

## SECTION 5 CONTAMINANT DISTRIBUTION AND OCCURRENCE

### 5.1 CONTAMINANTS OF CONCERN

The COC at CSSA are based on historically detected analytes (since the inception of the groundwater monitoring program in 1991) and process knowledge. Analytes detected above regulatory standards in soil and groundwater at CSSA is limited to a short list of chlorinated VOCs and metals. Appendix B includes a table of historical detections of contaminants in groundwater for both VOCs and metals. Of the analytes detected at CSSA, only a handful of organic and inorganic compounds exceed the appropriate Action Level (AL) or MCL as given in Table 5.1.

**Table 5.1 Contaminant Detections in Groundwater Above MCLs,  
1992-2004**

VOCs	Metals
PCE	Cadmium
TCE	Lead
<i>cis</i> -1,2-DCE	Nickel
<i>trans</i> -1,2-DCE	

At CSSA the inorganic constituents in groundwater normally analyzed for include arsenic, barium, cadmium, chromium, copper, lead, mercury, nickel, and zinc. Although there have been some metals exceedances on-post, they have been sporadic and limited largely to wells located in the interior areas of the post. Currently metals are not sampled at off-post locations due to the minimal or lack of on-post metals detections exceeding MCLs. With the exception of one location, historical samples obtained for off-post wells between 1995 and 2001 did not yield any metals concentrations above the MCLs. For the one well that exceeded the lead MCL, the 1996 follow-up sample resulted with no lead detection. Additional data from local water utility purveyors demonstrated that no public water wells exceed the MCLs for metals constituents.

The VOCs are components of solvents that were commonly used to clean grease and dirt from metal surfaces. At CSSA, solvents were used to degrease ordnance materiel. In 1995, CSSA discontinued the use of VOC solvents and replaced them with citrus-based cleaners. Until the late 1970s, there were no formal environmental regulations regarding the use or disposal of spent solvent. CSSA, like most other industrial facilities at the time, had no formal solvent disposal procedures. Based on investigations that have been completed-to-date, spent solvents may have been disposed of in SWMUs B-3 and O-1. SWMU B-3 was an on-site landfill where solvents were placed; it was closed in 1992. SWMU O-1 was a vinyl-lined oxidation pond that was used between 1975 and 1985 for the evaporation of spent liquids from ordnance maintenance activities. Another potential VOC source area has been identified near the SW corner of the facility. This area, designated AOC-65, is located at the Building 90 area, which is where solvents were used.

Volatile organic groundwater contamination at CSSA is caused by a group of chemical compounds commonly referred to as halogenated (chlorinated) solvents. PCE, TCE, and *cis*-1,2-DCE are the three most common VOCs found in the CSSA groundwater contamination plumes. The EPA drinking water MCLs for PCE and TCE are both 5 µg/L. The MCL for *cis*-1,2-DCE is 70 µg/L. Concentrations below the MCL are considered safe for drinking water. While other VOC constituents have been detected in CSSA groundwater, these three compounds are by far the most pervasive and likely to exceed the MCLs. Other notable compounds detected in CSSA groundwater below the MCLs include bromodichloromethane, bromoform, chloroform, dibromochloromethane, dichlorodifluoromethane, DCE (1,1 and *trans*-1,2 isomers), methylene chloride, naphthalene, toluene, and vinyl chloride (VC).

Through September 2004, (VC) has been a CSSA analyte in over 700 on-post samples. During that time, 20 detections (less than 3 percent of the sample population) ranging from 0.03 µg/L to 1.3 µg/L have been reported in 11 on-post wells. These wells include CS-D, CS-MW1-LGR, CS-MW1-BS, CS-MW1-CC, CS-MW2-LGR, CS-MW4-LGR, CS-MW9-BS, CS-MW12-BS, CS-MW12-CC, CS-MW16-CC, and CS-MW19-LGR. Nineteen of these samples are trace detections ranging between the laboratory MDL and the AFCEE RL (F-flagged data). Only one result originating from CS-MW16-CC has exceeded the AFCEE RL, and was reported at 1.3 µg/L upon its initial sampling in September 2003. Subsequent events have resulted in trace detections of less than 0.3 µg/L. Well CS-MW12-BS has the most detections of VC, with a total of 6 reported trace concentrations between March 2003 and September 2004. The current regulatory MCL is 2 µg/L. As of September 2004, no detections of VC have been reported in off-post wells sampled by CSSA. The presence of VC in groundwater, albeit small, is an indicator that the degradation of larger-chain chlorinated hydrocarbons is occurring.

## 5.2 EXTENT OF CONTAMINATION

The HCSM uses a layered approach to describe the hydrogeologic condition of the aquifer. The following sections describe the type and concentrations of contaminants detected within the model layers. Data points include groundwater samples collected from on-post monitoring wells and supply wells, and selected off-post domestic and public supply wells. Well types used to characterize the groundwater include on-post monitoring wells specifically screened within target intervals of the aquifer, as well as on- and off-post open boreholes completed in various intervals of the Middle Trinity aquifer. The groundwater plumes are characterized by more than 30 on-post wells and 45 off-post well locations.

In this HCSM, the plumes are defined by groundwater sampling results from December 2002 through June 2004 quarterly monitoring events. These events have been selected since they represent the greatest density of sampling locations over the 10 years of periodic monitoring at CSSA. Since the objective of the off-post private and public wells is to provide a sustainable source of potable water, those wells are usually completed throughout the entire thickness of the Middle Trinity aquifer. Typical completions are open borehole, with older wells having as little as 10 feet of surface casing. Newer wells are more likely to have 200 more feet of surface casing. These well completions are designed to maximize quantities of available LGR and CC groundwater, whereas most CSSA wells individually monitor those units.

Figure 5.1 shows the location and maximum extent of PCE, TCE, and *cis*-1,2-DCE detected between December 2002 and June 2004 within the Middle Trinity aquifer beneath CSSA. The

larger, centrally located area of contamination is referred to as Plume 1, while the latter in the SW quadrant is referred to as Plume 2. Plume 1 is a result of activities at SWMUs B-3 and O-1, and is mostly confined to within the limits of the facility. Some contaminant impact measured in off-post wells to the west of CSSA has been attributed to Plume 1. Contamination within Plume 2 is believed to originate from the industrialized portion of the facility at Building 90. Much of this plume appears to have migrated off-post to the west and south of CSSA.

The inherent difference in well design off-post has made the occurrence of contaminants within each of the model layers difficult to define. While stratification of the contaminants within the geologic layers has been well-demonstrated on-post, it is difficult to be certain in which interval the contamination is occurring in an open borehole well. Extensive groundwater sampling at cluster wells within the Middle Trinity aquifer has generally shown that VOC contamination occurs primarily in the LGR. Limited VOC concentrations have been reported in the BS and CC, but are typically below the CSSA RL.

One exception to this rule has been noted in the vicinity of former water supply well CS-16. This well was completed (open borehole) throughout the entire thickness of the Middle Trinity aquifer. It is believed that this construction style likely resulted in cross-contamination of the CC from the LGR. As a response to the potential for cross contamination, CS-16 has recently been re-completed by plugging of the BS and CC portions of the open borehole completion, leaving 114 feet of LGR open in the well, now redesignated as CS-16-LGR. To assess if cross contamination had occurred, a second well (CS-MW16-CC) was drilled in the vicinity of CS-16-LGR and is completed with 25 feet of screen in the CC. Sampling of CS-MW16-CC has indicated that PCE concentrations in excess of 200 µg/L within the CC at this location, and is evidence for the potential for inter-aquifer cross contamination within open borehole completions located proximal to contaminant source areas.

Based on these observations, this HCSM has assumed that VOC contamination in open borehole completions, both on- and off-post are most representative of contaminant conditions within the LGR portion of the aquifer. While this does not preclude impact to the underlying strata, those affects are currently suspected to be minimal and localized in comparison to the contaminant concentrations in the LGR. Hence, all open borehole completions (both on- and off-post) are only considered in the LGR (Layer 2) portion of the model.

Representations of the PCE, TCE, and *cis*-1,2-DCE groundwater plumes are presented Appendix C. When reviewing these maps, it is important to note that typically two analytical laboratories are used for the chemical analysis of groundwater for any given sampling event. Normally, one lab provides all the on-post results, while the latter provides the off-post results. This approach helps minimize the risk associated with laboratory errors affecting the entire population of data points. However, as a result, differing laboratory-dependent MDLs are reported for a particular compound. In the case of PCE for example, the on-post laboratory uses a MDL of 0.05 µg/L, while the off-post lab uses a 0.06 µg/L MDL.

This is an important consideration when attempting to image the size and plume geometry to the lowest of analytical levels. For the purpose of this report, the differences between the on- and off-post MDLs are considered negligible and are basically treated equally as non-detections. Thereby the lowest contour level was interpreted to represent the minimum plume area which accounted for any detection above a respective MDL. In some sampling events, wells at the edge of the plume vary from detection to non-detection as a temporal effect. To account for this fringe variability, a well which had a "F-flagged" detection (concentration reported between the MDL and the RL) in the prior sampling event was considered to be within the margin of the plume. This methodology would help dampen the effect of seemingly expanding and shrinking plume margins based solely upon the reporting of "F-flagged" data.

The remainder of the groundwater plume has been mapped using logarithmic concentration lines to represent the varying ranges of contamination detected in sampled wells. Beginning at 0.1 µg/L, each isoconcentration line increases exponentially by a factor of ten. This method of contouring allows for evenly-spaced isoconcentration lines in those source areas where there are drastic concentration changes in relatively small areas.

### **5.2.1 UGR (Layer 1)**

Of the UGR intervals, only UGR(D) and UGR(E) have been investigated during RFI and groundwater investigation activities. These are the only intervals of the UGR that have lateral groundwater movement occurring without being cropped out by the intersecting land surface. Vertical movement of groundwater to lower strata also occurs in these intervals where the interval is bisected by faults or fractures. Drilling data suggests that the UGR units UGR(D) and UGR(E) yield very little water, except at times when significant precipitation has occurred. Groundwater occurrence within unit D is probably laterally discontinuous and heavily dependent upon significant recharge and localized bioherms or fracture systems. Numerous RFI borings ranging in depths between 10 and 35 ft bgs has demonstrated that very little to no groundwater is readily available from the immediate near surface. Thus far, no freely yielding groundwater unit has been encountered within the UGR postwide. Past experience has shown that most 30-foot borings will eventually accumulate small quantities of water if allowed to stay open long enough.

#### **5.2.1.1 Plume 1**

Investigations of interval UGR(E) in the vicinity of Plume 1 included the VEWs installed at B-3. At B-3 (Plume 1), cis-1,2-DCE has been reported in excess of 27,000 µg/L, and nearly 3,000 µg/L of PCE.

#### **5.2.1.2 Plume 2**

Only a handful of wells near AOC-65 monitor the lower portion of interval UGR(D) and UGR(E). Specific investigations of interval UGR(E) in the vicinity of Plume 2 included the shallow PZs (-2, -4, and -6) at AOC-65 are mostly completed within this depth interval, and groundwater samples from these wells routinely result with solvent contamination that is in excess of the main plume within the LGR. Some Westbay intervals are completed in the UGR (D) but do not typically contain groundwater, i.e., the CS WB01 UGR-01 zone has remained dry for the entire monitoring period. At AOC-65 (Plume 2), lesser concentrations of PCE generally ranging between 30 µg/L and 60 µg/L are perched above the LGR. The upper zones of the Westbay wells are also completed in this interval, designated UGR-01 or UGR-02. The greatest

concentrations of solvents are reported at the near subsurface adjacent to the source area 13,400 µg/L at CS-WB03-UGR-01 3,400 µg/L from well AOC65-MW2A that is only 19 ft in depth.

During the July 2002 floods, this zone was saturated to the point where cascading groundwater and venting air could be heard in the open boreholes of AOC65-VEW13, -VEW14, -VMP6, -VMP7, and existing well AOC65-MW2B. Otherwise, this interval is generally low-yielding and is non-responsive to all but the heaviest rain events (flood scale). However, groundwater does persist in these wells, in almost a sump-like fashion. Nearly 16 months of monitoring (March 2003 through June 2004) show that water levels are mostly unwavering in this zone. Once the 2002 flooding effect had dissipated, groundwater fluctuations within this zone at AOC-65 typically varied by only several tenths of feet. By way of comparison, the deeper PZs (-1, -3, and -5) screened at the base of LGR(B) fluctuated by more than 50 feet during the same 16-month monitoring period.

Westbay intervals such as CS-WB01-UGR-01 and LGR-01 showed little to no response to recharge and infiltration. Interval CS-WB02-UGR01 is almost always devoid of groundwater except after the heaviest of rains.

Between the September 2003 and September 2004 monitoring periods, the UGR(E) portion of the Westbay monitoring zones remained without groundwater except for on instance in July 2004 at CS-WB02-UGR01. At that time, 3.45 µg/L PCE and 2.12 µg/L TCE were detected in this portion of the stratigraphy. Nearly 9 inches of rain fell at the facility over an 11-day period in November 2004 which was temporarily sufficient to saturate the uppermost UGR01 intervals in all the multi-port wells. Results indicate that a persistent source still exists, and that periodic flushing by intense rainfall can mobilize these perched contaminants that are probably otherwise bound to the matrix during the rest of the year.

### 5.2.2 LGR (Layer 2)

The LGR portion of the HCSM has the greatest occurrence and concentration of contaminants associated with past disposal activities in the Plume 1 and Plume 2 source areas. PCE, TCE, and *cis*-1,2-DCE have been detected in both on- and off-post monitoring wells throughout the central and southern portions of the model area (Appendix C-1, 4, 12, 17, 23, 28, and 35). Temporal data has been interpreted to show two distinct plumes, one located within the central portion of CSSA (Plume 1) and the other in the SW corner of the model area (Plume 2). In general, the plumes are separated by a set of on- and off-post wells that are consistently at, or below the laboratory MDLs. These wells include from west to east: I10-7, I10-6, OFR-4, RFR-9, CS-MW6-LGR, and CS-MW18-LGR.

#### 5.2.2.1 Plume 1

##### PCE

PCE within Plume 1 is centered around wells CS-D and CS-16-LGR (Figures C-1, 4, 12, 17, 23, 28, and 35). Beginning December 2000, CS-D began showing an increasing trend in contaminant concentration (Figure 5.2). Likewise, CS-16-LGR has shown a subtle decrease in contaminant concentration (Figure 5.3) since December 2001, possibly indicating the plume may be migrating westerly or the historical flow patterns in the area were altered during re-completion of CS-16-LGR and the drilling of CS-MW16-CC. PCE concentrations at CS-D normally exceed 180 µg/L, while CS-16-LGR typically ranges between 20 µg/L and 100 µg/L.

Concentrations in excess of 10 µg/L are usually present to the south at CS-MW1-LGR, and historically at CS-MW2-LGR. Additionally, PCE concentrations in excess of 1 µg/L can be expected to occur at CS-MW2-LGR and CS-MW5-LGR. The remainder of Plume 1 is defined by detections greater than the MDL (0.05µg/L) but less than 1µg/L. The total area that is encompassed by the 1 µg/L contour line is approximately 360 acres.

The northern Plume 1 within the LGR has been consistently defined by the lack of contamination at CS-G, CS-MWH-LGR, and CS-I. CS-MW9-LGR appears to be close to the plume margin, such that PCE concentrations just at the laboratory MDL have been reported (June 2003 through March 2004). The southeastern portion of Plume 1 has not been defined by wells free of contamination. CS-MW3-LGR establishes a control point to the NE, otherwise PCE concentrations near the on-post laboratory MDL of 0.05 µg/L appear to extend into the East Pasture as shown by results of CS-MW5-LGR, CS-MW4-LGR, and CS-MW17-LGR. The lack of contaminant detections along the northern portion of Ralph Fair Road defines the plume to the NW. The data indicates that municipal and private wells close to Fair Oaks Ranch have not been impacted by CSSA.

The PCE component of Plume 1 appears to migrate southwesterly beneath Ralph Fair Road near Jackson Woods. The migration of the plume in this direction may be attributed to several factors, including the natural groundwater gradient with a southwesterly vector, migration induced by long-time groundwater production from the CSSA well field (CS-9, CS-10, and CS-11), wells within Jackson Woods, and structural controls related to faulting or karstic features. The odd geometry of the plume suggests that structural controls may be a dominating force. The southwesterly nose of Plume 1 is located beneath both residential and agricultural properties between Ralph Fair Road and Old Fredericksburg Road. The southwestern tip of Plume 1 is demarcated by the lack of detections at FO-17, I10-4, I10-7, and OFR-4. Off-post detections in Plume 1 typically range between the MDL of 0.06 µg/L and 1 µg/L. With the exception of the SW portion, the location and geometry of Plume 1 appears to be static. As seen in the figures presented in Appendix C, the overall shape and geometry of the VOC plumes is also governed by the introduction of new monitoring wells during this time period and the temporal detection/non-detection patterns established at wells near the plume margin.

RFR-9, CS-MW18-LGR, and CS-MW6-LGR define the margins between the PCE fractions of Plume 1 and Plume 2. The total area of groundwater that appears to be impacted by PCE is 1,831 acres. Of this, 1,566 acres is on-post (including Camp Bullis), with the remaining 265 acres located off-post.

#### TCE

While it is postulated that TCE was used as solvent at the facility, TCE also occurs within the model area as a daughter product resulting from the reductive dehalogenation process of PCE (Figures C-2, 5, 13, 18, 24, 29, and 36). The distribution and occurrence of TCE readily mimics that of the PCE fraction of the plumes, and the total area of the plume is slightly less than the PCE fraction. As before, the TCE fraction of Plume 1 is centered around wells CS-D and CS-16-LGR (Figures 5.2 and 5.3). Wells with concentrations in excess of 1 µg/L include CS-4, CS-MW2-LGR, and CS-MW5-LGR, and cover approximately 386 acres of the post. CS-MW1-LGR consistently exceeds 10 µg/L, CS-16-LGR can exceed 100 µg/L, and CS-D is routinely between 250 and 300 µg/L. As with the PCE plume, the TCE plume is well defined to the north and west. However, the eastern and southern extents have not been completely defined by wells free of contamination. The plume has migrated southward onto Camp Bullis property, where trace TCE amounts have been seen in CS-1.

The TCE plume maps located in Appendix C indicate that most of the PCE degradation to TCE occurs along a line that roughly follows Salado Creek, which is also the direction of the

groundwater gradient. Once again, the plume margins can be variable based upon isolated occurrences of detections the laboratory detection limit. As an example, the data from March 2003 (Figure C-5) has an expanded plume geometry in comparison to prior and subsequent quarterly events. In this particular case, the solitary low-level presence of TCE is reported in an off-post area where PCE has been detected at JW-30. The total area of groundwater that appears to be impacted by TCE is 1,331 acres. Of this, 1,233 acres is on-post, with the remaining 98 acres located off-post.

#### *Cis*-1,2-DCE

*Cis*-1,2-DCE occurs within the HCSM area as a degradation product resulting from the reductive dehalogenation process and dilution of parent compounds PCE and TCE. The presence of *cis*-1,2-DCE indicates that the anaerobic conditions of the subsurface are somewhat favorable, and that natural attenuation processes are occurring. The *cis*-1,2-DCE plume is co-located with the PCE and TCE fractions, but covers a significantly smaller area (Figures C-3, 6, 14, 19, 25, 30, and 37). Once again, the greatest concentration of *cis*-1,2-DCE is associated with CS-D and CS-16-LGR (Figures 5.2 and 5.3). The center of the plume is the only area that exceeds the federal MCL of 70 µg/L. *Cis*-1,2-DCE concentrations in excess of 10 µg/L routinely occur at CS-MW1-LGR, followed by detections above 1 µg/L at CS-MW2-LGR and CS-MW5-LGR. Detections less than 1 µg/L repeatedly occur at CS-4, CS-MW4-LGR, and CS-W17-LGR. Approximately 260 acres of the plume exceed 1 µg/L of *cis*-1,2-DCE. The extent of the on-post *cis*-1,2-DCE plume extends to CS-MW9-LGR, CS-3, CS-2, CS-MW12-LGR, CS-MW19-LGR, CS-1, CS-MW17-LGR, and CS-MW3-LGR. An isolated off-post location associated with Plume 1 also occurs in Jackson Woods across Ralph Fair Road. Two wells, including Fair Oaks Ranch municipal well FO-J1 and private well JW-30, had detections of *cis*-1,2-DCE less than the RL during the March 2003 event (Figure C-6). The total area of groundwater that appears to be impacted by *cis*-1,2-DCE is 648 acres.

#### 5.2.2.2 Plume 2

##### PCE

PCE releases associated with past hazardous materials operations at Building 90 (AOC-65) have affected the LGR portion of the aquifer at the SW portion of CSSA and beyond (Figures C-1, 4, 12, 17, 23, 28, and 35). As stated previously, the plume appears to be distinct from Plume 1 as indicated by a line of wells free of PCE contamination. Geographically, the plume is smaller than Plume 1. The area of contamination extends from Building 90 southward beneath Leon Springs Villa and westward to Interstate 10. The southern and eastern extents of the plume have not been defined by wells free of contamination, and PCE is present in municipal wells LS-1, LS-2, LS-3, LS-4 and HS-2. Private well DOM-2 is the only southern well sampled that has not been impacted by groundwater contamination. The western extent is somewhat defined by lack of detections at I10-7, I10-4, I10-5, and RFR-12.

The plume morphology has remained consistent between December 2002 and June 2004. The area of the LGR aquifer impacted by PCE concentrations above the MDL is approximately 612 acres. PCE groundwater contamination in excess of 1 µg/L extends westward from the CS-MW8 cluster to OFR-3, and southward within Leon Springs Villa beneath 236 acres of land. Within this area, PCE concentrations within the LGR exceed the federal MCL of 5 µg/L on a



periodic basis. Wells consistently in excess of 10 µg/L occur 1,500 ft west-SW of Building 90 at RFR-10 and RFR-11.

### TCE

In the SW corner of CSSA, the 365-acre TCE degradation plume is co-located within the main PCE plume body in the LGR (Figures C-2, 5, 13, 18, 24, 29, and 36). The degradation to TCE has not occurred at the plume margins, thus the overall area of impacted groundwater is somewhat less than for PCE (Figures C-1, 4, 12, 17, 23, 28, and 35). Most concentrations are below the CSSA RL, with only four wells (OFR-3, RFR-10, RFR-11, and LS-7) exhibiting concentrations in excess of 1 µg/L (50 acres). Between December 2002 and June 2004, the plume remained static.

### *Cis*-1,2-DCE

In association with Plume 2, *cis*-1,2-DCE has been detected in three wells that range from CS-MW8-LGR located on-post, westward towards RFR-10 and OFR-3 located off-post (Figures C-3, 6, 14, 19, 25, 30, and 37). As much as 35 of the 43 acres mapped for *cis*-1,2-DCE contamination are located off-post. The *cis*-1,2-DCE plume off-post is co-located with the highest occurrence of Plume 2 PCE concentrations known to exist within the LGR.

## 5.2.3 Bexar Shale (Layer 3)

### 5.2.3.1 Plume 1

To date, only four monitoring wells (CS-MW1-BS, CS-MW6-BS, CS-MW12-BS, and CS-MW9-BS) have been installed to exclusively monitor the BS. While many wells penetrate the unit within the HCSM area, they have been included with the discussions regarding the LGR (Section 5.3.2). As shown in various Appendix C figures, PCE, TCE, and *cis*-1,2-DCE are only detected within the BS at CS-MW1-LGR. With the exception of *cis*-1,2-DCE (1.3 µg/L) and toluene (26 µg/L) at CS-MW1-BS, all VOC concentrations were reported at trace levels between the MDL and RL. While the representations of a single-point plume likely do not represent the true distribution of trace contamination within the BS (Appendix C), the current subsurface studies thus far indicate that the BS has been minimally impacted. As an example, trace detections of VC have been consistently reported in CS-MW12-BS and less often in CS-MW9-BS. The occurrence of VC in the BS is notable considering the rarity of detections within the LGR and CC as compared to its occurrence in the BS.

### 5.2.3.2 Plume 2

Only one BS well (CS-MW6-BS) is located in the vicinity of AOC-65. During the monitoring period (December 2002 through June 2004), trace detections of toluene, naphthalene, methylene chloride and *cis*-1,2-DCE (Figure C-9) have been reported in groundwater samples from that well. The occurrence of these compounds is sporadic, and some compounds may be associated with laboratory contamination (methylene chloride). The same compounds at comparable concentrations have also been reported in the LGR and CC counterpart wells at the CS-MW6 monitoring cluster.

## 5.2.4 Cow Creek (Layer 4)

To date, a total of ten (10) wells completed exclusively within the CC Limestone. Both methylene chloride and toluene are the primary VOC analytes detected within the CC wells, usually at trace concentrations below the AFCEE RL. Infrequent and isolated detections PCE, TCE, and VC have been reported at trace concentrations within the CC portion of the Plumes 1 and 2 areal extents. The exception to this generalization is where long-term cross-connection between the LGR and CC has occurred within open borehole well completions (CS-MW16 area). Appendix C figures depict the occurrences of PCE, TCE, and *cis*-1,2-DCE within the Cow Creek.

### 5.2.4.1 Plume 1

Sampling results within the CC from December 2002 through June 2004 are presented in Appendix C (Figures C-10, 11, 20, 21, 22, 32, 33, 34, 39, 41, and 41) depict the occurrences of PCE, TCE, and *cis*-1,2-DCE within the Cow Creek. Prior to September 2003, the CC wells were still being installed and are reflected as such in the maps. The plume delineation as it exists today was defined by the installation of well CS-MW16-CC.

Prior to September 2003, a solitary trace detection of *cis*-1,2-DCE was reported in CS-MW9-CC during the March 2003 event. While trace detections of methylene chloride and toluene have been reported in the CC wells, the lack of PCE, TCE, and *cis*-1,2-DCE in this unit was notable. By September 2003 well CS-MW16-CC had been incorporated into the monitoring network and changed the perception of on-post contamination within the CC unit.

Table 5.2 lists the results of grab samples collected during the installation and development of well CS-MW16-CC. This well is located 30 ft west of the original supply well, CS-16, which was an open borehole well extending from the LGR to the CC. Discrete interval packer samples were collected from the CC interval during coring in June 2003. Results indicated that significant levels of solvent contamination were in the CC groundwater (Table 5.2). PCE was detected to nearly 50 µg/L, while TCE and *cis*-1,2-DCE exceeded 100 µg/L. The borehole results were confirmed with a development sample collected in July 2003. After three weeks of additional well development pumping in August 2003, a post-development sample showed further reduced concentrations (as shown in Table 5.2). However, results from the June 2004 quarterly event indicate that CS-MW16-CC VOC concentrations have not remained reduced, and it would seem that relative concentration is a function of amount of recharge, or flushing of the vadose zone that has occurred prior to the sampling event.

Investigation data indicates that the CC has been impacted near Plume 1. However, current distribution data shows that the CC portion of Plume 1 is mostly confined to the area near the source, specifically near well CS-MW16-CC. At this time it is unclear whether contaminants have migrated downward through the BS, or whether inter-aquifer contamination has occurred as a result of open borehole completions in former water supply wells. The findings at CS-MW16-CC would seem to indicate that open borehole cross-contamination between units was a prime mechanism for the vertical migration of contaminants. This is supported by the hydraulic data that indicates that a downward vertical gradient exists over much of the year.

**Table 5.2 Sampling Results at Well CS-MW16-CC**

		CS-MW16-CC Corehole Discrete Interval Groundwater Sampling		CS-MW16-CC Extraction		
Date		June 2003		July 2003	August 2003	June 2004
Depth (ft bgs)		398-410'	411-423'	Pre-Development	Post-Development	Quarterly Sampling
Concentration ( $\mu\text{g/L}$ )	PCE	8.58	48.4	46.2	25	55
	TCE	95	131	129	66.8	120
	<i>cis</i> -1,2-DCE	135	139	101	93.2	120
	<i>trans</i> -1,2-DCE	1.86	3.51	5.64	3.61	1.8

#### 5.2.4.2 Plume 2

For the December 2002 through June 2004 groundwater monitoring events, Plume 2 within the CC is characterized by a sporadic occurrences of PCE, TCE, and *cis*-1,2-DCE at trace concentrations slightly in excess of the MDL. Routinely, trace concentrations of methylene chloride and toluene are also reported in the CC strata within the confines of Plume 2. While the detection within the CC is puzzling, it may be related to the occasional northward gradient that has been observed within CC wells around AOC-65 or to open borehole construction of former supply wells (such as CS-6, which was plugged in 1996) or active municipal and domestic supply wells in the area.

During the course of the environmental studies, a subject of interest has been the effect of well construction with respect to the occurrence of contamination. Thus far, the data has indicated that contamination is primarily regulated to the LGR portion of the Middle Trinity aquifer. Of concern is the long-term effect of potential cross contamination between the transmissive portions of the LGR and the CC.

Evidence of open borehole cross-contamination was found at off-post well RFR-10. This well was inspected and tested during July 2003 as part of the multi-port well investigation. During the inspection, discrete interval groundwater samples were collected from the private consumer well. Table 5.3 shows that nearly ten times the concentration of PCE is present in LGR than in the CC. It is suspected that the presence of VOCs in the CC is a localized phenomenon associated with the open borehole completion within a contaminated portion of the LGR. This hypothesis is supported by the lack of CC contamination concentration levels at, or near the AOC-65 source area.

**Table 5.3 Results of RFR-10 Discrete Interval Groundwater Sampling**

RFR-10 Depth (ft)	Concentration (µg/L)			
	Interval	PCE	TCE	DCE
160-198'	LGR	<b>91.7</b>	<b>16.2</b>	<b>0.56 J</b>
201-265'	LGR	<b>54.4</b>	<b>19.9</b>	<b>0.79 J</b>
302-366'	LGR	<b>5.07</b>	<0.10 U	<0.20 U
360-424'	LGR/BS	<b>4.86</b>	<0.10 U	<0.20 U
413-477'	BS/CC	<b>9.02</b>	<b>1.29</b>	<b>0.37 J</b>

As part of this study, multi-port well CS-WB04 was installed less than 100 feet away the open borehole well shown in Table 5.3 (RFR-10) to assess the effect of cross contamination within a borehole. The well was designed to divide and isolate the aquifer into smaller hydrostratigraphic segments, thereby allowing long-term discrete samples to be collected from small segments of the aquifer. The results for 13 months of monitoring are presented in Table 5.4. The first four months of screening showed low levels of PCE, TCE, and *cis*-1,2-DCE in comparable groundwater intervals as sampled in Table 5.3. However, beyond the December 2003 sampling event, these concentrations have all but dissipated in most intervals. Presumably since the natural groundwater flow through the borehole has been re-established. These results indicate that some cross-hole contamination occurred during the short time it took to install the well (one day), but has been restored to its natural condition over time.

Since that time, only trace detections of *cis*-1,2-DCE (less than 0.34 µg/L) have been reported in interval CS-WB04-CC01 (441.5-471.5'). The results from the multi-port well indicate that the level of contamination in the base of RFR-10 is not present within the same stratigraphic intervals of CS-WB-04. In this case, it appears that inter-aquifer mixing of contaminants at the ranch supply well is limited to the immediate vicinity (less than 100 ft) of the open borehole.

### 5.3 VERTICAL DISTRIBUTION OF CONTAMINANTS WITHIN THE AQUIFER

#### 5.3.1 Discrete Interval Groundwater Sampling

A total 92 discrete interval groundwater (DIGW) samples were collected at 18 well locations between April 2001 and July 2003 as documented in the CSSA Environmental Encyclopedia (**Volume 5, RL83 and TO42 Well Installation Reports**). Using borehole packers, the discrete samples were used to vertically profile the contaminant characteristics of perched water intervals, the LGR Limestone, and the CC Limestone. All samples were analyzed for target VOCs which included MEK, *cis*-1,2-DCE, *trans*-1,2-DCE, PCE, TCE, and toluene. In addition, acetone, isopropyl alcohol, and toluene, were identified early on in the drilling program as tentatively identified compounds (TIC), and were subsequently added to the target list. Isopropyl alcohol is the primary ingredient of the foaming agent occasionally used during the drilling, and acetone is a by-product of the isopropyl alcohol degradation.

The discrete interval packer test data strongly indicate that much of the residual contamination occurs in the upper 300 feet of the LGR Limestone. It was demonstrated consistently across the southwest portion of the facility that contaminant levels generally decreased to less than 1 µg/L below 300 feet bgs once the main production zone of the aquifer was penetrated (Figures 5.4 and 5.5). To better characterize the hydrologic profile in the vicinity of a known source area, discrete interval groundwater samples were obtained from wells near AOC-65 (Building 90 and vicinity). These included wells CS-MW7-LGR, CS-MW7-CC, CS-MW8-LGR, and CS-MW8-CC. Results indicate that increased concentrations of PCE, TCE, *cis*-1,2-DCE, and toluene were present in upper portions and/or perched waters of the LGR Limestone. Concentrations up to 57 µg/L of PCE, 20.5 µg/L TCE, 0.57 µg/L of *cis*-1,2-DCE, and 14.2 µg/L of toluene were encountered at three or more intervals at the CS-MW8 cluster location. Lesser concentrations of the same compounds were also encountered at CS-MW10 and CS-MW7 locations. A single detection of MEK (15 µg/L) and two detections of acetone (50 µg/L) were also reported at the CS-MW8 location. Similar results were reported for the CS-WB wells that were installed at the same locality.

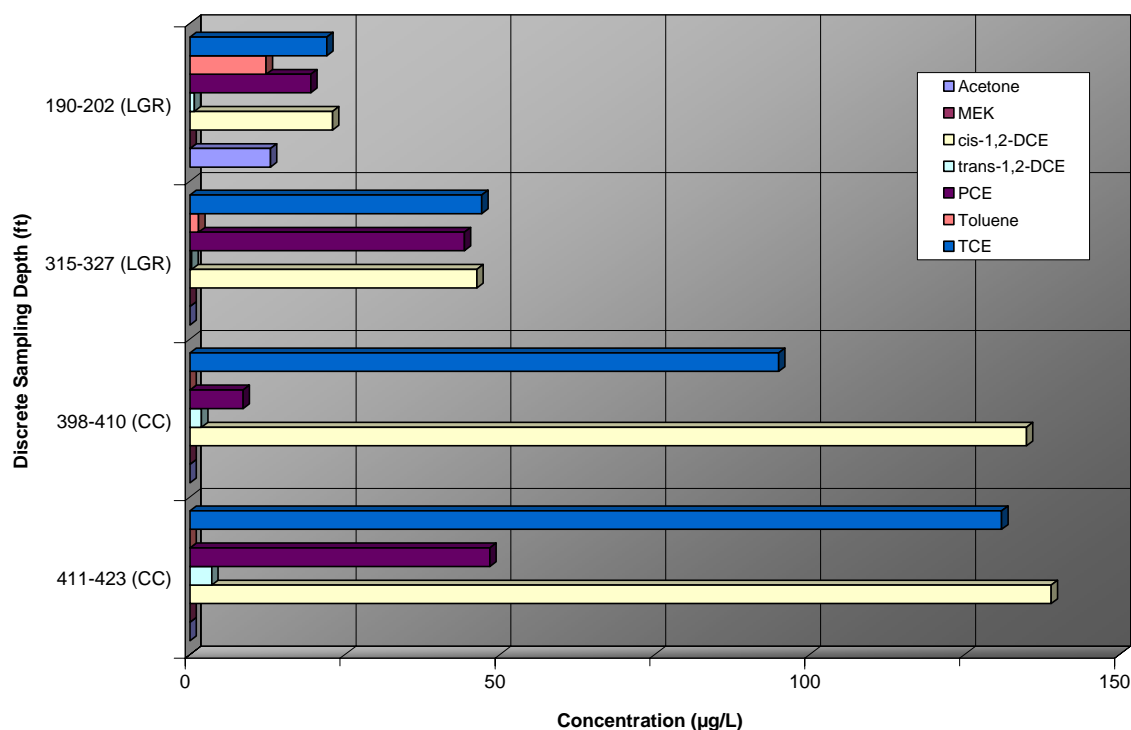
These results indicate that contaminants may be attenuated naturally by dilution and dispersion in the basal 60 feet of the LGR production zone. It is hypothesized that, regionally, within the LGR, the basal portion of the limestone yields most of the groundwater available from the formation. Depending on recharge conditions, upper water bearing zones in VOC source areas may also contribute significant well discharge at greater contaminant concentrations. Hence, well construction factors (e.g., casing depth) may play a critical role in the overall contaminant concentration present in a well. As an example, Figure 5.6 shows that contaminants have been detected throughout the entire thickness of the Middle Trinity Aquifer near former well CS-16, and is located adjacent to the Plume 1 source area. Previously, well CS-16 was an open borehole completion for more than 50 years until 2002 when the BS and CC portions of the well were plugged to mitigate the downward migration of contaminants.

### 5.3.2 Multi-Port Wells

#### 5.3.2.1 Methodology

The first phases of drilling were successful in monitoring the major water-bearing units of the Middle Trinity Aquifer (i.e., the Lower Glen Rose and the Cow Creek). For the most part, the investigations indicated that contaminants were diluting and attenuating within the major portion of the aquifer to levels below the MCLs. However, the implementation of the DIGW sampling around the Plume 2 area indicated that significant residual contamination was harbored in the lower yielding portions of the upper strata of the Glen Rose Limestone. While CSSA had demonstrated that a well capable of yielding moderate quantities of uncontaminated groundwater could be completed within the plume limits, concern grew regarding the impact of the upper strata contamination within the open borehole supply wells of off-post consumers. Of the 40 off-post wells sampled, six wells showed contamination above the MCL for PCE and/or TCE.

**Figure 5.6 CS-MW16-CC Discrete Interval Groundwater Sampling**



Some near-surface work near the Plume 2 source area had indicated that concentrations of 3,400 µg/L were present to depths of 20 feet. In the same area, the DIGW sampling indicated elevated concentrations to 300 feet below grade within the low-yielding portions of the strata. Beyond that depth, contamination quickly attenuates within the high-porosity basal reef which constitutes the major portion of the Lower Glen Rose's ability to transmit groundwater. The next step of the investigation was to better-define the hydrologic regime and occurrence of contaminants within the upper strata of the Lower Glen Rose.

The major goals of the next phase of work were to characterize the contamination in the upper 300 feet of Lower Glen Rose strata near the Plume 2 source area and evaluate the presence of contaminants within an existing off-post well. To be economically feasible, the monitoring criteria incorporated the use of multi-level monitoring in lieu of the traditional monitoring wells used previously at CSSA.

The final work plan was to drill three source area multi-level wells to depths of 300 feet, just above the main water-bearing unit. The existing wells showed that the main water-bearing unit is not impacted by contaminants. This well design also eliminates the risk of potential cross-contamination into the major portion of the aquifer. A fourth well was drilled at an off-post location to twin an existing domestic well. This multi-port well was designed to penetrate the full thickness of the Middle Trinity Aquifer to gain insight into the nature of the unit. Cross-contamination was not considered a threat since the existing domestic open-hole well has allowed for the co-mingling of groundwater for decades.

CSSA selected the Westbay™ MP38 system as the most appropriate for the site conditions with regard to depth, fluctuating water tables, and because it's modular design was not limited to a set number of monitoring ports. Prior to the mobilization of the Westbay team, all collected data from the drilling and testing phase was evaluated and integrated into a stratigraphic model. As shown in the Figure 5.7, the approach consisted of 17 unique monitoring zones with the Middle Trinity aquifer. The monitoring model included the basal unit of the Upper Glen Rose, 11 divisions of the Lower Glen Rose, 2 divisions of the Bexar Shale, and 3 divisions of the Cow Creek.

Hydraulic pressure data and groundwater sampling was conducted using the Westbay MOSDAX sampling probe. This instrument is a retrievable, wireline device that is lowered into and out of the well via a tripod and winch mechanism. Both absolute hydraulic pressure and temperature were obtained at each sampling port, in addition to retrieving as much as 1 liter of groundwater sample.

### 5.3.2.2 Results

Appendix D summarizes all analytical results for Westbay® samples collected between September 2003 and September 2004. Graphs of short list VOC concentrations from sampled monitoring zones in the Westbay® wells are presented in Figures 5.8 through Figure 5.11. The depths indicated for each monitoring zone represent the sampling interval open to the formation. Appendix E presents selected maps which depict the vertical distribution of the plume for the most pervasive contaminant, PCE.

Detections of PCE, TCE, and *cis*-1,2-DCE have occurred in all four Westbay® wells since the inception of the monitoring program. A prominent feature of the multi-port data is the apparent decrease in concentration since the inception of monitoring in September 2003. This effect is most notable in Figure 5.10, where the bottom zone (CS-WB03-LGR09) had decreased in concentration by approximately 70 percent from 148 µg/L (September 2003) to 44 µg/L (January 2004). Similar trends were noted from the other multi-port devices as well.

For example, it is postulated that the initial concentrations measured in CS-WB03 were a result of the borehole development prior to the installation of the multi-port well. The reasoning stems from discrete interval groundwater samples collected after the borehole completion in July 2004. During that activity, groundwater screening samples yielded 767 µg/L (229 to 241 ft) and 380 µg/L (298 to 310 ft), respectively. The multi-port data does not indicate those concentrations at those intervals, therefore it is assumed that such groundwater concentrations are within the capture radius of the borehole under pumping stress. It is clear that the borehole development prior to well installation temporarily skewed the natural groundwater condition which required 4 months to be restored to an equilibrated state. Since the multi-port wells have re-established equilibrium within the aquifer, contaminant concentration trends decreased or remained stable in most Westbay zones through September 2004. In general, contaminant concentrations in the Westbay zones decrease with distance away from AOC-65.

CS-WB03 is located closest to the Building 90 source area, and consistently records the highest concentrations of contaminants. In general, since the beginning of 2004 the concentrations in CS-WB03 zones typically range between 20 µg/L and 40 µg/L of PCE, with significantly lesser amounts of TCE being reported (Figure 5.10). For the zones that are

normally saturated (LGR03 through LGR09), the contaminant concentrations are for the most part ubiquitous and consistent throughout the section (HCSM layers LGR[B-E]). As seen in quarterly groundwater monitoring, the contamination attenuates in layer LGR(F) to trace detections of PCE (less than 1.1 µg/L) and TCE (less than 0.42 µg/L) in nearby wells. These wells include CS-MW6-LGR (580 ft north), CS-MW7-LGR (725 ft west), and CS-MW8-LGR (430 ft south).

CS-WB02 was installed nearly 300 feet south of CS-WB01 and the Building 90 source area. Compared to CS-WB03 and CS-WB01, relatively equal levels of PCE and TCE are present throughout the CS-WB02 vertical profile. Zones CS-WB02-LGR03 through -LGR09 are normally saturated throughout the year. Intervals CS-WB02-UGR01 is almost always devoid of groundwater except after the heaviest of rains. While groundwater can normally be expected in CS-WB02-LGR01, the same is not always true for the underlying zone, CS-WB02-LGR02. Like the other WB wells, CS-WB02 experienced a decline in concentrations since the inception of monitoring. Presumably for the reasons previously given regarding the re-establishment of natural groundwater flow following well development. PCE and TCE concentrations range between 15 µg/L to less than 5 µg/L in any given CS-WB02 monitoring interval. As seen in Figure 5.9, intervals CS-WB02-LGR04, -LGR05, and -LGR06 (HCSM layers LGR[C] and LGR[D]) consistently indicate lower PCE and TCE concentrations than the zones above and below. Interval CS-WB02-LGR09 (HCSM Layer LGR[E]) consistently exhibits the highest concentrations in the borehole for PCE and TCE, typically ranging between 4 µg/L and 11 µg/L.

Multi-port well CS-WB01 is located approximately 500 ft south of CS-WB03 and the Building 90 source area. Once again, for the zones that are normally saturated (LGR01 through LGR09) at CS-WB01, PCE and TCE are present at concentrations of less than 20 µg/L. At this location, the trend has been that TCE concentrations generally exceed PCE for most zones. The zone with the relatively highest concentration is LGR09 (HCSM layer LGR[E]). Lesser concentrations appear to occur within HCSM layer LGR(C) with zones CS-WB04-LGR04, -LGR05, and -LGR06. Of interest is the fact that both the LGR01 and LGR02 zone yield water at this location, whereas these zones are dry at CS-WB03. While it is uncertain, it is postulated that the operation of the AOC-65 SVE system has played a role in drying out those zones with similar completion depths near the source area and CS-WB03. This location is less than 100 ft from the CS-MW8 well cluster. While the CS-MW8-LGR well screen is only separated from the CS-WB01-LGR09 monitoring interval by 32 ft, the dilution of chlorinated organic contamination has diluted nearly twenty-fold within the basal reef structure that is HCSM layer LGR(F).

In similar fashion to the other locations, the UGR01 and LGR02 zones at CS-WB04 tend to be devoid of water. CS-WB04 sampling results through September 2004 have indicated that the upper zones (LGR01 through LGR04) in HCSM layers LGR(A), LGR(B), and LGR(C) are essentially without contamination. Between intervals LGR06 and LGR08, detections of PCE, TCE, and *cis*-1,2,-DCE components are reported at generally in the range of 1 µg/L. At CS-WB04, the zone with the greatest contamination (CS-WB04-LGR09) occurs at the base of HCSM layer LGR(E). Nearly equivalent levels of PCE and TCE are found at concentrations that generally range above the MCL between 6 µg/L and 11 µg/L. Below this depth, any solvent contamination in the remainder of the LGR, BS, and CC are at concentrations less than 1 µg/L. In fact, since January 2004, trace concentrations of solvents (*cis*-1,2-DCE) has only been detected in the CS-WB04-CC01 interval (HCSM layer CC[A]). More recent sampling events



(July and September 2004) have shown no detectable contamination below CS-WB04-LGR10 within the Middle Trinity aquifer. As stated previously, it appears that inter-aquifer mixing of contaminants at the RFR-10 ranch supply well is limited to the immediate vicinity of the open borehole as evidenced by the apparent lack of contamination detected in the BS and CC intervals of CS-WB04.

Between the September 2003 and September 2004 monitoring periods, the UGR(E) portion of the Westbay monitoring zones remained without groundwater except for on instance in July 2004 at CS-WB02-UGR01. At that time, 3.45 µg/L PCE and 2.12 µg/L TCE were detected in this portion of the stratigraphy. Nearly 9 inches of rain fell at the facility over an 11-day period in November 2004 which was temporarily sufficient to saturate the uppermost UGR01 intervals in all the multi-port wells. For the period that the UGR was water-bearing, samples were collected from the uppermost interval to assess what had not been previously possible.

The results of those sampling events are presented in Table 5.5. As shown in the table, the VOC concentrations at CS-WB01 and -WB-2 are generally consistent the results of lower zones within the aquifer, with results generally less than 10 µg/L for any given constituent. As indicated in the table, at those locations the UGR01 interval would drain between significant rain events such that intermediate samples could not be obtained. One sample was obtained from CS-WB04 at a PCE concentration of 9.51 µg/L. This is significant in the fact that routine samples from underlying intervals LGR01, -02, -03, and -04 have never resulted in any COC detections. The data indicates that the UGR01 interval has served as a perched conduit during periods of intense precipitation. For those open borehole wells with minimal surface casing, this contaminated perched groundwater is not impeded from entering the water supply that otherwise potentially yield uncontaminated LGR and CC groundwater.

Near the source area at CS-WB03, the UGR01 interval remained saturated for over a month, and samples obtained revealed concentrations up to 13,900 µg/L and 321 µg/L of PCE and TCE, respectively. The most recent results eclipse the concentrations previously detected in AOC65-MW2A by more than two-fold. The results indicate that a persistent source still exists, and that period flushing by intense rainfall can mobilize these perched contaminants that are probably otherwise bound to the matrix during the rest of the year.

**Table 5.5 Results of Multi-Port Interval Saturation  
November-December 2004**

	11/18/04	11/24/04	11/30/04 through 12/2/04	12/29/04
<b>CS-WB01-UGR01</b>				
<i>PCE</i>	6.58	<i>Dry</i>	1.5 J	<i>Dry</i>
<i>TCE</i>	<0.60	<i>Dry</i>	1.4 J	<i>Dry</i>
<i>cis-1,2-DCE</i>	<0.20	<i>Dry</i>	<0.20	<i>Dry</i>

**Table 5.5**  
**Results of Multi-Port Interval Saturation**  
**November-December 2004 (continued)**

	11/18/04	11/24/04	11/30/04 through 12/2/04	12/29/04
<b>CS-WB02 UGR01</b>				
<i>PCE</i>	7.02	<i>Dry</i>	9.25	<i>Dry</i>
<i>TCE</i>	2.26	<i>Dry</i>	1.4 J	<i>Dry</i>
<i>cis-1,2-DCE</i>	<0.20	<i>Dry</i>	<0.20	<i>Dry</i>
<b>CS-WB03 UGR01</b>				
<i>PCE</i>	13,900	9,170	9,640	13,400
<i>TCE</i>	215	294	227	321
<i>cis-1,2-DCE</i>	5.32	7.49	7.35	7.78
<b>CS-WB04 UGR01</b>				
<i>PCE</i>	9.51	<i>Dry</i>	<i>Dry</i>	<i>Dry</i>
<i>TCE</i>	<0.60	<i>Dry</i>	<i>Dry</i>	<i>Dry</i>
<i>cis-1,2-DCE</i>	<0.20	<i>Dry</i>	<i>Dry</i>	<i>Dry</i>
<b>J-</b>	<i>Result is between the MDL and RL</i>			
<b>NS-</b>	<i>Not Sampled</i>			

## 5.4 CONTAMINANT FATE AND TRANSPORT CONCEPTS

The fate of a contaminant in the environment is the length of time it is present in an unsafe form. The environmental fate considers whether a contaminant is persistent in environmental media, and into which media a contaminant will partition. Specific properties of the media and the contaminants determine which mechanism will have the dominant effect on the length of time a contaminant remains in the environment. Factors that affect the fate of a contaminant in the environment include mass transport and chemical degradation. These concepts are discussed in the following sections.

### 5.4.1 Mass Transport

Mass transport is the movement of hazardous constituents within a medium, or from one medium to another. Media that act as migration pathways include soil/rock in the unsaturated zone, groundwater, surface water, or air. Soil and rock properties such as chemistry and organic content, air temperature and pressure, and soil and water quality affect migration of contaminants. The characteristics of the contaminants also affect the potential for contaminant migration.

Primary transport mechanisms that may occur in the CSSA study area are volatilization, dispersion, dissolution, advection, and adsorption. Adsorption refers to the binding of metals or organic compounds to the soil or sediment. Some compounds adsorb more strongly to the clay fraction of a soil or sediment, while many organic compounds and some metals adsorb more

strongly to the organic fraction. In these cases, the higher the organic content in the soil, the less mobile these constituents will be. Sorption is defined as the accumulation of a chemical in the boundary region of the soil-water system. Factors affecting sorption include the physical makeup of the geologic media through which the contaminants are moving. The clay content, the specific surface area, and the cation exchange capacity of the media all affect the sorption of a contaminant.

Advection, sorption, dispersion, and diffusion are all processes that are more descriptive of contaminant migration in groundwater than soils. As mass transport process, advection contributes to the physical spreading of contaminated groundwater by carrying it with the inherent groundwater flow. The groundwater flow velocity depends on physical characteristics of the medium such as hydraulic conductivity, gradient, and effective porosity. Contaminants undergoing adsorption during advection will move at a rate less than the groundwater velocity. The retardation factor,  $R$ , describes the proportion of a contaminant undergoing adsorption during advection. For example, if the retardation factor is 2, the pollutant will move half as fast as the water.

Dispersion is also a mass transport process. Mechanically, dispersion is the spreading out of a contaminant plume caused by differences in water velocities in larger or smaller pores of the soil or rock. Typically, the effects of advection are much greater than the effects of dispersion in most cases. However, if groundwater velocity is very low, dispersion may be the dominant transport mechanism. Finally, diffusion is the molecular movement from areas of high concentration to areas of low concentration within a single medium. Diffusion is the dominant mechanism only when velocity and retardation factors are negligible.

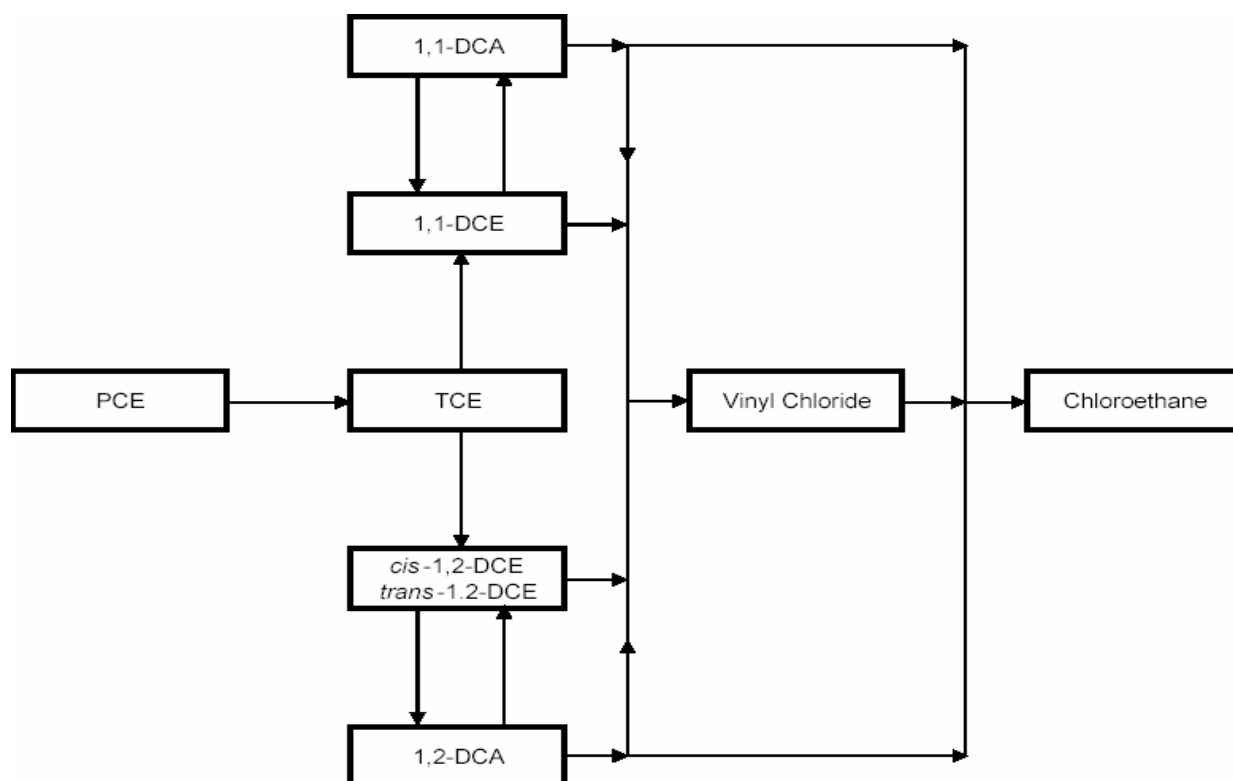
#### 5.4.2 Contaminant Degradation

Degradation is likely to be the primary mechanism affecting the fate of contaminants in the HCSM. Properties of organic compounds that are used to assess degradation include the degradation rate, the solubility, and the toxicity of the compound to bacteria in soil. The fate of metals is controlled by other properties. Metals may be converted into more innocuous forms by complexation and precipitation. Complexation is the mechanism by which metal ions are bound by larger molecules present in the aqueous fraction of the system. Precipitation is the formation of an insoluble metal compound.

PCE was the primary solvent used at CSSA, with some records indicating that TCE may have also been used for a period. Typically, TCE and *cis*-1,2-DCE are natural degradation products of PCE. These compounds result from dehalogenation (dechlorination) processes that occur in aerobic or anaerobic metabolic environments. The degradation of PCE can lead to the production of seven chlorinated volatile hydrocarbons. The transformation pathway for various chlorinated volatile hydrocarbons in environment is shown in Figure 5.12.

Current research has shown that there are several mechanisms, which result in the dehalogenation (e.g., dechlorination) of some classes of organic contaminants. These include stimulation of metabolic sequences through introduction of electron donor and acceptor combinations; addition of nutrients to meet the needs of dehalogenating micro-organisms, possible use of engineered micro-organisms, and use of enzyme systems capable of catalyzing reductive dehalogenation (EPA, 1991).

**Figure 5.12 Transformation Pathways for PCE within Environmental Systems  
(modified from EPA, 1991)**



An organic chemical is said to be reduced if it undergoes a net gain of electrons as the result of a chemical reaction (electron acceptor). Conversely, an organic compound is said to be oxidized if it undergoes a net loss of electrons (electron donor). Under aerobic environmental conditions, oxygen commonly acts as the electron acceptor when present. However, when oxygen is not present or has been depleted, microorganisms can use organic chemicals or inorganic anions as alternate electron acceptors under metabolic conditions referred to as fermentative, denitrifying, sulfate-reducing, or methanogenic. Generally, organic compounds present at a contaminated site represent potential electron donors to support microbial metabolism. However, halogenated compounds can act as electron acceptors, and thus become reduced in the reductive dehalogenation process, which is the replacement of a halogen on an organic molecule by a hydrogen atom (EPA, 1991).

The process listed in Figure 5.12 shows PCE converting to TCE via reductive dehalogenation. Likewise, TCE is reductively dehalogenated to either 1,1-DCE, *cis*-1,2-DCE, or *trans*-1,2-DCE with hydrogen (H<sub>2</sub>) and hydrochloric acid (HCl) by-products. In general, reductive dehalogenation of tetra- and tri-halogenated carbon atoms (PCE and TCE, respectively) is easier than di- or monohalogenated molecules, which is why many metabolic reactions appear to stall at the generation of DCE isomers. In the presence of favorable conditions, the DCE isomers can reductively dehalogenate to vinyl chloride, which is then easily converted to chloroethane via aerobic processes. The interaction of DCE and dichloroethane (DCA) isomers conveyed in the figure represent the mechanism by which a molecule may either gain or lose a double carbon bond. Depending on the conditions, the DCA isomers can

reluctantly be reduced to vinyl chloride via dehydrohalogenation or chloroethane by reductive dehalogenation (EPA, 1991).

The environmental conditions in the subsurface at CSSA have favored the reductive dehalogenation processes that convert PCE to TCE, then DCE. The generation of *trans*-1,2-DCE is less common, and is specifically limited to wells within the Plume 1 vicinity (CS-16-LGR, CS-D, CS-MW1-LGR, and CS-MW2-LGR). Trace concentrations slightly greater than the laboratory method detection limits (MDL) of vinyl chloride have been reported in as many as nine wells. Many of these occurrences were single detections at a well location, but do indicate that a minor amount of DCE is being reduced to vinyl chloride by dehalogenation. However, for the most part, the degradation process at CSSA appears to stall after the generation of *cis*- and/or *trans*-1,2-DCE. Concentrations of PCE, TCE, and DCE exceed MCLs within the HCSM area.

## 5.5 CONTAMINANT FATE AND TRANSPORT AT CSSA

This section conceptualizes the fate and transport mechanisms that are active at CSSA, and have ultimately dictated the distribution of contaminants within the Middle Trinity aquifer. The contamination will be addressed by source area and plume to help tie together the observations and measurements that have been collected during the course of the investigations. Figures 5.13 thru 5.16 conceptualizes the horizontal and vertical extent of the PCE plume within the Middle Trinity aquifer based upon the maximum extent of contaminants observed in June 2004. As described in previous sections, the occurrence of VOCs seems primarily limited to the LGR section of the Middle Trinity aquifer, and is reflected as such in the graphics. The occurrence of significant CC contamination is associated with well CS-MW16-CC as a result of the long-term open borehole completion of former CS-16 next to the SWMU B-3 source area. The occurrence of PCE contamination above the MCL of 5 µg/L within Plume 1 is contained within the facility. Plume 2 has migrated off post which has resulted with offpost MCL exceedances at the southwest corner of CSSA.

### 5.5.1 Source Area

Since 1996, extensive investigations have been completed to identify and define the potential source areas responsible for the occurrence of Plume 1 in CSSA groundwater. A series of geophysical surveys, soil-gas surveys, soil characterizations, and source removal investigations has led to the conclusion that SWMUs B-3 and O-1 were responsible for the VOC contaminants detected in well CS-16 and elsewhere since 1991. The actual contaminant source included solvents that were either disposed into an oxidation pond (O-1) or used as an accelerant for refuse burning within landfill cells (B-3). Likewise, beginning in 1999, investigations were completed to identify and define the potential source areas responsible for the occurrence of Plume 2 in CSSA groundwater. The actual contaminant source included solvents that were used and stored in vats within the building, or associated with discharges from a drain line to the nearby drainage ditch.

Regardless of the site, once the solvents were introduced to the environment, it was subjected to volatilization, and sorption to organic fractions of the soil and/or rock, or it migrated deeper into the stratigraphic profile by gravity, flushing, or meteoric waters. For the portion of contamination that remained within the source area, that fraction proved to be susceptible to volatilization and degradation. Soil-gas surveys and near-surface sampling has demonstrated that significant quantities of solvents remain within the disposal units, and that the degradation process of PCE is occurring, primarily due to large concentrations of DCE isomers now measured within the subsurface. For these portions of the solvent release, CSSA has implemented source removal via vapor extraction and waste removal by excavation and disposal at both plume source areas.

### 5.5.2 Vadose Zone

For the fraction of contaminants that mobilized beyond the source area, the solvents may migrate as a dense, non-aqueous phase liquid (DNAPL), and/or it may partition to the groundwater and soil-gas phases of the environment. Because DNAPLs have a specific gravity greater than water, they are able to penetrate through and below perched groundwater bodies and fractured strata that may otherwise be relatively impervious to groundwater. Within the vadose zone, a DNAPL will migrate downward, while succumbing to the mechanisms of dispersion and diffusion. Within fractured bedrock, these processes can be complicated by the erratic network or fractures and karstic features that act as preferred migration pathways. The chaotic nature of fracture and karst patterns are not well understood, but are expected to be the primary mechanism that allowed contaminants to seemingly migrate upgradient to CS-16 where it was detected in 1991. The long-term pumping of CS-16 as a supply well likely provided enough capture gradient to assist the northward migration of contaminants.

Along these pathways, DNAPLs can pool, where they may either enter the actual matrix of the rock, or be flushed by infiltrating water. The flushing effect is crucial for the solvent contamination to reach the main body of the aquifer. During precipitation events, infiltrating groundwater picks up and pushes the solvent advectively in the path of least resistance downward. In the instance of B-3, the disturbed nature of the overlying source area can exacerbate the recharge effect because of higher porosity backfill can accumulate and transmit greater quantities of groundwater downward than what may be expected within the natural stratigraphic horizon. For this reason, CSSA placed an impermeable cap on O-1 prior to closure in an effort to reduce, if not eliminate those recharge pathways.

### 5.5.3 Phreatic Zone

Dispersion of the solvent occurs as it migrates downward through faults, fractures, and karstic voids. The depth that groundwater occurs can fluctuate drastically with seasonal rainfall. For this report, the main body of the LGR aquifer is considered to be the basal 60 ft of the unit. However, groundwater does occur as much as 200 ft above the main body of the aquifer. Water-bearing strata and structure perched above the basal aquifer tends to be low-yielding, and its presence directly correlates to the recent environmental conditions.

Discrete interval groundwater sampling around AOC-65 indicates that the higher concentrations of solvent contamination are often associated with the lower yielding units that are stratigraphically higher than the main aquifer body. While the contamination dilutes and attenuates in the basal unit around AOC-65, this is clearly not the case within Plume 1. Wells

CS-16-LGR, CS-MW1-LGR, CS-MW2-LGR, and CS-MW5-LGR have demonstrated that groundwater contamination in excess of the MCLs exists within the main body of the aquifer. This would indicate that the source of contamination was either large enough to allow DNAPL to penetrate deep to this depth, or sufficient time has elapsed to carry the bulk of contamination downward into the LGR.

#### 5.5.4 Plume 1 Groundwater

While the concentrations detected in groundwater do not strongly suggest that DNAPL is present within the aquifer (less than 10 percent of the solvent solubility), significant residual contamination must persist near the source area. Slugs of contaminated percolating recharge continue to diffuse into the main body of the aquifer, where it is advectively transported in down gradient vectors. Along the main gradient path, sampling results indicate that a dilution/attenuation factor of roughly 10 is occurring over the 2,300-foot distance between the plume center (CS-D at 180  $\mu\text{g/L}$ ) and southward (CS-MW1-LGR at 17  $\mu\text{g/L}$ ). With the exception of the interior of plume centered around CS-D, CS-MS16-LGR, CS-MW1-LGR, and CS-MW2-LGR nearly all detections are below MCLs.

Advectively transported groundwater plumes tend to be long and narrow, which does not describe the PCE plume shown in Appendix C. Dispersion of the contaminants is occurring within Plume 1 by multiple paths of advection, likely due to structural features within the rock. Flow through these structural features, such as karst or fractures, may be controlling factors during abnormally high and low precipitation cycles, and may account for the multiple directions of plume migration. Notable is the SW migration of Plume 1 from the source area. It is hypothesized that the continual long-term pumping of the CSSA well field (CS-9, CS-10, and CS-11) and residential wells in Jackson Woods subdivision have drawn a portion of the plume southwestward along the fractures associated with faulting. The collective pumping of the communities and residences west of Ralph Fair Road has likely further pulled the contaminant plume along preferential pathways.

The geometry of the plume is also probably a function of the types of well construction used in the area. Most of the CSSA monitoring wells are constructed to monitor relatively short segments of the aquifer. The design is appropriate in reducing the possibility of further cross-contamination between strata, but also limits the amount of detections that may be measured at a location. This point has been well demonstrated at CS-MW8 where significant contamination was encountered in the upper 300 ft of strata, yet the final 25 ft monitoring point within the main aquifer body is essentially free of contamination. Given that most off-post wells are open borehole completions with minimal surface casing, these wells are more susceptible to detections of contaminants that occur within upper strata of the Glen Rose.

The presence of open borehole completions is also suspected to result in the minimal contamination of the underlying BS and CC. Within an open borehole, the predominant downward vertical component of flow allows for the co-mingling and loss of LGR groundwater into the CC Limestone. Conceptually, this draining effect through fully penetrating small diameter boreholes is minimal given the large area of the HCSM.

The natural attenuation of the PCE and TCE solvents appears to be occurring within the aquifer. The presence of *cis*-1,2-DCE within the Middle Trinity aquifer is attributable to the reductive dehalogenation of PCE and TCE. Those fractions of the plumes appear to coincide

with the location of Salado Creek. As a recharge feature with potentially increased porosity, Salado Creek may facilitate the favorable conditions required for the metabolic reduction of the solvents. To date, only very few instances of vinyl chloride have been detected in groundwater samples, indicating that the natural attenuation of PCE is stalling at *cis*-1,2-DCE. This can occur within a plume as the available electron donors are consumed during the biodegradation process.

### 5.5.5 Plume 2 Groundwater

Plume 2 appears to quite smaller than Plume 1. Drilling at the AOC-65 source area has shown that significant impact to the upper strata of the LGR has occurred. The results of discrete interval groundwater sampling from those locations are shown in Figures 5.4, 5.5, 5.8, 5.9, 5.10, and 5.11 clearly depict how contaminant concentrations attenuate with depth. The multi-port data seem to indicate that on post near AOC-65, the contamination for the most part equally distributed throughout layers LGR(A) through LGR(D). Recent multi-port evidence (Table 5.5) has demonstrated that significant residual contamination appears to be flushed from the UGR matrix during the heaviest of precipitation events. Likewise, the downgradient multi-port well (CS-WB04) seems to indicate that contaminants are preferentially transported in layers UGR(F) and LGR(D). The premise that contaminants are attenuated within the main body of the aquifer (LGR[F] and CC[A]) is supported by the results of CS-WB04.

A series of investigations which included seismic, direct current resistivity, AEMs, and ground truthing by drilling has indicated that a series of stepwise normal faults occur within the Plume 2 vicinity. Given the location of the source area at Building 90, the contaminant plume has spread in all directions southward. Within the LGR unit, the center of the plume has appeared to have moved westward towards RFR-10. Normally, the drift of plume center indicates that the source area has diminished and the plume is migrating by advection. However, the attributes of Plume 2 are potentially skewed by the co-mapping of cased and un-cased wells. Conceptually, the greatest concentration of plume still resides within CSSA (near AOC-65-MW2A and CS-WB03), and the bulk of the plume resides in upper unscreened strata of the LGR. This position will be substantiated with the addition of multiport well data in future HCSM updates.

Several faults inferred by the USGS (Figure 5.1) are located in the same area as Plume 2, and the distribution of contaminants is suspected to be related these fault locations. Wells with more elevated concentrations (RFR-10, RFR-11, LS-6, and LS-7) are positioned very close to the known faults. The orientation of the faults line up favorably between the Building 90 source area and wells with known contamination above the MCLs. The measured concentrations of contaminants within Leon Springs Villa and Hidden Springs probably resulted from the advective forces associated with the overall regional gradient towards the south. Contaminated groundwater, which has migrated southward across fault planes, is notably lower in overall concentrations, and are diluting as they are dispersed.

As with Plume 1, the shape of the plume is also probably a function of the types of well construction used in the area. Most of the CSSA monitoring wells are constructed in such a fashion to observe relatively short segments of the aquifer. The design is appropriate in reducing the possibility of further cross-contamination between strata, but also limits the amount of detections that may be measured at a location. Given that most off-post wells are open borehole



completions with minimal surface casing, these wells are more susceptible to detections of contaminants that occur within upper strata of the Glen Rose.

The presence of open borehole completions is also suspected to result in the minimal contamination of the underlying BS and CC in the vicinity of Plume 2. Within an open borehole, the predominant downward vertical component of flow allows for the co-mingling and loss of LGR groundwater into the CC limestone. Conceptually, this draining effect is minimal given the large area of the HCSM. The results from RFR-10 (Table 5.3) lend credence to this hypothesis. Those results also indicate that the upper strata of a minimally-cased well is the most contaminated, and co-mingling of these waters within the well bore result in groundwater exceeding MCLs. CSSA has demonstrated that wells with adequate casing are far less susceptible to producing contaminated water that resides in the upper strata of the LGR.

Natural attenuation processes presumably are in effect given the presence of TCE 5.3 and *cis*-1,2-DCE within Plume 2. Data indicates that dehalogenation is occurring within the interior of the plume where favorable anaerobic conditions are present. As with Plume 1, there seems to be insufficient electron donors to continue the degradation beyond *cis*-1,2-DCE. As would be expected, the relative contaminant concentrations in groundwater are inversely proportional to distance from the source area. Table 5.6 lists the average concentration of PCE and TCE within the multi-port monitoring zones at Plume 2. The data reflects the dates between January and September 2004, and represent data collected after the timeframe at which natural groundwater conditions had been restored following installation activities. As seen in Table 5.6, relative contaminant concentration decreases away from the source area (near CS-WB03) towards the south (CS-WB01) and southwest (CS-WB04). The table also indicates that the degradation of PCE to TCE is occurring as the plume migrates downgradient. In monitoring zones where both PCE and TCE are present, the average ratio of PCE to TCE decreases from 6.55 at the source area (CS-WB03) to 0.87 at the furthest downgradient position (CS-WB04). These relationships indicate that within 500 feet, the contaminant plume has degraded such that TCE has become the major constituent within select intervals.