WASHOE COUNTY DEPARTMENT OF WATER RESOURCES

Central Truckee Meadows Remediation District

2006 Annual Groundwater Monitoring Report

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LIST OF ACRONYMS AND ABBREVIATIONS

AMSL	above mean sea level
bgs	below ground surface
C	Celsius/Centigrade
CFR	Code of Federal Regulations
County	County of Washoe
°	degrees
DCA	dichloroethane
DCE	dichloroethylene
DNAPL	dense non-aqueous phase liquid
DPW	Department of Public Works
DWR	Washoe County Department of Water Resources
GAC	granular activated carbon
gpm	gallons per minute
K	hydraulic conductivity
m	meters
MCL	maximum contaminant level
MDL	method detection limit
NCDC	National Climate Data Center
ND	not detected
PCE	tetrachloroethylene
QA	quality assurance
QAPP	Quality Assurance Project Plan
QC	quality control
RAP	Remedial Action Plan
RCRA	Resource Conservation and Recovery Act

RI	Remedial Investigation
RI/FS	Remedial Investigation/Feasibility Study
SAP	Sampling and Analysis Plan
TCA	trichloroethane
TCE	trichloroethylene
TDS	total dissolved solids
TSS	total suspended solids
UCL	upper confidence limit
ug/kg	micrograms per kilogram
ug/L	micrograms per Liter
USCS	Unified Soil Classification System
U.S. EPA	United States Environmental Protection Agency
USGS	United States Geological Survey
UST	underground storage tank
VOCs	volatile organic compounds

EXECUTIVE SUMMARY

In the 1980's, the United States Environmental Protection Agency (EPA) began requiring municipal water systems to initiate monitoring for tetrachloroethene (PCE), a possible human carcinogen. In 1987, water from municipal supply wells in the Reno/Sparks area was first tested for PCE. PCE was detected in concentrations exceeding proposed drinking water standards in five of these wells. Groundwater wells in the central Truckee Meadows (CTM) are vital components of the local water supply system. These wells are needed to meet peak seasonal water demands or during times when Truckee River water is unavailable or is temporarily of poor quality. In 1995, the Nevada Legislature passed Senate Bill 489, providing the Washoe County Board of Commissioners (BCC) with the authority to create a district for the remediation of a groundwater contamination condition identified by the District Health Officer and by the Nevada Division of Environmental Protection (NDEP) Administrator. The Central Truckee Meadows Remediation District (CTMRD) program was created by the BCC in response to the widespread PCE contaminated groundwater recognized in the CTM by the District Health Officer and by the NDEP Administrator.

The CTMRD program provides a mechanism to prevent, protect, and mitigate PCE-impacted groundwater and also provides liability protection to those owners of impaired parcels whose activities have not contributed to the PCE contamination. The Washoe County Department of Water Resources (DWR) is charged with administering the CTMRD program on behalf of the BCC. Remediation fees are levied (in accordance with NRS 540A.265) against land parcels in the effected area. A large portion of the remediation fees have been utilized to date for the installation and operation of PCE treatment facilities for five municipal water supply wells. These facilities were installed at a cost of $6.2 M and presently treat approximately 1.5 billion gallons of water per year. The remediation fees have also been used for the development of the Remediation Management Plan (RMP), which by state statute (NRS 540A.260) must accommodate "any action which is reasonable and economically feasible in the event of the release or threat of release of any hazardous substance (in this case PCE) which may affect the water quality in this state." The RMP was developed and approved by the BCC in October 2002 and by NDEP in April 2003. The RMP defines the processes, procedures, and activities implemented to investigate and remediate PCE contamination within the CTM. These processes, procedures, and activities include regular and systematic groundwater monitoring in the CTM.

Groundwater monitoring provides the fundamental information needed to characterize and evaluate contaminant impacts to groundwater as well as to support the identification of those portions of the basin where specific potential sources of PCE that have resulted in the groundwater plumes are most likely to be located. In order to effectively monitor the widespread groundwater contamination by PCE in the CTM, DWR developed a Groundwater Monitoring Plan or GMP (Intera, 2004). The GMP describes the process for monitoring PCE and other related volatile organic compounds (VOCs) in groundwater in the CTM. The GMP was implemented by DWR beginning in December 2003, at which time the first, regularly scheduled, quarterly groundwater monitoring event was conducted.

The goals of the GMP include:

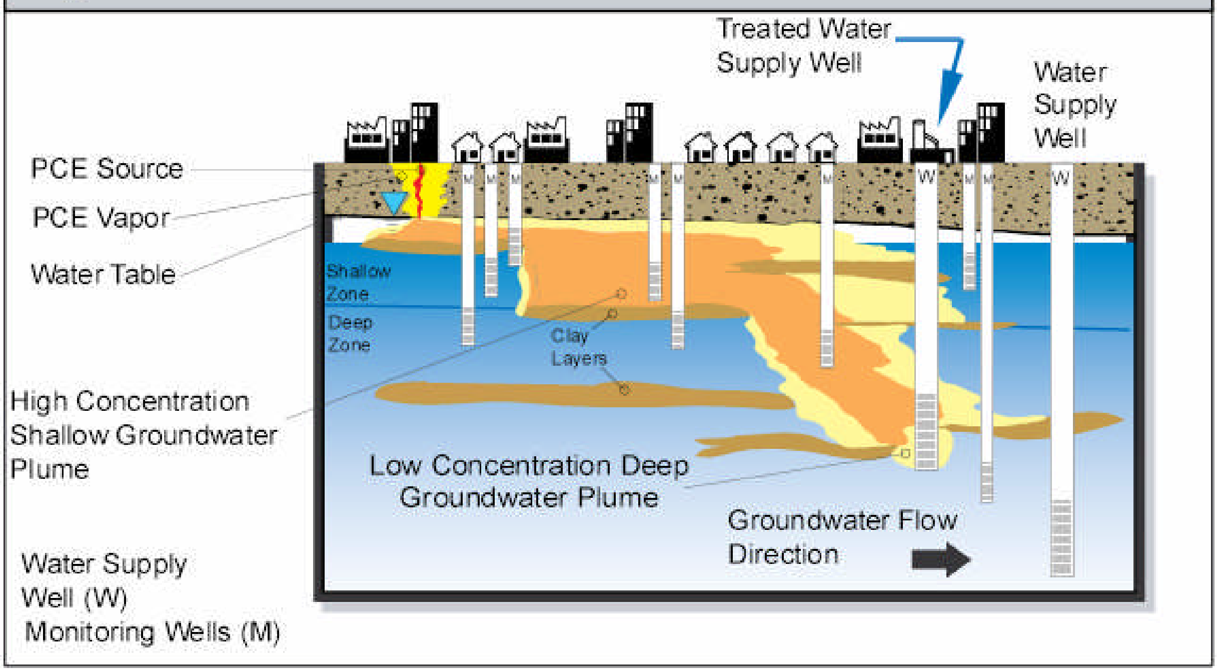
- Verifying data quality to ensure program objectives specified in the Quality Assurance Project Plan (QAPP) of the GMP (Intera, 2004) are met.
- Assessing lateral and vertical groundwater gradients and flow and water level trends over time using systematically collected groundwater elevation data.
- Systematically sampling groundwater quality to assess the horizontal and vertical distribution of PCE in the CTM.
- Evaluating the data generated through the GMP to gain a better understanding of PCE occurrences and transport mechanisms in the CTM.
- Identifying data gaps in the understanding of PCE occurrence and migration in the CTM.
- Providing recommendations for addressing key gaps in the information (i.e. “data gaps”) needed to meet the goals of the GMP.

GMP results have contributed to the current understanding that groundwater bearing zones in the CTM are contained in a complex three-dimensional aquifer system. This understanding has evolved significantly beyond previous representations of two principal water bearing aquifers in the CTM basin, vertically separated by a laterally extensive zone of lower permeability geologic materials. The terms Shallow Zone (instead of the previously used shallow aquifer) and Deep Zone (instead of the previously used deep aquifer) are now considered to be a more accurate representation of the aquifer and are being used for the categorization and presentation of groundwater monitoring data. This terminology also recognizes the utility in distinguishing the Shallow Zone: where PCE discharged from source areas first impacts groundwater; from the Deep Zone: where PCE contaminated groundwater originating in the Shallow Zone is captured by municipal water supply wells. These groundwater-bearing zones can be at least locally separated by lower permeability geologic layers or aquitards which prevent or reduce the vertical movement of groundwater (and contaminants). Previous representations of the CTM basin have inferred that the aquitards in the CTM are laterally extensive and provide significant hydraulic separation between the shallow and deep water bearing zones. This suggests that contaminants that might encounter groundwater close to the ground surface pose little risk to municipal water supply wells completed at much greater depths. Through evaluation of data generated during the GMP it is becoming increasingly evident that this is not the case. While several laterally discontinuous lower permeability geologic layers appear to provide some degree of local impedance to the vertical movement of groundwater and contaminants, the vertical extent of contamination and the shallow zone indicates that in other parts of the basin the Shallow and Deep Zones are in good hydraulic communication.

GMP results to date have defined a number of distinct areas of groundwater contaminated by PCE. These include seven Shallow Zone and three Deep Zone plumes. The ability to define the nature and extent of the groundwater contamination plumes is a function of the existing monitoring well network.

These plumes, as defined, may change (with respect to location and morphology) over time in response to groundwater movement or as additional monitoring wells are added to the network (as a function of surface location and the depth to which they are completed). The Shallow and Deep Zones are useful constructs for graphically representing the plumes but, in reality, the plumes that have been identified as shallow-deep pairs are three-dimensional features that are continuous across these zones. There are presently three Deep Zone plumes that have been identified (South Reno, Downtown Reno, and Downtown Sparks) as being a downward vertical projection of at least one Shallow Zone plume (Vassar / East Plumb, West 4th Street, and Victorian Avenue, respectively). Accordingly, every Deep Zone plume has at least one Shallow Zone plume spatially associated with it as a counterpart. This relationship reflects both a common origin for these plumes and a hydraulic connection between the Shallow and Deep Zones.

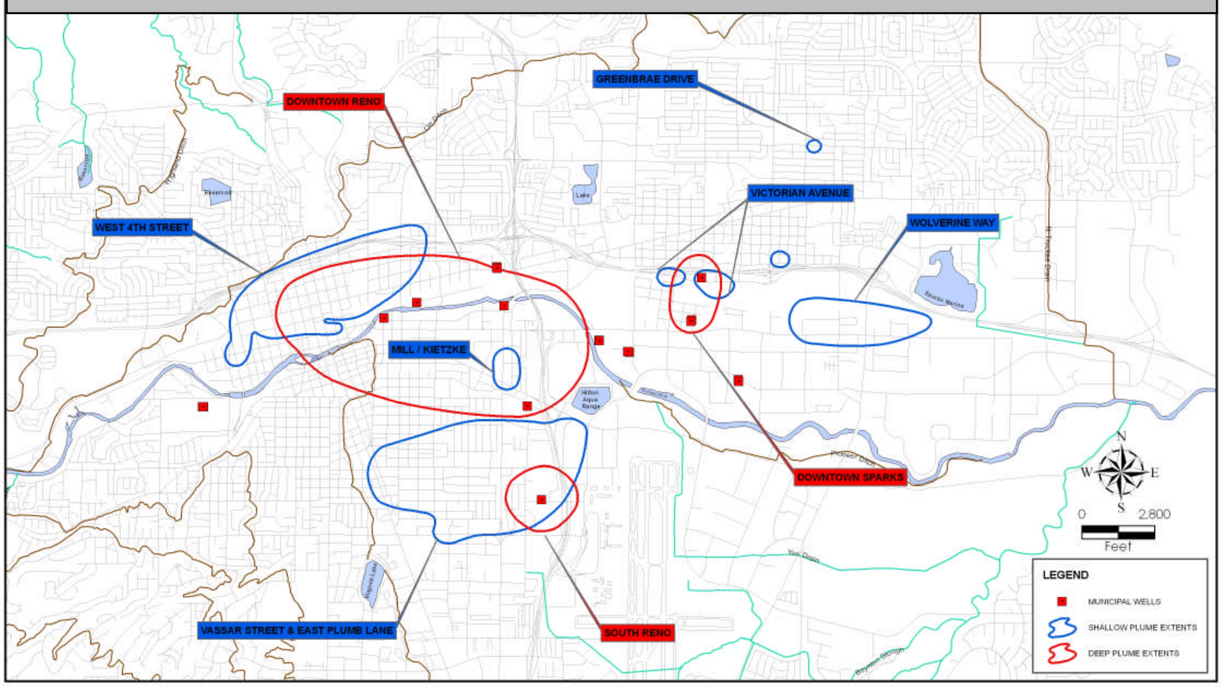
Figure E-1: Schematic PCE Contamination Cross Section



The three-dimensional nature of these contaminant plumes is shown schematically in **Figure E-1**. The man made nature and use practices for PCE require that the existing PCE groundwater contamination in the CTM must have originated at or near the ground surface at some time in the past. The presence of PCE plumes in the Deep Zone requires that PCE move vertically from the ground surface through the Shallow Zone and into the Deep Zone. An increased vertical hydraulic gradient associated with recharge from the Truckee River in the Shallow Zone and/or municipal well pumping in the Deep Zone is likely to have drawn the PCE contamination from the Shallow Zone down into the Deep Zone. This contamination would be readily drawn into the Deep Zone in areas where any hydraulic barrier separating the Shallow and Deep Zones is less developed or absent. The ultimate fate of PCE in the Deep Zone is migration toward and capture by a municipal water supply well (or other deep pumping well) where the PCE is removed from the aquifer. As shown in **Figure E-2**, each of the three presently recognized Deep Zone plumes has already reached a receptor well. There are currently three Shallow Zone plumes that do not yet appear to have reached the Deep Zone, based on the existing monitoring well network, or to have impacted a receptor well. These are the Mill / Kietzke, Wolverine Way, and Greenbrae plumes. These plumes pose a potential risk to existing wells and may also result in impacts to those wells unless preventative measures are taken.

Data gaps have been identified in the course of implementing the GMP to date. Addressing these data gaps will contribute to meeting the goals and objectives of the GMP. The following discussion summarizes several of the key data gaps and the recommendations for addressing them.

Figure E-2: 2006 Q1 Shallow and Deep PCE Plumes



Deficiencies in the Existing Monitoring Well Network

Many of the monitoring wells currently utilized as part of the GMP network were installed during the initial assessments for PCE in the CTM or were installed for other purposes not directly related to the

PCE contamination of groundwater. Based on what we know now, these wells are not optimally located, spaced, or designed for defining the extent of specific PCE plumes; or the pathways along which PCE could migrate from source areas, through a complex hydrogeologic environment, toward existing and/or potential receptors (i.e. municipal water supply wells). Vertical movement is an extremely important component of both groundwater flow and contaminant transport in the CTM. The migration of PCE (which is chemically stable and persistent under typical groundwater conditions in the CTM) from sources at or near the ground surface through the Shallow Zone to receptor wells in the Deep Zone allows this contaminant to be considered a chemical "tracer". The present distribution of PCE in the CTM is a direct indication that both lateral and vertical groundwater flow and PCE transport are and have been taking place. Additional wells to expand and/or augment the existing monitoring well network will be required in order to:

- Locate and characterize the specific places in the CTM where effective hydraulic communication exists between the Shallow Zone and the Deep Zone. This is an essential consideration in the ability to identify which Shallow Zone near source PCE plumes represent the greatest risk to the groundwater resource and to prioritize CTMRD program activities accordingly.
- Fill gaps in local hydrostratigraphic data, support preparation of additional detailed hydrogeologic cross sections, provide additional vertical control for PCE plume delineation, and address the lack of strategically placed key wells for PCE plume characterization.

Limited Information on Potential PCE Sources

Many current and historical Potentially Contaminating Activities or PCAs (such as PCE-using businesses) have been identified in the CTM, but relatively few confirmed PCE releases have been reported, relatively few specific PCE source areas have been identified, and even fewer PCE source areas have been evaluated to date.

- Leaking sanitary sewer lines can act as dispersed secondary sources of PCE. This potential release mechanism has been investigated in a limited number of targeted areas to date.
- A relatively small number of corrective actions have been undertaken or are underway at specific potential source areas. Most of these have yet to be completed.
- While it appears unlikely at this time that there are undiscovered major plumes in the CTM, there is the possibility/probability that additional, as yet unidentified sources and/or hot spots may exist. The significance of this data gap is highest for subregions where unprotected pumping wells (wells without wellhead treatment) exist.

- The persistent nature of and generally consistent PCE concentrations in groundwater plumes in the CTM suggests they may originate from relatively robust residual contaminant sources; however these sources have yet to be adequately identified and/or characterized.

Elevated concentrations of PCE have been detected in near surface soil, soil gas, and Shallow Zone groundwater at several potential source areas (PSAs) to date. However, the nature of and specific source(s) for the PCE contamination at these PSAs has yet to been determined and the potential threat posed to groundwater resources and human health by contamination present at these PSAs has not yet been adequately assessed.

DWR has identified four of these PSAs or “hot spots” associated with recognized PCE groundwater plumes in the CTM to undergo further investigation. These PSAs include: Downtown Sparks, the Mill/Kietzke area, the Vassar/E. Plumb area, and the W. 4th Street area. Additional investigation is needed in these areas in order to:

- Characterize the magnitude and extent of contamination;
- Assess the threat posed to groundwater;
- Assess other possible human health risks associated with these hot spots;
- Identify specific sources that may have contributed to these hot spots; and,
- Provide information to support a cost-benefit assessment of possible PCE source mitigation.

Results from these activities may be presented to NDEP or the Washoe County District Health Department (WCDHD) as the appropriate regulatory authorities, in accordance with the CTMRD Program Remediation Management Plan (RMP) approved by the Board in October 2002.

Gaps in the Understanding of Subsurface Lithology and Hydrostratigraphy

The systematic evaluation of the CTM hydrostratigraphy is being conducted to form a basis for addressing gaps in the understanding of subsurface lithology and hydrostratigraphy. This is being done using data from existing boreholes in conjunction with the development of a geological conceptual model to support the groundwater flow and transport model of the CTM. This evaluation will include:

- A representation of local and basin scale hydrostratigraphy with a more geologically consistent, systematic, and better documented framework for identifying/defining principal water-bearing units, as well as lithologic or structural impediments to groundwater (and contaminant) movement in the CTM;

- The identification and hydrogeological characterization of those areas within the CTM where vertical movement of groundwater (and contaminants) is relatively enhanced and movement from the Shallow to Deep Zone occurs; and
- Characterizing the detailed hydrostratigraphy and possible lithologic controls on PCE movement in and around potential contaminant source areas.

Addressing these data gaps will contribute to a geological conceptual model that: more accurately represents the hydrogeology of the CTM; more effectively supports a groundwater flow and contaminant transport model with improved predictive capabilities; and, provides increased probability of identifying areas where the hydraulic connection between the Shallow and Deep Zones (where municipal water supply wells are completed) is relatively well developed and greater risk to the local groundwater supply from PCE contamination is present.

Location and Nature of Subsurface Faults and/or Lithologic Discontinuities

The location, nature, and hydrogeologic properties of known, probable, and/or possible subsurface faults and/or lithologic discontinuities are presently poorly constrained in the CTM. The apparent importance of these features as influences on groundwater flow in both the Shallow and Deep Zones is becoming increasingly evident. These features are likely to also influence contaminant movement. The actual location of these hydraulic flow barriers is only relatively well constrained in a few locations where data from existing nearby wells clearly define pronounced changes in the water level elevation gradient or sharp apparent deviations in the groundwater flow direction. Data gaps associated with known, probable, and possible hydraulic flow barriers that have been identified to date include the following:

- The location, geologic character, and hydraulic properties of the Virginia Lake Fault Zone (VLFZ) are poorly constrained and inadequately understood.
- The location, geologic character, and hydraulic properties of the Harvard Way Barrier (HWB) are poorly constrained and inadequately understood.
- The effect and potential significance of the VLFZ and HWB have been high lighted as a result of the data analysis conducted as part of the GMP. It is possible (and perhaps likely) that other geological structures that function as hydraulic barriers will be recognized in the CTM.

Pumping tests using appropriately located pumping and observation wells could be used to substantiate the location and hydraulic properties of currently recognized hydraulic flow barriers (such as the VLFZ and HWB) along with other, yet to be recognized barriers.

Local Groundwater Flow Direction and Sources of Recharge

Existing data suggest that there is a significant local source of Shallow Zone recharge in the CTM. This source of recharge appears to drive downward vertical groundwater gradients and helps recharge the underlying Deep Zone by replacing groundwater that is removed during the seasonal pumping of municipal water supply wells. An obvious local recharge source is the Truckee River. The quantification of recharge derived from the Truckee River (as compared to other potential sources of Shallow and Deep Zone recharge, such as mountain front recharge and artificial recharge programs) is warranted. The data suggest that in some portions of the CTM, Shallow Zone recharge occurs more readily and at higher rates than in others.

Artificial recharge has a potentially significant effect (at least locally) on seasonal water levels. Artificial recharge can also affect vertical and lateral groundwater flow patterns. However, the influence of artificial recharge on PCE plume mobility has not yet been evaluated and is not well understood at this time. A better understanding of the potential influence of artificial recharge on plume capture or containment is needed.

In some areas, a Shallow Zone response to municipal well pumping in the Deep Zone pumping has been observed. In other circumstances, no such response is apparent. A lack of such a response could reflect differences in hydrostratigraphy, a source for rapid local recharge, and/or the effect caused by a hydraulic barrier (such as the VLFZ, HWB, or another as of yet unrecognized barrier). Alternatively, the magnitude of the Shallow Zone response could simply be unrecognized given the placement and/or resolution capabilities of the existing Shallow Zone monitoring network.

Groundwater flow and contaminant transport are strongly influenced both by recharge and by municipal water supply well pumping. The effect and interaction of these factors is strongly seasonal in nature. While the qualitative understanding of these influences has been substantially improved as a result of the 2006 GMP data analysis, additional hydrogeologic and hydrostratigraphic data are needed to quantify these influences, their relative importance, and their distribution. Addressing these data gaps will require a combination of activities including: the development of detailed hydrogeologic cross sections; and,the installation, logging and test pumping of wells targeted to specific depths and locations. These activities would be conducted in tandem with the creation of a hydrogeologic conceptual model to support the development of a groundwater flow and contaminant transport model of the CTM.

1. INTRODUCTION

This 2006 Annual Report summarizes the methods, results and findings of the 2006 first through fourth quarter (2006 Q1 to Q4) monitoring events conducted as part of the Groundwater Monitoring Plan (GMP) in support of the Central Truckee Meadows Remediation District program. The report also presents the most current understanding of groundwater flow and contaminant transport in the Central Truckee Meadows (the "Conceptual Model"), an inventory of data gaps in that understanding, and a summary of planned and recommended activities to address those data gaps. The work was performed pursuant to Purchase Order No. 5500005206 from Washoe County, dated August 3, 2006. The location of the Study Area is presented in **Figure 1.1**. **Figure 1.3** presents an overview of physical features in the Study Area. **Figure 1.4** shows the distribution of the contamination plumes that are the subject of this monitoring program.

1.1 Groundwater Monitoring Program Background

In the 1980's, the United States Environmental Protection Agency (EPA) began requiring municipal water systems to initiate monitoring for tetrachloroethene (PCE), a possible human carcinogen. PCE, a chlorinated organic solvent also known as perchloroethylene, tetrachloroethylene, or PERC, has been used extensively since the 1940's in chemical manufacturing and as a cleaner or degreaser. It has also been used in a variety of commercial/industrial operations including dry cleaning, auto repair and service stations, paint and machine shops, and chemical manufacturing. PCE use has declined since the late 1980's, with dry cleaning and chemical manufacturing being the principal uses of PCE today.

In 1987, water from municipal supply wells in the Reno/Sparks area was first tested for PCE. PCE was detected in concentrations exceeding proposed drinking water standards in five of these wells. Groundwater wells in the Central Truckee Meadows (CTM) need to meet the water demands of the area when the Truckee River has poor water quality or low flow conditions, and are vital components in the local water supply system. The State of Nevada Division of Environmental Protection (NDEP) completed studies in 1994 (Westec/SRK, 1994) concluding that PCE contamination of groundwater in the CTM was widespread and probably originated over time from many possible sources. Many of the sources were businesses that have been out of operation for many years (DWR, 2004).

In 1995, the Nevada Legislature passed Senate Bill 489, providing the Washoe County Board of Commissioners (BCC) with the authority to create a district for the remediation of a groundwater contamination condition identified by the District Health Officer and by the NDEP Administrator. The Central Truckee Meadows Remediation District (CTMRD) program was created in response to the PCE contaminated groundwater in the CTM. The CTMRD program provides a mechanism to mitigate the PCE-impacted groundwater and also provides liability protection to innocent property owners. The Washoe County Department of Water Resources (DWR) is charged with administering the CTMRD program on behalf of the BCC. In 1997, the Nevada State Legislature amended the Nevada Revised Statutes with the addition of NRS 540A.250 through 285 to include a mechanism to fund the CTMRD program. Beginning in July 1998 (the Washoe County 1998-1999 fiscal year), a “Remediation District fee” was added to property tax bills for water-using parcels served by water purveyors with wells located within the affected area.

A large portion of the collected remediation fees have been used for installation and operation of PCE treatment facilities for five municipal water supply wells. Additionally, these funds have been used for the development of the Remediation Management Plan (RMP), which by state statute (NRS 540A.260) must accommodate “any action which is reasonable and economically feasible in the event of the release or threat of release of any hazardous substance which may affect the water quality in this state.” The RMP was developed and approved by the BCC in October 2002 and by NDEP in April 2003. The RMP defines the processes and procedures utilized to investigate and remediate PCE contamination within the CTM, an essential element of which is groundwater monitoring. Groundwater monitoring provides the information used to characterize and evaluate the contaminant impacts to groundwater as well as to help identify potential sources of the PCE contamination. In order to effectively monitor the widespread groundwater contamination by PCE in the CTM, DWR developed a Groundwater Monitoring Plan (GMP - Intera, 2004). The GMP describes the process for monitoring PCE and other related volatile organic compounds (VOCs) in groundwater in the CTM. The GMP was implemented by DWR beginning in December 2003, at which time the first, regularly scheduled, quarterly groundwater monitoring event was conducted.

1.2 Groundwater Monitoring Program Objectives

Based on findings and results of GMP and RMP implementation to date, the following were the GMP objectives for 2006.

- Verify data quality and work with the contracted analytical laboratory to ensure that the data generated meets program objectives as specified in the Quality Assurance Project Plan (QAPP, contained in Intera, 2004).
- Collect monthly water level data.
    - Use these data to prepare quarterly potentiometric surface maps to assess the lateral groundwater gradient and flow direction over the course of the year.
    - Prepare vertical water level difference maps to assess potential vertical gradients and flow as well as potential vertical gradients and flow over the course of the year.
    - Prepare hydrographs for selected wells to assess water level trends over time.
- Sample wells in the monitoring program to assess the horizontal and vertical distribution of PCE in the CTM.

  - Evaluate PCE plume maps to characterize the distribution and potential migration of PCE in each plume.
  - Evaluate short and longer term PCE concentration trends in key wells in each plume area to assess contaminant migration and trends.

- Evaluate the GMP data generated in 2006 to gain a better understanding of PCE occurrence and transport in the CTM and prepare an up-to-date conceptual model, including the following specific tasks.
  - Evaluate the distribution of vertical hydraulic flow gradients in the CTM and how the gradient may change during the course of a year.
  - Evaluate the potential for vertical migration of PCE.
  - Identify known potential PCE contamination sources in each plume area and their relationship to recognized groundwater contamination.
  - Interpret lateral and vertical groundwater flow patterns and PCE transport in light of the following new data:
    - lithologic sections prepared by the DWR;
    - data regarding possible faults and groundwater flow barriers; and
    - data from aquifer tests conducted by DWR and others.
  - Assess the capture of known PCE plumes by receptor wells, the potential for concentrations in impacted municipal water supply (i.e. “receptor”) wells to change, and the potential that contamination will migrate to other municipal water supply wells that are not yet impacted.
- Identify data gaps to the understanding of PCE occurrence and migration in the CTM.
- Provide recommendations for activities to address data gaps.

1.3 Report Organization

The remainder of this report is organized as follows:

Section 2 includes an overview of the physical, geologic and hydrogeologic setting of the CTM.

Section 3 summarizes the field and laboratory methods and results of the 2006 groundwater monitoring program.

Section 4 discusses the data validation and data quality assurance evaluations conducted for the 2006 groundwater monitoring program.

Section 5 presents an overview of the current understanding of PCE contaminant hydrogeology in the CTM and presents an overview of the current regional conceptual model for PCE occurrence and transport in the CTM.

Section 6 presents conceptual models of PCE occurrence and transport for each PCE plume identified in the CTM.

Section 7 discusses data gaps identified as a result of the data evaluation, identifies planned activities to address these data gaps, and presents recommendations for additional activities that could be undertaken.

Section 8 includes a list of references cited in the report.

2. CENTRAL TRUCKEE MEADOWS REGIONAL SETTING

2.1 Physical Setting

The Truckee Meadows is a topographic basin bounded by the Virginia Range and Pah Rah mountains to the east, the Carson Range to the west, Steamboat Hills to the south, and the Peavine Mountain to the north. A topographic map showing the relationship of these physical features to the Reno/Sparks area and the Truckee Meadows basin is provided in **Figure 1.1**. A predominant feature in the Truckee Meadows basin is the Truckee River, which flows across the basin from west to east. Other tributary drainages flow into the Truckee River from the north or the south. The most significant tributary to the Truckee River in the Truckee Meadows is Steamboat Creek. Steamboat Creek flows from Washoe Lake, located south of the Truckee Meadows, and collects tributary flows from Galena Creek, Whites Creek, Thomas Creek, and agricultural return flows before joining the Truckee River at the eastern margin of the CTM .

Precipitation in the Truckee Meadows region ranges from approximately 6 to 10 inches per year. According to information provided by the National Oceanic and Atmospheric Administration (NOAA), the average annual precipitation in Reno area during the period from 1895 through 2003 was 7.49 inches per year, with a range of 1 to 13 inches per year. In the higher elevations of the Carson Range, which bound the Truckee Meadows to the west, annual precipitation is on the order of 40 inches per year (H. Klieforth, 1983). Measured precipitation at the Truckee River Ranger Station ranges from 16.04 inches to 54.56 inches per year, with an average annual precipitation of 32.51 inches (McGraw et. al., 2001). Precipitation that falls in the Carson Range and drains to the Truckee Meadows is a significant source of potential recharge to the CTM (either as mountain front recharge or as recharge originating from surface water features such as the Truckee River).

The Study Area is located in the central portion of the CTM as shown on **Figure 1.3**, and includes the core Reno/Sparks urban areas, suburban residential and commercial development, and peripheral undeveloped and/or agricultural land. The Reno/Sparks metropolitan area has the third greatest concentration of people in Nevada; only Las Vegas and Henderson rank higher.

The central portion of the Reno/Sparks metropolitan business and industrial district exists in and along the Truckee River. Downtown Reno is located both south and north of the Truckee River in the northwestern portion of the Truckee Meadows. Older commercial establishments as well as the historical railroad switching yards and corridors lie just east of downtown and west of U.S. Highway 395. Another older commercial and industrial area is located north of the Truckee River in Sparks, east of Reno. This area includes the Sparks Solvent/Fuel Site (SS/FS), the Sparks railroad yard, and numerous other industrial facilities whose operations date prior to 1970. More recent development of additional industrial land uses has expanded to the east of Reno-Tahoe International Airport and east of McCarran Boulevard in Sparks.

2.2 Geology

Five principal rock types comprise the geologic framework for the Truckee Meadows Basin. In order of decreasing age, these include:

- Late Paleozoic to Mesozoic metavolcanic and metasedimentary rocks;
- Mesozoic (Cretaceous) Sierran plutonic rocks;
- Cenozoic (Miocene) andesitic volcanic rocks;
- Cenozoic (Miocene-Pliocene [Neogene]) fluvial and deltaic/lacustrine sedimentary rocks; and
- Quaternary (Pleistocene) glacial outwash with modern fluvial and alluvial deposits.

2.2.1 Bedrock

Metamorphic, plutonic, and volcanic rocks comprise the bedrock that forms the mountains surrounding the Truckee Meadows, the low hills along the margins of the basin, and the basement beneath the younger sedimentary basin fill. These rock types are considered generally impermeable, except for the secondary permeability that has developed with fracturing. Granite outcrops are commonly fractured and jointed, and some fractures are mineralized, indicating groundwater flow at depth in the past. A deeply weathered surface on the plutonic rocks is evident where exposures exist (such as along Somerset Drive). Volcanic rocks are not present as continuous deposits, but rather occur as local accumulations up to hundreds of meters in thickness, probably as a function of proximity to Miocene volcanic centers. The Miocene volcanic rocks are considered to be gradational with the oldest part of the overlying Miocene to Pliocene sediments, although the volcanics unconformably underlie younger parts of the sedimentary section along a buttress unconformity on the east flank of the Carson Range (Cashman and Trexler, 2006). Based on the groundwater model developed by McDonald Morrissey Associates (MMA, 1993) for water resource management, depth to bedrock in the central and south Truckee Meadows basins had previously been characterized as greater than 3,000 feet and 2,500 feet, respectively. A recent reassessment of the Truckee Meadows based on gravity, surface mapping, and drill hole data (Widmer *et al.*, 2006; Widmer, 2006 and 2007) indicates that the Truckee Meadows basin configuration is more complex than had been previously thought and that bedrock depths are generally shallower than had been represented by McDonald Morrissey Associates.

2.2.2 Sedimentary Deposits

Sedimentary deposits in the Truckee Meadows basin consist of moderately consolidated to unconsolidated alluvial, fluvial, deltaic, lacustrine, and glacial materials. These materials are exposed in outcrop along the western margins of, and as fill within, the Truckee Meadows basin. These sedimentary deposits range in age from Miocene to modern and have typically been subdivided into the following two principal categories proposed by Cohen and Loeltz (1964):

- Moderately to poorly consolidated sediments of Miocene to Pliocene age; and
- Unconsolidated sediments of Pleistocene to modern age.

This general categorization has been maintained and used in groundwater models of the CTM basin since the first model was created in 1971 (Cooley and others, 1971).

Miocene to Pliocene Deposits

The Miocene to Pliocene rocks comprising what Cohen and Loeltz (1964) referred to as the "Truckee Formation" are massive to thinly bedded siltstone, silty sandstone, sandy conglomerate, diatomite, and diatomaceous silt- and sandstones exposed in the west and northwest parts of the basin, with the best surface exposures in the area where the Truckee River enters the basin. In the Truckee Meadows basin, these materials have historically been characterized as less permeable than the overlying Pleistocene to modern sediments, even though distinguishing between them within the basin itself can be difficult and quantitative hydraulic properties from where the Miocene to Pliocene materials have been distinguished to date are rare. Recent investigations (Cashman and Trexler, 2006) have described the Miocene to Pliocene sedimentary rocks that occur in the vicinity of the modern Truckee Meadows basin as the "Verdi Basin Sediments" (VBS) based on exposures in and around Verdi, Nevada, west of Reno. The VBS are representative of Neogene sediments deposited in paleo-basins that formed in response to complex intraplate tectonic activity during the northward migration of the Mendocino triple junction, and the progressive change from Cascadian subduction to dextral transform tectonics along the western margin of North America. Some of these paleo-basins (such as the Verdi basin) were subsequently exhumed along the Sierra Nevada – Basin and Range transition zone east of the modern Sierra crest. These Neogene sedimentary systems are considered to be sensitive indicators of local relief, the type of bedrock exposed to erosion, the nature and rate of subsidence, and drainage-basin configuration.

Pleistocene to Modern Deposits

These younger sediments are comprised of Pleistocene glacial outwash and modern fluvial and alluvial deposits. These deposits consist of varying proportions of silt, sand, and gravel that are complexly inter-bedded and inter-layered. Lenses of clay and clayey materials have also been observed. Glacial outwash sediments form significant surface deposits, primarily as mainstream terraces, along the Truckee River corridor from Verdi to west Reno. These poorly consolidated gravels and sands were deposited by the Pleistocene Truckee River system when it carried melt water and sediment from alpine glaciers in the Sierra. These sediments probably form a significant part of the Truckee Meadows basin fill. They are deposited on an angular unconformity with the underlying Neogene sediments.

Glacial terraces along the Truckee River in west Reno have been correlated with four glacial stages in the high Sierra that range in age from as old as 1 Ma (or less) to as young as 11,000 years (Birkeland, 1968; Phillips et al., 1996; Yount and LaPointe, 1997; Howle, 2000). The Hobart is the oldest and highest outwash terrace, and its identification in the Reno area most problematic. The Donner Lake and Tahoe terrace systems are well developed west of Reno. The youngest outwash terrace, Tioga, has not been mapped in the Reno area and is thought to be part of, buried by, or reworked by modern fluvial deposition. There are also uncharacterized higher, and presumed older, terrace surfaces along the Truckee Meadows valley margins; these have not been studied or correlated to glacial deposits in the Sierra.

The progressive eastward tilt of the glacial outwash deposits (Birkeland, 1968) means that glacial deposits (or reworked glacial deposits) are likely to be thicker within the Truckee Meadows basin than they are in the surface exposures west of Reno along the Truckee River corridor. Up to 60 meters of fluvial gravel and sand have been exposed in gravel quarries in the Reno area beneath the modern floodplain (Bell, pers. comm. 2006). Outwash debris is described to have traversed the Truckee Meadows basin and continued down the Truckee River canyon as far as present day Mustang (Birkeland, 1968). Workers in the area envision an alluvial fan of glacial outwash (*i.e.* the Peavine Fan of Bonham and Bingler, 1973) constructed from a point source in west Reno near where the present day Truckee River comes out of the canyon. This fan is not evident in modern topography because it has been tilted gently east and buried by the modern floodplain. The Pleistocene to modern glacio-fluvial sedimentary system may dominate the upper part of basin fill, especially in the north half of the Truckee Meadows basin. The Pleistocene terrace gravels project under the modern valley fill, so the outwash section (or reworked material derived from it) may form a thick wedge of coarse sediment in the Truckee Meadows basin.

2.2.3 Structural Development of Basin

Cashman and Trexler (2006) have described the structural development of the Central Truckee Meadows basin. The following summary has been distilled from their work.

The sedimentary record in the vicinity of the Truckee Meadows basin contains good evidence for deformational episodes both early and late in the basin history, and for no significant tectonism between about 10.5 Ma and 2 or 2.5 Ma. There is no direct evidence for the orientation or sense of faulting associated with basin initiation, but the apparently fault-derived granite-clast breccias near the base of the section suggest significant local topographic relief and therefore probably dip-slip faulting. In addition, complex fault geometries and kinematic evidence of reactivation suggest that at least some of the post-depositional faulting reactivated pre-existing fault surfaces. In particular, the steeply dipping fault surfaces with generally north strikes tend to exhibit oblique-slip motion (see below), which may indicate that these are controlled by the orientation of older surfaces which were reactivated in a new stress field. There are no fault-derived breccias throughout the rest of the Neogene section and sediment compositions indicate intermediate volcanic rocks in the source area, rather than the underlying Sierran granite. The uplift, incision, and high-energy fluvial system at the end of the

Neogene record indicate renewed tectonism, and the faults that offset the Neogene section are a direct record of post-depositional deformation.

Since the end of deposition, the Neogene section has been tilted eastward and folded into a broad, east-plunging syncline. The map pattern of the Neogene section (younger rocks exposed farther to the east) reflects this overall east dip. Bedding dips are not systematically steeper in the older part of the section, so all of the tilting appears to post-date deposition. The exception to this might be the youngest Neogene rocks (the "Gravels of Reno", exposed along West 4th Street) and the glacial outwash terraces (see below). In addition to the general east dip there is a broad synform in the Neogene rocks west of Reno, recording uplift of the Carson Range (to the south) and Peavine Mountain (to the north) relative to the Truckee River corridor.

Pervasive small-scale faults, comprising several fault sets, cut the Neogene section; most appear to have formed after the section was tilted. Although the major fault sets record primarily strike-slip motion, they were (at least in part) active simultaneously, and together accommodate generally east-west extension. A detailed analysis of the pervasive minor faults in the VBS diatomite exposure in the road and railroad cuts on West 4th Street provides insight into the styles and relative ages of post-depositional faulting. It reveals three main fault sets as follows.

- A set of moderately to gently northwest-dipping, down-to-the-northwest normal faults is the oldest fault set in the diatomite exposures along West 4th Street. These faults record extension, and may be in part synchronous with the tilting (although their strikes are oblique, rather than perpendicular, to the tilt direction). These faults were cut by the later faults and were not reactivated during the later faulting.
- North-to northwest-striking, steeply dipping faults exhibit dextral to dextral-normal oblique slip. Bedding, already sub-parallel to these faults, records significant drag folding near the larger faults. This drag folding results in bedding strike parallel to fault strike, and means that slip magnitude determinations using offset marker beds give minimum values, and probably greatly underestimate the total slip.
- Northeast-to east-northeast-striking, steeply dipping faults have sinistral or sinistral-normal oblique slip. They are commonly the most recent faults, but exhibit mutually cross-cutting relationships with dextral faults in several places, indicating that the two sets were, at least in part, active simultaneously. Most of the larger-offset faults in the 4th Street exposure belong to this set.

Deformation apparently continued on into the Pleistocene and possibly the Holocene. Birkeland (1968a) proposed that the Truckee Meadows basin has subsided asymmetrically during the Pleistocene, such that the east part of the basin dropped more than the west, tilting the basin fill to the east. He based this interpretation on the observation that successively older glacial outwash terraces in west Reno and Verdi are tilted more steeply than the modern river gradient, and the glacial terraces are buried at their eastern ends by modern alluvium.

2.2.4 Holocene Faults and Groundwater Flow Barriers

Recent gravity studies (Widmer *et al.*, 2007; Widmer, 2006 and 2007) combined with borehole data have resulted in a three-dimensional, high-resolution depth-to-basement model of the Truckee Meadows basin. This gravity model indicates that the Truckee Meadows basin is not a simple, fault-bounded basin as is typical in the Basin and Range Province. Rather, the basin floor is irregular and likely to result from a combination of displacement along geologic structures and paleo-topography. Some of the linear gravity gradient features have the same orientation as a horst-and-graben structure described at Somersett or as the small-scale fault sets observed in the diatomite exposed along West 4th Street. The faults in the Somersett exposure are demonstrably younger than everything but the soils capping the bluff, which only constrains the fault age there to younger than 10 Ma. However, geometrically, these strike-slip faults must be younger than tilt of the offset beds, or younger than <2.5 Ma.

Evaluation of potentiometric surface maps has identified a step in the Shallow and Deep Zone groundwater levels in a west to east direction across a north-northeast trending lineament associated with a gravity anomaly identified in the above study as well as several possible surface scarps. This contracted steepening of the lateral groundwater flow gradient is consistently observed along a north-south trend between the High Street and Morrill Avenue municipal water supply wells in the north, and between pairs of monitoring wells to the south (CTM49 and CTM50, and CTM14S and CTM15S, **Figures 1.3** and **3.1** through **3.8**). This steepening of the water table is interpreted to be caused by a linear or tabular zone of lower permeability associated with what has been termed the Virginia Lake Fault Zone (Widmer *et al*., 2007).

A similar step in the Deep Zone potentiometric surface is observed between well CTM33D and the Corbett Well, and has been termed the Harvard Way Barrier (HWB, **Figures 1.3** and **3.1** through **3.8**). At this location, there is no apparent step in the overlying Shallow Zone, resulting in a reversal of the vertical gradient from upward on the west side of the step to downward on the east side of the HWB (**Figure 3.9**). Although this feature is also associated with an apparent l gravity anomaly, the linear persistence or trend of this anomaly are not clear, surface expressions of the feature have not been identified and the step in Deep Zone water levels has only been observed at one location. Thus, it is not clear at this point in time whether the HWB is associated with a fault or with a lateral change in lithology. Either possibility could be responsible for the observed water level and gradient change.

The importance of potentially fault related barriers to groundwater flow is being increasingly recognized as an important part of the CTM hydrogeology. Ongoing work may result in the identification of additional hydraulic barriers and/or faults.

2.3 Hydrogeology

From a hydrogeologic perspective, the sedimentary deposits or “basin fill” in the CTM have traditionally been subdivided into two categories (MMA, 1993; CDM, 2002). The “Truckee Formation” (which has, to date, been defined as older and much less permeable materials) and the Quaternary “alluvium” (which has been defined as younger, less consolidated, and more permeable materials). The Quaternary alluvium, as so defined, has also historically been subdivided into the "younger" and "older" alluvium (Cohen and Loeltz, 1964).

As applied to the CTM, the Truckee Formation label is now recognized as a misnomer that has been applied in the past to the Neogene sedimentary rocks in the vicinity. These Neogene rocks are herein now called the Verdi Basin sediments (VBS), based on the work of Cashman and Trexler (2006) (see **Section 2.2.2**). The Quaternary sediments are some of the principal aquifer materials through which groundwater readily flows in the central Truckee Meadows and within which many municipal water supply wells have been completed (particularly in central and west Reno and along the Truckee River corridor). While the Quaternary sediments include some of the most transmissive materials known within the Truckee Meadows, some productive municipal water supply wells are now considered to also have been completed in the VBS. The near surface occurrence of transmissive materials like the Quaternary alluvium is likely to provide pathways through which contaminants (such as PCE) released at the surface can migrate. Along the Truckee River corridor, the potential for long-term down-cutting through and reworking of older sediments is also likely to have a significant influence on the potential vertical movement of groundwater and contaminants such as PCE.

As presented in the RMP (CDM, 2002), the geophysical logging and short-term transient monitoring performed during the initial Work Plan Development and Implementation Phase of the CTMRD program suggested a large ratio of horizontal hydraulic conductivity to vertical hydraulic conductivity (k_h/k_v) in the sediments within the CTM basin. It was suggested at the time that this apparent vertical anisotropy was caused by alternating high and low energy depositional environments that can be typical in valley fill deposits. Such dynamic depositional environments often result in discontinuous and interlayered coarse-grained and fine-grained materials, which in turn result in significant vertical anisotropy. However, the heterogeneity of these deposits can also result in a lack of continuity of the lower permeability materials, so that significant vertical groundwater flow is possible. The hydraulic conductivity of the bedrock materials has always been represented to be low. If that is indeed the case, the amount of water transmitted through the granodiorite and Tertiary volcanic rocks into the CTM basin may be relatively small.

2.3.1 Groundwater Flow

Groundwater moves beneath the land surface from areas of higher hydraulic head to areas of lower hydraulic head. Within the central Truckee Meadows, groundwater generally flows from west to east from the Sierra Nevada of the Carson Range toward the gap between the Pah Rah and Virginia Ranges through which the Truckee River leaves the basin. Locally, the direction of groundwater flow can be influenced by well pumping, underground injection of water, by the infiltration of water from the Truckee River, and by hydraulic flow barriers associated with geological features such as possible faults.

Shallow Zone

Since the implementation of the GMP in 2003 Q4, groundwater in the CTM has been consistently shown (Intera, 2006a and 2006b) to generally move from west to east in the Shallow (water table) Zone. A contracted steepening of the lateral groundwater flow gradient is consistently observed along a north-south trend between the High Street and Morrill Avenue municipal water supply wells in the north, and between pairs of monitoring wells to the south (CTM49 and CTM50, and CTM14S and CTM15S). This steepening of the water table is interpreted to be caused by a linear or tabular zone of lower permeability associated with what has been termed the Virginia Lake Fault Zone (Widmer *et al*., 2007). East and west of this zone of lower permeability, the water table groundwater contour lines are more widely spaced indicating relatively higher permeability sediments.

Groundwater flow in the Shallow Zone generally parallels the Truckee River. In the western portion of the CTM, the groundwater contours are generally straight and orthogonal to the river flow direction. As such, the contoured groundwater elevations show little influence from the river in this area, which could indicate that there is in fact little influence from the river on the Shallow Zone, and/or that infiltrated groundwater moves rapidly through the Shallow Zone to the Deep Zone and away from the river. In the central portion of the CTM, in the vicinity of downtown Reno, groundwater contours are deflected downstream as they cross the river, which suggests groundwater mounding associated with infiltration of river water. Continuing east, groundwater contours are deflected upstream and reflect movement toward the Truckee River and the gap between the Pah Rah and Virginia Ranges and discharge from the basin. The low-lying areas along eastern margins of the CTM near the base of the Pah Rah and Virginia Ranges are where the water table is most likely to intercept the ground surface and produce the springs and wetlands that have historically been common in those areas.

Aside from the above generalizations, little specific information is available to characterize the relationship between the Truckee River and the Shallow Zone and further study would be needed to better characterize the influence of the river on lateral and vertical groundwater flow. Localized high water table elevations have consistently been observed at CTM21S (near the intersection of Kietzke Lane and Kuenzli Street). CTM21S is a relatively shallow well, screened from 16 to 36 ft below ground surface (bgs), installed in proximity to the Truckee River. The relatively elevated water level at this well suggests a hydraulic connection to the river and associated infiltration. The silty sand layer in which this well is completed may be causing the infiltrating surface water to build-up or mound making this a perched water zone.

Deep Zone

Groundwater in the Deep Zone also generally moves from west to east. Review of quarterly Deep Zone groundwater elevation maps generated as part of the GMP to date (Intera, 2006b) show changes in Deep Zone water level elevation contours in response to pumping of the municipal water supply wells. The largest area of depressed Deep Zone groundwater levels connects the Downtown Reno and South Reno plume areas and causes groundwater from a large portion of the Deep Zone to be drawn toward the municipal water supply wells that occur in this area. Periodic localized cones of depression in the Deep Zone occur around other, more isolated, municipal water supply wells in other parts of the basin and are also observed to occur in response to groundwater pumping. The seasonal depression of water level elevation in the Deep Zone is most prominent during the summer and fall. Even though the municipal water supply wells are typically only pumped for part of the year, the water level elevations near these wells have been observed to remain relatively depressed for longer periods of time. This may be a function of the additional time required for groundwater to move through the aquifer system from sources of recharge and replace the groundwater that was removed by pumping from the Deep Zone.

As observed in the Shallow Zone, the linear or tabular zone of lower permeability associated with the Virginia Lake Fault Zone is also influencing groundwater elevations and flow in the Deep Zone. A similar step in the Deep Zone potentiometric occurs at the Harvard Way Barrier between well CTM33D and the Corbett Well. At this location, the lack of a step in the Shallow Zone water levels results in a reversal of the vertical gradient from upward on the west side of the Harvard Way barrier to downward on the east. The lateral persistence and trend of the Harvard Way Barrier have not been established.

Vertical Groundwater Flow

The groundwater elevation contour maps for the Shallow and Deep Zones generated since the implementation of the GMP (Intera, 2006a and 2006b) show distinct general differences between the water table (*i.e.* the Shallow Zone) and the Deep Zone. Of particular interest is the subdued expression or apparent lack of a water level response in the Shallow Zone in response to pumping stresses occurring within the Deep Zone. This suggests that at least local hydraulic separation may exist between these water bearing zones. The subdued expression or apparent lack of a water level response a the water table could also be due to infiltrating surface water from the Truckee River that replaces water in the Shallow Zone that has moved downward in response to pumping from the Deep Zone.

These two alternative processes (local hydraulic separation or relatively rapid recharge of the Deep Zone from the Truckee River through the Shallow Zone) and the potential inter-relationship between the Truckee River and the Shallow Zone require further evaluation. Groundwater in the Shallow Zone generally flows across the CTM to the east toward lower groundwater elevations. However, shallow groundwater will also flow vertically, from the water table into the Deep Zone, when the water level elevation in the Shallow Zone is higher than in the Deep Zone and there is a conduit or pathway along which groundwater movement can take place. The degree to which such flow might occur is controlled by the permeability and continuity of the geologic materials along potential vertical pathways between the water table (*i.e.* Shallow Zone) and the Deep Zone and the difference in groundwater elevation between them. Vertical flow will be small where the groundwater elevation difference is small and/or where the hydraulic conductivity of the geologic materials separating the zones is low and they are laterally continuous (effectively resulting in a hydraulic barrier). Where the groundwater elevation difference is large and the permeability of the geologic materials separating the two aquifers is relatively high or these layers are discontinuous (as a result of erosion, such as along the Truckee River corridor, or as a result of dynamic and heterogeneous depositional processes), the vertical component of groundwater flow could be significant. Vertical groundwater flow can also occur through a well that may pass through such a barrier.

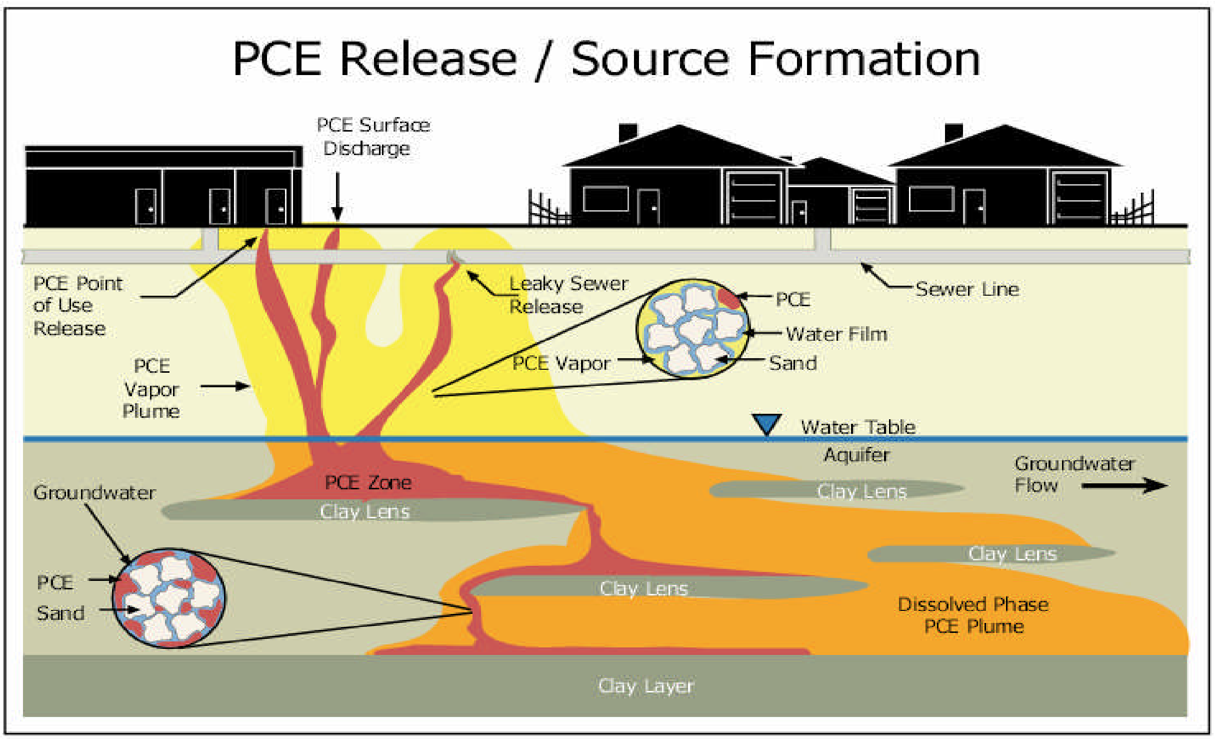
2.3.2 Groundwater Contaminant Transport

PCE has been shown, of those contaminants evaluated, to be the most widespread groundwater contaminant in the central Truckee Meadows (Intera, 2006a and 2006b). Plotting and contouring the data has identified discrete areas, or plumes, of PCE contamination. The shape and location of the PCE plumes within the central Truckee Meadows is defined by the existing wells in the groundwater monitoring network. Plume location and shape are subject to change over time as plumes can potentially move in response to groundwater flow or as greater spatial detail is provided through the addition of new monitoring wells to the network in important parts of the basin. PCE plumes tend to be elongate parallel to the direction of groundwater flow. Since the groundwater in the CTM generally flows from west to east, high concentrations at the western ends of plumes in the CTM can be considered indicative of proximity to a source of PCE (*i.e*., the proximal ends of the plumes). PCE concentrations within the individual groundwater plumes typically appear to decrease eastward (Intera, 2006a and 2006b) along the plume axes parallel to the general groundwater flow direction (*i.e*., the distal ends of the plumes).

A number of discrete PCE plumes have been identified to date in both the Shallow and Deep Zones. The Shallow Zone PCE plumes identified to date (Intera, 2006a and 2006b) include three apparently small, very local, plumes (Plumb/395, Matley Lane, and 2nd/Keystone) and seven larger plumes (West 4th Street, Vassar Street, E. Plumb Lane, Mill / Kietzke, Wolverine Way, Victorian Avenue, and Greenbrae) (**Figure 1.4**). There are three Deep Zone PCE plumes that have been identified to date (Intera, 2006a and 2006b) (**Figure 1.4**). The largest plume, referred to as the Downtown Reno plume, is generally located beneath what has been the historical industrial and commercial core of Reno, and is located along the 4th Street and the I-80 corridor. This plume has impacted four municipal water supply wells (High Street, Morrill Avenue, Kietzke Lane, and Mill Street Wells) to the point of requiring well head treatment. The South Reno plume is presently only poorly defined by a small number of wells in the immediate vicinity of the Corbett municipal water supply well. The Downtown Sparks plume has impacted the Sparks and Poplar #2 municipal water supply wells. The most direct possible explanation for the occurrence of these plumes at these locations is that pumping at the municipal wells completed in the deep aquifer has drawn the PCE contamination originating in the shallow aquifer down into the deep aquifer; however, these water supply wells, especially Poplar #2, may also be impacted by other sources. The source or sources of the impact to these wells has yet to be substantiated.

As discussed in **Sections 2.2.2** and **2.3.1**, the sediments that comprise the water-bearing strata in the CTM are heterogeneous, and there is not a distinct, laterally continuous, hydraulically-competent, separating layer between the Shallow and Deep Zones. In addition, the depths and screened intervals of the monitoring wells included in the CTM network is variable, and many of the wells were not originally installed for characterizing the vertical extent of the PCE plumes. As a result, the designation of Shallow and Deep Zone plumes is a simplified representation of a more complex aquifer system, and three dimensional distribution of PCE. In several cases, Shallow and Deep Zone plumes overlap, and represent what is most likely a single plume intercepted by both Shallow and Deep Zone wells. These overlapping plumes are the West 4th Street and Downtown Reno Plumes, the Vassar / East Plumb and South Reno Plumes, and the Victorian Avenue and Downtown Sparks Plumes.

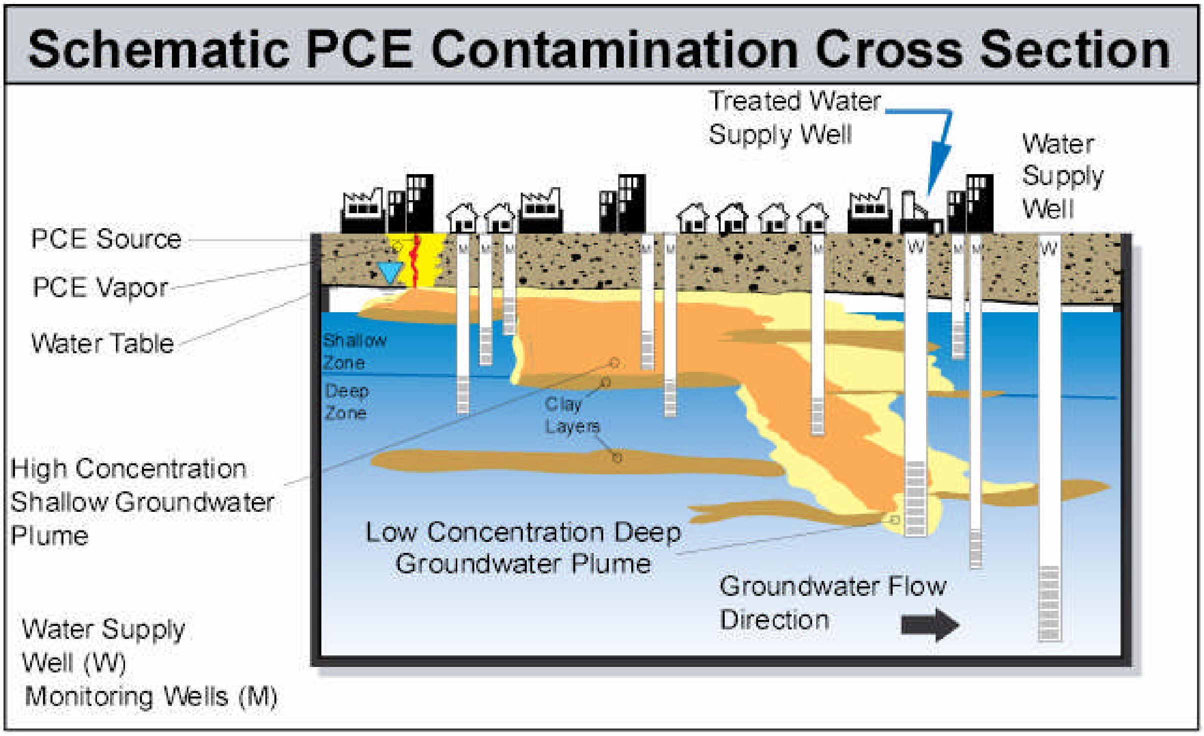
The conceptual figure below shows how a PCE release can impact subsurface materials and groundwater.



Pure PCE is more dense than water (approximately 1.6 times heavier than water) and has a low aqueous solubility. Given these properties, PCE is characterized as a dense nonaqueous-phase liquid (DNAPL) which tends to sink in water when present as a free phase. Even though the solubility of PCE is relatively low, the maximum concentration of dissolved PCE that can be present in associated groundwater is approximately 200,000 micrograms per liter (µg/L, NIOSH, 1994). This is five orders of magnitude greater than the drinking water maximum contaminant level (MCL) of 5 µg/L.

All PCE is associated with human activity and, by definition, originates at or near the land surface. Plumes of PCE contamination in the Shallow Zone form in response to PCE releases to the environment at or near the ground surface. These releases to the environment occur in response to improper storage (*e.g*., leaking containers without secondary containment), use, disposal (*e.g*., into a leaking sanitary sewer system or by surface disposal), or accidental discharge. Once released to the subsurface, the PCE drains downward under gravitational forces. Because the density of PCE is greater than that of water, if a sufficient volume is present, it continues to drain downward. As the PCE migrates, some of it is trapped in the pore spaces of the sediment through which it passes, leaving behind a trail of residual product in the soil matrix. If the migrating PCE encounters a barrier, such as a competent clay layer, the PCE product will collect there and form a pool. If drainage continues, the PCE will spread out along the barrier and continue migrating laterally, and may continue migrating vertically downward if it gets to the edge of the barrier or if the barrier has more permeable areas or fractures. Migration of product continues until the volume of PCE is insufficient to drive further movement.

As shown in the figure on Page 15, the groundwater that comes in contact with the PCE dissolves some of it, forming a dissolved-phase PCE plume that moves with the groundwater, developing plumes of PCE contamination such as those we observe in the CTM today. There is generally no continuous barrier separating the Shallow Zone from the Deep Zone in the CTMRD; however, a discontinuous series of lower permeability strata provides varying levels of impedance to vertical groundwater flow. PCE contamination in the Shallow Zone can ultimately become Deep Zone PCE contamination as a result of the vertical movement of DNAPL or PCE-contaminated groundwater. Deep Zone contamination can in turn impact and be captured by municipal water supply wells. This conceptual understanding is shown graphically in the figure on page 17.


Schematic PCE Contamination Cross Section
Treated Water Supply Well
Water Supply Well
PCE Source
PCE Vapor
Water Table
Shallow Zone
Deep Zone
Clay Layers
High Concentration Shallow Groundwater Plume
Low Concentration Deep Groundwater Plume
Groundwater Flow Direction
Water Supply Well (W)
Monitoring Wells (M)

3. SUMMARY OF 2006 GROUNDWATER MONITORING

3.1 Scope of Work

Field activities associated with the GMP include monthly groundwater level monitoring and quarterly water quality monitoring and sampling. Unless otherwise specified in this section, quarterly monitoring field activities were performed in accordance with the Standard Operating Procedures (SOPs) and Quality Assurance Project Plan (QAPP) in the Groundwater Monitoring Plan (Intera, 2004).

Monthly groundwater level monitoring at all accessible wells in the more than 150-well water-level network is scheduled to facilitate collecting data from individual wells at roughly one-month intervals. Wellhead monitoring for organic vapor emissions (using a photo-ionization detector [PID]), low density non-aqueous phase liquid (LNAPL) monitoring, and well condition assessment are performed in conjunction with groundwater level measurement at each well. These data are maintained in the CTMRD program database. Groundwater level measurements for the last month of each quarter are collected in conjunction with the quarterly sampling event. These data support the groundwater elevation analyses presented in subsequent sections of this report.

Water quality sampling is performed during the last month of a given quarter. Larger first (Q1) and third (Q3) quarter sampling events consist of a 161-well set. These larger events include both the 93 quarterly sampled wells and the 68 semi-annually sampled wells and are scheduled to coincide with the approximate beginning (Q1) and end (Q3) of seasonal groundwater demand in the central Truckee Meadows. Smaller second (Q2) and fourth (Q4) quarter sampling events include only the 93 quarterly sampled wells that provide the detail necessary to monitor PCE concentration trends and to characterize the dynamic processes that may occur within or near currently defined plumes in the central Truckee Meadows.

Low flow purge and sampling is the primary sample collection method that has been used for CTMRD program GMP sampling. Alternative sample collection methods that have or can be employed include: grab sampling (3-well volume high-flow purge/sample, purge/bail); minimum purge/sample; and, passive diffusion bag sampling where logistics require. These are used at a relatively small number of wells. Grab sampling methods are commonly used at municipal, irrigation, and industrial wells that, because of the high pumping rates, cannot be sampled using low-flow sampling methods. Passive diffusion bags and minimum purge methods are commonly used for either very low yield wells where low-flow purge rates are not sustainable or wells with long screen intervals where field parameter stability attainment can be problematic under low-flow conditions. In certain instances, several sampling methods may be employed at the same well. This commonly occurs when a new sampling method replaces a sample method that had been previously used at a given well. In that instance, paired sets of samples are collected using both methods so that the results can be compared to recognize and minimize any potential method-related bias during the transition.

Field water quality measurements and laboratory analyses for groundwater sampled as part of the GMP can include:

- Field parameters;
- Volatile organic compounds (VOCs); and,
- Monitored natural attenuation (MNA) parameters.

Field parameters are measured during flow cell monitoring and include pH, specific conductance, temperature, dissolved oxygen, turbidity, and oxidation-reduction potential. These measurements are taken at all wells where low-flow purging is performed. These measurements are compiled and included in the CTMRD program groundwater quality database as a means for tracking spatial and temporal variability of the aquifer system with respect to these parameters.

VOCs are analyzed in groundwater collected from every monitoring well sampled during a given quarter using USEPA method 8260B for all target analytes listed in the GMP QAPP (Intera, 2004).

MNA parameters were analyzed in groundwater collected in 2006 Q1 and Q2 from 33 monitoring wells prescribed for MNA assessment (Intera, 2004) to characterize potential natural attenuation processes within 4 contaminated regions where either PCE by-products or general groundwater characteristics favorable for natural attenuation of chlorinated solvents have been previously identified. Five other wells located in the Mill / Kietzke plume area, previously monitored for MNA parameters, were removed from the original set of 38 wells after these wells were abandoned in 2005. In 2006 Q3, MNA monitoring was discontinued because evidence for PCE degradation was limited even in the areas where some degradation products have been observed. MNA samples collected during 2006 Q1 and Q2 were analyzed for:

- Chloride (EPA method 300);
- Alkalinity (EPA 310.1);
- Sulfate (EPA 300);
- Total organic carbon (EPA 415.1);
- Nitrate (EPA 300);
- Nitrite (EPA 300);
- Ferrous iron (SM 3500-Fe D);
- Total iron (EPA 200.8); and,
- Manganese (EPA 200.8/6020).

3.2 Groundwater Monitoring Program Changes

3.2.1 Field Activity SOP Changes

Since the implementation of the GMP, modifications to the standard operating procedures (SOPs) for several field activities have taken place (Intera, 2006a). These modifications have improved the efficiency, effectiveness, data quality or logistical safety of the program, and have included changes to:

- The well total depth measurement protocol (to improve accuracy);
- The procedure for handling investigation-derived waste (IDW) (to improve effectiveness and efficiency, and reduce costs);
- The low flow sampling protocol (to improve data quality);
- The monitoring schedule (to improve effectiveness and efficiency);
- Eliminating the use of field test kits for monitored natural attenuation (MNA) parameters (to reduce costs and improve data quality); and
- Eliminating MNA monitoring beginning with the 2006 Q3 event because the data to support the effectiveness of MNA were not compelling.

All SOP changes were made based on the assessment of the GMP sampling activities and results and are designed to improve the quality and significance of the data collected.

3.2.2 Changes to Data Quality and Records Management

The data quality objectives for the GMP have been consistently met. The CTMRD program originally utilized a database based on the EQuIS® platform. This database was converted to a Microsoft Access ® platform, which allows for increased usability by DWR, other county agencies and other stakeholders. The use of a Microsoft Access® based database system also allows for manipulation of the data using the DWR Geographic Information System (GIS) software, ArcGIS®, without the purchase of additional extensions and plug-ins.

3.3 2006 Data Collection

3.3.1 Water Level Monitoring

During 2006, WCDWR staff performed monthly water level monitoring with the objective of collecting monthly “snapshots” of groundwater levels in the central Truckee Meadows. This schedule was modified starting in March 2006 when water level measurements collected during quarterly water quality sampling were used as for this monthly snapshot. Subsequent monthly water level measurements were re-scheduled to match the sequence and timing of quarterly water quality sampling. The new schedule is designed to make better use of manpower while retaining a water level data collection scheme that facilitates regular monthly monitoring for each well in the network. **Table 3.1**, below, provides a summary of data collection activities associated with groundwater level monitoring for 2006. Groundwater level data are provided on data CDs included with the 2006 Q1+Q2 and Q3+Q4 Groundwater Monitoring Reports (WorleyParsons, 2007 and 2008).

TABLE 3.1 - Summary Statistics for 2006 Groundwater Level Monitoring

2006 Q1	**JANUARY**	**FEBRUARY**	**MARCH**
SUCCESS RATE *(MONITORED WELLS/SCHEDULED WELLS)*	*143/150*	*141/150*	*144/150*
OPPORTUNISTICALLY MONITORED WELLS	6	1	11
TOTAL # MONITORED WELLS	149	142	155
WELLS WITH DETECTED LNAPL	0	0	0
2006 Q2	**APRIL**	**MAY**	**JUNE**
SUCCESS RATE *(MONITORED WELLS/SCHEDULED WELLS)*	*137/150*	*144/150*	*154/160*
OPPORTUNISTICALLY MONITORED WELLS	1	1	1
TOTAL # MONITORED WELLS	138	145	155
WELLS WITH DETECTED LNAPL	0	0	0
2006 Q3	**JULY**	**AUGUST**	**SEPTEMBER**
SUCCESS RATE *(MONITORED WELLS/SCHEDULED WELLS)*	*146/160*	*159/160*	*157/160*
OPPORTUNISTICALLY MONITORED WELLS	0	1	1
TOTAL # MONITORED WELLS	146	160	158
WELLS WITH DETECTED LNAPL	0	0	0
2006 Q4	**OCTOBER**	**NOVEMBER**	**DECEMBER**
SUCCESS RATE *(MONITORED WELLS/SCHEDULED WELLS)*	*153/160*	*150/160*	*155/160*
OPPORTUNISTICALLY MONITORED WELLS	1	0	6
TOTAL # MONITORED WELLS	154	150	161
WELLS WITH DETECTED LNAPL	0	0	0

3.3.2 Water Quality Monitoring

WCDWR staff performed the CTMRD program 2006 quarterly water quality monitoring as summarized below. Sample-specific details, including a list of wells sampled, corresponding sample ID, date/time of sampling, sample method/device used, and any special circumstances encountered during sampling are provided on the data CDs included with the 2006 Q1+Q2 and Q3+Q4 Groundwater Monitoring Reports (WorleyParsons, 2007 and 2008).

2006 Q1 Activities

Water quality monitoring was conducted between February 27 and March 30, 2006. 169 monitoring wells were sampled, including 160 scheduled wells and nine opportunistically sampled wells. One scheduled well was not sampled (CTM138) because it was temporarily paved over during road construction. An additional nine wells (including three TMWA, three USGS and three WCDWR monitoring wells) were opportunistically sampled because they either had not been previously characterized as part of the GMP or were being sampled for purposes not directly related to GMP. **Table 3.2**, below, provides a summary of samples collected and field methods used for the 2006 Q1 sample event.

2006 Q2 Activities

Water quality monitoring was conducted between June 1 and July 5, 2006. 113 monitoring wells were sampled, including 92 scheduled wells and 21 opportunistically sampled wells. One previously scheduled well (RETRACB20) was abandoned by its owner and was removed from the monitoring network. Twenty-one TMWA wells were opportunistically sampled because they had not been previously characterized (one well) or were municipal water supply wells (20 wells) that are sampled whenever operating to monitor groundwater quality in deeper portions of the basin utilized for public water supply. **Table 3.3**, below, provides a summary of samples collected and field methods used for 2006 Q2 sampling.

2006 Q3 Activities

Water quality monitoring between August 10 and October 4, 2006. 185 monitoring wells were sampled, including 163 scheduled wells and 22 opportunistically sampled wells. Two scheduled wells were not sampled (COR-4 and COR-12A) because they were temporarily paved over during road construction. One well was abandoned and removed from the sampling program (RETRACB20). The wells were sampled for VOCs only during the Q3 monitoring event. Sampling for MNA parameters was discontinued after 2006 Q2. **Table 3.4**, below, provides a summary of samples collected and field methods used for the 2006 Q3 sample event.

2006 Q4 Activities

Water quality monitoring between November 30 and December 14, 2006. 93 monitoring wells were sampled, including 92 scheduled wells and one opportunistically sampled well. Four scheduled wells were not sampled, one because it had been temporarily paved over during construction activities (COR-8A), and three because their sampling frequency was reduced to semi-annual due to four quarters with no detection of contaminants (RETRACB13, RETRACMWA and RETRACMWC). Four new wells were added to the quarterly monitoring program during 2006 Q4 (MW8ND, SSFSMW213, CORWSSMW1 and CORWSSMW2). One well that is normally sampled during Q1 and Q3 was opportunistically sampled during assessment of the well for the presence of floating separate-phase hydrocarbons (HV5M). The wells were sampled for VOCs only during the Q4 monitoring event. Sampling for MNA parameters was discontinued after 2006 Q2. **Table 3.5**, below, provides a summary of samples collected and field methods used for 2006 Q4 sampling.

TABLE 3.2- 2006 Q1 Water Quality Sampling and Field Methods Summary

	TOTALS:				***METHOD SUMMARY:***											
	# INDIVIDUAL WELLS SAMPLED	**# SAMPLES COLLECTED[1]**			**# LOW FLOW SAMPLE ANALYSES**			**# GRAB SAMPLE ANALYSES**			**# MINIMUM PURGE SAMPLE ANALYSES**			**# PDB SAMPLE ANALYSES**		
		VOC	MNA	FIELD PARA-METERS	VOC	MNA	FIELD PARA-METERS	VOC	MNA	FIELD PARA-METERS	VOC	MNA	FIELD PARA-METERS	VOC	MNA	FIELD PARA-METERS
GROUNDWATER SAMPLES:																
SCHEDULED	**160**	**219**	**34**	**140**	138	34	138	17	0	15	2	0	0	62		
NOT SCHEDULED	**6**	**9**	**0**	**5**	3	0	3	2	0	2	0	0	0	4		
NOT SAMPLED	**1**															
TOTAL GROUNDWATER	166	**228**	**34**	**145**	141	34	141	19	0	17	2	0	0	66		
QA/QC SAMPLES:																
FIELD DUPLICATES		**19**	**2**	**0**	11	2		2	0		0	0		6		
EQUIPMENT BLANKS		**10**	**2**	**0**	8	2		2	0		0	0				
FIELD BLANKS		**0**	**0**	**0**												
TRIP BLANKS		**42**	**0**	**0**												
TOTAL QA/QC		71	4	0												
TOTAL SAMPLES:		***299***	***38***	***145***	***160***	***38***	***141***	***23***	***0***	***17***	***2***			***72***		

[1] Total number of samples collected may include additional samples for purposes not directly associated with quarterly monitoring. These may include those for comparison of sampling methods, assessment of vertical distribution of PCE, etc.

TABLE 3.3 – 2006 Q2 Water Quality Sampling and Field Methods Summary

	TOTALS:				METHOD SUMMARY:											
	# INDIVIDUAL WELLS SAMPLED	# SAMPLES COLLECTED [1]			# LOW FLOW SAMPLE ANALYSES			# GRAB SAMPLE ANALYSES			# MINIMUM PURGE SAMPLE ANALYSES			# PDB SAMPLE ANALYSES		
		VOC	MNA	FIELD PARA-METERS	VOC	MNA	FIELD PARA-METERS	VOC	MNA	FIELD PARA-METERS	VOC	MNA	FIELD PARA-METERS	VOC	MNA	FIELD PARA-METERS
GROUNDWATER SAMPLES:																
SCHEDULED	**92**	**117**	**31**	**112**	88	31	88	25	0	24	0	0	0	4		
NOT SCHEDULED	**21**	**21**	**0**	**0**	0	0	0	21	0	0	0	0	0	0		
NOT SAMPLED	**1**															
TOTAL GROUNDWATER	**113**	**138**	**31**	**112**	88	31	88	46	0	24	0	0	0	4		
QA/QC SAMPLES:																
REPLICATES		**13**	**2**	**0**	8	2		3	0		0	0		2		
EQUIPMENT BLANKS		**5**	**2**	**0**	5	2		0	0		0	0				
FIELD BLANKS		**0**	**0**	**0**												
TRIP BLANKS		**28**	**0**	**0**												
TOTAL QA/QC		**46**	**4**	**0**												
TOTAL SAMPLES:		***184***	***35***	***112***	***101***	***35***	***88***	***49***	***0***	***24***	***0***	***0***	***0***	***6***		

[1] Total number of samples collected may include additional samples for purposes not directly associated with quarterly monitoring. These may include those for comparison of sampling methods, assessment of vertical distribution of PCE, etc.

TABLE 3.4 – 2006 Q3 Water Quality Sampling and Field Methods Summary

	TOTALS:				***METHOD SUMMARY:***											
	# INDIVIDUAL WELLS SAMPLED	**# SAMPLES COLLECTED [1]**			**# LOW FLOW SAMPLE ANALYSES**			**# GRAB SAMPLE ANALYSES**			**# MINIMUM PURGE SAMPLE ANALYSES**			**# PDB SAMPLE ANALYSES**		
		VOC	MNA	FIELD PARA-METERS	VOC	MNA	FIELD PARA-METERS	VOC	MNA	FIELD PARA-METERS	VOC	MNA	FIELD PARA-METERS	VOC	MNA	FIELD PARA-METERS
GROUNDWATER SAMPLES:																
SCHEDULED	**163**	**220**	**0**	**160**	140	0	140	12	0	5	17	0	15	50		
NOT SCHEDULED	**22**	**22**	**0**	**2**	0	0	0	29	0	2	0	0	0	0		
NOT SAMPLED	**2**															
TOTAL GROUNDWATER	**185**	**242**	**0**	**162**	140	0	140	41	0	7	17	0	15	50		
QA/QC SAMPLES:																
FIELD DUPLICATES		**19**	**0**	**0**	10	0		3	0		1	0		5		
EQUIPMENT BLANKS		**14**	**0**	**0**	9	0		5	0		0	0				
FIELD BLANKS		**1**	**0**	**0**												
TRIP BLANKS		**38**	**0**	**0**												
TOTAL QA/QC		**72**	**0**	**0**												
TOTAL SAMPLES:		***314***	***0***	***162***	***159***	***0***	***140***	***49***	***0***	***7***	***18***	***0***	***15***	***55***		

[1] Total number of samples collected may include additional samples for purposes not directly associated with quarterly monitoring. These may include those for comparison of sampling methods, assessment of vertical distribution of PCE, etc.

TABLE 3.5 – 2006 Q4 Water Quality Sampling and Field Methods Summary

	TOTALS:				METHOD SUMMARY:											
	# INDIVIDUAL WELLS SAMPLED	# SAMPLES COLLECTED [1]			# LOW FLOW SAMPLE ANALYSES			# GRAB SAMPLE ANALYSES			# MINIMUM PURGE SAMPLE ANALYSES			# PDB SAMPLE ANALYSES		
		VOC	MNA	FIELD PARA-METERS	VOC	MNA	FIELD PARA-METERS	VOC	MNA	FIELD PARA-METERS	VOC	MNA	FIELD PARA-METERS	VOC	MNA	FIELD PARA-METERS
GROUNDWATER SAMPLES:																
SCHEDULED	**92**	**100**	**0**	**96**	94	0	94	2	0	2	3	0	0	6		
NOT SCHEDULED	**1**	**1**	**0**	**1**	0	0	0	1	0	0	0	0	0	0		
NOT SAMPLED	**4**															
TOTAL GROUNDWATER	**93**	**101**	**0**	**97**	94	0	94	3	0	2	3	0	0	6		
QA/QC SAMPLES:																
REPLICATES		**9**	**0**	**0**	7	0		2	0		0	0		2		
EQUIPMENT BLANKS		**7**	**0**	**0**	0	0		7	0		0	0				
FIELD BLANKS		**0**	**0**	**0**												
TRIP BLANKS		**19**	**0**	**0**												
TOTAL QA/QC		**35**	**0**	**0**												
TOTAL SAMPLES:		***136***	***0***	***97***	***101***	***0***	***94***	***12***	***0***	***2***	***3***	***0***	***0***	***8***		

[1] Total number of samples collected may include additional samples for purposes not directly associated with quarterly monitoring. These may include those for comparison of sampling methods, assessment of vertical distribution of PCE, etc.

3.4 2006 Laboratory Methods and Results

Table 3.6 summarizes the analyses performed on samples collected during the 2006 quarterly monitoring events. Samples collected during the 2006 Q1 monitoring event were submitted to Environmental Science Corp. of Mt. Juliet, TN. Samples collected during the Q2 through Q4 monitoring events were submitted to Alpha Analytical of Sparks, Nevada. Both laboratories are certified by the State of Nevada for analysis of waste water and drinking water under the Clean Water, Safe Drinking Water and Resource Conservation and Recovery Acts. Alpha also holds certification under the National Environmental Laboratory Accreditation Program (NELAP). Complete analytical results are tabulated on the data CDs included with the 2006 Q1+Q2 and Q3+Q4 Groundwater Monitoring Reports (WorleyParsons, 2007 and 2008). PCE analytical data are posted and contoured on **Figures 3.1** through **3.8**.

Table 3.6 - Summary of 2006 Q1 Laboratory Analytical Program

Event	Data Packages	Number of Samples Analyzed									
		VOCs EPA 8260B	Alkalinity EPA 310.2	Cl/NO_3/ NO_2/SO_4 EPA 9056	Ferrous Iron 3500Fe-B	Dissolved Fe and Mn EPA 6010B	TOC EPA 9060	TS EPA 160.3	TDS EPA 160.1	pH, Temp EPA 150.1/ SW9040B	TPH EPA 8015
2006 Q1	17 Level II Mod 2 Level IV	181 / 47	34 / 4	34 / 4	34 / 4	34 / 4	34 / 4	0 / 1	0 / 1		
2006 Q2	17 Level III 4 Level IV	115 / 41	32 / 5	32 / 4	31 / 4	31 / 4	31 / 4	31 / 4	1 / 0		
2006 Q3	33 Level III 4 Level IV	231 / 72	2 / 0	1 / 0		1 / 0			1 / 0	1 / 0	
2006 Q4	19 Level III 2 Level IV	98 / 38	1 / 0								1 / 0
	Total	**625 / 198**	**69 / 9**	**67 / 8**	**65 / 8**	**66 / 8**	**65 / 8**	**31 / 5**	**2 / 1**	**1 / 0**	**1 / 0**

Notes:

QA/QC	Quality Assurance/Quality Control
Level II Mod	Modified Level II laboratory package including sample results, method blanks, laboratory control spike, matrix spike/matrix spike duplicate and surrogate summary data.
Level III	Level III laboratory package including sample results, method blanks, laboratory control spike, matrix spike/matrix spike duplicate and surrogate summary data.
Level IV	Level IV laboratory package including all Modified Level II data and calibration, instrument tune, internal standards, interference check and serial dilution/post-digestion spike data.
VOCs	Volatile Organic Compounds
TOC	Total Organic Carbon
TS	Total Solids
TDS	Total Dissolved Solids
Fe	Iron
Mn	Manganese
TPH	Total Petroleum Hydrocarbons

3.5 2006 Regional Water Level Data

Potentiometric surface maps for the Shallow Zone and Deep Zone during 2006 are presented in **Figures 3.1 through 3.8**. These figures illustrate that the predominant groundwater flow direction during 2006 was from west to east, with a strong influence from the Truckee River and from seasonal municipal pumping that was previously discussed in **Section 2**. Several Deep Zone, coalescing groundwater depressions are apparent during Q2 and expanded during Q3 in the vicinity of the Mill Street, Kietzke Lane and High Street Wells, the Corbett Well and further east around the Pezzi Well. Groundwater flow in the Deep Zone in the central portion of the CTM was toward these wells during Q2 and Q3. The development of these water level depressions coincides with the peak municipal pumping periods during the summer and early fall months. A corresponding, but more subdued, groundwater elevation depression develops in the Shallow Zone in the vicinity of the Mill Street and Corbett Wells during Q2 and expands during Q3. The formation of a groundwater depression in the Shallow Zone in response to pumping from municipal water supply wells that are screened in the Deep Zone indicates that the Shallow and Deep Zones are hydraulically connected in this area and that groundwater is flowing downward from the Shallow Zone into the Deep Zone. In Q4, the groundwater depressions that were evident in the Shallow and Deep Zones have largely rebounded and groundwater flow is again predominantly from west to east throughout the CTM. This coincides with the cessation of municipal well pumping and the resumption of natural and artificial recharge processes.

Hydrographs of water levels in selected monitoring wells in the CTM are shown in **Tables 6.1 to 6.9**. These hydrographs illustrate that the water levels during the winter of 2005/2006 are some of the highest recorded during the 6-year hydrograph periods. These high water levels may be a result of above average precipitation recorded between 2004 and 2006 . Shallow Zone water levels during 2006 Q3 generally showed a significant decline relative to the higher levels observed in Q1 and Q2. In Q4, water levels water levels typically rose from Q3 levels. Deep Zone water levels typically show a depression during Q3 followed by pronounced recovery during Q4.

Maps showing the difference in water levels between the Shallow and Deep Zones during 2006 (**Figure 3.9**) reflect the trends discussed above. These maps identify areas with relative upward and downward water level gradients and provide insight into understanding the potential vertical movement of groundwater in the CTM. Downward gradients are evident in a belt generally along the Truckee River (particularly the western reach). These areas of downward gradient become more pronounced, expand and extend south of the river into the area of the Deep Zone water level elevation depression discussed above in Q2 and Q3. Downward relative gradients are at their greatest magnitude and extent during Q3. In Q4, the area with a downward relative gradient is considerably reduced in areal extent, with relative downward water level elevation differences exceeding 10 feet limited to the area from the Morrill Avenue Well to the High Street Well. Near neutral or upward gradients are otherwise prevalent throughout the area of interest at this time.

Examination of the Q3 potentiometric surface and water level difference maps also accentuates the apparent influence that other features or processes may be having on groundwater levels. These features or processes may include mountain front recharge, local geothermal upwelling, and structurally controlled hydraulic flow barriers. An area of upward gradients is prevalent to the west of the Corbett Well in the area between the VLFZ and HWB, just north of the apparent core of what has been defined as the Moana geothermal area (Flynn and Ghusn, 1984). These upward gradients persist even when groundwater depressions (that have formed in response to municipal well pumping) are present to the north. The groundwater depressions that form in the downtown Reno area in Q3 expand laterally westward to the approximately location of the VLFZ, and accentuate the groundwater level drop across this feature from west to east. This reflects the apparent prominence of the VLFZ as a partial barrier to groundwater flow.

Examination of the potentiometric surface and water level difference maps also indicates that these features and/or processes appear to have a greater influence on water levels in this area than previously recognized. Upward gradients are prevalent to the west of the Corbett Well in the area between two inferred faults, just north of the apparent core of the Moana geothermal area. The prevailing vertical groundwater gradient direction is downward outside of this area. The potentiometric surface maps show more closely spaced contours in the areas where the faults are suggested to be, which is consistent with the presence of a subsurface barrier to groundwater flow.

3.6 2006 Regional PCE Distribution Data

PCE concentrations observed during the Q1 through Q4 monitoring events in shallow and deep wells are contoured in **Figures 3.1** through **3.8**. The lateral and vertical extent of the shallow and deep plumes appear relatively unchanged during 2006; and they do not appear to have not changed significantly since 2003 Q4 during the course of the monitoring program. Several of the shallow plumes are at least partly coincident with deep plumes. This occurs where shallow plume outlines overlap with deep plume outlines (as shown on **Figure 1.4**). This suggests that these overlapping Shallow and Deep Zone plumes are actually representations of relatively shallower and deeper portions of what are in reality vertically continuous, three-dimensional plumes which have formed in response to downward vertical gradients as discussed in **Section 5.2** and shown on **Figure 3.9**. This appears to be true of the Vassar / East Plumb Lane and South Reno Plumes, the West 4th Street and Downtown Reno Plumes, and the Victorian Avenue and Downtown Sparks Plumes (**Figure 1.4**). The relationship between these Shallow and Deep Zone plume counterparts is discussed in greater detail in **Section 5.2**.

4. SUMMARY OF DATA QUALITY ASSURANCE REVIEW

This section summarizes the 2006 laboratory data quality assurance/quality control (QA/QC) data review and validation. The objectives, requirements and procedures of the QA/QC program for the GMP are outlined in detail in the QAPP. Details regarding the 2006 QA/QC program and data validation results are presented in the 2006 Q1+Q2 and Q3+Q4 Groundwater Monitoring Reports (WorleyParsons, 2007 and 2008). During the QA/QC data review and validation, data generated from implementation of the 2006 Q1 and Q2 field and analytical programs were assessed for conformance with the following Data Quality Indicators (DQIs) defined in the QAPP:

- Accuracy;
- Precision;
- Representativeness;
- Comparability; and
- Completeness.

Data review included assessment of laboratory data deliverables and QA/QC samples (blank, spike and duplicate samples) for conformance with project data quality objectives (DQOs). Data validation included review of Level IV laboratory QA/QC packages to assess the conformance of instrument calibration, instrument tune, internal standards, interference checks, serial dilutions and post-digestion spikes with project DQOs.

Data that failed to meet project DQOs based on the data review and validation were flagged to identify the limitations to their reliability or usefulness. Data flags were entered into the project database and are included in the electronic tables on the data CDs in the 2006 Q1+Q2 and Q3+Q4 Groundwater Monitoring Reports (WorleyParsons, 2007 and 2008). Corrective actions were identified and implemented as appropriate. Although the QA/QC program encompasses all data collected for the project, the subsequent sections focus only on data related to the detection and quantification of the Target Analytes defined in the QAPP.

Tables 4.1 through 4.4 summarize the results of the 2006 field and laboratory data QA/QC review, performed using the Level II Modified, Level III and Level IV QA/QC level packages and Electronic Data Deliverables (EDDs) provided by the laboratory and field data provided by DWR. Additional details regarding the QA/QC data review and validation procedures are presented in the 2006 Q1+Q2 and Q3+Q4 Groundwater Monitoring Reports (WorleyParsons, 2007 and 2008). These reports also include a data CD with summary tables presenting additional information regarding any QA/QC deficiencies that were identified and data flags that were applied, as well as a complete listing of laboratory analytical data and water level measurement data.

Table 4.1 - Summary of 2006 Q1 QA/QC Review

Review Item	QAPP Frequency Achieved	QAPP Acceptance Criteria Met	Date Tables in 2006 Q1+Q2 Groundwater Monitoring Report Presenting Results
Electronic Data Deliverable 10% Check	--	Yes	
Sample Event Table and Database Agreement	--	Yes	
Analytical Reports and Chain-of-Custody Documentation	--	Yes	
Preservation and Hold Times	--	Yes	
Analytical Methods and Reporting Limits	--	Yes	
Field Equipment Blank Samples	Yes	No	Table A.1 lists detections in field equipment blank samples. (Two samples affected)
Trip Blank Samples	Yes	No	Table A.2 lists detections in trip blank samples. (Seven samples affected)
Laboratory Method Blank Samples	Yes	Yes	
Laboratory Control Samples (LCS)	Yes	Yes	
Matrix Spike/Matrix Spike Duplicate Samples (MS/MSD)	Yes	No	Table A.3 lists samples with MS/MSD results outside of acceptance criteria. (Three samples affected)
Surrogate Spikes	Yes	No	Table A.4 lists samples with surrogate results outside of acceptance criteria. (102 samples affected)
Field Duplicate Samples	Yes	No	Table A.5 lists field duplicate RPD results exceeding acceptance criteria. (One sample affected)
Laboratory Duplicate Samples	Yes	No	Table A.6 lists samples with laboratory duplicate RPD results exceeding acceptance criteria. (23 samples affected)
Calibration Data	Yes	Yes	
Instrument Tune	Yes	Yes	
Internal Standards	Yes	Yes	

Table 4.2 - Summary of 2006 Q2 QA/QC Review

Review Item	QAPP Frequency Achieved	QAPP Acceptance Criteria Met	Date Tables in 2006 Q1+Q2 Groundwater Monitoring Report Presenting Results
Electronic Data Deliverable 10% Check	--	Yes	
Sample Event Table and Database Agreement	--	Yes	
Analytical Reports and Chain-of-Custody Documentation	--	Yes	
Preservation and Hold Times	--	Yes	
Analytical Methods / Reporting Limits	--	Yes	
Field Equipment Blank Samples	Yes	No	Table B.1 lists detections in field equipment blank samples. (Five samples affected)
Trip Blank Samples	Yes	Yes	
Laboratory Method Blank Samples	Yes	Yes	
Laboratory Control Samples (LCS)	Yes	No	Table B.2 lists samples with LCS results outside of acceptance criteria. (Six samples affected)
Matrix Spike/Matrix Spike Duplicate Samples (MS/MSD)	Yes	No	Table B.3 lists samples with MS/MSD results outside of acceptance criteria. (Two samples affected)
Surrogate Spikes	Yes	Yes	
Field Duplicate Samples	Yes	Yes	
Laboratory Duplicate Samples	Yes	No	Table B.4 lists samples with laboratory duplicate RPD results exceeding acceptance criteria. (12 samples affected)
Calibration Data	Yes	No	Table B.5 lists samples with calibration results outside of acceptance criteria. (Seven samples affected)
Instrument Tune	Yes	Yes	
Internal Standards	Yes	No	Table B.6 lists samples with internal standard results outside of acceptance criteria. (46 samples affected)
Interference Checks	Yes	Yes	
Serial Dilution/Post-Digestion Spike Results	Yes	Yes	

Table 4.3 - Summary of 2006 Q3 QA/QC Review

Review Item	QAPP Frequency Achieved	QAPP Acceptance Criteria Met	Date Tables in 2006 Q3+Q4 Groundwater Monitoring Report Presenting Results
Electronic Data Deliverable 10% Check	--	Yes	
Sample Event Table and Database Agreement	--	Yes	
Analytical Reports and Chain-of-Custody Documentation	--	Yes	
Preservation and Hold Times	--	Yes	
Analytical Methods and Reporting Limits	--	Yes	
Field Equipment Blank Samples	Yes	No	Table A.1 lists detections in field equipment blank samples. (Six samples affected)
Trip Blank Samples	Yes	No	Table A.2 lists detections in trip blank samples. (Seven samples affected)
Field Blank Samples	Yes	Yes	
Laboratory Method Blank Samples	Yes	Yes	
Laboratory Control Samples (LCS)	Yes	No	Table A.3 lists samples with LCS results outside of acceptance criteria. (Ten samples affected)
Matrix Spike/Matrix Spike Duplicate Samples (MS/MSD)	Yes	No	Table A.4 lists samples with MS/MSD results outside of acceptance criteria. (Two samples affected)
Surrogate Spikes	Yes	Yes	
Field Duplicate Samples	Yes	Yes	
Laboratory Duplicate Samples	Yes	No	Table A.5 lists samples with laboratory duplicate RPD results exceeding acceptance criteria. (Ten samples affected)
Calibration Data	Yes	Yes	
Instrument Tune	Yes	Yes	
Internal Standards	Yes	Yes	

Table 4.4 - Summary of 2006 Q4 QA/QC Review

Review Item	QAPP Frequency Achieved	QAPP Acceptance Criteria Met	Date Tables in 2006 Q3+Q4 Groundwater Monitoring Report Presenting Results
Electronic Data Deliverable 10% Check	--	Yes	
Sample Event Table and Database Agreement	--	Yes	
Analytical Reports and Chain-of-Custody Documentation	--	Yes	
Preservation and Hold Times	--	No	Table B.1 lists samples analyzed past hold time. (One sample affected)
Analytical Methods and Reporting Limits	--	Yes	
Field Equipment Blank Samples	Yes	Yes	
Trip Blank Samples	Yes	Yes	
Laboratory Method Blank Samples	Yes	Yes	
Laboratory Control Samples (LCS)	Yes	No	Table B.2 lists samples with LCS results outside of acceptance criteria. (The affected analyte was not detected in the associated samples; therefore, qualifiers were not applied to the data)
Field Equipment Blank Samples	Yes	Yes	
Trip Blank Samples	Yes	Yes	
Laboratory Method Blank Samples	Yes	Yes	
Laboratory Control Samples (LCS)	Yes	No	Table B.2 lists samples with LCS results outside of acceptance criteria. (The affected analyte was not detected in the associated samples; therefore, qualifiers were not applied to the data)
Field Equipment Blank Samples	Yes	Yes	
Trip Blank Samples	Yes	Yes	
Internal Standards	--	Yes	

Notes:

QA/QC = Quality Assurance/Quality Control

RPD = Relative Percent Difference

-- = Not applicable

1 = Assessment of analytical result compliance with QAPP criteria is limited to WCDWR-specified target analytes.

5. OVERVIEW OF CENTRAL TRUCKEE MEADOWS CONTAMINANT HYDROGEOLOGY

The following sections present an overview of what has been learned regarding the character of PCE contamination in the central Truckee Meadows since the implementation of systematic groundwater monitoring in 2003 Q4 (WorleyParsons, 2007; Intera, 2006a and 2006b).

5.1 Hydrogeology

A graphical representation of the current understanding of major features influencing groundwater flow in the CTM is presented as **Figure 5.1** and **5.2**. The major features of this conceptual understanding are summarized below. The use of the terms Shallow Aquifer (for the water table zone) and Deep Aquifer (for the deeper water bearing zone where the municipal water supply wells are completed) was used by CDM for expediency and does not appropriately characterize the current understanding that the existing groundwater bearing zones are contained in a more complex three-dimensional aquifer system. The terms Shallow Zone and Deep Zone are now being used for the categorization and presentation of monitoring data; this recognizes that the conceptual model will continue to evolve with the introduction, use, and subdivision of the various water bearing zones considering both their relative locations and heterogeneous lithological make-up.

5.1.1 Lithologic and Structural Control

As shown in **Figure 5.1**, the principal known water bearing intervals in the CTM are interpreted to be the Verdi Basin Sediments (VBS) and the overlying Quaternary sediments. In much of the basin, the juxtaposition of alternating higher and lower energy deposits has resulted in heterogeneous basin fill sediments with discontinuous and interlayered coarser-grained and finer-grained materials. This has created varying but at least locally significant vertical anisotropy (CDM, 2002; WorleyParsons, 2007). As a result, the vertical distribution of coarser grained, water-producing strata and finer grained strata that impede vertical groundwater flow is heterogeneous and complex.

The Shallow Zone hydrostratigraphic units include Quaternary glacial outwash and Quaternary to Holocene fluvial sediments underlain by Quaternary and Tertiary fluvial sediments. These sediments are heterogeneous and consist of varying proportions of silt, sand, and gravel that are poorly to well sorted and complexly inter-bedded and inter-layered. Lenses of clay and clayey materials have also been observed. The glacial outwash sediments are generally coarser grained, more poorly sorted, and more chaotic than the underlying or overlying fluvial sediments. The near surface occurrence of more transmissive materials is likely to provide pathways through which contaminants (such as PCE) released at the surface can migrate vertically downward.

The Deep Zone hydrostratigraphic units include heterogeneous Quaternary glacial outwash and Quaternary and Tertiary fluvial sediments. These sediments also consist of interbedded sand, gravel, silt and clay and dip slightly eastward. The Tertiary Verdi Basin Sediments are generally finer grained than the younger fluvial sediments, but the VBS also contains coarser sedimentary intervals that are similar in character to the younger fluvial sediments. It can be difficult to identify this transition in boring logs. Historically (Cohen and Loeltz, 1964), the VBS have been considered less favorable as water-bearing strata than the overlying Quaternary sediments. However, while the Quaternary sediments do include what have been recognized as some of the most transmissive materials within the Truckee Meadows, some productive municipal water supply wells are now considered to have been completed in the VBS.

The Shallow Zone and Deep Zone can be grossly separated by lower permeability strata of varying lateral continuity. The potential effectiveness of these lower permeability layers to impede vertical groundwater flow varies from location to location in the basin, depending on the lateral continuity and vertical complexity of these layers or packages of layers .

Along the Truckee River corridor, sediments can be scoured and reworked, disrupting depositional stratification and creating well sorted, predominantly coarse grained conduits in which vertical permeability has been potentially increased. These reworked sediments may locally extend into or through any finer grained strata that may separate the Shallow Zone from the Deep Zone. Along the Truckee River corridor, this potential for long-term down-cutting through and reworking of older sediments is likely to have a potentially significant influence on the vertical movement of groundwater and contaminants such as PCE.

Recent studies (Widmer *et al.*, 2006; Widmer, 2006 and 2007) indicate that the Truckee Meadows basin is not a geometrically simple, fault-bounded basin. Gravity modeling of the underlying bedrock surface indicates that the basin floor is irregular and likely to have resulted from paleo-topography and displacement along multiple fault structures . The primary fault structure that has been identified to date is the Virginia Lake Fault Zone (VLFZ), an apparently northerly trending and westward dipping normal fault zone identified from gravity studies, surface topographic expression, and a west to east drop (step) in the potentiometric surface in both the Shallow and Deep Zones. The depth of the basin fill sediments ranges from approximately 1,300 to 1,600 feet on the west side of the VLFZ and 600 to 900 feet east of the VLFZ. The variability in basin fill thickness is interpreted to result primarily from paleotopography. Based on stratigraphic evidence from boring logs, the apparent structural offset in the younger basin fill sediments is approximately 50 feet or less. The VLFZ, and other possible lateral groundwater flow barriers such as the Harvard Way Barrier, are relatively thin, vertically oriented zones of lower permeability that impede, but do not stop, lateral groundwater flow.

The VLFZ appears, at least locally, to be a substantial barrier to groundwater flow. This is evident from steepening groundwater level elevation gradients across the VLFZ in the Shallow and Deep Zones as measured in wells just north of the Truckee River and near the intersection of Holcomb Avenue and Vassar Street. During aquifer test pumping on either side of the VLFZ to date, only a slight response has been observed in wells on the opposite side of the VLFZ. This could be related to the degree of hydraulic separation across the VLFZ and/or the masking of any response across the VLFZ due to readily available local recharge (such as from the Truckee River). The VLFZ appears to limit the westward propagation of the Shallow and Deep Zone response to the seasonal pumping that takes place east of the VLFZ. The VLFZ may also have an influence on the apparent eastern (downgradient) extent of the West 4th Street plume. Existing data suggest that PCE migrates across the VLFZ and impacts the Morrill Avenue, Kietzke Lane and Mill Street municipal pumping wells. The specific influence the VLFZ may impart toward impeding groundwater flow and contaminant migration in conjunction with seasonal municipal well operation and potential local recharge from the Truckee River (see below) are not well understood or characterized.

5.1.2 Groundwater Occurrence and Flow

Within the central Truckee Meadows, groundwater generally flows from west to east, from the Carson Range and Peavine Mountain toward the Truckee narrows, between the Pah Rah and Virginia Ranges, where the Truckee River exits the basin (**Figures 3.1 to 3.8**). Locally, the direction of groundwater flow is influenced by well pumping, underground injection of water, infiltration of water from the Truckee River, and hydraulic flow barriers associated with geological features such as the VLFZ (**Figure 5.1**).

Water-bearing zones in the Truckee Meadows can be at least locally separated by lower permeability geologic layers or aquitards which prevent or reduce the vertical movement of groundwater (and contaminants). Previous conceptual models inferred that the aquitards in the CTM were laterally extensive and provided significant hydraulic separation between the shallow and deep water bearing zones. Through evaluation of water level data, aquifer test data, and the local response of Shallow Zone wells to Deep Zone pumping , it is becoming increasingly clear that this is not the case. The evolving conceptual model now includes several laterally discontinuous, likely heterogeneous lower permeability geologic layers that appear to provide varying degrees of local impedance to the vertical movement of groundwater and contaminants. In some cases these appear to be locally impervious ; whereas, in other cases, they appear to provide little impedance to vertical groundwater and contaminant movement . In cases where little impedance is apparent, the Shallow and Deep Zones are in good hydraulic communication.

Groundwater flow in the Shallow Zone is from west to east and generally parallels the Truckee River. Shallow Zone water level data show evidence of recharge from the river (e.g. deflection of water level contours and local mounding), especially through downtown Reno. Groundwater in the Deep Zone also generally moves from west to east. Prominent seasonal depression of water level elevations in the Deep Zone occurs in those parts of the basin where pumping municipal water supply wells are located. Several deep, coalescing groundwater depressions form during the summer and fall in the vicinity of the Mill Street, Kietzke Lane, 4th Street, and Morrill Avenue wells, the Corbett well, and further east around the Pezzi well. Groundwater flow in the Deep Zone in the central portion of the CTM is toward these wells during summer and fall. The development of these depressions coincides with peak municipal pumping demands. Even though the municipal water supply wells are typically only pumped for part of any given year, the rebound in water level elevations near these wells after pumping has ceased occurs over a 3 to 6 month time period. This apparently is a reflection of the additional time required for groundwater to move through the aquifer from recharge sources and replace the groundwater that was removed by pumping.

The vertical movement of groundwater water is an important consideration in the evolving conceptual model for PCE contamination in the CTM. Vertical groundwater movement is strongly influenced by groundwater pumping for municipal supply, by recharge from the Truckee River, by hydraulic flow barriers (such as the VLFZ), and also by potential geothermal upwelling (**Figure 5.1**). Comparison of Shallow and Deep Zone groundwater level elevations since the implementation of the GMP (Intera, 2006a and 2006b; WorleyParsons, 2007) show distinct general differences between the Shallow and Deep Zones of the aquifer. Of particular interest are downward gradients along the Truckee River (**Figure 3.9**), which persist throughout the year, but are at a maximum during the summer and fall. These observations indicate that the Truckee River is likely to be a major local driver for downward groundwater flow gradients and recharge. As discussed previously, alluvial sediments in the Truckee River corridor are likely to be scoured and reworked, potentially creating coarse grained conduits in which stratification has been disrupted and vertical permeability increased. The apparent presence of Shallow Zone groundwater mounding along the Truckee River also suggests that the river could influences lateral groundwater (and contaminant) movement. It is possible that the river could represent a significant barrier or impediment for lateral groundwater flow in the Shallow Zone.

An example of the apparent hydraulic communication between the Shallow and Deep Zones and the influence of the Truckee River is indicated by the hydrograph response in Shallow Zone key wells of the West 4th Street Subregion to pumping of the Deep Zone Reno High and High Street municipal wells and to changes in Truckee River stage (see **Section 6.2.3** and **Figure 6.15a**). In the Mill / Kietzke Subregion, no drawdown was reported during a 24-hour pumping test of the Mill Street Well by ARCO, in a nearby Shallow Zone observation well ARCO6018MW16, 122 feet to the northwest (BAI, 1999); however, drawdown has been observed in Shallow Zone observation well CTM9S (approximately 2,000 feet northwest of the pumping well) in response to more sustained pumping of the Mill Street Well (Intera, 2006b, see also **Section 6.2.5**). This suggests the presence of an aquitard of limited lateral extent or with a southward dip. The formation of a water level depression of up to 10 feet in the Shallow Zone water table in the vicinity of the Mill Street and Corbett Wells has been documented during the summer and fall (**Section 6.2.5**), indicating that flow from the Shallow Zone to the Deep Zone occurs in that area when vertical gradients are at their maximum. These data suggest that hydraulic communication between the Shallow Zone and the Deep Zone is better west of the VLFZ than east of the VLFZ, and that inflow of Truckee River water to replace downward flowing groundwater may also take place more rapidly west of the VLFZ.

Data from aquifer tests conducted in the CTM also support the presence of spatial variability in the impedance to vertical groundwater flow across the CTM, as summarized below.

Summary of Key Aquifer Tests in the Central Truckee Meadows

Pumping Well	Response in Shallow Zone Observation Wells	Response in Deep Zone Observation Wells
High Street	Response west of the VLFZ; No response east of the VLFZ.	Response west of the VLFZ; Limited response east of the VLFZ.
Morrill Avenue	Slight response east of the VLFZ; No response west of the VLFZ.	Response east of the VLFZ; Limited response west of the VLFZ.
Mill Street	Response in well 2000 feet west of the pumping well during long term pumping; No response immediately surrounding the well during 24-hour pump test.	Yes.

The VLFZ is currently considered to be a steeply dipping, north-northeast trending tabular zone of lower permeability that acts as an impediment to groundwater flow. Steep gradients in groundwater elevation are observed across the VLFZ in the Shallow and Deep Zones near the Truckee River, and in the Deep Zone in the Vassar / East Plumb Subregion. As summarized above, during aquifer tests using the High Street and Morrill Avenue Wells, Shallow Zone observation wells on the opposite side of the VLFZ from the pumping well did not experience measurable drawdown. In addition, seasonal groundwater depressions that form beneath downtown Reno and to the south near the Corbett Well expand westward to the VLFZ, but do not appear to cross this barrier. These observations suggest a relatively high level of impedance to lateral groundwater flow across the VLFZ; however, groundwater flow appears to be rapid enough to keep the water table on the west side of the VLFZ from rising to the ground surface. The mechanism and nature of groundwater flow across the VLFZ, and its interaction with the Truckee River, is not well understood at this time.

A similar steep gradient in the Deep Zone potentiometric surface occurs across the Harvard Way Barrier between well CTM33D and the Corbett Well. At this location, the lack of a steep gradient in the Shallow Zone water levels results in a reversal of the vertical gradient from upward on the west side of the Harvard Way barrier to downward on the east. The lateral persistence and trend of the Harvard Way Barrier to the north and south have not been established. Additional, and as yet undiscovered, barriers to lateral groundwater flow may also exist in the CTM.

5.2 PCE Contamination

5.2.1 PCE Occurrence and Transport

GMP results have confirmed that PCE is the most widespread contaminant of those monitored by DWR in the CTM. Plotting and contouring the GMP data reveals a number of distinct areas of groundwater contaminated by PCE. **Figure 6.1** shows the outlines of seven Shallow Zone and three

Deep Zone plumes. The extent of the groundwater contamination plumes has been defined by the existing monitoring well network. The definition of these plumes may change (with respect to occurrence and shape) over time in response to groundwater movement or as additional monitoring wells are added to the network (both in terms of surface location and the depth to which they are completed (**Figures 3.1** to **3.8**). In addition, the Shallow and Deep Zones are useful constructs for graphically representing the plumes but, in reality, the plumes that have been identified as shallow-deep pairs are three-dimensional features that are continuous across these zones. To illustrate this, there are three Deep Zone plumes that have been identified (South Reno, Downtown Reno, and Downtown Sparks). Each of these is superimposed by at least one Shallow Zone plume (Vassar / East Plumb, West 4th Street, and Victorian Avenue, respectively). Thus every deep plume has at least one shallow plume spatially associated with it as a counterpart. This relationship reflects a common origin for these plumes. Comparison of plume maps for both the Deep and Shallow Zones suggests that the horizontal distribution of PCE contamination has been relatively stable for the time period since the GMP was implemented.

The three-dimensional nature of these contaminant plumes is shown graphically in **Figure 5.2** and indicates downward migration of PCE from potential source areas through the Shallow Zone and continued migration to the Deep Zone. The existing PCE contamination must have originated at or near the ground surface at some time in the past. The presence of PCE plumes in the Deep Zone requires that PCE move vertically from the ground surface through the Shallow Zone and into the Deep Zone. An increased vertical hydraulic gradient associated with recharge from the Truckee River and/or municipal pumping in the Deep Zone is likely to have drawn the PCE contamination from the Shallow Zone down into the Deep Zone. This effect may be enhanced by the observed eastward (downgradient) dip of the water-bearing strata (**Section 5.1.1**). The contamination would be readily drawn into the Deep Zone in areas where the hydraulic barrier separating the Shallow and Deep Zones is less developed or absent. The ultimate fate of PCE in the Deep Zone is migration toward and capture by a municipal water supply well (or other deep pumping well) where the PCE is removed from the aquifer. Each of the three Deep Zone plumes has already reached a receptor well. There are currently three Shallow Zone plumes that have not yet been demonstrated to have impacted the Deep Zone or to have reached a receptor well. They are the Mill / Kietzke, Wolverine Way, and Greenbrae Plumes. These plumes may eventually reach receptor wells.

5.2.2 Groundwater Modeling

Based on an earlier conceptual understanding of the CTM, Camp, Dresser & McKee (CDM) prepared a numerical groundwater flow and contaminant transport model of the CTM using their DYNFLOW® code (CDM, 2002). Based on an evaluation by Intera (2006a) This model produces calibration results meet standard industry criteria; however, the CTM DYNFLOW-based groundwater flow model has deficiencies that inhibit using the model as an effective program management tool. These limitations include:

- The model is based on a proprietary software platform. The software does not readily interface with the CMTRD program database or with the Washoe County Geographic Information System (GIS).
- The model, as currently configured, is suitable for regional scale flow analysis rather than for investigation of contaminant transport of individual PCE plumes.
- The underlying geological conceptual model is inadequate, based on what is now known about the Truckee Meadows basin, and casts doubt on the ability of the groundwater model to accurately represent the flow and transport relationship between the Shallow Zone (water table) and Deep Zone in critical areas of importance to the CTMRD program.
- The DYNFLOW model is based on pre-existing groundwater models developed and updated over time by several different contractors for water resource management only. Fundamental and sufficient documentation on the hydraulic parameters and boundary conditions for the DYNFLOW model is not available to DWR.

More widely used, industry-standard groundwater flow modeling platforms are available that can meet CTMRD program objectives more effectively and efficiently (*e.g.*, GMS/MODFLOW). A sensitivity analysis of the DYNFLOW model was performed (Intera, 2006a) to investigate the sensitivity of the model output (*i.e.*, heads at target wells) to the variability of selected input parameters (*e.g.*, hydraulic conductivity). The model was determined to be most sensitive to the magnitude of the various recharge input quantities and especially to the Truckee River leakance to the Shallow Zone.

A conceptual model that would be consistent with the measured PCE dissolved-phase plume concentrations in the Deep Zone allows for direct hydraulic communication (no effective hydraulic barrier or aquitard) between the Shallow Zone and Deep Zone in certain areas of the basin. Existing data suggest that such areas of direct hydraulic communication occur in Downtown Reno and to the west of the Mill and Kietzke water supply wells.

A new basin-wide groundwater flow and contaminant transport model could be based on CTMRD program investigations to determine the hydrogeologic characteristics and hydraulic properties of the geologic materials that form the transition between the Shallow and Deep Zones in the CTM aquifer.

5.2.3 Water Supply Pumping and Plume Capture

TMWA operates a network of 27 municipal water supply wells. Five of these wells have been impacted by PCE at concentrations above the MCL and are equipped with wellhead treatment systems to remove PCE. These wells are used under the Pumping Plan to contain the Deep Zone Plumes while at the same time being used for municipal water supply. The pumping of these wells in 2006 compared to the Pumping Plan is presented in **Figure 5.3**.

The 2005 *Pumping Plan Analyses* (Intera, 2006b) predicts the percentage of each plume's area that is captured by each receptor well. (The analysis suggests that the majority of the West 4th Street/Downtown Reno plume is being captured by the wells fitted with PCE treatment equipment. However, it is now recognized that the hydrogeology of this area is relatively complex and may not be effectively represented in the DYNFLOW groundwater flow model used for the analysis.) The key findings of this analysis were as follows.

- Due to limitations of the existing groundwater model to simulate the vertical movement of groundwater and contaminants (**Section 5.2.1**), these predictions are not considered realistic for Shallow Zone plumes such as the Vassar / East Plumb and West 4th Street Plumes. However, the predictions of capture percentages for Deep Zone plumes are believed to be more reasonable.
- **Figure 5.3** compares Pumping Plan Option 1B and 2B versus actual pumping for the year 2006. The Option 1B and 2B scenarios are identical except for the assumed pumping rates for the five treated wells (Mill, High, Kietzke, Morrill, and Corbett). The principal difference between Option 2B and 1B is that 2B has more pumping at the Kietzke Lane Well. As a result, the percentage of the Downtown Reno plume that is captured by the Kietzke Lane Well is increased and the percentage captured by the Mill Street Well is decreased, in Option 2B.
- The principal difference between Option 2B and 2006 actual pumping is that the 2006 actual pumping for the Mill Street Well is 18 percent greater. The Mill Street Well is in a strategic location near the downgradient edge of the Downtown Reno plume. As a result, changes in the pumping rate at for Mill Street Well can significantly affect the percentage of the plume captured by that well. In this case the 18 percent increase in pumping is estimated to result in an 8 percent increase in the area of the Downtown Reno plume captured by the Mill Street Well.

The above analysis does not consider the effect from using the wells for recharge in the winter and spring. In addition, the analysis may not effectively represent plume behavior recognizing that the downgradient extents of the Downtown Reno and South Reno plumes are currently poorly constrained. Although capture of the majority of these plumes appears likely, the existing groundwater model is inadequate to effectively confirm the full extent of plume capture.

Figure 5.4 shows the PCE mass removal rates and total PCE mass removed by each of the five wells equipped with wellhead treatment systems. The graphs show the competition between the various wells for capture of the Downtown Reno plume.

5.2.4 Monitored Natural Attenuation (MNA)

Although evaluation of the Monitored Natural Attenuation (MNA) data from wells in the Mill / Kietzke plume (Intera, 2006c) indicates that limited biodegradation may be occurring, most of this evidence is observed at a single monitoring well, CTM-13S. This well has exhibited the consistently highest concentrations of PCE in this plume and is located where carbon substrate available for natural attenuation reactions has been locally increased due to the presence of petroleum fuel compounds (BTEX) from a possible nearby fuel leak. Based on the MNA data generated during the GMP to date, the subsurface environment in the CTM has been identified to be typically carbon poor and the conditions required to promote reductive dechlorination of PCE are not naturally present. These factors result in an environment that is not favorable for natural biodegradation of PCE in groundwater. Using the EPA scoring protocol (Wiedemeier *et al.*, 1998) the highest score calculated for the Mill-Kietzke plume was 13. According to EPA guidance, a score of 15 or more is needed to indicate that significant contaminant biodegradation is taking place. Under the general conditions present in the CTM, PCE will be relatively stable and persistent.

6. PLUME SUBREGION CONCEPTUAL MODELS

6.1 Methods and Approach

6.1.1 Designation of Subregions

The ten major PCE plumes that have been identified to date in the CTM are presented in this report as parts of nine subregions that have been defined for the purposes of evaluation and presentation. Each subregion is a three-dimensional volume of the CTM basin material that contains a distinct PCE plume. The hydrogeologic properties of the subregions are used to develop conceptual models (presented below) that attempt to explain plume behavior. The lateral boundaries of the subregions define rectangles that are typically elongated in the west to east direction as shown on **Figure 6.1**. The boundaries of each subregion have been established so that they entirely encompass a plume, its potential source areas, and any actual or potential receptor wells.[1] The subregion lateral boundaries also include wells that are non-detect for PCE on all sides of each plume. Vertically, the subregions are bounded by the depths of the wells within the plume. Thus each subregion is designated to be either a “Shallow Zone” or “Deep Zone” subregion. As explained below, some plumes extend vertically across subregion boundaries. Accordingly, the subregions do not necessarily include wells that are non-detect for PCE above and below each plume.

Shallow Zone wells are screened across or near the water table, and typically range in depth from 30 to 90 feet bgs. Deep Zone wells are screened beneath one or more lower permeability layers at depths typically greater than 120 feet bgs, in an apparently confined or semi-confined aquifer. Given the heterogeneous nature of the CTM basin fill, the lateral extent of these lower permeability layers has not been established, but it is recognized that low or semi-permeable (i.e. aquitard) layer or layers are locally present within the interval between the Shallow Zone and the Deep Zone. The municipal water-supply wells in the CTM are screened in what has been defined as the Deep Zone.

The Shallow and Deep Zones are useful constructs for graphically representing the plumes but, in reality, the three subregion pairs that have corresponding shallow and deep plumes encompass, in reality three-dimensional features that are continuous across the vertical subregion boundaries. To illustrate this, there are three Deep Zone plumes that have been identified (Downtown Reno, South

[1] Receptors are defined as points of groundwater use or potential groundwater use that are, or historically were, impacted by PCE. Thus, they include both active and inactive municipal water supply wells (receptor wells) in which PCE has been detected either above or below the Maximum Contaminant Level (MCL) established by EPA for PCE in drinking water. Any production well in the basin could be a potential receptor; however, in this study the term is applied only to those wells that are at risk of being impacted by known contamination based on the presently available data.

Reno, and Downtown Sparks). Each of these is superimposed, at least in part, by one or more Shallow Zone plumes. Thus every deep plume has at least one shallow plume spatially associated with it as a counterpart. This relationship reflects a common origin for these plumes. The three-dimensional data distributions presented in the conceptual models discussed below clearly indicate downward migration of PCE from potential source areas to plumes in the Shallow Zone and continued downward vertical migration into the Deep Zone. The ultimate fate of PCE in the Deep Zone generally is migration toward and capture by a municipal water supply well (or other deep pumping well) where the PCE is removed from the aquifer. Each of the three Deep Zone plumes has already reached a receptor well. These Deep Zone plumes appear to be connected to four of the seven Shallow Zone plumes. Thus there are currently three Shallow Zone plumes that have not yet been demonstrated to have impacted the Deep Zone or to have impacted a receptor well. They are the Mill / Kietzke, Wolverine Way, and Greenbrae Plumes. These plumes may eventually reach receptor wells.

The designation and use of subregions as a method of organizing, evaluating, and presenting GMP information about the CTM plumes takes advantage of the static locations of the potential plume sources and receptors or potential receptors. This results in apparently stable distributions of PCE concentrations. Individual PCE molecules can move (e.g. from source to receptor where applicable) within the plumes, but the overall extent of the plumes appears not to change appreciably .

Utilizing subregions as an organizational tool promotes the present understanding of the plume conceptual models. These subregion conceptual models are flexible and subject to change as additional data become available and our knowledge and understanding increases.

6.1.2 Analytical Tools

The following data analysis tools are used in this report to evaluate the subregions and plumes to develop conceptual models:

- **Project Database –** Water quality and water level data from the project database was queried to evaluate PCE concentration and water level trends.
- **Cross Sections –** DWR is preparing lithologic cross sections for each plume subregion based on interpretation of available well lithologic and geophysical logs. For this report, lithologic cross sections were only available for the Vassar Street / East Plumb Lane Subregion. Additional cross sections are under preparation, and will be included in the subregional evaluations presented in future reports.
- **Potentiometric Surface Maps –** Potentiometric surface maps for the Shallow and Deep Zone groundwater elevations during the 2006 monitoring events were prepared by DWR and are presented as **Figures 3.1 through 3.8**. These maps were used to assess the lateral hydraulic gradients and groundwater flow.

- **Plume Maps –** PCE isoconcentration contour maps for the Shallow and Deep Zone groundwater elevations during the 2006 monitoring events were prepared by DWR and are presented as **Figures 3.1 through 3.8**. These maps were used to assess the concentrations and distribution of PCE in each plume.
- **Water Level Difference Maps –** The Shallow and Deep Zone potentiometric surface data for each monitoring event were geospatially analyzed to prepare maps of the differences in groundwater elevation between the Shallow and Deep Zones during 2006. These maps are presented as **Figures 3.9** and were also prepared at a subregional scale as referenced in **Section 6.2**. They were used to assess vertical gradients and groundwater flow during the year.
- **Plume Concentration Change Maps –** The Shallow and Deep Zone PCE isoconcentration contour data for each monitoring event were geospatially analyzed to prepare maps of the change in PCE concentrations between the 2006 Q1 and Q2, Q2 and Q3, and Q3 and Q4 monitoring events. These maps were prepared at a subregional scale as referenced in **Section 6.2**. They were used to assess short term changes in PCE concentrations across each plume during 2006.
- **Key Well Trend Analysis[2] –** The analytical data for key wells were statistically and graphically analyzed to evaluate longer term concentration trends in various parts of the plume and subregion. The results of these analyses are presented as **Tables 6.1** through **6.9**. Statistical trend analysis was conducted using the Mann-Kendall test in 3-year segments, so that the results would be representative of current well behavior and yet cover a long enough period to filter out short term and seasonal trends. Shorter term trends were evaluated based on review of the time-concentration graphs.
- **Well Hydrograph Analysis –** Well hydrographs were plotted along with time-concentration data for selected key wells in **Tables 6.1** through **6.9**. This analysis was conducted on a preliminary basis to assess whether there is evidence for correlation between PCE concentrations and water levels that would warrant more systematic evaluation.
- **Stacked Graphs –** Stacked graphs of average water level profiles and average Shallow/Deep Zone water level difference profiles were prepared for the four quarterly monitoring events in 2006 for each subregion as referenced in **Section 6.2**. Each stacked-graph profile represents the average water level elevation in the west-east direction (*i.e.*, the general direction of groundwater flow). The averages are calculated from contoured data (shown on **Figures 3.1**

[2] Key wells are defined as strategically-located wells for analysis of plume behavior, and include well that are representative of plume conditions in near-source, mid-plume and distal locations, as well as upgradient wells, downgradient sentry wells and receptor (impacted municipal water supply) wells.

through **3.8**) spanning the width of a subregion in the north-south (*i.e.*, cross-gradient) direction. The purpose of these graphs is to allow evaluation of water-level and vertical gradient profiles across the subregion for each quarter, and assess potential vertical groundwater flow.

- **Shallow-Deep Plume Pair Concentration Profiles –** PCE concentration profiles for overlapping Shallow and Deep Zone plumes were prepared for the baselines shown on **Figure 6.1**. Thus the PCE concentration profiles are independent of subregion geometry and are peak values along the plume axes rather than averages along the subregion axes.. These profiles were used to compare overlapping Shallow and Deep Zone PCE concentrations projected along the plume axes, and assess whether effects of downward PCE migration are evident.
- **DWR Source Database –** Information regarding Potential Contaminating Activities (PCAs)[3] and PCE sources[4] has been generated by past investigations (e.g. McGinley and Associates, 2002) and has been compiled into a PCE using business database by DWR. Potential sources have been identified during investigations of sewer subregions (**Figure 6.2a**) (Kleinfelder, 2003) and investigations at NDEP and WCDHD Corrective Action Sites (**Figure 6.2b**).

6.1.3 Key Questions

The conceptual models for each subregion are presented in terms of key questions that have been developed to organize and prioritize what is known about each subregion and the plume(s) therein. These questions have been designed to gather the most important information for characterizing the plumes in a concise manner. Since the same questions will be applied consistently to all the subregions, comparison of the answers from one subregion/plume to another (where appropriate) can help identify critical data gaps.

[3] Potential Contaminating Activities (PCAs) are defined as PCE-using businesses where the current or historical legal use of PCE, PCE discharge to sewers, or PCE spillage could cause releases to the subsurface environment. The presence of a PCA does not necessarily mean that a release has occurred or will occur. It is possible that there are new PCAs in the area that have not been identified, or that some of the previously identified PCA sites are no longer using PCE.

[4] Sources are defined as identified subsurface releases that have impacted or threaten to impact groundwater resources or receptor wells. Note that a release of PCE to soil may or may not impact groundwater depending on the nature of the release and the extent and timeliness of any cleanup efforts. Identified sources may be at varying stages of characterization and additional sources may be identified in the future.

Groundwater Occurrence and Flow

- *What is the hydrostratigraphy of the subregion?*
- *What lateral and vertical hydraulic gradients are influencing groundwater flow?*

Plume Characteristics

- *What is the extent and distribution of PCE in the plume?* [5]

PCE Sources

- *To what extent have source areas been identified?*

PCE Concentration Trends and Migration

- *Are PCE concentrations increasing or decreasing?*
- *Is the plume stable or migrating laterally?* [6]
- *Is there evidence of vertical migration?*

Receptors

- *Are municipal water supply wells impacted or have they been in the past?*

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[5] The PCE concentration contours shown on **Figures 3.1** through **3.8** present a reasonable interpretation of the spatial relationships of concentrations in the monitoring wells, however, these contours are subject to change based on an evolving understanding of the conceptual models and the availability of new data. Thus the conceptual model discussions presented in this report may occasionally differ from the contoured plume interpretations shown on the figures.

[6] For the sake of clarity, the conceptual model descriptions presented below use the term “PCE migration” when referring to movement of a plume outline, especially the leading edge of a plume. The term “PCE transport” is used when referring to the movement of individual molecules of PCE within a plume. This distinction is significant because some of the plumes are hydraulically controlled to a significant degree; in these cases the plumes outline do not migrate appreciably. Nevertheless, PCE within the plumes is transported by groundwater flow from the potential source area to the plumes’ receptor wells, where the PCE is removed from the aquifer.

- *What is the risk that PCE concentrations at receptor wells will increase?*
- *What is the risk that additional wells will be impacted?*

6.2 Plume Subregion Evaluations

Descriptions of the nine subregions and the plumes within are presented in the following sections.

6.2.1 Vassar / East Plumb Lane Plume Subregion

The Vassar / East Plumb Subregion boundary outlines the Shallow Zone counterpart to the Deep Zone South Reno Subregion (described in **Section 6.2.2**). As defined, the lateral boundaries of the Vassar / East Plumb Subregion coincide with the boundaries of the South Reno Subregion (**Figure 6.1**). The Deep and Shallow Zones in the South Reno and Vassar / East Plumb Subregions appear to be at least locally separated by a partial barrier to upward vertical groundwater flow (based on a limited number of wells completed in the Deep Zone). This barrier (or aquitard) appears to occur within the Glacial Outwash alluvium, at depths greater than 50 feet and less than 175 feet bgs (*i.e.* above the screened interval of well CTM33D).

PCE sources (of presently uncertain origin) within the Vassar / East Plumb Subregion directly impact the Shallow Zone as evident by the PCE plume there. The data suggest that PCE has migrated downward from the Shallow Zone within the Vassar / East Plumb Subregion to form the Deep Zone plume of the South Reno Subregion. The Corbett municipal water supply well is screened in the Deep Zone and is located in the center of the PCE plume (as presently defined based on the existing Deep Zone wells within the plume) within the underlying South Reno Subregion. It is the receptor well for PCE migrating laterally in the Shallow Zone through the Vassar / East Plumb Subregion and vertically downwards to the Deep Zone.

Groundwater Occurrence and Flow

What is the hydrostratigraphy of the subregion?

- The upper stratigraphic interval consists of what has been defined as Quaternary Glacial Outwash Alluvium, which extends to depths of approximately 200 feet bgs in the subregion. The Glacial Outwash Alluvium overlies what have been interpreted (Washoe County DWR) as Tertiary-aged Verdi Basin Sediments (Trexler and Cashman, 2006). Bedrock consists of Mesozoic crystalline and Cenozoic volcanic rocks (Trexler and Cashman, 2004). The depth to bedrock varies from approximately 850 to 1,500 feet bgs in the subregion based on a borehole intercept and gravimetric data (Widmer *et al.*, 2006; Widmer, 2006 and 2007).
- Two apparently steeply dipping features with an inferred north-northeast trend are suggested to occur within this subregion. The features appear to act as partial barriers to groundwater

flow (**Figures 1.2** and **6.3**). These features are inferred faults, characterized by west-to-east rapidly steepening groundwater gradients in the Shallow and Deep Zones (**Figures 3.1** through **3.8**).

- The western most of these features, the Virginia Lake Fault Zone (the VLFZ, Widmer *et al.,* 2007), has been previously discussed by other workers (e.g. NBMG, 1976; CDM, 2002), and is further characterized by water level discontinuities and topographic expression in the form of a west-facing scarp. The VLFZ passes through the Vassar / East Plumb Subregion near well CTM49, and is projected north-northeastward between CORWSSMW2 and the Morrill Avenue well in the West 4th Street Subregion. Gravity studies suggest the VLFZ is a normal fault that dips steeply westward. A recent regional cross section (Widmer, 2007) crosses the CTM from west to east approximately 1,000 feet north of the Vassar / East Plumb Subregion and indicates that volcanic bedrock is approximately 1,400 feet bgs on the west side of the VLFZ and 650 feet bgs on the east. The difference in bedrock elevation is interpreted to result largely from paleotopographic relief. Because there are no nearby wells that have intercepted bedrock, this has not been confirmed by lithologic or geophysical logs in the immediate vicinity of the fault. Drill log data compiled by DWR including data from wells installed for the CTMRD indicate that structural displacement in Neogene strata across the VLFZ is less than 50 feet.
- Alluvial strata are interpreted to have a gentle eastward apparent dip east of the VLFZ (Widmer *et al.*, 2006). West of the VLFZ, in the western portion of the CTM, steeper eastward dips (in surface exposures near and west of West McCarran Blvd) get shallower close to the VLFZ. Cross sectional interpretation performed by DWR using drill and geophysical logs in the Vassar / East Plumb Subregion shows gently eastward dipping strata in the glacial outwash and underlying VBS.
- The eastern feature, referred to herein as the Harvard Way Barrier (HWB), is inferred based on west-to-east water level drops and associated geological discontinuities identified in wells and well logs at only one transect point. Accordingly, the nature and attitude of this barrier is presently poorly defined. There are currently insufficient wells to verify the nature, extent, and continuity of this barrier, or to more firmly establish whether the observed groundwater level effects are related to faulting or to changes in aquifer lithology. For purposes of this report, the Harvard Way Barrier is considered to be a normal fault that parallels the Virginia Lake Fault Zone.

What lateral and vertical hydraulic gradients are influencing groundwater flow?

- The lateral groundwater flow direction and gradient in the subregion remained relatively constant throughout the year: west to east with a steeper gradient (approximately 0.03) near the VLFZ on the west side of the subregion, and a gentler gradient (approximately 0.002) in the eastern portion of the subregion. In Q3, the observed lateral gradient in the eastern portion of the subregion is noticeably steeper (approximately 0.004) and oriented more northerly in response to the expansion of a depression in the potentiometric surface in the area around the Mill Street and Corbett Wells in the northeast portion of the subregion (**Figure 3.5**). In the core of this depression the lateral groundwater gradient appears to be very small and cannot be effectively measured or resolved using the existing monitoring well network. This depression in the potentiometric surface is attenuated, but still present in Q4 (**Figure 3.7**)

- The vertical groundwater flow direction appears to be generally upward between the VLFZ and the Harvard Way Barrier throughout the year (**Figure 6.3**). In the northwest corner of the subregion, downward gradients are present, and are apparently driven by recharge from the Truckee River. In addition, downward vertical gradients are evident in the northeast portion of the subregion in response to pumping of the Corbett and Mill Street Wells as discussed above and in **Section 6.2.5**. In Q3, the downward vertical gradient reaches an annual maximum in the northeast portion of the subregion. In Q4, upward or neutral water level differences predominate throughout the subregion.

- Upward flow in the central part of the subregion may be driven by convection from geothermal sources in the southwestern part of the subregion (*i.e.*, the Moana Geothermal System) and/or mountain front recharge and possible damming effects caused by the Harvard Way Barrier. The extent and magnitude of vertical gradients are not presently quantifiable at this scale due to the small number of Deep Zone monitoring wells in the subregion.

- The water level drop in the Shallow Zone across the VLFZ is more pronounced than in the Deep Zone. This results in an apparent reversal of the vertical gradient direction from downward west of the VLFZ to upward east of the VLFZ (**Figure 6.3**).

- The water level drop in the Deep Zone across the Harvard Way Barrier is more pronounced than in the Shallow Zone. This results in an apparent reversal of the vertical gradient direction from upward west of the inferred fault to downward east of the inferred fault (**Figure 6.3**). On the west side of the Harvard Way Barrier, the nearest monitoring well (CTM33D) is screened in the Deep Zone and has a water level elevation above land surface. These data suggest that the HWB is a relatively effective barrier to lateral groundwater movement in the Deep Zone and that shallow groundwater crosses the Harvard Way Barrier and is drawn downward on the east side by pumping at the Corbett Well.

- Seasonal trends in water levels generally are characterized by higher water levels in the winter and spring, and lower water levels in the summer and fall (**Table 6.1**). Based on water level monitoring data, the groundwater gradients are somewhat independent of seasons, but the elevations vary seasonally.

- Hydrographs for selected key wells included in **Table 6.1** indicate that water levels reached some of the highest levels observed to date in the winter of 2005 and spring of 2006. Water levels in these wells dropped in Q3 and Q4.

Plume Characteristics

What is the extent and distribution of PCE in the plume?

- The Vassar and East Plumb Lane plumes occur in an area that extends east approximately from Virginia Street to Highway 395, and north approximately from East Plumb Lane to an area that is one to two blocks north of Vassar Street (**Figure 6.1** and **6.4**). PCE is identified in Shallow Zone monitoring wells to a depth of at least 50 to 60 feet bgs, but there are currently no monitoring wells screened between 50 and 150 feet bgs in the central area of this subregion to define the vertical distribution of PCE within these plumes. The Vassar and East Plumb Lane plumes are interpreted to be vertically connected to the South Reno plume, which impacts the Corbett Well in the Deep Zone (**Section 6.2.2**).
- The lateral extent of the Vassar and East Plumb plumes (as defined based on the existing wells) remained essentially unchanged during 2006. However, it should be noted that there are presently no shallow monitoring wells to confirm the downgradient extent of the plumes in the area east of the Corbett well.
- PCE hot spots have been identified near the northwest and southwest extremes of the Vassar and East Plumb Lane plumes, near the locations of wells CTM48 and CTM52, respectively (**Figures 3.1, 3.3, 3.5, 3.7** and **6.4**). PCE concentrations in monitoring wells near the hotspots vary from approximately 22 to 73 µg/L between Q1 and Q4. PCE concentrations tend to decrease with distance to the east of these hot spots and appear to be below detection limit concentrations approximately 6,000 feet east of the Vassar Street hot spot and 4,500 feet east of the East Plumb Lane hot spot, in an area downgradient from the Corbett Well. The maximum plume concentrations are aligned along axes connecting the two hot spots to the Corbett Well, and the Vassar and East Plumb Lane plumes are interpreted to commingle in the area between the hot spots and the Corbett Well. The commingled plume will hereafter be referred to as the Vassar / East Plumb plume.

PCE Sources

To what extent have source areas been identified?

- Several PCAs have been identified near the two hot spots (**Figure 6.4**). These PCAs are mainly current or former dry cleaners and auto repair shops on Wells Ave. and East Plumb Lane. These two hot spots are also located within Sewer Investigation Subregions 2 and 6, and downgradient from Sewer Investigation Subregion 8 (Kleinfelder, 2003) as shown on **Figure 6.2a**.

- o In Sewer Investigation Subregion 2, PCE was detected in waste water at concentrations of up to 2,600 µg/L, which is above rules-of-thumb for the presence of DNAPL (Cohen and Mercer, 1993). Defects were identified in the sewer line along the reach where PCE was detected. Impacted soil and soil vapor indicated the presence of a PCE release near the intersection of the alley between Vassar and Arroyo Streets with Wells Avenue (referred to by Kleinfelder as the North Alley Source Site), upgradient of well CTM48. This release is immediately adjacent to a dry cleaner located at the southwest corner of Vassar Street and Wells Avenue. A second, smaller release was identified beneath the alley between Arroyo and East Pueblo Streets, west of Wells Avenue (referred to by Kleinfelder as the South Alley Source Site).
- o In Sewer Investigation Subregion 6, PCE was detected in waste water at concentrations up to 480 µg/L and sewer line defects were identified. Impacted soil, soil vapor, and groundwater suggest the presence of a PCE release from the sewer beneath Wrondel Way between Casazza Drive and East Plumb Lane (referred to by Kleinfelder as the Wrondel Source Site), near wells CTM51 and CTM52. This location is a short distance east of a former dry cleaner.
- o In Sewer Investigation Subregion 8, PCE was detected in waste water at concentrations up to103.6 µg/L. No defect information was available regarding the condition of this reach of sewer line. Nevertheless, impacted soil and soil vapor indicated the presence of PCE contamination near the sewer line beneath Holcomb Avenue about 100 feet south of its intersection with Wonder Street, near well CTM49 (referred to by Kleinfelder as the Holcomb Source Site). This release is immediately adjacent to a dry cleaner; however, this dry cleaner reportedly has not used PCE since at least 2003. CTM49 is located downgradient of this release. Groundwater in CTM49 was not contaminated with PCE prior to March 14, 2005, but currently shows PCE contamination with an increasing concentration trend. CTM49 is not currently considered a key well for the Vassar Street plume because it has not been determined whether the shallow groundwater contamination associated with this area is connected to that plume (DWR, personal communication).

- The Plumb Lane Plaza (Wrondel Way) NDEP Corrective Action Site has been reported in the Vassar / East Plumb Lane Subregion.
- The concentrations of PCE detected in groundwater to date are not indicative of the presence of DNAPL; however, PCE concentration trends (discussed below) indicate the presence of persistent sources. Because DNAPL sources are often difficult to find, it is

possible that localized residual DNAPL sources may exist in the Vassar / East Plumb Subregion.

PCE Concentration Trends and Migration

Are PCE concentrations increasing or decreasing?

- The 2006 PCE concentration change maps (**Figure 6.4**), and the key well trend analysis (**Table 6.1**) show that groundwater PCE concentrations fluctuate somewhat in the hot spot areas. In some cases, the results of statistical trend analysis have changed with new data generated during the year as noted below, but there does not appear to be a sustained trend or pattern across the plume area.
    - Key well trend analysis through 2006 Q4 indicates that PCE concentrations in USGS LISTON (located downgradient of the Wrondel Source Site at the head of the East Plumb Lane plume) displays an increasing trend since 2004. Well CTM51, also downgradient of this source area, showed an increasing trend over the last four years based on statistical analysis through 2006 Q2, but shows a decreasing trend when data through 2006 Q4 are analyzed.
    - CTM52 shows alternating increasing and decreasing short-term fluctuations, but no statistically distinguishable trend during 2003 Q4 through 2006 Q4.
    - CTM48 (located downgradient of the North Alley Source Site at the head of the Vassar Street plume) shows a decreasing trend through 2006 Q4.
    - USGS WOOSTER, located close to the Corbett Well and near the distal end of the East Plumb Lane plume, did not show a statistically distinguishable trend through 2006 Q2, but data through 2006 Q4 does show an increasing trend. PCE concentrations in this well have increased since June 2005 and currently exceed the MCL.
    - Well CTM 18S, located in what is in the distal portion of either the Vassar Street plume or the Mill/Kietzke plume, displays a decreasing trend since 2004; however, as discussed in greater detail in **Section 6.2.5**, this well may in fact be completed in a distal portion of the Mill Kietzke plume and have no bearing on the Vassar Street plume..
    - Concentrations remained relatively unchanged in the distal areas of the Vassar / East Plumb plume. A slight increase in PCE concentrations was observed in wells CTM39S and CTM38D. It is important to note here, however, that the PCE concentrations in wells CTM39S and CTM38D may not be genetically associated with the Vassar / East Plumb plume. It is possible that the PCE present in these wells may be a detached portion of the Mill / Kietzke plume as discussed in greater detail in **Section 6.2.5**.

- In some of the wells for which hydrographs were evaluated, there may to be a correlation between water levels and PCE concentrations; however, clear and consistent correlations have yet to be identified (**Table 6.1**).

Is the plume stable or migrating laterally?

- The Corbett Well is hydraulically influencing at least a portion of the Vassar/E. Plumb plume. There are insufficient downgradient wells to confirm complete capture, but the outline of the plume as defined by the existing wells has not changed significantly over time. Based on the data points available, the portion of the plume that is being influenced does not appear to be migrating; however, there are presently no wells to confirm the downgradient extent of the plume). The potentiometric surface maps presented in **Figures 3.1, 3.3, 3.5** and **3.7** illustrate that the plume occurs in an area with eastward groundwater flow and is elongated in an eastward direction; therefore, the groundwater and PCE within the plume area are being transported eastward toward the Corbett Well. The Vassar Street plume could potentially be moving past the Corbett Well to the north, toward CTM39S and CTM38. However this possibility has not been clearly demonstrated by an adequate distribution of monitoring well data or capture zone analysis. It is also possible that the PCE present in these wells may be a detached portion of the Mill / Kietzke plume as discussed in greater detail in **Section 6.2.5**.
- The Corbett Well has been operating with well head treatment since 1998 (**Figure 5.3**). Pumping volumes, PCE removal rates and the total annual PCE mass removed were at a maximum for the Corbett Well from 2000 to 2004. The well has been operated at lower cumulative annual extraction rates in 2005 and 2006.
- The VLFZ and the Harvard Way Barrier affect groundwater flow (as discussed previously) and are likely to slow the lateral migration of PCE.
- When TMWA installed a test well prior to installation of the Corbett Well, no PCE was detected (B. Ojiambo, TMWA, personal communication) on what is now recognized to be on the east side of the Harvard Way Barrier. The fact that PCE has since impacted the Corbett Well suggests that either (1) PCE had not migrated past the Harvard Way Barrier prior to this time; or (2) PCE had migrated past the Harvard Way Barrier in the Shallow Zone and was drawn downward into the Deep Zone when the Corbett Well began operating.

Is there evidence of vertical migration?

- The presence of PCE in the South Reno plume around the Corbett Well indicates that PCE is being drawn downward near this well. Downward vertical downward gradients are observed downgradient (east) of the Harvard Way Barrier (where the Corbett well is located) and could be driving the bulk of this migration. However, based on the available data, we cannot distinguish whether (or to what extent) PCE is also being drawn laterally through the Harvard Way Barrier in the Deep Zone, as further explained below.

- The vertical groundwater flow direction is interpreted to have been upward in the area between the Virginia Lake Fault Zone and the Harvard Way Barrier throughout the year. In the area east of the Harvard Way Barrier the vertical groundwater gradient was near neutral during 2006 Q1 and Q2, downward in Q3 (when groundwater demand was highest), and again near neutral in Q4. Even though a vertical upward gradient has been observed at well CTM33D, this well has been found to contain PCE (**Section 6.2.2**). The vertical gradient and distribution of PCE in the Deep Zone upgradient of the Harvard Way Barrier has not been completely investigated or characterized to date due to the fact that there are only two Deep Zone wells between the Virginia Lake Fault Zone and the Harvard Way Barrier. No PCE has been detected in the other Deep-Zone well (HOLCOMBMW) in this subregion.
- PCE concentration profiles constructed across the Vassar / East Plumb Subregion (**Figure 6.5**) show that PCE concentrations in the Shallow Zone plumes decrease with distance downgradient from CTM33D. However, corresponding PCE concentrations in the underlying Deep Zone (South Reno Subregion) increase with distance downgradient of CTM33D. These paired shallow and deep concentration profiles are consistent with PCE being transported vertically from the Shallow to the Deep Zone by downward migration induced by pumping of the Corbett receptor well.

Receptors

Are municipal water supply wells impacted or have they been in the past?

- The receptor wells for the Vassar and East Plumb Lane Plumes are the Corbett Well and the Terminal Well. In the Deep Zone of the South Reno Subregion, the Corbett Well is impacted and the Terminal well has been historically (when regularly utilized) impacted. Because these wells are screened in the Deep Zone and are part of the South Reno Subregion, they are discussed in greater detail in **Section 6.2.2**.

What is the risk that PCE concentrations at receptor wells will increase?

- PCE concentrations in CTM48, near the North Alley Source Site (located in the hot spot at the head of the Vassar Street plume) have been decreasing (**Table 6.1**); whereas, PCE concentrations in key wells near the Wrondel Source Site (located in the hot spot at the head of the East Plumb Lane plume) have been stable or increasing (see wells CTM51, CTM52 and USGSLISTON in **Table 6.1**). PCE concentrations in USGS WOOSTER, near the Corbett Well, have shown an increasing trend since 2005 Q2 and are currently above the MCL for PCE. As such, it is likely that PCE concentrations along the flow path of the East Plumb Lane plume may reasonably be expected to increase. Concentration trends indicate that PCE in groundwater extracted by the Corbett Well has also been increasing over time (see **Section 6.2.2**) .

- The downgradient extents of the Vassar Street and East Plumb Lane Plumes in the Shallow Zone is presently not defined by the existing monitoring wells (i.e. there are no wells showing PCE concentrations below the reporting limit to define the leading edge of the plume). These plumes could actually extend further downgradient near or beyond the Terminal Well. Thus if the Terminal Well were to resume regular operation, PCE could be captured by and impact that well. Thus the conceptual model for PCE impacts that have been observed at the Corbett Well could potentially be repeated at the Terminal Well if it is operated on a regular basis.

What is the risk that additional wells will be impacted?

- There are no nearby receptor wells other than the Corbett and Terminal Wells that would reasonably be expected to be impacted if the Corbett Well were turned off and the Vassar Street and East Plumb Lane plumes migrated further eastward. There are more distant potential receptor wells (Longley Lane 1, Hidden Valley 5, and Pezzi) located on the east side of the Reno/Tahoe Airport.

6.2.2 South Reno Plume Subregion

The South Reno Subregion is the Deep Zone downward vertical continuation of the Shallow Zone Vassar / East Plumb Subregion (described in **Section 6.2.1**). The lateral boundaries of the South Reno Subregion coincide with the boundaries of the Vassar / East Plumb Subregion (**Figure 6.1**). Based on a limited number of wells completed in the Deep Zone of the South Reno Subregion, it may be at least locally vertically isolated from the Shallow Zone (Vassar / East Plumb Subregion) by a partial barrier to vertical groundwater flow. This barrier or aquitard may occur within the Quaternary glacial outwash, at depths greater than 50 feet and less than 175 feet bgs.

Potential PCE sources occur within the Vassar / East Plumb Subregion and directly impact the Shallow Zone. Data suggest that PCE in the underlying Deep Zone South Reno Subregion originated in the Vassar / East Plumb Subregion and has migrated downward from there. The Corbett municipal water supply well is screened in the Deep Zone and (currently) defines the center of the PCE plume in the South Reno Subregion. It is the receptor well for PCE in the South Reno Subregion.

Groundwater Occurrence and Flow

What is the hydrostratigraphy of the subregion?

- The general hydrostratigraphy and major geologic features potentially influencing groundwater flow of the South Reno Subregion are the same as for the Vassar / East Plumb Subregion, described in **Section 6.2.1**.
- Shallow Zone wells discussed in this report are completed in the Glacial Outwash Alluvium. Deep Zone wells in the South Reno Subregion are interpreted to be completed in the Verdi Basin Sediments (DWR, 2007).

What lateral and vertical hydraulic gradients are influencing groundwater flow?

- There are only four deep zone monitoring wells in the South Reno Subregion (CTM27D, HOLCOMBMW, CTM33D, and CTM17D). Thus the lateral and vertical gradients in the South Reno Subregion are known only approximately. However, it is apparent from contouring of water levels in these and surrounding wells that in 2006 Q1 and Q2 the lateral groundwater gradient in the Deep Zone in this subregion was eastward with a magnitude of approximately 0.004 (**Figure 3.4**), and in 2006 Q3 shifted to northeastward with a magnitude of approximately 0.01 (**Figure 3.6**). This change occurred in response to the formation of a groundwater depression in the vicinity of the Mill Street, Kietzke Lane and High Street Wells interpreted to have been caused by pumping of these wells. In 2006 Q4 (after the pumping wells had been turned off), the gradient returned to a configuration similar to that observed in 2006 Q2 (**Figure 3.8**).
- Existing groundwater-level data suggest upward gradients are prevalent between the VLFZ and the Harvard Way Barrier. Upward flow in this central part of the subregion could potentially be driven by mountain front recharge or by convection from geothermal sources in the southwestern part of the subregion (*i.e.*, the Moana Geothermal System). In the northwest corner of the subregion, downward gradients are apparently driven by recharge from the Truckee River. In the area east of the Harvard Way Barrier, downward gradients are driven by pumping at the Corbett Well (**Figure 6.6**).
- Across the VLFZ, the water level drop in the Shallow Zone appears to be more pronounced than in the Deep Zone, resulting in a reversal of the vertical gradient direction from downward west of the fault to upward east of the fault (**Figure 6.6**).
- Across the Harvard Way Barrier, the water level drop in the Deep Zone is more pronounced than in the Shallow Zone, resulting in a reversal of the vertical gradient direction from upward (based on a limited number of wells) west of the fault to downward east of the fault. On the west side of the Harvard Way Barrier, the nearest monitoring well (CTM33D) is

screened in the Deep Zone and has an artesian water level. These data suggest that the Harvard Way Barrier is a relatively effective barrier to lateral groundwater movement in the Deep Zone and that shallow groundwater crosses and is drawn downward on the east side of this barrier by pumping at the Corbett Well (**Figure 6.6**).

- Seasonal trends in water levels are generally characterized by higher water levels in the winter and spring, and lower water levels in the summer and fall (**Table 6.2**). Based on water level monitoring since the inception of the GMP in 2003 Q4, the groundwater gradients are somewhat seasonally independent, but the elevation magnitudes vary seasonally. The seasonal effects are likely driven first by variations in municipal well pumping and second by variations in recharge.
- The hydrograph for well CTM17D indicates that groundwater levels were at their highest since the monitoring record began in 2000 (**Table 6.2**) during the winter and spring of 2005-2006 . In 2006 Q2, water levels fell and in 2006 Q4 they again rebounded to a relatively high elevation. This is consistent with the water level trends for the Deep Zone in this part of the CTM.

Plume Characteristics

What is the extent and distribution of PCE in the plume?

- The PCE contamination in the Deep Zone comprising the South Reno plume is currently defined by only three wells (CTM33D, CTM17D, and the Corbett Well). These wells occur within a small geographic area, approximately 1,000 feet in diameter. The nearest existing Deep Zone well in the upgradient direction (HOLCOMBMW) from this grouping is approximately 1 mile west of CTM33D (on the upgradient side of the Harvard Way Barrier), in the source area of the Vassar plume although HOLCOMBMW is not impacted by PCE. The screened interval of HOLCOMBMW is unknown. The nearby Shallow Zone well CTM46 is impacted by PCE. While PCE has been detected in the Terminal well in the past, this well has not been used in recent years as much as it had been previously. The South Reno plume is presently not interpreted to have impacted the Terminal Well. In summary, the actual extent of the South Reno plume is unconfirmed but is currently represented to be present in the proximity of the Corbett Well and the Harvard Way Barrier. The key question is whether, and to what extent, the South Reno plume is present on the west side of the HWB.
- The peak PCE concentration in the South Reno plume (as observed at the Corbett Well) has been 27.2 µg/L. During the current reporting period, the PCE concentration decreased from 23 µg/L in Q2 to 16 µg/L in Q3 (the Corbett Well was not pumping or sampled during Q4).

PCE Sources

What potential PCE sources have been identified?

- In order to impact the Deep Zone in the South Reno Subregion, any PCE released near the land surface must first pass downward through the Shallow Zone at or near the point of origin. As such, the most likely source of PCE for the South Reno Subregion is the shallow plume in the Vassar / East Plumb Subregion. Thus, the location/types of PCAs that could impact the South Reno Subregion and information regarding identified releases within the subregion boundaries are described in **Section 6.2.1** (Vassar / East Plumb Lane Subregion).
- NDEP Corrective Action Sites relevant to the South Reno Subregion are discussed in **Section 6.2.1** (Vassar / East Plumb Lane Subregion).
- The concentrations of PCE detected in groundwater observed to date in the South Reno Subregion are not indicative of the presence of DNAPL.

PCE Concentration Trends and Migration

Are PCE concentrations increasing or decreasing?

- PCE concentration change maps (**Figures 6.7**), and key well trend analysis (**Table 6.2**) shows that PCE in key wells exhibited variable concentration trends but individual wells did not significantly change during 2006 as noted below.
    - The historical peak PCE concentration in the South Reno plume (as observed at the Corbett Well) has been 27.2 µg/L. During the current reporting period, the PCE concentration decreased from 23 µg/L in Q2 to 16 µg/L in Q3 (the Corbett Well was not pumping or sampled during Q4). PCE concentrations in the Corbett Well indicate an increasing trend since PCE measurements began in 1987.
    - CTM17D has had variable trends over time. Since 2005 Q2 , PCE concentrations in CTM17D have been increasing.
    - PCE concentrations in CTM33D, located west of the Harvard Way Barrier, remained essentially unchanged in 2006, which is consistent with long-term PCE concentrations in that well.
- No seasonal trends in PCE concentrations are apparent.
- There may be a correlation between increasing water levels and increasing PCE concentrations in well CTM17D; however, no correlation between water levels and PCE concentrations are apparent in data for other wells in the South Reno Subregion.

Is the plume stable or migrating laterally?

- The poorly defined areal extent of the plume does not allow an assessment of plume migration/stability at this time. At least a portion of the plume is hydraulically contained by the capture zone of the Corbett Well. The South Reno plume has been defined based on data from only two monitoring wells (CTM33D and CTM17D) and the Corbett Well. At least partial hydraulic containment of this plume may continue as long as the Corbett Well is regularly operated.

Is there evidence of vertical migration?

- The vertical groundwater flow direction appears to have been upward in the area between the Virginia Lake Fault Zone and the Harvard Way Barrier during 2006. The vertical groundwater flow direction appears to have been near neutral in the area east of the Harvard Way Barrier, during 2006 Q1, Q2 and Q4, and downward in Q3. Note that even though a vertical upward gradient is observed at well CTM33D, this well has been found to contain PCE (at low concentrations less than 3 µg/L since being installed in 2001 and at concentration less than 2.0 µg/L during 2006). Since there is only one other deep well (HOLCOMBMW) upgradient of CTM33D beneath the Vassar Street or East Plumb Lane plumes (**Section 6.2.1**), the distribution of PCE in the central and near-source part of the South Reno Subregion is not known.
- Seasonally, downward gradients are more prevalent east of the Harvard Way Barrier, when the Corbett Well is pumping. In 2006, the Corbett Well began pumping in June and downward gradients were apparent during the Q3 monitoring event. The resulting downward flow direction is shown on **Figure 3.6**. During periods of pumping, the Shallow Zone Vassar / East Plumb Lane plumes are likely to be drawn downward immediately after crossing to the east side of the Harvard Way Barrier. This interpretation remains qualified since there are insufficient deep and intermediate-depth wells to rule out other possibilities, such as downward migration in areas of the Vassar / East Plumb Lane Subregion between the deep monitoring wells HOLCOMBMW and CTM33D, and potential lateral migration through the Harvard Way Barrier in the Deep Zone.
- The shallow-deep PCE concentration profiles (**Figure 6.6**) show that PCE concentrations in the South Reno plume increase with distance downgradient from CTM33D. However, PCE concentrations in the Shallow Zone (Vassar / East Plumb Subregion) are decreasing with distance downgradient of CTM33D. Therefore the PCE concentration profiles indicate that PCE mass is being transported downward from the Shallow Zone into the Deep Zone as groundwater flows to the east of CTM33D in the Vassar / East Plumb and South Reno Subregions.

Receptors

Are municipal water supply wells impacted or have they been in the past?

- The receptor wells for the Vassar and East Plumb Lane Plumes are the Corbett Well and the Terminal Well. Groundwater pumped from the Corbett Well contained PCE at a concentration of 23 µg/L in 2006 Q2. This well is equipped with a wellhead treatment system and is operated for municipal water supply and, in a remedial capacity, to control the spread of the Vassar and East Plumb Lane plumes.
- The Corbett Well has been outfitted with well head treatment equipment for PCE since 1998 (**Figure 5.3**). Pumping volumes, PCE removal rates and the total annual PCE mass removed were at a maximum for the Corbett Well from 2000 to 2004. The well has been operated at lower cumulative annual extraction rates in 2005 and 2006.
- The Terminal Well is located a short distance from the Corbett Well, in a generally downgradient direction, and is completed at greater depth. The Terminal well is not currently being used. Low concentrations of PCE have been detected in the Terminal well in the past (0.5 µg/L in 2004). The Terminal well is currently used in a limited capacity and is available for drought supply.

What is the risk that PCE concentrations at receptor wells will increase?

- PCE concentrations in key wells near the North Alley Source Site, located in the hot spot at the head of the Vassar Street plume) have exhibited no trend or are decreasing. There are presently no key wells available to characterize trends in the Vassar Street plume along the flow path downgradient from the hot spot toward the Corbett Well. PCE concentrations in key wells near the Wrondel Source Site (located in the hot spot at the head of the East Plumb Lane plume) have shown overall increasing trends since the inception of the GMP (2003 Q4). PCE concentrations in USGS WOOSTER, near the Corbett Well, have shown an increasing trend since June 2005 and are currently above the MCL for PCE. As such, it is likely that PCE concentrations along the flow path of the East Plumb Lane plume may reasonably be expected to increase, PCE concentrations in the Corbett Well itself may also continue to increase.
- Continued operation of the Corbett Well is part of the CTMRD program Pumping Plan, which is intended to maximize containment and minimize migration of PCE to new areas. As stated above, PCE has also been detected in the Terminal Well. It is noted that the Terminal Well could be threatened if it were operated more regularly, particularly if the Corbett Well were shut down for an extended period of time. However, the Corbett Well was shut down from 1995 through 1997 (while the PCE treatment equipment was installed) without PCE being detected at the Terminal Well. The Corbett Well has operated each year since PCE treatment equipment was installed.

- As discussed in **Section 6.2.1**, the downgradient extent of the Vassar Street and East Plumb Lane Plumes in the Shallow Zone have not been defined, and could extend near or beyond the Terminal Well. In this scenario, if the Terminal Well were to resume operation, the South Reno Subregion near that well could impacted by PCE that would be transported downward from the Vassar / East Plumb Lane Subregion and beyond the Corbett Well. Thus the conceptual model for the impacts observed at the Corbett Well could potentially be extended to the Terminal well and result in PCE impacts there.

What is the risk that additional wells will be impacted?

- There are no nearby receptor wells other than the Corbett and Terminal wells that would reasonably be expected to be impacted if operation of the Corbett Well was suspended for any reason and existing plumes (commingled Vassar/E Plumb and South Reno) migrated eastward. There are more distant potential receptor wells (Longley Lane 1, Hidden Valley 5, and Pezzi) located on the east side of the Reno/Tahoe Airport.

6.2.3 West 4th Street plume Subregion

The West 4th Street Subregion is the Shallow Zone counterpart to the Deep Zone Downtown Reno Subregion (described in **Section 6.2.4**). The lateral boundaries of the West 4th Street Subregion are coincident with the western half of the Downtown Reno Subregion (**Figure 6.1**).

Potential PCE sources within the West 4th Street Subregion directly impact the Shallow Zone. The data suggest that the underlying Downtown Reno Subregion is impacted indirectly by PCE that has migrated downward from the West 4th Street Subregion. The High Street, Morrill Avenue, Kietzke Lane, 4th Street, and Mill Street municipal water supply wells are screened in the Deep Zone and have been impacted by the PCE plume within the Downtown Reno Subregion. These are the receptor wells for the PCE occurring and migrating laterally in the West 4th Street Subregion and vertically downward into the Downtown Reno Subregion.

Groundwater Occurrence and Flow

What is the hydrostratigraphy of the subregion?

- The West 4th Street-Downtown Reno Subregion is interpreted to be underlain by three main packages of strata: heterogeneous fluvial strata (Quaternary and Tertiary), Quaternary glacial outwash, and lower-energy fluvial-lacustrine strata (Tertiary). The upper stratigraphic interval of recent fluvial deposits, glacial outwash, and fluvio-lacustrine deposits extends to depths of approximately 200 feet bgs in the subregion. The Quaternary deposits overlie Tertiary-aged Verdi Basin Sediments (Trexler and Cashman, 2006). The underlying bedrock consists of Mesozoic crystalline and Cenozoic volcanic rocks (Trexler and Cashman, 2004).

- The depositional environment in this subregion since the Sierran uplift (in the past roughly 2 million years) is likely to have been characterized by a relatively high energy river environment that has alternately eroded, reworked and deposited alluvial sediments in a west-east corridor along the course of the Truckee River. Extremely heterogeneous but locally very transmissive (*i.e.,* coarser grained and well sorted) strata would be expected in the high energy portions of such an environment. Materials indicative of such an environment have been encountered in some wells (e.g. the Reno High well). Therefore, it is considered reasonable to assume that there are relatively well developed local hydraulic connections between the Shallow and Deep Zones where this scouring, incision, and reworking process is likely to have created vertical pathways over time.

- The VLFZ (Section 6.2.1) is inferred to cross this subregion and to form a partial barrier to groundwater flow. This fault zone is characterized by a steep localized groundwater gradient (decreasing from west-to-east) in both the Shallow and Deep Zones, as shown on **Figures 3.1** through **3.8** and **Figure 6.11**. The depth to bedrock is projected to be approximately 1400 feet bgs west of the VLFZ in the subregion based on gravimetric data that was calibrated with and borehole intercepts (Widmer, 2006). East of the VLFZ, the depth to bedrock is projected to be approximately 650 feet. This difference in bedrock elevation is interpreted to result largely from paleotopographic relief. Because there are no nearby wells that have intercepted bedrock, this has not been confirmed by lithologic or geophysical logs in the immediate vicinity of the fault. Drill log data compiled by DWR (including data from wells installed for the CTMRD) indicate that structural displacement across the VLFZ is less than 50 feet.

- The VLFZ crosses the subregion between CTM8D and the Morrill Avenue Well. Displacement on the VLFZ is down to the west and, based on the review of lithologic and geophysical logs for the High Street and Morrill Avenue Wells, appears to be less than 50 feet in the basin fill materials penetrated by these wells. E-logs for both wells identify sequences of low resistivity (bedded low energy clay-silt strata interpreted to be part of the VBS) strata starting at roughly 400 feet bgs.

- Water levels are lower east of the fault in both Shallow Zone and Deep Zone well completions. Based on cross sectional interpretation by DWR, it appears that the VLFZ acts as a flow barrier due to it's own hydraulic properties (*e.g.*, sorting or particle alignment along the fault plane or the development of gouge) rather than the offset/juxtaposition of strata with contrasting hydraulic properties.

- The basin fill strata are interpreted to have a gentle eastward apparent dip east of the VLFZ (Widmer *et al.*, 2006). West of the VLFZ, in the western portion of the CTM, relatively steep eastward dips (up to 30 degrees or more in surface exposures in the western portion of the basin) get shallower to the east, and are interpreted to be less than 10 degrees close to the

VLFZ. Cross sectional interpretation by DWR using lithologic and geophysical logs show gently eastward dipping strata in the vicinity of the VLFZ .

- Based on the conceptual model that strata (while heterogeneous) dip eastward in accordance with the prevailing groundwater flow direction, transmissive packages of strata may provide natural pathways for groundwater and PCE to also move downward while flowing from west to east.

What lateral and vertical hydraulic gradients are influencing groundwater flow?

- The West 4th Street Subregion contains approximately 80 monitoring wells. Thus the lateral hydraulic gradient is relatively well constrained. The lateral groundwater flow direction in the subregion is to the east, parallel to the Truckee River, with a gradient of approximately 0.005. There is a pronounced increase in the groundwater gradient in the immediate vicinity of the VLFZ (approximately 0.01) (**Figures 3.1**, **3.3, 3.5** and **3.7**). The easternmost portion of the subregion impinges upon an apparent groundwater ridge beneath the Truckee River and a groundwater depression within the Mill-Kietzke Subregion. These features show pronounced seasonal variation and are discussed further in **Section 6.2.5.** The West 4th Street Subregion, on the other hand, has shown little seasonal variability with respect to lateral groundwater gradient.

- Seasonal trends in water level elevation are generally characterized by higher water levels in the winter and spring, and lower water levels in the summer and fall. Based on water level data, the groundwater gradients are largely independent of seasons, but the elevations vary seasonally. The stacked graphs for the West 4th Street Subregion (**Figure 6.13**) and the vertical water level difference maps for 2006 (**Figure 6.11)** indicate that vertical head differences east of the VLFZ vary seasonally and reach a maximum downward gradient in Q3. West of the VLFZ, little vertical gradients remain much more subdued throughout the year and little seasonal variation is observed.

- Groundwater-level data suggest that downward vertical gradients are prevalent in the West 4th Street Subregion, especially near the Truckee River (note the red areas on **Figure 6.11**). The observed downward flow direction is consistent with recharge from the Truckee River contributing to elevated groundwater levels in the Shallow Zone along the river. This downward gradient is seasonally accentuated by pumping at the High Street, Morrill Avenue and Reno High wells (which lower groundwater levels in the Deep Zone). The vertical groundwater gradient was calculated to be approximately 0.025 in 2006 Q2. Downward vertical gradients are greatest east of the VLFZ, especially near the river. Upward or neutral gradients were observed in southeastern part of the subregion throughout the year and could potentially be influenced by mountain front recharge or by groundwater convection from the Moana Geothermal System as discussed in **Section 6.2.1**.

- The vertical water level difference maps for the West 4th Street Subregion (**Figure 6.11**) indicate that downward gradients were most pronounced and widespread in Q2 and especially Q3, during the period of municipal pumping from the Reno High, Morrill Avenue, High Street, 4th Street, Kietzke Lane and Mill Street Wells. The Truckee River stages were observed to be highest during Q2 (based on data for the Reno Gage available from the NOAA website). In Q1 and Q4, a more subdued downward trend was observed, with a lower magnitude and a more limited lateral extent, generally closer to the Truckee River. Downward gradients were at their lowest magnitude and lateral extent of the year in Q4.
- Shallow Zone water levels west of the VLFZ show an inverse correlation with pumping of the Reno High and High Street Wells and a positive correlation with the Truckee River stage (**Figures 6.15a** and **6.15b**). At the shallow-deep well pair of CTM7S/CTM8D, located just west of the VLFZ and south of the Truckee River, it is evident that downward gradients predominate and the Shallow and Deep Zone groundwater elevations follow the same general trends. However, water levels in this well pair indicate that the Shallow Zone is dominantly influenced by the Truckee River, while the Deep Zone appears to be more strongly influenced by municipal well pumping. This suggests that downward gradients and groundwater flow are driven both by recharge from the Truckee River and by municipal well pumping. Groundwater that moves downward from the Shallow Zone into the Deep Zone in response to pumping appears to be rapidly replaced by recharge from the Truckee River.
- East of the VLFZ, the seasonal vertical gradient and recovery of water levels in the Deep Zone is evidence of downward flow from the Shallow Zone. The Truckee River passes through the West 4th Street plume and is a plausible source of recharge. In addition, the river passes just south and east (downgradient) of the West 4th Street plume. The presence of PCE in the Deep Zone southeast of the West 4th Street plume is further evidence for recharge from the river accompanying downward groundwater flow and PCE migration from the Shallow to the Deep Zone.
- Across the VLFZ from west to east, the water level drop in the Deep Zone is more pronounced than in the Shallow Zone, steepening the downward vertical gradient (**Figure 6.11**). Note that at present, the monitoring well network is not sufficient to constrain the lateral location and distance over which the groundwater levels drop across the fault except at most locations. As drawn, the groundwater level contour maps are based solely on interpretation of the point data at the existing wells, and where these are not located as well pairs across the VLFZ, the water level drop is not shown as occurring across a linear zone. Therefore, the actual water level drop in the deep zone probably occurs primarily across the
- In the West 4th Street Subregion only one Deep Zone well (CTM4D) is north of the Morrill Avenue Well. Thus Deep Zone water levels in the West 4th Street Subregion are not well defined in the area north of the Truckee River and west of the projection of the VLFZ. As a result, the effects of the VLFZ on Deep Zone water levels and vertical head differences in

the area north of 4th Street are also not well understood. Groundwater contouring using the existing data may underestimate Deep Zone water levels and, consequently, overestimate the vertical head differences west of the VLFZ in the northern third of the West 4th Street Subregion. This would create the impression that the VLFZ has less effect on Deep Zone water levels or vertical head differences than might be expected.

Plume Characteristics

What is the extent and distribution of PCE in the plume?

- The West 4th Street plume, as defined by existing wells, extends east approximately from Washington Street to Sutro Street, and north approximately from 3rd Street to Interstate 80 (**Figure 6.12**). Near Wells Avenue, the plume is interpreted to extend to well CTM37S, located about a block north of Interstate 80, near 9th Street and Morrill Ave.
- There are few monitoring wells screened between 60 and 125 feet bgs in this subregion to define the vertical distribution of this plume in the Shallow Zone at depths greater than 50 feet bgs. As will be discussed in **Section 6.2.4**, the West 4th Street plume is believed to be the Shallow Zone counterpart to the Deep Zone Downtown Reno plume that has impacted the High Street, Morrill Avenue, Kietzke Lane, 4th Street, and Mill Street Wells. Based on vertically spaced analytical data plotted on a hydrostratigraphic section prepared by DWR, the inferred vertical profile of the plume in the Shallow and Deep Zones plunges to the east, and loosely parallels the apparent dip of strata.
- The maximum PCE concentration observed in the West 4th Street plume typically occurs in well CTM28S. This well defines the plume hot spot near the intersection of West 4th and Ralston Streets in the western portion of the plume. PCE concentrations detected in this well varied from 26 to 190 µg/L during 2006. PCE concentrations tend to decrease with increasing distance to the east-northeast from CTM28S.
- Review of plume maps constructed since the implementation of the GMP indicates that the list of wells in the West 4th Street and Downtown Reno Subregions in which PCE has been detected has generally not changed, but that in some wells, notably CTM37S, CTM1S and KEYSTONEMW1, concentrations have fluctuated above and below the detection limit. The general outline and configuration of the West 4th Street plume has not changed over time, except as follows:
    - CTM37S, the main downgradient control point for the east-northeast extent of the plume has fluctuated above and below the detection limit, and the apparent downgradient extent of the plume therefore has differed somewhat.
    - PCE contamination of groundwater has also been observed west of what has typically been defined as the West 4th Street plume. This contamination has been observed at low

concentrations in one or more of three wells (CTM2S, CTM1S, and KEYSTONEMW1) near Keystone Avenue between 2nd Street and 5th Street. . When present, the contamination in these wells has sometimes been inferred to be connected to the West 4th Street plume, such as during 2006 Q1 (**Figure 3.1**), but may be alternatively be a smaller, isolated plume as shown for Q2, Q3 and Q4 (**Figures 3.3, 3.5 and 3.7**).

  - Prior to 2005 Q4, detections of PCE in COR8A and COR9 were contoured as a small separate plume located between the RETRAC railroad trench and the Truckee River, based on PCE concentrations observed in wells in the intervening area. Since 2005 Q4, and the abandonment of the wells in the intervening area, they have been contoured as part of the West 4th Street plume.

- There are no wells located between the West 4th Street plume hot spot at CTM28S and upgradient wells CTM1S, KEYSTONEMW1 and CTM2S. A number of PCAs (most notably existing and former dry cleaners) exist in this area, and it is not known if CTM28S is representative of the actual hot spot for this plume or whether other hot spots or release locations exist in this subregion.

- The West 4th Street plume is delineated by relatively few wells to the north and the northeast. The apparent downgradient extent of the plume appears to be temporally variable. PCE that has been contoured as part of the West 4th Street plume has been observed as far east as well CTM37S. CTM37S is located on the west side of the northerly projection of the VLFZ (as mapped) and the VLFZ appears to essentially terminate the downgradient extent of the plume. While this presently appears to be a reasonable interpretation, based on the existing data, there are no nearby wells located east VLFZ projection to confirm the downgradient extent of the plume or provide hydrogeologic or lithologic evidence for the presence of the VLFZ near CTM37S. It is possible that low concentrations of PCE are present in groundwater to the east of CTM37S.

- There are presently no monitoring wells located between well MW9NS and the RPD well cluster (to the north-northeast) and CTM9S near the Mill/Kietzke plume to the east. A number of PCAs are located in this area south of the Truckee River, but there are no monitoring wells to confirm the presence or absence of groundwater contamination or potential PCE sources. The Sierra Chemical site is also in this area and is a potentially contributing source to the Mill/Kietzke plume (**Section 6.2.5**).

- The inferred vertical profile of the West 4th Street/Downtown Reno PCE plume suggests that it plunges to the east, and loosely parallels the apparent dip of strata. Highest PCE concentrations may be localized in or proximal to contacts between strata with contrasting hydraulic properties. Data plotted by DWR on a hydrogeologic cross section for this area support the interpretation that the deeper portion of the plume is localized in the upper screens of the High St. well and is likely to impact successively deeper screens of the Morrill

Ave. and Kietzke Ave. municipal wells as it moves (and plunges progressively deeper) to the east.

PCE Sources

What potential PCE sources have been identified?

- A large number of PCAs have been identified in the West 4th Street Subregion (**Figure 6.10**). These PCAs are mainly current and former dry cleaners and auto repair shops. They are scattered throughout the subregion with a high density of occurrence in the southern and eastern portions of the present plume area. To the extent that potential sources have been identified, the data available to date do not include soil or groundwater sampling that could be used to identify specific source areas that could be the subject of targeted investigation or remediation.
- The West 4th Street plume's maximum concentrations are typically observed in well CTM28S near the intersection of 4^{th} and Ralston Streets. There are several existing and historical PCAs in this immediate area. The area between CTM28S and upgradient well CTM2S has the potential to contain one or more PCE release sites, but the presence and/or location of such a release site has not been confirmed by soil, soil vapor or groundwater monitoring data.
- Two DWR Sewer Investigation Subregions (Subregions 7 and 8, Kleinfelder, 2003) are located partially within the West 4th Street Subregion, but do not appear to be associated with the West 4th Street plume. Sewer Investigation Subregion 8 is associated with the Vassar Street plume, as described in **Section 6.2.1**. The results of a sewer sampling investigation (WCDWR, 2002) conducted in the western portion of the plume were also discussed in GeoTrans (2002). Out of 18 locations sampled, PCE was detected only in the waste water sample collected upgradient of the plume hotspot, about half way between wells CTM1S and CTM28S.
- The concentrations of PCE detected in groundwater in the West 4^{th} Street plume to date are not indicative of the presence of DNAPL; however, elevated PCE concentrations in this area have been apparent over a 20-year period. This suggests that persistent PCE sources, which could include localized areas with residual DNAPL, may be present.
- There are four NDEP Corrective Action Sites in or immediately adjacent to the West 4th Street Subregion (**Figure 6.2b**). Information retrieved from the NDEP files regarding these sites is presented in McGinley and Associates(2002) and is summarized below.
    - **Site 3 – Project C (Silver Legacy) Construction Site.** The Project C (Silver Legacy) Pump Test/Dewater System NDEP site is located near the center of the West 4^{th} Street subregion, east (downgradient) of the apparent plume hotspot (at CTM28S). The peak

PCE concentration detected in groundwater at the Project C site was 240 µg/L in October 1993 during construction dewatering operations, which is in the range of concentrations observed at CTM28S. Significant petroleum hydrocarbon contamination was also detected at the Project C site, but based on the available data, a source for the PCE was not identified.

- **Site 4 – Keystone Square Site.** Elevated concentrations of PCE were detected in groundwater monitoring wells at the Keystone shopping center, located west (upgradient) from the apparent West 4th Street plume hot spot at CTM28S. Parcel 5 at this site was the site of a dry cleaner and PCE was detected in soil at concentrations up to 9,200 µg/kg near an underground storage tank. Soil remediation was implemented and the NDEP granted no further action status to the site. The peak PCE concentration detected in groundwater at this site was 111 µg/L in October 1996. It should be noted that comments contained in the McGinley and Associates (2002) report suggest that documentation of the investigation and remediation of this site was incomplete.

- **Site 6 –Downtown Reno VOC Site.** The boundaries of the Downtown Reno VOC site (see Appendix K.1 of McGinley and Associates, 2002) was defined based on the initial investigation of PCE contamination in the Reno area, conducted in the early 1990's (Westec/SRK, 1994). These boundaries are roughly similar to the boundaries of the West 4th Street Subregion described in this report (**Figure 6.1**). The peak PCE concentration detected in groundwater in the Downtown Reno VOC site was 480 µg/L in July 1993. This peak concentration was observed in a monitoring well for the service station at the NW corner of 4th and Ralston Streets near CTM28S, which is the apparent location of the current hot spot of the West 4th Street plume. In addition, it is noteworthy that elevated PCE (190 µg/kg in September 1993) was identified in soil samples collected at 23 feet bgs while drilling well MW1ND. As of 2006 Q2, groundwater from this well is non-detect. MW1ND is about 1,000 feet south-southwest (roughly cross-gradient) of CTM28S, and is also 1,000 feet downgradient of the isolated minor hotspot currently observed at CTM2S. A total of 320 PCAs were identified throughout this area, most of which were historical operations prior to 1970. Because of the large number of PCAs, Westec/SRK (1994) suggested that correlating PCE concentrations with specific source areas was deemed not possible.

- **Site 8 – Sierra Chemical Site.** This site is immediately east of Renown Medical Center and lies just beyond the eastern boundary of the West 4th Street Subregion, downgradient of the West 4th Street plume as presently defined. Site 8 includes the extreme northwest corner of the Mill / Kietzke Subregion. Groundwater was not sampled at Site 8 at the time of the corrective action but two soil samples contained PCE, with a peak concentration of 1,100 µg/Kg. Sierra Chemical is the only NDEP site in the Mill / Kietzke Subregion to date where a PCE release has been identified. Because the upgradient extent of the Mill / Kietzke plume has not been identified, it is possible that the Mill/Kietzke plume could extend upgradient to the Sierra Chemical site (**Section 6.2.5**).

- DWR mentions the following additional information regarding the release and or detection of PCE at specific sites in the West 4th Street Subregion (DWR, personal communication):
  - Anecdotal mention of possible solvents associated with the Gold Dust West site at 4th Street and Vine Street;
  - PCE encountered during excavation for construction of the Silver Legacy hotel/casino (see Site 3, discussed above);
  - Groundwater discharged to the Truckee River from Harrah's elevator shaft has been required by NDEP to be treated for VOCs; and
  - "Reno Hydrocarbon Study" in downtown during the early 1980's (no specific info apparently available).

PCE Concentration Trends and Migration

Are PCE concentrations increasing or decreasing?

- In general, PCE concentrations in the West 4th Street plume have remained relatively constant over time, and the areal extent of the plume has also been interpreted to have remained relatively constant. While the concentrations of PCE detected in groundwater to date do not meet rules-of-thumb for the presence of DNAPL (generally thought to be approximately 1 percent of the aqueous solubility, see Feenstra and Cherry, 1988), the presence of persistent sources indicates this is a possibility.
- The 2006 PCE concentration change maps (**Figure 6.12**) and key well trend analysis graphs for West 4th Street and Downtown Reno (**Tables 6.3** and **6.4**) show that PCE concentrations increased in the plume hotspot area of the West 4th Street plume and in the western hot spot area of the Downtown Reno plume from Q1 to Q2 and Q2 to Q3, but then decreased from Q3 to Q4. These appear to be short-term fluctuations around a relatively stable mean. PCE concentrations in the Deep Zone are further discussed in **Section 6.2.4**.
- Key well trend analysis for the West 4th Street Subregion shows no long-term statistically significant trend in PCE concentrations (**Table 6.3**). It is noted that prior to 2004, CTM3S had an increasing trend and CTM37S had a decreasing trend.
- No seasonal trends in PCE concentrations or correlation between water levels and PCE concentrations are apparent in water quality data for the West 4th Street plume.
- No clear correlation between water levels and PCE concentrations is apparent in data for the West 4th Street Subregion. **Table 6.3** suggests an inverse correlation between PCE and

water levels in some years during 2001 to 2006, but this correlation is not consistent and may easily be an artifact of independent variations in the PCE and water-level data.

Is the plume stable or migrating laterally?

- The interpreted downgradient extend of the West 4th Street plume appears to have remained generally unchanged since monitoring began in 2003; however, the northeast (downgradient) end of the West 4th Street plume is defined by a single well, CTM37S. CTM37S is located on the west side of the northward projection of the VLFZ (as mapped) and the VLFZ essentially terminates the downgradient extent of the plume. This appears to be a reasonable interpretation of the interaction between the plume and the VLFZ; however, there are no nearby wells located east of the mapped VLFZ to confirm the downgradient extent of the plume, provide hydrogeologic or lithologic evidence for the presence of the VLFZ near CTM37S, or monitor potential downgradient migration in the Shallow Zone. It is possible that low concentrations of PCE are present in groundwater east of CTM37S.
- Lateral transport of PCE within the West 4th Street plume is currently interpreted to be limited by the hydrostratigraphy, vertical groundwater flow gradient in the plume area, recharge from the Truckee River and the presence of the VLFZ (as described below).
    - Based on the vertical distribution of analytical data plotted on the hydrostratigraphic section prepared by DWR, the apparent dip of strata may be causing the PCE plume to plunge toward the east, and thus limiting its lateral migration in the Shallow Zone.
    - The vertical hydraulic gradient was significantly greater than the horizontal groundwater flow gradient in the plume area during Q2 and Q3, when the municipal water supply wells were pumping. For example, the vertical groundwater gradient in the plume area was calculated to be approximately 0.025 (downward) in Q2, whereas the shallow horizontal groundwater gradient varied from 0.004 to 0.006 (eastward) in 2006 Q2. Even in the presence of a semi-permeable aquitard or lower permeability material between the Shallow and Deep Zones, a significant downward component to groundwater flow and contaminant transport would be expected in the subregion, which would limit the extent of lateral PCE migration.
    - Recharge from the Truckee River decreases or partly reverses the local lateral gradient by elevating shallow groundwater levels near the river, forming a slight groundwater mound in the area downgradient of where the plume has been defined. In addition, river recharge could be diluting shallow contamination as it flows to the east-southeast and crosses the river corridor. Both effects probably contribute to the shallow plume configuration.

- The VLFZ is interpreted to decrease the lateral gradient (and groundwater flow velocity) in the plume area by forming a lower permeability barrier to groundwater flow and contaminant transport downgradient (southeast) of the plume.
- The persistence of PCE concentrations in the Deep Zone east of the VLFZ, despite extensive municipal groundwater pumping, appears to reflect a relatively constant transport of PCE across the VLFZ. The inferred mechanism for PCE transport across the VLFZ, and the determination whether it preferentially occurs at certain locations, during certain times, or under certain conditions is not presently understood. Also, as discussed previously (see discussion of *Groundwater Occurrence and Flow* earlier in this section), the potential interaction between the Truckee River and the VLFZ is not presently well understood.

Is there evidence of vertical migration?

- The preceding discussion suggests that there is significant vertical transport of PCE in the West 4th Street Subregion. This interpretation is supported by the observed distribution of PCE in the Shallow and Deep Zones in the area of the West 4th Street plume as shown on the stacked graphs for this subregion (**Figure 6.13**). Factors that influence the balance between vertical and horizontal gradients in this area include recharge from the Truckee River and pumping from the High Street and Morrill Avenue Wells, which increases the local vertical gradient and hydraulically controls a portion of the plume.
- Since the lateral boundaries of the plume are not interpreted to change appreciably, there is no “plume migration” *per se,* but rather a constant transport of PCE mass within the plume. Downward gradients are prevalent in the West 4th Street Subregion (**Figures 6.11** and **6.13**). These gradients increase when municipal water supply wells are pumping. As a result, PCE in the Shallow Zone is likely to be transported downward at an accelerated rate during periods when the municipal water supply wells are pumping (typically in Q2 and Q3).
- The shallow-deep PCE concentration profile (**Figure 6.12**) shows that PCE concentrations in the Shallow Zone West 4th Street plume decrease with increasing distance down gradient from the apparent hot spot (at or near CTM28S at 4th and Ralston Streets). However, PCE concentrations at corresponding locations in the Downtown Reno Subregion (Deep Zone) increase with increasing distance down gradient from the apparent hot spot. Therefore, the PCE concentration profiles suggest that PCE, originating near the apparent West 4th Street hot spot, is migrating downward through the Shallow Zone into the Deep Zone in this area.
- Based on vertical distribution of analytical data plotted on the hydrostratigraphic section prepared by DWR, the inferred vertical profile of the West 4th Street / Downtown Reno plume suggests that it plunges to the east, and loosely parallels the apparent dip of strata. The highest PCE concentrations may be localized in or proximal to contacts between strata with contrasting hydraulic properties. Data support the interpretation that the deeper portion of

the plume is localized in the upper screens of the High Street Well and is likely to impact successively deeper screens of the Morrill Avenue and Kietzke Lane municipal wells as it moves (and plunges progressively deeper) to the east.

- The most prevalent VOCs other than PCE detected in wells in the West 4th Street and Downtown Reno Subregions are TCE and chloroform. These compounds have also been detected in the Mill Street, High Street, Kietzke Lane, 4th Street, and Morrill Avenue wells. TCE can be a degradation product of PCE and chloroform is a disinfection byproduct that is likely to be derived from chlorinated water. Detections of both compounds are relatively common in the West 4th Street and Downtown Reno plumes, but much less common in groundwater from the other subregions. Although these compounds are too widespread to be useful in identifying specific source areas, the fact that they were detected in shallow wells in the West 4th Street plume, deep wells in the Downtown Reno plume, and the Downtown Reno plume receptor wells supports the interpretation that these wells penetrate a single three-dimensional plume system in which PCE migrates laterally eastward and vertically downward.

- The subregional cross section prepared by DWR suggests that PCE has impacted the Deep Zone in the area upgradient of the river corridor.

Receptors

Are municipal water supply wells impacted or have they been in the past?

- Data regarding PCE migration discussed earlier in this section support the interpretation that the deeper portion of the West 4th Street / Downtown Reno plume is localized in the upper screens of the High Street Well and likely impacts successively deeper screens of the Morrill Avenue and Kietzke Lane municipal wells as it moves (and plunges progressively deeper) to the east.

- The receptor wells for the West 4th Street plume are the High Street, Morrill Avenue, Kietzke Lane, 4th Street, and Mill Street Wells. Groundwater pumped from the High Street, Morrill Avenue, Kietzke Lane, and Mill Street Wells contained PCE at concentrations ranging from 10.7 to 24.8 µg/L, 8.3 to 25.8 µg/L, 5.9 to 12.9 µg/L, and 0.5 to 38.9 µg/L, respectively during 2006. These wells are equipped with wellhead treatment systems and are operated for municipal water supply and to contain the West 4th Street and Downtown Reno plumes (Intera, 2006b). Samples collected from he 4th Street Well did not contain PCE in 2006, but historically contained PCE at concentrations ranging from 0.2 to 2.5 µg/L (with one excursion to 15.4 µg/L). Additional information regarding receptor wells is discussed in **Section 6.2.4**.

What is the risk that PCE concentrations at receptor wells will increase?

- PCE concentrations in the Morrill Avenue, Kietzke Lane and High Street Wells have shown generally flat concentration trends with only minor increasing or decreasing variations since the year 2000; whereas, PCE concentrations in the Mill Street Well have shown an increasing trend since 2000. he PCE concentrations in the West 4th Street plume key wells have not changed appreciably, thus it is anticipated that concentrations in the near-source High and Morrill receptor wells will also not change appreciably in the near future. PCE concentration trends in the downgradient Kietzke Lane and Mill Street Wells are discussed further in **Section 6.2.4**, in relation to the Downtown Reno plume.

- PCE was detected in the 4th Street well between 1990 and 2000 at generally increasing concentrations between 0.3 and 2.5 µg/L (with a single excursion to 15.4 µg/L). Since 2000, PCE detections have been intermittent in this well and at generally decreasing in concentrations. PCE was not detected in 2006. The low and sporadic detections of PCE are consistent with its location near the northern lateral boundary of the Downtown Reno plume. In recent years, this well has only been intermittently used, which, combined with implementation of the pumping plan, has evidently contained the northward lateral migration of the plume. If pumping of the 4th Street Well is increased, the plume could be pulled northwards and PCE concentrations in the well could increase.

What is the risk that additional wells will be impacted?

- PCE contamination in the West 4th Street plume is not likely to migrate to new Shallow Zone wells, providing flows are maintained in the Truckee River and the High Street and Morrill Avenue Wells continue to be operated. Continued operation of the High Street and Morrill Avenue Wells is a key component of the Pumping Plan (SPPCo, 2000; Intera, 2006b), intended to maximize containment of known PCE plumes by wells currently fitted with PCE treatment equipment (**Figure 5.3**). Further evaluation would be required to determine whether the West 4th Street plume would begin to migrate to other wells if the High Street and Morrill Avenue Wells were not operated routinely.

- As discussed above, the PCE migration pathway for the West 4th Street plume is vertically downward into the Deep Zone defined by the Downtown Reno Subregion. Lateral (eastward) migration of PCE in the Downtown Reno Subregion, and the potential for additional wells to be impacted therein, is further discussed in the **Section 6.2.4**.

6.2.4 Downtown Reno Subregion

The Downtown Reno Subregion is the Deep Zone counterpart to the Shallow Zone West 4th Street Subregion (described in **Section 6.2.3**). The lateral boundaries of the Downtown Reno Subregion contain the boundaries of the West 4th Street Subregion (**Figure 6.1**). The West 4th Street Shallow Zone and Downtown Reno Deep Zone are presumed to be vertically separated by geological materials with low(er) hydraulic conductivities. Where present, these materials are likely to have limited lateral extent and act as a partial barrier to vertical groundwater flow. West of the VLFZ, the vertical groundwater gradient, the distribution of PCE and response of Shallow Zone wells to Deep Zone pumping suggest that geologic materials with low hydraulic conductivities may be less prominent.

The Deep Zone in the Downtown Reno Subregion is impacted indirectly by PCE that has migrated downward from the Shallow Zone in the West 4th Street Subregion (and possibly from the Shallow Zone in the Mill / Kietzke Subregion). The High Street, Morrill Avenue, Kietzke Lane, 4th Street, and Mill Street municipal water supply wells are screened in the Deep Zone and impacted by the PCE plume in the Downtown Reno Subregion. These are the receptor wells for the PCE originating in the Shallow Zone in the West 4th Street Subregion that ultimately migrates downward to the Deep Zone in the Downtown Reno Subregion.

Groundwater Occurrence and Flow

What is the hydrostratigraphy of the subregion?

- The general hydrostratigraphy and major geologic features potentially influencing groundwater flow of the Downtown Reno Subregion are the same as for the West 4th Street Subregion, described in **Section 6.2.3**. The West 4th Street-Downtown Reno Subregion is interpreted to be underlain by three main packages of strata: heterogeneous fluvial strata (Quaternary and Tertiary), Quaternary glacial outwash, , and lower-energy fluvial-lacustrine strata (Tertiary). The upper stratigraphic interval of recent fluvial deposits, glacial outwash, and fluvio-lacustrine deposits extends to depths of approximately 200 feet bgs in the subregion.. The Quaternary deposits overlie Tertiary-aged Verdi Basin Sediments (Trexler and Cashman, 2006). The underlying bedrock consists of Mesozoic crystalline and Cenozoic volcanic rocks (Trexler and Cashman, 2004).
- The VLFZ (Widmer et al., 2007) is inferred to cross this subregion and to form a partial barrier to groundwater flow. This fault is characterized by west-to-east groundwater level drop in both the Shallow and Deep Zones, as shown on **Figures 3.1** through **3.8** and **Figure 6.18**. It is discussed in greater detail in **Section 6.2.1**. The depth to bedrock is projected to vary from approximately 1400 feet bgs west of the VLFZ in the subregion based on gravimetric data that was calibrated with and borehole intercepts (Widmer, 2006 and 2007). East of the VLFZ, the depth to bedrock decreases to 650 to 800 feet bgs beneath the east half of the Downtown Reno Subregion (the portion of the subregion that is beyond the boundary (east) of the West 4th Street Subregion). This difference in bedrock elevation is interpreted to result largely from paleotopographic relief. Because there are no nearby wells that have intercepted bedrock, this has not been confirmed by lithologic or geophysical logs in the immediate vicinity of the fault. Drill log data compiled by DWR (including data from wells installed for the CTMRD) indicate that structural displacement across the VLFZ is less than 50 feet.

- There are no immediately nearby wells that have intercepted bedrock. The deepest wells in the subregion are the High St. well (drilled total depth of 753 ft), located west of the VLFZ and the Morrill Ave. well (drilled total depth of 667 ft) located to the east of the VLFZ. Neither of these wells encountered bedrock.

What lateral and vertical hydraulic gradients are influencing groundwater flow?

- Twenty-three (23) Deep Zone monitoring or municipal water supply wells are completed in the Downtown Reno Subregion. Thus the lateral groundwater flow gradient in the Downtown Reno Subregion is reasonably well characterized. The groundwater flow direction in the Downtown Reno Subregion is generally eastward, and is dominated by a steep lateral gradient on the western portion of the subregion near the VLFZ and a large, seasonal groundwater depression that is at its maximum extent and vertical magnitude during the peak municipal well (the Morrill, High Street, Kietzke Lane, 4^{th} Street, and Mill Street Wells) pumping period (summer and fall) in the area (**Figure 3.6** and **Figure 3.8**). The groundwater gradient across the VLFZ steepened during the course of the 2006 from approximately 0.017 in Q1 to 0.03 in Q2 and Q3, and back to 0.024 in Q4.
- Vertical groundwater level difference maps between the Shallow and Deep Zones identify a band with an apparently downward water level gradient along the Truckee River (**Figures 6.16**). This downward gradient is most pronounced in the area of the groundwater depression east of the VFLZ that is discussed above, and increases in both magnitude and extent during Q2 and especially Q3. In the south central part of the subregion, an area of downward water level differences to the west is separated by the VLFZ from an area of upward water level differences to the east. This area of upward water level differences is the northward extension of central portion of the Vassar / East Plumb/South Reno Subregion between the VLFZ and the Harvard Way Barrier that may be influenced by either mountain front recharge or geothermal upwelling as was discussed in **Section 6.3.1**. In the central portion of the Downtown Reno Subregion, the VLFZ separates an area of high downward water level differences on the east (that corresponds with the above-described groundwater level depression) from an area with more moderate downward water level differences on the west.
- During the summer and fall, a prominent depression forms in the potentiometric surface of the Deep Zone as a result of municipal pumping. At this time, groundwater flow in the subregion is largely toward the Morrill Avenue, Kietzke Lane and High Street Wells, toward the Mill Street and Corbett Wells to the south, toward the 4^{th} Street well to the north (when it is being operated) and toward the Pezzi Well to the east. A groundwater divide forms between the Pezzi Well and the Downtown Reno area.
- Seasonal trends in water levels generally are characterized by higher water levels in the winter and spring, and lower water levels in the summer and fall. Based on water level

monitoring data, the groundwater gradients are somewhat independent of seasons, but the elevations vary seasonally.

- Additional information regarding groundwater movement in this subregion is discussed in **Section 6.3.1**.

Plume Characteristics

What is the extent and distribution of PCE in the plume?

- The Downtown Reno PCE plume extends east approximately from Ralston Street to east of Highway 395, and north approximately from East Taylor Street / Automotive Way to 6th Street. (**Figure 6.1** and **6.17**). The plume extends beneath the Truckee River. The Deep Zone Downtown Reno PCE plume is currently observed in the High Street, Morrill Avenue, Kietzke Lane, and Mill Street municipal water supply wells. At present, there are insufficient monitoring wells east of the plume to fully define its downgradient extent.

- Based on the vertical distribution of analytical data plotted on the hydrostratigraphic section prepared by DWR, the vertical profile of the West 4th Street / Downtown Reno plume appears to plunge to the east, and loosely parallels the apparent dip of strata. Data support the interpretation that the deeper portion of the plume is localized in the upper screens of the High St. well and is likely to impact successively deeper screens of the Morrill Ave. and Kietzke Ave. municipal wells as it moves (and plunges progressively deeper) to the east.

- The maximum concentrations in the Downtown Reno plume typically occur in two separate apparent hot spots, one located in the western and one in the eastern portion of the plume. These wells showed PCE concentrations ranging from 44 to 98 µg/L during 2006 Q1 and Q2. The PCE concentrations detected in these wells remained relatively constant and in this range in Q3 and Q4 (**Table 6.4**). The eastern hot spot is south of the Truckee River and located near well CTM-10D, where PCE was observed at a concentrations ranging from 130 to 160 µg/L during 2006. Graphical evaluation of time-series concentrations in wells CTM-10D shows that concentrations increased from 32 µg/L in June 2003 to 270 µg/L in 2004, and have decreased to 160 µg/L since that time (**Table 6.4**).

- The maximum plume concentrations are aligned along an axis connecting the two hot spots to the High Street and Mill Street Wells. These two hot spots define a core located in the approximate centerline of the plume that includes the High Street, Mill Street, Morrill Avenue, and Kietzke Lane Wells. It is noted that there are presently no Deep Zone monitoring wells between these two hot spots. It is possible that elevated PCE concentrations may be continuous in the area between the two hot spots, forming an elongated core aligned with the groundwater flow direction. PCE concentrations decrease to non-detect at a distance approximately 2,500 feet upgradient (west) of the western hot spot, and 2,500 feet downgradient (east) of the eastern hot spot.

PCE Sources

What potential PCE sources have been identified?

- In order to impact the Downtown Reno Subregion, any PCE released near the land surface must first pass downward through the Shallow Zone of the West 4th Street Subregion into the Deep Zone of the Downtown Reno Subregion. As such, the location/types of PCAs and sources that could impact the Downtown Reno Subregion are described in **Section 6.2.3** (West 4th Street Subregion). PCAs in the Mill / Kietzke Subregion (**Section 6.2.5**) could potentially impact the Downtown Reno Subregion as well.
- The concentrations of PCE detected in groundwater to date do not indicate the presence of DNAPL; however, the fact that elevated PCE concentrations have persisted since 1987 suggests the plume may be derived from persistent sources that could potentially include localized residual DNAPL.
- There is a lack of monitoring wells southeast of the High Street Well and the Truckee River. A number of PCAs have been identified in this area. There is a possibility that additional, as yet unidentified PCE sources could be present in this area that could have impacted the Shallow and Deep Zones.

PCE Concentration Trends and Migration

Are PCE concentrations increasing or decreasing?

- The 2006 PCE concentration change maps (**Figure 6.17**), and the key well trend analysis (**Table 6.4**) indicate that:
    - PCE concentrations at the Morrill Avenue and Kietzke Lane Wells show an overall decreasing trend;
    - PCE concentrations in the High Street Well do not show a statistically distinguishable trend;
    - PCE concentrations in the Mill Street Well are increasing; and
    - PCE concentrations in the High Street Well remained essentially unchanged.
- During 2006 Q2, PCE concentrations in a number of key wells (MW6ND, CTM10D, CTM8D, CTM137, CTM30D, MW10ND, COURTHOUSE, and CTM22D) were observed to increase; however, concentrations in most of these wells decreased in subsequent quarters (**Figure**

6.17). With the exception of CTM22D and CTM30D, these wells show a decreasing trend or no distinguishable statistical trend (**Table 6.4**).

- PCE concentrations observed in CTM10D during 2006 are significantly higher than have been observed in the past, but are currently decreasing. Time-series PCE concentrations in this well show an increase from 32 µg/L in June 2003 to 270 µg/L in 2004. PCE concentrations have decreased to 160 µg/L since that time (**Table 6.4**).
- No seasonal trends in PCE concentrations are apparent in data for the Deep Zone in the Downtown Reno Subregion.
- No correlation between groundwater elevation and PCE concentrations is apparent in data for the Deep Zone in the Downtown Reno Subregion.

Is the plume stable or migrating laterally?

- No lateral migration of the Downtown Reno plume is apparent based on the monitoring data for 2006. This is currently attributed to the hydraulic control caused by prescribed pumping at the High Street, Morrill Avenue, Kietzke Lane, and Mill Street Wells. However, there are presently gaps in the deep monitoring well network downgradient of the pumping wells that precludes confirming complete hydraulic control of the Downtown Reno plume. Significant hydraulic control of the Downtown Reno plume is likely to continue as long as the High Street, Morrill Avenue, Kietzke Lane, and Mill Street Wells are operated in accordance with the Pumping Plan (Intera, 2006b).
- As discussed previously in **Section 5.2.3**, the 2005 Pumping Plan Analyses (Intera, 2006b) suggests almost complete capture of the Downtown Reno plume by prescribed pumping of the above wells. It should be noted, however, the Pumping Plan Analyses evaluation does not include potential effects from the use of the wells to recharge groundwater during the winter and spring. **Figure 5.4** shows that the Mill Street and Kietzke Lane Wells appear to compete for capture of the plume, depending on the relative amount that each of these wells is pumped.

Is there evidence of vertical migration?

- Downward gradients are prevalent in the Downtown Reno Subregion (**Figure 6.16 and 6.18**). As a result, PCE from the Shallow Zone West 4th Street and Mill / Kietzke plumes has the potential to migrate downward throughout the areal extent of those plumes providing that a hydraulic connection between the Shallow and Deep Zones is present (as discussed further in **Sections 6.2.3** and **6.2.5)**.
- The Shallow-Deep Zone PCE concentration profile (**Figure 6.14**) shows that PCE concentrations in the Downtown Reno plume increase with distance downgradient from the Shallow Zone hot spot. However, PCE concentrations in the Shallow Zone (West 4th Street

Subregion) decrease with distance downgradient of the hot spot. These PCE concentration profiles suggest that PCE is migrating downward through the Shallow Zone into the Deep Zone.

- The inferred vertical profile of the West 4th Street/Downtown Reno PCE plume suggests that it plunges to the east, and loosely parallels the apparent dip of strata. Vertical profiling suggests that the highest PCE concentrations may be localized in or proximal to contacts between lithologies with contrasting hydraulic properties. Data support the interpretation that the deeper portion of the plume is localized in the upper screens of the High Street Well and is likely to impact successively deeper screens of the Morrill Avenue and Kietzke Lane municipal wells as it moves (and plunges progressively deeper) to the east.

- PCE contamination occurs to a depth of at least 182 ft bgs at MW6ND (screened at 182-192 feet). This well's screened elevation is within the upper portion of the screened interval of the High Street Well (133-511 feet) and the Morrill Avenue Well (178-578 feet), located downgradient of MW6ND, and slightly above the screened interval of the Kietzke Lane Well (233-498 feet), located still further downgradient along the center line of the plume. If the contamination at MW6ND originated at the same source as the apparent hot spot at West 4th Street and Ralston (near CTM28S), contaminated groundwater apparently dives relatively more steeply through the Shallow Zone between the hot spot and MW6ND than in the Deep Zone along the river corridor between High Street and Kietzke Lane Wells. This is despite the fact that observed vertical gradients (**Figure 6.16**) and a subregional cross section prepared by DWR indicate that in the vicinity of the West 4th Street hot spot, vertical gradients have a relatively small downward component. If the PCE in MW6ND is coming from the known hot spot near 4th Street and Ralston, it's vertical migration may be enhanced by local conditions such as a relatively greater vertical connection between Shallow and Deep Zones, or the West 4th Street source could be relatively deep seated.. Alternatively, contamination in MW6ND may have a different source (the Keystone Square, MW1ND vicinity, and CTM2S hotspots are all potential sources).

- Based on the available data, it appears that both hydrostratigraphic control and relatively large downward vertical gradients caused by pumping and Truckee River recharge contribute to downward movement of the plume in this area. While it may be logical to consider river recharge as a local mechanism for driving shallow PCE contamination downward, it should be noted that a plume cross section developed by DWR suggests that PCE originating in the Shallow Zone has already impacted the Deep Zone upgradient of the river.

Receptors

Are municipal water supply wells impacted or have they been in the past?

- The receptor wells for the Downtown Reno plume are the High, Morrill, Kietzke, and Mill Street Wells. The Galletti and 4th Street wells are also considered receptor wells based on historical PCE impacts and potential future risk. Groundwater pumped from the High Street, Morrill Avenue, Kietzke Lane, and Mill Street Wells contained PCE at concentrations ranging from 10.7 to 24.8 µg/L, 8.3 to 25.8 µg/L, 5.9 to 12.9 µg/L, and 0.5 to 38.9 µg/L during 2006. These wells are equipped with wellhead treatment systems, and are operated for municipal water supply and to maximize containment of the West 4th Street and Downtown Reno plumes when operated in accordance with a prescribed pumping schedule.

- Since the time treatment measures were implemented, PCE removal rates (in terms of pounds per millions of gallons pumped) from the Mill Street Well have increased nearly three-fold, whereas PCE removal rates from the High Street, Morrill wells have decreased, and PCE removal rates from the Kietzke well have remained constant or decreased slightly (**Figure 5.4**). In terms of the total mass of PCE removed from the wells, since 2004, most of the PCE mass removed has come from the Mill Street Well.

- As discussed previously, the 2005 Pumping Plan Analyses (Intera, 2006b) indicate that almost the entire Downtown Reno plume would be captured by prescribed puming of the High, Morrill, Kietzke, and Mill Street Wells. It is interesting to note that the bulk of the Downtown Reno plume capture under the Pumping Plan is accomplished by the Mill St (37%) and Kietzke Lane (31%) wells. This competition between wells for the capture of the plume, based on historical pumping and PCE mass removal, can be seen graphically in **Figure 5.4**. Is important to note that the influence of recharge to plume containment has yet to be evaluated, and that modeling of pumping plan performance relies on an existing groundwater flow model that is based on an incomplete understanding (and lack of evaluation) of the three dimensional movement of water and contaminants (particularly between the Shallow and Deep Zones) in response to pumping (**Section 5.2.3**).

What is the risk that PCE concentrations at receptor wells will increase?

- The High Street, Morrill Avenue and Kietzke Lane Wells have shown relatively consistent PCE concentrations since the year 2000. Since PCE concentrations in most Downtown Reno plume key wells are also relatively consistent, it appears likely that PCE concentrations in the High Street, Morrill Avenue, and Kietzke Lane municipal water supply wells will continue to exhibit only minor changes in wellhead PCE concentrations.

- PCE concentrations in the Mill Street Well exhibit a steadily increasing trend over time. The highest PCE concentration recently observed in the Downtown Reno plume occurred in monitoring well CTM10D (160 µg/L in 2006 Q1 and Q2), located a short distance to the northwest (and upgradient) of the Mill Street Well. The data suggest that a concentration front arrived at CTM10D between June 2003 and June 2004, and may be migrating toward the Mill Street Well, located approximately 1,900 feet to the southwest. If this interpretation is correct, PCE concentrations in the Mill Street Well are likely to continue to increase in the future.

- The High Street and Morrill Avenue Wells are located upgradient of the Mill Street and Kietzke Lane Wells. When pumping, the High Street and Morrill Avenue Wells capture part of the Downtown Reno plume that would otherwise impact the Mill Street and Kietzke Lane Wells. Therefore, if pumping at the High Street and Morrill Avenue Wells is discontinued, it is possible that PCE concentrations in the Mill Street and Kietzke Lane Wells could increase.

What is the risk that additional wells will be impacted?

- The 2005 Pumping Plan Analyses (Intera, 2006b) predicts the percentage of each plume's area that is captured by each receptor well. Due to the limitations of the existing groundwater model to simulate the vertical movement of groundwater and PCE from the Shallow Zone to the Deep Zone, the model predictions are not considered reasonable for Shallow Zone plumes such as the West 4th Street plume. However, the predictions of capture percentages for Deep Zone plumes such as the Downtown Reno plume are considered to be more reliable. As discussed above, most of the Downtown Reno plume is projected to be captured by the High, Morrill, Kietzke and Mill Street Wells when they are operated in accordance with the pumping plan.

- Note that the influence of off season recharge on plume containment has yet to be evaluated, and that current simulations of pumping plan performance relies on a groundwater flow model that is based on an incomplete understanding of the three dimensional movement of water and contaminants in response to pumping (**Section 5.2.3**). In addition, there are currently an inadequate number of monitoring wells downgradient of the Downtown Reno plume to verify pumping plan performance and to provide sentinel capability in the event of potential migration of the plume.

- The areal extent of the Downtown Reno plume has not appeared to change (based on the existing monitoring well network) since quarterly PCE contouring began in 2003 Q4. This is attributed to the hydraulic control created by operating the existing treated wells in accordance with a prescribed pumping schedule. Therefore, PCE contamination in the Downtown Reno plume is not considered likely to migrate downgradient and impact other w wells as long as the treated wells continue to operate in accordance with the pumping plan. The downgradient extent of the Downtown Reno plume is likely to be largely contained by the Mill Street and Kietzke Lane Wells. The Pumping Plan analysis (Intera, 2006b), estimates that 10% of the Downtown Reno plume is NOT captured by these wells and is potentially moving downgradient (east). Continued operation of the High Street, Morrill Avenue, Kietzke Lane, and Mill Street Wells in accordance with the Pumping Plan is intended to maximize containment of known PCE plumes. If the Pumping Plan wells were to shut down, the Downtown Reno plume could potentially migrate downgradient (east) toward the Galletti, 21st Street, Poplar #2, Poplar #1, Pezzi, Hidden Valley, and Greg Street wells.

6.2.5 Mill / Kietzke Plume Subregion

The Mill / Kietzke Subregion is one of two Shallow Zone counterparts (along with West 4th Street) to the Deep Zone Downtown Reno Subregion (described in **Section 6.2.4**). The lateral boundaries of the Mill / Kietzke Subregion are contained within the eastern half of the Downtown Reno Subregion (**Figure 6.1**). The Mill / Kietzke Shallow Zone and Downtown Reno Deep Zone are presumed to be, at least locally, vertically separated by geological materials with low(er) hydraulic conductivities. These materials are likely to have limited lateral extent and act as a partial barrier to vertical groundwater flow.

Groundwater Occurrence and Flow

What is the hydrostratigraphy of the subregion?

- The upper stratigraphic interval consists of Quaternary alluvium and glacial outwash. The alluvium overlies Tertiary-aged Verdi Basin Sediments (Trexler and Cashman, 2006). The bedrock consists of Mesozoic crystalline and Cenozoic volcanic rocks (Trexler and Cashman, 2004). Recent regional cross sections based on interpretation of gravity data calibrated by borehole intercepts (Widmer, 2006 and 2007) suggest the thickness of the quaternary alluvium is approximately 150 to 300 feet and the depth to bedrock in the subregion is approximately 650 to 800 feet.
- During a 24-hour pumping test of the Mill Street Well by ARCO (BAI, 1999), no drawdown was reported in a nearby (122 feet to the north west) Shallow Zone observation well (ARCO6018MW16); however, drawdown has been observed in Shallow Zone observation well CTM9S (approximately 2,000 feet west of the pumping well) in response to more sustained pumping of the Mill Street Well (Intera, 2006b). This suggests that the Shallow Zone in the Mill / Kietzke Subregion is only locally separated from the underlying Deep Zone (Downtown Reno Subregion) by a relatively lower permeability sediments.
- Shallow Zone wells in this subregion are completed in the Quaternary deposits. Deep Zone wells along the Truckee River corridor are also generally completed in the Quaternary deposits. However, away from the Truckee River corridor and in the eastern portion of the CTM (generally east of Highway 395), Deep Zone wells are commonly completed in the Tertiary Verdi Basin Sediments.
- A hydrostratigraphic cross section prepared by DWR indicates that the water-bearing strata in this subregion dip southeastward.

What lateral and vertical hydraulic gradients are influencing groundwater flow?

- The Mill-Kietzke plume Subregion is characterized by a generally southeastward lateral groundwater flow direction. Seasonally observed features include a groundwater ridge beneath the Truckee River and a groundwater depression in the vicinity of the Mill Street and Corbett Wells (**Figures 3.1**, **3.3, 3.5** and **3.7**). These features show pronounced seasonal variation that occurs in response to municipal well pumping and recharge from the Truckee River. Municipal well pumping occurs in the Deep Zone and groundwater recharge from the river takes place initially in the Shallow Zone. ,During Q1 and Q2, groundwater flow was predominantly southeastward, with a gradient of approximately 0.0025 in 2006 Q1 and 0.0023 in 2006 Q2 in areas away from the river. During that time a gradient up to 0.01 was observed near the river. In Q3, the gradient in areas away from the river was more southerly as the Shallow Zone groundwater depression associated with municipal well pumping in the Deep Zone spread laterally. In Q4, the groundwater depression was smaller, but still more prominent than in Q2. As a result, groundwater gradients were still more to the south. The magnitudes of the lateral gradients during Q3 and Q4 remained similar to those observed during Q1/Q2.
- **Figure 6.19** shows that pronounced downward vertical water level differences expanded from near the river southward to encompass the entire subregion between Q2 and Q3. In Q4, neutral to slightly upward water level differences were restored across all but the northwestern-most corner of the subregion.
- The observed pattern of Shallow-Deep Zone water level differences across the subregion appears to reflect the influence of municipal well pumping during the summer and fall and the influence of recharge from mountain front recharge and the Truckee River to the northwest and northeast, respectively.
- Hydrographs for selected key wells included in **Table 6.5** indicate that water levels reached some of the highest levels observed during the period of record in the winter of 2005 and spring of 2006. Water levels in these wells subsequently dropped during 2006 Q3 and Q4.

Plume Characteristics

What is the extent and distribution of PCE in the plume?

- There some uncertainty regarding the nature and extent of the Mill / Kietzke plume. As presently defined by data from existing monitoring wells, the plume is located in the area approximately bounded by Lewis Street to the north, Gould Street to the west, Yale Way to the south, Matley Lane to the southeast, and Golden Lane to the east (**Figures 6.1** and **6.20**). The plume is elongated along a north-northwest – south-southeast axis (apparently originating at or near CTM13S) and extends from the apparent hot spot at ARCO6018MW11 for at least 600 feet downgradient toward the Mill Street Well. In general, the downgradient extent of the plume has not changed, except as noted above, but this may be largely a function of where existing monitoring wells are located. The plume is defined by control points to the southwest and to the east. The extent is not defined to the northwest (upgradient) or the southeast (downgradient). The Sierra Chemical corrective action site is located upgradient from the Mill/Kietzke plume as presently defined. While PCE contaminated soil was found at that site, no assessment of potential groundwater contamination was conducted. Additional data may indicate that PCE contamination is present in groundwater upgradient from the Mill / Kietzke plume (as presently defined). Further data and evaluation may also indicate that PCE contamination at CTM-39D and CTM-18S represents detached portions of the Mill / Kietzke plume. In either case, the DWR would redefine the subregion boundary by extending it to the north and/or south.

- Review of the plume maps generated since 2003 shows that the wells in the Mill / Kietzke Subregion in which PCE has been detected has generally not changed. However in some wells, notably CTM11S, concentrations have fluctuated above and below the detection limit. Consequently, the Mill Kietzke plume has been mapped as either confined to the immediate area around the intersection of Mill Street and Kietzke Lane when PCE is not detected in CTM11S, and as extended to include the area around CTM38D/CTM39S when PCE is detected in CTM11S. Accordingly, CTM38D/CTM39S have been contoured as part of the Mill / Kietzke plume, the Vassar / East Plumb plume, or both.

- It is possible that portions of what originated as the Shallow Zone Mill / Kietzke plume may have detached and migrated to a position downgradient from the Mill Street Well to the area around CTM11S, CTM38D, and CTM39S, and potentially extending toward the Corbett Well. The apparently discrete PCE hot spot defined by CTM38D is distal from the apparently most likely PCE source in the area and occurs deeper in the Shallow Zone (CTM38D is screened from 75-95 feet bgs) than the contamination presently detected by shallower monitoring wells completed in the Mill / Kietzke plume located upgradient and to the west. The contamination observed at CTM38D could actually be connected to, and thereby represent an extension of, the Mill / Kietzke plume.

- As presently contoured , the PCE detected at CTM38D has been included (**Figures 3.1, 3.3, 3.5** and **3.7)** within the commingled Vassar / East Plumb Lane plume. However, upon review, the groundwater chemistry and PCE concentration data suggest that contamination detected in CTM38D is most likely to be related to the Mill / Kietzke plume and not the Vassar / East Plumb plume.
  - The ARCO6018 suite of wells, CTM11S and CTM38D have a unique and similar water quality signature, including MTBE, 111-TCA and potential daughter products of PCE (TCE and cis-12-DCE). As such, the water quality in these wells can be interpreted to represent impacts from the same or similar sources. This source or sources includes the recalcitrant portion of a petroleum hydrocarbon source (MTBE), an additional solvent source (111-TCA), and the potential daughter products of a PCE source that is

commingled with a hydrocarbon plume. This water quality signature is not observed in well CTM18S.

- o Evaluation of trend graphs along potential flow lines indicates that ARCO6018MW11 and ARCO6018MW12 share similar trends and CTM11S and CTM38D (**Table 6.5**). There are presently insufficient data to make a determination regarding any potential trend relationships between the ARCO6018MW suite of wells and CTM11S/CTM38D. While water quality data suggest that CTM11S and CTM38D intercept the same plume, the contamination ultimately observed in these wells may be subject to a variety of upgradient sources and local influences that do not directly effect the downgradient wells.
- o Well CTM18S shares a similar water quality signature and trend pattern to the Vassar/E. Plumb near-source wells CTM48 and CTM52, but is dissimilar from well CTM38D. This suggests that this well intersects groundwater that is art of the Vassar/E. Plumb plume and not the Mill/Kietzke plume.

- Based on the screened intervals of existing monitoring wells, the Mill / Kietzke plume has been observed over a vertical interval from 28 feet bgs to 70 feet bgs. While 28 feet bgs is representative of the water table elevation in this subregion, this plume may be present at depths greater than 70 feet bgs. Additional monitoring wells with deeper screened intervals would be required to define the vertical extent of this plume.
- Deep Zone monitoring well CTM10D (located about 360 feet west of the Mill / Kietzke plume as presently defined) exhibits elevated concentrations of PCE (as high as 270 µg/L in 2004). However, Shallow Zone well CTM9S at approximately the same location has been non-detect with respect to PCE. While well CTM9S may not be strictly representative of the shallow zone in this area (the well is screened in material of low permeability), this suggests that the Deep Zone contamination west of the Mill / Kietzke plume is part of the Downtown Reno plume. The Downtown Reno plume appears to be drawn eastward by the regional groundwater flow gradient and the seasonal pumping of the Mill Street Well (**Section 6.2.4**).

PCE Sources

To what extent have source areas been identified?

- Several PCAs have been identified near the Mill / Kietzke plume, mostly north of Mill Street and east of Kietzke Lane. These include a number of auto repair shops, dry cleaners and auto paint shops located at the intersection of Mill Street and Kietzke Lane, at the intersection of Sunshine Lane and Prosperity Street, and in the block bounded by Lewis Street and Prosperity Street to the north and south, respectively, and Sunshine Lane and Golden Lane to the west and east, respectively.

- Sewer Investigation Subregion 1 (Kleinfelder, 2003) is coincident with the main Mill /Kietzke plume (**Figure 6.2a**). PCE was detected in sewer wastewater at concentrations up to 34,000 µg/L in association with sewer line defects. These detected concentrations are consistent with rules of thumb for the presence of DNAPL in the sewer system (Feenstra and Cherry, 1988). Impacted soil and soil vapor indicated PCE releases at three locations: near the intersection of Prosperity Street and Golden Lane, the intersection of Prosperity Street and Sunshine Lane, and along Kietzke Lane between Prosperity Street and Mill Street (Kleinfelder, 2003).
- The Kietzke Lane release area correlates with the location of the plume hot spot near ARCO6018MW11 (**Figures 3.1 and 3.3**). The release area at Prosperity Street and Sunshine Lane correlates with the second highest PCE concentrations (28 µg/L in CTM13S) observed during 2006 Q1.
- McGinley and Associates (2002) identified 28 PCAs in the vicinity of the Mill / Kietzke plume; however, a release of PCE to the subsurface was only documented at one facility the former Sierra Chemical Site (**Figure 6.2b**). (PCE detection of 1,100 µg/kg in soil beneath a former UST). However, a full site assessment, including a groundwater investigation has not been conducted at this facility (McGinley and Associates, 2002).
- Sierra Chemical was designated as NDEP corrective action Site number 8, and is the only NDEP corrective action site with associated chlorinated solvents within the Mill / Kietzke Subregion. This Site is in the northwestern corner of the subregion, and lies near the eastern border of the West 4th Street Subregion (**Section 6.2.3**). Because the upgradient extent of the plume has not been identified, it is possible that the plume extends upgradient to this site.
- There is anecdotal evidence that another PCA in this area is the former State of Nevada asphalt testing laboratory that was formerly located on the northwest corner of Mill Street and Kietzke Lane. WCDWR is currently working to obtain additional information about this site.
- The concentrations of PCE detected in groundwater to date do not indicate the presence of DNAPL; however, persistent PCE concentrations suggest that localized areas with residual DNAPL could be present.
- The PCE plume is commingled and/or overprinted by a hydrocarbon release from the gas station on the southeast corner of Mill Street and Kietzke Lane which occurred in 1998. The hydrocarbon release has contributed MTBE contamination and may have contributed to an apparently small amount of PCE degradation accompanied by the genesis of PCE daughter products.

PCE Concentration Trends and Migration

Are PCE concentrations increasing or decreasing?

- Three hot spots contributing to the Mill/Kietzke plume have been indentified based on soil vapor surveys, soil sampling and groundwater sampling as discussed in the previous section. Additional sources may exist that have yet to be identified.
    - The highest groundwater PCE concentrations have been observed in well ARCO6018MW11, located near the hot spot located along Kietzke Lane between Prosperity Street and Mill Street, where the highest soil and soil vapor concentrations were detected during the 2003 sewer subregion investigation (Kleinfelder, 2003). In the latter part of 2005 and during early 2006 PCE concentrations spiked in this well and reached a maximum PCE concentration 850 µg/L in 2006 Q2. The PCE concentrations detected in this well have since decreased to 84 µg/L in Q3 and 69 µg/L in Q4. Overall, PCE concentrations in this well show an increasing trend (**Table 6.5**) for the period of record.
    - The second highest groundwater PCE concentrations are usually detected in samples from Well CTM13S, located near the hot spot identified west of the intersection of Prosperity Street and Sunshine Lane. PCE soil vapor and soil concentrations detected at this hot spot were lower than those detected at the hot spot on Kietzke Lane, (Kleinfelder, 2003). PCE concentrations have been decreasing in this well since March 2004 (**Table 6.5**).
    - CTM42 is located near the third hot spot, identified at the intersection of Prosperity Street and Golden Lane. The PCE concentrations detected in soil and soil vapor at this hot spot were the lowest among the three hot spots identified in Sewer Investigation Subregion 1 (Kleinfelder, 2003). PCE has only been reported in samples from CTM42 once, during the 2006 Q4 monitoring event.
- The 2006 PCE concentration change and relative concentration change maps, and the key well trend analysis show that PCE concentrations increased in the southern portion of the Mill / Kietzke plume (to CTM11S), especially in hot spot well ARCO6018MW11, and decreased slightly in the northern half of the Mill / Kietzke plume.
- Key well trend analysis through 2006 Q4 (**Table 6.5**) indicates that PCE concentrations in the subregion showed variable trends. The following trends are evident from 2003 Q4 through 2006 Q4:
    - Concentrations in wells ARCO6018MW11 and ARCO6018MW12 show an increasing trend, and well ARCO6018MW11 shows a dramatic increase in concentrations from 11.34 µg/L in September 2005 to 850 µg/L in June 2006. These wells are located near

and downgradient of the hot spot with the highest soil and soil gas concentrations that was identified during the 2003 Sewer Subregion Investigation (Kleinfelder, 2003), respectively.

- Well CTM13S displays a decreasing trend and well CTM63D did not display a statistically distinguishable trend. These wells are located near and downgradient of the second plume hot spot discussed above, and indicate a different concentration trend from the Kietzke Land hot spot.
- Concentrations of PCE detected in well CTM11S, a shallow well located between the main Mill-Kietzke plume and well CTM38D, increased from ND in 2006 Q1 to 6.4 µg/L in 2006 Q4. Overall, well CTM11S displayed no statistically distinguishable trend.

Is the plume stable or migrating laterally?

- PCE concentrations in the Mill / Kietzke plume appear to be increasing in the vicinity of one of the apparent source areas (ARCO6018MW11 – from 2005 Q3 to the present) and just downgradient of this apparent source area (at ARCO6018MW12 – from 2004 Q4 to present). One possible explanation for this apparent plume strengthening may be the rising water table, contacting and dissolving residual PCE in the area around ARCO6018MW11. This interpretation is supported by the correlation between increasing PCE concentrations and a significant rising of the water table between 2005 Q4 and 2006 Q2 (approximately 10 feet rise measured in CTM63) accompanied by a significant PCE concentration increase in ARCO6018MW11 during the same period (from 18 to 850 µg/L).
- PCE concentrations in several monitoring wells (e.g., CTM 63 and CTM64) peripheral to the plume appear to have decreased with the increasing water levels. A possible explanation is that the rising water table is causing a dilution effect in the portions of the plume not near a source.
- The areal extent of the Mill/Kietzke plume does not appear to change during 2006. There is presently some significant uncertainties, given the number and screened intervals of existing monitoring wells, as to the nature and extent of this plume at or near the leading edge. The Mill/Kietzke plume could commingle with the Vassar / East Plumb plume in the vicinity of CTM-18S. However, this potential interpretation has not been substantiated by an adequate distribution of monitoring well data or capture zone analyses.

Is there evidence of vertical migration?

- As discussed previously, the presence of PCE in Deep Zone well CTM10D and its absence in the adjacent shallow well CTM9S suggests that PCE is migrating laterally toward the Mill Street Well as part of the Downtown Reno plume (**Section 6.2.4**).

- The PCE concentration profile for the Mill / Kietzke and Downtown Reno subregions for 2006 Q2 (**Figure 6.22**) does not suggest any PCE mass transfer (migration) from the Shallow Zone Mill / Kietzke plume to the Deep Zone Downtown Reno plume.
- Most of the monitoring wells within the Mill / Kietzke plume are completed to depths less than 60 feet bgs. In the Mill / Kietzke source areas, the two deepest Shallow Zone wells (CTM44 and CTM64) are both 70 feet deep. These two wells have markedly lower PCE concentrations than a nearby shallower well (CTM13S, extending to 55.5 feet bgs). This suggests that PCE concentrations near the Mill /Kietzke plume source areas are primarily impacting the uppermost portion of the Shallow Zone.
- The Mill / Kietzke subregion cross section prepared by DWR indicates southeastward dipping strata and a southeastward plunging plume. This is consistent with the following additional observations, which suggest the possible presence of a southward plunging plume extending from the Mill / Kietzke source areas toward well CTM38D, which has historically been contoured as part of the Vassar / East Plumb Lane Plume.
    - Groundwater elevation contours indicate that the Mill/Kietzke plume is located in an area where the vertical movement of groundwater and contaminants is likely to occur. During the late spring to early fall, when municipal water supply well pumping from the Deep Zone takes place, water levels in the Shallow Zone are drawn down by up to about 10 feet. This indicates downward groundwater movement across the area where the Mill/Kietzke plume has been identified. The heterogeneous nature of the underlying sediments and the distribution of existing monitoring wells contributes to the actual pathway for the downward movement of groundwater and contaminants not known being defined at this time. However, the presence of a downward hydraulic gradient (as observed) would cause a plunging plume.
    - CTM11S is not completed very far below the water table. This well is likely to intercept the top of a plunging plume on only some occasions, depending on water levels and/or vertical gradients, which would explain why PCE would only intermittently be detected in this well.
    - CTM38D is located along the downgradient axis of the Shallow Zone plume. Because the screened interval of CTM38D is only slightly deeper than the other shallow wells in the area, intersection of plunging plume by this well would be a reasonable expectation given the downward hydraulic gradient and/or the downward plunge of the strata.
- While vertical migration appears to be occurring in the form of a plunging shallow plume, there is presently no evidence to substantiate that PCE contamination from the Mill / Kietzke plume is being captured by the Mill Street Well; however, there is also no evidence to disprove it conclusively.

- The additional contaminants (MTBE, 111-TCA, TCE, and cis-12-DCE) detected in at least portions of the Mill / Kietzke plume have not been detected to date in the Mill Street Well.
- During the parts of the year when drawdown in the underlying Deep Zone is greatest, the Shallow Zone is drawn down by up to about 10 feet. Such a downward hydraulic gradient could cause a plunging plume that has the potential to reach the Mill Street Well.
- The Mill Street Well has a PCE concentration trend that bears greater similarity to CTM10D than to Shallow Zone wells completed in the Mill/Kietzke plume. This suggests that the Mill Street Well intercepts the Downtown Reno plume.
- There is no apparent hydrogeologic impediment to migration of PCE to the Mill Street Well from the Downtown Reno plume. It is reasonable to assume that this is the most direct and predominant source of PCE transport to the well.
- Vertical profiling has not detected PCE at intermediate depths between the Mill / Kietzke plume and the screened interval of the Mill Street Well.
- Nevertheless, partial capture is possible given the potential for vertical movement of shallow groundwater (and PCE) to the Deep Zone across the plume area in response to municipal water supply well pumping.

Receptors

Are municipal water supply wells impacted or have they been in the past?

- The candidate receptor wells for the Mill / Kietzke plume are the Mill Street, Corbett, and Terminal wells. Groundwater pumped from the Mill Street and Corbett Wells contained PCE at 36 and 23 µg/L, respectively, in 2006 Q2. Low concentrations of PCE have been detected in the Terminal well in the past (0.5 µg/L in 2004). The Mill Street and Corbett Wells are equipped with wellhead treatment systems and are operated for municipal water supply. The Terminal well is currently not used on a regular basis but is available for drought supply.
- The available water quality data suggest the Mill Street Well may not be capturing any PCE from the Shallow Zone Mill / Kietzke plume, or may be capturing only a small portion of the plume.
- If the PCE contamination observed at CTM38D is an apparently detached subplume originating in the Mill / Kietzke plume source area, then pumping of the Corbett Well may be contributing to the migration of PCE from the Mill /Kietzke plume. It is possible that the Corbett Well may also be capturing part of the Mill/Kietzke plume.

What is the risk that PCE concentrations at receptor wells will increase?

- PCE concentrations have increased in some of the wells used to define the hot spots of the Mill / Kietzke plume (e.g. at ARCO6018MW11 and ARCO6018MW12). This indicates a possibility for future plume strengthening and increased risk to downgradient receptor wells.
- As stated above, if the PCE contamination obsered at CTM38D is a detached portion of the Mill/Kietzke plume, it is possible that PCE originating as part of the Mill / Kietzke plume will be captured by the Corbett Well.

What is the risk that additional wells will be impacted?

- Based on the data discussed in the preceding sections, it appears that the Mill / Kietzke plume is not significantly captured by Mill Street Well. It appears more likely that the plume is moving east-southeast toward and potentially past the CTM38D, 39S well cluster. While the characterization of the relationship between the Shallow and Deep Zones in the groundwater model used for the 2005 Pumping Plan Analyses (Intera, 2006b) are somewhat suspect, the results of that analysis suggest that 0% of the Mill / Kietzke plume is being captured by municipal water supply wells.
- The Terminal Well is located a short distance from the Corbett Well, but is closer to the Mill / Kietzke plume than the Corbett Well. If the assumptions regarding PCE at CTM38D are

correct, or if PCE migrates closer to the Terminal Well in the Shallow Zone, the Terminal well could be threatened if it were operated on a regular basis.

- Impact to additional wells further down-gradient (south and east - such as Pezzi or the Hidden Valley wells) is possible. This possibility is not considered likely if the assumption that the Corbett Well is capturing the Mill / Kietzke plume is correct, and the Corbett Well continues to be operated in a remedial capacity.

6.2.6 Victorian Avenue Plume Subregion

The Victorian Avenue Subregion is the Shallow Zone counterpart to the Deep Zone Downtown Sparks Subregion (described in **Section 6.2.7**). The lateral boundaries of the Victorian Avenue Subregion coincide with the Downtown Sparks Subregion (**Figure 6.1**). The Victorian Avenue Shallow Zone and Downtown Sparks Deep Zone are presumed to be vertically separated by geological materials with low(er) hydraulic conductivities. These materials are likely to have limited lateral extent and act as a partial barrier to vertical groundwater flow.

Groundwater Occurrence and Flow

What is the hydrostratigraphy of the subregion?

- The upper stratigraphic interval consists of Quaternary alluvium. The Quaternary alluvium overlies Tertiary-aged Verdi Basin Sediments (Trexler and Cashman, 2006). The underlying bedrock consists of Mesozoic crystalline and Cenozoic volcanic rocks (Trexler and Cashman, 2004). Recent regional cross sections based on interpretation of gravity data calibrated by borehole intercepts (Widmer, 2006 and 2007) suggest the thickness of the Quaternary alluvium is approximately 150 to 300 feet and the depth to bedrock in the subregion is approximately 650 to 900 feet.

- Shallow Zone wells discussed in this report are completed in the Quaternary alluvium. Deep Zone wells along the Truckee River corridor are also generally completed in the Quaternary alluvium. However, distal from the Truckee River and in the eastern portion of the CTM (generally east of Highway 395) Deep Zone wells are completed in the Tertiary Verdi Basin Sediments.

What lateral and vertical hydraulic gradients are influencing groundwater flow?

- The lateral groundwater flow direction across the Victorian Avenue plume Subregion has been consistently to the east-southeast during 2006. The magnitude of the gradient was observed to be 0.003 during 2006 Q1 and Q2, and decreased slightly to 0.002 during Q3 and Q4 (**Figures 3.1, 3.3, 3.5** and **3.7**). Historically observed horizontal groundwater flow directions varied from 30 degrees south of east to 38 degrees north of east at a gradient that ranged from 0.002 to 0.03 for the general area around the Sparks Avenue and Poplar#2 wells (HGC, 2005).

- During 2006 Q1, the vertical water level elevation difference between the Shallow Zone and Deep Zone was mostly neutral or upward in the central and eastern portion of the subregion, and slightly downward in the western portion (**Figure 6.23**). A pronounced downward vertical water level difference between the Shallow and the Deep Zones developed across the western portion of the subregion, intensified and spread eastward in Q2 and Q3. In Q4, the vertical water level difference across the subregion was neutral to upwards. This is consistent with observed vertical gradients in the vicinity of the Sparks Avenue well, which have been shown to vary seasonally (HGC, 2005). Upward vertical gradients (up to 0.11) are evident during the winter and early spring, while downward vertical gradients (up to 0.79) are evident in late spring through the fall and appear to occur in response to municipal well pumping.
- Water level elevations in selected key wells during late 2005 and early 2006 were at their highest levels since 2003 (**Table 6.6**). In Q3, water levels fell and then rose again during Q4.

Plume Characteristics

What is the extent and distribution of PCE in the plume?

- The Victorian Avenue plume occurs in the Shallow Zone and overlies the northern portion of (and may be continuous with) the Downtown Sparks plume. The Victorian Avenue plume is a narrow east-west trending plume that is approximately bounded by A Street to the north, Nugget Avenue to the south, South 18th Street to the west and Victorian Plaza Circle to the east. (**Figures 6.1** and **6.24)**. The approximate western and eastern limits of the plume are presently defined by the NDOT and CTM70 wells, respectively. Based on the screened intervals of the Victorian Avenue plume key wells, the plume is at least as shallow as 20 feet bgs (in well CTM70) and at least as deep as 100 feet bgs (in well NDOT).
- In a vertical sense, the upper and lower extent of the Victorian Avenue plume has been roughly delineated in the area of the monitoring well cluster around the Sparks Avenue well (HGC, 2005). In that cluster, PCE has been detected in Deep Zone well CTM67, suggesting that PCE in the Shallow Zone may extend or be drawn downward into the Deep Zone Downtown Sparks plume (HGC, 2005).
- Based on recent data, there appear to be multiple locations in what is presently defined as the Victorian Avenue plume where PCE concentrations are elevated above those in the surrounding area (*i.e.* hot spots). The maximum PCE concentration has been observed in the monitoring well cluster around the Sparks Avenue well, where PCE was detected at a

concentration of 17 µg/L in 2004 Q2. An apparently lower concentration secondary hot spot has been sporadically observed in the vicinity of NDOT, where the maximum detected concentration to date has been 7.2 µg/L (in 2005 Q1). The presence of multiple apparent hot spots suggests the possibility that there may be multiple PCE sources in this subregion, and that the Victorian Avenue plume may be either a composite plume or a series of smaller coalescing plumelets that are responding collectively to pumping of the Sparks Avenue well. Given the spatial distribution of existing shallow monitoring wells in this subregion and the depth distribution of their screened intervals, the characterization of this plume cannot be more definitive at this time. DWR plans to conduct additional investigation in this area to more thoroughly characterize the nature of the plume and potentially contributory sources.

- The plume is contoured as being approximately 500 feet longer during Q3 and Q4 than in Q1 and Q2. This is the result of PCE being observed in well CTM69 during 2006 Q3 and Q4 where PCE concentrations were previously below the detection limit during 2006 Q1 and Q2. As contoured (see **Figures 3.5** and **3.7**) the presence of PCE in CTM69 suggests that the plumelets (centered around the NDOT and CTM70 wells, respectively) previously contoured as being distinct plumes are contiguous and the coalesced plume is collectively longer.

PCE Sources

To what extent have source areas been identified?

- A number of PCAs including auto repair shops, dry cleaners, auto paint shops and one chemical manufacturer, are or have been located in the Victorian Avenue Subregion; however, none of the PCAs are located in the immediate vicinity of the identified plume (**Figure 6.24**). Further investigation into potential PCE sources in this subregion by DWR is planned.
- Sewer Investigation Subregion 9 is located approximately 1,400 feet southwest of the interpreted plume area (**Figures 6.2a** and **6.24**). Investigation of this sewer investigation subregion did not detect any sewer defects or significant soil source areas.
- The concentrations of PCE detected in groundwater to date do not indicate the presence of DNAPL in this subregion.
- The Harrah's Automobile Collection (Site No. 1 on **Figure 6.2b**) NDEP corrective action site is located in the Victorian Avenue Subregion. The Sparks Solvent/Fuel Site is also an NDEP corrective action site and is located to the east of this subregion. The Sparks Nugget also maintains an underground injection permit for the discharge of groundwater (treated for PCE using granular activated charcoal) using an infiltration gallery located immediately northwest of CTM68.

PCE Concentration Trends and Migration

Are PCE concentrations increasing or decreasing?

- The 2006 PCE concentration change (**Figure 6.24**), and the key well trend analysis (**Table 6.6**) show that, from 2006 Q1 to 2006 Q2, PCE concentrations changed very little in either the western hot spot (around NDOT) or the eastern hotspot (around CTM70).
- Key well trend analysis through 2006 Q2 (**Table 6.6)** indicates that PCE concentrations in key wells exhibited the following trends between 2004 and 2006 Q2:
    - No statistically distinguishable trend (concentrations ranging from 9.1 to 17 µg/L; all above MCL) in well CTM70, located in the eastern portion of the plume;
    - No statistically distinguishable trend (concentrations ranging from 3.3 to 7.1 µg/L; currently above MCL) in CTM66, located in the central portion of plume;
    - Increasing trend (concentrations ranging from non-detect to 1.4 µg/L; all below MCL) in CTM65, located in the central portion of plume; and
    - No statistically distinguishable trend (concentrations ranging from non-detect to 1 µg/L; all below MCL) in CTM69, located in the western portion of plume.

Is the plume stable or migrating laterally?

- Based on the very minor fluctuations in PCE concentrations in all of the key wells, the Victorian Avenue plume appears to be stable (*i.e.*, there is no apparent change in plume dimensions or significant change in plume PCE concentrations), and there is no indication of a migrating plume core. This includes the most downgradient well (CTM70), which exhibits no PCE concentration trend. However, the potential for multiple PCE sources and multiple PCE 'plumelets' in the Shallow Zone in this subregion make the evaluation of possible plume stability with the existing monitoring well network difficult.
- The Victorian Avenue plume could potentially be moving past the CTM70 to the east. However this possibility has not been clearly demonstrated by an adequate distribution of monitoring well data or capture zone analysis.

Is there evidence of vertical migration?

- PCE has been detected in (Deep Zone) well CTM67 (located in the same well cluster as Shallow Zone wells CTM65 and CTM66) and the Sparks Avenue well, suggesting that the Victorian Avenue plume is contributing to or is continuous with the Downtown Sparks plume due to downward migration induced by municipal pumping (HGC, 2005). As stated previously, the presence of multiple possible hot spots within the Victorian Avenue plume suggests that it may in fact be a composite plume or a series of coalescing plumelets that are responding collectively to pumping of the Sparks Avenue well. DWR plans to conduct further investigation of the vicinity of the Victorian Avenue plume beginning in 2008.

Receptors

Are municipal water supply wells impacted or have they been impacted in the past?

- Assuming that there is vertical hydraulic communication between the Shallow and Deep Zones in this subregion, the receptor wells for the Victorian Avenue plume are the Sparks Avenue, Poplar#1 and Poplar#2 wells. Groundwater samples from the Poplar#2 well collected between 1989 and 2006 contained PCE at concentrations ranging from below detection to 7.8 µg/L. PCE was detected in Poplar#2 during 2006 at up to 1.75 µg/L (in 2006 Q3). Groundwater sampled from the Sparks Avenue well between 1989 and 2006 contained PCE at concentrations ranging from below detection to 7.6 µg/L. PCE was detected in Sparks Avenue during 2006 at up to 7.6 µg/L when sampled at a time after the pump was turned on after having been off for a while. Groundwater sampled from the Poplar#1 well (during 2000 and 2003) contained PCE at concentrations below the detection limit (< 0.5 µg/L). The Poplar#1 well is not routinely used to meet water demand.
- Since the receptor wells are screened in the Deep Zone in the Downtown Sparks Subregion, further discussion regarding potential impact to receptor wells is provided in the Downtown Sparks plume subregion evaluation (**Section 6.2.7**).

What is the risk that PCE concentrations at receptor wells will increase?

- A discussion regarding potential increases in PCE concentrations in receptor wells is provided in the discussion regarding the Downtown Sparks Subregion (**Section 6.2.7**, below).

What is the risk that additional wells will be impacted?

- Based on the relatively low PCE concentrations detected in the Victorian Avenue plume, it is not currently considered likely that lateral migration of this plume (as presently characterized) would threaten other receptor wells. It is noted however that the potential risk posed to the Dilworth and Stanford wells should be considered.

6.2.7 Downtown Sparks Plume Subregion

The Downtown Sparks Subregion is the Deep Zone counterpart to the Shallow Zone contained in the Victorian Avenue Subregion (described in **Section 6.2.6**). The lateral boundaries of the Downtown Sparks Subregion coincide with the Victorian Avenue Subregion (**Figure 6.1**). The Victorian Avenue Shallow Zone and Downtown Sparks Deep Zone are vertically separated by geological materials with low(er) hydraulic conductivities (HGC, 2005). These materials are likely to have limited lateral extent and act as a partial barrier to vertical groundwater flow.

Groundwater Occurrence and Flow

What is the hydrostratigraphy of the subregion?

- The upper stratigraphic interval consists of Quaternary alluvium. The Quaternary alluvium overlies Tertiary-aged Verdi Basin Sediments (Trexler and Cashman, 2006). The bedrock consists of Mesozoic crystalline and Cenozoic volcanic rocks (Trexler and Cashman, 2004). Recent regional cross sections based on interpretation of gravity data calibrated by borehole intercepts (Widmer, 2006 and 2007) suggest the thickness of the quaternary alluvium is approximately 150 to 300 feet and the depth to bedrock in the subregion is approximately 650 to 900 feet.
- Shallow Zone wells discussed in this report are typically completed in the Quaternary alluvium and glacial outwash. Deep Zone wells located along the Truckee River corridor can also be completed in the Quaternary materials, particularly in the western portion of the basin. However, distal from the Truckee River and in the eastern portion of the CTM (generally east of Highway 395) Deep Zone wells can also be completed in transmissive intervals of the Tertiary Verdi Basin Sediments.

What lateral and vertical hydraulic gradients are influencing groundwater flow?

- The lateral groundwater flow direction across the Downtown Sparks Subregion was observed to be easterly to east-southeasterly at a gradient of approximately 0.002 during 2006 Q1 and Q2 (**Figures 3.2** and **3.4**, respectively). During Q2, a groundwater divide appears to develop between the Downtown Sparks plume and the groundwater depression in the Downtown Reno Subregion to the west. In Q3, this groundwater divide is approximately 1,000 feet west of the Downtown Sparks plume (**Figure 3.6**). Groundwater west of the divide flows west to northwest and is captured by pumping municipal water supply wells. Groundwater east of the divide flows southeast to south at a gradient of approximately 0.002. In Q4, apparent remnants of the groundwater divide occur as two groundwater mounds approximately 3,000 feet west-northwest and west-southwest of the plume (**Figure 3.8**).
- During 2006 Q1, the vertical water level differences between the Shallow and Deep Zones are observed to indicate a mostly neutral or upward gradient in the central and eastern portion of the subregion, including the area where the Downtown Sparks plume is located, and a slightly downward gradient in the western portion of the subregion (**Figure 6.28**). The downward vertical gradient observed in the western portion of the subregion in Q1 steepens and spreads eastward over a larger area during Q2 and Q3 until a downward gradient

encompasses almost the entire subregion. In Q4, the vertical gradient across the subregion is neutral to upwards.

- The vertical water level differences discussed above are consistent with observed vertical gradients in the immediate vicinity of the Sparks Avenue well. The local vertical gradient near the Sparks Avenue well has been shown to vary seasonally (HGC, 2005). Upward vertical gradients (up to 0.11) are evident during the winter and early spring, while downward vertical gradients (up to 0.79) are evident in late spring through the fall while municipal water supply wells are pumping.

- Seasonal trends in water levels generally are characterized by high(er) water levels in the winter and spring, and low(er) water levels in the summer and fall. Consistent with this observation, during late 2005 and early 2006 groundwater elevations in selected key wells were at their highest levels since measurements began in 2003 (**Table 3.7**). Groundwater levels fell (compared to levels measured in 2006 Q2) during 2006 Q3, and then rose again in Q4.

Plume Characteristics

What is the extent and distribution of PCE in the plume?

- The Downtown Sparks plume occurs in the Deep Zone, but may be vertically continuous with the Victorian Avenue plume, which occurs in the Shallow Zone and overlies the northern portion of the Downtown Sparks plume. The extent of the Downtown Sparks plume is not well constrained by the limited number of existing Deep Zone wells in this area. The plume apparently extends southward approximately from Victorian Avenue to Glendale Avenue, and eastward approximately from South Rock Boulevard to Victorian Plaza Circle. (**Figures 6.1 and 6.28**). The minimum northern and southern limits of the plume are defined by PCE detections in CTM67 and CTM75, respectively. The plume is not presently well defined or constrained to the west and east and could actually be significantly larger in that dimension. Based on the screened intervals of the Downtown Sparks plume key wells in which PCE has been detected, the Downtown Sparks plume is at least as shallow as 101 feet bgs in the northern portion of the plume (at CTM67) and at least as deep as 172 feet bgs in the southern portion of the plume (at CTM75). Recognizing that PCE is present in both the Sparks Avenue and Poplar #2 wells, the Downtown Sparks plume may extend to (or beyond) the bottom of the screened intervals in those wells.

- In the northern portion of the Downtown Sparks plume area, PCE is detected in CTM67, but not in the adjacent deeper well CTM68. However, PCE has been regularly observed in the Sparks Avenue well (deeper than CTM68 and screened from 152 to 272 feet bgs). These spatial relationships may delineate the complex vertical extent of the plume or illustrate local hydrostratigraphic controls on PCE distribution in an area that may be close to multiple potential sources.

- In the southern portion of the Downtown Sparks plume, near the Poplar #1 and Poplar #2 municipal water supply wells, PCE has been observed in CTM75 and Poplar #2, but not in the adjacent shallower monitoring well (CTM74) or in Poplar #1. These relationships may help delineate the vertical extent of the plume in that portion of the subregion. However, recognizing that the screened intervals for Poplar#1 and Poplar#2 are much longer than the screened interval for CTM75, the presence of measurable PCE in Poplar #2 could imply that groundwater entering the long screens of the Poplar wells may have significantly diluted PCE concentrations compared to CTM75. Analytical data for Poplar#2 (screened from 146 to 286 feet bgs) include sporadic detections of PCE at concentrations ranging from below detection to 7.8 µg/L between 1989 and 2006. Accordingly, it is possible that PCE is present at concentrations higher than those that been observed at the Poplar #2 wellhead in relatively thin, discrete intervals below 172 feet bgs in the southern portion of the plume. The limited data from existing CTM monitoring wells define the Downtown Sparks plume as plunging with depth toward the Poplar wells.

- The greatest concentration of PCE is found at the northern end of the Downtown Sparks plume (30 to 52 ug/L in CTM67 in 2006). PCE concentrations in the Downtown Sparks plume appear (based on existing wells) to decrease towards the south, to a minimum detected concentration of 1.2 to 3.8 µg/L in CTM75 in 2006. It is not understood at this time how the PCE concentrations observed in CTM67 may relate to potential PCE sources.

PCE Sources

To what extent have source areas been identified?

- A discussion regarding identified PCAs and potential PCE sources to the Downtown Sparks plume are provided in the Victorian Avenue plume subregion evaluation (**Section 6.2.6**).

- If the Downtown Sparks plume is connected to the overlying Victorian Avenue plume they would have, at least in part, the same surface source or sources. However, maximum PCE concentrations (observed in existing monitoring wells) in the Victorian Avenue plume are lower than in the Downtown Sparks plume as presently defined based on the existing data. This would appear to be inconsistent with the two plumes being connected. However, one possibility would be that the Victorian Avenue plume is not homogeneous and the contamination observed in CTM67 is the vertical continuation of another, as of yet, poorly defined Shallow Zone plume or plumelets, located farther to the north or northwest of the Victorian Avenue plume.

- The concentrations of PCE detected in groundwater of the Downtown Sparks plume to date are not indicative of the presence of DNAPL.

PCE Concentration Trends and Migration

Are PCE concentrations increasing or decreasing?

- The 2006 PCE concentration change (**Figure 6.28**), and the key well trend analysis (**Table 6.7**) show that, from 2006 Q1 to 2006 Q4, PCE concentrations have increased at CTM67 and have remained almost unchanged in the southern area of the plume near CTM75.
- Key well trend analysis through 2006 Q4 (**Table 6.7**) indicates that PCE concentrations in key wells showed the following trends from 2004 through 2006:
    - PCE concentrations in key well CTM75 decreased from 3.4 to 3.8 µg/L during Q1/Q2 to 1.2 to 1.8 µg/L in Q3/Q4 (**Table 6.7**). During the period of evaluation, concentrations in this well do not display a statistically distinguishable trend;
    - PCE concentrations in key well CTM67 increased from 30 to 41 µg/L in Q1/Q2 to 46 to 52 µg/L in Q3/Q4 (**Table 6.7**). During the period of evaluation, concentrations in this well display an increasing trend;
    - PCE concentrations in the Poplar#2 and Sparks Avenue wells are generally decreasing, although only the Poplar#2 Well displays a statistically significant decreasing trend during the period of evaluation;
    - **Figure 6.28** and **Table 6.7** indicate that PCE concentrations have remained relatively consistent in key wells in this plume throughout 2006.
        - No statistically distinguishable trend (all non-detect concentrations; all below MCL) in well CTM68, located in the northern portion of the plume, and in CTM74, located in the southern portion of plume;
        - No statistically distinguishable trend (concentrations ranging from non-detect to 7.95 µg/L; currently below MCL) in CTM75, located in the southern portion of plume;
        - Increasing trend (concentrations ranging from 18 to 57 µg/L; all above MCL) in CTM67, located in the northern portion of plume; and
        - Decreasing trend (concentrations ranging from below detection to 7.8 µg/L; currently below MCL) in Poplar#2, located in the southern portion of plume.
- In addition, the Sparks Avenue well shows no statistically distinguishable trend between 2002 and 2006.

Is the plume stable or migrating laterally?

- The plume area is presently poorly defined by the existing well network. This plume may be hydraulically controlled by pumping of the Sparks Avenue and Poplar#2 wells, although this can not be confirmed with the existing well network. Any hydraulic influence on or control of the plume is likely to continue as long as these wells are consistently operated.
- The Downtown Sparks plume could potentially be moving to the south, or to the east. However this possibility can't be evaluated or clearly demonstrated without an adequate distribution of monitoring wells, well data, or capture zone analysis. However, there is no evidence of plume migration in 2006 based on the existing data.

Is there evidence of vertical migration?

- As discussed previously and evaluated in HGC (2005), the Downtown Sparks plume may be connected to the overlying Victorian Avenue plume.
- Data suggest that the Downtown Sparks plume is plunging with depth, towards the south. Operation of the Sparks Avenue well may have drawn PCE contamination into the Deep Zone . In the southern portion of the Downtown Sparks plume the downward vertical extent of the plume is delineated roughly by Poplar #1 and Poplar 2. HGC (2005) interpret that the Sparks Avenue well contains a PCE contribution originating from a local source, while the main source for PCE impacting Poplar#2 is regional contaminated groundwater already in the Deep Zone that may have originated (based on a capture zone analysis) to the northwest (and might possibly be drawn from the leading edge of the Downtown Reno plume when the Poplar#2 well is pumping).

Receptors

Are municipal water supply wells impacted or have they been in the past?

- The receptor wells for the Downtown Sparks plume are the Sparks, Poplar#1 and Poplar#2 wells. The Sparks Avenue and Poplar#2 wells have shown low but generally increasing PCE concentrations under steady state pumping conditions since they were originally sampled in 1987 (HGC, 2005). PCE concentrations in these wells under steady state pumping conditions remain below the MCL.

What is the risk that PCE concentrations at receptor wells will increase?

- The Downtown Sparks plume is defined on the basis of relatively few monitoring wells surrounding the Sparks Avenue and Poplar #2 Wells. PCE concentrations in two key monitoring wells (CTM67 and CTM75) in the northern and southern portions of the plume have remained relatively stable, fluctuating within a relatively narrow range, during the past three years. The Sparks Avenue and Poplar#2 wells have shown low but generally increasing PCE concentrations under steady state pumping conditions since they were originally sampled in 1987 (HGC, 2005). The key well trend analysis conducted as part of this investigation indicates that PCE concentrations in the Sparks Avenue well have been relatively stable since 2002 and Poplar #2 shows a decreasing trend since early 2004 (**Table 6.7**). Existing data suggest that multiple sources may be contributing to the Victorian Avenue and Downtown Sparks plumes. However these plumes can not be thoroughly characterized with the existing monitoring wells. Therefore there may be multiple commingled plumes or coalescing plumelets in this subregion and future concentration trends in the Sparks Avenue and Poplar #2 wells are difficult to predict. WCDWR is planning to conduct additional investigations of the source areas and nature of the plumes in this subregion beginning in 2008.

- If any of the Deep Zone contamination impacting the Sparks Avenue or Poplar#2 wells originates upgradient, the 2006 pumping plan has been designed to more effectively capture existing upgradient Deep Zone contamination. Under the 2006 pumping plan potential downgradient migration of Deep Zone PCE from the Downtown Reno plume will decrease and PCE concentrations in the Poplar#2 and Sparks Avenue wells may go down.

What is the risk that additional wells will be impacted?

- The Downtown Sparks plume is not likely to migrate downgradient if downgradient wells (e.g., Greg Street, Dilworth, and Stanford wells) are not regularly operated.

6.2.8 Wolverine Way Plume Subregion

Groundwater Occurrence and Flow

What is the hydrostratigraphy of the subregion?

- The upper stratigraphic interval consists of Quaternary alluvium. The Quaternary alluvium overlies Tertiary-aged Verdi Basin Sediments (Trexler and Cashman, 2006). The bedrock consists of Mesozoic crystalline and Cenozoic volcanic rocks (Trexler and Cashman, 2004). Recent regional cross sections based on interpretation of gravity data calibrated by borehole intercepts (Widmer, 2006 and 2007) suggest the thickness of the Quaternary alluvium is approximately 100 feet and the depth to bedrock in the subregion is approximately 900 to 1,000 feet.
- Shallow Zone wells discussed in this report are typically completed in the Quaternary alluvium and glacial outwash. Deep Zone wells located along the Truckee River corridor can also be completed in the Quaternary materials, particularly in the western portion of the basin. However, distal from the Truckee River and in the eastern portion of the CTM

(generally east of Highway 395) Deep Zone wells can also be completed in transmissive intervals of the Tertiary Verdi Basin Sediments.

What lateral and vertical hydraulic gradients are influencing groundwater flow?

- The lateral groundwater flow direction across the Wolverine Way plume Subregion has been consistently to the east-southeast during 2006. The magnitude of the gradient was 0.003 during 2006 Q1 and Q2 and decreased slightly to 0.0025 in Q3 and Q4 (**Figures 3.1, 3.3, 3.5** and **3.7**).
- Vertical gradients across the subregion are generally neutral to upwards. An area of downward vertical water level differences (between the Shallow and Deep Zones) developed near the western edge of the subregion during Q1; increasing in magnitude and spreading eastward during Q2 and Q3 (**Figure 6.30**). Downward vertical gradients were also evident in the southeast corner of the subregion Q2. These changes in vertical gradient vary seasonally to the west and southwest, possibly in response to municipal groundwater pumping, and periodically to the southeast, where several industrial wells are located. .
- Water levels in the two key wells for which hydrographs were prepared were at their highest levels (since 2003) in late 2005 and early 2006 (**Table 6.8**). In 2006 Q3, water levels fell (relative to those measured in early 2006) and then rose again in Q4.

Plume Characteristics

What is the extent and distribution of PCE in the plume?

- The Wolverine Way plume occurs in the Shallow Zone. The Wolverine Way plume is a narrow east-west trending plume whose approximate boundaries extend somewhat north of Wolverine Way and Dunn Circle, east of Watson Way, south of Glendale Avenue, and west of Linda Way (**Figures 3.1, 3.3, 3.5** and **3.7**). The minimum western and eastern limits of the plume are generally defined by PCE detections in SSFSMW204 and SSFSMW207, respectively.
- The plume is contoured as being apparently about 2,000 feet longer in Q3 and Q4 than in Q1 and Q2 (**Figures 3.1, 3.3, 3.5** and **3.7**). This is a visual artifact resulting from using a lower concentration threshold (0.625 µg/L, close to the analytical reporting limit and potentially providing better perspective on plume extents and PCE concentration distribution) to define plume margins beginning in 2006 Q3. This resulted in the appearing to be longer than had been represented previously . PCE concentrations in SSFSMW207 (the furthest downgradient well that has been included in the Wolverine Way plume) have been as high as 11 µg/L and have been consistently observed since 1991. Changing the lower contour limit and SSFSMW207 in the Wolverine Way plume as of 2006 Q3 is simply an operational definition and does not imply or infer migration or expansion of the plume.

- Based on the screened intervals of the Wolverine Way plume wells in which PCE has been detected, the plume is at least as shallow as 9 feet bgs (in well SSFSMW204) and at least as deep as 62 feet bgs (in SSFSMW212); however, the downward extent of the Wolverine Way plume has not been delineated throughout the known lateral extent of the plume. There are no wells screened in the Deep Zone in the vicinity of the Wolverine Way plume. The Stanford and Apollo water supply wells are located approximately 2,000 feet north and 2,200 feet southeast of the Wolverine Way plume, respectively. PCE has not been detected in these wells; however, PCE has been detected at up to 2.2 µg/L in PurinaMW, located several hundred feet east (downgradient) the Apollo Well, and screened to a similar depth. In addition, there are four industrial wells (PDM, COLOITECW1, CW2 and CW3) located more than 2,250 feet southeast of SSFSMW207 that are screened across either deeper intervals in the Shallow Zone or potentially into the Deep Zone (to a maximum depth of 179 feet bgs). While PCE has been observed in these wells, how they may relate to the Wolverine Way plume or other potential sources of PCE contamination is not known at this time.
- The hot spot of the Wolverine Way plume (as contoured by DWR) occurs in the western and central areas of the plume, encompassing wells SSFSMW204, SSFSMW205 and SSFSMW212 (**Figures 3.1, 3.3, 3.5** and **3.7**), with the most westerly well (SSFSMW204) having the highest previous PCE concentrations. As contoured, PCE concentrations decrease towards the eastern edge of the plume, in the downgradient direction. The data used by DWR to define the Wolverine Way plume does not presently include any data from the wells located on the Sparks Solvent/Fuel Site (SS/FS) or any data generated on behalf of the Vista Canyon Group (the responsible party for that site) as part of SS/FS monitoring.

PCE Sources

To what extent have source areas been identified?

- A number of PCAs have been identified in the vicinity of the Wolverine Way plume. Many of the PCAs were identified in conjunction with the sewer investigation (Kleinfelder, 2003) and are scattered throughout what was defined as Sewer Investigation Subregion 9 and in the greater plume area. These include automotive repair shops, auto paint shops, paint shops, chemical manufacturers, and a dry cleaner.
- Sewer Investigation Subregion 9 is located at the head of the Wolverine Way plume (**Figures 6.2a** and **6.31**) as contoured. Investigations were performed along Dermody Way north of Glendale Avenue and Bigelow Way, and along Glendale Avenue between Marietta Way and Dermody Way (Kleinfelder, 2003). No sewer defects were identified. A passive soil gas survey found evidence of a PCE release to soil near the intersection of Dermody

Way and Glendale Avenue; however, the detected concentrations were lower than those detected in other Sewer Investigation Subregions.

- A regulatory agency file review performed by McGinley and Associates (2002) identified Harrah's Auto Collection, located just north of Icehouse Avenue, as a facility with historical PCE detections in groundwater. Harrah's Auto Collection was designated as NDEP corrective action Site number 1. A PCE concentration of 2,000 µg/L was detected in 1995 in MW-4, located approximately 200 feet northwest of the intersection of Dermody Way and Bigelow Way. McGinley and Associates speculated that some, if not all, of the detected contamination originated from an offsite location, including the Sparks Solvent/Fuel Site (SS/FS). The SS/FS is also an NDEP corrective action site, immediately north of the Wolverine Way plume, being regulated for petroleum hydrocarbon and chlorinated solvent contamination of groundwater.

- The maximum concentrations of PCE in samples from what has been defined as the Wolverine Way plume is 380 µg/L in SSFSMW204 in May 1993; however, higher PCE concentrations have been detected in wells associated with SS/FS. Thus, the concentrations of PCE detected in the Wolverine Way plume may or may not be associated with the presence of DNAPL; however, concentrations in key wells in the upgradient and plume core areas are generally decreasing, which is consistent with a diminishing source and a detached plume.

PCE Concentration Trends and Migration

Are PCE concentrations increasing or decreasing?

- **Figure 6.31** and **Table 6.8** indicate that PCE concentrations have remained relatively consistent in key wells in this plume throughout 2006. It is potentially important to note that this assessment of the Wolverine Way plume does not take any data from wells on the SS/FS into consideration.

- Key well trend analysis through 2006 Q4 (**Table 6.8**) indicates that PCE concentrations in key wells showed the following trends from 2004 to 2006:
    - No statistically distinguishable trend (concentrations ranging from 1.6 to 3.5 ug/L; all below MCL) in well SSFSMW207, located in the eastern, distal portion of the plume,
    - Decreasing trend (concentrations ranging from non-detect to 31 ug/L; mostly above MCL) in SSFSMW204, located at the western, hot spot edge of the plume; and
    - Decreasing trend (concentrations ranging from 5.7 to 11 ug/L; all above MCL) in SSFSMW205, located in the central portion of plume.

Is the plume stable or migrating laterally?

- Historically, the Wolverine way was likely captured by pumping from Helms Pit (now Sparks Marina) for dewatering purposes. Pumping was discontinued when the presence of PCE was detected; however, the presence of Sparks Marina may still be exerting some level of influence on local groundwate flow. Decreasing PCE concentration trends in SSFSMW204 and SSFSMW205 (at western edge and central portions of plume, respectively), are consistent with a detached plume core slowly diminishing, migrating downgradient to the east and dispersing. The increasing concentration trend in SSFSMW212 (east of the plume core) indicates lateral transport to the east. Since the plume is not hydraulically controlled by a receptor well and water supply wells are located to the northeast and southeast, these data suggest that plume migration is possible. Given the relatively constant PCE concentrations (*i.e.*, no statistically distinguishable trend) in the most downgradient well (SSFSMW207) an alternative interpretation is that under current conditions this well is near the downgradient plume edge where contaminant attenuation is in rough equilibrium with contaminant migration.
- The Wolverine Way plume could potentially move past SSFSMW207, towards the northeast and the Stanford well or Sparks Marina Lake or toward the other wells to the southeast. However this possibility has not been clearly demonstrated by an adequate distribution of monitoring well data or capture zone analysis.

Is there evidence of vertical migration?

- At this time, in the absence of additional wells in the Wolverine Way plume subregion that are screened deeper in the Shallow Zone, or within the Deep Zone; there is no way to effectively evaluate the possibility for vertical groundwater and PCE migration in the Wolverine Way plume subregion. However, the deepest detection of PCE in the plume is near the downgradient end of the plume, indicating it is possible the plume could be plunging in that direction. In addition, there are four industrial wells (PDM, COLOITECW1, CW2 and CW3) located more than 2,250 feet southeast of SSFSMW207 that are screened across either deeper intervals in the Shallow Zone or potentially into the Deep Zone (to a maximum depth of 179 feet bgs) in which PCE has been detected. While these wells are located along the general lateral transport direction of the Wolverine Way plume, how they may relate to the plume or other potential sources of PCE contamination is not known at this time.
- The vertical water-level difference maps for the subregion (**Figure 6.30**) indicate that vertical gradients in the plume area were generally neutral or upward in Q1 and Q4, and downward groundwater flow and/or PCE migration would not be expected under such conditions. However, downward gradients that could drive vertical migration were evident near SSFSMW204 (in the upgradient, hot spot area of the plume) in Q2 and Q3, and downgradient of the mapped extent of the plume in the southeast portion of the subregion in Q1 and Q2.

Receptors

Are municipal water supply wells impacted or have they been in the past?

- There have been no municipal water supply wells impacted by the Wolverine Way plume. PCE concentrations of up to 2.2 µg/L have been observed in the TMWA PurinaMW test well.
- There are several industrial wells located more than 2,000 feet southeast of SSFSMW207 that are screened across either deeper intervals in the Shallow Zone or potentially into the Deep Zone (to a maximum depth of 179 feet bgs). While PCE has been observed in these wells, how they may relate to the Wolverine Way plume or other potential sources of PCE contamination is not known at this time

What is the risk that PCE concentrations at receptor wells will increase?

- Not Applicable.

What is the risk that additional wells will be impacted?

- The nearest municipal water supply wells to the Wolverine Way plume are the Stanford well, located approximately 0.58 miles to the northeast, and the Greg well, located approximately 0.63 miles to the southwest (**Figures 3.1** through **3.8**). The possibility that PCE from the Wolverine Way plume (or the greater SS/FS) might impact the Stanford or the Greg well has not yet been evaluated. The Stanford well is one of four (along with the Sparks High, Dilworth, and Prater Way wells) municipal water supply wells north of SS/FS that have a collective capacity of approximately 8,000 gallons per minute (GPM). This influence that these wells might have on groundwater flow and potential contaminant migration in the vicinity of the Wolverine Way plume needs to be evaluated.

6.2.9 Greenbrae Plume Subregion

Groundwater Occurrence and Flow

What is the hydrostratigraphy of the subregion?

- The upper stratigraphic interval consists of Quaternary alluvium. The Quaternary alluvium overlies Tertiary-aged Verdi Basin Sediments (Trexler and Cashman, 2006). The bedrock consists of Mesozoic crystalline and Cenozoic volcanic rocks (Trexler and Cashman, 2004). Recent regional cross sections based on interpretation of gravity data calibrated by borehole intercepts (Widmer, 2006 and 2007) suggest the thickness of the Quaternary alluvium is approximately 100 feet and the depth to bedrock in the subregion is approximately 900 to 1,000 feet.

- Shallow Zone wells in the Greenbrae subregion are typically completed in the Quaternary alluvium. While there are presently no Deep Zone wells in this subregion, any Deep Zone wells would be expected to be completed in the Tertiary Verdi Basin Sediments.

What lateral and vertical hydraulic gradients are influencing groundwater flow?

- The lateral groundwater flow direction across the Greenbrae subregion was to the southeast at an approximate gradient of 0.0025 to 0.0029 based on water levels measured in DWR monitoring wells during 2006 Q1 and Q2 (**Figures 3.1** and **3.3**, respectively). The groundwater gradient observed across the Greenbrae subregion during 2006 Q3 and Q4 was southeast with a magnitude of 0.002 (**Figures 3.5** and **3.7**).
- The vertical groundwater level difference in the subregion in both 2006 Q1 and 2006 Q2 was downward in the northwestern half of the subregion (where the Greenbrae plume originated), and upward in the southeastern half of the subregion, where the Prater Way, Dilworth, and Stanford municipal water supply wells are located (**Figure 6.33**). These wells are not being utilized to meet water supply demands at this time. In 2006 Q3, a downward gradient was observed across the entire subregion, but was more pronounced in the northwest half than in the southwest half. In 2006 Q4, groundwater level differences were similar to those observed during Q1, with slight upward trends in the southeast and downward trends in the northwest portions of the subregion.
- Average groundwater elevations were relatively constant through 2006 (**Figures 3.1, 3.3, 3.5** and **3.7**). Water levels in a key well (CTM55) were at their highest levels (since 2003) during early 2006, and then dropped somewhat in Q3 and Q4 (**Table 6.9**).

Plume Characteristics

What is the extent and distribution of PCE in the plume?

- The Greenbrae plume occurs in the Shallow Zone. The Greenbrae plume was originally defined by groundwater sampling data generated during early 2003 from McGinley and Associates and DWR in the immediate vicinity of the Greenbrae Shopping Center (WCDWR, 2005). The shopping center is on the parcels located northwest of the intersection of 4th Street and Greenbrae Drive in Sparks. The plume was originally delineated by monitoring wells MW-1 through MW-10, installed by McGinley and Associates as part of the Greenbrae Shopping Center corrective action administered by NDEP, and to the south and southeast by monitoring wells CTM54, CTM55 and CTM61 installed by DWR. MW-1 is located near the suspected plume source at the Greenbrae Shopping Center and contained PCE concentrations as high as 150 µg/L in February 2002. The lateral extent of the plume Greenbrae PCE plume was identified to exceed 5 µg/L for a maximum horizontal extent of at least 1,000 feet at that time. During 2006, PCE attributed to the Greenbrae plume was observed in only two off site wells (CTM55 and CTM56), and five on-site wells that are not in the CTMRD monitoring program and therefore not used in contouring the data for this report (monitoring wells MW-1, 3, 4, 6 and 7 – installed as part of the NDEP corrective action). The plume appears to have originated at the Greenbrae Shopping Center, is elongated in the southeastern direction, and has potentially migrated laterally and/or vertically downward beyond CTM56, and thus beyond the framework of the existing monitoring network.

- **Figure 6.34**, and **Table 6.9** indicate that PCE concentrations in existing wells have been either relatively consistent or have decreased in 2006. PCE concentrations in the identified key well also show a decreasing trend.
- The downward vertical extent of the Greenbrae plume has not been delineated throughout the known lateral extent of the plume. There are no wells screened in the Deep Zone, or at deeper intervals within the Shallow Zone, in the vicinity of the Greenbrae plume.
- Review of historical data indicates that the core hot spot of the Greenbrae plume appears to have migrated away from the monitoring well network in the Greenbrae Subregion, and that the plume itself may have migrated laterally or vertically beyond the frame of reference of the existing monitoring well network.

PCE Sources

To what extent have source areas been identified?

- Several PCAs, including four dry cleaners, were identified in the area northwest of where the Greenbrae plume was first defined (**Figure 6.34**).
- Sewer Investigation Subregion 4 (Kleinfelder, 2003) was centered on the area around 4th Street and Greenbrae Drive (**Figures 6.2a and 6.34**). PCE was observed during this investigation in wastewater at concentrations up to 1,000 µg/L, but no sewer defects were identified in the area where PCE was detected. However, a soil vapor survey did identify potentially anomalous PCE in soil vapor that may represent a possible sewer release area along 4th Street north of O Street.
- McGinley and Associates (2002) identified Buck 75 Dry Cleaners (located in the Greenbrae shopping center) as the most likely source of PCE detected in the groundwater. Greenbrae shopping center was designated as NDEP corrective action Site number 2 (McGinley and Associates, 2002), and is the only NDEP corrective action site within the Greenbrae Subregion (**Figure 6.2b**). A groundwater PCE concentration of 150 µg/L was detected in the hotspot of the Greenbrae Shopping Center plume in February 2002 (McGinley and Associates, 2005). As of 2004 Q1, the PCE concentration in the well defining the core of the plume had decreased to 34 µg/L (DWR, 2005).

- The concentrations of PCE detected in groundwater to date are not indicative of the presence of DNAPL.

PCE Concentration Trends and Migration

Are PCE concentrations increasing or decreasing?

- **Figure 6.34**, and **Table 6.9** indicate that PCE concentrations have been either relatively consistent or have decreased throughout 2006 in the area where this plume was first identified. PCE concentrations in CTM55, from 2004 to 2006, showed no statistically distinguishable trend. PCE concentrations during this period ranged from below detection to 3.5 µg/L. CTM55 is located in the downgradient portion of where the Greenbrae plume was originally defined.

Is the plume stable or migrating laterally?

- The lack of a statistically distinguishable PCE concentration trend in CTM55 is consistent with its off-axis position near the downgradient plume edge. The available monitoring data are limited and provide no evidence for plume migration *per se*; however, the observed decreasing PCE concentrations, downward vertical gradients, and lack of PCE daughter products that would be indicative of contaminant degradation, all suggest that the plume could be migrating laterally or vertically beyond the frame of reference provided by the existing monitoring well network.

Is there evidence of vertical migration?

- At this point in time, the absence of monitoring wells in the Greenbrae plume subregion screened deeper within the Shallow Zone or within the Deep Zone precludes the evaluation of the possibility of lateral or vertical migration of the Greenbrae plume as defined based on 2003 data. As discussed above, it is possible that the plume is migrating both laterally and vertically beyond the frame of reference provided by the existing monitoring well network. In addition, the possibility of a high concentration PCE plume core (potentially sourced at the Buck 75 Dry Cleaners) that is diving beneath and beyond CTM55 cannot be ruled out based on existing data.

Receptors

Are municipal water supply wells impacted or have they been in the past?

- There have been no municipal water supply wells impacted to date by the Greenbrae plume.

What is the risk that PCE concentrations at receptor wells will increase?

- Not applicable.

What is the risk that additional wells will be impacted?

- The nearest municipal water supply wells to the Greenbrae plume are the Stanford well, located approximately 0.83 miles to the south-southeast, the Dilworth well, located approximately 0.58 miles to the south, and the Prater Way well, located approximately 0.56 miles to the southeast (**Figures 3.1** through **3.8**). Currently, none of these wells are operating and none have been impacted by PCE. However, all three wells are potential receptor wells for the Greenbrae Drive plume after the wells begin pumping. Based on capture zone simulations by TMWA (B. Ojiambo, personal communication, 2006) the Greenbrae PCE plume would be captured by the Dilworth well over a 30-40 year time period should that well become operational.
- In the absence of wells screened deeper in the Shallow Zone, and/or in the Deep Zone; it is not possible to adequately evaluate the PCE contamination risk to any of these municipal water supply wells.

7. CONCLUSIONS

7.1 Data Gaps

Data gaps identified during the GMP to date are discussed in the following sections. A general discussion of data gaps is presented in **Section 7.1.1**, followed by additional sections that discuss specific data gaps identified for each subregion. In the subregion sections, specific data gaps are discussed in narrative form, with each discussion followed by a numbered listing of specific data that would be needed to fill these data gaps. Numbering of the specific data elements is included for ease of reference and future tracking.

7.1.1 General Data Gaps

General Data Gap 1 – Existing Monitoring Well Network

Many of the monitoring wells currently utilized in the GMP were installed during reconnaissance level assessments for PCE in the CTM or were installed for other purposes not directly related to PCE contamination of groundwater. Because these wells are completed at a variety of depths, often with relatively long screened intervals, they are not optimally designed for the purpose of monitoring the extent and potential migration of specific known PCE plumes or the pathways along which PCE could migrate from source areas, through a complex hydrogeologic environment, toward existing and/or potential receptors. Vertical movement is an extremely important component of both groundwater flow and contaminant transport of PCE in the CTM. The migration of PCE, which is stable and persistent under typical conditions in the CTM, from sources at the ground surface through the Shallow Zone to receptor wells in the Deep Zone allows this contaminant to be considered a chemical "tracer". The present distribution of PCE in the CTM is a direct reflection that both lateral and vertical groundwater flow and PCE migration are taking place. Expansion and/or augmentation of the existing monitoring well network will be required to address the following data gaps:

- Locating and characterizing those specific places in the CTM where effective hydraulic communication exists between the Shallow Zone and the Deep Zone.
- Overcoming the limitations in local hydrostratigraphic data, preparing detailed hydrogeologic cross sections, evaluating the vertical placement and length of screened intervals of shallow and deep wells used in PCE plume contouring, and addressing the lack of strategically placed key wells for plume characterization.

General Data Gap 2 – PCE Sources

Many current and historical Potentially Contaminating Activities or PCAs (such as PCE-using businesses) have been identified in the CTM, but relatively few confirmed PCE releases have been reported, relatively few specific PCE source areas have been identified, and even fewer PCE source areas have been evaluated to date.

- Leaking sanitary sewer lines may have acted (or may be acting) as dispersed secondary sources of PCE. This potential release mechanism has only been investigated in a limited number of targeted areas to date.
  - Further investigation into potential secondary sources associated with sanitary sewer lines at other locations may identify additional source areas.
  - Secondary sources associated with sewer leaks have been identified by investigations performed to date in the Vassar / East Plumb and Mill / Kietzke Subregions. Further investigation of these secondary sources would be needed to further characterize them.
- A relatively small number of corrective actions have been undertaken or are underway at specific potential source areas. Most of these have yet to be completed.
  - A protocol for assessing the potential threat that a PCE source poses to the groundwater resource, as a means for prioritizing risk and remedial action, needs to be identified. DWR and NDEP are working to develop such a protocol as part of the ongoing Remediation Management Plan update.
- While it appears unlikely at this time that there are undiscovered major plumes in the CTM, there is the possibility/probability that additional, as yet unidentified sources and/or hot spots may exist. The significance of this data gap is highest for subregions where unprotected pumping wells (wells without wellhead treatment) exist.
- The persistent nature of and generally consistent PCE concentrations in groundwater plumes in the CTM suggests they may originate from relatively robust contaminant sources; however these sources have yet to be adequately identified and/or characterized.

General Data Gap 3 – Subsurface Lithology and Hydrostratigraphy

Systematic evaluation of the CTM hydrostratigraphy is ongoing. This work is being conducted using data from existing boreholes in conjunction with the development of a geological conceptual model to support a groundwater flow and transport model of the CTM. The systematic evaluation of the CTM hydrostratigraphy is being done to form a basis for addressing gaps in the knowledge of subsurface lithology and hydrostratigraphy:

- A representation of local and basin scale hydrostratigraphy with a more geologically consistent, systematic, and better documented framework for identifying/defining principal water-bearing units, as well as lithologic or structural impediments to groundwater (and contaminant) movement in the CTM;
- The identification and hydrogeological characterization of those areas within the CTM where vertical movement of groundwater (and contaminants) is relatively enhanced and movement from the Shallow to Deep Zone occurs; and
- Characterizing the detailed hydrostratigraphy and possible lithologic controls on PCE movement in and around potential contaminant source areas.

Addressing these data gaps would result in a geologic model that more accurately represents the hydrogeology of the CTM and will more effectively support a groundwater flow and contaminant transport model with improved predictive capabilities , and provide increased probability ofidentifying those areas where hydraulic connection between the Shallow and Deep Zones (where municipal water supply wells are completed) is relatively well developed and greater risk to the local groundwater supply from PCE contamination is present.

General Data Gap 4 – Subsurface Faults and/or Lithologic Discontinuities

The location, nature, and hydrogeologic properties of known, probable, and/or possible subsurface faults and/or lithologic discontinuities are presently poorly constrained in the CTM. The apparent importance of these features (*e.g.*, the Virginia Lake Fault Zone [VLFZ] and the Harvard Way Barrier [HWB]) as influences on groundwater flow in both the Shallow and Deep Zones is becoming increasingly evident. These features are likely to also influence contaminant movement. The actual location of these hydraulic flow barriers is only relatively well constrained in a few locations where data from existing nearby wells clearly define pronounced changes in the water level elevation gradient or sharp apparent deviations in the groundwater flow direction. Data gaps associated with known, probable, and possible hydraulic flow barriers that have been identified to date include the following:

- The location, geologic character, and hydraulic properties of the VLFZ are poorly constrained and inadequately understood.
    - Based on the existing data, it is not possible to determine whether the VLFZ is a single structural feature or a linear trending zone within which multiple structural features are present over some finite width. The VLFZ could also be continuous or comprised of multiple, discontinuous segments.
    - The surface location of the VLFZ is undefined in the area north of the Truckee River and south of the Vassar East Plumb/South Reno Subregions (beyond wells CTM50 and CTM46).
    - Data to characterize the nature of the VLFZ with depth are unavailable.

  - Due to the above limitations, it is not know how the hydraulic properties of the VLFZ vary laterally and vertically. While the hydraulic gradient steepens on the west side of the VLFZ, the lack of groundwater discharge at the surface there indicates the VLFZ to be at least locally semi-permeable to groundwater movement. The detection of apparently stable PCE plumes aligned and presumable continuous in the third dimension across the VLFZ indicates that it is also at least semi-permeable to contaminant migration. Yet pumping tests using the High Street and Morrill Avenue Wells (located on either side of the VLFZ) suggest that significant pumping stresses are not transmitted across the VLFZ. It is suggested that pumping stresses in the vicinity of the VLFZ could be masked by rapid recharge from a local source. It is possible that pumping stresses could be masked by rapid recharge from the Truckee River. More data are needed to evaluate how and where groundwater and PCE are transmitted across the VLFZ. One suggested approach would be to conduct a rigorously controlled pumping test at a time when water levels in the Truckee River are low, or at sufficient distance from the river that river recharge would be unlikely to be a significant influence.
  - The overlapping West 4th Street/Downtown Reno plumes cross the area where the VLFZ and Truckee River intersect. The potential interaction of the VLFZ with groundwater, the PCE plumes, and the Truckee River is not well understood.
- The location, geologic character, and hydraulic properties of the HWB are poorly understood.
  - Based on the existing data, it is not possible to determine whether the HWB is a single structural feature or a linear trending zone within which multiple structural features are present over some finite width. The HWB could also be continuous or comprised of multiple, discontinuous segments.
  - The location of the HWB is unknown away from those wells (CTM33D and Corbett/CTM17D) where the presence of this hydraulic flow barrier was first recognized. The HWB could potentially extend beyond the South Reno Subregion and there are little data to constrain its orientation and lateral extent..
  - The hydraulic properties of the HWB have not been characterized and the specific influence this flow barrier may have on groundwater flow and contaminant transport in the Shallow and Deep Zones is poorly understood. It is not presently known if and how the HWB contributes to the presence of the upward vertical gradient that has been observed in the Deep Zone in at least part of the South Reno Subregion. If the HWB does cause or contribute to the observed upward vertical gradient in the South Reno Subregion, the extent to which this effect might persist away from CTM33D and Corbett/CTM17D is not known. More data would be needed to evaluate how and where groundwater and PCE are transmitted across the HWB. One suggested

approach would be to conduct a rigorously controlled pumping test with carefully installed and screened pumping and observation wells.

- The effect and potential significance of the VLFZ and HWB have been high lighted by the data analysis conducted as part of the GMP. It is possible (and perhaps likely) that other geological structures that function as hydraulic barriers will be recognized in the CTM. Pumping tests using appropriately located pumping and observation wells could be used to substantiate the location and hydraulic properties of currently recognized hydraulic flow barriers (such as the VLFZ and HWB) along with other, yet to be recognized barriers. Specifically:
    - An appropriate protocol for characterizing potentially significant groundwater flow barriers can be defined;
    - Additional monitoring wells can be installed in key areas to provide appropriate horizontal and vertical control; and
    - High stress pumping tests (long duration and high flow rate) can be conducted in those key areas where groundwater and contaminant movement is likely to be influenced by potentially significant barriers.
    - Data from these tests can be incorporated into the subregion conceptual models and CTM groundwater flow and transport model to improve the understanding in these key areas. At present such high priority data are lacking in the vicinity of the following municipal water supply wells:
        - Corbett;
        - Terminal;
        - 4th Street;
        - Poplar #1 and #2;
        - Sparks Avenue;
        - El Rancho
        - View Street
        - Kietzke; and
        - Mill Street.

General Data Gap 5 – Groundwater Flow and Recharge

The data (see **Section 6.2.3** through **Section 6.2.5**) suggest that there is a significant local source of Shallow Zone recharge that, in turn, drives downward vertical groundwater gradients and helps recharge the underlying Deep Zone replacing groundwater that is removed during the seasonal pumping of municipal water supply wells. An obvious local recharge source is the Truckee River. The quantification of recharge derived from the Truckee River (vs. other potential sources of Shallow and Deep Zone recharge, such as mountain front recharge and TMWA's municipal well recharge program) warrants a re-evaluation. The data (see **Section 6.2.3**) suggest that in some areas Shallow Zone recharge occurs more readily and at higher rates than in others. The projection of the VLFZ intersects the Truckee River where the West 4th Street and Downtown Reno plumes have been identified in an area of intensive seasonal municipal well pumping. The complex interaction between these factors is not presently well understood.

TMWA's artificial recharge program has a potentially significant effect (at least locally) on seasonal water levels. Artificial recharge can also affect vertical and lateral groundwater flow patterns. However, the influence of artificial recharge on plume mobility and capture has not been considered or evaluated and is not well understood at this time. A better understanding of the potential influence of the artificial recharge program on plume capture or containment is needed.

In some areas, a Shallow Zone response to Deep Zone pumping has been documented. In other circumstances, no such response has been observed. A lack of such a response could reflect differences in hydrostratigraphy, rapid local recharge (such as surface water from the Truckee River) and/or the effect caused by a hydraulic barrier (such as the VLFZ, HWB, or another as of yet unrecognized barrier). Alternatively, the magnitude of the Shallow Zone response could simply be unrecognized given the placement and/or resolution capabilities of the existing Shallow Zone monitoring network.

Groundwater flow and contaminant transport are strongly influenced both by apparent recharge from the Truckee River and by municipal water supply well pumping. The effect and interaction of these factors is strongly seasonal in nature. While the qualitative understanding of these influences was improved substantially based on the 2006 GMP data analysis, additional hydrogeologic and hydrostratigraphic data are needed to quantify these influences and their relative importance. Such data could be derived from the development of detailed cross sections, and the installation, logging and test pumping of wells targeted to specific depths and locations. This work should be conducted in tandem with development of a hydrogeologic conceptual model to support development of an updated groundwater flow and transport model of the CTM.

7.1.2 Vassar / East Plumb – South Reno Subregions Data Gaps

The PCE contamination that has been identified as the Vassar and East Plumb plumes is currently presumed, based on existing data, to be the source of the impacts to the Corbett well. This presumption has yet to be confirmed. Assuming this presumption is correct, the driver for and pathway(s) where by PCE originating in the Vassar / East Plumb Subregion migrates vertically from the Shallow Zone to the Deep Zone to reach the Corbett Well has yet to be determined. As discussed earlier under General Data Gap 4, the location, geological characteristics, and hydraulic properties of the HWB (and its potential influence on lateral and vertical groundwater flow and contaminant transport) are poorly understood. An apparently upward gradient in the central Vassar / East Plumb Subregion suggests that the Deep Zone in that area should be free of PCE. At present there are only two Deep Zone wells in that area to define groundwater elevation (and gradient) and water quality. Accordingly, the hydrostratigraphy, groundwater gradient, and PCE distribution in the central part of the subregion are not currently well understood. One of the two existing Deep Zone wells is CTM33D, which is located a short distance west (upgradient) of the HWB. This well is artesian and contains low concentrations of PCE. The PCE observed in this well could be a local outlier, or part of a potentially significant, larger but as yet undefined , PCE plume located in the central portion of the South Reno Subregion.

Data Gap VEP/SR-1 Additional intermediate and deep wells are needed in the central portion of the subregion between the VLFZ and the HWB to better assess the hydrostratigraphy, gradients, PCE distribution, and migration pathways .

Data Gap VEP/SR-2 Aquifer testing using the Corbett and/or the Terminal Wells, are needed to assess the effect of the HWB on groundwater flow and contaminant transport, and to better assess the contaminant pathway for PCE migration to the Corbett Well and to assess the potential threat to the Terminal Well.

In the western portion of the Vassar / East Plumb – South Reno Subregion, the location and potential influence of the VLFZ is currently not well characterized. Data to effectively assess the effect of the VLFZ on groundwater flow and contaminant transport in the Vassar / East Plumb – South Reno Subregion are not available.

Data Gap VEP/SR-3 Additional investigation, possibly including installation of shallow and deep monitoring wells near the VLFZ and conducting aquifer testing, would be needed to better assess the effect of the VLFZ on groundwater flow and contaminant transport in the Vassar / East Plumb – South Reno Subregion. If the pumping test were conducted in the Vassar / East Plumb Subregion, it would also be necessary to install a pumping well specifically for the test. Otherwise, an alternative test location outside this subregion along the strike of the VLFZ would need to be identified.

The downgradient extent of the Vassar East Plumb/South Reno Plumes has not been defined in the Shallow or the Deep Zones downgradient (east) of the immediate Corbett Well area. These plumes could be present near or beyond the Terminal Well. The downgradient extent of these plumes could put the Terminal Well at greater risk of PCE impact if it were regularly operated. The extent of these plumes could also put other downgradient wells (LongleyLane1, HV-5, Pezzi) at risk of PCE impact.

Data Gap VEP/SR-4 Additional shallow and deep monitoring wells would be needed to define the downgradient extent of these plumes and to support pumping tests of the Corbett, Terminal, and other potentially at risk wells.

Elevated PCE concentrations have been recently detected in CTM49 (below detection through 2005, as high as 36 µg/L in 2006 Q2). The extent of this "hot spot" has not been determined. CTM49 is on the west side of the VLFZ, and represents a potential PCE source that appears to be separate from the source(s) closer to the hot spot of the Vassar plume as currently defined. The contamination at CTM49 appears to be a relatively small hot spot that is distinct from and not continuous with the Vassar plume. Therefore any contaminant contribution from this hot spot, across the VLFZ, to the Vassar plume (and by extension, to the South Reno plume in the Deep Zone) may not comprise a significant mass of PCE. However,additional investigation is needed to substantiate the nature, extent, and potential risk associated with the PCE contamination identified in CTM49.

Data Gap VEP/SR-5 Additional investigation of the CTM49 area hot spot would be needed confirm its contribution to the Vassar / East Plumb – South Reno plume.

7.1.3 West 4th Street – Downtown Reno Subregions Data Gaps

Specific individual source areas for the West 4th Street/Downtown Reno plume have not been investigated or identified to date. No near potential source soil and groundwater sampling has been conducted to date to identify or characterize potential sources. In addition, as discussed below, there are several areas where PCAs are present but data are lacking to determine whether releases are present.

Data Gap W4/DR-1 To identify and characterize potential PCE sources contributing to the West 4th Street/Downtown Reno plume phased and focused investigation is needed. Such investigation would build on an integrated records review, site-specific sampling, and potentially installation of additional groundwater monitoring wells as discussed below under Data Gaps W4/DR-2 and W4/DR-3.

There are no wells located between the West 4th Street plume hot spot (as currently defined at CTM28S) and the apparently upgradient wells CTM1S, KEYSTONEMW1 and CTM2S. A number of PCAs (most notably dry cleaners) are also located in this area. Consequently, it is not known if any other hot spots or release locations are present in this important area. In addition, there are no shallow wells located between well MW9S and the RPD well cluster on the west, and the Mill Street plume on the east. A number of PCAs are located in this area south of the Truckee River, but there are no monitoring wells to confirm the presence or absence of PCE contamination. Notably, the lack of Shallow Zone wells in this area (as well as the lack of Deep Zone wells, as discussed below) also means that it is not possible to assess whether a potential source of Shallow and Deep Zone contamination exists east of the VLFZ. Given this lack of data, the distribution of PCE in this area and the role of the VLFZ as a potential impediment to contaminant migration cannot be adequately assessed.

Data Gap W4/DR-2 Further investigation, including the installation of additional Shallow Zone monitoring wells, would be required to identify the presence, and determine the nature and extent of potential PCE sources contributing to the West 4th Street/Downtown Reno plume and to better define the possible existence, nature, and extent of any contaminated groundwater located upgradient of the plume as currently defined .

Data Gap W4/DR-3 Further investigation, including the installation of additional Shallow Zone monitoring wells, would be required to identify the presence, and determine the nature and extent of potential PCE sources contributing to the West 4th Street/Downtown Reno plume and to better define the possible existence, nature, and extent of any contaminated groundwater located downgradient of the plume as currently defined. Proximal to and east of the VLFZ, additional Shallow Zone wells would be needed in the area approximately bounded by Holcomb Avenue, Mill Street, 4th Street, and Kietzke Lane to characterize water levels and PCE distribution in this area, and to assess the influence of the VLFZ on shallow groundwater flow and contaminant transport pathways.

There are significant areas along the core of the Downtown Reno plume where no Deep Zone wells currently exist to assess or verify the presence of PCE in groundwater subject to capture by municipal water supply wells (such as the area between CTM137, CTM30D and the High Street Well on the west to the Kietzke Lane Well and CTM-10D to the east). Currently, the plume in the area between these wells has been contoured (based on the existing data) as having lower PCE concentrations; however, if significantly higher PCE concentrations are present in groundwater in this area, the mass of PCE in the Downtown Reno plume could be significantly greater than currently represented. As discussed above, the lack of Deep Zone (and Shallow Zone) monitoring wells in this area also leads to an incomplete understanding of the role of the VLFZ may have relative to groundwater flow and contaminant migration.

Data Gap W4/DR-4 Further investigation, including the installation of Deep Zone monitoring wells, are needed in the area between CTM137, CTM30D and the High Street Well on the west, and the Kietzke Lane Well and CTM-10D to the east, to more thoroughly characterize the Downtown Reno plume and groundwater flow and contaminant transport across the VLFZ.

There are presently no Deep Zone wells to delineate the downgradient extent of the Downtown Reno plume in the area east of the Mill Street and Kietzke Lane Wells. The Pumping Plan Analysis (Intera, 2006b) indicates that a small portion of the Downtown Reno plume may not be captured by the Mill Street or Kietzke Lane Wells. The extent of the Downtown Reno plume downgradient of the Mill Street and Kietzke Lane Wells has not been defined and the degree of plume capture resulting from Pumping Plan implementation has not been confirmed.

Data Gap W4/DR-5 Additional Deep Zone monitoring wells, are needed in the area east of the Mill Street and Kietzke Lane Wells to define the downgradient extent and assess the potential migration of the Downtown Reno plume past the Pumping Plan wells.

Data Gap W4/DR-6 Data generated through addressing Data Gap W4/DR-5 could be used in conjunction with the updated groundwater flow and transport model to re-visit the prescribed pumping schedule in the pumping plan in order to maintain the pumping schedule required to cost effectively capture the Downtown Reno plume.

In the West 4th Street Subregion, the location and potential influence of the VLFZ is currently not well characterized. The specific influence the VLFZ may impart toward impeding groundwater flow and contaminant migration in conjunction with seasonal municipal well operation and potential local recharge from the Truckee River (see below) are not well understood or characterized.

Data Gap W4/DR-7 Water levels in new monitoring wells installed in response to Data Gaps W4/DR-3 and W4/DR-4 would be monitored to assess seasonal fluctuations in lateral and vertical water level gradients across the VLFZ to refine the understanding of the VLFZ's influence on groundwater flow and control on the extent of the westward expansion of the seasonal response to Deep Zone municipal well pumping in the area east of the VLFZ .

Data Gap W4/DR-8 New monitoring wells installed in response to Data Gaps W4/DR-3 and W4/DR-4 could be used as observation wells during future aquifer tests to gain a refined understanding of the municipal well capture zones in the area when PCE distribution, proximity of the Truckee River, and presence of the VLFZ all have a potential influence on groundwater flow and contaminant transport.

Data Gap W4/DR-9 Logs from new monitoring wells installed in response to Data Gaps W4/DR-3 and W4/DR-4 would provide data to improve the understanding of local hydrostratigraphy, including the continuity of hydrostratigraphic units on either side of the VLFZ.

Data Gap W4/DR-10 Data generated through addressing Data Gaps W4/DR-3, 4, 7, 8 and 9 would support the refinement and the understanding of the VLFZ's influence on contaminant transport in the Shallow and Deep Zones in the West 4th Street/Downtown Reno plume.

As discussed under General Data Gap 4, the location, geologic characteristics, and hydraulic properties of the HWB and its influence on groundwater flow and contaminant transport are poorly understood. Depending on the orientation, extent, and characteristics of the HWB, its influence on groundwater flow and contaminant transport could extend to the north into the Mill/Kietzke and West 4th Street/Downtown Reno Subregions.

Data Gap W4/DR-11 Additional investigation, including installation of Shallow and Deep Zone monitoring wells along the projected trend of the HWB and/or conducting additional aquifer testing in this area, are needed to assess the location, geologic characteristics, and hydraulic properties of the HWB and its potential influence on groundwater flow and contaminant transport .

Vertical groundwater flow is an important driver for contaminant transport from PCE sources occurring at or near the ground surface. Vertical transport is necessary for PCE to migrate from the source at or near the surface into groundwater, with groundwater (as a dissolved phase) through the Shallow Zone, and downward toward receptor wells completed in the Deep Zone. The GMP data show that downward vertical gradients are at a maximum in the area east of the VLFZ during peak municipal groundwater pumping times in the summer and fall. The GMP data also suggest that the Truckee River is a potentially significant local source of Shallow Zone recharge that could, in turn, drive downward vertical groundwater gradients, and promote recharge of the underlying Deep Zone in response to the seasonal pumping of municipal water supply wells. The southeastern extent of the West 4th Street plume is currently contoured, based on existing monitoring well data, as generally parallel to and lying a short distance northwest of the Truckee River. This relationship suggests that local recharge from the river may act as a barrier to lateral PCE plume movement . Although the presence of PCE in the High Street, Morrill Avenue, Kietzke Lane and Mill Street Wells confirms that downward vertical migration of PCE is occurring both west and east of the VLFZ, the existing monitoring well network provides insufficient detail to resolve vertical hydraulic gradients, PCE distribution, and hydrostratigraphy to define contaminant pathways. Defining contaminant pathways is further complicated by the presence of the VLFZ, which is projected to intersect the Truckee River near the apparent downgradient extent of the West 4th Street plume. Better resolution of PCE migration pathways could be obtained by addressing the data gaps described below.

Data Gap W4/DR-12 Further definition and refinement of data gaps related to vertical groundwater flow and PCE transport in the West 4th Street / Downtown Reno Subregion could be achieved through a more rigorous analysis of existing stratigraphic, water level, contaminant distribution, and pumping test data. The results of this analysis could be used to define specific activities to address the refined data gaps. For example: (1) a detailed hydrostratigraphic analysis could be conducted to identify potential spatial and vertical lithologic correlations with water level trends, river stage and pumping patterns; and (2) pumping test data for the High Street, Morrill Avenue and Kietzke Lane wells could be critically evaluated in light of the hydrostratigraphic data gleaned.

Data Gap W4/DR-13 Activities referenced under Data Gap W4/DR-10 are also applicable to addressing data gaps related to vertical groundwater flow and contaminant transport. This would be complemented with the installation of additional shallow and intermediate depth monitoring wells near the Truckee River (perhaps in Brodhead Park, where the VLFZ and Truckee River are indicated to intersect). Addressing this data gap should include an assessment of the inter-action between seasonal Deep Zone municipal water well pumping, potential Truckee River recharge, local hydrostratigraphy, and the VLFZ in contributing to vertical groundwater flow and contaminant transport.

Data Gap W4/DR-14 The results generated through addressing Data Gap W4/DR-13 could be used to develop an updated quantitative assessment of the recharge components in the water budget for the CTM. These would potentially include the Truckee River, mountain front recharge, artificial recharge, and recharge from other sources (such as irrigation, and leaking distribution and/or wastewater collection systems).

Shallow Zone water level responses to Deep Zone pumping differ on either side of the VLFZ. A Shallow Zone response west of the VLFZ to municipal well pumping west of the VLFZ (at the Reno High Well) has been recognized, but a seasonal groundwater level depression has not been defined to date. East of the VLFZ, a depression of up to 10 feet (approximately) in the shallow water table has been observed during the summer and fall near the Mill Street Well, but Shallow Zone responses to Deep Zone pumping tests were observed to be sporadic. These observations could reflect differences in the degree of hydraulic separation between the Shallow and Deep Zones, differences in the recharge response to pumping, or differences in the ability of the existing monitoring wells to detect the shallow zone response to pumping on the east and west sides of the VLFZ.

Data Gap W4/DR-15 Information gleaned while addressing Data Gaps W4/DR-10, 13 and 14 could be applied to gain improved understanding of the hydrostratigraphy on the east and west sides of the VLFZ, and the interaction between the Deep Zone, the Shallow Zone, and the Truckee River in response to municipal pumping.

The time series PCE concentration trend for well CTM10D indicates a sharp increase, from 51 µg/L to 210 µg/L, that could represent the arrival of a concentration front in 2004 Q2. If this is correct a similar significance increase in PCE concentration could be observed at the Mill Street Well.

Data Gap W4/DR-16 Characterizing a possible increase in risk to the Mill Street Well, would require an assessment of the potential source for the increase in PCE contamination observed at CTM10D, characterization of the Deep Zone contamination in the vicinity of CTM10D , and determining the travel time to, and degree of capture by, the Mill Street Well. This assessment would be informed by data while addressing Data Gaps W4/DR-3 and W4/DR-4.

In order to verify the performance of the Pumping Plan and the degree of capture of the Downtown Reno and West 4th Street plumes the following data gaps would need to be addressed:

Data Gap W4/DR-17 The hydrogeology would need to be re-evaluated and more effectively represented in a groundwater flow and solute transport model than what is represented in the existing DYNFLOW or MODFLOW models. Such a more effective representation would include data generated through addressing the data gaps discussed in this section, especially those pertaining to the degree of hydraulic connection between the Shallow and Deep Zones, the effect of the VLFZ and Truckee River (and possibly the HWB), the three dimensional distribution of PCE in the West 4th Street/Downtown Reno plume, and defining the capture zones of municipal water supply wells in the context of such a more effectively represented model.

Data Gap W4/DR-18 High stress pumping test (high flow, long duration) data would need to be evaluated in detail and incorporated into the re-evaluated groundwater flow and solute transport model.

7.1.4 Mill / Kietzke Subregion Data Gaps

It is apparent that the Shallow Zone Mill / Kietzke plume projects from the vicinity of CTM9S and CTM 13S to the southeast, past the Mill Street Well, to the contaminated groundwater detected in the CTM11S, CTM38D and CTM39S wells. The extent of the plume is relatively well constrained by monitoring wells to the southwest and the east, but it is open to the northwest (upgradient) and to the southeast (downgradient). Wells that would constrain the downgradient extent do not presently exist. Wells to substantiate potential PCE migration pathways for the Mill / Kietzke plume similarly do not exist . PCE from the Mill / Kietzke plume could be impacting the Terminal and Corbett Wells or could potentially impact them in the future. Similarly, the Mill / Kietzke plume may be present in the upgradient direction (beyond the currently defined extent) as far to the northwest as the Sierra Chemical NDEP corrective action site. Other PCAs have also been identified in the upgradient area, and multiple potential contributory sources to the Mill/Kietzke plume cannot be ruled out at this point in time.

Data Gap MK-1 Further investigation, potentially including additional monitoring wells, would be required to better define the possible existence, nature, and extent of the Mill/Kietzke plume upgradient and downgradient of its currently mapped location.

A seasonal groundwater level depression (of up to 10 feet) occurs in the Shallow Zone in the Mill / Kietzke Subregion in response to pumping of municipal water supply wells completed in the Deep Zone. This indicates that there is vertical hydraulic connection between the two zones in this area. Potential factors contributing to the location, magnitude, and areal extent of this seasonal depression at the water table include the local hydrostratigraphy (vertical hydraulic conductivity, the extent of lateral groundwater inflow and the source(s) and magnitude of the recharge components that respond to municipal well pumping . At this time, the definition and relative interaction of the factors contributing to this are not well enough defined to quantify the pathway and extent of vertical groundwater movement induced by seasonal pumping. Data gaps that need to be addressed include the following.

Data Gap MK-2 Conducting a high stress pumping test using the Mill Street (and or Kietzke Lane) Well would help to assess the vertical leakance and flow of groundwater from the Shallow Zone into the Deep Zone.

Data Gap MK-3 Conduct a detailed evaluation of existing lithologic logs (potentially complemented with additional subsurface investigation) to develop a refined understanding of the hydrostratigraphy in the vicinity of the Mill Street (and/or Kietzke Lane) Well and to define the three dimensional distribution of hydraulic parameters in the vicinity of the Mill Street (and/or Kietzke Lane) Well.

Data Gap MK-4 Utilizing the results derived from addressing the data gaps listed above, a local water budget for groundwater flow to the Mill Street (and/or Kietzke Lane) Well could be defined and the location and hydraulic properties of those areas where the Shallow and Deep Zones are in communication can be determined.

There are no recognized hydrogeologic impediments to the PCE from the Downtown Reno plume (east of the VLFZ) migrating to the Mill Street Well. Based on the available data, the Downtown Reno plume is presently considered to be the principal source of PCE impacts to the Mill Street Well. The well network in the vicinity of the Mill/Kietzke plume has a gap in the vertical extent of existing well screens between 95 feet bgs and 326 ft bgs. This gap precludes the assessment of PCE distribution at intermediate depths below the existing monitoring wells and the top of the screened interval of the Mill Street Well. While partial capture of the Mill/Kietzke plume by the Mill Street well is possible, the presence of PCE southeast of the Mill Street Well (in CTM11S and CTM38D) suggests that the Mill/Kietzke plume is, at least in part, migrating downgradient past the Mill Street well. The amount of the Mill/Kietzke plume captured, if any, by the Mill Street well is not known.

Data Gap MK-5 Additional monitoring wells are needed in this subregion. Vertically-targeted sampling is needed to better define the three dimensional distribution of PCE in the area around the Mill/Kietzke plume and the Mill Street Well.

Data Gap MK-6 Data generated during the hydrogeologic evaluation conducted to address Data Gaps MK-2 to MK-4 would substantially refine the understanding of the contaminant transport drivers and pathways in effect around the Mill Street well.

As discussed earlier under General Data Gap 4, the location, geological character, and hydraulic properties of the HWB are poorly understood. Consequently the potential influence of the HWB on lateral and vertical groundwater flow and contaminant transport can not be characterized.

Data Gap MK-7 (Same as Data Gap W4/DR-11) Additional investigation, including installation of Shallow and Deep Zone monitoring wells along the projected trend of the HWB and/or conducting additional aquifer testing in this area, are needed to assess the location, geologic characteristics, and hydraulic properties of the HWB and its potential influence on groundwater flow and contaminant transport .

7.1.5 Victorian Avenue – Downtown Sparks Subregions Data Gaps

The relationships between the Downtown Sparks plume and the Victorian Avenue plume (as presently defined) are not well understood. These plumes (as defined by the existing wells) appear to be orthogonal to each other. This appearance is simply a function of the convention used to define the plumes using the existing wells. The actual plume configurations may be different. The actual plume configuration(s) may be a function of multiple PCE sources contributing to a series of plumelets or a coalescing composite plume in an area characterized by complex hydrostratigraphy that is under the local influence of municipal water supply well pumping. This interpretation is considered applicable to the Victorian Avenue plume and Sparks Avenue well. PCE captured by the Poplar #2 well may be derived in part from the Downtown Reno plume.

Potential sources for the PCE contamination detected in the Sparks Avenue and Poplar #2 wells include downgradient migration of PCE from the Downtown Reno plume, downward migration of the known Victorian Avenue plume, or migration from another, as yet unidentified, nearby source or sources. The mechanism and pathways for contaminant migration from these potential sources are not well understood.

Data Gap VA/DS-1 Additional investigation is required to identify and characterize potential sources for the PCE detected in the Sparks Avenue and Poplar #2 Wells. Such an investigation is planned for early 2008 (see **Section 7.2**).

Data Gap VA/DS-2 Additional monitoring wells and vertically-spaced groundwater sampling may be needed to assess and characterize the three dimensional nature of any plumelets or coalescing plumes in the Victorian Avenue – Downtown Sparks Subregion.

There are insufficient data to characterize how the response from pumping the Sparks Avenue and Poplar #2 wells is transmitted to the Shallow Zone and whether there is spatial variability in this response. The HGC report (HGC 2005) has evaluated the response to a 24-hour pumping period in the immediate vicinity of the pumping wells. Existing data do not represent conditions under sustained pumping or within a large enough area to assess potential spatial variability.

Data Gap VA/DS-3 Additional pumping tests are needed to further assess the nature and distribution of the connection between the Shallow and Deep Zones in the Victorian Avenue – Downtown Sparks Subregion.

Data Gap VA/DS-4 Additional monitoring wells may be required to provide water level and aquifer response data to further assess the connection between the Shallow and Deep Zones in the Victorian Avenue – Downtown Sparks Subregion.

The Victorian Avenue plume (as presently defined) may not be entirely captured by the Sparks Avenue well (and possibly the Poplar #2 well). The plume may potentially be migrating eastward past the Sparks Avenue well in the Shallow Zone. The potential capture of the Victorian Avenue plume has not been evaluated.

Data Gap VA/DS-5 Additional aquifer testing and capture zone analyses would need to be conducted for the Sparks Avenue, Poplar #2, Stanford and Prater Way wells to gain a better understanding of plume migration and capture.

7.1.6 Wolverine Way Subregion Data Gaps

Several PCAs and two NDEP corrective action sites (Harrah's Auto Collection and SS/FS) are located near the head of and/or adjacent to the plume (as presently defined). A passive soil vapor survey (Kleinfelder, 2003) identified relatively low PCE concentrations at one sewer investigation location near the plume. To date, however, an assessment into the possible specific source or sources for the plume has not been conducted. It is presently unknown if and how this plume (as defined by DWR) is related to known PCAs and/or corrective actions sites. It is also unknown whether there is a persistent source for the Wolverine Way plume (and where this source might be located), or if the core hot spot of the plume has potentially migrated away from the source(s).

Data Gap WW-1 A compilation and review of existing data (including data from the Harrah's and SS/FS corrective action sites) would provide a more holistic and better integrated perspective on groundwater contamination, flow, and potential migration pathways in this area. A better understanding of plume configuration, plume dynamics, and relationships to potential source areas will provide a better basis for assessment of threats to groundwater and prioritization of mitigation activities.

Data Gap WW-2 Further investigation, potentially including the installation of monitoring wells, would be required to determine the location and concentration of sources potentially contributing to the plume.

The lateral extent of this plume is not defined by the data generated solely by DWR, and there are no intermediate or deep monitoring wells in the vicinity of the plume utilized by DWR to characterize its vertical extent. It has not been established whether this plume poses a potential risk to nearby municipal water supply wells (*e.g.*, the Stanford or Dilworth wells).

Data Gap WW-3 To better understand the potential the lateral extent, migration and potential receptor wells for this plume, an evaluation would need to be conducted that incorporates pumping test data from the Stanford Way Well and data from monitoring wells at the SS/FS.

7.1.7 Greenbrae Drive Subregion Data Gaps

The Greenbrae plume was originally defined by data generated during 2004 Q1. At that time maximum PCE concentrations in the plume were 34 µg/L and concentrations above the MCL were observed along the apparent plume axis over a distance of more than 1000 feet. Since that time PCE concentrations in existing wells have decreased. The lack of any concurrent increase in PCE daughter products suggests that the Greenbrae plume may have migrated away from the existing monitoring wells. The extent of potential vertical or downgradient migration (to the southeast) is not known. In addition, there is still a lack of intermediate or deep monitoring wells in the vicinity of the Greenbrae plume to effectively characterize the vertical extent of the plume and possible vertical groundwater flow gradients in this area.

Data Gap GD-1 Additional monitoring wells would be needed to identify the present location of this plume and to monitor its potential migration over time.

Data Gap GD-2 Additional monitoring wells and vertically discrete groundwater sampling would be needed to assess the three dimensional distribution of this plume.

The Prater Way, Dilworth and Stanford wells are located downgradient from the Greenbrae plume as defined during 2004 Q1. These wells are not currently being used for water supply. It is not known if these wells would be receptors for the Greenbrae plume if pumping is commenced.

Data Gap GD-3 Aquifer testing and capture zone analyses would need to be conducted for the Dilworth, Stanford and Prater Way wells to gain a better understanding of potential capture of the Greenbrae plume by these wells.

7.2 Planned Activities

The following activities are currently planned to help address the above data gaps.

- DWR is preparing additional hydrostratigraphic cross sections for the designated subregions. Data from these cross sections will be used to update the subregional conceptual models as it becomes available.
- DWR plans to install 30 additional monitoring wells in 2008 to better delineate the extent of the PCE plumes, monitor potential plume migration, and to provide early warning capability for downgradient municipal water supply wells. DWR plans to conduct controlled aquifer testing to better understand the hydraulic connection between the Shallow and Deep Zones and the potential pathways whereby PCE contamination originating near the ground surface is being transported into the Deep Zone.
- DWR plans to begin additional investigation into the potential sources of the Victorian Avenue plume(s) during 2008.   This will include identifying assessing potential sources, their relationship to the plumes, and the pathways along which PCE is migrating from the source(s) to the Sparks Avenue and Poplar #2 wells.
- DWR plans to begin additional investigation into the potential sources of the West 4th Street plume during 2008. This will include identifying assessing potential sources, their relationship to the plume, and the pathways along which PCE is migrating from the source(s) into Deep Zone and impacting the High Street, Morrill Avenue, Kietzke Lane, and Mill Street wells.
- DWR plans to begin additional investigation into the potential sources of the Vassar Street plume during 2008. This will include identifying assessing potential sources, their relationship to the plume, and the pathways along which PCE is migrating from the source(s) into the Deep Zone and impacting the Corbett well.
- DWR plans to begin additional investigation into the potential sources of the E. Plumb Lane plume during 2008. This will include identifying assessing potential sources, their relationship to the plume, and the pathways along which PCE is migrating from the source(s) to the Corbett well.
- DWR plans to begin additional investigation into the potential sources of the Mill/Kietzke plume during 2008. This will include identifying assessing potential sources, their relationship to the plume, and the pathways along which PCE is migrating from the source(s) toward either the Mill Street well or to the Terminal and/or Corbett wells.
- DWR is presently developing an updated groundwater flow and solute transport model for the CTM utilizing all the data generated during implementation of the GMP. This model is intended to have a more accurate representation of basin hydrogeology and be more able to accurately

simulate the horizontal and vertical movement of water and contaminants in response to groundwater withdrawal and recharge processes.

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