SECTION 6
SUMMARY AND CONCLUSIONS

6.1 SUMMARY AND CONCLUSIONS

CSSA is located in northwestern Bexar County approximately 19 miles NW of downtown San Antonio. At one time located in a rural setting, sprawling development of the San Antonio metroplex has encroached upon the facility, placing it adjacent to residential and commercial properties. The CSSA mission, receipt, storage and issuance of ordnance, materiels, as well as, quality assurance testing and maintenance of military weapons and ammunition, is associated with the maintenance of ordnance materiel, the use of industrial solvents as a degreasing agent was implemented from the 1950's through 1990. Citrus-based solvents have now replaced chlorinated solvents. As a result of past operations, releases of PCE to the environment have occurred from multiple source areas within CSSA.

The release of contamination to the environment occurred at several locations, including leaks, spills, and discharges from Building 90 (AOC-65) were degreasing operations occurred, and at landfill/surface impoundments (SWMUs B-3 and O-1) where solvents were discharged. SWMU O-1 was a lined oxidation pond that received waste fluids from the Building 90 operations. Nearby at B-3, spent solvents would be utilized as an accelerant for burning refuse within landfill cells.

The release of solvents to the environment has resulted in contamination of the Middle Trinity aquifer, which is the primary drinking water source for the area. The Middle Trinity aquifer is composed of calcareous mudstones and limestones of the LGR Limestone, BS, and CC Limestone. Locally, the BS serves as a confining unit between the water-bearing LGR and CC limestones. The site is located within the BFZ, which structurally influences and re-directs the groundwater flow paths.

The detection of solvent contamination (PCE and daughter products TCE and *cis*-1,2-DCE) was first reported by the TDH in 1991. Beginning in 1992, CSSA undertook a series of investigations to identify potential source areas for the groundwater contamination, which identified B-3 and O-1 as likely candidates. Starting in 1996, the first of 45 monitoring wells were installed. Well installation has continued through September 2003. Off-post contamination was first reported by CSSA in 1999 at private well LS-7. Since that time, solvent contamination has been detected in 26 off-post private and public water supplies. The U.S. Army has installed point-of-use treatment systems at eight off-post well locations where concentrations exceed 80 percent of the federal MCL (5 μg/L) for PCE and TCE.

For the HCSM, horizontal and vertical boundaries were established to define the model area. Horizontal boundaries were based upon the watersheds units that bound the contamination area between Cibolo, Leon, and Salado Creeks. The vertical limits of the model include the lower portion of the UGR Limestone (Upper Trinity aquifer) and all of the Middle Trinity aquifer, which is bounded below by the Hammett Shale. The strata of the model area were divided into five layers based upon lithologic formation, and then further divided into 13 subunits based upon hydraulic and stratigraphic character. Of the subunits, two intervals stand out as groundwater producers: the basal 60 ft of the LGR (LGR[F]) and the upper 30 ft of the CC (CC[A]). While other portions of the stratigraphic profile contain groundwater, their yield is low, except locally where structural or karstic features prevail.

Most water production wells are completed as open boreholes to maximize groundwater yield, and they include varying lengths of surface casing to facilitate borehole stability or isolate less desirable groundwater strata. Observation wells at CSSA consist of cased and screened wells that discretely monitor 25-foot segments of the LGR, BS, or CC Limestone. Often, these wells are arranged in clusters at a single location. By monitoring the individual members of the aquifer, an assessment regarding the occurrence and distribution of contaminants within the Middle Trinity aquifer can be ascertained.

Information regarding the subsurface was compiled from borehole data, geophysics, and surface mapping to create a conceptual stratigraphic model. Data indicates that the LGR is typically an average thickness of 320 ft, and is overlain by a thin layer UGR normally 50 ft in thickness, but the thickness depends on the local topography. However, the UGR comprises nearly 90 percent of the surface outcrop, while exposures of the LGR only typically occur in the lowlands and creek beds. The underlying BS is normally 60 ft in thickness, and, the facies does not outcrop anywhere in the Hill Country. The underlying CC unit is typically 75 ft in thickness, and is known only to outcrop along the Guadalupe River to the NE. Drilling operations typically only penetrated the upper 15 ft of the Hammett Shale for logging purposes only, and was not further addressed in this study.

Extensive drilling indicated that the bulk of the main groundwater body occurred within the basal portion of the LGR and the upper portion of the CC. The occurrence of groundwater within these units was implicitly related to the massive moldic porosity and karstic features associated with reef-building events and fossiliferous biostromes capable of storing large quantities of water. Occasionally, large volumes of groundwater could also be produced from well-developed reefs above the basal unit, or from significant perched fracture or karstic features. Otherwise, groundwater yields in the UGR and the top 250 ft of the LGR are minimal. Likewise, groundwater production from the BS is minimal at best. According to the injection packer testing, the CC was found to have the potential of transmitting the greatest amount of groundwater, but its natural water quality is less desirable than that of the LGR.

Additional testing of aquifer properties employed the use of Hydrophysical logging. A good relative measure of hydrophysical properties was conducted at CS-WB04 where the well extends through the entire thickness of the Middle Trinity aquifer. The HpL interpretation estimates that 100 percent of the measured groundwater flow originates from only a total of 23 feet of permeable strata or fractures within the Lower Glen Rose and Cow Creek. According to the testing, only five zones of groundwater flow were interpreted between HCSM layers LGR(D and E). Conversely, significant increases in groundwater flow were measured in the reefal portion of layer LGR(F), where the average hydraulic conductivity was nearly 3.5 times greater than the average conductivity of LGR(D and E). The amount of total estimated flow from the LGR during the HpL testing resulted with 85 percent of the groundwater production originated from LGR(F). When considering the entire thickness of the Middle Trinity aquifer, the Lower Glen Rose accounted for 92 percent of the entire production at CS-WB-04 and the Cow Creek accounted for the remaining 8 percent. No measurable flow was reported from the Bexar Shale interval. The HpL logging provides a characterization of ambient flow occurring during July

2003. At that time, water levels overall were decreasing in elevation at CSSA. The hydraulic conditions observed will be consistent with flow behavior during a period of declining water levels.

Based upon measurements at observation wells, the regional groundwater flow is generally to the south-SE. The LGR typically has a southward gradient that is deviated around mounding which occurs at CS-MW4-LGR and CS-G. The BS has exhibited the potential for either northward or southward flow, depending upon the season. Likewise, the CC has exhibited erratic flow paths with seasonally radial flow from mounded areas, to a northeastward flow possibly related to off-post pumping along Ralph Fair Road.

Long-term monitoring shows that groundwater response to precipitation events can be swift and dramatic. Depending on the severity of a precipitation event, the groundwater response will occur within several days, or even hours. Average precipitation events do not invoke much response from shallow PZs within the LGR, yet main aquifer body wells will respond within a week. Such observations seem to indicate that the preponderance of recharge observed occurs elsewhere upon the outcrop, and not necessarily within CSSA.

Using continuous datalogging devices within a multi-port well, a significant increase in the resolution of recharge mechanics were observed. As measured in the LGR multi-port well, aquifer response to significant recharge typically occurs as an increased pressure gradient that emanates from the lower zones upwards. The mechanism by which the aquifer appears to be bottom filling is either that the recharge to the lower zones occurs elsewhere on a regional scale (perhaps at outcrop areas), or that well-developed structural conduits convey the recharge downward quickly to the bottom of the LGR. Recharge to the upper LGR strata occurs more slowly, and appears to be less of a function of direct infiltration at the site in comparison to effects of vertical and lateral leakage. The data recorders indicated that under intense precipitation events that an inter-aquifer gradient reversal occurs, providing the mechanism by which lower strata seemingly can recharge the upper strata through a network of fractures inherent to the bedrock. Once the recharge event has subsided, the aquifer resumes to its natural state of typically downward inter-aquifer gradient.

For the entire Middle Trinity aquifer, data obtained from the on-post well clusters indicate that for most of the year, a downward vertical gradient exists within the Middle Trinity aquifer. Differences in drainage rates often leave the potential head of the BS well above the potential head of the LGR and CC. The large differences in potential head suggest that the BS locally acts a confining barrier between the LGR and CC.

The average precipitation at CSSA is typically above 32 inches per year. The 30-year record (1971-2000) results in a mean annual rainfall average of 37.36 inches in Boerne, Texas. The CSSA weather station reported a 35.39 annual average between 1999 and 2002. As little as 17 inches and as much as 52 inches of precipitation have been reported within a single year. In an attempt to estimate an annual water balance, approximately 67 percent of the annual precipitation is expected to be lost to evapotranspiration. Another 29 percent is assumed to be lost to surface runoff annually, while the remaining 4 percent recharges the Middle Trinity aquifer (based upon published literature values). Assuming these estimates are valid, CSSA can be expected to consume between 9 percent and 27 percent of its annual recharge. Likewise, within the model area between 31 percent and 95 percent of the estimated recharge volume can be consumed by the collective groundwater consumers. These values are likely biased low since groundwater is obviously removed from storage during periods of drought, meaning the discharge will exceed recharge. CSSA implements a drought management plan to better manage its groundwater resources during times of reduce precipitation.

At CSSA, the VOC COCs are PCE, TCE, and *cis*-1,2-DCE. These COCs exceed federal MCLs in relatively small areas. In terms of contamination, PCE and to a lesser extent TCE are the parent products while TCE and *cis*-1,2-DCE are by-products resulting from biodegradation processes. Thus far, only sporadic trace detections of vinyl chloride have been reported. The lack of widespread vinyl chloride detections indicate that the reductive chlorination processes have stalled with the production of *cis*-1,2-DCE, which is indicative to lack of potential electron donors within the system.

Contamination from the past disposal activities as resulted in multiple groundwater units, referred to as Plume 1 (B-3 and O-1) and Plume 2 (AOC-65). Contamination is most widespread within the LGR water-bearing unit. Environmental studies have demonstrated that most of the contamination resides within the LGR, therefore all open borehole completions are considered to represent that unit.

At Plume 1, areas in excess of the MCL occur around wells CS-D, CS-MW1-LGR, CS-MW2-LGR, and the CS-MW16 cluster. Concentrations in excess of 200 µg/L have been reported at CS-D, CS-16-LGR, and CS-MW16-CC near the source area. This plume has advectively migrated southward to CS-1 at Camp Bullis, and west-SW toward CSSA well field (CS-9, CS-10, and CS-11) and several to off-post public and private wells. Over most of the plume area, contaminant concentrations are below 1 µg/L. In contrast, little to no contamination within the BS and CC has been consistently identified within Plume 1.

Contamination at Plume 2 originated at or near Building 90, and has spread southward and westward from the post. The greatest concentrations of solvents are reported at the near subsurface adjacent to the source area (13,400 µg/L at CS-WB03-UGR01). Within the post, concentrations in excess of 100 µg/L have been reported in perched intervals above the main aquifer body. However, as evidenced by the multi-port wells, once the main aquifer body is penetrated, the concentrations are diluted to trace levels. Off-post, concentrations in excess of the MCLs has been detected in private and public wells with open borehole completions. Concentrations exceeding 25 µg/L have been reported 1,200 ft west-SW of CSSA at RFR-10. Vertical profiling within that well show that discrete intervals within uncased upper strata contribute PCE concentrations over 90 µg/L. Only sporadic, trace concentrations of solvents have been detected in BS and CC wells within Plume 2.

The style of well completion can affect the concentration detected at a location. At CSSA, monitoring wells have been purposely designed to case off contamination present within upper strata in an effort to reduce cross-contamination between water-bearing units. This style of well has typically resulted in a groundwater sample from the main portion of the aquifer that has little to no contamination present. In contrast, most off-post wells are designed to maximize yield from all portions of the aquifer, resulting in the co-mingling of stratified groundwater with varying degrees of contamination. Within an open wellbore, the net effect is that perched waters with high concentrations of solvents are contaminating relatively pristine groundwater held within the main body of the aquifer. This scenario, coupled with the tendency of downward vertical flow, has potentially created pockets of cross contamination into the basal unit of the LGR, BS, and CC members of the Middle Trinity aquifer.

Results from the AOC-65 study seem to indicate that the bulk of contamination is locked within the upper 300 ft of strata, and may have a tendency to move laterally rather than vertically. This is supported by the elevated concentrations detected in the upper portions of the RFR-10 borehole. The method by which the contamination is transmitted horizontally is unconfirmed, but is likely related to the extensive NE-SW faulting in the area, possibly secondary dissolutioning along these preferential planes, and pumping of off-post wells.

From the onset, contaminant levels were detected in nearly all CS-WB04 monitoring zones, including the BS and CC. The HCSM layers with the most prolific concentrations were LGR(D) an LGR(E), with significantly lesser amounts reported in LGR(F) and all BS and CC layers. At CS-WB04 within the BS and CC layers, these concentrations have all but dissipated in most intervals beyond the December 2003 sampling event (Figure 5.11). The first four months of monitoring indicated decreasing concentration trends in most zones, presumably since the natural groundwater flow through the borehole has been re-established. These results indicate that some crosshole contamination occurred during the short time it took to install the multi-port well (8 hours), but has been restored to its natural condition over time.

6.2 RECOMMENDATIONS

The following are recommendations for satisfying data gaps within the HCSM and CSSA groundwater program in general. The next HCSM update will include additional data from Westbay multi-port wells which will provide insight to the nature and extent of contaminants around AOC-65, and off-post near RFR-10. Other significant data to be included are the USGS HEM survey and the AOC-65 recharge study.

6.2.1 Stratigraphy and Hydrology

To truly complete a postwide model, additional wells with borehole information should be considered. Stratigraphic and hydraulic uncertainties exist within the southern, eastern, and northwestern portions of the facility. A series of 2-inch wells that penetrate through the LGR Aquifer would assist in completing the stratigraphic model, provide additional groundwater elevation control points, and provide additional locations for aquifer screening. In addition, the apparent groundwater mounding seen at CS-MW4-LGR could be addressed and better defined. Boreholes should be logged using standard geophysical tools as well as a borehole imaging system (optical televiewer).

With regard to the hydrologic budget, the loss and/or gain by ephemeral streams are unknown. Gauging stations along points of both Salado Creek and headwaters of Leon and Cibolo Creeks should be considered. Additional pumping and usage data from local municipalities should be pursued to better estimate the amount of groundwater consumed annually.

6.2.2 Contaminant Distribution

Plume 1 may require additional delineation to the west of the source area. Over the past several years, the center of the plume has appeared to migrate westward towards well CS-D. To delineate the plume to the MDL, additional wells within the East Pasture and along Salado Creek should be considered. Off-post drilling locations to be considered would include westward within Jackson Woods and southward within Camp Bullis. Thus far, Plume 1 has also not been defined to the east towards Camp Bullis with contaminant-free monitoring wells.

Additional investigation within Plume 2 may include additional up gradient wells for potential remediation pilot studies (push-pull), and perhaps 300-foot wells to assess and/or recover contaminated groundwater near the source area. Additional delineation to levels below the MDL would require wells southward of Leon Springs Villa and Hidden Springs Estates.

6.2.3 Other Considerations

The inspection and sampling of off-post wells has demonstrated that the style of well completion can likely play a role in the quality of groundwater that can be produced from a well seemingly within the margins of the plume. A sufficient length of cemented surface casing through most of LGR is considered to be a proactive approach in minimizing the amount of contamination that would be available to enter an open borehole. Specifically, surface casing that isolates the UGR and layers LGR(A-E) would be a protective step in ensuring that groundwater is extracted from zones of lesser contamination, namely LGR(F) and CC(A). Future data collection for off-post wells should include water level data, where the construction of the off post well allows collection of that data. Where possible, flow meters to monitor water consumption by the off post well owner should also be considered to develop water supply well usage data and determine the affect (if any) on groundwater quality.

The Trinity-Glen Rose Groundwater Conservation District (TGRGCD) has been established for northern Bexar County, and has invoked requirements regarding casing installations and geophysical logging. The current District policies mandate that all newly-installed wells provide enough surface casing to prevent the commingling of UGR and LGR groundwater. CSSA has compiled enough compelling evidence that additional surface casing within the vicinity of the facility can be beneficial the groundwater end user with negligible impact to overall well yield. Consideration should be given to provide these findings to the TGRGCD such that they may amend their well construction requirements for those wells located proximal to CSSA.