4.3 HYDROGEOLOGIC SETTING

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Geologic Setting

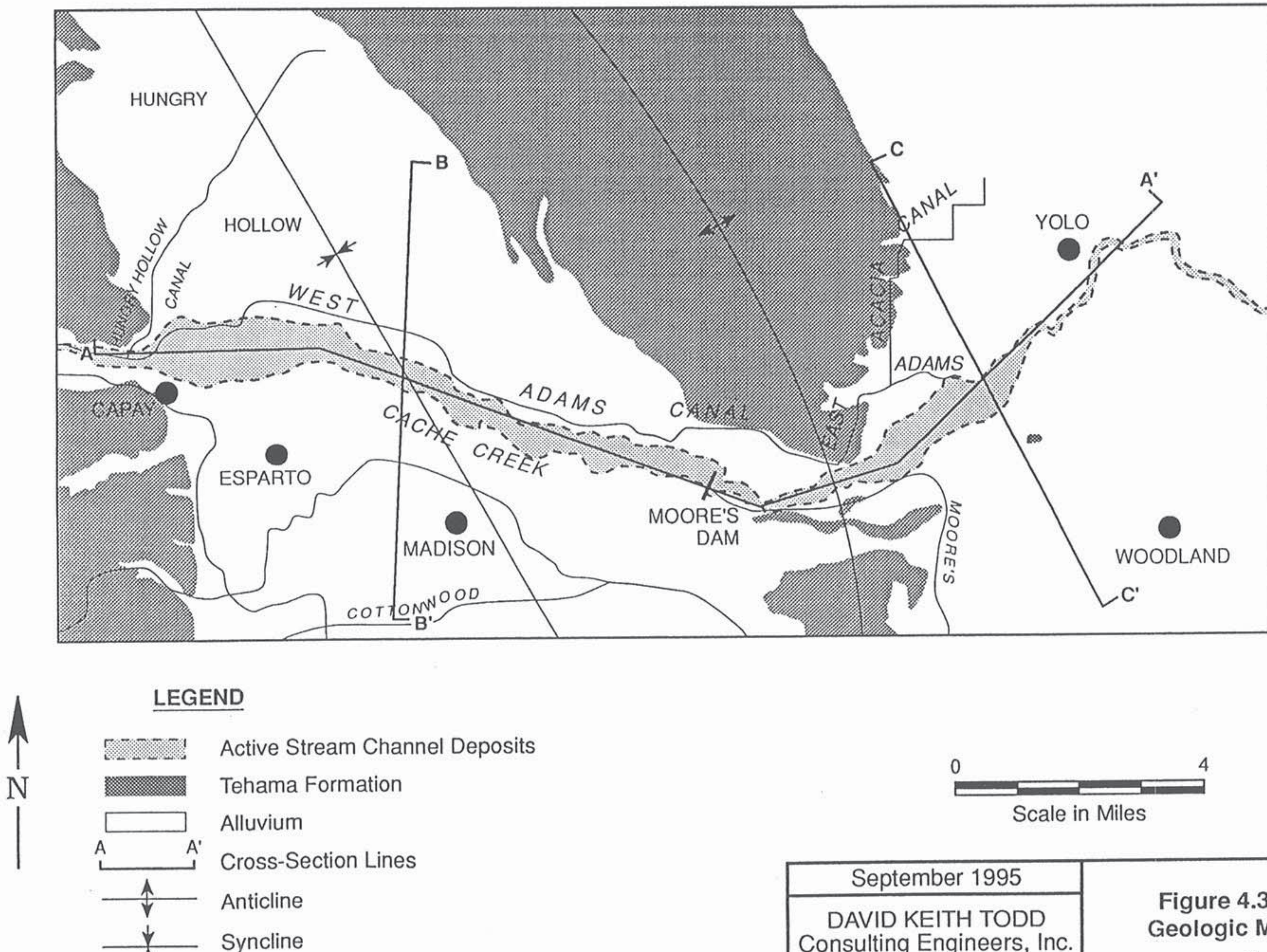
The study area lies at the western edge of the Central Valley geomorphic province. The Central Valley is a large northwest trending structural trough filled with sediment to a depth as great as ten miles. The sediments consist of continental and marine deposits ranging in age from Jurassic to Holocene.[1]

The study area is underlain by Quaternary (Holocene and Pleistocene) alluvial and basin deposits, Quaternary (Pleistocene) Red Bluff Formation, and Tertiary (Pliocene) Tehama Formation (see Figure 4.3-1). The Quaternary alluvium has been subdivided into the following subunits: Holocene stream channel deposits, Holocene younger alluvium, Holocene basin deposits, and Pleistocene older alluvium known as the Modesto Formation. For the purposes of this report, Quaternary formations are hereafter referred to as alluvium. The Quaternary alluvium consists of unconsolidated gravel, sand, silt, and clay reaching thicknesses of up to 150 feet. The Red Bluff Formation consists of highly weathered red gravels, generally less than 50 feet thick, overlying the Tehama Formation. The Tehama Formation consists of several hundred to 2,000 feet of green, gray, and tan conglomerate, sandstone, and siltstone.[2] These deposits are underlain at depth by Eocene marine sedimentary rocks.[3]

The geologic structure of the project area is dominated by the Dunnigan Hills anticline and Madison syncline, as illustrated in Figure 4.3-1. The thickest deposits of alluvium have accumulated in the area of the Madison syncline. East of the syncline, the anticline brings Tehama Formation to the surface in the form of the Dunnigan Hills and Plainfield Ridge. The eastern edge of the Dunnigan Hills north of the study area (near Zamora) is bounded by a normal (near-vertical) fault with the downdropped side to the east. Bryan[4] has suggested that this Zamora fault may extend further to the south, thereby, passing through the study area in the eastern portion of the Teichert Woodland property. However, Bryan described Dunnigan Hills/Plainfield Ridge as solely a fault-related structure with an east bounding fault and a western fault passing through the vicinity of Esparto. As described above, subsequent geologic studies indicate folding as the dominant geologic factor, with faulting limited to north and west of the study area. If the east-bounding fault does extend south across the study area, it likely occurs northeast of Teichert Woodland and the small isolated outcrop of Tehama Formation shown northwest of Woodland on Figure 4.3-1. The folds and faults described above have extensively deformed the Tehama and Red Bluff Formations.

Aquifers and Groundwater Occurrence

The important groundwater-bearing formations in the Cache Creek Basin include Quaternary alluvial and basin deposits and Tertiary Tehama Formation. The Red Bluff Formation probably does not contain significant amounts of groundwater because known outcrops tend to be thin and



References: Helley and Harwood, 1985; Harwoc ' Helley, 1987.

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Figure 4.3-1
Geologic Map

occur in dissected uplands. Although the Red Bluff Formation may occur at depth between the alluvium and Tehama Formation (in which case it may be a significant groundwater bearing unit), it is difficult to distinguish this formation from others in drill cuttings.[5]

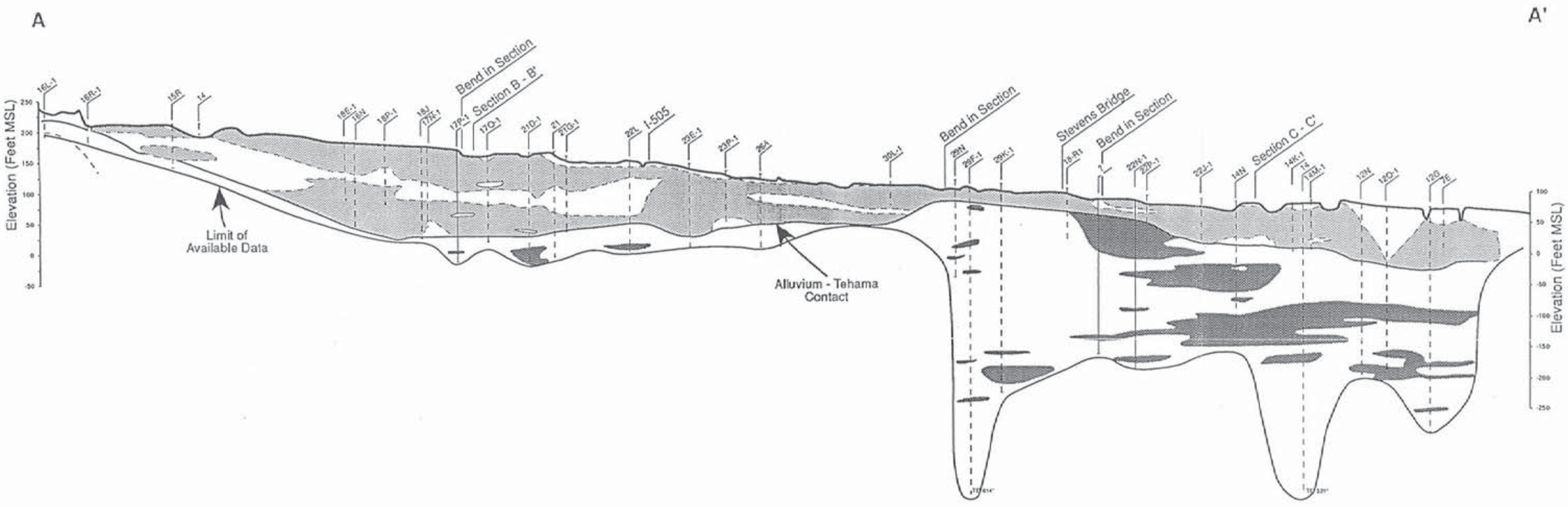
The groundwater-bearing units consist of varying amounts of gravel, sand, silt, clay. In general, alluvium is considered to be more permeable than Tehama Formation because of a greater percentage of coarse materials and less consolidation. The distribution of sand/gravel versus clay/silt layers are illustrated in Figures 4.3-2 through 4.3-4. The locations of the cross-sections are shown on Figure 4.3-1. These cross-sections show the relative abundance of sand and gravel units in alluvium relative to the Tehama Formation. West of Plainfield Ridge, the alluvium tends to be thickest beneath Cache Creek and becomes thinner with distance from the creek (see Figure 4.3-3). East of Plainfield Ridge, the alluvium maintains a relatively constant thickness (see Figure 4.3-4).

The Dunnigan Hills anticline effectively divides the Cache Creek groundwater basin into upper and lower basins, because the Tehama Formation has lower permeability than the alluvium. Thus, the anticline behaves as a groundwater dam maintaining higher groundwater elevations in the upper basin west of the anticline. However, alluvium-filled gaps interrupt Plainfield Ridge, allowing groundwater to flow through where Cache Creek and Willow Slough cross the axis of the anticline. In addition, groundwater can flow directly across Plainfield Ridge, albeit more slowly, through the Tehama Formation.

Some uncertainty exists regarding the contact between alluvium and the Tehama Formation because of their similarity in drill cuttings. This is due, in part, to the fact that much of the alluvium is derived from erosion and subsequent deposition of the Tehama Formation present in the western Coast Range adjacent to Cache Creek.[6] Therefore, the contact between the alluvium and Tehama Formation was reevaluated based on previous investigations including, but not limited to, Wahler,[7] Hubbard,[8] Luhdorff and Scalmanini,[9] Scott,[10] and Helley and Harwood.[11]

Wahler constructed numerous regional cross-sections and delineated the contact based on driller's logs. This work provides the foundation for much of the current understanding of local hydrogeology. A subsequent regional investigation of the contact between alluvium and Tehama Formation was completed using downhole geophysical logs and geologic logs.[12] Hubbard delineated the contact as being shallower compared to the Wahler study in some areas, particularly, Hungry Hollow and the area east of the Dunnigan Hills.

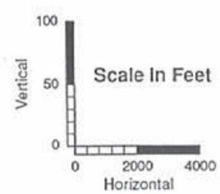
However, Hubbard's study was regional; thus surface mapping and more localized subsurface investigations have been useful in refining local conditions. Helley and Harwood performed detailed surface geological mapping of the study area. This mapping revealed, for example, a small, isolated outcrop of Tehama Formation northwest of Woodland, which provides additional evidence that the alluvium may be shallower in this area than depicted in the Wahler cross-sections. Similarly, the local studies by Luhdorff & Scalmanini and Scott, although limited to alluvium, have been helpful in delineating the minimum depth of alluvium within the respective study areas.



LEGEND

- Alluvium (Sand and Gravel)
- Tehama Formation (Sand and Gravel)
- Fine-grained Sediments above Limit of Available Data

Reference: Adapted from Wahler (1982)



September 1995	Figure 4.3-2 Geologic Profile A - A'
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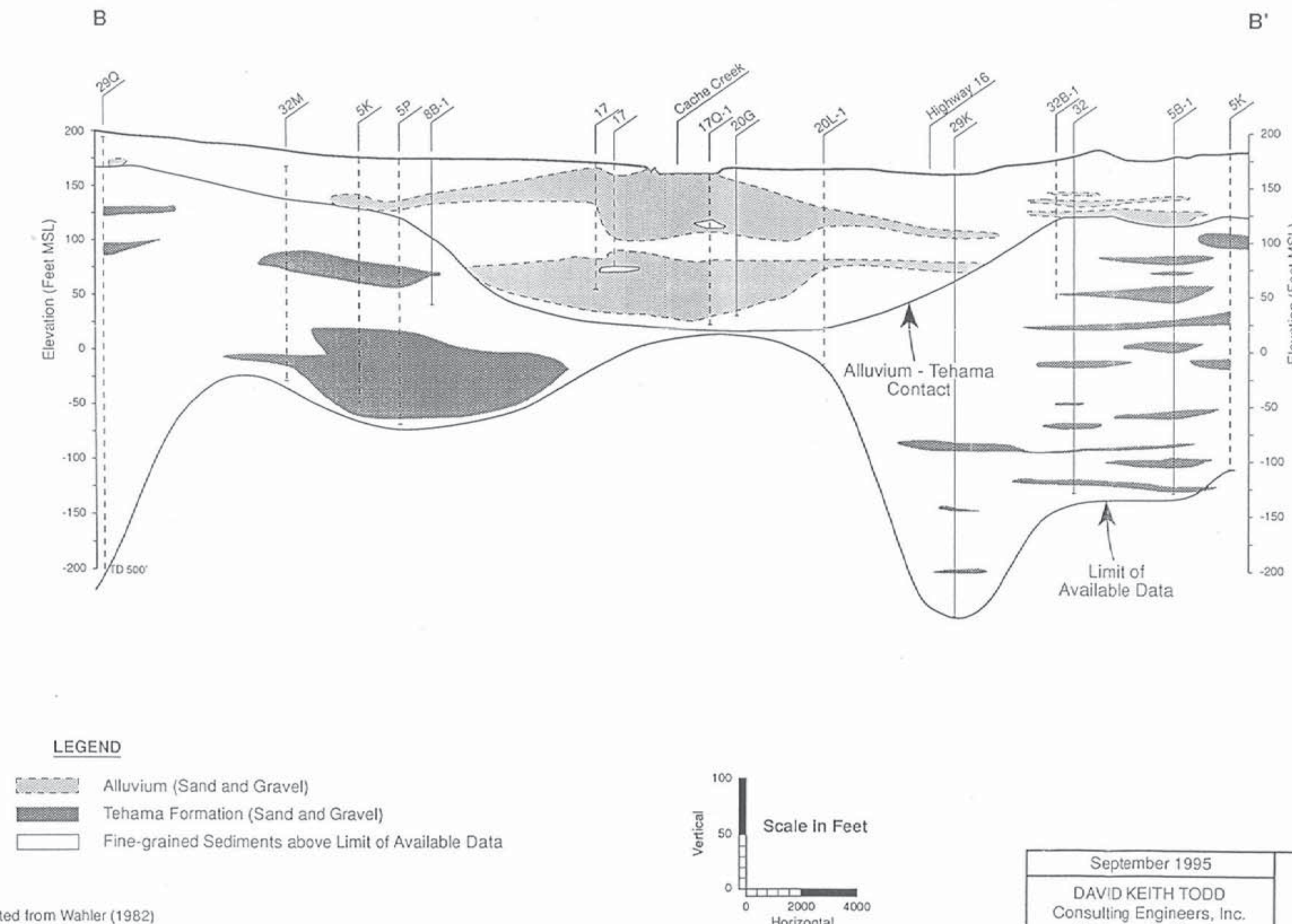

Reference: Adapted from Wahler (1982)

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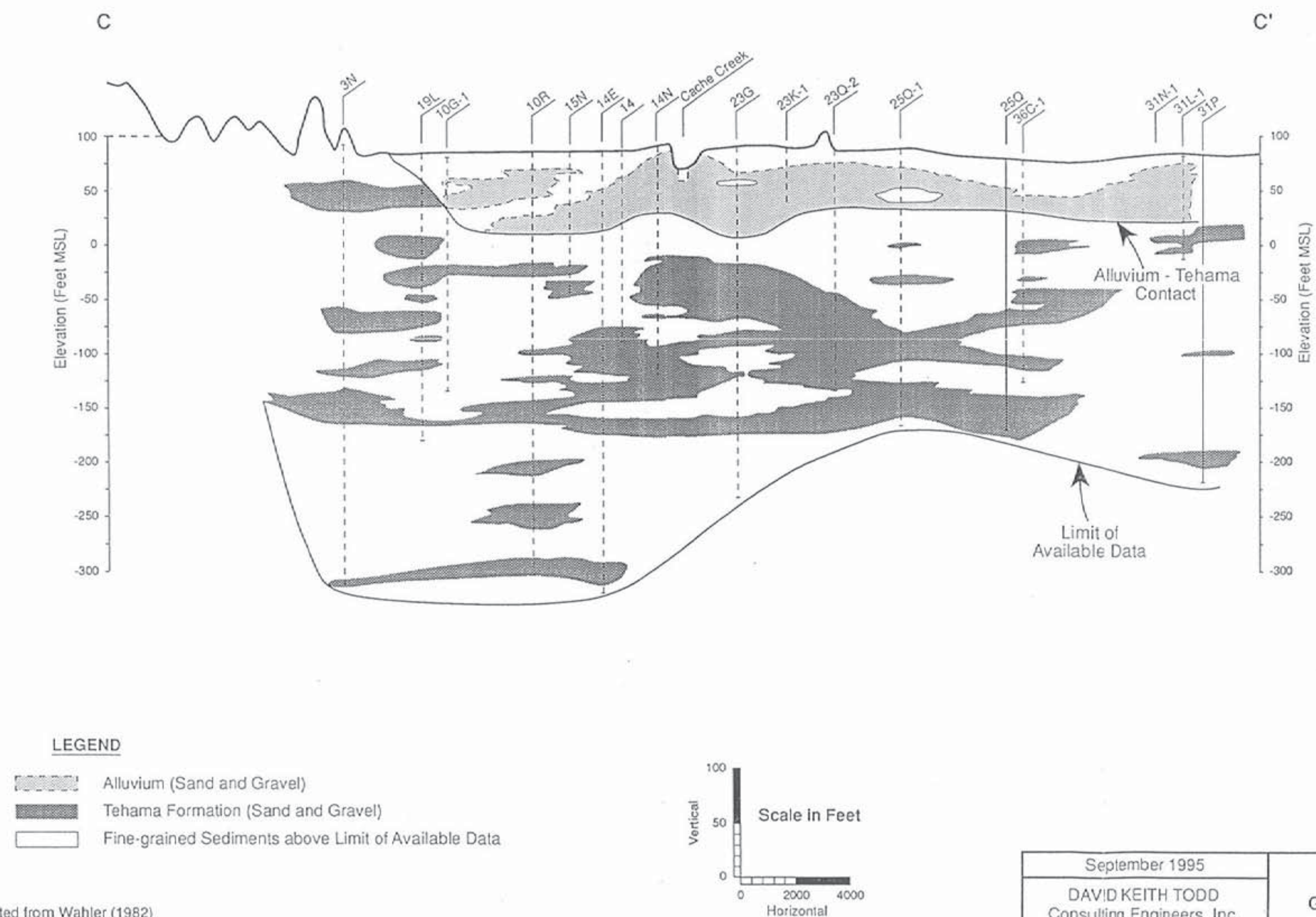
Figure 4.3-3
Geologic Profile
B - B'



Reference: Adapted from Wahler (1982)

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Figure 4.3-4
Geologic Profile
C - C'

The revised alluvium-Tehama contact is depicted on selected cross-sections derived from the Wahler study, but based on more recent information from Hubbard, Helley and Harwood, and the localized studies (Figures 4.3-2 to 4.3-4). The use of borehole geophysical logs in the Hubbard study provides a better basis for defining the contact than geologic logs alone. In addition, surface geologic mapping and smaller scale studies of areas such as Teichert Woodland helped refine the contact in local areas.

In addition, driller's logs were obtained for reference during the course of this study. A well qualification effort also was undertaken, involving classification of wells according to the alluvium-Tehama Formation contact defined in this investigation. Approximately two-thirds of the wells could be classified as being screened in either alluvium or Tehama. The remaining wells could not be categorized due to lack of information regarding well depths and screen intervals.

Of the classified wells, alluvial wells are located generally near the creek and associated primarily with aggregate company monitoring programs. Most wells in the extensive DWR database were classified as being screened in the Tehama Formation and are typically more distant from the creek. However, classification of several wells near Cache Creek was not possible; some of these likely penetrate Tehama Formation.

As part of the well qualification effort, consideration was also given to separation of the alluvial aquifer into two units - a shallower unconfined unit and a deeper confined unit. Our review of available data indicates that the alluvium can be treated as one unit on a regional basis, but consideration should be given to the two unit concept on a local basis.

Unfortunately, the areal distribution of wells in the two aquifers and the lack of ability to categorize a significant portion of the wells are not conducive to constructing groundwater contour maps for separate aquifers on a regional basis. Therefore, the groundwater contour mapping completed for this study represents a composite of the two aquifers, similar to previous groundwater contouring efforts.

Aquifer Hydraulic Properties

The hydraulic properties of aquifers include transmissivity, hydraulic conductivity, and storativity. *Transmissivity* and *hydraulic conductivity* are measures of an aquifer's ability to transmit water. *Storativity* is a measure of the amount of water a given aquifer volume will yield to a pumping well. The review of available data indicates that no formal pumping tests of wells have been conducted to evaluate aquifer parameters.

However, preliminary estimates of transmissivity may be obtained from specific capacity data. *Specific capacity* is a measure of the productivity of a well, and is computed as the pumping rate divided by the water level drawdown in a well. The specific capacities of wells screened in alluvium are generally estimated to be 10 to 100 times greater than specific capacities of wells screened in the Tehama Formation.[13] In general, alluvial specific capacities are greater than 100 gpd/ft, whereas Tehama specific capacities are less than 10 gpd/ft.[14] The average specific capacity of 180 wells in the Cache Creek basin was determined to be approximately 80 gpm/ft.[15]

This corresponds to a transmissivity of 160,000 gpd/ft using the rule of 2000.[16] Similarly, specific capacity data compiled from driller's logs in the area just south of Cache Creek and east of I-505 yielded a hydraulic conductivity of 3,000 gpd/ft^2 and a transmissivity estimate of 150,000 gpd/ft for alluvium.[17] These transmissivity estimates compare favorably, and are within the estimated range of transmissivity values for Yolo County of 23,000 to 346,000 gpd/ft.[18]

The storativity of unconfined aquifers corresponds to *specific yield.* Specific yield can be estimated based upon geologic logs, with values typically ranging from 3 percent for clay to 25 percent for gravel. Due to the interbedded nature of alluvial deposits, average specific yields for a given depth interval in the Cache Creek basin typically range from 5 to 15 percent.[19,20,21] Within the study area, specific yields are greatest in the immediate vicinity of Cache Creek and least along Plainfield Ridge.[22] This distribution reflects the greater specific yields in alluvium compared to Tehama Formation.

Groundwater Storage

An initial evaluation of groundwater storage capacity was completed in 1961.[23] This study was based on geologic descriptions provided in well logs. Geologic descriptions were grouped into different categories which were assigned a specific yield value. The assignment of specific yield was as follows:

gravel	25 percent
sand, sand and gravel mixtures	20 percent
tight/hard sand, sandstone, fine sand	10 percent
clay and gravel mixtures, cemented gravel	5 percent
clay, silt, sandy clay, lava rock	3 percent

The Sacramento Valley was divided into subareas, of which four (Cache Creek, Low plains south of Dunnigan Hills, Low plains east of Dunnigan Hills, and Plainfield Ridge) are relevant to the study area. These subareas include most of the overlap between townships 9N, 10N, and 11N and ranges 2W, 1W, 1E, and 2E. The combined groundwater storage capacity of these subareas in the 20-200 foot interval was estimated to be 2.35 million acre-feet.

Another study published in 1961[24] also calculated groundwater storage capacity in the 20-200 foot interval, and assigned the same specific yield values as used by Olmsted and Davis. The study area generally encompassed the overlap between townships 8N (northern half only), 9N, and 10N, and ranges 2W, 1W, 1E, and 2E. The groundwater storage estimate of 2.28 million acre-feet was similar to the Olmsted and Davis estimate.

A subsequent evaluation was completed for groundwater in storage in Yolo County for 1974.[25] The County was divided into six groundwater basins, of which significant portions of four basins lie in the study area. The estimated groundwater storage capacity for these four basins was 6.81 million acre-feet in the 20 to 420 foot interval. The amount of groundwater in storage in 1974 was approximately 6.32 million acre-feet or 93 percent of capacity. The groundwater storage estimates in this study are greater than previous studies due to a doubling of the depth interval and a larger study area. Assignment of specific yield values was similar to previous studies.

Another evaluation of groundwater storage was completed by DWR and USGS in 1978. Groundwater storage capacity for 1965 groundwater levels was calculated for the area encompassing the overlap of townships 9N and 10N with ranges 2W, 1W, 1E, and 2E. The estimates were 1.94 million acre-feet in the 20 to 200 feet interval, 4.0 million acre-feet in the 20 to 400 feet interval, and 6.14 million acre-feet in the 20 to 600 feet interval. Specific yield values were assigned as follows:

coarse sand and gravel	18 to 25 percent
fine sand	13 to 17 percent
clay with fine sand	8 to 12 percent
clay and silt	1 to 7 percent
rock	0 percent

This assignment of specific yield values is generally consistent with previous studies.

Each of the studies summarized above utilizes slightly different study areas and, in some cases, different depth intervals. However, in considering these factors it is apparent that calculated groundwater storage capacities are relatively consistent among the different studies.

The specific yield values assigned to various geologic descriptions in these studies were reasonable and consistent with the literature. However, while specific yield values of 18 to 25 percent are appropriate for unconsolidated sands and gravels found in alluvium in the study area, such values are too high for the consolidated sands and gravels which typically occur in the Tehama Formation. This would not be a problem if consolidation were a property easily recognized in drill cuttings, because a consolidated sand or gravel would be assigned a specific yield value of 5 to 10 percent according to the studies cited above. Unfortunately, consolidation is not readily recognized in drill cuttings, and coarse Tehama deposits are simply noted as sands and gravels in most driller's logs. As a result, Tehama sand and gravel deposits may be assigned values of 20 percent instead of the 10 percent that is more appropriate.

For the reason cited above, the amount of total groundwater storage available in the Tehama Formation is estimated to be less than calculated in previous studies. Inserting the reduced specific yield value and assuming the Tehama contains 25 percent coarse deposits[26] results in a reduction of 30 to 40 percent (relative to previous studies) for groundwater storage in the Tehama Formation.

The reduction in total groundwater storage in the alluvium and Tehama Formation combined, however, would be less than the 30 to 40 percent estimated for the Tehama Formation alone. This is because specific yield values used in previous studies are appropriate for alluvium and, therefore, alluvial groundwater storage remains the same. Estimates of total groundwater storage for the upper 200 feet (where alluvial deposits dominate) would be reduced on the order of 10 to 15 percent, whereas total groundwater storage in the upper 500 to 600 feet (where Tehama Formation dominates) would be reduced by approximately 25 percent.

Comparison of driller's logs with geophysical logs indicates that driller's logs tend to underestimate the amount of coarse grained material by approximately six to seven percent.[27] This will also affect the groundwater storage calculation by underestimating the total amount of groundwater storage. Thus, the coarse fractions in the alluvium and Tehama Formation were assumed to be approximately five percent greater than noted on driller's logs, and groundwater storage estimates were increased by the appropriate amount. This consideration partially counters the reduction in storage discussed above. Considering both inaccuracies in driller's log descriptions (i.e. difficulty in distinguishing consolidated sand/gravel and underestimation of coarse fractions) results in a net reduction of 5 to 10 percent for the upper 200 feet and 20 percent for the upper 500 to 600 feet.

Accordingly, the estimated 6.81 million acre-feet of groundwater storage capacity[28] has been reevaluated. A reduction of 20 percent results in a revised groundwater storage capacity of approximately 5.0 million acre-feet.

Groundwater Quality

The first groundwater quality analyses were reported by Bryan.[29] Groundwater samples from the Esparto-Madison and Woodland areas were found to be more highly mineralized than average for the Sacramento Valley. Total dissolved solids (TDS) ranged from 328-356 parts per million (ppm) for the Esparto-Madison area to 363-624 ppm for the Woodland area. Hardness ranged from 218-249 ppm for Esparto-Madison to 192-461 for Woodland. In general, the groundwater was classified as good for irrigation, but less satisfactory for other uses due to the amounts of calcium, magnesium, and sodium present in the water. Boron was not analyzed in this early study.

A groundwater quality evaluation in 1961[30] noted that groundwater in Cache Creek basin was hard to very hard (greater than 100 ppm as $CaCO_3$). Groundwater in the northern part of Hungry Hollow was classified as Class 1 irrigation water (i.e. excellent to good). Class 1 waters were defined as follows: TDS less than 700 ppm, conductance less than 1,000 umho/lm, chlorides less than 175 ppm, sodium less than 60 ppm, and boron less than 0.5 ppm. The remaining areas of Cache Creek groundwater basin were classified as Class 2 or 3 (i.e. good to poor), depending primarily on the boron concentration. Elevated boron concentrations in groundwater were attributed to water diverted from Cache Creek for irrigation.[31].

Surface waters of Cache Creek have elevated concentrations of boron derived from mineralized waters contributed by the North Fork Cache Creek and Bear Creek tributaries. Surface water quality samples from North Fork Cache Creek and lower Bear Creek were collected for analysis between 1938-1941. Results indicated high concentrations of boron, sodium, chloride, and TDS, especially at low flows. Water quality samples collected from Cache Creek near Capay Dam between 1930 and 1956 indicate that irrigation water diverted during summer low flows contained in excess of 1.8 ppm of boron.[32] Elevated boron concentrations in these Cache Creek tributaries are likely derived from the saline springs in the Rumsey Hills (a.k.a. Capay Hills) which border Capay Valley to the east-northeast. These springs have boron concentrations ranging from 45-215 ppm, sodium concentrations of 2,400 to 8,000 ppm, chloride concentrations of 4,400 to 16,500 ppm, and TDS in the range of 9,246 to 27,998 ppm.[33]

Class 3 water was noted just west of Plainfield Ridge and east of Woodland. Groundwater in the Class 3 areas was very hard with high boron concentrations. Class 3 boron concentrations were defined as greater than 2 ppm.

It was also noted that groundwater from deeper wells has lower boron concentrations and reduced hardness. However, boron concentrations in deeper groundwater were still classified as Class 2 waters (0.5 to 2 ppm). This observation is likely due to the fact that shallow groundwater would be more influenced by recharge from Cache Creek and percolation from irrigation water derived from Cache Creek.

A review of groundwater quality data for Yolo County was completed in 1975.[34] This study utilized data collected primarily by DWR for the time period from the 1950s to 1970s. Boron was noted to be the constituent of most concern with the highest concentrations located in the vicinity of Cache Creek near Madison, Woodland, and Knight's Landing. The average concentration in these areas was 4 ppm, reflecting elevated boron concentrations found in surface water from Cache Creek.

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