SECTION 2
BACKGROUND

2.1 SITE SUMMARY

2.1.1 Site Description

The CSSA installation consists of 4,004 acres immediately east of Farm to Market Road (FM) 3351, and approximately half a mile east of Interstate Highway (IH) 10 (Figure 2.1). Camp Bullis borders CSSA on the north, east, and southeast (SE). The land on which CSSA is located was used for ranching and agriculture until the early 1900s. During 1906 and 1907, six tracts of land were purchased by the U.S. Government and designated the Leon Springs Military Reservation. The lands included campgrounds and cavalry shelters.

Land surrounding CSSA is primarily residential or used for ranching. The area between CSSA and the nearby community of Leon Springs is primarily residential, composed of Leon Springs Villa, Hidden Springs Estates, and The Dominion developments. Some ranching/agricultural land is intermingled within those developed communities.

The western side of Ralph Fair Road and to the north of CSSA, is primarily ranch land with some ranch-style dwellings. A few businesses that serve the city of Fair Oaks community are located in a strip center at the NW corner of CSSA. Fair Oaks development consists of approximately 2,000 houses and takes up most of the northwest (NW) quadrant of the CSSA vicinity. The development is located at the convergence of Bexar, Comal, and Kendall Counties and extends northward well beyond Cibolo Creek.

The vicinity immediately west of CSSA is composed of a mixture of residential and ranching acreage. Several large-acreage properties are to the west of CSSA and contain multiple ranch-style dwellings. The residential community of Jackson Woods is also adjacent to the west perimeter of CSSA, and consists of approximately 40 multi-acreage tracts. The southwest (SW) quadrant is primarily ranching property with the exception of the IH 10 and Ralph Fair Road intersection where commercial activities are found.

Further information regarding the site description of CSSA is provided in the CSSA Environmental Encyclopedia **(Volume 1-1, Background Information Report)**.

2.1.2 Historical Information

CSSA was a segment of the original Leon Springs Military Reservation and was transferred to the jurisdiction of the Chief of Ordnance as an ammunition depot for the San Antonio Arsenal in 1933. In June 1949, CSSA was transferred to the Red River Army Depot (RRAD). CSSA is now under McAlester Army Ammunition Plant, US Army Field Support Command, Army Materiel Command (CSSA, McAAP, US AFSC, AMC). Historically, its mission was training, evolving to ordnance storage, maintenance, and testing. CSSA currently consists of operations buildings, igloo storage magazines, U. S. Department of Agriculture (USDA) grazing acreage, and unused land.

General information regarding the history of CSSA is provided in the CSSA Environmental Encyclopedia **(Volume 1-1, Background Information Report).**

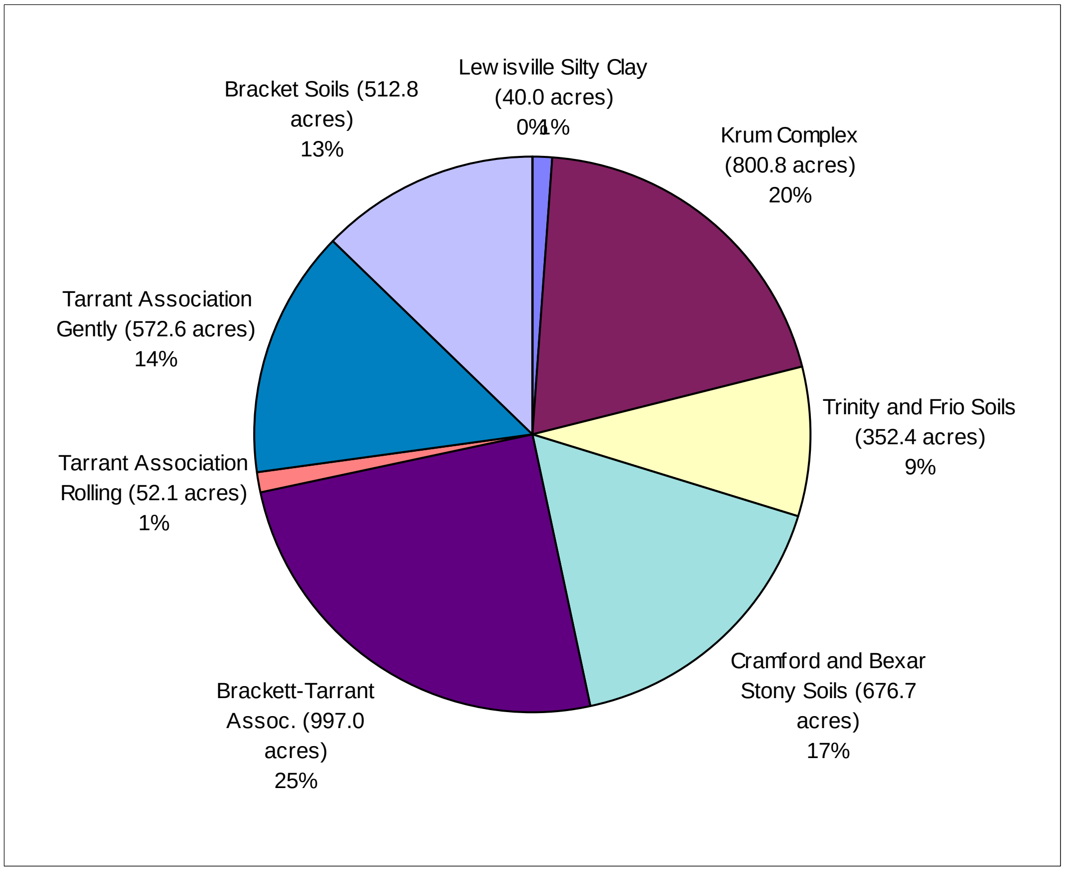
2.2 ENVIRONMENTAL SETTING

It is recommended that the **Soils and Geology** and **Groundwater Resources** sections of the CSSA Environmental Encyclopedia **(Volume 1-1, Background Information Report)** be reviewed for understanding of the local physiography, geology, stratigraphy, structure, and hydrology. Specific knowledge of the environmental conditions is beneficial to understanding the development of the local groundwater resources near CSSA. For completeness, pertinent sections are briefly summarized below for this report.

2.2.1 Soils

In general, soils at CSSA are thin, dark-colored, gravelly clays and loams. The soil types are strongly influenced by topography and the underlying limestone. All soil classifications used for this report are taken from the USDA Soil Conservation Service (now the Natural Resource Conservation Service (NRCS) soil survey series for Bexar County, Texas (USDA, 1991). A total of eight soil types occur at CSSA. Figure 2.2 shows the portion of CSSA each soil type covers.

Figure 2.2 CSSA Eight Soil Types by Area Percentage



Brackett Soils

Brackett (BrE) soils occur over 12.8 percent (512.8 acres) of the CSSA lands. These soils cover a large portion of the east pasture and the inner cantonment at CSSA. These loamy and clayey soils are thin (about 4 inches thick), grayish-brown, and strongly calcareous. Gravel and cobblestone lithics occur at the surface and shallow subsurface. The soils can develop over soft limestone and are underlain by hard limestone, which gives the slopes a stairstep appearance.

Tarrant Soils

At CSSA the Tarrant soils occur along the outer edges of the Salado Creek floodplain. The soils are thin and form over hard, fractured limestone. The surface layer is usually about 10 inches thick and is a dark grayish-brown, calcareous, clay loam with scattered gravel and cobblestones within and on the surface layer. Two types of Tarrant soils occur at CSSA: Gently undulating Tarrant soils (TaB) and rolling Tarrant association soils (TaC).

The TaB areas are typical of prairie and plateau topography. They occur primarily in areas not occupied by streams, such as the north-central area of the inner cantonment at CSSA. This soil type covers 14.3 percent (572.6 acres) of CSSA. The soils are dark colored, very shallow, calcareous, and clayey, and are best suited for native grasses and range use.

The TaC is found on the eastern sides of hills in areas not occupied by streambeds. This soil type occurs over only 1.3 percent (52.1 acres) of CSSA lands. The slopes tend to have a gradient of 5 to 15 percent. The soils are dark colored, very shallow, clayey, weakly calcareous, and typically more stony than TaB.

Brackett-Tarrant Association

Brackett-Tarrant association soils (BtE) cover 24.9 percent (997.0 acres) of CSSA. At CSSA, this soil type is found north of the inner cantonment in the north pasture. The slopes of ridges are Tarrant soils which are clayey, calcareous, and very dark grayish-brown. The BrE soils are light grayish-brown and calcareous. Tarrant soils make up 65 percent of the association and BrE make up 20 percent.

Crawford and Bexar Stony Soils

Crawford and Bexar stony soils (Cb) occupy portions of both the inner and outer cantonments, for a total of 16.9 percent (676.7 acres) of CSSA. They occur in broad, nearly level to gently undulating areas. The soils are stony, very dark gray to dark reddish-brown, noncalcareous clay, about 8 inches thick. Bexar soils range from a cherty clay loam to gravelly loam.

Trinity and Frio Soils

The Trinity and Frio soils (Tf) cover 8.8 percent (352.4 acres) of CSSA. The soils are frequently subjected to flooding, and are the main channel soils for Salado Creek and a large tributary that joins the creek in southwestern CSSA. Some areas are subject to thin sediment depositions, while other areas are scoured. Channels are poorly defined and are of small capacity. Trinity soils are 3 to 5 feet (ft) deep and are composed of clayey to gravelly loam. Frio soils are a dark grayish-brown clay loam, 3 to 4 ft deep.

Krum Complex Soils

The Krum Complex soils (Kr) make up the remaining soils covering the streambeds and floodplains, 20.0 percent (800.8 acres) of CSSA. The soils are dark grayish-brown or very dark grayish-brown, calcareous, and approximately 30 inches thick. The soils developed from slope alluvium of the limestone prairies. The Kr receives sediments and runoff from higher elevation soils and is highly prone to hydraulic erosion if unprotected.

Lewisville Silty Clay

A minor soil type found at CSSA is the Lewisville silty clay (LvB). This soil type covers only 1.0 percent (40.0 acres) of CSSA. It typically occupies long, narrow, sloping areas separating nearly level terraces from upland soils. Surface soils are dark grayish-brown about 20 inches thick. This is a highly productive soil but is also susceptible to hydraulic erosion if unprotected.

2.2.2 Physiography

CSSA is characterized by a rolling terrain of hills and valleys in which nearly flat-lying limestone formations have been eroded and dissected by streams draining to the east and SE. Normal faulting has occurred near the central area and the southern boundary of the installation. Regionally however, two major trends of fractures extend NW-SE and northeast (NE)-SW. Faulting in the limestone units has juxtaposed strata of different ages, but fault scarps and traces are almost absent because many of the various calcareous lithologies weather similarly. The faults are NE-SW trending, but most are not as continuous as the fractures. Soil cover is relatively thin, and bedrock is frequently exposed in most areas other than stream valleys.

River and stream dissection of limestone is the major surface feature at CSSA. Most major rivers and streams originating in the Edwards Plateau NW of CSSA tend to follow the NW-SE regional fracture patterns. Resistive limestone beds crop out as topographic highs, but none of these beds form buttes or mesas. Rather, the predominant physiography is hills and "saddles" which lead to stream valleys. Topographic relief across the area ranges from about 1,100 to 1,500 ft above sea level.

2.2.3 Geology

2.2.3.1 Stratigraphy

The oldest and deepest known rocks in the HCSM area are Paleozoic age (225 to 570 million years ago) schists of the Ouachita structural belt. They underlie the predominant carbonate lithology of the Edwards Plateau. The Cretaceous-age sediments were deposited as onlapping sequences on a submerged marine plain and, according to well logs and outcrop observations, these sediments thicken to the SE. Figure 2.3 summarizes the Cretaceous System stratigraphy, which represents the Trinity Group Travis Peak Formation shallow marine deposits. The Travis Peak Formation attains a maximum thickness of about 940 ft and is divided into five members, in ascending order: the Hosston Sand, the Sligo Limestone, the Hammett Shale, the CC Limestone, and the Hensell Sand (and BS facies). Overlying the Travis Peak Formation, but still a part of the Cretaceous-age Trinity Group, is the Glen Rose Limestone. For this HCSM, the units of interest are the Glen Rose Limestone, BS, and CC Limestone that form the Middle Trinity aquifer.

The Hammett Shale (HS), which overlies the Sligo Limestone, has an average thickness of 60 ft. It is composed of dark blue to gray fossiliferous, calcareous, and dolomitic shale. It pinches out north of the HCSM area and attains a maximum thickness of 80 ft to the south. Above the Hammett Shale is the CC Limestone, which is a massive fossiliferous, white to gray, shaley to dolomitic limestone that attains a maximum thickness of 90 ft down dip in the area. The youngest member of the Travis Peak Formation is the Hensell Sand, locally known as the BS. The shale thickness averages 60-80 ft, and is composed of silty dolomite, marl, calcareous shale, and shaley limestone, and thins by interfingering into the Glen Rose Formation.

The upper member of the Trinity Group is the Glen Rose Limestone. The Glen Rose Limestone was deposited over the Travis Peak BS and represents a thick sequence of shallow water marine shelf deposits. This formation is divided into upper and lower members. At CSSA, the Glen Rose is exposed at the surface and in stream valleys (Figure 2.4).

The Upper Glen Rose (UGR) consists of beds of blue shale, limestone, and marly limestone with occasional gypsum beds (Hammond, 1984). Based on well log information, the thickness of the upper member reaches 500 ft in Bexar County. The thickness of this member at CSSA is estimated from well logs to be between 20 and 150 ft.

The LGR, underlying the UGR, consists of a massive fossiliferous limestone, grading upward into thin beds of limestone, marl, and shale (Ashworth, 1983). The lower member, according to area well logs, is approximately 300 ft thick at CSSA. Isolated areas of reef rock have also been identified in the LGR. The boundary between the upper and lower members of the Glen Rose Limestone is defined by a widespread fossil stratigraphic marker known as the Corbula bed (Whitney, 1952). The Corbula bed is 0.5-5 ft thick and contains small pelecypod clamshells, which are three to five millimeters in diameter. Presence of the Corbula fossil indicates a slightly more saline depositional environment than fossils found above and below the Corbula. A gypsum bed has also been identified close to the Corbula bed.

<u>*Structure*</u>

The predominant structural features in the area are regional vertical fractures, the regional dip, and the Balcones fault zone (BFZ) escarpment. Regional fractures are the result of faulting in the Cretaceous sediments and in the deeper Paleozoic rocks. The two sets of fracture patterns trend NW-SE and NE-SW across the region. The regional dip is to the east and SE at a grade of about 100 ft per mile near the fault zone in Bexar and Comal Counties, decreasing 10-15 ft per mile NW of CSSA.

The BFZ is a series of high-angle normal faults that generally trend NE and SW. Total displacement in NW Bexar County is approximately 1,200 ft. The faulting is a result of structural weakness in the underlying Paleozoic rocks and subsidence in the Gulf of Mexico basin to the SE. The down drop blocks outcrop as progressively younger strata from NW-SE across the fault zone. In addition to major faulting along the BFZ, numerous minor NW-SE-trending faults also occur. These faults are laterally discontinuous and their displacement is small. Figure 2.5 generically diagrams the regional geology and structure based on the groundwater modeling efforts performed by the Texas Water Development Board (TWDB) (2000).

2.2.4 Groundwater Hydrology

Groundwater occurrence and movement at CSSA have been studied since 1992, and continue to be studied due, in part, to the complex geologic environment. Results of a preliminary evaluation of groundwater contamination in 1992 were included in a report entitled **Hydrogeologic Report for Evaluation of Groundwater Contamination at Camp Stanley Storage Activity, Texas** (Engineering Science [ES], 1993). This work was updated in the **Groundwater Investigation and Associated Source Characterizations** (Parsons Engineering Science [Parsons ES], 1996).

Three aquifers are present in the area of CSSA: the Upper, Middle, and Lower Trinity aquifers. These divisions are based on hydraulic continuity. The Travis Peak Formation and the Glen Rose Formation are the principle water-bearing units. Beneath these are metamorphosed Paleozoic rocks, which act as a lower hydrologic barrier. Only the Middle and Upper Trinity aquifers are addressed for this HCSM.

Middle Trinity aquifer

The primary groundwater source at CSSA is the Middle Trinity aquifer, the most prolific producer with the best quality of water of the three Trinity aquifers. Typical wells in this formation are completed as open holes without well screens. The Middle Trinity aquifer consists of the CC Limestone, the BS (Hensell Sand), and the LGR Limestone. The average combined thickness of the aquifer members is approximately 460 ft (Figure 2.6). The only member found in outcrop at CSSA is the LGR, which has been mapped north of CSSA along Cibolo Creek and within the central and SW portions of CSSA (Figure 2.4).

The LGR portion of the Middle Trinity aquifer derives its recharge from direct precipitation on the outcrop and stream flow infiltration. Stream flow loss has been observed in Cibolo Creek, which is north of CSSA, between the towns of Boerne and Bulverde, where stream flow is diverted underground via sinkholes except during flood stages. This is the only area of the LGR that is considered to be part of the recharge zone for the Edwards Aquifer (Edwards, 1987). In other portions of the Texas Hill Country, the upper member of the Glen Rose Limestone is sometimes considered to be a confining unit below the Edwards Aquifer.

In the area of CSSA, the BS acts as a hydrologic barrier to vertical leakage except where faulted; therefore, most recharge to the CC Limestone comes from overlying up dip formations. On a regional scale, it is inferred that the CC is in natural hydraulic communication with the LGR due to extensive faulting in the area. The bottom of the CC Limestone forms the base of the Middle Trinity aquifer (Figure 2.7). The Middle Trinity aquifer appears to be unconfined in the CSSA area.

The Middle Trinity aquifer yields fresh to slightly saline water throughout the area and is the most widely used source of water in the area. Although high in mineral content, water in the lower member of the Glen Rose Limestone is normally very good quality. The water increases in dissolved solids content near the BFZ owing to an increase in sulfate ions. No drinking water wells are known to have been completed only in the CC Limestone near CSSA; therefore, the water quality of that limestone member has not been documented in research literature. Wells that draw from the CC only are located significantly up dip of the CSSA vicinity. Most water wells in the area obtain Middle Trinity water for public supply, irrigation, domestic, and livestock purposes.

Upper Trinity aquifer

The Upper Trinity aquifer consists of the UGR Limestone. Recharge to the Upper Trinity aquifer is from direct precipitation to UGR Limestone outcrop and from stream flow infiltration. Movement of groundwater in the Upper Trinity is restricted to lateral flow along bedding planes between marl and limestone, where solution has enhanced permeability. Static water levels in adjacent wells completed in different beds within the UGR are often different, demonstrating the possibility that beds are not hydraulically connected by avenues of vertical permeability. The only place where extreme development of solution channels is reported is in evaporite layers in or near the outcrop of the UGR Limestone. Discharge from the Upper Trinity aquifer is predominantly from natural flow through seeps and springs and from pumping. The Upper Trinity aquifer is, in general, unconfined. Fluctuations in water levels in the Upper Trinity are predominantly a result of seasonal rainfalls and in some areas, may be impacted by pumping from domestic and public wells. Figures 2.8 and 2.9 show the thickness and mapped basal contact of the Upper Trinity aquifer.

Upper Trinity water is generally of poor quality and most wells achieve only low production. Evaporite beds in the Upper Trinity introduces excessive sulfate into the water. Few wells obtain water solely from the Upper Trinity aquifer.

2.2.5 Surface Water Hydrology

The CSSA area can be characterized as hilly with stony soils and high runoff potential. Natural stream channels on CSSA generally have broad floodplains, and portions of CSSA are within the 100-year floodplain. Salado, Leon, and Cibolo Creeks drain surface water from CSSA. Approximately 75 percent of CSSA is in the Salado Creek watershed, 15 percent in the Cibolo Creek watershed, and 10 percent in the Leon Creek watershed. Most of the active-use areas of CSSA are in the Leon Creek watershed, including a wastewater treatment plant, which drains into a tributary of Leon Creek at the southern boundary of CSSA. All of these streams are intermittent at CSSA.

The Salado Creek watershed, with its headwaters located in the adjacent City of Fair Oaks extends in a broad swath across CSSA from NW to SE. Impervious cover in Fair Oaks is currently estimated at 5 to 10 percent. Drainage from Camp Bullis to the east also flows across CSSA to Salado Creek. Impervious cover for CSSA within the Salado Creek watershed is substantially less than 5 percent, with much of the area undeveloped except for dirt and gravel roads.

Three tributaries of Cibolo Creek, which originate on CSSA, drain the northeastern part of the outer cantonment. The area of the Cibolo Creek watershed within CSSA is undeveloped except for dirt and gravel roads. Impervious cover in the Cibolo Creek watershed is minimal.

A tributary of Leon Creek, originating on CSSA, drains the SW quarter of the inner cantonment. Overall, impervious cover within the Leon Creek portion of CSSA is estimated at approximately five percent or less, much of which is located along Tompkins Road and McElroy Drive.

Rainfall runoff is conveyed to natural stream flow channels by ditches and sheet flow in the developed areas of CSSA. CSSA has sufficient relief to allow rapid conveyance of runoff from developed areas, and in the undeveloped areas, runoff flows overland to natural channels.

2.2.6 Meteorology and Climate

CSSA is located in the south-central part of Texas on the Balcones escarpment. NW of the installation, the terrain slopes upward to the Edwards Plateau; to the SE, the terrain slopes downward to the Gulf Coastal Plains. This results in a modified subtropical climate, predominantly marine during the summer months and continental during the winter months. The resulting weather is characterized by hot summers with daily temperatures above 90 degrees Fahrenheit (°F) over 80 percent of the time and mild winters with below-freezing temperatures occurring on an average of only about 20 days per year. Average annual temperature is 69°F. The highest average daily maximum temperature is 95°F in July, and the lowest average daily minimum temperature is 39°F in January. Temperature extremes for the period of weather records range from 0°F to 108°F.

CSSA is situated between a semi-arid region to the west and the coastal area of heavy precipitation to the east. Between the years of 1934 and 1999, the annual rainfall at Boerne averages 33.66 inches (Esquilin, *et al*., 2000). Precipitation is fairly well distributed throughout the year, with the heaviest amounts occurring in May and September. Approximately 61 percent of the rainfall occurs over the period from April through September and is primarily due to thunderstorms. Damaging hail seldom occurs, but light hail is common with springtime thunderstorms. Since CSSA is only 140 miles from the Gulf of Mexico, tropical storms occasionally affect the post with strong winds and heavy rains. Spring rainfalls are associated with frontal systems while summer rainfalls are associated with thunderstorms and tropical weather. Measurable snowfall occur only once every 3 or 4 years.

2.3 PREVIOUS AND CURRENT INVESTIGATIONS

2.3.1 Regional Studies

Several studies on groundwater development and availability within the Trinity aquifer have been produced over the past 20 years. These studies range from graduate-level thesis to major governmental projects. Described below are regional studies widely regarded as a definitive body of work conducted within the hydrostratigraphy of interest.

Ground-Water Availability of the Lower Cretaceous Formations in the Hill Country of South-Central Texas (Ashworth, 1983)

Ashworth (1983) performed a study to describe the hydrologic characteristics of the Trinity Group Formations of the south-central Texas Hill Country. The study area encompassed approximately 5,800 square miles at the edge of the Edwards Plateau, along the BFZ. The study area included all of Kendall, Kerr, Real, and Bandera Counties and portions of Hays, Gillespie, Comal, Bexar, Medina, Uvalde, and Blanco Counties. CSSA is located in the northern portion of Bexar County. Drainage basins within the study area include the Guadalupe, San Antonio, Nueces, and Colorado River drainage basins.

Ashworth collected hydrologic data from high-capacity public supply, irrigation, and industrial wells and attempted to gather data from perennial springs. Wells completed within the Middle Trinity aquifer, the portion of the Trinity Group that is present at CSSA, yielded slightly saline water. Water from the LGR Limestone was hard, but of good quality, as was water from the Hensell Sand (geologic facies to the BS) and CC Limestone. The Hensell Sand water had high iron concentrations in some localities. Water quality decreased toward the south and southeastern edges of the study area where the total dissolved solids increase substantially.

The primary recharge source for the Trinity Group is from rainfall and seepage from lakes and streams. Within the study area, the Glen Rose Limestone and the Hensell Sand outcrops receive direct recharge. Underlying units, such as the CC Limestone, derive recharge from vertical leakage. Water that recharges the Trinity Group flows down dip, south-SE, at a hydraulic gradient of 0.005. Hydraulic gradient is a dimensionless number or ratio that can be represented in any unit of measure such as feet per foot, meters per meter or miles per mile. Groundwater flow paths generally follow decreasing topography, except in areas of continuous pumpage or springs.

Predicated on base flow received by the Guadalupe River, the effective recharge to the Trinity Group aquifer is estimated at 200,000 acre-feet per year (acre-ft/yr). Base flow was measured at a gauging station located in an area of little groundwater pumpage derived from groundwater discharge into the river. This discharge amount should match the recharge amount assuming the aquifer remains nearly filled.

Most of the streams in the study area traversed the Middle Trinity aquifer units and are effluent streams, gaining water from the units they traverse. The exception to this rule is Cibolo

Creek, which is influent, losing its water to sinkholes unless flood periods are occurring. The largest water loss from Cibolo Creek was observed along its path from Boerne to Bulverde, where it flows over the Glen Rose Limestone. CSSA lies directly south of Cibolo Creek, within a few miles of Boerne.

Pumping tests were performed for several Trinity Group wells. For the Middle Trinity aquifer, a transmissivity coefficient of 1,700 gallons per day per foot (gpd/ft) was calculated. Groundwater in the Trinity Group is under artesian (confined) and water table conditions. Wells under artesian conditions have a storativity range of 10^{-5} to 10^{-3}, whereas wells under water-table conditions have a storativity range of 0.1 to 0.3. Storativity, also known as the coefficient of storage, is a dimensionless number used to express the storage capacity of an aquifer. It is briefly defined as the volume of water taken into or released from storage per unit change in head per unit area.

Wells in the Trinity Group are usually under artesian conditions, except for shallow wells. Confined or artesian conditions are present in units that are overlain by confining units such as the Bexar or Hammett Shales. Glen Rose Limestone outcrops over much of the study area and over the whole CSSA area. Shallow wells that only penetrate the Glen Rose Limestone are under water-table conditions.

Hydrogeology of the LGR Aquifer, South-Central Texas (Hammond, 1984)

Hammond (1984) completed his doctoral thesis on the hydrogeology of the LGR aquifer. The study area included Blanco, Comal, Kendall, Kerr, Bandera, Uvalde, Medina, and Bexar Counties. Hammond found that the hydrologic properties of the LGR Limestone varied widely over short distances and that the groundwater had regional and local flow systems.

The LGR consists of biomicrite, dolomite, micritic marl, and reef deposits. The unit reaches its maximum thickness of approximately 400 ft in the eastern portion of the Edwards Plateau area. Early Miocene uplift of the eastern Edwards Plateau subjected the LGR to sub-areal weathering, which developed secondary permeability through carbonate dissolution in fracture zones.

The regional groundwater flow system in the LGR is controlled by syndepositional permeability and primary porosity. Hydrologic parameters for the regional groundwater system were 240 to 3,220 gpd/ft for transmissivity and 3.4×10^{-5} to 1.0×10^{-3} centimeters per second (cm/sec) for hydraulic conductivity.

Groundwater Availability of the Trinity aquifer, Hill Country Area, Texas: Numerical Simulations through 2050 (TWDB, 2000)

A three-dimensional, numerical groundwater flow model of the Middle Trinity aquifer in the Hill Country area of south-central Texas was developed to help estimate groundwater availability and water levels in response to pumping and potential future droughts. The model included historical information on the aquifer and incorporated results of new studies on water levels, structure, hydraulic properties, and recharge rates. A steady-state model was calibrated for 1975 hydrologic conditions when water levels in the aquifer were near equilibrium, and a transient model was calibrated for 1996 through 1997 when the climate transitioned from a dry to a wet period.

Using the model, values of recharge, hydraulic conductivity, specific storage, and specific yield were calibrated for the aquifer. The model was used to predict future water levels and saturated thickness under drought-of-record conditions using estimates of future groundwater demands based on demand numbers from the Regional Water Planning Groups. The model predicts that the area near Cibolo Creek in northern Bexar, southern Kendall, and western Comal Counties were the most susceptible to future water level declines due to increased demand and potential droughts.

If a drought similar to the drought-of-record were to occur, the model suggested that water levels may decrease as much as 100 ft in this area by the year 2010 and that a large part of the aquifer may be depleted in this area by the year 2030. Hays, Blanco, Travis, southeastern Kerr, and eastern Bandera Counties could experience moderate water level declines (50-100 ft) in response to projected demands and potential drought as early as 2010. The model suggested that major rivers may continue to flow seasonally even with increased pumping and under drought conditions.

2.3.2 Camp Stanley Environmental Studies

2.3.2.1 CSSA Groundwater Investigation Summary (1991 to Present)

Contaminants were initially detected in CSSA Well CS-16, shown in Figure 2.1, during routine water supply testing in April 1991. Drinking water withdrawals at CS-16 ceased immediately. Follow-up sampling confirmed concentrations of trichloroethene (TCE) and tetrachloroethene (PCE) above drinking water maximum contaminant levels (MCLs) and the well was permanently taken out of service. Comprehensive investigation of groundwater contamination at CSSA began in 1992. The effort started with preliminary evaluations to establish the extent of the problem without invasive field techniques, namely analyzing groundwater samples from existing CSSA wells and geophysical surveys to identify potential contamination source areas. Samples from Well CS-D, located west of Well CS-16, also exhibited concentrations of PCE and TCE that exceeded MCLs. Camera surveys were also performed at CSSA wells to inspect the integrity of existing casings and to document general conditions inside the wells. Following this effort, the **Hydrogeologic Report for Evaluation of Groundwater Contamination** (ES, 1993) was submitted to the appropriate regulatory agencies for comment and approval.

A groundwater monitoring and reporting program was initiated in 1994 and established that groundwater flow gradients generally varied from south-southwest to south-southeast. The monitoring continued to show above-MCL volatile organic compound (VOC) contamination in Wells CS-16 and CS-D. Attempts to identify specific contaminated zones in several CSSA wells through discrete groundwater sampling proved inconclusive. Nevertheless, after review of geophysical and video logs, additional surface casing was installed to 200 ft below ground surface (bgs) in Wells CS-2, CS-3, CS-4, CS-16, and CS-D to seal off shallow water-bearing zones that could have been contributing to migration of VOC contamination through open boreholes. Investigation activities continued in 1995, including additional downhole geophysical logging, discrete interval sampling, and well upgrades. In addition, periodic monitoring of several off-post domestic water supply wells was eventually initiated. At that time, none of the offsite wells sampled showed evidence of contamination.

Other work in 1995 relating to groundwater contamination issues focused on source characterization. To help identify potential sites, historical records were examined and interviews with CSSA employees were conducted to locate potential SWMUs and other AOCs. Sites were examined throughout CSSA where waste had been dumped and/or burned during past disposal activities. Areas showing unusual topography were also considered possible waste burial locations. Electromagnetic (EM) and ground penetrating radar (GPR) surveys were conducted at some of these sites in early 1995, followed by soil-gas surveys in areas where anomalies were identified.

Subsequently, SWMU B-3 and the abandoned oxidation pond SWMU O-1, located in the NE corner of the Inner Cantonment, were identified as potential VOC source areas. The pond once held waste fluids and sludge from CSSA's weapons bluing operations. The pond was abandoned and filled in 1985. At SWMU B-3 there had been a wide trench where solid and liquid wastes were apparently burned. The trench was backfilled in the early 1990's. Additional geophysical surveys, soil gas sampling, soil boring, and sampling continued at CSSA. Results indicated that SWMU B-3 and O-1 contained significantly higher concentrations of VOC contaminants than other sites. Analytical results showed PCE in SWMU O-1 soil samples and PCE, TCE, and *cis*-1,2-dichloroethene (DCE) in soil at SWMU B-3. Results of these investigations are provided in the **Technical Memorandum on Soil Boring Investigations** (Parsons ES, 1995b), the **Technical Memorandum on Surface Geophysical Surveys at High Priority Sites** (Parsons ES, 1995c), and the **Technical Memorandum on Surface Geophysical Surveys, Well 16 Source Characterization** (Parsons ES, 1995a).

Other activities completed at about this time included mapping of two fault zones through CSSA by Parsons. One narrow fault zone courses through the southern portion of CSSA trending SW-NE. A second, wider fault zone bisects CSSA immediately south of CS-16, trending west to east. At an October 1995 meeting involving EPA, TCEQ, AFCEE, CSSA, and their consultants, it was agreed that groundwater work at CSSA would continue to focus on source characterization. Quarterly groundwater monitoring and reporting continued.

In 1996, CSSA initiated additional source characterization at SWMU B-3 and O-1 in preparation for source removal. Additional detailed geophysical work was completed in areas around CS-16 and south to CS-1. CSSA had two monitoring wells (CS-MW1-LGR and CS-MW2-LGR) installed south of CS-16. The wells were drilled into the bottom of the LGR Formation (320 to 361 ft bgs) and completed with 140 and 141 ft of casing, respectively in 1999. These wells were recompleted with a 20-screen section in the bottom of the LGR. Periodic TCE concentrations above MCLs were found in both wells. The **Groundwater Investigation and Associated Source Characterization Report** (Parsons ES, 1996), which includes source characterizations of SWMU B-3 and O-1, was submitted to the regulatory agencies.

CSSA began groundwater monitoring using a QED MicroPurge® Low-Flow system in early 1997. Camera surveys were completed in CS-1, CS-9, and CS-11, followed by upgrading that included carbon dioxide (CO_2) rehabilitation treatments. Ongoing work for SWMU and AOC site characterizations did not reveal additional potential sources contributing to the CS-16 area plume. However, past use of solvents in CSSA Building 90 was suspected as a potential source of contamination in the SW corner of the post. From 1998 through January 2004, CSSA continued monitoring water levels and conducting groundwater sampling on a quarterly schedule. Groundwater monitoring reports are included in **Volume 5** of the **CSSA Environmental Encyclopedia.**

In 1998 planning for the installation of several clustered monitoring wells throughout CSSA was also initiated. The intention of the well clusters was to assist in the ongoing characterization of groundwater contamination at CSSA. The wells provided for monitoring of the major water-bearing zones in the LGR, BS, and CC portions of the Middle Trinity aquifer. To date, 30 new monitoring wells and six piezometers (PZs) have been installed within the LGR, BS, or CC portions of the Middle Trinity aquifer.

In 1999, an offsite well survey was conducted in the areas surrounding the CSSA facility. As many as 130 private or public supply wells were tentatively identified within one mile of CSSA. Of these, nearly 100 wells were positively identified and mapped. Most wells in the locality developed their water resources from the Middle Trinity aquifer. The typical well construction for the area includes an open borehole completion through the LGR, BS, and CC portions of the aquifer with minimal surface casing. This methodology ensured adequate yield, but could enhance the likelihood of cross-contamination between water-bearing units. As part of the quarterly monitoring program, select offsite wells were sampled for the presence of target contaminant analytes.

As a result of the 1999 well survey, CSSA initiated an offsite well sampling program in December 1999. Based on this sampling, it was discovered that PCE and/or TCE was present in both public and private drinking water wells to the west and SW of the facility. These events lead to the search for another area of contaminant release, which ultimately lead to AOC-65, a solvent vat area in Building 90 where solvent had been used in the past.

Investigations performed at AOC-65 included soil borings, soil-gas surveys, multiple geophysical sensing techniques, and shear-wave seismic surveys. The objectives of those investigations were to identify pathways for migration specifically related to stratigraphic and structural features. Results of these investigations culminated with the installation of two pilot study vapor extraction systems. A weather station and transducers were installed at the site to aid in a groundwater recharge study.

In July and August 2001, two pumping tests were performed on CSSA wells CS-10 and CS-16. The tests were conducted to get a better sense of the hydraulic character of the Middle Trinity aquifer. The tests were conducted in wells that were open to both producing intervals of the aquifer: the Glen Rose Limestone and the CC Limestone. Groundwater pumping rates between 45 and 80 gallons per minute (gpm) were achieved, and measurable drawdown was observed at distances up to 700 ft away. Transmissivity values ranged between 1,600 and 2,300 gpd/ft, and aquifer storativity between 0.00008 and 0.005. Storativity, also known as the coefficient of storage, is a dimensionless number used to express the storage capacity of an aquifer. It is briefly defined as the volume of water taken into or released from storage per unit change in head per unit area. The resultant hydraulic conductivity ranged between 4.2×10^{-4} and 4.7×10^{-4} cm/sec.

The installation of additional wells is currently being planned, and the on- and off-post quarterly groundwater monitoring program currently continues. Future well installations will include the use of multi-level monitoring devices to aid in the vertical delineation of contaminants. A chronology of work conducted in association with the groundwater investigation is provided in **Volume 1-1** of the **CSSA Environmental Encyclopedia.**

2.3.2.2 USGS Surface and Aerial Mapping

In 2003 CSSA contracted the U.S. Geological Survey (USGS) to perform surface geologic and EM mapping at the facility. Much of the planned activities will build upon, or be performed in conjunction with Camp Bullis. Other regional entities also contributing to the effort include the San Antonio Water System (SAWS) and the Edwards Aquifer Authority (EAA).

The geologic survey will be a continuation of the mapping already performed at the neighboring Camp Bullis facility. The mapping will include the UGR hydrostratigraphic zones already defined during the Camp Bullis survey. Additionally, hydrologic zones will be identified and defined for the LGR outcrop areas. Results of this mapping effort will be used to update and refine the HCSM.

CSSA and Camp Bullis also contracted with the USGS Crustal Imaging Team to perform an aerial EM (AEM) survey of both U.S. Army facilities and private entities (SAWS/EAA). The process utilizes an EM drone towed in linear flight paths above the land surface by a helicopter. The method will employ the same geophysical principles utilized by the resistivity surveys conducted at AOC-65, but at a regional scale. Research by the USGS in other parts of Central Texas (Seco Creek) demonstrates that the method is able to identify the major stratigraphic and structural features affecting the regional groundwater regime in the Edwards Aquifer. The CSSA survey was completed in the fall of 2003 and to date preliminary data has been received.