solute plume to 0.66 ft/day in the distal portion.

4.1.3.2 Regional Aquifer

The current arrangement of monitoring wells in the regional aquifer does not permit determination of hydraulic gradient. Additionally, there are no available site-specific data for hydraulic conductivities for the regional aquifer. Therefore, groundwater flow in the regional aquifer cannot be further evaluated.

4.2 Vadose Zone

4.2.1 Soil Vapor

The distribution of PCE in soil vapor above the water table (Figure 30) generally follows PCE concentrations in perched groundwater; however, the highest PCE concentrations in soil vapor are located at well MW-PD-6, wells at the former Oliver's Cleaners property, and at well 7AZP-6. The PCE concentration at well MW-PD-6 may originate through a preferential migration pathway since no PCE was detected in the LNAPL from this well in 2012; however, it could also be originating from a separate PCE source in nearby vadose soils.

The heterogeneous distribution of PCE concentrations at the former Oliver's Cleaners property (Figure 31) suggests the presence of DNAPL in the vadose zone. PCE and TCE soil vapor concentration trends in nested wells 7AZP-1, 7AZP-2, 7AZP-3 and 7AZP-4 (Appendix I) show a generally decreasing trend since 2002 at all depths. Based on the November 2011 sampling event

(no sampling was performed between 2008 and 2011), PCE concentrations at the 15 foot and 30 foot bls probes in wells 7AZP-1, 7AZP-2 and 7AZP-3 appeared to increase after the SVE system was shut down in early 2009 (rebound effect). The probes in well 7AZP-4 did not show this increase. TCE may be originating from both soil vapor movement and reductive dechlorination of PCE, so the changes in concentration are less interpretable.

PCE concentrations with depth for wells 7AZP-1, 7AZP-2, 7AZP3, 7AZP-4 and 7AZP-8 for sampling events between 2002 and 2011 are also presented in Appendix I. The more recent sampling event trends, since remediation with SVE, generally show higher PCE concentrations with depth, compared with the earlier sampling event trends. This may indicate that steady state equilibrium has not been reached for soil vapor in vadose soils since vapor extraction operation ceased.

The SVE system that operated under the ERA at the Site removed a substantial amount of contaminant mass from the vadose zone. However, the leveling off of the measured SVE influent concentrations of PCE indicates that PCE removal became in large part diffusion-dominated. PCE is likely present in relatively low permeability lenses of finer grained materials that also have higher water saturations and/or possibly contain residual DNAPL. When the SVE system was shut down, the concentrations in the coarser-grained materials likely rebounded due to diffusion from the lower permeability sources. Additionally, PCE dissolved in the LNAPL (diesel) at the perched water table and groundwater can also diffuse into vadose zone soils. 2011 soil vapor measurements reflect the extent of rebound and the distribution of COCs in the vadose zone below the former Oliver's Cleaners property.

4.2.2 Shallow Soil Gas Investigation

The shallow soil gas investigation under the asphalt at the former Oliver's Cleaners property was conducted mainly to evaluate whether shallow soil gas might present a potential health risk for future uses at the property. As discussed in Section 3.2.2, PCE and TCE were detected in soil gas samples at values up to 499,000 $\mu g/m^3$ and 16,900 $\mu g/m^3$, respectively. An attenuation factor of 0.03 (EPA, 2013) was used to screen PCE and TCE concentrations against ambient air screening levels (Table 16). The attenuation factor calculations indicate that PCE and TCE exceed the ambient air screening levels for industrial exposures (EPA, 2012) at most of the soil gas sample locations. Based on this criterion, vapor intrusion is potentially a concern at the former Oliver's Cleaners property for future commercial development.

4.3 LNAPL Distribution and Character

The LNAPL (diesel) body from the UPRR Passenger Depot site, located on the water table to the southwest of the Site, extends below the former Oliver's Cleaners property. The outline of the mobile LNAPL body appears to be stable over time indicating that the LNAPL has reached an equilibrium condition for lateral spreading. Figure 12 provides LNAPL thickness contours for the perched groundwater in the study area based on data collected during the March 2013 monitoring event. LNAPL thickness has continued to increase from 2002 through 2013 at MW-PD-12, where the source is believed to have originated, but has not increased substantially in other wells across the Site (Appendix H).

The response of LNAPL thickness to changes in water table elevation varies considerably between monitoring wells (Appendix H). Some redistribution of mobile LNAPL is evident in association with water level variations, but the effect is not uniform across the area where LNAPL is present, e.g. a decline in water table elevations between 2008 and 2012 correlates with the appearance of LNAPL in 7AZP-3. This variability likely reflects heterogeneity in the soil matrix that locally controls the behavior of the LNAPL body.

Table 6 presents a compilation of VOCs detected in LNAPL samples from select monitoring wells (seven in total) between March 2002 through November 2012. In addition to PCE and TCE, the trimethylbenzene isomers, naphthalene, butylbenzenes, 4-isopropyltoluene, propylbenzenes and BTEX, that are typical diesel fuel constituents, have appeared frequently. Appendix J presents the time series for PCE and TCE concentrations in LNAPL samples from 7AZP-2 and 7AZP-4, where these compounds have consistently appeared over time. The initial trends are difficult to interpret; however, PCE concentrations appear to have decreased, especially in 7AZP-4, following the one-day sparge pilot test in late 2007.

4.4 Groundwater

4.4.1 Perched Groundwater

The predominant contaminants reported from groundwater at the Site are the chlorinated ethenes PCE, TCE and *cis*-DCE. Vinyl chloride has not been reported in groundwater at the Site, although it has been reported in soil vapor at the former Oliver's Cleaners property. The 1,2-dichloroethenes are comprised of 75% or more of the *cis* isomer, consistent with microbial reductive dechlorination of PCE and TCE (Pankow and Cherry, 1996).

In addition to the chlorinated ethenes, contaminants in groundwater include MTBE, not associated with the Site, and various petroleum hydrocarbon compounds. Chloroform and MEK

have also been sporadically reported. The hydrocarbon compounds are predominantly restricted in distribution to wells associated with the LNAPL body at the Site. MTBE associated with the Yellow Cab property extends downgradient from the LNAPL and commingles with the chlorinated ethene solute plume.

1,2-dichloroethane has been persistently reported in groundwater from MW-PD-5. This constituent does not appear to be Site-related based on its occurrence upgradient of the former Oliver's Cleaners property. The presence of a relatively high chloride concentration and 1,2-dichloroethane in MW-PD-5 is anomalous; 1,2-dichlorethane has otherwise only been sporadically reported from MW-PD-6 and MW-PD-7. This well is located upgradient of the former Oliver's Cleaners property and side-gradient to the LNAPL body. The source of the constituents is not evident from available information.

4.4.1.1 Contaminant Distribution

The areal extent of the chlorinated ethene solute plume in the perched groundwater is relatively well-defined by the existing monitoring well network (Figure 2). VOC results indicate that the distribution of contaminants in the perched groundwater has not changed significantly from 2008. The downgradient extent of VOCs in the perched groundwater is relatively well established. The groundwater sample from the monitoring well farthest downgradient, 7AZP-11, had detectable, but below the AWQS, concentrations of VOCs in November 2012.

The center of mass of the PCE solute plume has shifted downgradient from the former Oliver's Cleaners property (Figure 13). Concentrations of TCE exceeding the AWQS also occur downgradient, although the highest concentrations are found at the former Oliver's Cleaners property (7AZP-2) and upgradient at MW-PD-6 (Figure 14). In contrast, the highest concentrations of *cis*-DCE and *trans*-DCE occur below and immediately adjacent to the LNAPL body downgradient from the former Oliver's Cleaners property (Figures 15 and 16).

Concentrations of PCE, TCE, and *cis*-DCE in April 2008 samples from perched groundwater collected near the former Oliver's Cleaners property were reduced when compared with samples from the same wells collected in October 2007 (HGC, 2008a, 2008d). Only samples from 7AZP-2 at 9 µg/L PCE and from 7AZP-3 at 5.6 µg/L. TCE remained above the AWQS in the vicinity of the source area. This was partially due to SVE system operation, but reductions in the center of the source area at 7AZP-4 are more likely attributable to the air sparge pilot testing conducted in November 2007 since these concentrations rebounded in the October 2008 monitoring event (HGC, 2012c).

Although there is considerable variability in the time series (Appendix K), concentrations of the chlorinated ethenes generally have declined over the period of observation (2002-2013) in the vicinity of the former Oliver's Cleaners property. Reductive dechlorination is evidently occurring in the perched groundwater below the LNAPL in this area. Concentrations of all the chlorinated ethenes in 7AZP-4 are declining, which appears to be associated with the air sparge pilot test in late 2007. However, PCE and TCE concentrations, in general, recovered following the air sparge test.

4.4.1.2 Groundwater Geochemistry

A compilation of stable purge parameters for groundwater sampling from February 2005 to May 2012 is provided in Table 4. Relevant historical geochemical parameters from these results include DO and oxidation-reduction potential (ORP). There is no evident association between DO and ORP values and many associated values are thermodynamically unable to coexist (Figure 36). Some of the variation may be due to spurious DO measurements, since atmospheric oxygen can easily contaminate samples, and these purge parameters were not originally intended for geochemical evaluation. Detectable levels of DO are present in samples associated with LNAPL. This suggests that the mass loading of hydrocarbons to groundwater from the LNAPL is minimal since aerobic biodegradation of petroleum hydrocarbons rapidly consumes available oxygen. The historical ORP values show little indication of the strongly reducing conditions that would be conducive to extensive reductive dechlorination of chlorinated ethenes in groundwater.

Geochemical parameters from the March 2013 sampling event are summarized in Table 5. Nitrate as N values are converted to nitrate (NO_3) concentrations and ORP values are converted to E_h values. There is no discernable pattern associated with the distribution of geochemical parameter values. The geochemical parameters do not indicate the presence of strongly reducing conditions associated with degradation of petroleum hydrocarbon compounds from the LNAPL in groundwater (Figure 17). This suggests that the LNAPL along the margins of the LNAPL body is substantially depleted in soluble petroleum hydrocarbon constituents that could serve as electron donors for reductive dechlorination.

The Site lacks monitoring wells in locations that would clearly establish background geochemical conditions in the perched groundwater. Well MW-PD-5 was selected as a location not impacted by chlorinated ethenes, although it is impacted by petroleum hydrocarbon contamination. Well 7AZP-10 was selected because it is outside the chlorinated ethene solute plume and not likely to be impacted by hydrocarbons. Unfortunately, well MW-PD-5 shows anomalously high chloride concentrations and well 7AZP-10 contains extensive phreatophyte

roots in the screened interval that appear to have impacted local groundwater chemistry. These conditions make interpretation difficult.

Dissolved organic carbon (DOC) is slightly elevated in samples associated with LNAPL in wells 7AZP-2 and YC-5, but not significantly in comparison to values from the other monitoring locations (Figure 18) that are uniformly low. The DOC values overall are indicative of a system that is substantially starved for organic carbon, even in the vicinity of LNAPL.

The VOC solute plume in the perched groundwater appears to be largely aerobic (Figure 19), supported by the relatively high E_h values from wells lacking LNAPL (Figure 17). There is a zone of depleted DO extending downgradient from the LNAPL along the western half of the VOC solute plume to the vicinity of wells MW-PD-30 and 7AZP-5. Similarly, nitrate concentrations are depleted in this same area, as well as associated with the LNAPL at the former Oliver's Cleaners property (Figure 20). This indicates that aerobic respiration and denitrification have occurred in these areas to some extent.

Ferrous iron does not display a pattern associated with significant iron reduction of petroleum hydrocarbons from the LNAPL (Figure 21). The distribution suggests the presence of locally anoxic microenvironments within the VOC solute plume where iron-reducing conditions are present.

Sulfate concentrations are relatively high (Table 5) and the evidence for sulfate reduction is equivocal based on the distribution of sulfate concentrations (Figure 22) and associated concentrations of sulfide (Figure 23) that are uniformly very low. Groundwater appears to be depleted in sulfate beneath the LNAPL at the former Oliver's Cleaners property and extending downgradient to BF-1; sulfate has returned to apparent background levels at BF-3. Depleted sulfate concentrations at well 7AZP-5 are anomalous and could indicate a zone of depleted sulfate extending downgradient from the LNAPL along the western margin of the VOC solute plume.

There is limited evidence for methanogenesis occurring locally at the Site. The distribution of methane in the perched groundwater is shown in Figure 24. Detectable methane is found at wells 7AZP-2 and YC-5 associated with LNAPL, suggesting some methanogenic activity. However, reported methane concentrations are quite low, ranging from 0.015 to 0.072 mg/L, suggesting that methanogenesis is localized. Methane was also detected at low concentrations at wells 7AZP-5 and 7AZP-9, suggesting methanogenesis at or upgradient of these locations.

There is no notable increase in alkalinity (Figure 25), as would be expected from extensive biodegradation of petroleum hydrocarbons.

The distribution of chloride concentrations is shown in Figure 26. Reductive dechlorination would be expected to show a progressive increase in chloride downgradient through the solute plume. Chloride concentrations at the Site do not show any variation that could be attributed to release of chloride by reductive dechlorination. This is likely due to the fact that chloride concentrations in the perched groundwater are in the hundreds of mg/L range and natural variation would mask any potential contribution from degradation of µg/L concentrations of chlorinated ethenes.

The typical geochemical pattern associated with extensive petroleum hydrocarbon biodegradation is not evident at the Site. Evidence of petroleum hydrocarbon biodegradation from geochemical parameters in wells with LNAPL is not clear. The apparent depletion of DO, nitrate and sulfate below the LNAPL body indicates petroleum hydrocarbon biodegradation; however, the presence of detectable amounts of these constituents suggests that sampling may have occurred across several redox zones and that petroleum hydrocarbon biodegradation and its associated strongly reducing conditions may be restricted to the area immediately surrounding the LNAPL. This limits the aquifer volume over which extensive microbial reductive dechlorination of chlorinated ethenes can occur at the Site.

The apparent lack of vinyl chloride in groundwater combined with the absence of detectable ethene or ethane (Table 5) suggests either that reductive dechlorination past *cis*-DCE is minimal or that vinyl choride is being degraded as quickly as it is generated.

In summary, the perched groundwater is largely aerobic (or suboxic), even in proximity to the petroleum hydrocarbons in the LNAPL. Reductive dechlorination appears to be occurring in groundwater immediately associated with the LNAPL where petroleum hydrocarbons are dissolving and being biodegraded based on the presence of the daughter products TCE, *cis*-DCE and *trans*-DCE. However, there is no evidence for conditions suitable for reductive dechlorination of PCE and TCE to occur downgradient from the immediate vicinity of the LNAPL.

4.4.2 Regional Aquifer

Contaminants have been observed only sporadically in regional aquifer wells 7AZR-1, 7AZR-2, MW-PD-19 (now abandoned) and 7AZR-3 (installed in 2012). PCE and TCE were detected in well 7AZR-1 during the June 2002 sampling event, but subsequently have not been reported in the regional aquifer wells associated with the Site. *Cis*-DCE was detected in well 7AZR-1 in March 2004. Detections of acetone, MEK, methylene chloride, and benzene exhibit no consistent

pattern, suggesting that they are not Site-related. These constituents have occurred at concentrations less than relevant AWQS or tap water RSLs (EPA, 2012).

4.5 Contaminant Transport and Fate

Vertical concentration profiles for the chlorinated ethenes in the vicinity of the former Oliver's Cleaners property generally decrease upward from the water table to 15 feet bls, indicating that volatilization from the LNAPL is acting as a source for soil vapor contamination by vapor diffusion. Additionally, the high concentrations for PCE and TCE reported at shallower depths on the former Oliver's Cleaners property suggest the presence of localized pockets of DNAPL or entrapment of these constituents in low permeability zones in the vadose zone. The relatively high concentrations of PCE and TCE found in shallow soil gas (5 feet bgs) indicate that the asphalt is acting as a vapor barrier.

Soil vapor can be either a source for, or a product of, groundwater contamination depending upon the concentration distribution for the two phases. This can be evaluated using Henry's law and empirical data on the ratio of concentrations in soil vapor (C_{sv}) to concentrations in groundwater (C_{gw}). An empirical C_{sv}/C_{gw} ratio that exceeds the dimensionless Henry's law constant (H′) for a chemical suggests that soil vapor is a source for groundwater contamination; a ratio that is less than H′ suggests that groundwater is a source for soil vapor contamination.

Tables 17 through 20 present recent data from monitoring wells without LNAPL for PCE, TCE *cis*-DCE and *trans*-DCE, respectively, with the calculated C_{sv}/C_{gw} ratios and H′ for the chemical. PCE in soil vapor appears to be a source for groundwater contamination in the vicinity of the former Oliver's Cleaners property at 7AZP-1, 7AZP-3 and MW-PD-29, and at MW-PD-7 upgradient of the former Oliver's Cleaners property; PCE appears to be a product of vaporization from groundwater at the other locations. The results for TCE, *cis*-DCE and *trans*-DCE do not show a consistent pattern, suggesting a more complex dynamic interaction between soil vapor and groundwater concentrations.

The transport and fate of organic solutes in groundwater is controlled by advection, dispersion, sorption to the aquifer matrix and transformation/degradation reactions. Estimated average linear velocities of groundwater flow in the perched groundwater are on the order of 100 to 240 feet per year (section 4.1.3.1).

Sorption to the aquifer matrix and associated retardation of solute transport is likely to be minimal for the COCs in groundwater at the Site. Reported organic carbon contents for the aquifer matrix are uniformly low (Table 8). Sorption to organic carbon does not dominate the

sorption capacity at values less than 0.1%, where sorption to mineral surfaces becomes an important component. Therefore, estimates of retardation based on sorption to organic carbon are not justified.

The Site is atypical in that the association of chlorinated ethenes with petroleum hydrocarbons does not reflect the expected pattern with biodegradation of petroleum hydrocarbons consuming the available electron acceptors to produce the strongly reducing conditions amenable to microbial reductive dechlorination of chlorinated ethenes. However, the presence of reductive dechlorination products of PCE indicates that the process has occurred at the Site, although current geochemical conditions are not suitable for extensive microbial reductive dechlorination in the solute plume away from the immediate area of the LNAPL.

The current petroleum hydrocarbon solute plume is restricted to the immediate vicinity of the LNAPL source and does not extend an appreciable distance downgradient. Groundwater geochemistry indicates that the PCE solute plume downgradient and away from the LNAPL is substantially aerobic. PCE and TCE are oxidized chlorinated organics that are recalcitrant under oxidizing conditions and would not be expected to degrade under aerobic conditions. In contrast, the DCE isomers are sufficiently reduced to serve as electron donors under aerobic conditions and can be directly oxidized to carbon dioxide, water and chloride (Bradley, 2003).

The current distribution of chlorinated ethenes in groundwater suggests that microbial reductive dechlorination of PCE may be occurring in the petroleum hydrocarbon fringe around the LNAPL. The center of mass of PCE has moved downgradient from the source area into the aerobic portion of the solute plume. TCE is centered along the edge of the LNAPL northwest of the source area where microbial reductive dechlorination appears to be occurring and extends into the aerobic portion of the groundwater at low concentrations. The center of mass for *cis*-DCE and *trans*-DCE coincides with TCE northwest of the source area and their restricted distribution suggests that these compounds may be degrading through direct oxidation as they enter the aerobic portion of the solute plume.

TCE in groundwater is present upgradient from the former Oliver's Cleaners property in the area of MW-PD-6 (Figure 14) and elevated concentrations of PCE are present in soil vapor above the LNAPL at this location also (Figure 30). The potential exists for a preferential migration pathway in the vadose zone to have carried PCE soil vapor to this location, so the potential that its presence at MW-PD-6 is Site-related cannot be discounted based on available information. Alternatively, there may be an as yet unidentified PCE source in the vicinity of MW-PD-6.

5. LAND AND WATER USE

Appendix A presents the Land and Water Use Study Report. The Land and Water Use Study is consistent with AAC R18-16-406(D) for evaluating the current and reasonably likely future uses of land and water within the Land and Water Use Study area that have been impacted or are threatened by the Site release.

The Land and Water Use Study includes general land use information, such as the current type of use, density and character, and current water uses. Future land and water use changes, based on information from City of Tucson and the current owner of the former Oliver's Cleaners property, as well as any knowledge of population projections, plans for future development and local land and water use plans, have been considered.

Land use within the Land and Water Use Study area generally consists of a mix of commercial properties, residential properties and roads. At the current time, approximately 34.3% of the land within the Study area is zoned for commercial use; 29.8% is zoned for residential use; 1.4% is vacant; 34.5% is roadways/right-of-ways for COT.

There are no current or future anticipated uses for groundwater or surface water at the Site. The perched groundwater is not considered a drinking water source and there are no surface water uses within the Site area. There are currently no drinking water wells within the perched or regional groundwater in the vicinity of the Site and no new drinking water wells can legally be drilled into the perched or regional groundwater. As many as three unused regional aquifer wells are located within the Land and Water Use Study area and should be abandoned per ADWR regulations as they could potentially pose a risk as conduits.

The Land and Water Use Study report was used in the baseline risk assessment and to formulate the Remedial Objectives (ROs) for the Site.

6. RISK EVALUATION

A HHRA is presented in Appendix B. The objective of the HHRA is to evaluate and quantify potential human health risks associated with the Site that will support decision-making regarding appropriate remedial actions. Based on the lack of current or reasonably anticipated future use of the perched groundwater as a water supply, the risk assessment does not consider exposures due to direct ingestion, inhalation or dermal contact with contaminated groundwater. Additionally, due to the apparent lack of ecological receptors, ecological risk is not considered.

Chemicals of potential concern (COPCs) for the HHRA are determined using conservative criteria for reporting frequency and risk-based screening values, combined with consideration of location and availability of toxicity information.

6.1 Exposure Assessment

Characterization of the exposure setting is based on an evaluation of current land use in the vicinity of the Site (Appendix A). Land use in the area of the Site includes commercial and residential settings and identified potential receptors include residents and commercial workers. Additionally, passers-by and utility workers are identified as potential receptors based on the current land use at the former Oliver's Cleaners property.

The potentially complete exposure pathways at the Site involve transport of vapor-phase contaminants to outdoor and indoor air with subsequent inhalation exposure. A quantitative estimate of the magnitude of potential exposures to the selected COPCs at the Site is calculated for the identified receptors. Vapor intrusion to indoor air is evaluated using the US EPA implementation (EPA, 2004) of the Johnson and Ettinger (1991) model and an empirical attenuation factor (EPA, 2013) to estimate indoor air concentrations of VOCs and scenarios for slab-on-grade and basement construction are included. Vapor transport to outdoor air is evaluated using a vapor diffusion model combined with an atmospheric mixing zone calculation for the passer-by scenario and a trench mixing zone calculation for the utility worker scenario.

Exposure concentrations for inhalation are calculated using standard exposure frequency and duration factors for residential and commercial worker scenarios. Reasonably conservative exposure factors are developed for the passer-by scenario.

6.2 Toxicity Assessment

Relevant toxicity values for the COPCs are identified using the most current toxicity values consistent with EPA's toxicity value hierarchy provided in OSWER Directive 9285.7-53 (EPA, 2003). Acute and subchronic reference concentrations are identified for use in the utility worker scenario.

6.3 Risk Characterization

The results of the exposure assessment and toxicity assessment are combined to estimate non-cancer hazards and cancer risk at the Site. Individual chemicals may have both carcinogenic and non-cancer health effects that are evaluated separately.

The resulting estimates of cancer risk and health hazard for vapor intrusion to indoor air are slightly greater for the basement scenarios than for the associated slab-on-grade scenarios, but not significantly so. The calculated total excess cancer risk estimates for the residential exposure scenarios range from 7.5×10^{-7} to 1.0×10^{-6} and the calculated hazard index (HI) for non-cancer effects ranges from 0.19 to 0.23. Cancer risks are less than or equal to the accepted *de minimis* target value of 1×10^{-6} and the HI values are less than the accepted target of one for non-cancer health effects. The principal risk drivers for the residential scenarios are PCE and TCE.

The calculated total excess cancer risk estimates for the commercial worker vapor intrusion scenarios range from 3.1×10^{-9} to 7.6×10^{-5} and the calculated HI for non-cancer effects ranges from 0.00054 to 21. Estimated cancer risks exceed the accepted *de minimis* target value of 1×10^{-6} and the HI values for non-cancer health effects are greater than the accepted target of one for buildings adjacent to the former Oliver's Cleaners property. The principal risk drivers for the commercial worker scenarios are PCE and TCE.

The calculated estimates of total excess cancer risk and HI associated with outdoor air inhalation exposure by passers-by at the former Oliver's Cleaners property are 1.2×10^{-9} and 0.00034, respectively. The values for utility workers at the former Oliver's Cleaners property are 2.1×10^{-9} for total excess cancer risk and HIs of 0.084 for acute non-cancer effects and 0.00066 for subchronic non-cancer effects. These values are significantly less than levels of concern for both scenarios.

The risk and health hazard estimates for residential exposures are lower than those for commercial exposures due to the fact that the locations for residential exposures are away from the former Oliver's Cleaners property. In contrast, the commercial exposures include locations

on and adjacent to the former Oliver's Cleaners property, where exposure concentrations are significantly greater.

The potential health hazard associated with *cis*-DCE cannot be evaluated directly owing to the lack of an inhalation toxicity value.

6.4 Future Use

The HHRA explicitly considered current use scenarios. However, the screening evaluation for non-residential indoor air at the former Oliver's Cleaners property, performed to assess potential future commercial development (Section 4.2.3), indicates that PCE and TCE may constitute a health risk for this scenario.

Framing the screening evaluation in terms of risk, the excess cancer risk and health hazard associated with each of the shallow soil gas samples from the former Oliver's Cleaners property are shown in Table 21. The values were calculated using an attenuation factor of 0.03 and the same exposure calculations for a commercial worker used in the risk assessment (Appendix B). The excess cancer risks for PCE range from 5.6×10^{-7} to 3.2×10^{-4} and the hazard quotients (HQs) range from 0.15 to 85. The excess cancer risks for TCE range from $<1.3\times10^{-7}$ to 1.7×10^{-4} and the HQs range from 0.046 to 58.

7. REMEDIAL OBJECTIVES

The ROs for the Site, pursuant to AAC R18-16-406(I), are based on the field investigation results and historical data, the Land and Water Use Study, and the Risk Assessment. The RO report is included as Appendix N.

Existing standards and guidelines, such as AWQS and other criteria accepted by ADEQ as appropriate for the media being evaluated, were used to evaluate potential effects on human receptors that may be exposed to COCs above appropriate standards or guidelines.

A preliminary evaluation of applicable or relevant and appropriate requirements (ARARs) for setting cleanup goals for the purposes of this RI indicates that, due to the presence of COCs in perched groundwater and soil at the Site, Arizona AWQS under 18 AAC 11-4 and Arizona soil remediation levels (SRLs) under 18 AAC 7-2 are applicable requirements. Additionally, Safe Drinking Water Act maximum contaminant levels (MCLs) are considered applicable requirements. There are no available standards for contaminants in soil vapor. Due to the proximity of commercial and industrial properties to the Site and the potential for vapor intrusion into buildings, the OSHA permissible exposure limits (PELs) are considered to be relevant and appropriate requirements. The EPA RSL table (EPA, 2012) lists Superfund human health screening values for soil, air, and tap water. The RSLs are not promulgated standards, but rather guidance values that are considered.

The ROs focus on contaminants and media of concern and exposure routes and receptors. The ROs will be used during alternatives development, where remediation goals are established based on ARARs, to identify appropriate remedial technologies. Because there are no current or future anticipated uses for perched groundwater or surface water at the Site, the only identified exposure pathway of concern involves potential vapor intrusion into residential or commercial buildings. Therefore, there is no need for a RO for perched groundwater or surface water.

The RO for soil at the Site is to restore soil conditions to the remediation standards for non-residential use specified in A.A.C. R18-7-203 that are applicable to PCE, TCE, and *cis*-DCE at the Site.

The RO for regional groundwater at the Site is to protect the use of the groundwater supply by the City of Tucson from contamination at the Site.

8. DATA GAPS

There are existing gaps in the Site-related data discussed within this RI report. The data gaps and recommendations to satisfy the gaps, which include additional well installation, groundwater sampling, or other testing, are detailed further in Section 9 and include:

- There is uncertainty regarding the extent of the PCE solute plume along the northwest margin due to the large spacing between monitoring wells in this area. This is also the situation between wells 7AZP-9 and 7AZP-12 at the north-central extent of the plume, as concentrations in groundwater samples from well 7AZP-9 have exceeded the AWQS for PCE, while 7AZP-12 is dry. This data gap needs to be addressed with additional monitoring wells and groundwater samples.
- Soil vapor PCE and groundwater TCE contamination exist upgradient of the Site at well MW-PD-6. The available data do not support a determination of whether this contamination is Site-related or due to another source. Pneumatic testing and/or additional vapor wells are necessary to evaluate this issue.
- The availability of geochemical data is minimal, as these data were collected for selected monitoring wells during a single event in 2013. Geochemical data are the basis for the evaluation of natural attenuation, so additional data from groundwater sampling would be useful to provide a more comprehensive picture of conditions in the perched groundwater.
- The mass of contaminants in the subsurface cannot be estimated and, based on the most recent evaluation, contamination still exists in LNAPL on the water table and possibly in soils beneath the former Oliver's Cleaners property. This data gap cannot be easily addressed and would require substantial additional investigation that does not appear warranted.

9. CONCLUSIONS

The nature and extent of contamination at the Site was investigated and the risks posed to human health were evaluated. The extent of the chlorinated organic solute plume in the perched groundwater is defined, except for some uncertainty regarding the extent along the northwest margin due to the large space between 7AZP-5 and 7AZP-11. The existing monitoring well network is too sparse to allow for adequate resolution of groundwater flow paths and monitoring of natural attenuation.

The existing monitoring wells in the regional aquifer are located along the axis of the solute plume in the perched groundwater and appear to be positioned appropriately to detect the potential impact of contaminants from the perched groundwater, if vertical leakage or a conduit into the regional aquifer exists. Two additional perched groundwater monitoring wells, one located to the west of well 7AZP-9 and south of well 7AZP-11, and one between well 7AZP-9 and well 7AZP-12 (currently dry) would allow better side-gradient and downgradient delineation of the PCE plume.

The predominant natural attenuation mechanism for PCE and TCE in the perched groundwater solute plume is expected to be dispersion, resulting in dilution. Reductive dechlorination of PCE and TCE is evidently occurring and is associated with the LNAPL based on the presence of the DCE isomers. However, geochemical conditions downgradient of the LNAPL body are predominantly aerobic and further reductive dechlorination would not be expected to occur within the solute plume. The available information suggests that *cis*-DCE and *trans*-DCE are likely being directly oxidized.

The LNAPL body and associated chlorinated ethenes appear to be an ongoing source of contamination to perched groundwater and soil vapor. Residual chlorinated ethenes, predominantly PCE and TCE, in the form of DNAPL entrapped in low permeability zones in the vadose zone, likely also contribute to ongoing soil vapor contamination.

Additional soil vapor measurements may be warranted in the future to track the dynamic behavior of soil vapor concentrations. The highest soil vapor concentrations were detected at former Oliver's Cleaners property locations (wells 7AZP-2 and 7AZP-4; and shallow soil gas investigation points) or directly to the west of the property (well MW-PD-14). High PCE concentrations in soil vapor and TCE concentrations above the AWQS in perched groundwater at well MW-PD-6 appear to be Site-related, although they occur "upgradient" of the former Oliver's Cleaners property, based on currently available information. This is considered a data

gap for the RI that should be addressed by evaluating pneumatic properties between the former Oliver's Cleaners property and well MW-PD-6 with a SVE or similar test.

Site-related human health risks associated with the perched groundwater solute plume downgradient of the former Oliver's Cleaners source area appear to be minimal as the potential for vapor intrusion is quite small and there are no drinking water wells in the perched groundwater. PCE and TCE concentrations in shallow soil gas below the asphalt at the former Oliver's Cleaners property generally exceed screening criteria for non-residential indoor air. These COCs may present an issue for commercial workers in buildings on adjacent properties and for potential commercial development at the former Oliver's Cleaners property that should be addressed.

As many as three unused regional aquifer wells are located within the Site and should be abandoned per ADWR regulations, as they could potentially pose a risk as conduits from the perched aquifer to the regional aquifer.

10. REFERENCES

Anderson, S.R. 1987. Cenozoic Stratigraphy and Geologic History of the Tucson Basin, Pima County, Arizona, U.S. Geological Survey, Water-Resources Investigations Report 87-4190, 20 p.

Anderson, T.W., Freethley, G.W., and Tucci, Patrick. 1992. Geohydrology and water resources of alluvial basins in south-central Arizona and parts of adjacent states: U.S. Geological Survey Professional Paper 1406-B, 67 p.

Arizona Department of Environmental Quality (ADEQ). 1999. Preliminary Assessment/Site Inspection Report: Oliver's Cleaners.

ADEQ. 2008. Soil Vapor Sampling Guidance. July 10. Revised May 19, 2011.

ADEQ, 2012. Site Summary, Union Pacific Railroad (UPRR) Tucson Passenger Depot, LUST File #3953.02-.05; ADEQ Facility ID # 0-008574. December 18, 2012.

ADEQ, 2013. Fact Sheet: Union Pacific Railroad Company Passenger Depot, Underground Storage Tank Site – Fall 2013, Report No. FS 13-17.

ARCADIS Geraghty & Miller (ARCADIS). 2000. Groundwater Monitoring Report. 445 North Sixth Avenue, BSF Property No, 127620, ADEQ Lust File No. 4715.0505, ADEQ Facility ID 0-007556.

Basin & Range Hydrogeologists, Inc. (B&R). 1996a. Project Status Report, Yellow Cab Company of Tucson, Tucson, Arizona. May 1996.

B&R. 1996b. Site Characterization Report, Yellow Cab Company of Tucson, 411 North Fifth Avenue. Facility ID No. 0-006763, LUST File No. 1136.01, Civil Action No. CV 95-11404. December 27, 1996.

B&R. 1998. Corrective Action Plan, Yellow Cab Company of Tucson, 411 North Fifth Avenue. Facility ID No. 0-006763, LUST File No. 1136.01, Civil Action No. CV 95-11404. April 24, 1998.

B&R. 2000. Supplemental Site Characterization and Aquitard Investigation Report, 411 North Fifth Avenue, Yellow Cab Company of Tucson. Facility ID No. 0-006763, LUST File No. 1136.01, Civil Action No. CV 95-11404.

Bradburne, Briller & Johnson, LLC (BB&J), 2001. Risk-Based Closure Report, Former BFRC Facility. January 2001.

Bradley, P.M. 2003. History and ecology of chloroethene biodegradation: A review. Bioremediation Journal, v 7(2), p. 81-109.

Brown, P.W. 2005. Standardized Reference Evapotranspiration: A New Procedure for Estimating Reference Evapotranspiration in Arizona. University of Arizona Cooperative Extension Publication AZ1324, 12 p.

CH2M-Hill. 2012. Corrective Action Plan, Union Pacific Railroad Company Passenger Depot Site. January, 2012.

Davidson, E.S. 1973. Geohydrology and water resources of the Tucson basin, Arizona. U.S. Geological Survey, Water Supply Paper 1939-E, 81 p.

Environmental Resources Management (ERM). 2000. Union Pacific Railroad Company, Draft Remedial Investigation Report-Passenger Depot Site-Tucson Arizona. ADEQ VRP Facility No. 100149-00. Volume I of IV. December 2000.

Environmental Protection Agency (EPA).1988. Guidance for Conducting Remedial Investigation and Feasibility Studies Under CERCLA. Interim Final. EPA/540/G-89/004. October 1988.

EPA. 2003. Human health toxicity values in Superfund risk assessments (memorandum dated 5 December 2003): U.S. Environmental Protection Agency, OSWER Directive 9285.7-53. [http://www.epa.gov/oswer/riskassessment/pdf/hhmemo.pdf]

EPA. 2004. Johnson and Ettinger (1991) Model for Subsurface Vapor Intrusion into Buildings. [http://www.epa.gov/oswer/riskassessment/airmodel/johnson_ettinger.htm]

EPA. 2012. Regional Screening Levels for Chemical Contaminants at Superfund Sites. http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/index.htm

EPA. 2013. OSWER Final Guidance for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Sources to Indoor Air (External Review Draft).

Geraghty & Miller (G&M). 1997a. LUST Quarterly Monitoring Report, Fourth Quarter 1996, Former Firestone Service Center. April 2, 1997.

G&M. 1997b. Corrective Action Plan for Former Bridgestone/Firestone Site. July 25, 1997.

Hanson, R.T., and J.F. Benedict. 1994. Simulation of ground-water flow and potential for land subsidence, Upper Santa Cruz basin, Arizona: U.S. Geological Survey, Water-Resources Investigations Report 93-4196, 47 p.

Houser, B.B. L. Peters, R.P. Esser, and M.E. Gettings. 2005. Stratigraphy and Tectonic History of the Tucson Basin, Pima County, Arizona, Based on the Exxon State (32)-1 Well. U.S. Geological Survey Scientific Investigations Report 2004-5076. 37 p.

Hydro Geo Chem, Inc. (HGC). 2004a. Groundwater and Soil Gas Monitoring Report, March 2004, 7th Street and Arizona Avenue WQARF Site, Tucson, Arizona. May 25, 2004.

HGC. 2004b. Groundwater and Soil Gas Monitoring Report, May 2004, 7th Street and Arizona Avenue WQARF Site, Tucson, Arizona. June 21, 2004.

HGC. 2005a. Groundwater Monitoring Report, February 2005, 7th Street and Arizona Avenue WQARF Site, Tucson, Arizona. March 31, 2005.

HGC. 2005b. Groundwater Monitoring Report, May 2005, 7th Street and Arizona Avenue WQARF Site, Tucson, Arizona. June 24, 2005.

HGC. 2006a. Field Work Plan, 7th Street and Arizona Avenue WQARF Site, Tucson, Arizona. January 9, 2006.

HGC. 2006b. Draft Work Plan Addendum, 7th Street and Arizona Avenue WQARF Site, Tucson, Arizona. February 17, 2006.

HGC. 2006c. Groundwater Monitoring Report, November 2005, 7th Street and Arizona Avenue WQARF Site, Tucson, Arizona. March 13, 2006.

HGC. 2006d. Groundwater Monitoring Report, May 2006, 7th Street and Arizona Avenue WQARF Site, Tucson, Arizona. July 27, 2006.

HGC. 2007a. Monitor Well Installation Report, 7th Street and Arizona Avenue WQARF Site, Tucson, Arizona. June 8, 2007.

HGC. 2007b. Groundwater Monitoring Report, April 2007, 7th Street and Arizona Avenue WQARF Site, Tucson, Arizona. July 27, 2007.

HGC. 2008a. Groundwater Monitoring Report, October 2007, 7th Street and Arizona Avenue WQARF Site, Tucson, Arizona. January 11, 2008.

HGC. 2008b. Monitor Well Installation Report, 7th Street and Arizona Avenue WQARF Site, Tucson, Arizona. January 21, 2008.

HGC. 2008c. Air Sparge Pilot Testing Report, 7th Street and Arizona Avenue WQARF Site, Tucson, Arizona. February 28, 2008.

HGC. 2008d. Groundwater Monitoring Report, April 2008, 7th Street and Arizona Avenue WQARF Site, Tucson, Arizona. June 25, 2008.

HGC. 2008e. 2008 Operation and Maintenance Summary Report, 7th Street and Arizona Avenue WQARF Site, Tucson, Arizona. August 18, 2008.

HGC. 2012a. Soil Gas Sampling & Well Abandonment, ADEQ Task Assignment No. ADEQ 12-011179. January 16, 2012.

HGC. 2012b. Groundwater Monitoring and Soil Gas Sampling Report, May 2012, 7th Street and Arizona Avenue WQARF Site, Tucson, Arizona. July 20. 2012.

HGC. 2012c. Groundwater Monitoring Report, October 2008, 7th Street and Arizona Avenue WQARF Site, Tucson, Arizona. October 17, 2012.

HGC. 2013. Remedial Investigation/Feasibility Study Work Plan, 7th Street and Arizona Avenue WQARF Site, Tucson, Arizona. March 8, 2013.

Johnson, P.C. and R.A. Ettinger. 1991. Heuristic model for predicting the intrusion rate of contaminant vapors into buildings. Environmental Science and Technology, v. 25, p. 1445-1452.

Kleinfelder and HGC. 2003. Early Response Action Evaluation Report, 7th Street and Arizona Avenue Water Quality Assurance Revolving Fund (WQARF) Site Tucson, Arizona. July 2003.

Mason, D.A., and L. Bota. 2006. Regional Groundwater Flow Model of the Tucson Active Management Area, Tucson, Arizona: Simulation and Application. Arizona Department of Water Resources, Modeling Report No. 13.

National Climatic Data Center (NCDC). 2011. 1981–2010 U.S. Normals Data. http://www.ncdc.noaa.gov/cdo-web/datasets/NORMAL_DLY/stations/GHCND:USW00023160/detail

Pankow, J.E. and J.A. Cherry. 1996. Dense chlorinated solvents and other DNAPLs in groundwater: History, behavior, and remediation. Waterloo Press (Portland, OR) 522 p.

Petro Enviro Tech, 1990. Site Characterization: September 1990, Yellow Cab of Tucson. September 1990.

Sheppard, P. R., A. C. Comrie, G. D. Packin, K. Angersbach and M. K. Hughes. 2002. The climate of the US Southwest. Climate Research 21(3): 219-238.

Woodward-Clyde. 1994. Site Characterization Report, Former Firestone Service Center, Tucson, Arizona, LUST #4715.0505, FAC I.D. #0-007556. August 1994.

11. LIMITATIONS

The opinions and recommendations presented in this report are based upon the scope of services and information obtained through the performance of the services, as agreed upon by HGC and ADEQ. Results of any investigations, tests, or findings presented in this report apply solely to conditions existing at the time HGC's investigative work was performed and are inherently based on and limited to the available data and the extent of the investigation activities. No representation, warranty, or guarantee, express or implied, is intended or given. HGC makes no representation as to the accuracy or completeness of any information provided by other parties not under contract to HGC to the extent that HGC relied upon that information. This report is expressly for the sole and exclusive use of ADEQ and for the particular purpose that it was intended. Reuse of this report, or any portion thereof, for other than its intended purpose, or if modified, or if used by third parties, shall be at the sole risk of the user.