LOWER CACHE CREEK GROUNDWATER STUDY

4.4 HISTORICAL PERSPECTIVE

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Introduction

The objectives of the historic review of groundwater resources along lower Cache Creek are to:

- document trends in groundwater levels and quality;
- evaluate factors affecting groundwater resources, including rainfall, streamflow diversions, pumpage, and aggregate mining; and
- provide a realistic perspective for groundwater management in the future.

This review has focused on the vicinity of Cache Creek from near Capay to Yolo, extending outward to encompass the mining resource zones that are the subject of the Cache Creek Resource Management Plan. However, the regional nature of the groundwater resource necessitates consideration of the overall groundwater basin (Figure 4.1-1). The basin boundary on the west consists of the contact of the unconsolidated alluvium and Tehama Formation with the less permeable, consolidated formations of the Coast Ranges. On the south, the boundary is defined by the watershed and groundwater flow divides between the Cache Creek and Putah Creek basins. Similarly on the north, the boundary is the divide between Cache Creek watershed and watersheds draining directly to Colusa Basin (e.g., Oat Creek). The eastern boundary is the Sacramento River.

Specific tasks involved in fulfilling these objectives include the compilation of historic information on groundwater quantity and quality, and identification of data gaps; documentation of groundwater level and quality trends; and analysis of factors in those trends. In addition, this historical review has included documentation of changes in groundwater storage and aggregate industry activities along the Creek.

Early History (to 1940)

This section portrays groundwater conditions prior to about 1940, and provides a preliminary examination of factors affecting groundwater quantity and quality. Although scant quantitative data exist to document early conditions, this review of early history is useful in establishing the overall hydrologic context for groundwater resources and providing a realistic perspective for groundwater management in the future.

This early history is subdivided into three parts, describing early surface water irrigation, the aggregate industry, and groundwater resources under essentially pre-development conditions and under conditions of early surface water irrigation.

Development of Surface Water Irrigation

In Yolo County, early agriculture was dominated by dry-farming of grain. As described in 1870 in the *Western Shore Gazetteer*, the available agricultural land already had been claimed and placed into cultivation of dry-farmed grains. Nonetheless, development of irrigated agriculture began as early as 1856 with construction of Moore's Ditch. This construction marked one of the earliest water supply developments in California specifically for irrigation.[1] Moore's Ditch irrigated about 1,000 acres.[2] Some lands also were irrigated with surface water pumped from pools along Cache Creek below Moore's Dam.

Subsequently, other irrigation canals were constructed, including the Adams Ditch in 1870. However, diversions from Cache Creek stimulated considerable litigation, especially over summer low flows. This resulted in consolidation of the various water supply facilities and water rights by the Yolo County Consolidated Water Company in 1903. The water system was then expanded through construction of the Winters Canal.[3]

By 1913 about 24,000 acres were irrigated between Cache and Putah Creeks, with much of the water used in the Woodland area (east of Plainfield Ridge) and only a small portion in the Esparto-Madison area. An important crop in the Woodland area at that time was sugar beets, a crop requiring a moderate water application of about three acre-feet per acre per year.

High commodity prices during World War I encouraged expansion of irrigation. In addition, rainfall from 1918 to 1938 was moderate to low in the area (see Figure 4.2-1), placing a disadvantage on rain-dependent farming. By the 1920s, the ditch system was owned by Yolo Water, Light, & Power Company.[4] A concrete diversion dam was built at Capay, and the ditch system was improved. Development of irrigation continued during the 1920s, while the 1930s were characterized by little irrigation expansion due to economic depression. Nonetheless, 32,000 acres were planted to sugar beets alone in Yolo County in 1938,[5] along with extensive acreage of alfalfa, almonds, and field and truck crops.

As documented in Figure 4.2-5, total irrigation diversions have been documented from 1929 to present. Through the period 1929-1939, diversions ranged from about 13,000 acre-feet in 1931 (a dry year) to nearly 133,000 in 1938. Highest diversions occurred in 1936, 1937, and 1938 as a result of above-average rainfall and increased availability of streamflow. Overall, diversions in that decade averaged only 70,000 acre-feet per year (afy).

Aggregate Industry

Historically, the principal mining activity in Yolo County has been sand and gravel mining, although between 1873 and 1947, the chief mineral product of the County was quicksilver.[6] Cache Creek has been the major source of sand and gravel since early settlement, primarily for building roads and railroads.

As shown in Figure 4.2-7, information on sand and gravel production prior to 1940 is incomplete, but demonstrates mining activity in the range of 8,500 to 148,000 tons per year. As explained in the Available Data section, this production level is generally representative of excavation of sand and gravel from Cache Creek, but may include mining elsewhere in Yolo County and does not include non-saleable fine materials.

Longitudinal profiles of the Cache Creek thalweg or channel bottom have been compiled for a number of years from 1905 to 1994 as shown in Figure 4.4-1. Overall, these profiles indicate a lowering of the channel bed elevation, which has been ascribed to in-channel mining.[7] The two highest profiles, from the 1905 and 1953 topographic maps, show relatively little difference in thalweg elevation in the intervening four decades, although declines are apparent in the vicinity of Esparto Bridge, Moore Dam, and I-5 Bridge.

Groundwater Resources

Data on groundwater conditions prior to 1940 are scanty. However, sufficient qualitative descriptions exist to describe groundwater levels, flow patterns, and quality under relatively natural, undeveloped conditions.

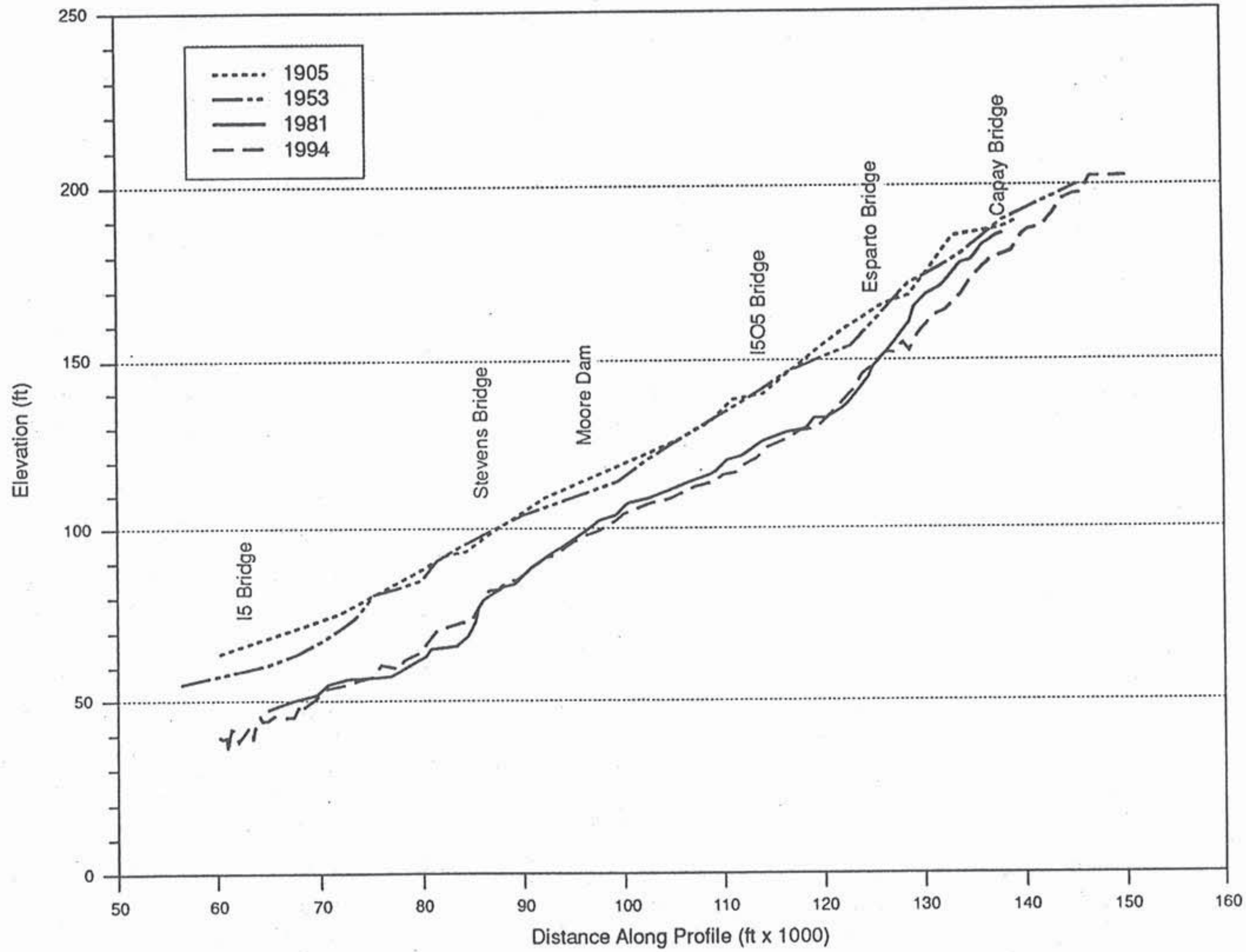
Groundwater Recharge and Discharge

Prior to 1900, Cache Creek was described as follows: "In the summer the waters of Cache Creek disappear at intervals or sink in the sand...",[8] indicating an intermittent and ephemeral flow pattern, with recharge to groundwater. Cottonwood Slough is similarly described as dry in summer with its flow disappearing where the creek reaches the plains. In contrast, Willow Slough is described as generally perennial, reflecting groundwater discharge into the creek. Cache Creek apparently also was perennial at Plainfield Ridge, with well-wooded banks and a year-round supply for Moore's Ditch.[9]

Recharge also occurred through distribution of floodwaters across the plains, especially south of Cache Creek. As noted in the *Gazetteer*:

> During high water, when the heavy rains have swollen Cottonwood Creek to the dimensions of a powerful stream, and Cache Creek to a formidable river, their waters are united in the overflow, and Cache Creek discharges a large volume of water through the Cottonwood Plains, which finds an outlet to the tules through Willow Slough.

A U.S. Geological Survey (USGS) investigation of groundwater was conducted in the Sacramento Valley between about 1910 and 1915.[10] This investigation provides the first water table contour map of Yolo County, documenting conditions in 1912-1913, illustrated in Figure 4.4-2. This map shows a general eastward groundwater gradient along Cache Creek, and a southeastward gradient in Hungry Hollow. The map also reveals the damming effect of the less permeable materials underlying Plainfield Ridge. Depths to groundwater are reported to be less than six feet west of the ridge, and twenty feet just east. Groundwater flow across Plainfield Ridge is described as occurring via Cache Creek and the North Fork of Willow Slough. Review of the 1912-1913 map also shows that east of the ridge, Cache Creek acted as a source of groundwater recharge, as indicated by the convexity of groundwater contours along the creek.

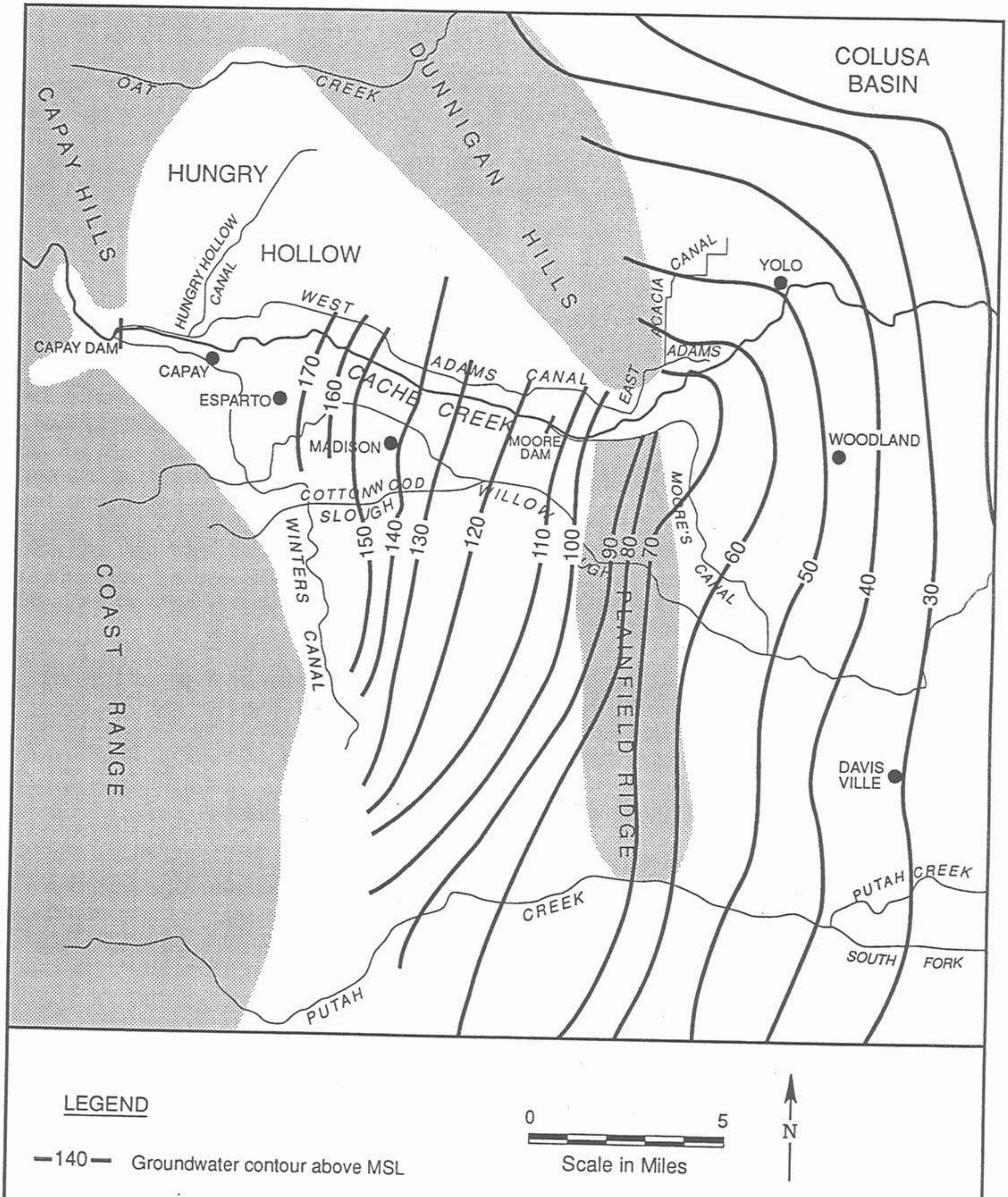


: Northwest Hydraulic Consultants, 1995

September 1995

DAVID KEITH TODD
Consulting Engineers, Inc.
Berkeley, California

Figure 4.4-1
Longitudinal Profiles
From
Topographi Maps



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DAVID KEITH TODD
Consulting Engineers, Inc.
Berkeley, California

Figure 4.4-2
1912 - 1913
Groundwater Level
Map

East of the ridge, groundwater discharge into Cache Creek then could percolate again or exit the basin as streamflow or through evapotranspiration of riparian vegetation (indicated by historical descriptions of "well-wooded banks"). Discharge also occurred as subsurface flow toward the Yolo Basin to the east as indicated in the 1912-1913 water table map. Willow Slough was a source of groundwater discharge, as suggested by the concavity of groundwater contours south of Woodland.

Groundwater Development

The first irrigation well in the Sacramento Valley was installed near Woodland in 1877. Yet groundwater development prior to 1900 was limited to include domestic and stock use, and some pumpage for irrigation of orchards, alfalfa, and sugar beets.[11] Unlike other groundwater basins notably in Southern California, flowing artisan conditions did not occur to any extent in the Cache Creek area and early groundwater development was limited by its dependence on pumps.

During the early 1900s, however, the availability of gasoline engines, electric motors, and centrifugal pumps allowed use of large amounts of shallow groundwater. In 1900 in the Woodland area about twenty pumps were in use, including eight used for diversion from Cache Creek pools below Moore's Dam. The latter pumps were subject to insufficient supply after mid-July. In contrast, irrigators pumping from wells reported an unlimited supply.[12] Nonetheless, most pumping plants were abandoned subsequently as a result of a series of relatively wet years and improved operation of the irrigation ditch system.

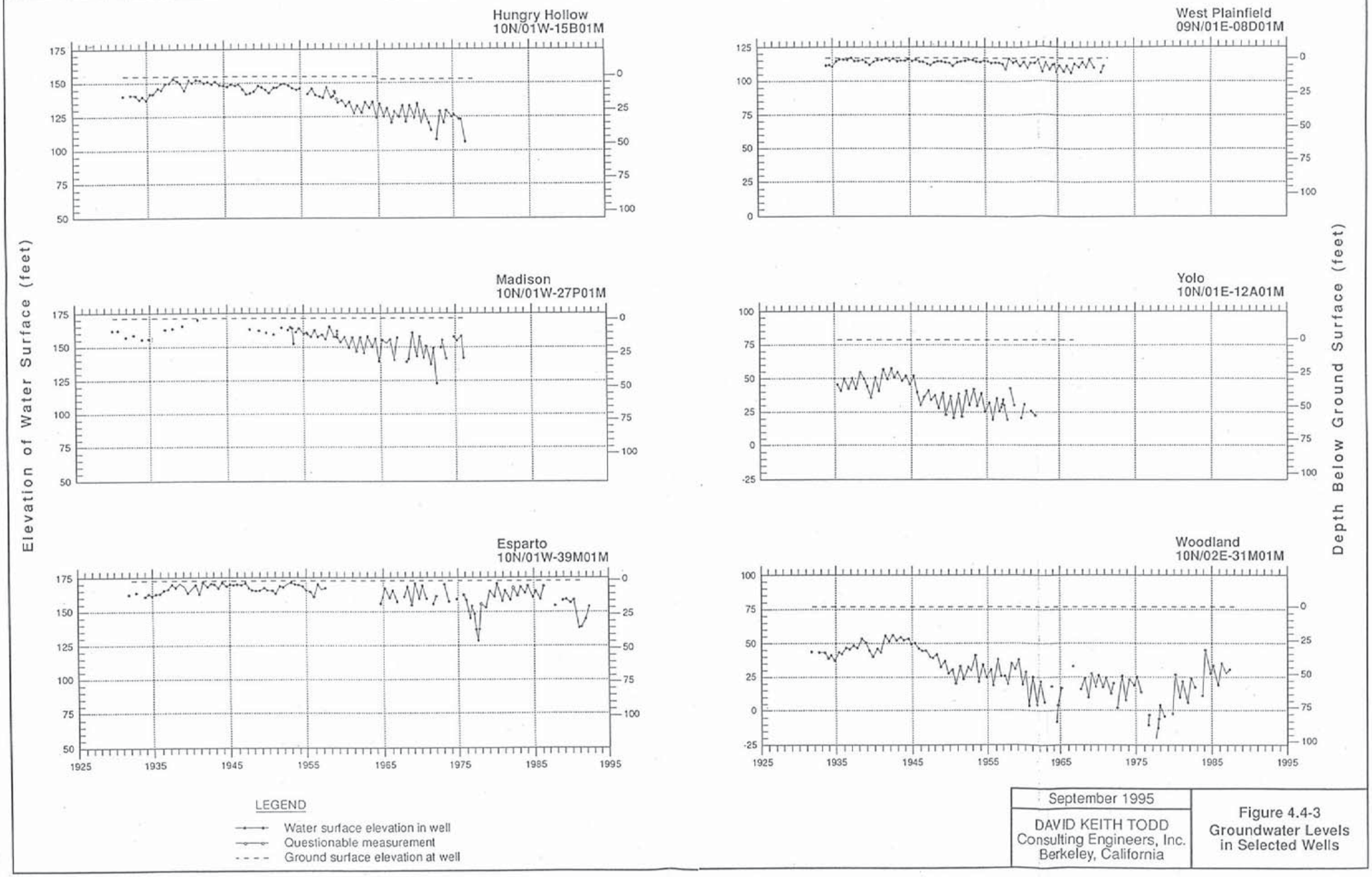
However, by 1913, 37 pumping plants irrigated nearly 8,000 acres in the Woodland area, while in the Esparto-Madison area about 148 acres were irrigated with water pumped from wells.[13] This renewed use of pumped groundwater resulted from a combination of factors including the demand by sugar beet companies for reliable irrigation water, the dry years of 1910 through 1912, and increasing efficiency of pumps. In the 1920s development of deep-well turbine pumps and rural electrification led to widespread use of groundwater for irrigation.[14].

Groundwater also was developed for municipal purposes. The City of Woodland purchased its waterworks from a private company in 1892, including four wells and a centrifugal pump with a Westinghouse motor. Subsequently, a new water plant west of town was constructed including two additional wells. The Woodland water system grew gradually through incorporation of existing, neighborhood wells and water systems and through installation of municipal wells.[15]

Groundwater Levels

General descriptions of groundwater up to about 1900 report shallow depths to groundwater of about 10 to 25 feet.[16] The *Western Shore Gazetteer* reports depths to groundwater of about 18 feet near Woodland, about 22 feet around Cottonwood (south of Madison), and deeper skirting the foothills.

Water level records for a number of wells extend back to the 1930s. A number of representative hydrographs are reproduced in Figure 4.4-3. In reviewing the years up to 1940, groundwater levels were at their lowest in 1934, reflecting seven years of drought and reduced recharge from



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DAVID KEITH TODD
Consulting Engineers, Inc.
Berkeley, California

Figure 4.4-3
Groundwater Levels
in Selected Wells

rainfall and streamflow. In addition, surface water diversions were quite low in the early 1930s, resulting in reduced groundwater recharge from irrigation. All of the hydrographs indicate rising groundwater levels after 1935, because of high rainfall from 1935 into the early 1940s.

Nonetheless, the various hydrographs also demonstrate the influence of other factors. One of these factors is the local source of irrigation water: surface water or groundwater. The hydrograph representing the Esparto area shows a relatively small range of water level change of about ten feet from 1934 to 1941. This reflects widespread surface water irrigation in the area, which represents a source of recharge. This irrigation recharge ameliorates the decline in groundwater levels that would occur because of lack of rainfall recharge. In comparison over the same period, the Madison hydrograph shows a somewhat larger range of water level change of fifteen feet, reflecting the local pumpage of groundwater. This pumpage represents a discharge that amplifies any groundwater level decline due to lack of rainfall.

A similar pattern is apparent in comparison of the hydrographs for Yolo, depending on groundwater pumpage, and Woodland, in an area of surface water and groundwater irrigation. The Yolo well shows significant seasonal groundwater level changes. Groundwater levels in summer in this area decline not only because of the lack of seasonal rainfall recharge, but also because of the additional groundwater discharge for summer irrigation. The Woodland well shows less pronounced seasonal changes as irrigation provides summer recharge, offsetting the lack of rainfall recharge.

A second factor in the magnitude of groundwater level changes is location or hydrogeologic setting. It is notable that groundwater levels in the Hungry Hollow, Esparto, Madison, and West Plainfield wells all approached ground surface between 1938 and 1941, reflecting not only the increased rainfall recharge during this period, but also the damming effect of Plainfield Ridge. All four wells are west or upgradient of the Ridge. The effect is particularly notable in well 9N/1E-8D1 representing the west Plainfield area, where groundwater levels remain constantly within ten feet of ground surface, constrained by the limited discharge of groundwater across Plainfield Ridge. East of the ridge, groundwater levels rose to record high levels in 1938 and the early 1940s, but remained about 25 feet below ground surface.

In addition, the local character of the hydrogeology may affect groundwater level fluctuations. In areas of really limited, thin, or less permeable aquifers, groundwater level variations tend to be larger because there is less groundwater storage to provide water to wells or less permeable aquifer to transmit groundwater to wells. This may be a factor in the northern portion of Hungry Hollow, where permeable materials tend to be limited and variations are relatively large. In contrast, the Esparto area, characterized by relatively steady groundwater levels, is an area of deep, extensive, permeable aquifer materials that can readily provide water to wells.

Groundwater Quality

Early descriptions of groundwater quality in Yolo County seldom included praise. The 1870 *Western Shore Gazetteer* reported that well water was hard throughout the county, and around Woodland was "strongly impregnated with mineral." The USGS investigation noted local groundwater contained much more mineral matter than the average for the Sacramento Valley.

Reported concentrations of total dissolved solids ranged from 363 to 624 parts per million, and groundwater quality was hard to very hard.[17] Two water quality records from the Esparto-Madison area were comparable. No trend data are available prior to 1940.

Summary

Prior to significant water development in the Cache Creek area, groundwater generally occurred at fairly shallow depths, representing a full groundwater basin. Groundwater levels sloped gently from west to east, generally paralleling the ground surface. The major exception to this pattern was the damming effect of Plainfield Ridge, which results in relatively shallow groundwater west of the ridge.

Natural recharge to groundwater under pre-development conditions occurred primarily from rainfall, streamflow in Cache Creek and other creeks, and overland flooding, especially south of Cache Creek over the Cottonwood Plains. Natural discharge of groundwater from the basin above Plainfield Ridge occurred through flow into Cache Creek and Willow Slough at the ridge. East of the ridge, groundwater was discharged from the basin through evapotranspiration of riparian vegetation or as subsurface flow.

The limited groundwater level trend data, available as early as 1930, indicate groundwater levels changing largely in response to rainfall conditions, but also reflecting the local source of irrigation water (surface water or groundwater) as well as the effect of Plainfield Ridge. The small scale of aggregate extraction activities prior to 1940 would have resulted in no significant effect on groundwater resources.

The development of irrigation represented the most significant source of change in the groundwater system during this period. This change included reduction of in-channel streamflow because of irrigation diversions, and a likely reduction of in-channel recharge. The irrigation diversions of streamflow reflected the natural pattern of overland flooding through the Cottonwood Plains. However, it differed in season and duration, and would result in increased water consumption by crops, increased summer return flows, and potential increases in total dissolved salts in groundwater. In addition, the development of irrigation affected the groundwater system directly through development of groundwater resources for irrigation. This created a new avenue of groundwater discharge (well pumpage and subsequent consumptive use by crops). Such discharge causes groundwater level declines near pumping wells, which in turn result in the following:

- enhanced recharge of rainfall, streamflow, and irrigation return flow;
- more rapid cycling of water through the groundwater system, particularly in the zones being tapped by wells and overlying zones; and
- alterations in groundwater flow and discharge patterns.

These changes are discussed in greater depth in the following sections, which address the substantial changes in groundwater resources from 1940 to the present, and the factors in those changes.

Middle History, 1941 - 1977

Rainfall from 1941 to the mid-1970s was fairly equable, without extremely dry or wet years and with average rainfall approximating the long-term average of 17 inches at Davis. Nonetheless, the period was defined by substantial change in the Cache Creek groundwater system.

In 1941, groundwater was at record high levels, and the basin was essentially full. Groundwater had been used for irrigation for over 60 years, but generally remained ancillary to surface water irrigation. Yolo County was largely claimed for agriculture (dry-farming and irrigation) and aggregate mining was limited.

By 1977, groundwater levels were at record lows, reflecting drought and intensive pumpage mostly for irrigation purposes. Surface water supplies for irrigation proved inadequate, resulting in expansion of groundwater pumpage and prompting construction of Indian Valley reservoir. Agriculture in Yolo County expanded nearly to its present-day limits and was predominantly irrigated. In response to regional urbanization and public works projects, aggregate mining expanded considerably to present day levels, evoking the enactment in 1979 of the County ordinance limiting mining operations in Cache Creek.

Expansion of Irrigated Agriculture

After World War II, irrigated agriculture expanded, stimulated by high commodity prices as well as the availability of improved land levelling equipment.[18] Although tens of thousands of acres in the County were still dry-farmed for small grains and almonds, agriculture increasingly shifted to irrigated alfalfa, orchards, truck and field crops. In 1950 sugar beets were the principal crop in the County.[19]

Land use mapping by the California DWR in 1961 reveals that 47,900 acres were cropped in the area of the Bird Valley, Esparto, Madison, and Woodland topographic maps. As indicated in Table 4.4-1, irrigated acreage increased significantly between 1961 and 1976 at the rate of about 1,350 acres per year to eventually encompass 68,200 acres in 1976. Irrigated agriculture supplanted dry farming particularly in Hungry Hollow and west of Esparto. In addition, substantial infilling occurred downgradient of the major local canals, as dry farm grain and safflower were switched to irrigated crops. Previously unirrigated almonds increasingly were supplied with water.

Expansion of irrigation in northern Hungry Hollow was based primarily on groundwater. Elsewhere, a combination of groundwater and surface water supplies were the source of expanded irrigation.

As indicated in the bar graph of irrigation diversions (Figure 4.2-5), flows diverted into local canals increased to amounts typically exceeding 90,000 afy but under 150,000 afy. Diversions from the mid-1940s through the early 1970s were increased substantially over the average diversions of 70,000 afy from 1929 through 1939, and were also remarkably steady.

TABLE 4.4-1

EXTENT OF IRRIGATED AGRICULTURE
CACHE CREEK AREA, 1961-1989, ACRES

Topographic Quadrangle	1961	1976	1989
Bird Valley			
Total	983	2,628	6,008
South[1]	980	2,650	4,550
Esparto	7,278	11,204	13,227
Madison	17,171	26,567	27,315
Woodland	22,472	27,773	26,940
TOTAL[2]	47,900	68,200	72,000

SOURCE: California Department of Water Resources
1 Hungry Hollow area, south of Oat Creek.
2 Rounded values include Woodland, Madison, Esparto and south Bird Valley.

Aggregate Extraction

As shown in Figure 4.2-7, aggregate production data for the 1940s are incomplete, but indicate production generally below 500,000 tons per year. During this period, five commercial producers operated along Cache Creek, clustered near Esparto and Yolo.[20] Most of the sand and gravel production supplied needs for roads and buildings.

Beginning in the 1950s, the industry also supported major projects like construction of Monticello Dam, building of the deepwater channel and harbor for Port of Sacramento, and expansion of the state and federal highway systems. Production at this time was centered on the Madison/Esparto area and Yolo with six producers, including Schwarzgruber, Pacific Cement, Teichert, and Granite Construction near Yolo; and Madison Sand & Gravel at Madison and Esparto.[21] Given the increased construction, aggregate production generally doubled from 1953 to 1975 (see Figure 4.2-7). Excavation data, representing the amount of material actually removed from the creek channel during this period, indicate a similar rising trend and a peak excavation in 1978 of 4.13 million tons.

Referring back to Figure 4.4-1, longitudinal profiles of Cache Creek indicate a lowering of the channel bed elevation, particularly since the 1950s. From the 1950s to 1973-1974 the thalweg was lowered along the entire creek channel from Capay Bridge to below Yolo. Maximum lowering over this period exceeded ten feet near Madison (river mile 16) and below Steven's Bridge (river mile 9). This lowering reflected the increased excavation from Cache Creek discussed above.

Groundwater Resources

As indicated at the beginning of this section, the period from 1941 to the mid-1970s was marked by substantial change in the Cache Creek groundwater system. This change, expressed as a long-term decline in groundwater levels and storage, resulted from an imbalance of groundwater discharge over recharge.

Groundwater Recharge

As indicated in the early history sections, the development of irrigation has been the most significant factor affecting groundwater resources. Two effects of surface water irrigation were 1) reduction of in-channel flows and recharge because of irrigation diversions, and 2) distribution of surface water across the basin resulting in increased summer return flows and widespread recharge of surplus irrigation water.

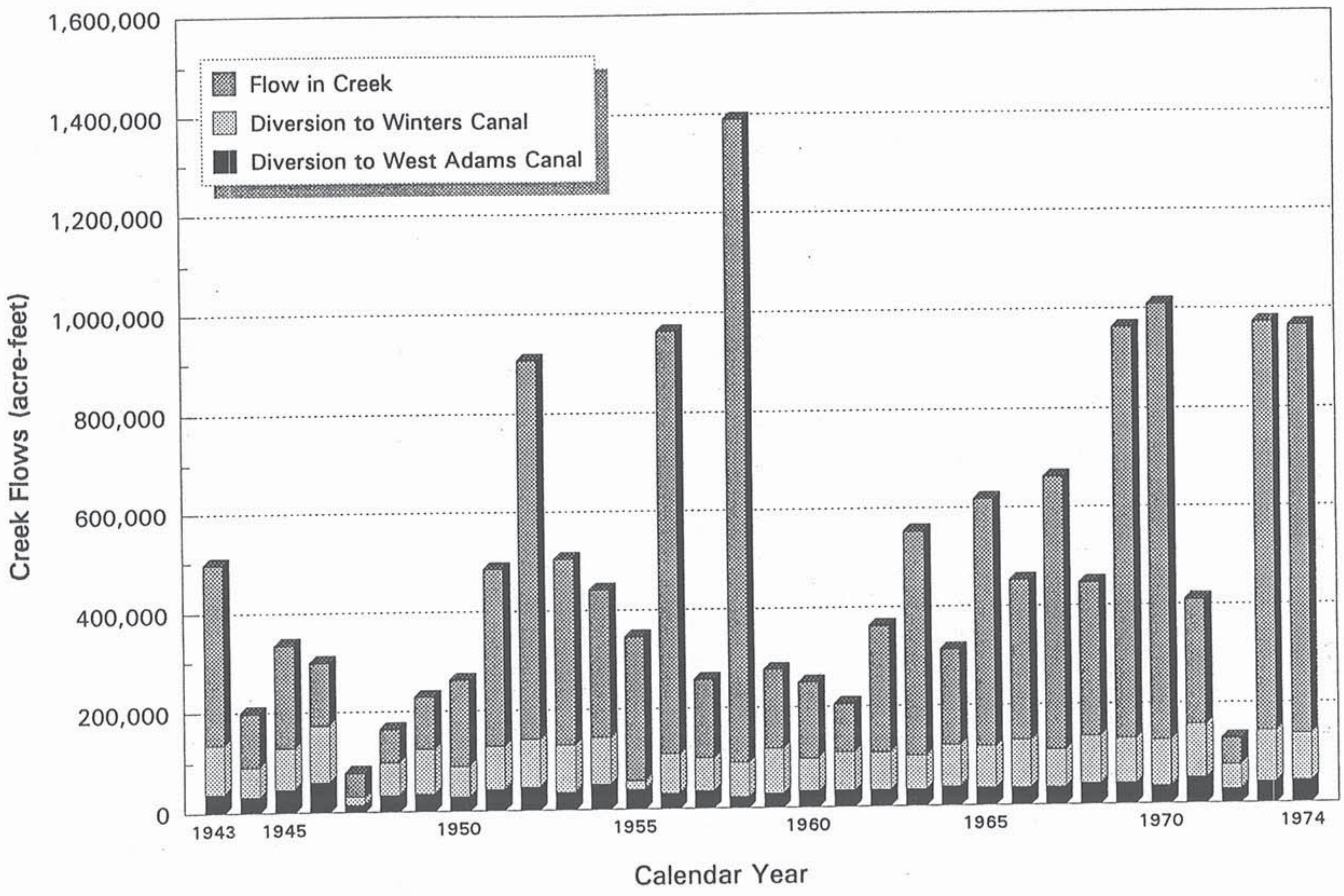
For the period 1943 to 1974, irrigation diversion and streamflow data are available to evaluate this change in the local hydrologic system. As presented in the Available Data section, streamflow data are available at Yolo from 1903 to present, with a complete record at Capay from 1942 through 1974. Diversion data also are available for this period, allowing evaluation of the inflows and outflows from Cache Creek in the study area. Because the inflows to the creek equal outflows over the long term, this evaluation is termed a water balance.

Streamflow passing the Capay gage represents the major inflow to the creek. This flow is supplemented by irrigation return flows from Alder Canal (see the schematic diagram of canals, Figure 4.2-4). Major outflows include the diversions into the West Adams, Winters, and Moore's canals and streamflow past Yolo gage. All of the above flows are measured. The remaining unmeasured flows are the discharge of groundwater to the stream (an inflow) and the recharge of streamflow to groundwater (an outflow). Because inflows and outflows must balance, the net groundwater flow can be estimated in the water balance equation:

Inflows at Capay and Alder	-	Outflows to canals and at Yolo	=	net groundwater recharge/discharge.

Along Cache Creek between Yolo and Capay, groundwater flows into the stream in certain reaches in most years, while in other reaches surface water flows out to recharge the groundwater. The above equation solves for the net groundwater recharge or discharge along the stream between Capay and Yolo. In most years, recharge to groundwater is larger than groundwater discharge. Precipitation and evapotranspiration along the channel are regarded as generally minor, largely offsetting factors and are not quantified in this evaluation. No significant streams enter Cache Creek in the study reach, so surface water inflow also is negligible.

Figure 4.4-4 illustrates the distribution of streamflow at Capay Dam from 1943 to 1974. As indicated by the total height of each bar, flow in the creek ranges from less than 100,000 to 1,400,000 afy. Of this amount, a small but fairly steady flow is diverted, typically amounting to less than 150,000 afy during this period. Of these diversions, most of the water is sent southward into Winters Canal. In about one-third of all years during this period, diversions account for 40 percent to 65 percent of flows. More typically, a major portion of the streamflow (mostly winter high flows) passes the dam to flow eastward.



October 1995

DAVID KEITH TODD
Consulting Engineers, Inc.
Berkeley, California

Figure 4.4-4
Distribution of
Water at Capay Dam
1943 - 1974

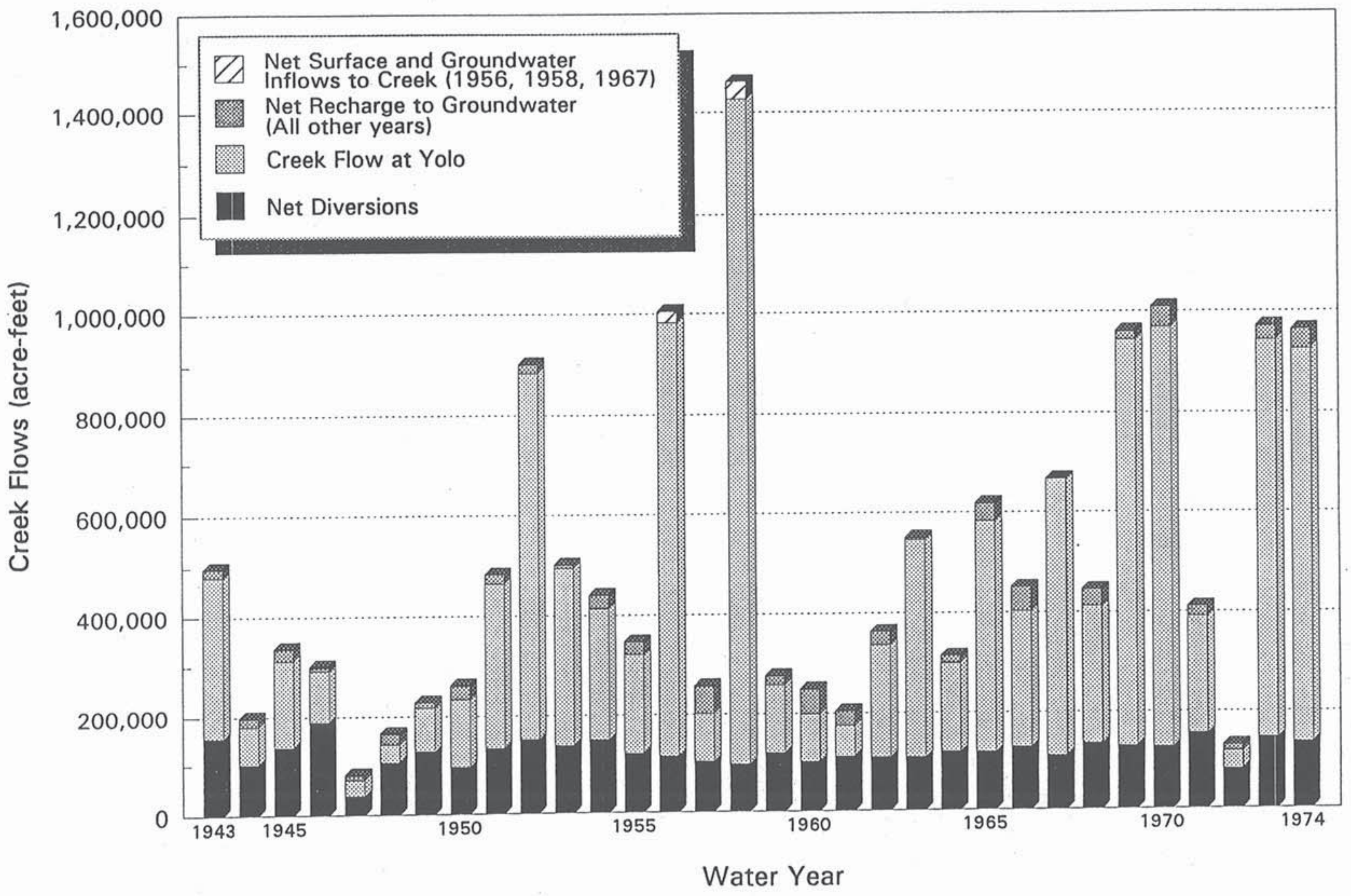
Figure 4.4-5 illustrates the distribution of water between Capay and Yolo into inflows and outflows. This bar graph differs from the previous graph in including flows past Yolo, thus allowing an accounting of surface water between Capay and Yolo. The full height of each bar represents the entire flow at Capay or Yolo, whichever is greater. Typically through this period, the flow at Yolo was less than that at Capay. Exceptions are 1956 and 1958, both wet years, and 1967 (when flow in the creek apparently gained by a small amount, about 1,000 acre-feet). In these years the flows were greater at Yolo, reflecting a net inflow of groundwater, rainfall, and surface floodwaters. Otherwise, streamflow at Yolo is less than at Capay, because of net losses to groundwater recharge (and small losses to evapotranspiration).

The stream outflows shown in Figure 4.4-5 include the net diversion for irrigation. This accounts for the outflow to Adams, Winters, and Moore's canals plus the inflow from Alder Canal. Through this period, these net diversions typically ranged from 100,000 to 150,000 afy. It is noteworthy that diversions account for a significant portion of total streamflow in low-flow, drought years. As a result, in the years when the least flow is available for groundwater recharge in the channel, most of that flow is diverted away into canals. This would tend to make channel recharge more variable seasonally and from year to year, and to increase the magnitude of groundwater level changes in areas recharged by the creek.

Nevertheless, the major outflow is the creek flow past Yolo, which occurs primarily in wet years. Once net diversions are accounted for, the difference between Capay and Yolo flows represent the net outflow to groundwater recharge with the exception of the three gaining years (1956, 1958, 1967) discussed above. Average recharge to groundwater during this period is 24,800 afy, not including the three years with net gains. This value is similar to those derived in previous studies, which reported estimated Cache Creek recharge values of 22,400 afy for the period 1962-1971[22] and 27,620 afy for the period 1959-1979.[23] Recharge along Cache Creek also has been estimated for the period 1954 to 1959.[24] The resulting value of 34,000 afy is considerably greater than results of this and other studies, resulting largely from inclusion of rainfall on the channel (9,000 afy).

Inspection of Figure 4.4-5 indicates that net groundwater recharge exceeded 50,000 afy in 1957 and 1960, despite relatively limited streamflow and the considerable diversions from the creek. Review of the hydrographs in Figure 4.4-3 shows that groundwater levels were relatively low at this time, providing available groundwater storage space in local aquifers and recharge capacity. The doubling of net recharge in 1957 and 1960 thus illustrates the considerable recharge capability of the Cache Creek channel and the capacity of the groundwater basin to be recharged following depletion.

To provide some perspective on the significance of Cache Creek recharge, it was noted that during this period some 100,000 to 150,000 afy were diverted from the channel for irrigation. Assuming that a conservative 15 to 20 percent of diverted flows contribute to groundwater recharge through deep percolation of applied irrigation water and canal leakage, then 15,000 to 30,000 afy, or an average of 22,500 afy are recharged throughout the area served by the canal system. This is comparable to the stream recharge.



October 1995

DAVID KEITH TODD
Consulting Engineers, Inc.
Berkeley, California

Figure 4.4-5
Water Distribution
Between Capay and Yolo
1943 - 1974

Groundwater Development

Although groundwater irrigation in the Cache Creek area was developed first to supplement surface water during dry years, groundwater use expanded to be a significant alternative to surface water irrigation by the 1950s.[25]

As noted previously, data are lacking on amounts of groundwater pumpage for irrigation. Nonetheless, estimates are available based on sales of electric power and pump test records.[26] Estimates of groundwater pumpage for the years 1966-1968 were compiled on a township basis, and can be summarized for the general study area as shown in Table 4.4-2. As indicated, the available estimates of irrigation pumpage span three years, including two relatively dry years (1966 and 1968) and one wet year, 1967, when pumpage was reduced because of available rainfall and surface water irrigation. The estimated groundwater pumpage in these three years ranged from 46,000 to over 69,000 afy, and averaged 60,800 afy. This is about one-half of the average surface water diversion for the same years.

TABLE 4.4-2

ESTIMATED GROUNDWATER PUMPAGE FOR IRRIGATION, CACHE CREEK STUDY AREA, 1966-1968, AFY

Township	1966	1967	1968
T10N R1E	27,400	18,700	27,200
R1W	33,900	24,000	35,500
R2W	4,090	2,950	4,790
T11N R1W	0	30	557
R2W	1,300	887	1,200
TOTAL$_2$	66,690	46,567	69,247

SOURCE: Mitten, 1971.

Although the estimates span three years, they represent essentially a snapshot of pumpage in the late 1960s and do not provide insight into trends. Nonetheless, review of available data on irrigated acreage and surface water diversions, and on well drilling do provide evidence for a substantial increase in groundwater pumpage from the 1950s through the 1970s.

As documented in Table 4.4-1, irrigated acreage in the study area increased from 47,900 to 68,200 acres between 1961 and 1976. Assuming an average water application rate of three feet per year throughout this period, then irrigation water demands increased from about 144,000 to 205,000 afy. Surface water diversions during this period increased somewhat to meet this demand: in 1961 diversions amounted to 109,800 acre-feet, and in 1975 were 137,400 acre-feet.[27] However, as shown in Figure 4.2-5, diversions over the entire period from the mid-1940s through the early 1970s were steady. Accordingly, groundwater pumpage supplied the shortfall. If estimated water demand in 1961 amounted to 144,000 acre-feet, and surface water satisfied 109,800 acre-feet, then an estimated 34,200 acre-feet of groundwater was pumped in 1961. Similarly, if estimated water demand in 1976 was 205,000 acre-feet, and surface water satisfied 137,400 acre-feet, then an estimated 67,600 acre-feet of groundwater was pumped in 1976. This analysis suggests a doubling of groundwater pumpage for irrigation in the 15 years between 1961 and 1976.

Figure 4.2-5 shows that surface water diversions in 1977 were zero. Assuming that irrigation water demand was the same in 1977 as in 1976, and that all farmers had access to groundwater, then it can be surmised that a very large amount of groundwater was pumped in 1977. Because all farmers do not have access to groundwater, it is unlikely that groundwater pumpage tripled from 1976 to 1977 to satisfy the full demand of 205,000 acre-feet. Nonetheless, it may easily have doubled.

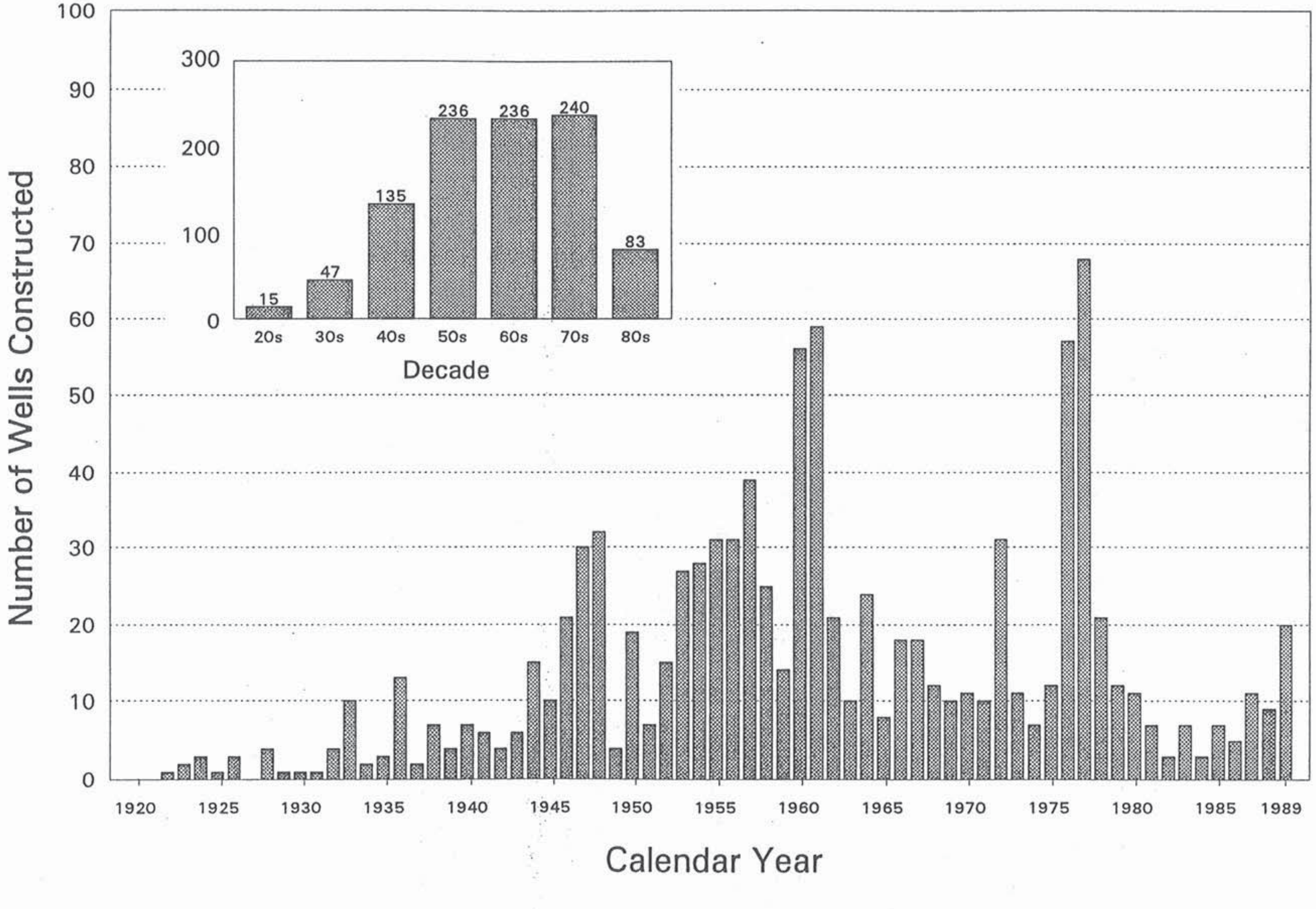
Figure 4.4-6 documents the number of water well drillers reports filed with the DWR from the 1920s to the 1990s for the Cache Creek area (townships 10N/1E and 1W). Filing of such reports has been required since the 1950s, and although compliance probably is not complete, the number of report filings is indicative of well drilling activity and groundwater use. As shown in Figure 4.4-6, the number of drillers reports is small until the mid-1940s, and then increased substantially. In the 1940s, 126 drillers reports were filed, and in the 1950s, 1960s, and 1970s this number doubled to nearly 240 wells per decade, indicating substantial activity in groundwater development and use. The very large number of wells drilled in 1960 and 1961 probably reflects not only increases in irrigation, but also the drought conditions of 1959 through 1961.

The large number of wells drilled in 1976 and 1977 not only reflect extreme drought, but support the supposition that substantial quantities of groundwater were pumped in those two years, especially 1977.

Groundwater pumpage for municipal supply also increased. As shown in Figure 4.2-6, City of Woodland pumpage ranged generally from 6,000 to 7,000 afy in the 1960s, or about one-tenth of agricultural groundwater pumpage. Subsequently in the late 1960s to early 1970s, municipal pumpage increased to about 9,000 afy.

Groundwater-Surface Water Relationships

The general interaction of Cache Creek and groundwater has long been recognized as including several gaining (groundwater discharge) and losing reaches (groundwater recharge), which vary in length according to local depths to groundwater. In general, Cache Creek loses flow to groundwater recharge in the reach below Capay Dam, gains flow above Plainfield Ridge, and again loses flow in the reach between Stevens Bridge to Yolo.



October 1995	Figure 4.4-6
DAVID KEITH TODD Consulting Engineers, Inc. Berkeley, California	Wells Constructed In 10N/1E and 10N/1W 1920 - 1989

The most comprehensive study of groundwater interaction with surface water was completed by Richardson and Rantz.[28] This study utilized temporary stream gaging at eight locations along Cache Creek between 1952 and 1957. The results showed losing reaches located between Capay and Esparto Bridge (0 to 20 cfs), Moore Dam to the Dunnigan Hills Anticline (0 to 15 cfs), and Dunnigan Hills Anticline to Yolo (64 cfs). The reach between Esparto Bridge and Madison Bridge was mostly gaining (0 to 12 cfs). The reach between Madison Bridge and Moore Dam varied from gaining during wet years (0 to 27 cfs) to losing during dry years (0 to 10 cfs). Another study conducted from 1953-54 to 1958-59[29] documented losing reaches between Capay Dam and Dunnigan Cutoff (Highway 505), and Moore Dam to 1.5 miles southwest of Yolo. A gaining reach was noted between Dunnigan Cutoff and Moore Dam.

The interactions of groundwater and streams changed through the period because of declining groundwater levels. As a result, Cache Creek was reported in autumn 1977 to be losing flow to groundwater recharge along its entire length.[30]

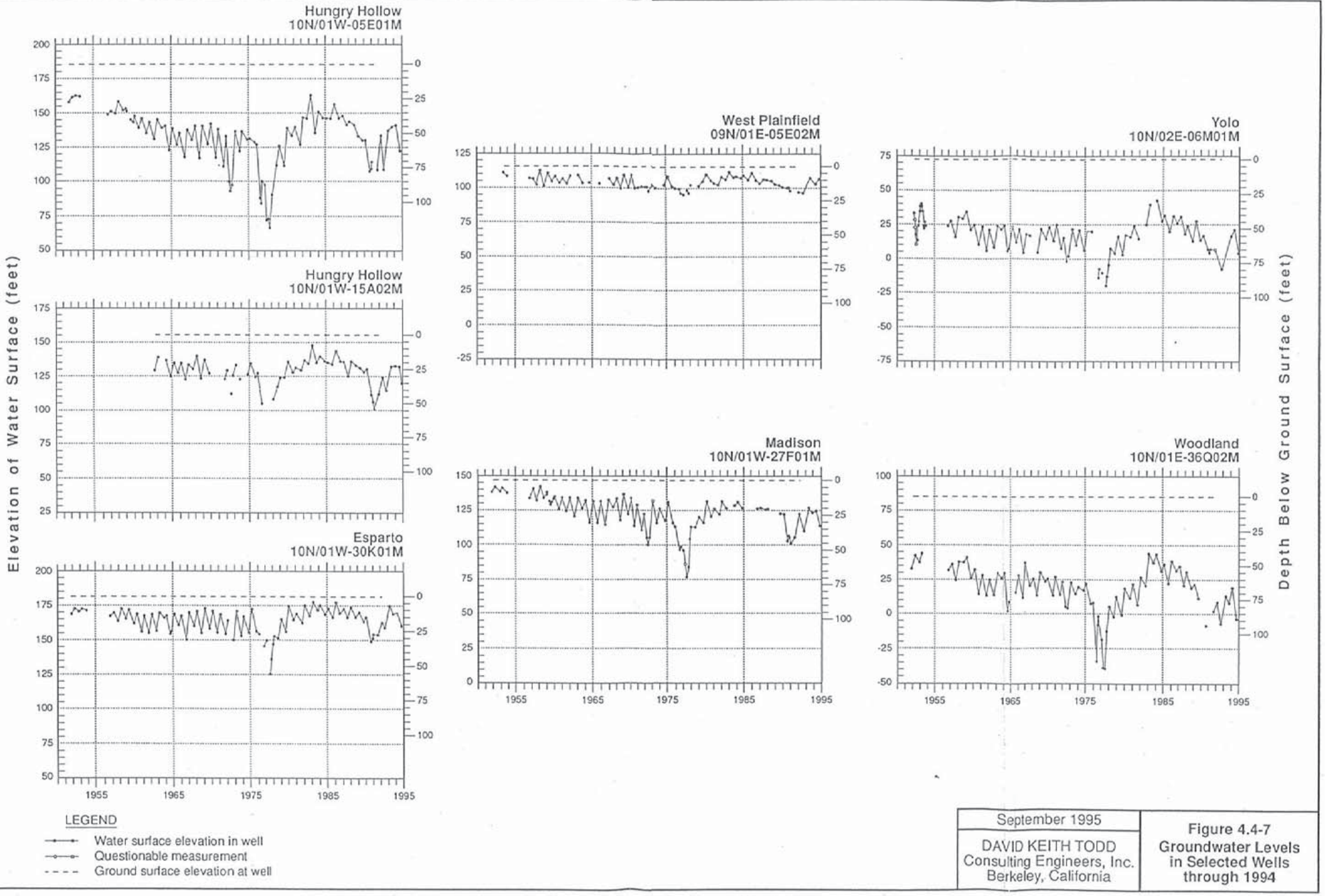
Groundwater Levels

As noted previously, groundwater development was relatively minor until the 1950s. Accordingly, groundwater levels and flow were influenced primarily by available rainfall and streamflow. As a result, groundwater levels were at their lowest in 1934, reflecting seven years of drought, and subsequently were at essentially "full-basin," all-time high levels in the early 1940s,[31] reflecting high rainfall in the late 1930s and early 1940s.

Thereafter, as shown by selected hydrographs in Figure 4.4-7, groundwater levels declined until the late 1970s, especially in Hungry Hollow and east of Plainfield Ridge near Woodland and Yolo. Groundwater level declines were particularly pronounced in northern Hungry Hollow (approaching 100 feet of decline in Well 10N/5E1) as a result of groundwater pumping, relative lack of local recharge from streamflow and surface water return flow, and aquifer limitations. Declines were less severe in southeastern Hungry Hollow (Well 10N/15A2), reflecting recharge from areas irrigated by Cache Creek diversion and directly from Cache Creek. Groundwater levels in the Esparto area remained relatively constant, reflecting the continuing availability of surface water irrigation return flows as a source of groundwater recharge (see Early History). In areas of water level decline, groundwater levels reached their minimum during the drought of 1976-77.

The aerial pattern of groundwater level decline is illustrated by review of a series of groundwater level contour maps, including Figure 4.4-2, showing high groundwater level conditions in 1912-1913, and Figures 4.4-8 through 4.4-10, showing conditions in spring 1959, spring 1977, and fall 1977.

The groundwater contour map for spring 1959 (Figure 4.4-8) shows a regional gradient and movement of groundwater from west to east similar to the 1912-1913 map.[32] However, overall groundwater levels are lower in 1959 than in 1912-1913, reflecting in part the relatively meager rainfall in the 1950s (see Figure 4.4-8). The 1959 map differs substantially from the earlier map in Hungry Hollow and the area east of Plainfield Ridge. The Hungry Hollow area in 1959 was



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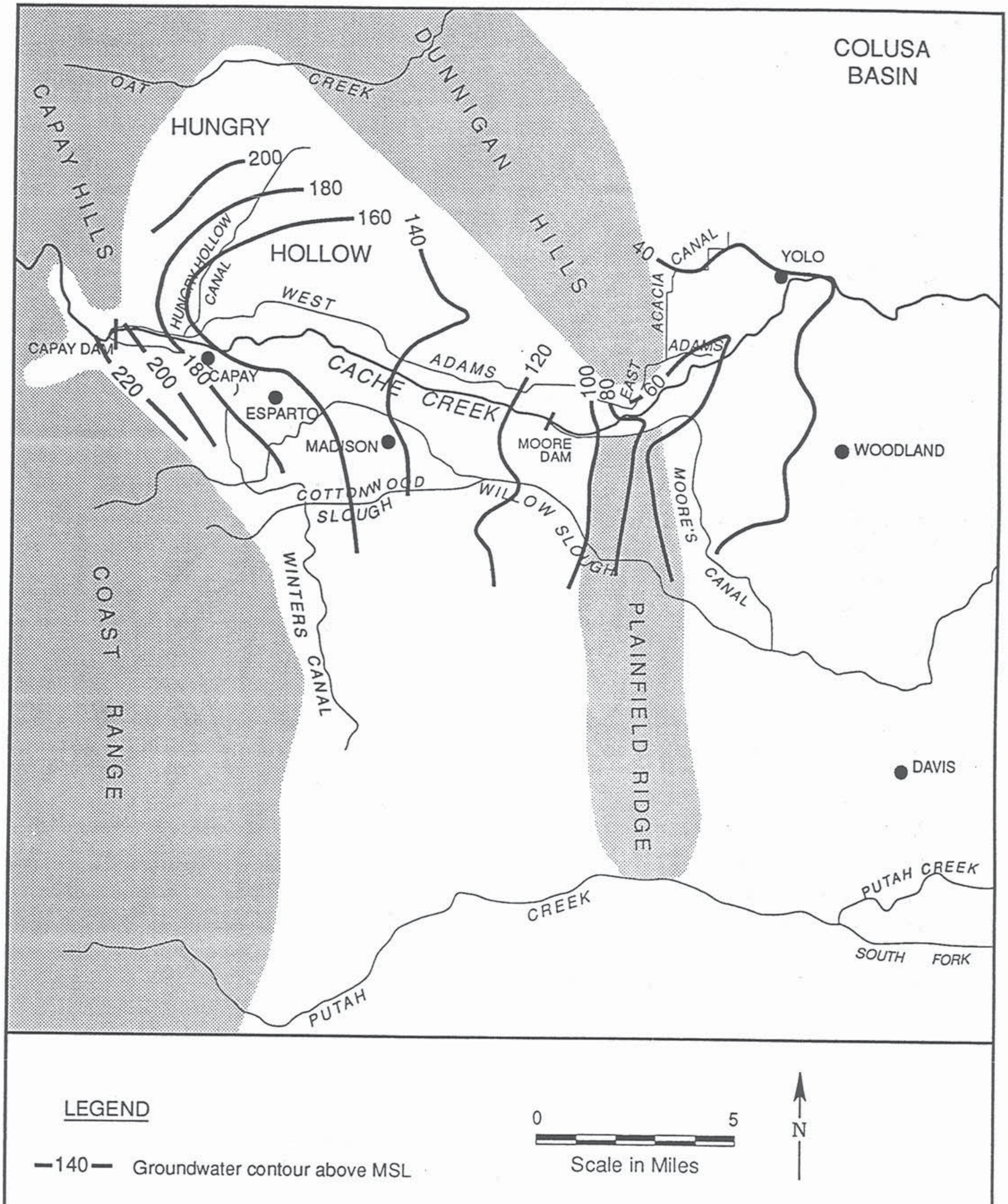
DAVID KEITH TODD
Consulting Engineers, Inc.
Berkeley, California

Figure 4.4-7
Groundwater Levels
in Selected Wells
through 1994



Reference: Adapted from Wahler (1981)

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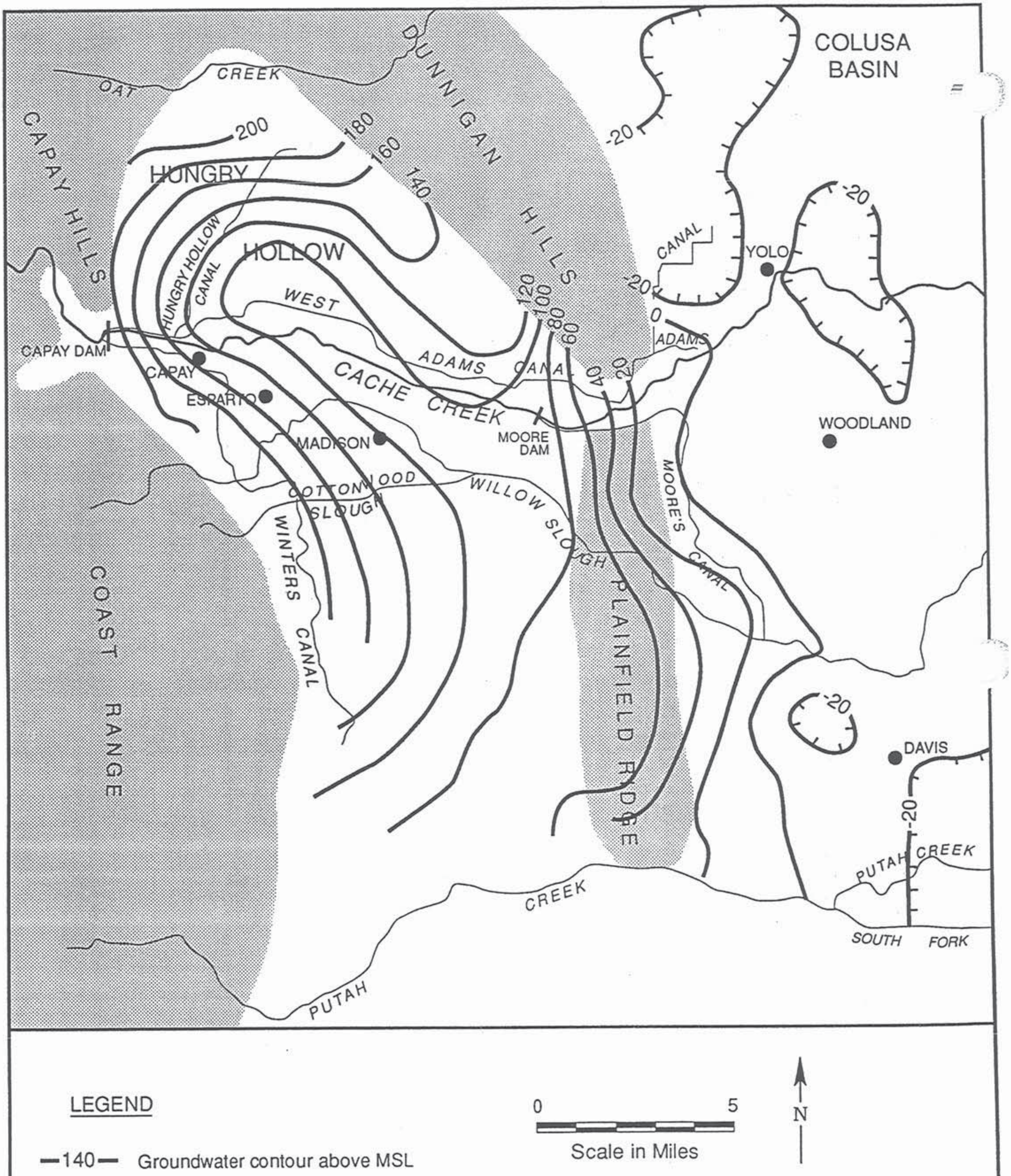
Consulting Engineers, Inc.
Berkeley, California

Figure 4.4-8
Spring 1959
Groundwater Elevation
Contour Map



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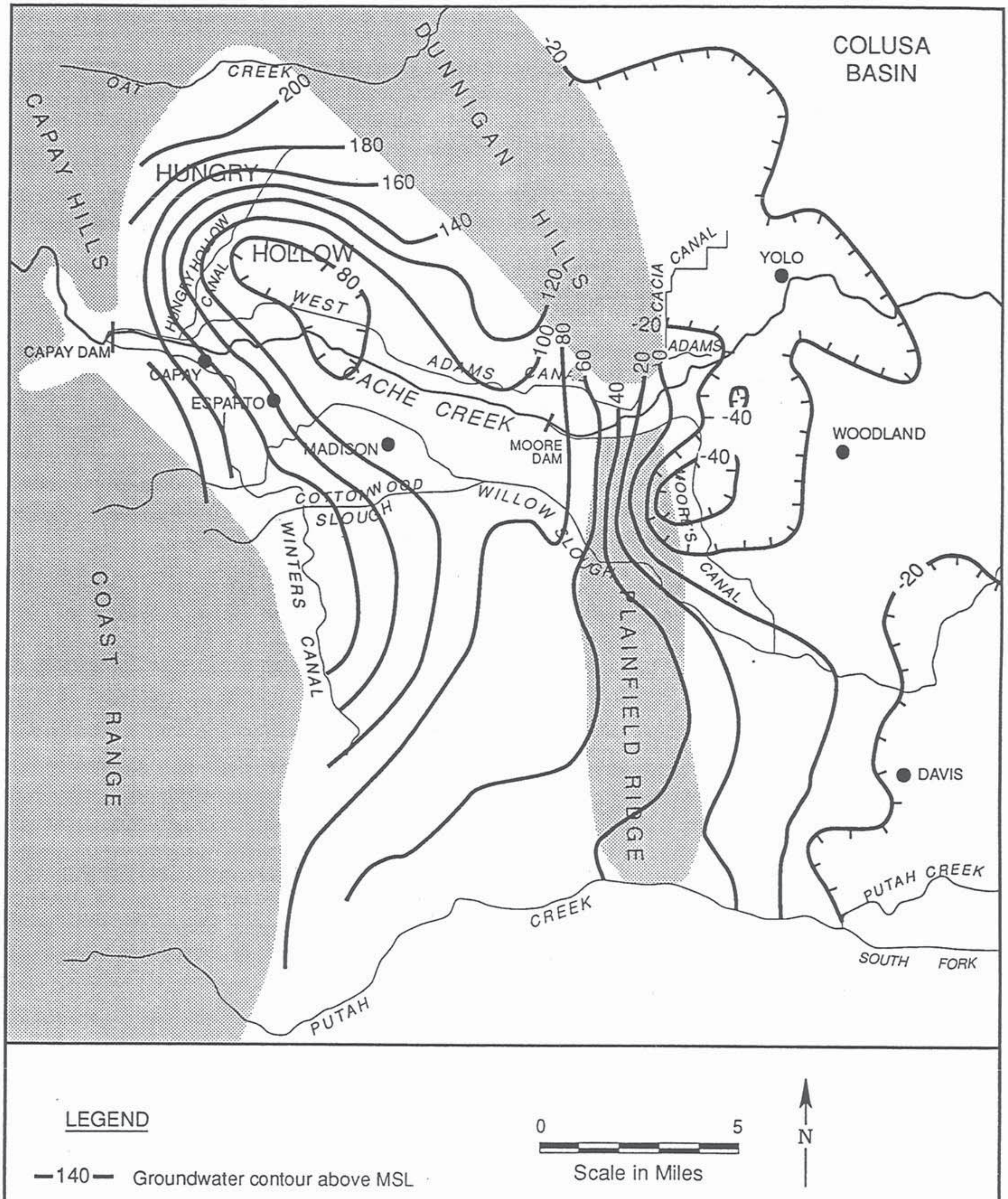
Consulting Engineers, Inc.
Berkeley, California

Figure 4.4-9
Spring 1977
Groundwater Elevation
Contour Map

Reference: Adapted from Luhdorff and Scalmanini (1992)



Reference: Adapted from Luhdorff
and Scalmanini (1992)

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DAVID KEITH TODD
Consulting Engineers, Inc.
Berkeley, California

Figure 4.4-10
Fall 1977
Groundwater Elevation
Contour Map

marked by a broad depression in groundwater levels, best expressed by the 150 foot-contour that loops westward toward Capay. Other, less pronounced depressions in groundwater levels can be identified south of Cache Creek. These depressions in groundwater levels indicate a convergence of groundwater toward areas of intensive pumping.

East of Plainfield Ridge, another broad depression is indicated southwest of Woodland, which is defined on the west by the close spacing of contour lines along Plainfield Ridge, and on the north by the relatively high groundwater levels beneath Cache Creek east of Plainfield Ridge. The steep groundwater gradient along Plainfield Ridge is due to a combination of intensive pumping to the east and the damming effect of the Tehama Formation along Plainfield Ridge.

The relatively high groundwater levels beneath the Cache Creek east of the Ridge are caused by percolation of surface water into the subsurface (defining a losing reach). Gaining and losing reaches along Cache Creek are not well defined west of Plainfield Ridge due to distortion of contour lines by pumpage. Groundwater contours just west of Plainfield Ridge suggest the possibility of a recharge mound beneath Willow Slough. This would indicate a change in Willow Slough from generally perennial (receiving groundwater discharge) to providing groundwater recharge. However, this feature may be less indicative of Willow Slough recharge and more the result of convergence of groundwater to the north and south due to pumping.

The groundwater contour map for fall of 1959[33] shows increasing effects from groundwater pumpage, particularly in Hungry Hollow and east of Plainfield Ridge. Review of the groundwater hydrographs (Figure 4.4-7) indicates that these conditions generally persisted and intensified through the 1960s and into the 1970s, largely as a result of increased groundwater pumping.

Figure 4.4-9 is a groundwater contour map for spring 1977.[34] Groundwater levels in spring normally are near the seasonal peak, reflecting recharge from winter rain and runoff and the relative lack of groundwater pumping in winter. However, the spring 1977 map, reflecting drought conditions, shows closed pumping depressions already forming in Hungry Hollow, south of Cache Creek near I-505, and near Woodland and Yolo. By fall of 1977 (Figure 4.4-10) large pumping depressions had developed in Hungry Hollow, and particularly near Woodland and Yolo, where groundwater levels were pulled down to forty feet below mean sea level. These conditions resulted from the extreme lack of rainfall and surface water deliveries during the 1976-1977 drought and (as indicated in the section on groundwater development) intensive pumpage of groundwater.

Groundwater Storage

Estimates of total groundwater storage for the study area are described in Hydrogeologic Setting. To summarize briefly, a number of investigations (using various study areas and hydrogeologic parameters) generally agree that a very large amount of groundwater is available in storage in the Cache Creek region, approximating some two million acre-feet in the uppermost 200 feet of the groundwater basin.

During the 1960s and 1970s, however, significant declines in groundwater storage occurred. In 1975, the water balance was estimated for Yolo County.[35] Using a study period of 1963-1972, an overdraft of 12,000 acre-feet per year was computed. Similarly, Clendenen and Associates[36] computed indicated an overdraft of 18,900 acre-feet per year.

At the same time, the potential for permanent change in groundwater storage capacity due to lowering of the Cache Creek channel became a public concern. In 1976, a report on aggregate extraction in Yolo County[37] initially proposed that aggregate extraction had caused more than 10 feet of stream channel lowering between Esparto Bridge and Moore Dam. This lowering of the thalweg (stream channel elevation) in turn had caused a 10-foot reduction in groundwater levels over a 30 square mile area west of Plainfield Ridge. This conclusion was based on analysis of springtime groundwater levels between 1953 and 1974, which reported that spring groundwater levels did not exceed the stream thalweg elevation. An analogy to a chipped tea cup was presented to explain the mechanism by which groundwater storage had been permanently reduced. The loss in groundwater storage capacity was estimated to be 17,000 to 38,000 acre-feet, depending on the value of specific yield used in the calculation. The validity of the tea cup analogy subsequently was challenged, as will be described in the Recent History section.

Groundwater Quality

Two evaluations of groundwater quality were conducted, one in 1961[38] and another in 1975.[39] These are described in some detail in Hydrogeologic Setting. The 1961 evaluation echoed observations from 1870 and 1923 (see Early History) that groundwater in the Cache Creek area is hard to very hard, with total dissolved solids generally less than 700 ppm. The two studies, however, identified boron as an element of concern, as water containing elevated boron may be harmful to sensitive crops.

Elevated boron concentrations were attributed to water diverted from Cache Creek for irrigation. The 1961 DWR study notes that groundwater from deeper wells generally has lower boron concentrations than does shallow groundwater. This would reflect the considerable influence on shallow groundwater of 1) direct recharge from Cache Creek, and 2) percolation of irrigation water derived from Cache Creek. The latter is identified as the major factor in boron concentrations in the basin. This suggests an overall pattern of increasing boron in areas irrigated by Cache Creek diversions. However, data on boron concentrations in groundwater are scanty, especially after the 1950s, and no convincing trends could be discerned.

Although the 1975 study states that groundwater quality with respect to nitrate is very good, it also identified a slight overall increase in nitrate in groundwater since the mid-1950s. High nitrate levels can be associated with agricultural activity. As with boron, nitrate data that could reveal trends during this period are lacking.

Summary

To summarize the period 1941-1977, rainfall from 1941 to the mid-1970s approximated the long-term average rainfall of 17 inches at Davis. Generally, the rainfall was moderate, without extremely dry or wet years until the severe drought of 1976-1977. Diversions out of Cache Creek also were steady through much of this period. Thus two of the major factors discussed in the earlier period remained relatively steady through much of the middle history.

The period 1941 to 1977 was marked by substantial change in the groundwater system. Groundwater levels declined from record highs as the beginning of the period to record lows in 1977. Broad depressions in groundwater levels developed, altering the regional groundwater flow pattern from a general west to east flow to patterns of groundwater flow converging into major pumping areas. Stream/groundwater interrelationships were changed as groundwater levels declined, reducing groundwater discharge to streams and increasing recharge of streamflow.

The major cause of this change was increased groundwater pumping, primarily for irrigation. Irrigated acreage increased between 1961 and 1976 at the rate of about 1,350 acres per year. Given that stream diversions were relatively steady through this period, most of the increase in irrigation was based on groundwater. Well drilling activity increased significantly in the 1950s, 1960s, and 1970s, and groundwater pumping for irrigation apparently doubled in the 15 years between 1961 and 1976. An overdraft situation was documented by the mid-1970s, and concerns were raised that boron and nitrate concentrations were increasing in groundwater. At the same time, the substantial growth of aggregate mining in Cache Creek and the documented decline of the channel thalweg resulted in concern that mining had caused a permanent decline in groundwater levels and basin storage capacity.

Recent History, 1978-1995

The period from 1941 through 1977 was characterized by progressive change: an expansion of irrigated agriculture, an increase in well drilling and groundwater pumping, growth in the aggregate mining industry, and sustained declines in groundwater levels. In contrast, recent groundwater history is better characterized as the establishment of a dynamic equilibrium expressed in fluctuating groundwater levels.

In brief, the expansion of irrigated agriculture and groundwater pumping slowed considerably. At present, much of the readily irrigable land is irrigated, and surface water and groundwater irrigation facilities are largely in place. The mining industry also apparently has changed from a growth industry to one bounded by regulations and modulated by fluctuating demands for construction materials. Groundwater levels since 1978 have been marked by successive increase, decrease, and increase again in response to variable rainfall, and irrigation water supply and demand.

Irrigated Agriculture

Agriculture in the 15 years prior to 1975 was characterized by rapid expansion of irrigated acreage, on the order of 1,350 acres per year. Referring back to Table 4.4-1, review of the acreage for 1976 and 1989 indicate that expansion of irrigation continued, although at a lower rate averaging about 300 acres per year. The expansion was most notable in the Hungry Hollow area, where irrigated acreage nearly doubled between 1976 and 1989. Minor infilling and expansion of irrigation occurred in the Esparto and Madison areas, while irrigated agriculture near Woodland declined as a result of urbanization.

The 1989 land use mapping is notable for including information on the source of irrigation water. This information also is available on County GIS maps. Review of these maps reveals general geographic patterns with implications for groundwater resources, summarized below.

- Irrigation north and west of the Hungry Hollow canal is based primarily on groundwater. The relative lack of local groundwater recharge in Hungry Hollow and reliance on groundwater extraction suggests that this area tends to be a net sink for groundwater, characterized by a pumping depression in groundwater levels and convergent flow.
- Irrigation south of the Hungry Hollow canal and north of Cache Creek relies on surface water, or surface water plus groundwater. A few parcels rely on groundwater.
- Irrigation between Cache Creek and Highway 16 to Road 94b is based almost entirely on groundwater. This area's dependence on groundwater suggests that local consumptive groundwater use exceeds recharge.
- Areas south of Highway 16 and west of Woodland rely on surface water supplemented with groundwater. This area may be net source of groundwater recharge, given available surface water.
- Irrigation in areas north and east of Woodland is based primarily on groundwater, supplemented locally with surface water. Groundwater consumption in such areas may exceed local recharge.

A major development in Yolo County's irrigation water supply was the completion in 1975 of Indian Valley Dam and Reservoir on the North Fork of Cache Creek. This reservoir, operated by Yolo County Flood Control and Water Conservation District with a design yield of 48,000 afy, became operational just before the onset of the 1976-1977 drought and thus had little effect on water supplies until after the drought, when surface water was available for storage and use.

Review of the histogram of irrigation diversions, Figure 4.2-5, reveals that diversions increased with completion of Indian Valley Reservoir. Beginning in 1978, irrigation diversions approached 200,000 afy and generally were in the range of 150,000 to 190,000 afy.

Despite the availability of increased surface reservoir storage since 1974, irrigation diversions became more variable than those during the 1940s, 1950s, and 1960s, largely in response to increased variation in annual rainfall amounts (see Davis precipitation, Figure 4.2-1). Review of Figure 4.2-5 indicates, however, that the variation in rainfall experienced since the mid-1970s is perhaps more typical of the long rainfall record than the moderate rainfall pattern of the three preceding decades.

Aggregate Extraction

Review of Figure 4.2-7, illustrating sand and gravel production and extraction along Cache Creek, shows that mining activities continued to increase into the 1970s. This increased activity, plus observations of changes along the creek channel, raised concern among some County residents over potential impacts of mining. In response, the Yolo County Board of Supervisors established the Aggregate Resources Advisory Committee in 1975. The purpose of this group was to examine potential impacts of gravel extraction in Yolo County, define alternative management actions and policies, and make recommendations to the Board of Supervisors. As a result, a study, *Aggregate Extraction in Yolo County,*[40] was prepared. This study described impacts of streambed lowering and widening, and presented a number of recommendations. These recommendations included monitoring and various studies of the channel, technical measures to control erosion (e.g. check dams and jetties), establishment of conditional use permits for mining, establishment of a fixed thalweg, and encouragement of off-channel mining.

Subsequently in 1979, Yolo County adopted the Interim In-Channel Surface Mining Regulations. This ordinance pertains to existing and new surface mining operations in the channel, and requires that all new mining operations have a surface mining permit, while existing operations are required to have an operation application on file. The ordinance specifies permit contents, fees, and reporting requirements and sets standards for mining operations. Noteworthy among these were standardized setbacks and excavation slopes; affirmation of reclamation requirements, particularly to agricultural uses; fixing of a theoretical thalweg; and establishment of limitations on annual sand and gravel extraction for each operator. Limitations for each operator were based on the highest annual extraction in 1976, 1977, or 1978; the sum of these limitations is 4.38 million tons per year.

Review of Figure 4.2-7 shows that mining increased substantially in the 1970s, increasing from 2.6 million tons in 1975 to a peak of 4.13 million tons in 1978. Thereafter, mining has fluctuated between 1.30 and 3.77 million tons and has averaged 2.63 million tons per year. The graph suggests that aggregate mining along Cache Creek has changed from an industry characterized by growth in production prior to the 1970s, to an industry with varying production, limited by County ordinance and affected primarily by the fluctuating demands of the construction industry.

A significant development after 1975 has been the initiation of off-channel mining, which likely will characterize the future of sand and gravel mining along Cache Creek. Off-channel mining was first permitted for Solano Concrete in 1980 and initiated in 1981. Since that time, off-channel mining has accounted for approximately 600,000 tons per year of total excavation.

Groundwater Resources

Groundwater Recharge

Rainfall during the past 20 years has been characterized by significant variability. As illustrated in Figure 4.4-7, the extreme drought of 1976 and 1977 marked the lowest annual rainfall since 1877, with the two lowest back-to-back years on record. Similarly, the 1982 and 1983 seasons experienced the highest rainfall amounts since 1889-1890, and were the two highest back-to-back years on record. Although the period began with the extreme drought of the mid-1970s and included the prolonged drought of 1987-1991, the overall period is characterized by above average rainfall of about 20 inches per year at Davis.

As described in the Middle History section, during that period information was available on streamflow and diversions, allowing a water balance analysis for the creek and estimation of creek recharge. Net recharge was estimated to average 24,800 afy from 1943 to 1974 (comparable to previous estimates), with peak recharge exceeding 50,000 afy in 1957 and 1960. With the loss in the mid-1970s of the Cache Creek gage at Capay, such an analysis is not possible for recent years without simulation of streamflow data at Capay.

Wahler[41] simulated several years of Capay streamflow to extend his evaluation of stream recharge through 1979. This evaluation indicated recharge amounting to 114,000 acre-feet in 1978, or about four times the average annual recharge. As noted for the peak recharge years of 1957 and 1960 (see Middle History), this substantial recharge reflects the effect of groundwater storage depletion in the preceding extreme drought years of 1976 and 1977. The 1978 recharge dramatically illustrates the recharge capability of Cache Creek and the capacity of the groundwater basin to recover following drought and depletion.

The Middle History also documented the relative importance of surface water irrigation as a source of recharge, indicating that estimated offstream recharge of surplus irrigation water (22,500 afy) was comparable to instream recharge (24,800 afy). Applying a parallel analysis to the period after 1977, a larger flow was diverted from the channel for irrigation than before Indian Valley Reservoir. This flow amounted to about 150,000 to 190,000 afy. Assuming that a conservative 15 percent contributes to groundwater recharge, then 22,500 to 28,500 afy, or an average of 25,500 afy are recharged throughout the area served by the canal system. Note that a recharge value of 15 percent alone was used in contrast to the 15 to 20 percent value used previously. This assumes improvements in irrigation management.

Comparison of the estimated recharge from irrigation prior to and after 1977 suggests that the expansion of surface water irrigation resulted in a small increase in groundwater recharge from that source, from 22,500 to 25,500 afy. As noted before, no recent information are available to assess in-channel recharge for comparison. However, extrapolation of the 1943-1974 average value of 24,800 afy to the present time indicates that off-channel, indirect recharge of Cache Creek water is comparable to in-channel recharge of Cache Creek water.

Groundwater Development

No data, or even estimates are available on amounts of groundwater pumping for irrigation over the past 20 years. However, information on irrigated acreage and surface water diversions can be instructive regarding recent groundwater use. While review of this information indicated a substantial increase in groundwater use prior to 1976, only a small increase is suggested from 1976 to 1989.

As shown in Table 4.4-1, irrigated acreage in the Cache Creek area increased from 68,200 acres in 1976 to 72,000 acres in 1989. As in the Middle History section, assuming an average water application rate of three feet per year, then irrigation water demands increased from about

205,000 to 216,000 afy. Surface water diversions increased after 1974 with construction of Indian Valley Reservoir. However, because of drought conditions in 1989 surface water diversions amounted to 143,900 acre-feet, only somewhat greater than the 1975 diversion of 137,400 acre-feet. As before, the 1976 diversions were not used for comparison because of the extreme drought condition. Assuming that groundwater pumpage supplied the shortfall between estimated irrigation demands and surface water deliveries, then an estimated 67,600 acre-feet of groundwater were pumped in 1976, and 72,100 acre-feet of groundwater were pumped in 1989. In contrast to the doubling of pumpage indicated for 1961 to 1976, this analysis suggests an increase in groundwater use from 1976 to 1989 of only seven percent. Given the relatively high rainfall of the recent period, it is reasonable to assume that pumpage has remained steady, even decreasing in wet years.

Similarly, review of Figure 4.4-6, illustrating well drilling activity from 1920 through 1989, indicates considerable installation of wells from the 1940s through the 1970s, and a leveling off of well drilling in recent decades. The obvious exception to this trend is the large peak in well drilling in 1976 and 1977, when 124 wells are known to have been drilled in response to the severe drought and lack of available surface water. It is noteworthy that the recent drought of the late 1980s did not prompt a sharp rise in well drilling activity as in 1960-1961 and 1976-1977. This probably is due to 1) the pre-existence of back-up wells from the earlier droughts, and 2) the existence of Indian Valley Reservoir, whose storage augmented surface water supplies so that diversions continued until 1989 despite drought.[42]

Putting 1976 and 1977 aside, drilling averaged about ten wells per year from 1975 through 1988, substantially reduced from the heyday of drilling in the mid-1950s. Given that this well drilling activity includes installation of replacement wells drilled in the 1930s and 1940s (assuming a 40-year average well lifetime), then well drilling records indicate that development of groundwater to provide water for expansion of agriculture slowed from 1975 onward.

Groundwater pumpage by the City of Woodland was fairly steady through the 1970s, reflecting in part conservation measures implemented during the 1977-1978 drought. However, the early 1980s were characterized by an increase in groundwater pumpage, rising to a peak exceeding 13,000 afy in 1987. Thereafter, pumpage has been steady at 12,000 to 13,000 afy, reflecting in part renewed conservation efforts.

To summarize, review of available information on irrigation water demands and available supplies indicates that the growth in groundwater development for agriculture generally levelled off from 1975 to 1989. Well drilling activity supports this conclusion. Municipal groundwater use increased to a peak in 1987, but has been fairly constant since that time.

Groundwater Contour Maps

Regional groundwater contour maps are available for a number of years, including spring 1980,[43] spring 1983, and spring and fall 1991.[44] In addition, a groundwater contour map for spring 1993 was developed as part of this study.

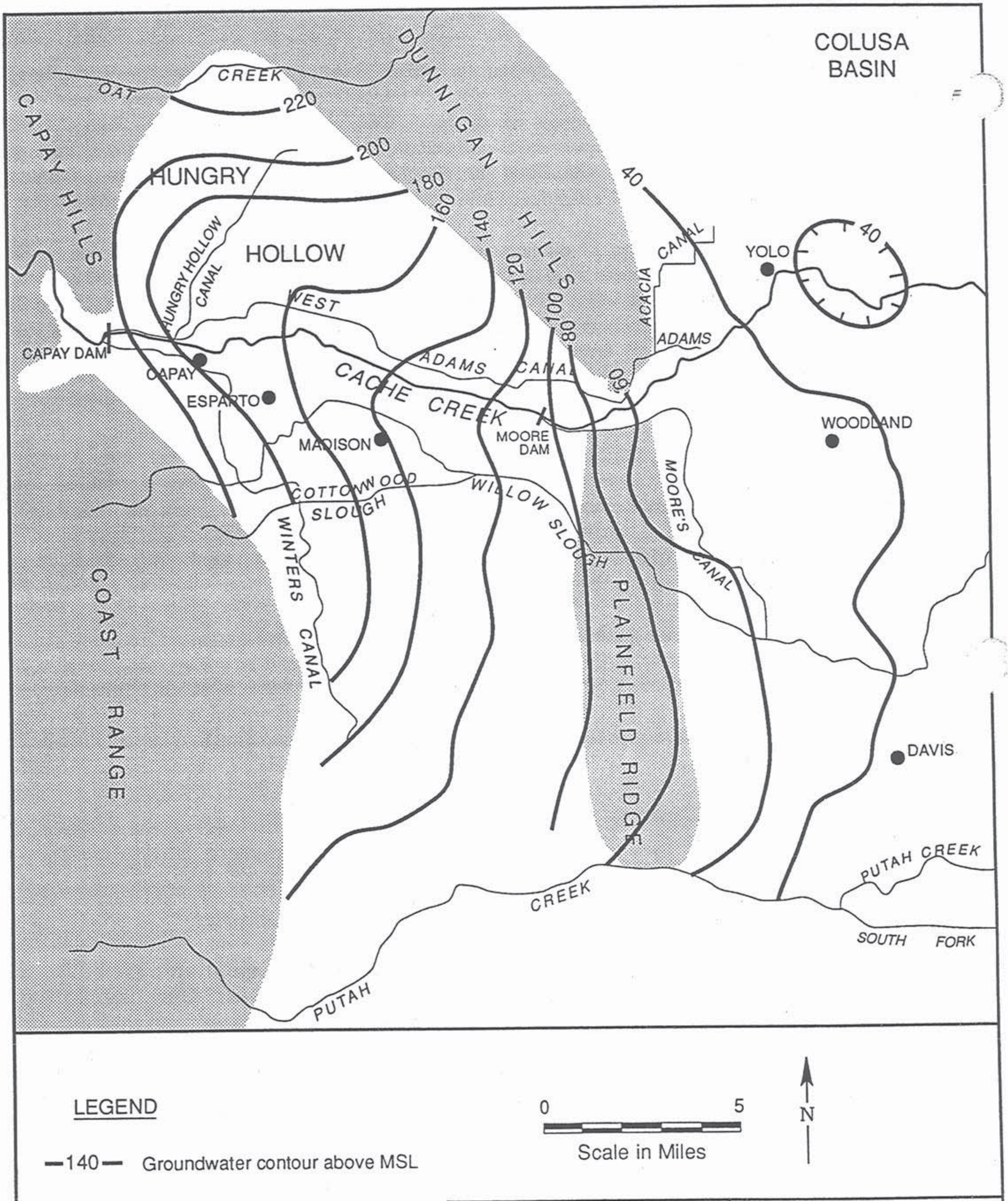
As described in the Middle History section, the fall 1977 contour map (Figure 4.4-10) depicted conditions following a severe drought and period of intensive groundwater pumping. Figure 4.4-11, depicting groundwater contours in the spring of 1983,[45] reflect conditions following several years of increased rainfall and two back-to-back record rainfall years. The comparison of the two maps is striking, as the 1983 map shows the disappearance of the closed contours indicating groundwater depressions, and restoration of the general west to east movement of groundwater.

Nevertheless, the continuation of groundwater pumping and return of drought conditions in the late 1980s resulted in the redevelopment of closed pumping depressions, as shown in the contour map for fall 1991 (Figure 4.4-12). Note that the depressions are neither as deep or broad in fall 1991 as in fall 1977. This is due to the fact that the recent drought, though prolonged, was not as extreme as the 1976-1977 drought (see rainfall in Davis, Figure 2-1). In addition, the effects of the latter drought were ameliorated by the increased availability of surface water for irrigation due to the presence of Indian Valley Reservoir, although diversions fell to zero in 1990.

Figure 4.4-13 illustrates groundwater level contours as of spring 1993, reflecting the most recent available data from DWR as well as the monitoring programs of the aggregate companies. An attempt was made to prepare contour maps for shallow and deep aquifers; however, a sufficient distribution of data points was not possible. Therefore, the map presented in Figure 4.4-13 represents a composite of both aquifers similar to previous groundwater contouring efforts. The prominent features are similar to previous maps and include:

- the general gradient of groundwater from west to east;
- a broad groundwater depression in Hungry Hollow due to intensive pumpage;
- a possible recharge mound associated with Willow Slough west of Plainfield Ridge;
- close spacing of contour lines along Plainfield Ridge;
- a recharge mound beneath Cache Creek east of Plainfield Ridge; and
- a groundwater depression around Woodland due to pumpage.

Additional features include a small groundwater trough in the Esparto area (likely due to pumpage), a possible recharge mound beneath Cache Creek between Capay and Esparto (indicating a losing reach), and a groundwater trough along Cache Creek between I-505 and Plainfield Ridge, indicating convergence of groundwater and possibly suggesting a gaining reach. However, the latter convergence may also reflect groundwater pumping in the area south of Cache Creek which relies on groundwater for irrigation. Insufficient local monitoring wells are available to resolve this question.



Reference: Adapted from Luhdorff and Scalmanini (1992)

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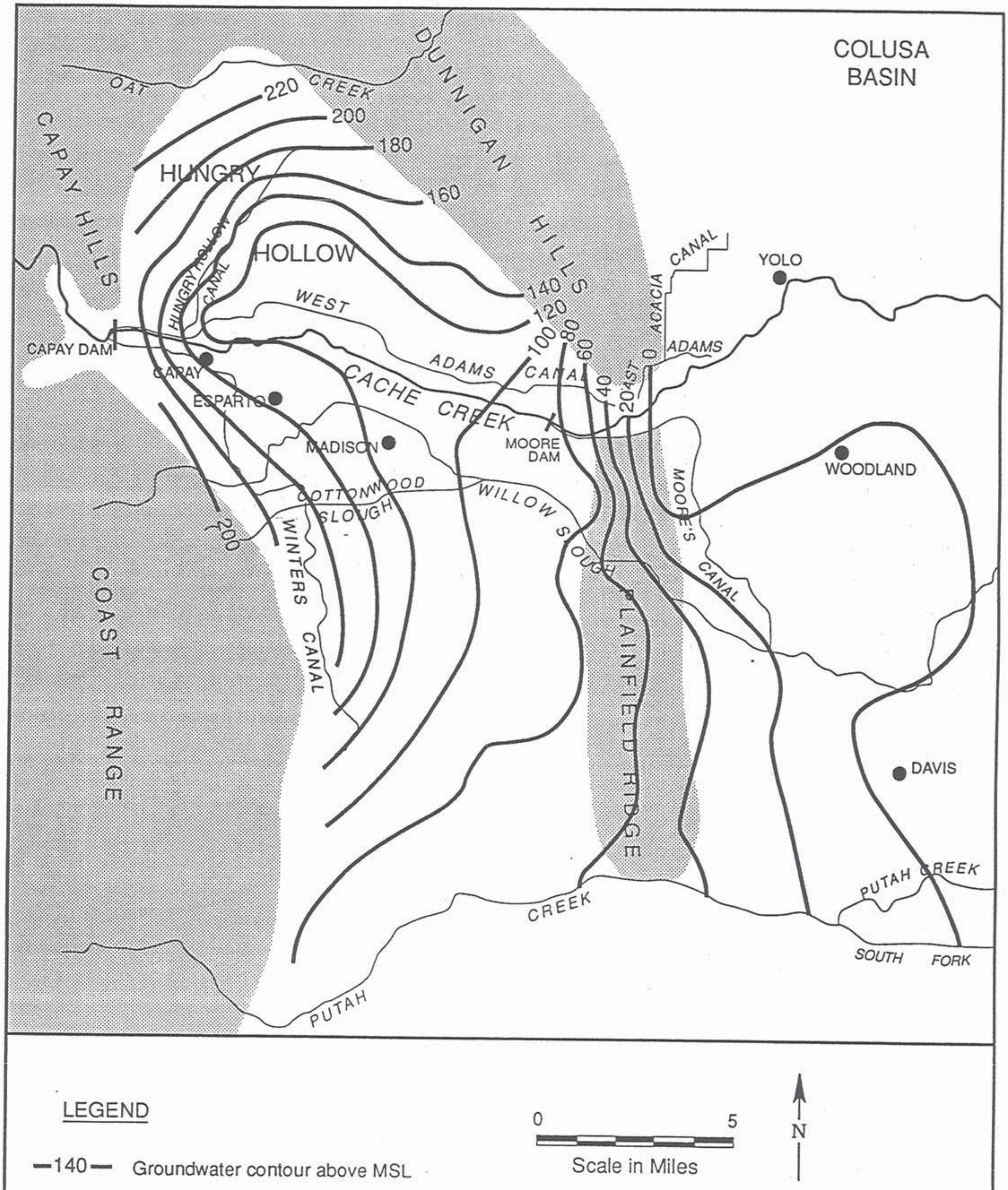
DAVID KEITH TODD
Consulting Engineers, Inc.
Berkeley, California

Figure 4.4-11
Spring 1983
Groundwater Elevation
Contour Map



Reference: Adapted from Luhdorff and Scalmanini (1992)

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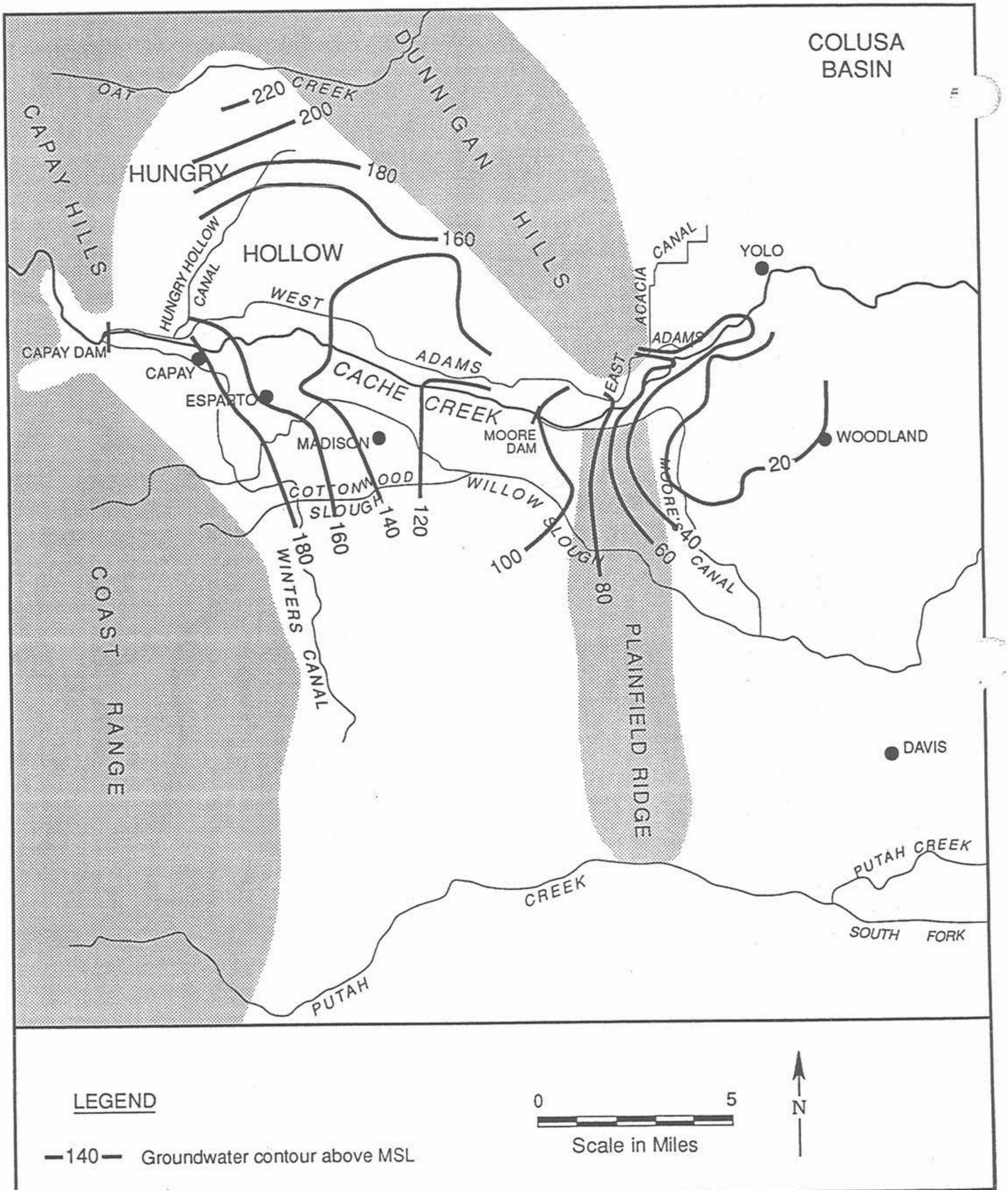
Consulting Engineers, Inc.
Berkeley, California

Figure 4.4-12
Fall 1991
Groundwater Elevation
Contour Map



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Consulting Engineers, Inc.
Berkeley, California

Figure 4.4-13
Spring 1993
Groundwater Elevation
Contour Map

Groundwater Levels

As discussed in the previous section, major portions of the Cache Creek basin experienced declining water levels from the 1950s through the mid 1970s, reaching a minimum in 1977. Returning again to Figure 4.4-7, groundwater levels subsequently recovered to 1950s levels between about 1978 and 1984. This is exemplified by hydrographs representing conditions in Hungry Hollow, Yolo, and Woodland. Water levels in Well 10N/1W-30K1 (Esparto) exceeded 1950s levels in the early and mid-1980s.

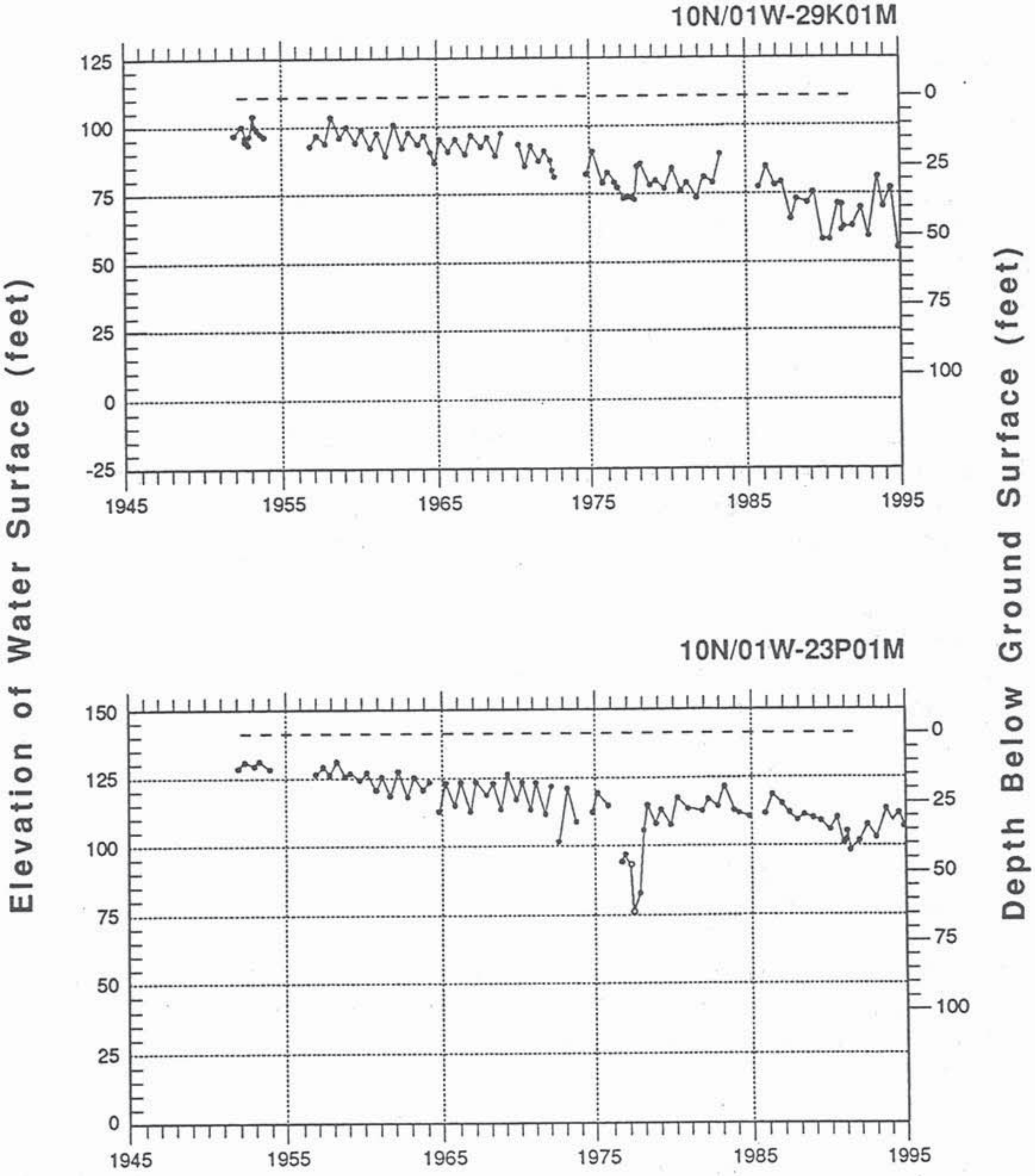
Groundwater levels declined again between 1984 and 1992, reflecting drought conditions and pumping. However, as shown in Figure 4.4-7, groundwater levels in the recent drought remained higher that in the 1976-1977 drought by as much as 25 feet in the Esparto area, 30 feet near Woodland, and 40 feet in Hungry Hollow. As noted before, this reflects the fact that the recent drought was not as extreme as the 1976-1977 drought and was moderated by Indian Valley Reservoir. Groundwater levels after 1993 have been characterized by a rising trend.

The early 1980s rise in groundwater levels is significant, particularly in the basin above Plainfield Ridge, because it rebuts the permanency of groundwater level declines suggested in the 1976 Woodward-Clyde report (see Middle History section). That report, relying on thalweg and groundwater level data from 1953 to 1974, documented declines in the thalweg of 6 to 16 feet.

The report also documented declines in groundwater levels over an approximate 30 square mile area above Plainfield Ridge. Declines averaging about ten feet were ascribed to thalweg lowering. This decline was described by analogy to a chipped teacup; prior to gravel mining and channel lowering, the groundwater basin could fill to the brim. Channel mining was described as causing a chip in the groundwater basin, so that after channel lowering, the groundwater levels could rise only to the bottom of the chip. Thus, seasonally high groundwater levels were permanently lowered.

The Woodward-Clyde report indicates a broad distribution of wells in which water level declines occurred that were ascribed to thalweg lowering.[46] This area of groundwater level declines extended as much as three miles north of the creek in Hungry Hollow, and as much as two miles south.[47] Review of current hydrographs in those areas indicates that water levels in the 1980s typically recovered to 1950s levels. Of sixteen wells examined in the 1976 report, nine wells in Hungry Hollow and south of Esparto experienced full recovery. Accordingly, the groundwater level declines in these wells were the result of intensive pumpage and drought, and not caused by thalweg lowering. Furthermore, the effect was temporary and reversible.

Of the sixteen examined wells, two additional wells were dropped from the monitoring program and five experienced only partial recovery from the 1950s to the 1980s. Of these, two groundwater hydrographs, shown in Figure 4.4-14, show decreasing water levels from the 1950s through 1994. Both of these wells are located immediately adjacent to Cache Creek (within 1,000 feet) near I-505 (23P1) and Stephens bridge (29K1). In this area, groundwater is relatively shallow and the 15 to 20 feet of thalweg lowering could affect groundwater levels. The first well, 10N/1W-23P1, recorded groundwater levels within about ten feet of ground surface in the 1950s. These high groundwater levels have not recurred, even in 1983 when groundwater rose



LEGEND

—•—•	Water surface elevation in well
—○—○	Questionable measurement
- - - -	Ground surface elevation at well

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DAVID KEITH TODD
Consulting Engineers, Inc.
Berkeley, California

Figure 4.4-14
Groundwater Levels i
Two Wells Showing
Thalweg Effect

to about twenty feet below ground surface. Similarly in well 10N/1E-29K1, groundwater levels were about five below ground surface in the early 1950s. Although data are missing for spring 1983 peak levels, the magnitude of water level fluctuations in the well suggest that the spring 1983 level did not reach the level of 1950s peaks, but may have been ten feet lower. Although the screened zones in well 29K1 are unknown, well 23P1 is known to be screened in alluvium. The decline in peak levels in these two wells may reflect the effect of thalweg lowering.

However, it is noteworthy that well 10N/1E-29K1 has experienced declines not only in peak groundwater levels, but also in minimum groundwater levels. For example, the lowest recorded groundwater levels occurred in autumn 1994 (about 55 feet below ground surface), and not autumn 1977 as in most local wells. This trend is less easily attributed to thalweg lowering, which is limited to the uppermost 25 feet or less. Such a decline may be due to a local increase in groundwater pumping. In addition well 29K1 is a deep well, probably tapping the Tehama Formation, and the connection between its water levels and the creek are uncertain.

In addition to the two wells described above, three additional wells may indicate some influence of thalweg lowering. These three wells include 10N/1W-21J1, 10N/1W-27C1, and 10N/1W-27F1 located within one mile of the creek near Madison. As exemplified by the hydrograph for well 10N/1W-27F1 (see Figure 4.4-7) peak water levels in the early 1980s are within about ten feet of 1950s levels, but do not match them. This may reflect thalweg lowering and/or intensive pumpage.

Groundwater Storage

Estimates of total groundwater storage for the study area are summarized in Hydrogeologic Setting. As with groundwater levels, the primary recent issue regarding groundwater storage has involved the suggested permanent loss of 17,000 to 38,000 acre-feet of groundwater storage capacity due to lowering of the stream thalweg.[48]

In response, a subsequent evaluation of groundwater storage changes was prepared for the 1979 to 1988 time period.[49] This time period extended from the 1979 enactment of the mining ordinance (prohibiting mining below the theoretical thalweg) to 1988, the year of the most recent available data available at the time of the study. The results showed a groundwater storage increase of 8,000 to 11,000 acre-feet over this period. This study used the same study area as the Woodward-Clyde study (insofar as it was defined), and comparable specific yield values of 8.9 and 12 percent. This increase in storage indicated that the "teacup analogy" is not completely valid, and demonstrated that significant groundwater storage had not been lost permanently as a result of thalweg lowering. Furthermore, it was noted that selection of a study period ending in 1983 (following two record wet years) would have demonstrated an even larger groundwater storage increase, indicating the sensitivity of the groundwater storage change calculation to the selected time period and its average rainfall.

Groundwater-Surface Water Relationships

The presentation of the teacup analogy[50] focused concerns on impacts of mining and groundwater-surface water interrelationships. As a result, several surveys of gaining and losing reaches along Cache Creek have been conducted.

Observations during the mid to late-1970s[51] noted losing reaches from Capay Dam to Highway I-505 and from Moore Dam to Yolo. The intervening reach from I-505 to Moore Dam was deemed a gaining reach. A change was noted in the I-505 to Moore Dam reach from previous conditions[52] of gaining during wet years and losing during dry years, to a condition of always gaining. Conversely, a change was observed in the Esparto Bridge to Madison Bridge reach from gaining[53] to losing. These observed changes in groundwater-surface water interaction were attributed to lowering of the stream bed (I-505 to Moore Dam) and lowering of water levels because of pumpage and downstream bed lowering (Esparto Bridge to Madison Bridge).

A 1984 study[54] reported conditions for Spring 1983 as gaining between Esparto Bridge and one mile upstream of Moore Crossing and losing elsewhere. The most recent study of stream-aquifer interaction was conducted for the 1988-89 season.[55] This study concluded that, overall, Cache Creek is gaining west of the anticline and losing east of the anticline. More specifically, a losing reach was noted between Capay to Esparto Bridge (10 to 20 cfs), while the Esparto Bridge to Madison Bridge segment was reported as neither gaining or losing. From Madison Bridge to the Plainfield Ridge anticline, groundwater levels in alluvium were noted to be above the thalweg, implying a gaining reach. Below Plainfield to Yolo, water levels were noted to be below the thalweg, implying a losing reach.

For this study, information on groundwater levels in the alluvium relative to the thalweg elevation was reviewed for selected properties. Specific properties and data references are noted in parentheses. This review indicates the following:

- Between Esparto and Madison Bridges[56] the stream is losing during the dry season, with no net gain or loss during the wet season.[57]
- Between Madison Bridge and Moore Dam (Solano Concrete) the channel is losing during the dry season and gaining during the wet season.[58]
- Immediately up- and down-gradient of Plainfield Ridge (Teichert Woodland) the channel generally is gaining up-gradient of the anticline and losing down-gradient.

The studies summarized above consistently show losing reaches between Capay and Esparto Bridge, and between the Plainfield Ridge to Yolo. The reaches between Esparto Bridge and Plainfield Ridge have been variously characterized as gaining or losing, depending on changes in thalweg elevation and groundwater levels (due to pumpage and recharge). Wet years and years of surplus surface water supplies tend to result in longer gaining reaches in the segment between Esparto Bridge and Plainfield Ridge, whereas drought years tend to result in longer losing reaches. Thus, the stream-aquifer interaction must be viewed as a dynamic process related to groundwater recharge, pumpage, surface water diversion, as well as thalweg lowering.

Groundwater Quality

Groundwater quality in the study area was evaluated by the U.S. Geological Survey[59] using groundwater samples collected in the summers of 1980 and 1981. This study was based on groundwater samples collected from approximately 113 wells in Yolo County, approximately 25 of which were located in Township 10 North. Total dissolved solids (TDS) was less than 500 ppm over much of the study area including Hungry Hollow and west of Madison. However, a broad area extending from Madison to Woodland had TDS in excess of 500 ppm. Hardness was noted to be in excess of 180 ppm over most of the area, although hardness was less than 180 ppm from Capay through Hungry Hollow. Chloride concentrations were found to be less than 25 ppm north of Cache Creek and west of Madison. Areas south of Highway 16 and around Woodland were reported to have chloride concentrations ranging from 25 to 100 ppm. Nitrogen concentrations were found to be less than 10 ppm throughout the study area. Elevated boron concentrations were reported in a broad area east of Madison. High boron concentrations in wells sampled near Cache Creek indicated that the creek was a likely source of boron.

An investigation of groundwater geochemistry in the Sacramento Valley was conducted by the U.S. Geological Survey.[60] This investigation focused on trends in groundwater quality throughout the valley, documenting a general increase in TDS in the southwestern portion of the valley (termed South Alluvial Fans. Although none of the selected wells for the evaluation of TDS trends was located in the Cache Creek Basin specifically, the study is indicative of the potential problem with TDS increases.

The California DWR maintains a groundwater quality database, which was updated for the Cache Creek area specifically for this study. Although this database is useful for evaluation of groundwater quality over time, it is far more limited than the comparable groundwater level database. Numerous wells in the DWR database have data only for isolated sampling events, and are not amenable to historic analysis. However, sufficient records do exist for five wells in the study area from the late 1960s or early 1970s until present to allow evaluation of groundwater quality over time.

Time-series plots of total dissolved solids (TDS), electrical conductivity (EC), and chloride (Cl) are shown for five wells in Figures 4.4-15(a-e). Concentrations of the constituents fluctuate over time, but do not show significant net changes in concentration.

Review of the previous USGS and DWR investigations and existing data on ground water quality do not show significant changes in groundwater chemistry. However, as pointed out in previous sections, the development of intensive irrigation based on both surface water and groundwater has dramatically changed the local groundwater system, with potential implications for groundwater quality.

First, the diversion of surface water from Cache Creek (which began in 1856) into a widespread irrigation system has altered the quantity, timing, and quality of recharge water in irrigated areas away from the creek. Under unirrigated conditions, the major source of recharge in such areas would be high quality rainfall and overland floodflows. Overall quantity of recharge probably

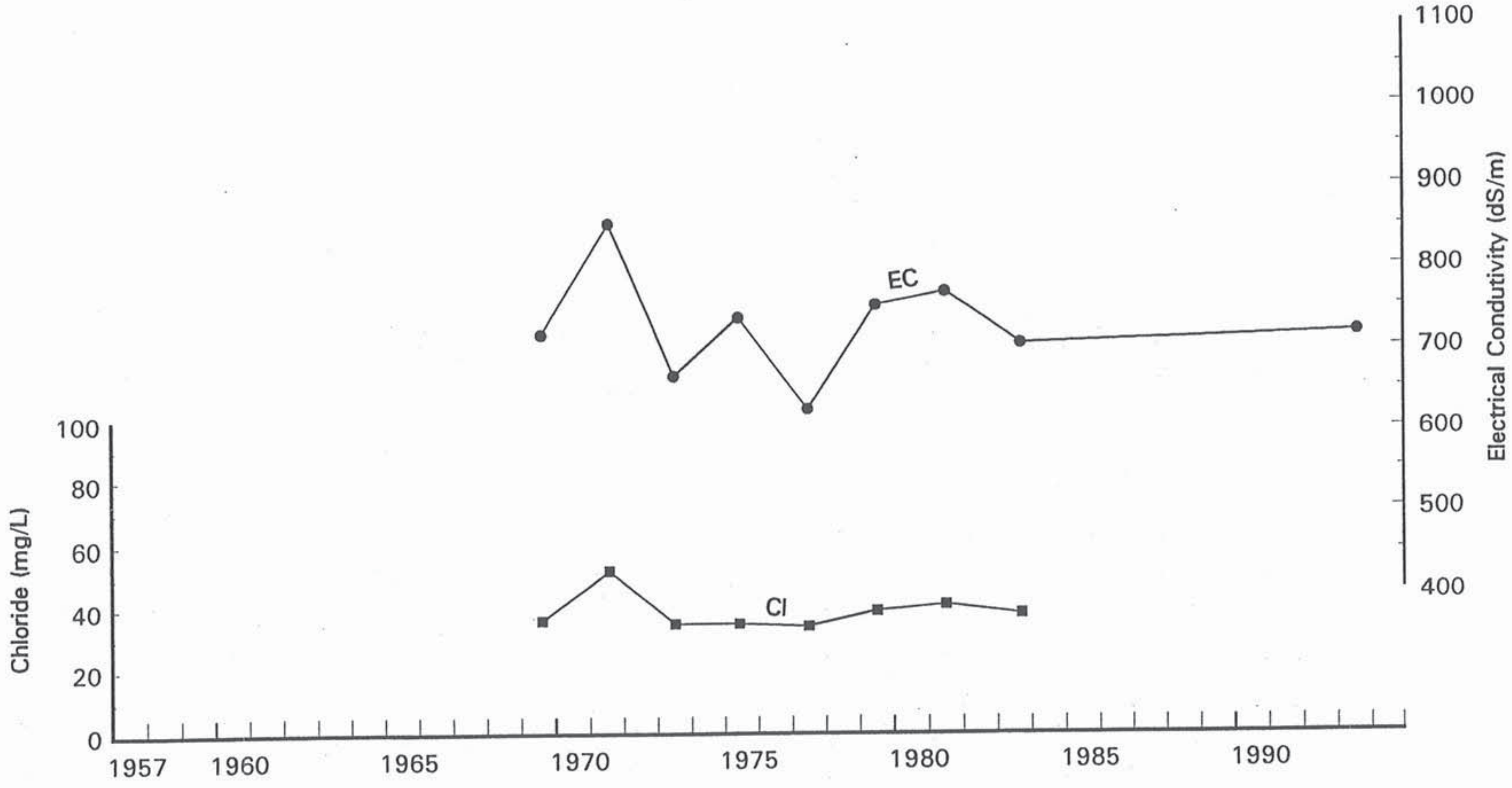

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Figure 4.4-15a
Water Chemistry
Well 10N/2W 26M1
Lamb Valley

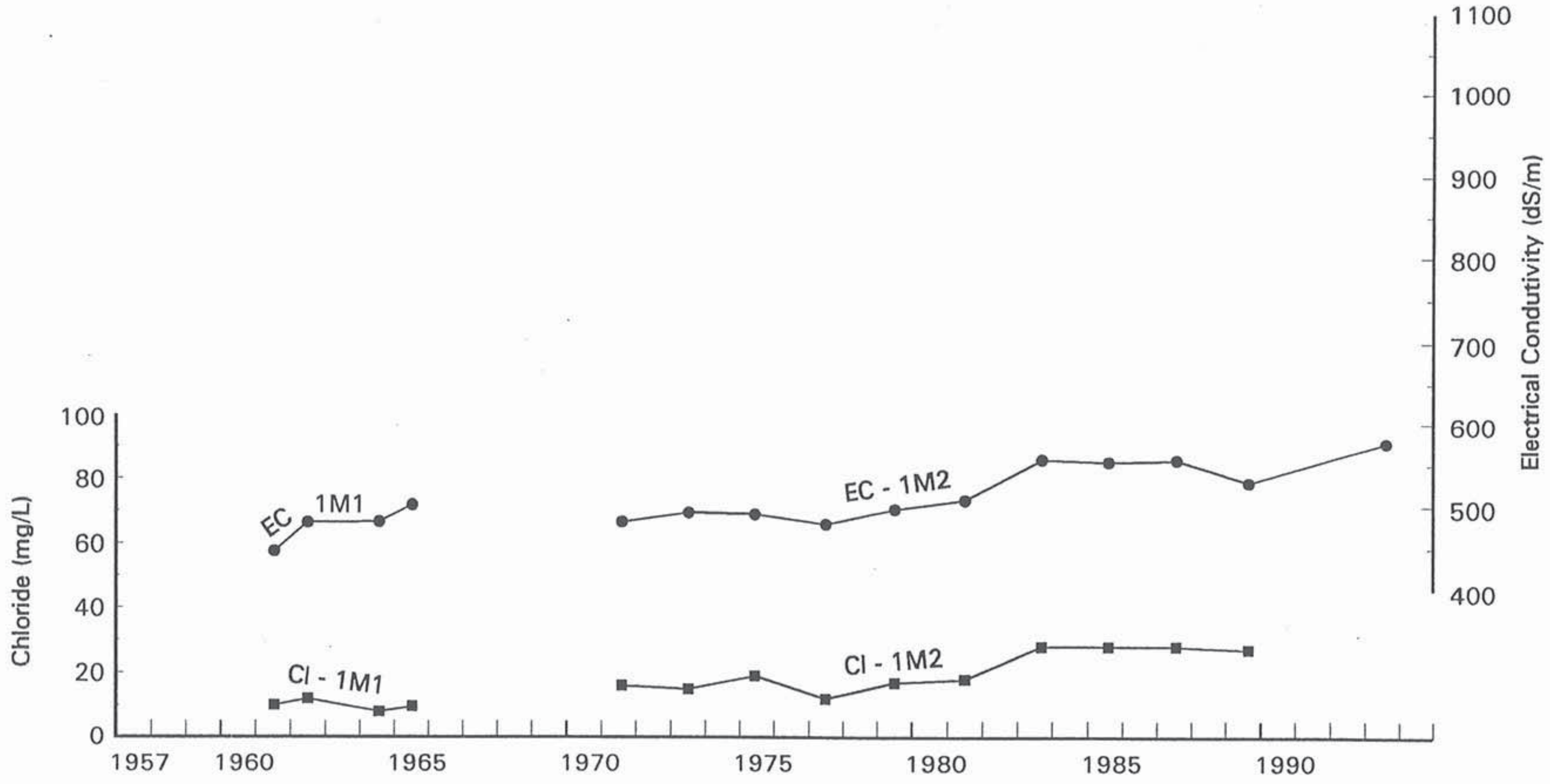

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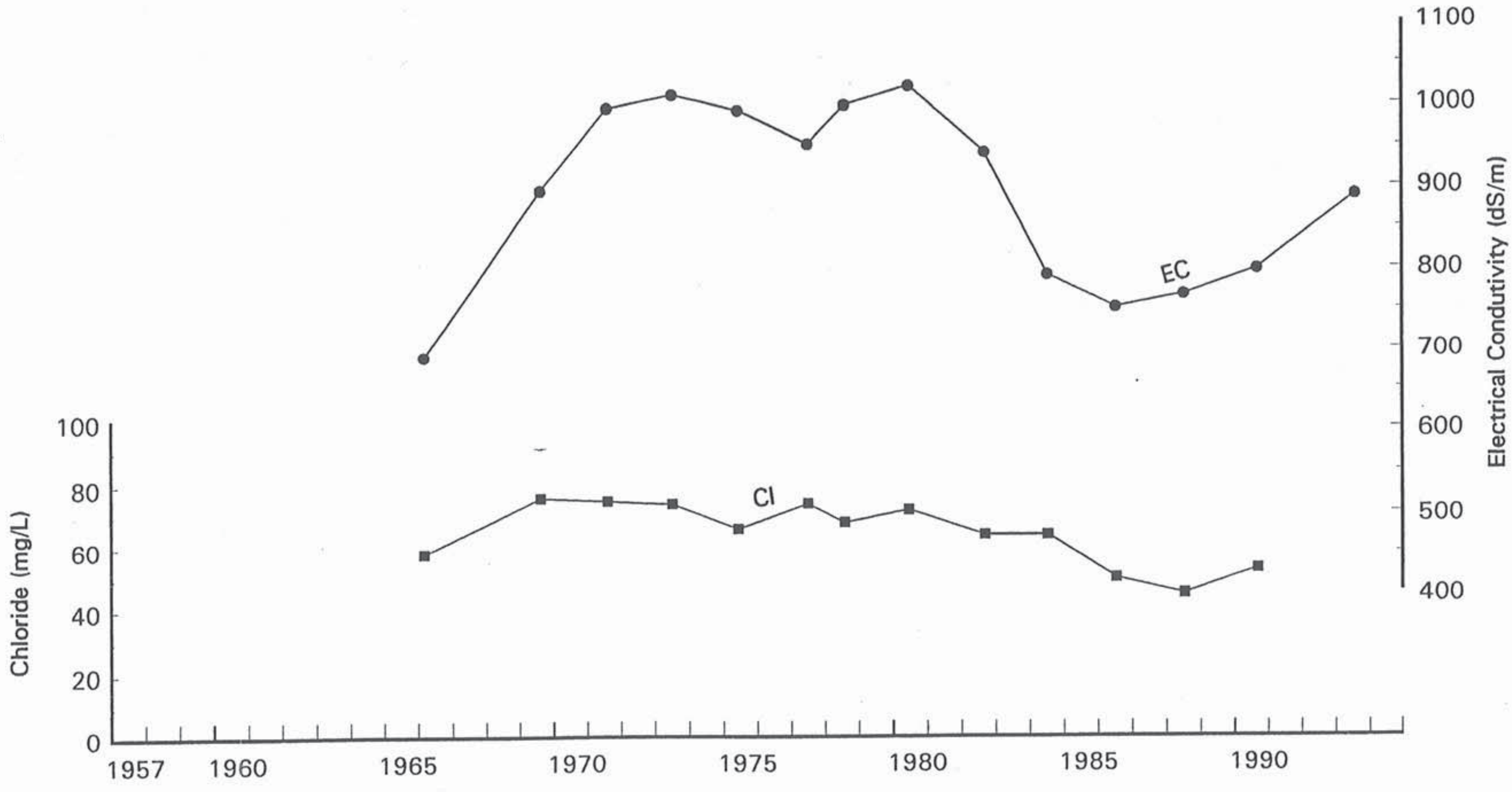
Figure 4.4-15b
Water Chemistry
Wells 10N/2W 1M1
And 10N/2W 1M2
Hungry Hollow



October 1995	Figure 4.4-15c Water Chemistry Well 10N/1W 27C1 Madison
DAVID KEITH TODD Consulting Engineers, Inc. Berkeley, California	

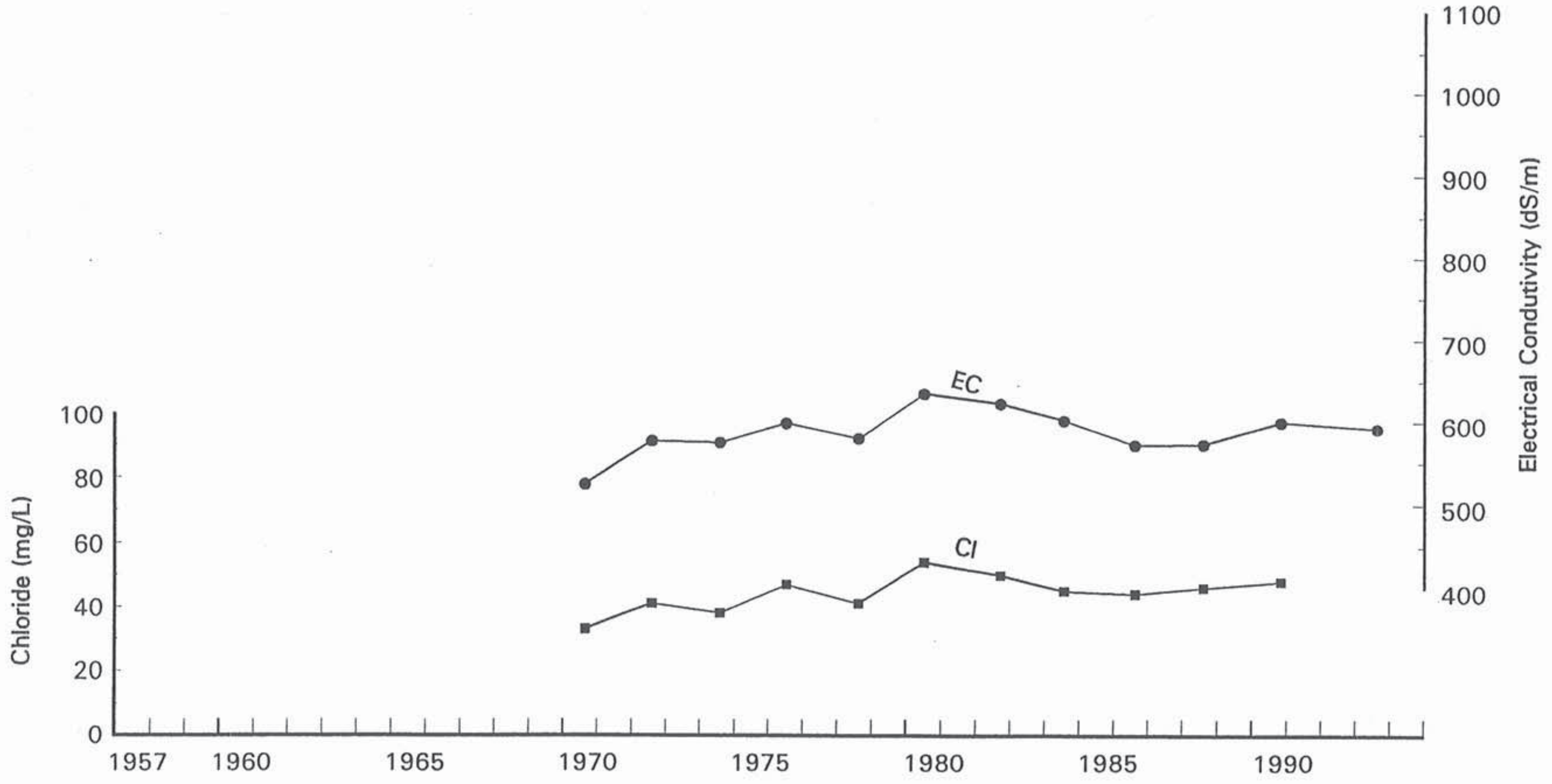


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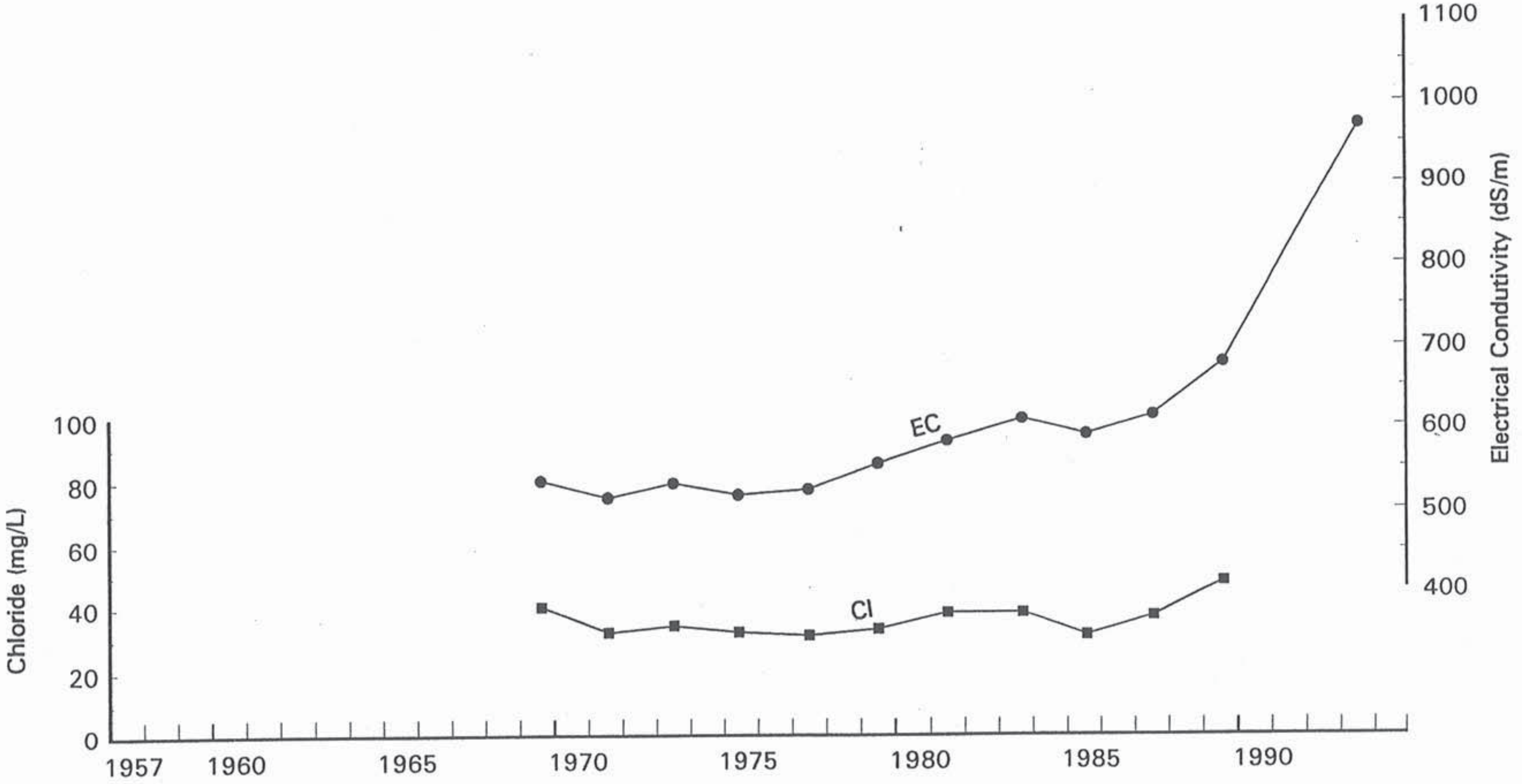
Figure 4.4-15d
Water Chemistry
Well 10N/1E 33J1
Plainfield Ridge



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Consulting Engineers, Inc.
Berkeley, California

Figure 4.4-15e
Water Chemistry
Well 10N/1E 15H2
Yolo

has been increased, but the major sources of recharge now are irrigation return flows and canal seepage of Cache Creek water in addition to rainfall. Crop water consumption and the attendant increase in total dissolved solids in return flows represents a potential for groundwater quality deterioration. It is likely that the widespread occurrence of boron (associated with Cache Creek) in Yolo County is the result in part of surface water diversions and irrigation.

Second, the development of groundwater for irrigation has resulted in increased cycling of water through the aquifer system. Under pre-development conditions, movement of water through the groundwater basin probably was a slow, predominantly shallow phenomenon. With development of groundwater pumping, groundwater is extracted at depth, enhancing recharge of available surface water, and resulting in an accelerated turnover of water. Development of groundwater also results in areas with depressed groundwater levels and convergent flow. This convergent flow entails increased cycling and reuse of irrigation water in the area (with the potential for increased TDS), and decreased outflow or flushing of the basin.

Such cycling has been corroborated in Yolo County through study of stable isotopes (deuterium and oxygen 18) and carbon 14 age dating of groundwater.[61] These studies indicated replacement of older, rainfall-derived groundwater in the Cache Creek area with younger water derived through irrigation from Cache Creek. Such irrigation water was indicated to be enriched with stable isotopes, suggesting a parallel enrichment or concentration of total dissolved solids through evaporation. The isotope studies also indicated a correlation of increased cycling of irrigation water with elevated nitrate concentrations in the Davis area.

Summary

After 1976, the expansion of irrigated agriculture slowed considerably, so that at present, much of the readily irrigable land is irrigated, either by surface water, groundwater, or both. The last major improvement to surface water irrigation facilities was completion of Indian Valley Reservoir in 1975. Water supply from this reservoir not only increased overall irrigation supply, but also ameliorated the effect of the recent drought. Groundwater irrigation facilities also are largely in place, following substantial well drilling activities in the 1950s, 1960s and 1970s. Following substantial growth from the 1950s to the late 1970s, the mining industry also has shifted to a pattern of varying mining activity. Since 1979, mining has been regulated by Yolo County's Interim Mining Regulations.

Groundwater levels since 1978 have been marked by a pattern of successive increase, decrease, and increase again. The fundamental factors affecting historical groundwater levels are recharge and discharge. Recharge occurs through rainfall percolation, streamflow percolation along losing reaches, percolation of excess surface water irrigation, and canal leakage. Discharge under current conditions occurs primarily through groundwater pumping, plus discharge of groundwater to Cache Creek with subsequent evapotranspiration losses or outflow past Yolo.

Rainfall, however, is the fundamental independent variable in groundwater levels in the Cache Creek area. Annual rainfall is the major factor in recharge from rainfall percolation and streamflow recharge, and a prime factor in the amount of surface water irrigation and canal flow. The amount of rainfall also influences the amount of groundwater pumping. As a result, the lowest recorded groundwater elevations occurred during the extreme drought of 1976-1977, while the highest recent water levels occurred because of the wet years from 1978 to 1983.

The secondary factors tend to be interdependent; the most important of these are surface water diversions and groundwater pumping. Surface water diversions remove flows from the creek that could be available for in-channel recharge, but disperse those flows over farmland, resulting in widespread recharge of return flows. The surface water reservoirs also distribute surplus water from a high rainfall year to the following year(s). The net effect of the availability of surface water therefore is to enhance groundwater recharge and minimize groundwater discharge through pumping, or in other words, to raise groundwater levels.

Groundwater pumping removes groundwater from the aquifer system, resulting in decreased groundwater elevations, and increased cycling of water through the aquifer system. However, because many agricultural parcels in the Cache Creek area have access to both surface water and groundwater for irrigation, there has been a historic interplay between use of surface water and groundwater. When one source has been less desirable because of cost, quantity or quality, the alternative source is used more.

Accordingly, although rainfall amount is the fundamental factor in most years, the interplay of surface water and groundwater irrigation is necessary to explain groundwater levels in selected years. For example, although 1993-94 was an exceedingly dry year and 1992-93 was a very wet year, over 60 percent of hydrographs examined showed higher groundwater elevations in the spring of 1994 relative to the spring of 1993. The likely explanation is that surface water diversions in the summer of 1993 far exceeded those in the summer of 1992. Thus, groundwater pumpage was likely considerably reduced in summer 1993 relative to summer 1992, and more excess irrigation water was available for recharge in summer 1993. This allowed groundwater elevations following the dry year of 1993-94 to be greater than groundwater elevations following the wet year of 1992-93 in the majority of wells.

Review of groundwater level hydrographs illustrating conditions from the 1930s to present indicate that the magnitude of groundwater level changes is greater currently than in the past. The combined effect of drought and intensive pumping has resulted in the lowest recorded groundwater levels, reaching 125 feet below ground surface in Hungry Hollow and near Woodland in 1977. Nonetheless, the groundwater basin has a substantial capacity for recovery. By 1983, groundwater recovered as much as 100 feet to high 1950s levels. These changes, however, highlight the alteration of the overall groundwater system, including the increased recharge of irrigation water with implications for groundwater quality.

The last factor in groundwater levels, discharge and outflow via Cache Creek, is governed by the relative elevations of the groundwater and channel bottom. Groundwater elevations are determined by the interplay of factors described above, but the elevation of the channel bottom has been lowered significantly by in-channel mining. Potential effects of this channel lowering on groundwater involve groundwater drainage to the creek and a permanent groundwater level decline and storage loss. This impact has not been as great as suggested in the late 1970s. Nonetheless, lowering of the thalweg may have resulted in a decline of groundwater levels by about ten feet in close proximity to the creek between Madison and Stephens Bridge. Accordingly, fixation of the thalweg through the Interim Mining Ordinance was a prudent measure that protects groundwater storage in the Cache Creek basin.

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44. Scalmanini, Op. Cit.

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46. Figure 11, Woodward-Clyde, Op. Cit.

47. Figure 22 in Woodward-Clyde, Op. Cit.

48. Woodward-Clyde, Op. Cit. 1976, 1979.

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