

GROUNDWATER CONDITIONS BENEATH DISTRICT
OWNED LANDS IN THE WESTLANDS WATER DISTRICT

prepared for
Westlands Water District
Fresno, California

by
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April 30, 2009

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Re: Groundwater Evaluation of
District Owned Lands

Dear Russ:

Submitted herewith is our report on groundwater conditions beneath the District owned lands. We appreciate the cooperation of District staff and the California Department of Water Resources in providing information for this report.

Sincerely Yours,



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KDS/pe

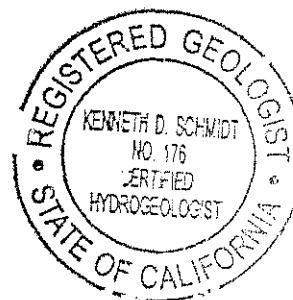
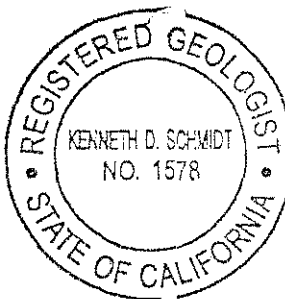


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GROUNDWATER CONDITIONS BENEATH DISTRICT OWNED LANDS IN THE WESTLANDS WATER DISTRICT

INTRODUCTION

The Westlands WD owns 80,000 acres of land that were acquired as part of settlement agreements for agricultural drainage problems, and also the 9,300-acre Broadview Water District (Figure 1). These lands have been retired from irrigation. This evaluation focuses on the potential pumpage of groundwater from existing and new wells on these lands. First, groundwater conditions are described, including subsurface geologic conditions, well data, depth to water, the direction of groundwater flow, water-level elevations, pumpage, well production, recharge, land subsidence, and groundwater quality. Two major aquifers are discussed in this report. The upper aquifer is above the Corcoran Clay, a widespread clay layer and confining bed beneath all of the area evaluated. This evaluation focuses primarily on the lower aquifer, due primarily to groundwater quality considerations and other factors.

Five subareas were selected for this evaluation and are shown in Figure 1. These are from north to south: 1) the Broadview WD, 2) Mendota (primarily west and southwest of Mendota), 3) Tranquillity (primarily west and southwest of Tranquillity), 4) Five Points (generally northwest and west of Five Points), and 5) Lakeside (the District owned lands southeast of the Avenal Cutoff Road).

Three reports by the U.S. Geological Survey (USGS) contain

FIGURE 1 - LOCATION OF SUBAREAS AND SUBSURFACE GEOLOGIC CROSS SECTIONS

substantial information that was used in this evaluation. The first was prepared in 1957 by G. H. Davis and J. F. Poland (Water Supply Paper 1360-G). The second was prepared in 1971 by R. E. Miller, J. H. Green, and G. H. Davis (Professional Paper 497-E). The third was prepared in 1990 by K. Belitz and F. J. Heimes (Water Supply Paper 2348). The most recent of these USGS reports focused on shallow groundwater. These reports provide the subsurface geologic and hydraulic framework for understanding groundwater conditions in terms of groundwater pumping in the Westlands WD. Another USGS report, Professional Paper 437-I, prepared by Ireland Poland, and Riley in 1984 focused on land subsidence. Two other USGS reports (Bertoldi and Le Blanc, 1969, and Bertoldi, 1971) focused on groundwater quality in the area.

SUBSURFACE GEOLOGIC CONDITIONS

Subsurface Geologic Cross Sections

Figure 1 shows the locations of four subsurface cross sections that were presented in Professional Paper 497-E, and pass through or near one or more of the subareas. All of these sections provide information on the Corcoran Clay, the upper and lower aquifers, and the base of the fresh groundwater. The base of the fresh groundwater is the boundary between the overlying groundwater with an electrical conductivity more than 3,000 micromhos per centimeter at 25°C, and the underlying groundwater with an electrical conductiv-

ity of less than 3,000 micromhos. An electrical conductivity of 3,000 micromhos is approximately equal to a total dissolved solids (TDS) concentration of 2,000 mg/l. "Fresh" groundwater was historically (decades ago) considered to be water usable for irrigation of most crops. Cross Section A-A' extends from the northwest near the west edge of the Broadview WD, to the southeast through Cantua Creek, northeast of Huron, to near the Avenal Cutoff Road. This section is generally perpendicular to the dip of the alluvial deposits, which is to the southwest. The other three cross sections are generally oriented from northeast to southwest, along the dip of the deposits. Cross Section B-B' extends from the northeast near Mendota to the southwest, generally along Panoche Road to near I-5. Cross Section C-C' extends from the northeast near San Joaquin to the southwest, through Cantua Creek, to past I-5. Cross Section D-D' extends from a point between Helm and Burrell on the northeast, to the southwest, generally parallel to and several miles northwest of Highway 145, to near I-5.

Subsurface cross sections were not available for most of the Broadview WD, nor for the Lakeside Subarea. Therefore, two new subsurface cross sections were developed as part of this evaluation. Cross Section E-E' extends from the northeast near Firebaugh to the southwest, through the north part of the Broadview WD. Cross Section F-F' extends from the northeast through the Lakeside Subarea, generally parallel to Highway 41, to the southwest near

Kettleman City.

Section A-A' (Figure 2) is located near the southwest edges of all of the subareas that are northwest of Highway 145. Cross Section A-A' shows that the Corcoran Clay generally becomes deeper and thins to the southeast along this section. The top of the clay ranges from about 400 to 700 feet deep along the parts of the cross section that are near the subareas. The base of the fresh groundwater is about 1,300 feet deep along the section beneath the Broadview WD. The base of the fresh groundwater is much deeper along the part of the section south of the Broadview WD. The base is almost 3,900 feet deep beneath the Tranquillity Subarea, about 2,500 feet deep beneath the Five Points Subarea, and about 2,700 feet deep north of the Lakeside Subarea.

Cross Section B-B' (Figure 3) shows the southwesterly dip of the Corcoran Clay beneath the Mendota Subarea. The top of the clay is about 400 feet deep near the northeast edge and about 600 feet deep near the southwest edge of the Mendota Subarea. The clay averages about 50 to 60 feet in thickness along the part of the section in the Mendota Subarea. A zone of brackish groundwater was shown above the clay in part of the Mendota Subarea. The base of the fresh groundwater is about 800 feet deep near the northeast edge of this subarea and about 1,500 feet deep near the southwest edge.

Cross Section C-C' (Figure 4) shows subsurface conditions in

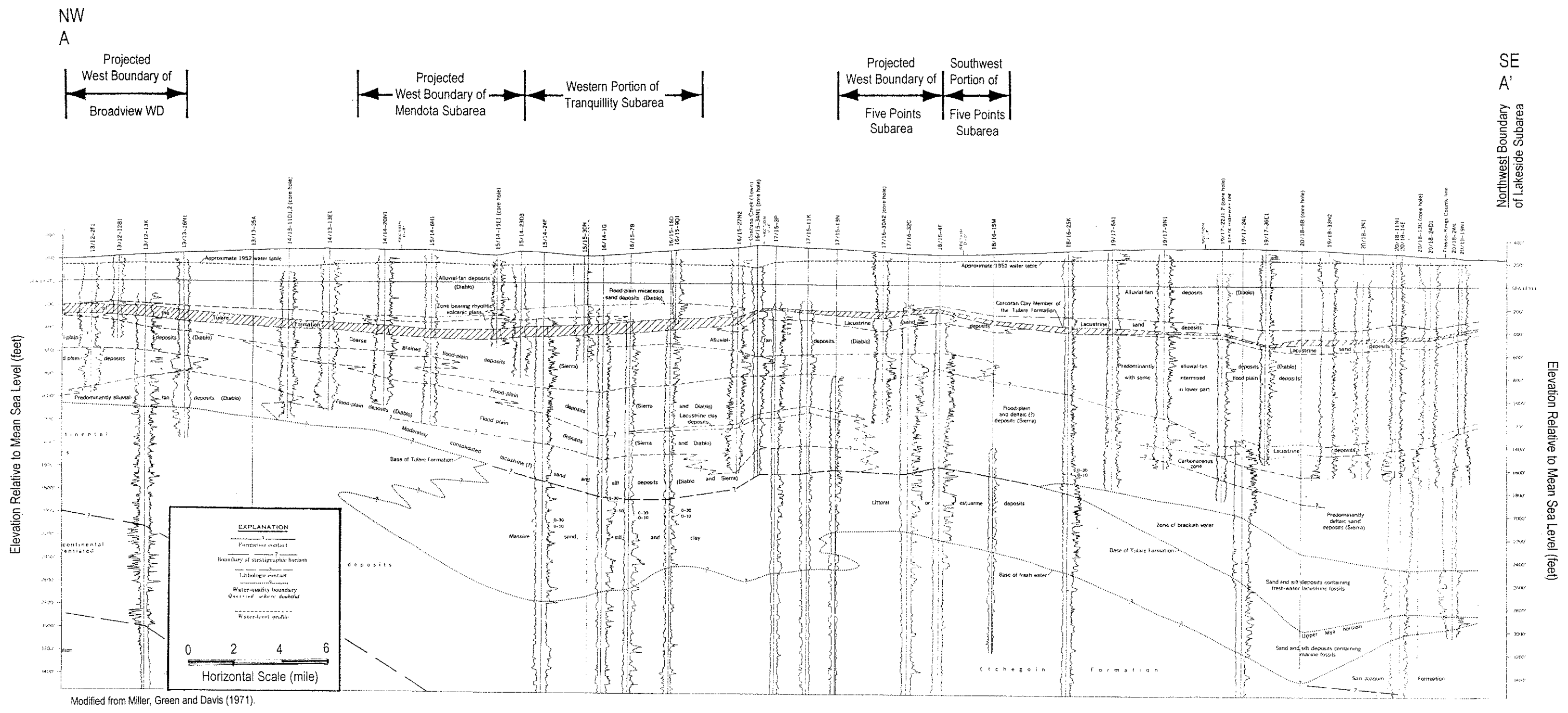


FIGURE 2-SUBSURFACE GEOLOGIC CROSS SECTION A-A'

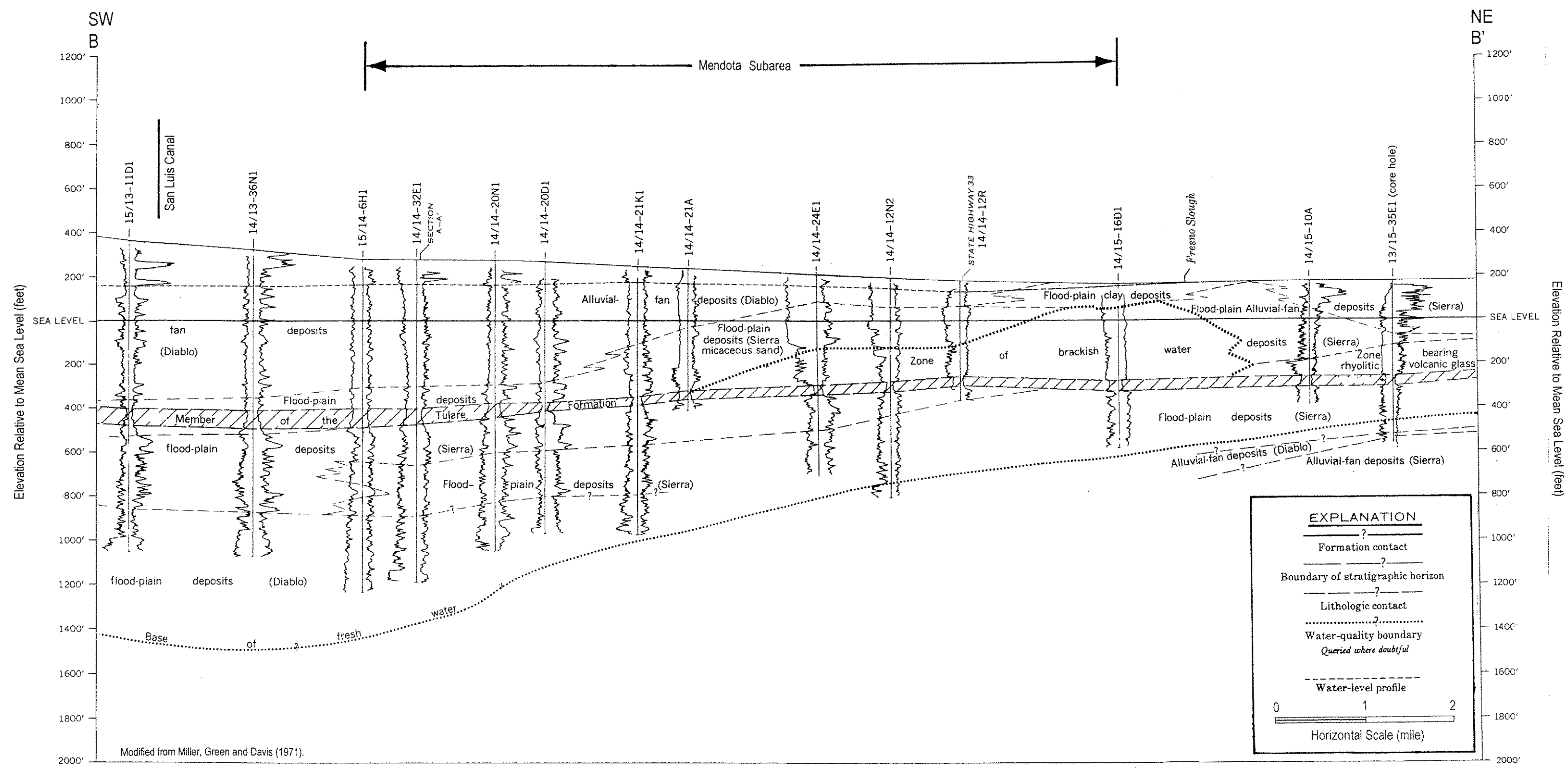


FIGURE 3-SUBSURFACE GEOLOGIC CROSS SECTION B-B'

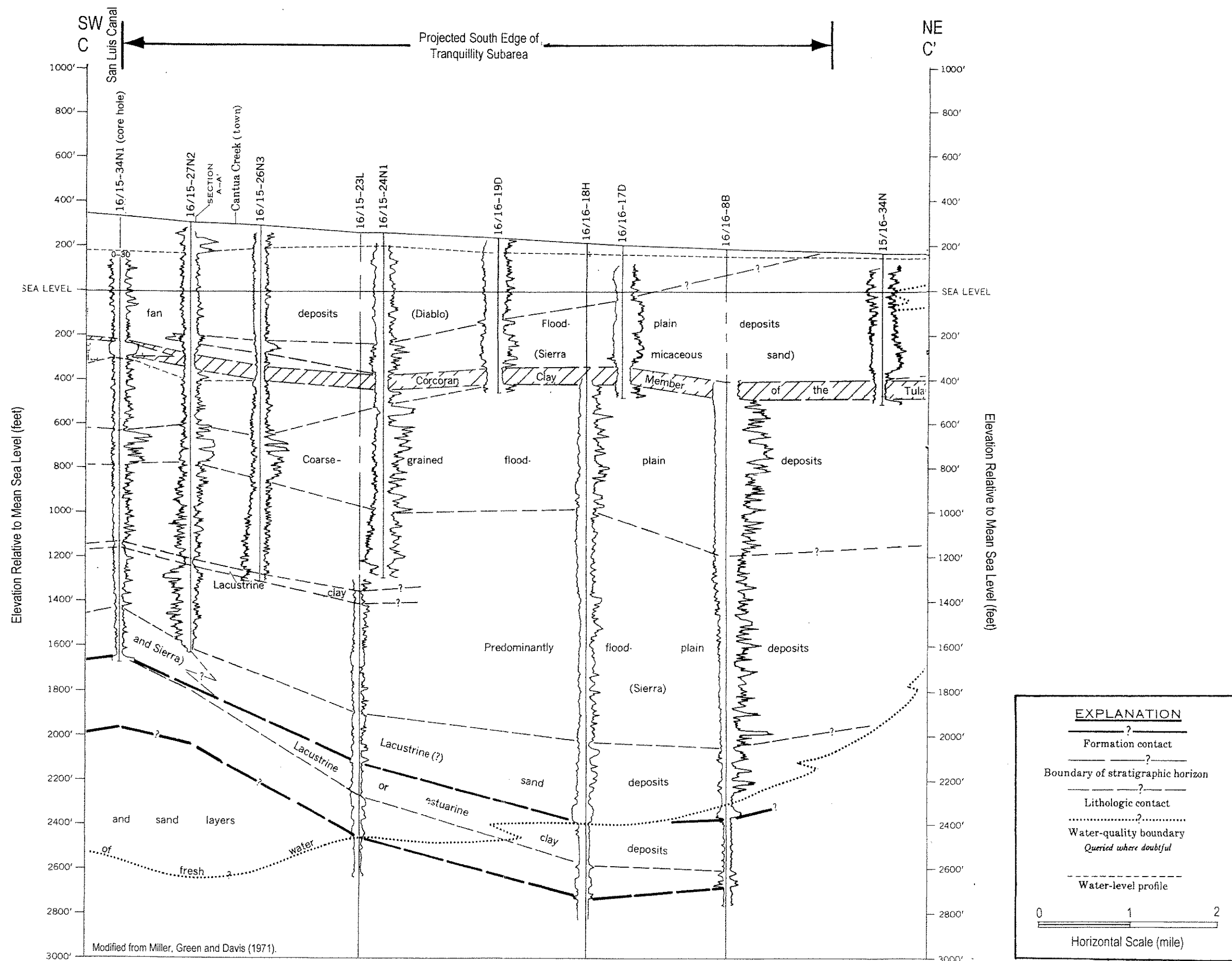


FIGURE 4-SUBSURFACE GEOLOGIC CROSS SECTION C-C'

the area between the Tranquillity and Five Points Subareas. The top of the Corcoran Clay is about 600 to 650 feet deep along the part of the section near the Tranquillity Subarea. The average thickness of the clay is about 70 to 80 feet near the Tranquillity Subarea. The base of the fresh groundwater is about 2,300 to 2,700 feet deep along the part of this section opposite the south part of the Tranquillity Subarea.

Cross Section D-D' (Figure 5) shows the subsurface conditions beneath the south part of the Five Points Subarea. The Corcoran Clay is bifurcated into two layers to the southwest along this section. The top of the Corcoran Clay is about 500 to 600 feet deep along the part of this section near the Five Points Subarea. The clay averages about 40 to 50 feet in thickness (including both layers). Fresh groundwater is indicated above about 1,500 feet deep along most of this section in or opposite the Five Points Subarea. There is a zone of brackish water below this fresh groundwater that extends to depths ranging from about 1,900 to 2,150 feet. Additional fresh groundwater is present below this brackish water and above depths ranging from 2,500 to 3,000 feet deep.

Cross Section E-E' (Figure 6) shows subsurface geologic conditions along the north edge of the Broadview Water District. The top of the Corcoran Clay is about 370 to 440 feet deep along this section and is deeper to the southwest. The clay ranges from about 80 to 100 feet in thickness along the section. Major water-

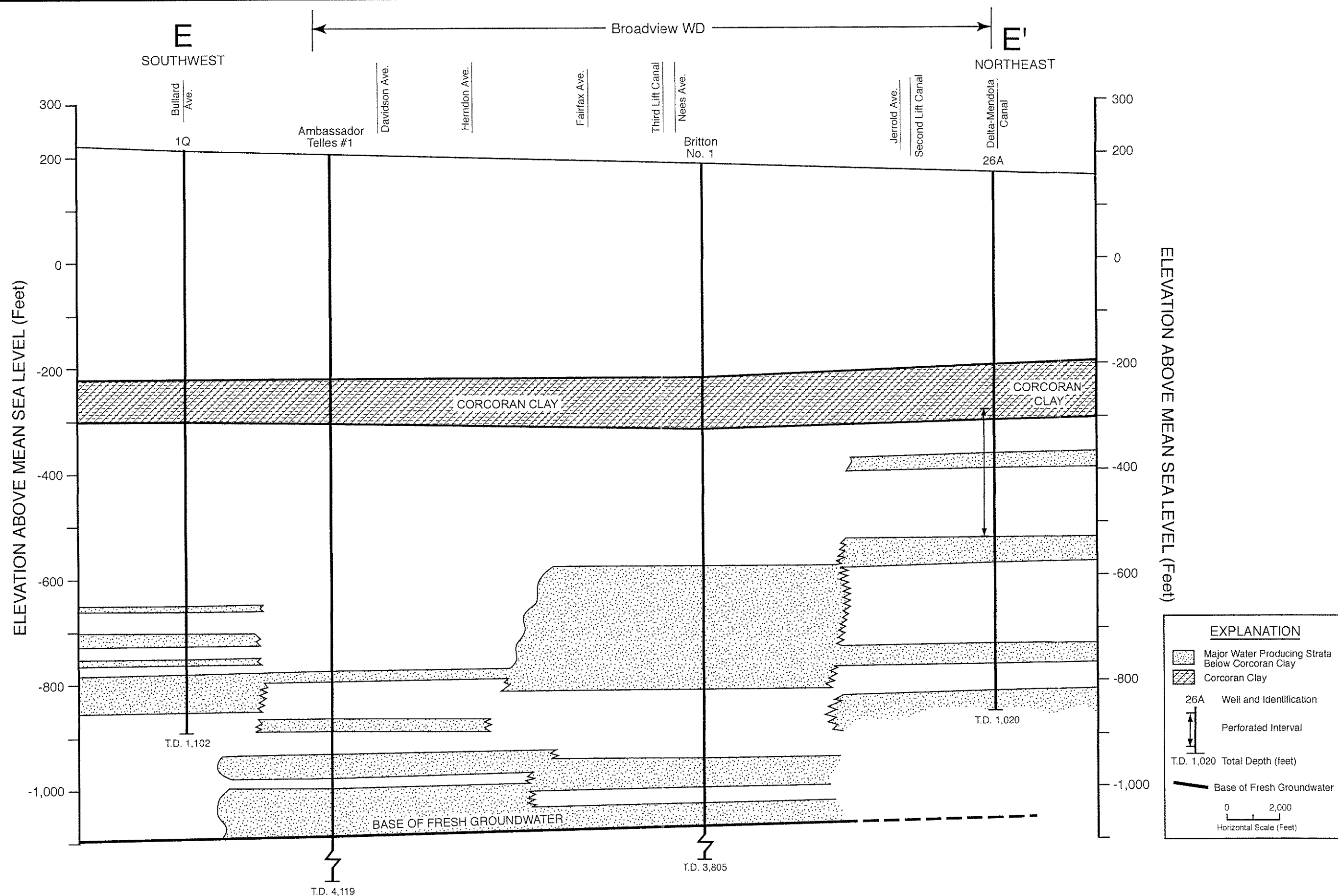


FIGURE 6 - SUBSURFACE GEOLOGIC CROSS SECTION E - E'

producing strata below the Corcoran Clay are shown on the section. Substantial water-producing strata are indicated below a depth of about 800 feet. Examination of electric logs for oil and gas test holes in the vicinity indicates that the base of the fresh groundwater is about 1,250 feet deep along this section. This has been a limiting factor for the maximum depth of irrigation wells in the vicinity.

Cross Section F-F' (Figure 7) shows subsurface conditions in the Lakeside Subarea. There is no productive upper aquifer in the Lakeside Subarea in terms of large-capacity irrigation wells. The top of the Corcoran Clay ranges from about 650 to 700 feet deep along this section. The clay ranges from about 25 to 80 feet thick along this section. The major water-producing strata below the Corcoran Clay are shown on this section. Substantial water-producing strata are present along the north part of the section below a depth of about 1,200 feet. Along the part of the section south of Orange Avenue, clay and other fine-grained strata are predominant below the Corcoran Clay. These fine-grained strata are associated with the ancestral Tulare Lake bed. The depth to the base of the fresh groundwater ranges from about 2,000 to 2,100 feet deep along this section. This has been a limiting factor for the maximum depth of large-capacity water supply wells in the vicinity.

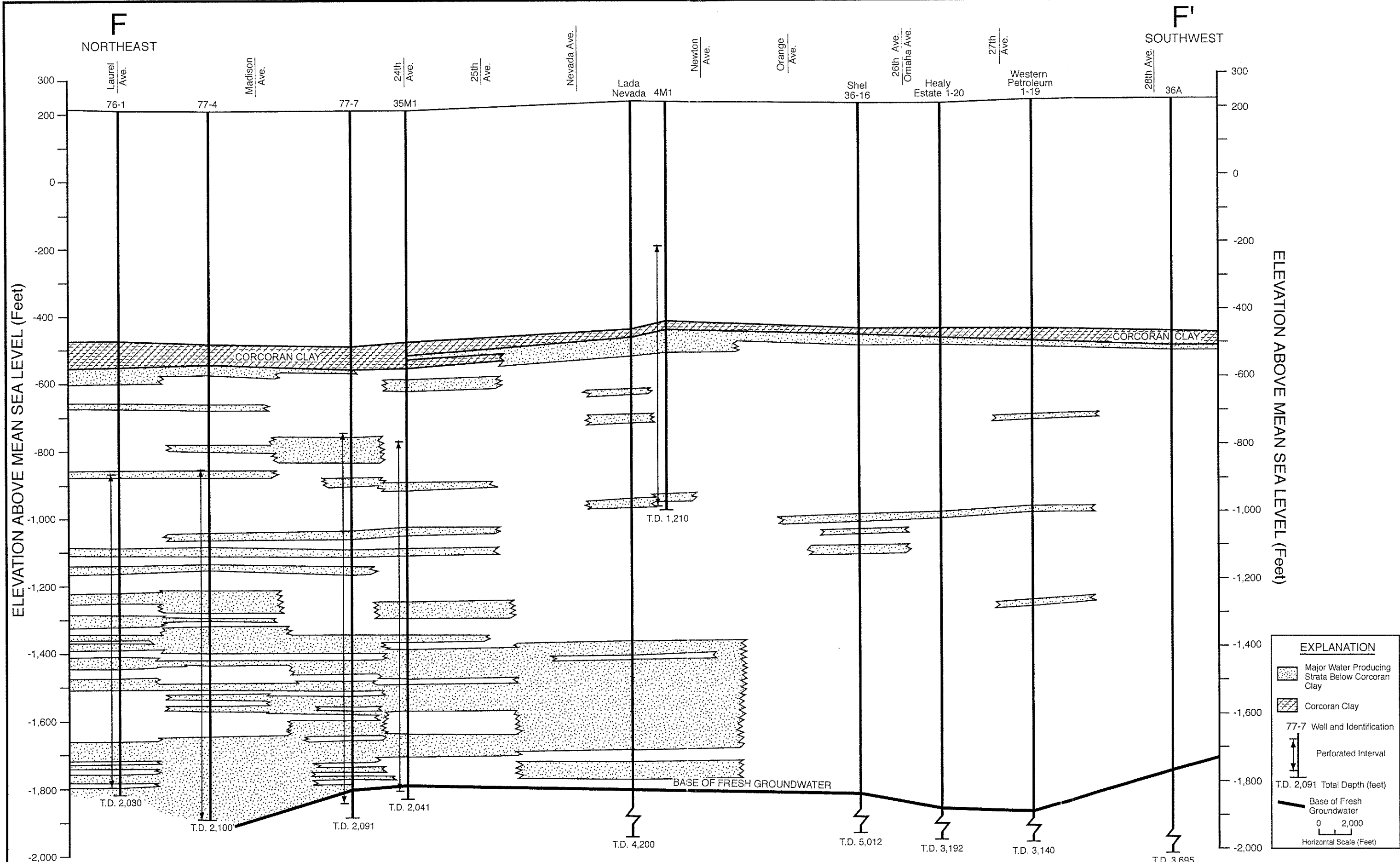


FIGURE 7 - SUBSURFACE GEOLOGIC CROSS SECTION F - F'

Base of the Corcoran Clay

Regional maps are available for the Corcoran Clay, including maps in USGS Water Supply Paper 1999-H, by M. G. Croft (1972), which covers the part of the San Joaquin Valley south of Mendota. As part of this evaluation, electric logs for a number of wells were reviewed and the depth to the base of the Corcoran Clay was determined and plotted in each subarea, and compared to those indicated on previous maps. Maps are provided in this report for the three subareas where there are relatively large differences in depth to the base of the Corcoran Clay.

Broadview WD

Depth to the base of the Corcoran Clay ranges from about 500 to 550 feet and increases to the southwest beneath the Broadview WD. Because of poor quality groundwater in the upper aquifer, the base of the Corcoran Clay is considered the top of the usable groundwater.

Mendota Subarea

Figure 8 shows the depth to the base of the Corcoran Clay in the Mendota Subarea. Depth to the base of this clay is about 500 feet beneath the City of Mendota near the northeast corner of the subarea, and increases to more than 750 feet near the southwest part of the subarea. Poor quality groundwater also limits the use of the upper aquifer in much of this subarea, and thus the base of

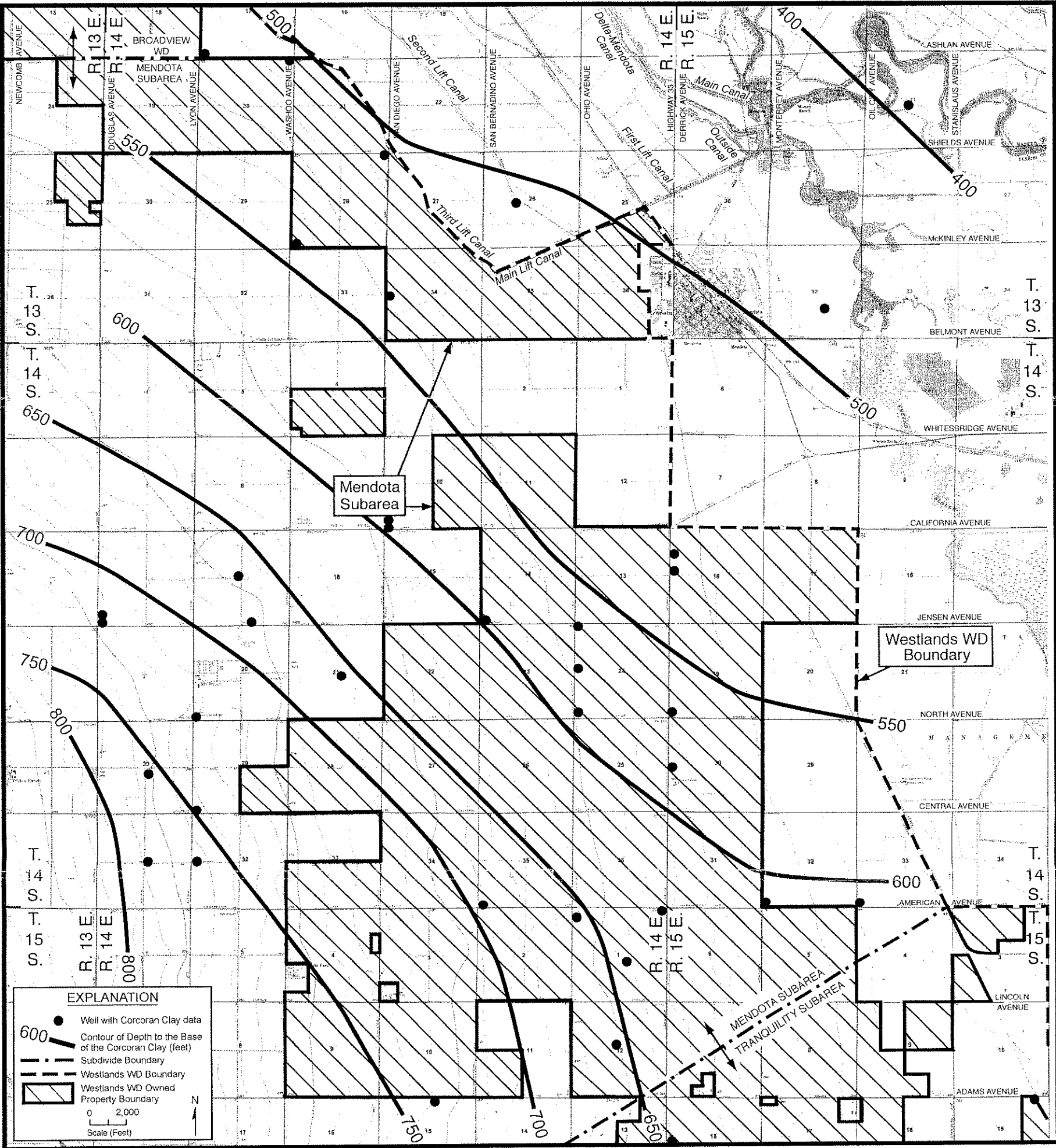


FIGURE 8 - BASE OF CORCORAN CLAY IN THE MENDOTA SUBAREA

the Corcoran Clay is often the top of the usable groundwater.

Tranquillity Subarea

Figure 9 shows depth to the base of the Corcoran Clay in the Tranquillity Subarea. Depth to the base of the Corcoran Clay ranges from about 600 feet near the northeast corner of the subarea to about 800 feet near the southwest corner. Both the upper and lower aquifers are tapped in this subarea.

Five Points Subarea

Depth to the base of the Corcoran clay in the Five Points Subarea (Figure 10) ranges from about 600 to 850 feet, and generally increases to the southwest. Both aquifers are tapped in much of this subarea, except in the southwest part. In the southwest part of the subarea, substantial clay is present in Coast Range deposits above and below the Corcoran Clay, and the productivity of the upper aquifer is much lower than farther east.

Lakeside Subarea

Depth to the base of the Corcoran Clay in the Lakeside Subarea ranges from about 650 to 750 feet and increases to the southwest. Because of the substantial clay and other fine-grained deposits in the part of the subarea located south of Orange Avenue, the Corcoran Clay has little hydrologic significance in this part of the subarea.

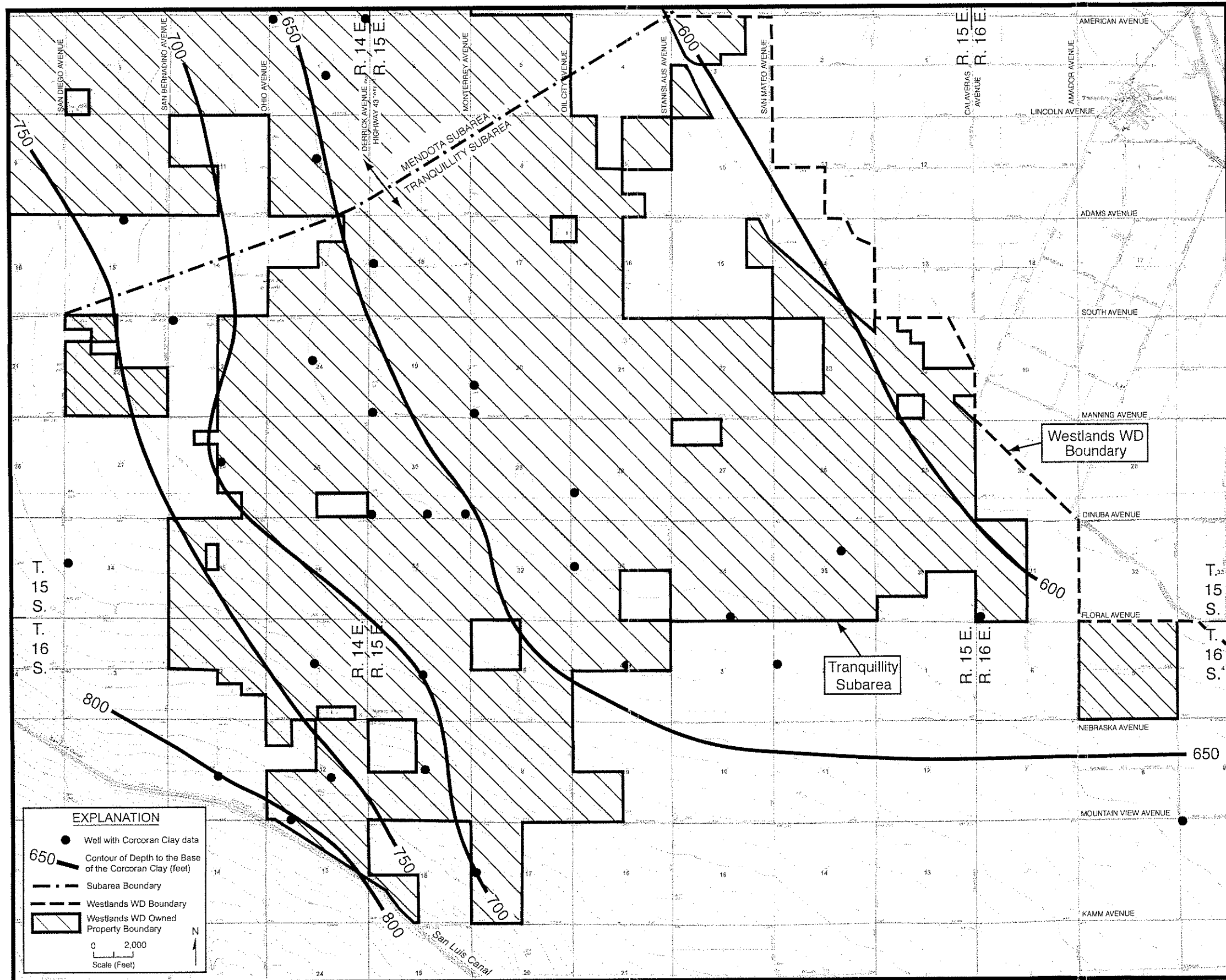


FIGURE 9 - BASE OF CORCORAN CLAY IN THE TRANQUILLITY SUBAREA

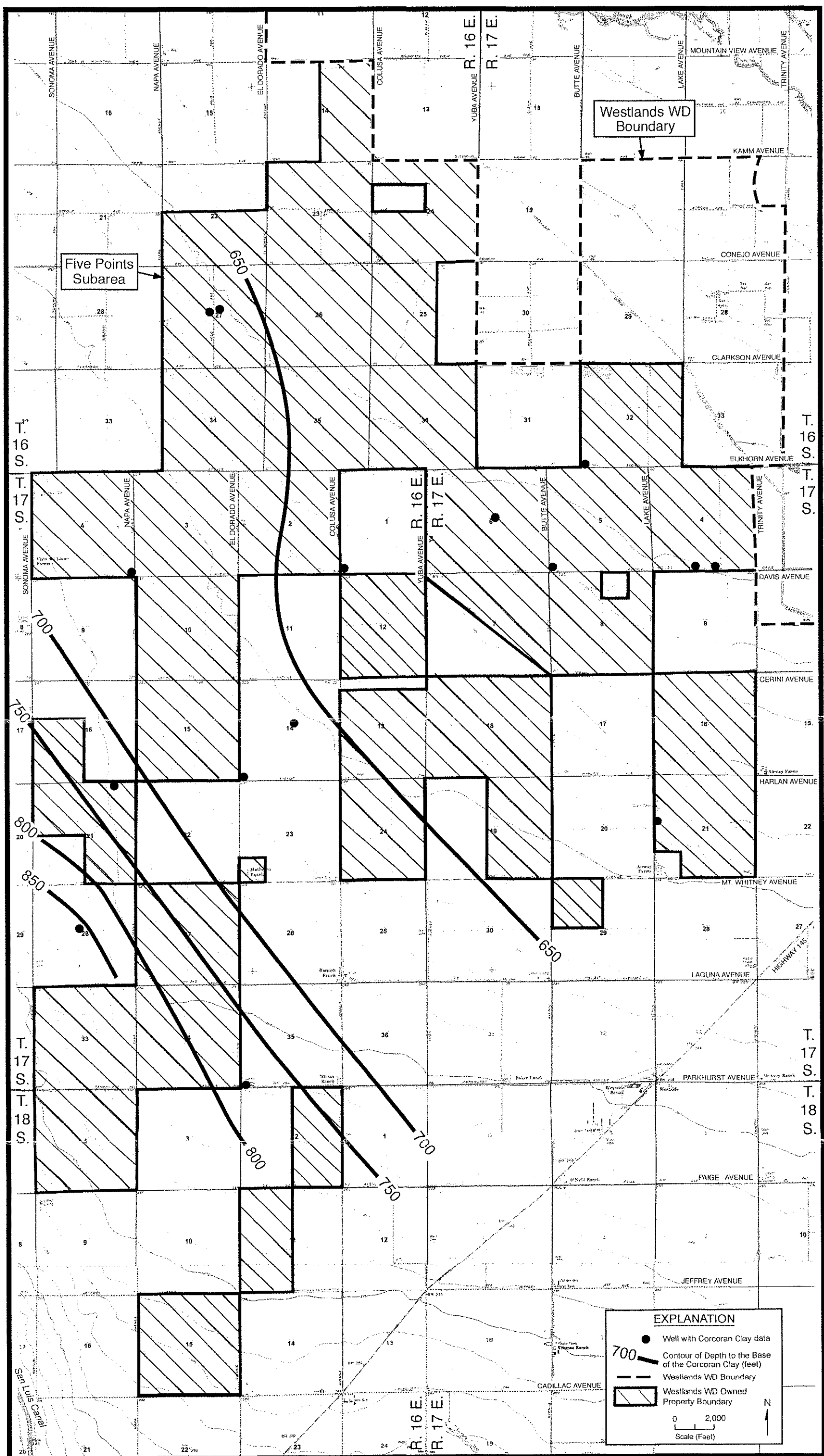


FIGURE 10 - BASE OF CORCORAN CLAY IN THE FIVE POINTS SUBAREA

Base of Fresh Groundwater

Maps are provided in this section for the three subareas that have relatively large differences in depth to the base of the fresh groundwater.

Broadview Subarea

A review of electric logs for deep wells in and near the Broadview WD indicates that the base of the fresh groundwater is about 1,300 feet deep.

Mendota Subarea

Figure 11 shows depth to the base of the fresh groundwater in the Mendota Subarea. Depth to the base of fresh groundwater increases to the south and ranges from less than 1,000 feet beneath the north part of the subarea to more than 1,600 feet near the south boundary. This base is essentially the maximum depth to which wells can be drilled to produce suitable quality groundwater.

Tranquillity Subarea

Figure 12 shows depth to the base of the fresh groundwater in the Tranquillity Subarea. Depth to the base of the fresh groundwater ranges from about 1,900 to more than 3,000 feet, and increases to the southwest in the subarea. This base is considered the maximum depth that irrigation wells can be drilled to produce water of suitable quality for irrigation.

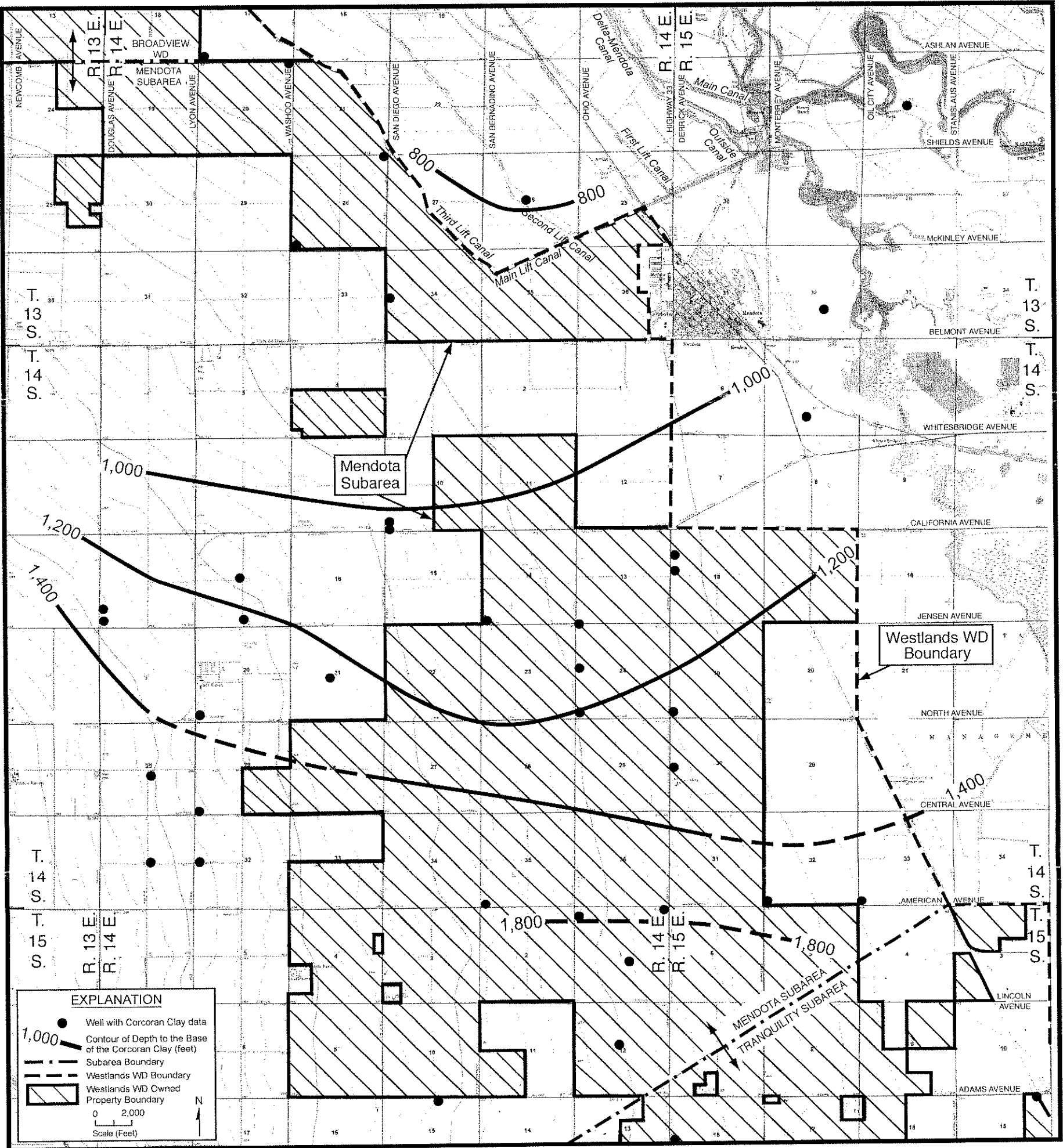


FIGURE 11 - BASE OF FRESH GROUNDWATER IN THE MENDOTA SUBAREA

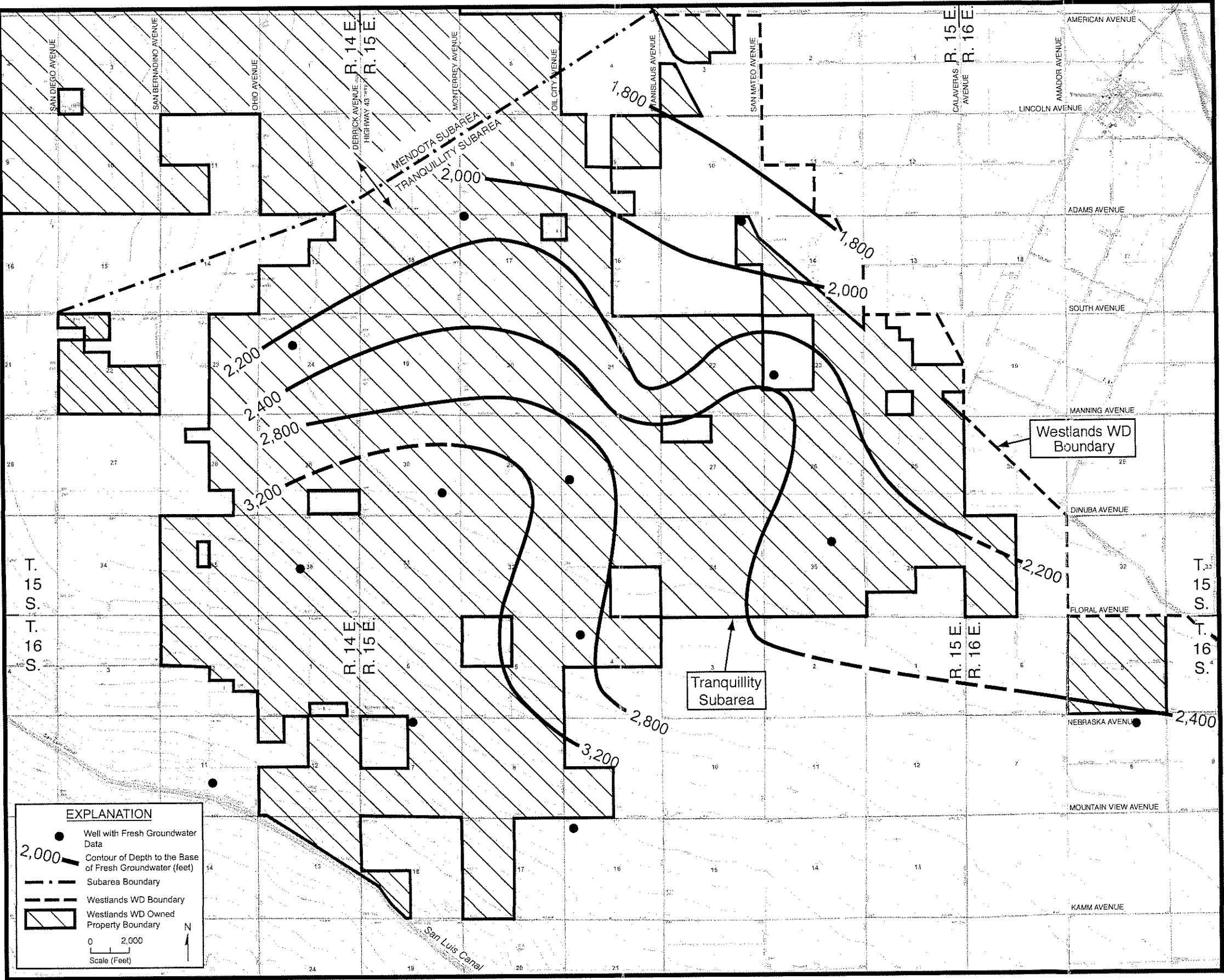


FIGURE 12 - BASE OF FRESH GROUNDWATER IN THE TRANQUILLITY SUBAREA

Five Points Subarea

The Five Points Subarea (Figure 13) is unusual compared to the other subareas, in that brackish water is present both below and above freshwater in part of the subarea. The top of the brackish groundwater is commonly about 1,500 feet deep in the area east of El Dorado Avenue. The base of the underlying fresh groundwater in that part of the subarea ranges from about 2,200 to more than 3,000 feet deep. In the part of the subarea generally west of El Dorado Avenue, depth to the base of the lower fresh groundwater is often more than 3,000 feet deep. Future deep irrigation wells in part of this subarea should be selectively perforated in areas where the brackish water is present, if water of better quality is desired.

Lakeside Subarea

Depth to the base of the fresh groundwater ranges from about 2,000 to 2,100 feet beneath most of the subarea. This is thus the effective maximum depth of irrigation wells in the subarea.

DATA FOR WELLS ON DISTRICT OWNED LANDS

The Westlands WD provided a map showing recently active wells on District owned lands as of the end of 2007. Le Blanc (1970) provided data for wells in the Dos Palos-Kettleman City area, which includes all of the subareas. Completion reports for wells drilled after 1969 were obtained from both the Westlands WD and the California Department of Water Resources in Fresno for use in this

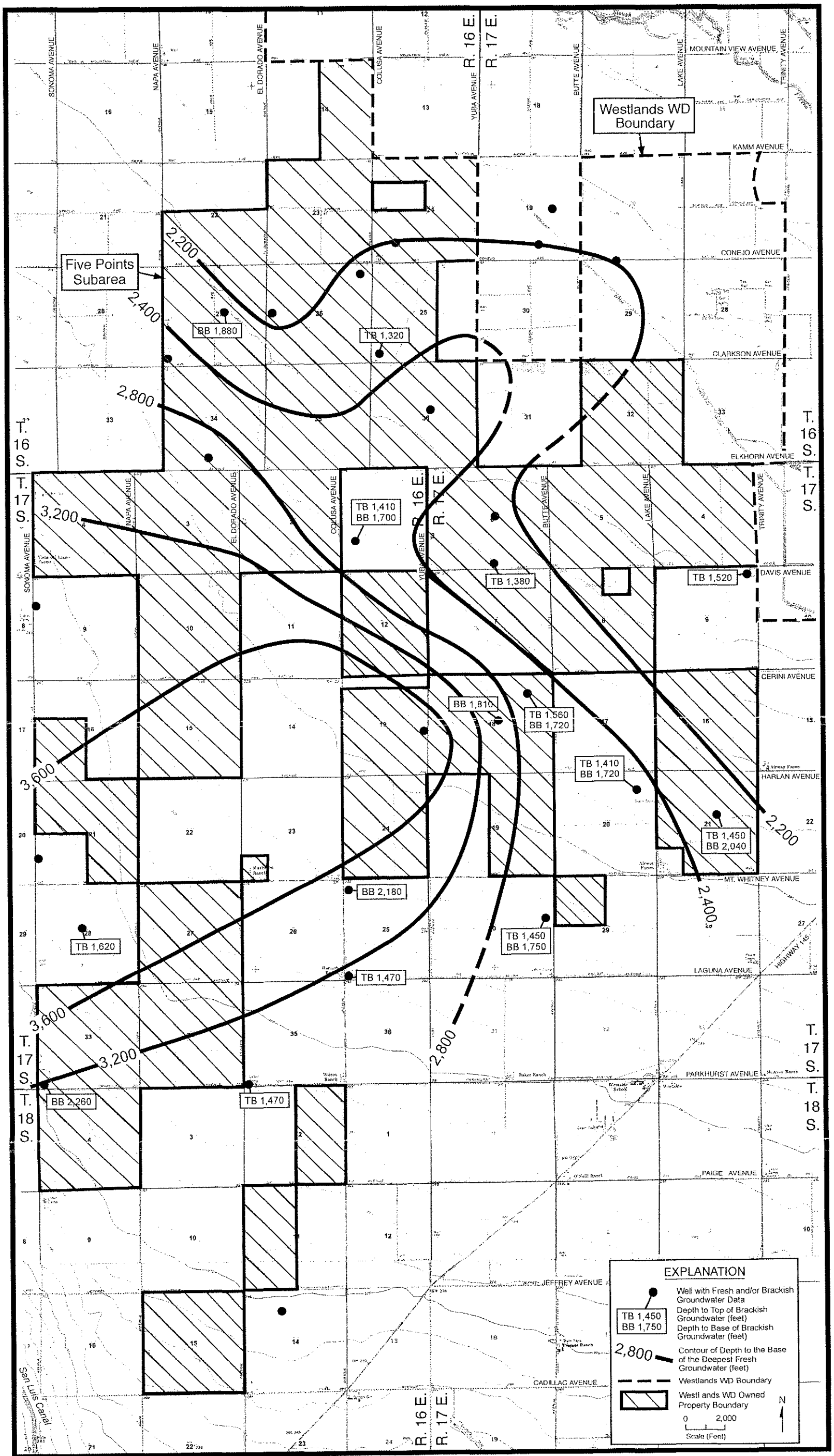


FIGURE 13 - BASE OF FRESH GROUNDWATER IN THE FIVE POINTS SUBAREA

evaluation. Completion reports were available for only about two-thirds of the recently active wells that were constructed after 1969. For the subareas south of the Broadview WD, the depths or perforated intervals of recently active wells are shown on maps in this section of the report.

Broadview WD

There are no known recently active irrigation wells in the Broadview Water District. However, Le Blanc (1970) indicated that at least three wells were drilled in the District, ranging in depth from 800 to 1,430 feet. Two of these wells were indicated to be composite wells, perforated both above and below the Corcoran Clay, whereas the third tapped only the lower aquifer. There are two adjoining areas to the Broadview WD where lower aquifer wells have been constructed in recent decades. One is to the west in the Panoche WD, where a number of irrigation wells have been drilled, commonly to depths ranging from about 900 to 1,200 feet. Some other lower aquifer wells have been constructed along the Delta-Mendota Canal, north of the Broadview WD. These wells generally range in depth from about 700 to 1,000 feet. As discussed in a subsequent section of this report, the quality of groundwater above the Corcoran Clay and below a depth of about 1,200 mg/l in the Broadview WD is generally poor. Groundwater in the depth interval between about 600 and 1,200 feet deep has generally been of suit-

able or marginal quality for irrigation of crops.

Mendota Subarea

There are a number of recently active wells in the Mendota Subarea (Figure 14). Some of these wells solely tap the upper or lower aquifer, and others are composite, tapping both aquifers. Lower aquifer wells are more predominant in the part of the subarea west of Ohio Avenue and south of California Avenue. Upper aquifer wells generally are 500 feet deep or less in the north part, and more than 600 feet deep in the southwest part of the subarea. Lower aquifer wells north of Jensen Avenue are generally about 900 feet deep, and south of North Avenue are up to 1,400 feet deep.

Well data from Le Blanc (1970) indicate that many older wells in this subarea were perforated too shallow and others were perforated too deep to produce good quality water. These wells produced high TDS water and most of them were subsequently abandoned or destroyed. Also, because of the high rate of subsidence and generally corrosive groundwater (due to high salinity and hydrogen sulfide) in at least part of the Mendota Subarea, casing failure may have occurred due to these factors.

Tranquillity Subarea

There are a number of recently active wells in the Tranquillity Subarea (Figure 15). Many wells east of Stanislaus Avenue are about 500 to 550 feet deep and tap the upper aquifer. In contrast,

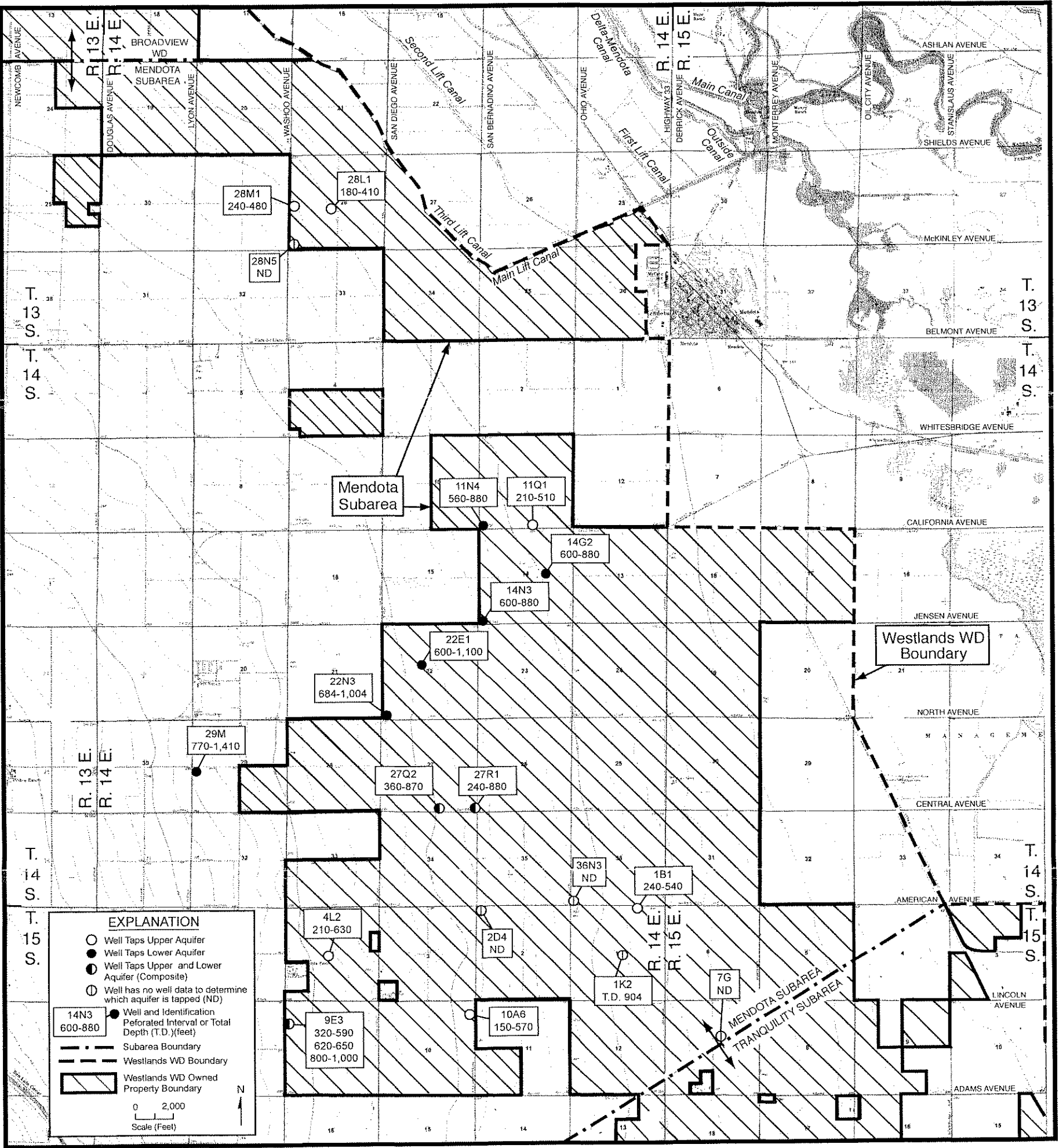


FIGURE 14 - DATA FOR RECENTLY ACTIVE WELLS IN THE MENDOTA SUBAREA

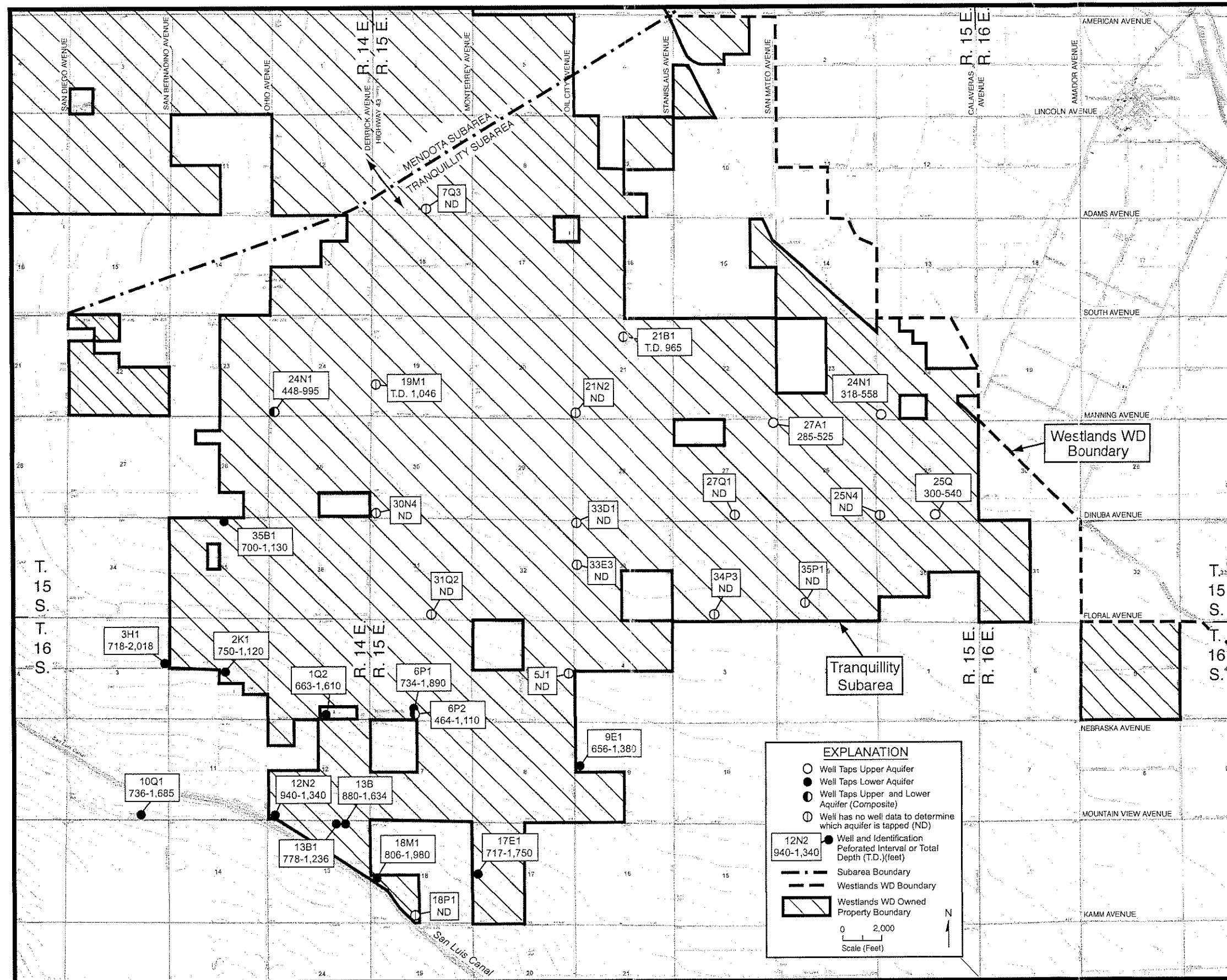


FIGURE 15 - DATA FOR RECENTLY ACTIVE WELLS IN THE TRANQUILLITY SUBAREA

most recently active wells west of Monterey Avenue tap the lower aquifer and are considerably deeper, generally ranging from about 1,100 to 2,000 feet in depth. Records indicate that a number of irrigation wells were drilled in this subarea after 1976. Some of the wells in the west part of the subarea are composite wells, tapping both aquifers.

Five Points Subarea

Many recently active wells in the northeast part of this subarea are about 500 to 600 feet deep and tap the upper aquifer (Figure 16). Most of the lower aquifer wells that were recently active are south of Elkhorn Avenue and west of El Dorado Avenue, or south of Mt. Whitney Avenue. Wells tapping the lower aquifer are generally deeper to the southwest. This is primarily because water levels are deeper and more fine-grained strata are present above the major water-producing sands toward the southwest. Most lower aquifer wells range from about 900 to 1,600 feet in depth. However, some wells near the southwest corner of the subarea are more than 2,000 feet deep.

Lakeside Subarea

There are apparently no recently active irrigation wells in the subarea. However, a number of irrigation wells were drilled in the part of the subarea north of Nevada Avenue and east of 25th Avenue in the late 1970's (Figure 17). Depths of most of these

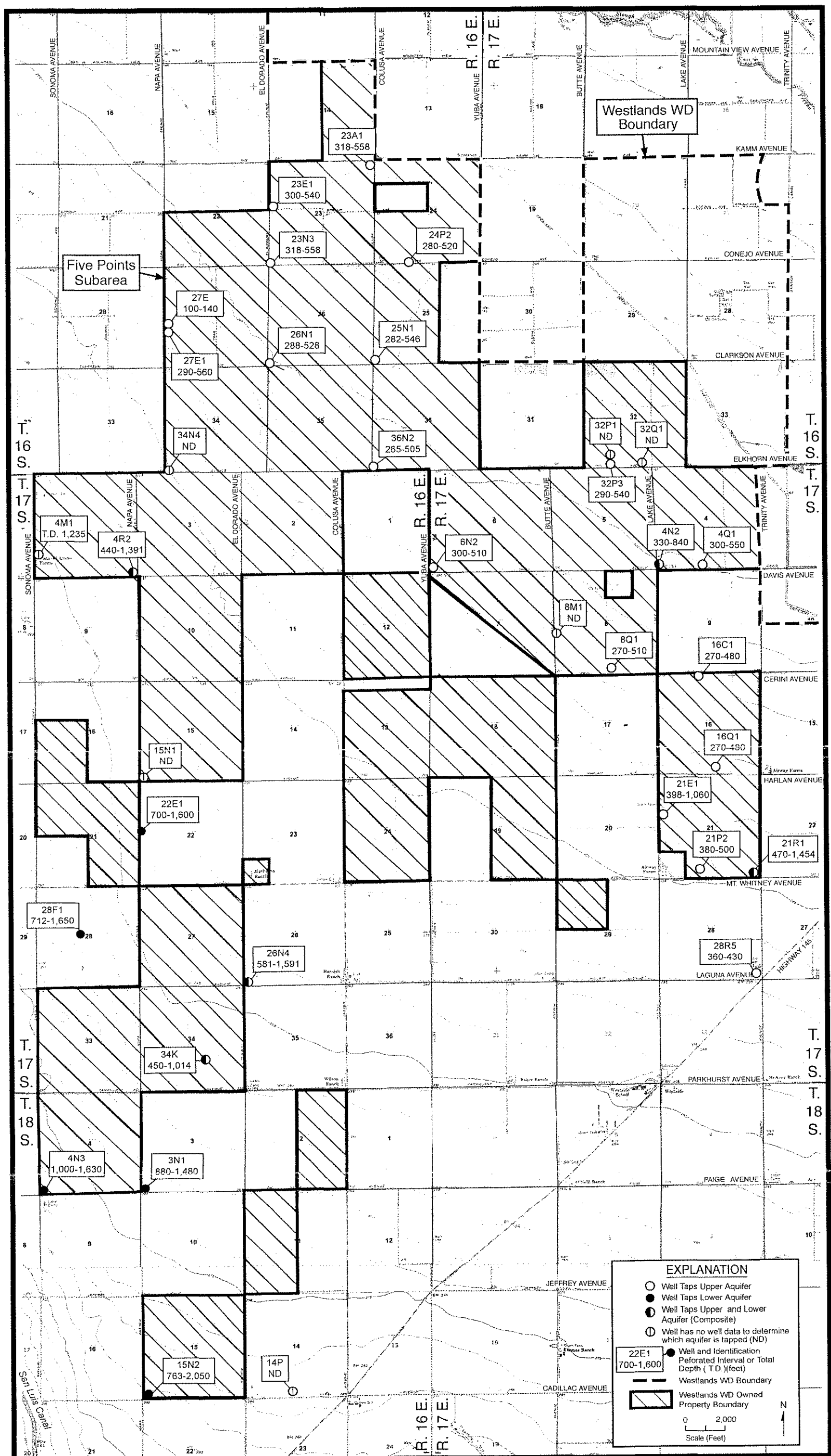


FIGURE 16 - DATA FOR RECENTLY ACTIVE WELLS IN THE FIVE POINTS SUBAREA

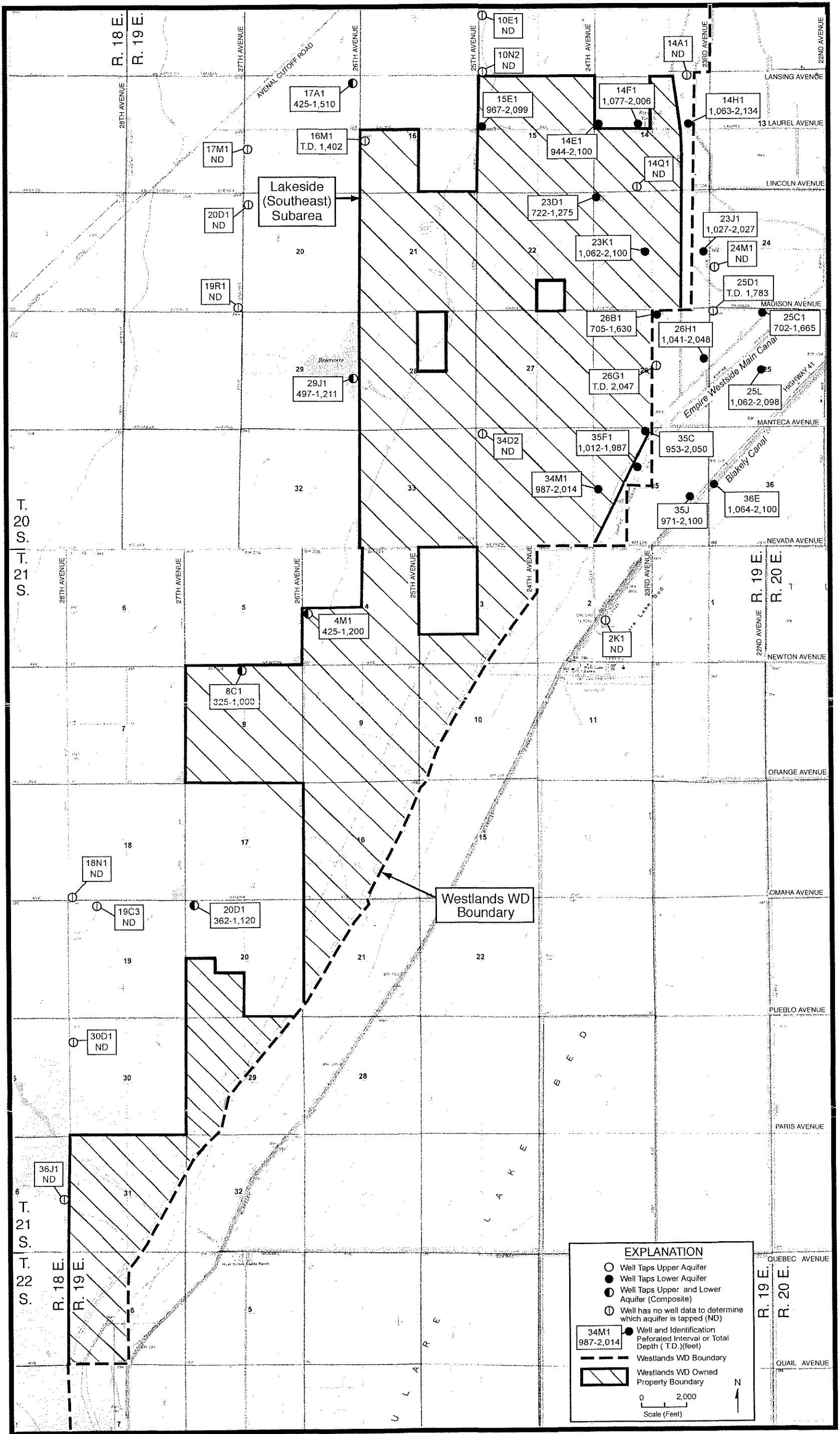


FIGURE 17 - DATA FOR RECENTLY ACTIVE WELLS IN THE LAKESIDE SUBAREA

wells ranged from about 1,600 to 2,100 feet. The wells were constructed relatively deep due to the predominance of clay or other fine-grained deposits above a depth of about 1,000 feet. Le Blanc (1970) indicated that a few composite wells, ranging in depth from about 1,000 to 1,200 feet, were drilled in or near the south part of this subarea, south of Nevada Avenue. Available data indicate that it is unlikely that new large-capacity irrigation wells can be constructed in the part of this subarea south of Newton Avenue, due to the predominance of fine-grained strata.

WATER LEVELS

In this section of the report, the water levels in upper aquifer are briefly discussed. This is followed by a more detailed discussion of water levels in wells tapping the lower aquifer, including depth to water, water-level elevations, the direction of groundwater flow, and historical variations in water levels. Water-level records were obtained from the Westlands WD, California Department of Water Resources (DWR), and U. S. Bureau of Reclamation (USBR) for use in this evaluation.

Upper Aquifer

Prior to significant pumpage in the area (i.e., the early 1900's), groundwater in most of the upper aquifer flowed to the northeast toward the Fresno Slough in the area south of Mendota, and toward the San Joaquin River north of Mendota (Mendenhall,

Dole, and Stabler, 1916). Davis, et al, (1959) indicated that in Spring 1952, the direction of groundwater flow in the upper aquifer was still to the northeast beneath much of the Westlands WD. However, by 1965, pumping in and near the Westlands WD had reversed the direction of the flow, and groundwater in the upper aquifer was moving to the southwest and into the District. Belitz and Heimes (1990) indicated that after San Luis Canal Water was imported (starting in 1967) and pumping in the District decreased, the northeasterly flow of groundwater in the upper aquifer had resumed in most of the part of the Westlands WD east of the San Luis Canal by October 1994. Maps by the DWR for the upper aquifer in the early 2000's cover the part of the area evaluated herein that is east of Highway 33 (Derrick Avenue). Groundwater generally moved away from the Mendota Pool and Mendota Wildlife refuge north of Elkhorn Avenue to the south-southeast or southeast, toward a pumping depression along McMullin Grade in the James ID, northeast of Helm. There were other depressions north and east of Five Points and near Five Points, and groundwater was flowing toward these depression.

Depth to water in the upper aquifer ranged from less than 20 feet to more than 400 feet in the mid-1980's, and was generally less than 100 feet deep in most areas east of the San Luis Canal.

A major limitation on using upper aquifer groundwater in part of the Westlands WD is generally high TDS concentrations (normally from two to three time higher than in the lower aquifer), and a

limited saturated thickness in some areas. In the Broadview WD and Mendota Subarea, high TDS concentrations are present in groundwater in the upper aquifer. Near and west of the San Luis Canal, fine-grained deposits are common in the upper aquifer, and thus well production from this aquifer is limited. Often, only a thin sand layer above the Corcoran Clay, along with water from the lower aquifer, is tapped by irrigation wells. In the Lakeside Subarea, adequate yields for irrigation wells aren't generally obtainable from the upper aquifer. Prior to the importation of surface water to the Westlands WD, wells were generally drilled progressively deeper in some areas, due to declining water levels. The lower aquifer was the major source of supply in most of the District by the 1950's.

Lower Aquifer

Westlands WD prepares annual (December) water-level maps for the lower aquifer (Sub-Corcoran Clay), showing the depth to water in wells and water-level elevations. Prior to 1989, the DWR prepared lower aquifer maps for the part of the San Joaquin Valley where the Corcoran Clay was present. Some of the most useful water-level elevation maps are 25-foot contour interval maps prepared by the Westlands WD in the 1980's. Because of the confined conditions and periodic pumping of some wells in the winter, it is more difficult to prepare such detailed maps for drought periods,

and they are not available. Many of the Westlands WD water-level maps don't show contours beneath the east part of the District, where large parts of the subareas are located. Because of this, KDSA collected water-level data from various sources and prepared water-level elevation contours for selected periods in the subareas south of the Broadview WD. Lower aquifer water-level measurements are not available for the Broadview WD. Water-level elevations in the lower aquifer near the east edge of the subareas are important in evaluating groundwater inflow into the Westlands WD under varying conditions.

Depth to Water

Depth to water along the east edge of the subareas has ranged from less than 100 feet in wet years, such as the mid-1980's, to about 200 feet near the end of drought periods, such as 1993. In contrast, depth to water near the San Luis Canal near the subareas has generally ranged from about 250 to 300 feet in wet years, to about 350 to 450 feet in dry years. Depth to water near the west edge of the District (near I-5) has ranged from about 500 to 600 feet during wet years to about 700 to 800 feet near the end of drought periods, and prior to importation of canal water.

Water-Level Elevations

Davis and Poland (1957) provided a water-level elevation map for the lower aquifer in the Mendota-Huron area for Spring 1951.

This map is considered to be representative of the early 1950's when most of the water supply in the District was from deep wells. Pumpage was estimated to be about one million acre-feet per year at the time. This map indicates that water-level elevations were an average of about 50 feet above mean sea level near the east edge of the subareas to an average of about 100 feet below mean sea level near the San Luis Canal. The water-level elevations indicated that groundwater was flowing into the subareas from the northeast.

Figure 18 shows water-level elevations in the lower aquifer in wells in December 1965. This period was selected to be representative of maximum pumping conditions before importation of water from the San Luis Canal commenced. Water-level elevations were near sea level near the northeast edge of the Mendota Subarea, and about 30 feet below sea level near the northeast edge of the Tranquillity Subarea. Water-level elevations were about 20 feet below sea level near the northeast edge of the Five Points Subarea, and about 50 to 80 feet below sea level in the Lakeside Subarea. Groundwater was flowing into the Mendota, Tranquillity, and Five Points Subareas from the northeast, and into the Lakeside Subarea from the southeast. Groundwater was flowing into the District and moving towards I-5 in most of the area north of Fargo (Cadillac) Road. The lowest water-level elevations (about 300 feet below sea level) were near I-5 north of Packard Avenue. There were two depression cones south of this road. One was centered near the Hanford-Armona Road

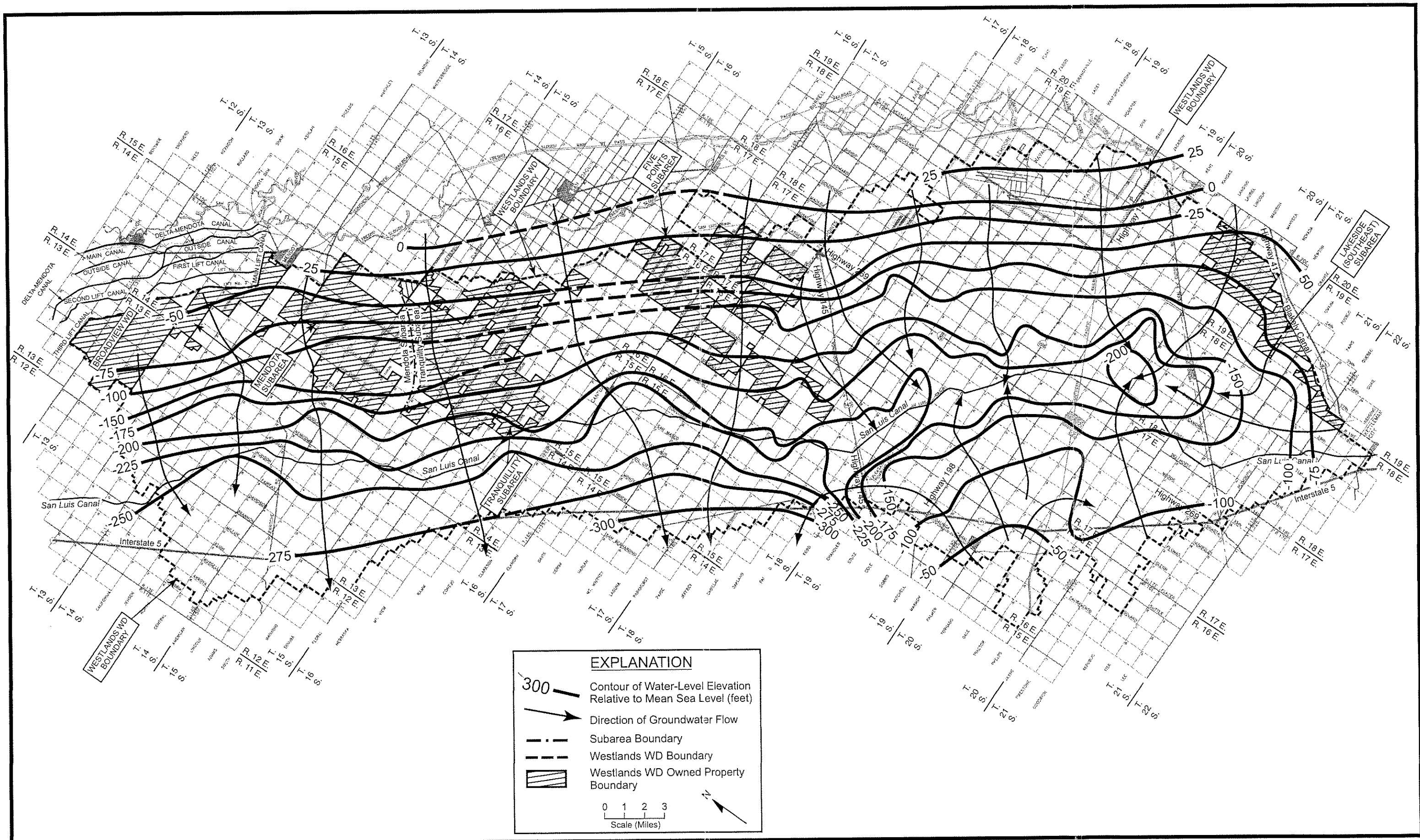


FIGURE 18 - WATER-LEVEL ELEVATIONS IN LOWER AQUIFER WELLS IN DECEMBER 1965

(Ford) and the San Luis Canal and the other was located southeast of Huron. Water-level elevations in both of these depressions were more than 200 feet below sea level. A recharge area was indicated in the area west of Huron, where groundwater from Pleasant Valley was flowing through Pasajero Gap and Los Gatos Creek (Arroyo Pasajero) streamflow contributed to the recharge. Groundwater in this area was flowing to the northeast, east, and southeast.

Figure 19 show water-level elevations in the lower aquifer in December 1986. This period was selected to show water levels after substantial recovery, due to minimal pumpage. Except for the 1976-77, drought water levels in lower aquifer wells in the subareas rose substantially after 1967 due to decreased pumping. In December 1986, water levels were about 80 to 90 feet above sea level near the northeast edge of the Mendota Subarea, and about 80 to 100 feet above mean sea level near the northeast edge of the Tranquillity Subarea. North of South Avenue, the direction of groundwater flow was to the southwest, and groundwater was flowing into the subareas from the northeast. South of South Avenue, groundwater was flowing to the northwest and into the Tranquillity Subarea from the south and southeast. Near the northeast edge of the Five Points Subarea, water-level elevations were about 50 to 70 feet above mean sea level. North of Elkhorn Avenue, the direction of groundwater flow was to the southwest and into the subarea from the east and northeast. South of Elkhorn Avenue the flow direction was

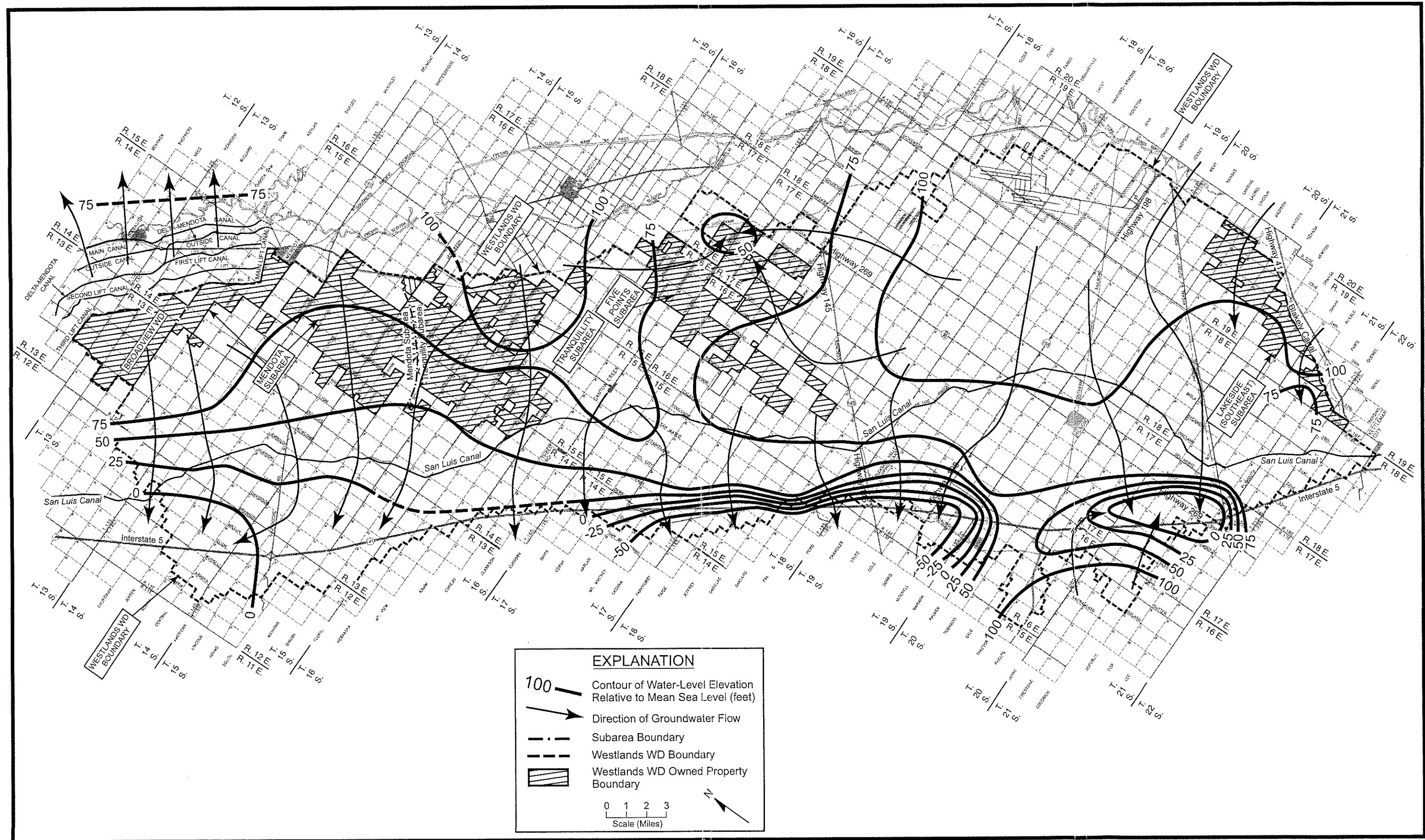


FIGURE 19 - WATER-LEVEL ELEVATIONS IN LOWER AQUIFER WELLS IN DECEMBER 1986

to the northwest, and groundwater was flowing into the subarea in the lower aquifer from the east and southeast. In the Lakeside Subarea, water-level elevations ranged from about 70 to 120 feet above mean sea level. The direction of groundwater flow was to the west in the part of the subarea north of Nevada Avenue and to the northwest in the part south of Nevada Avenue.

Figure 20 shows water-level elevations in November-December, 1993. This period was selected to be representative of deeper water levels near the ends of prolonged droughts, when there has been substantial pumping from lower aquifer wells in and near the Westlands WD. Near the northeast edge of the Mendota Subarea, water-level elevations ranged from near sea level to about 20 feet above mean sea level, and the direction of groundwater flow was to the southwest. Water-level measurements are sparse for lower aquifer wells near the northeast edge of the Tranquillity Subarea for November-December, 1993, but water-level elevations were apparently about 20 feet above mean sea level. The direction of groundwater flow was also to the southwest. Water-level elevations near the northeast edge of the Five Points Subarea were about 10 feet above mean sea level, and the direction of groundwater flow was to the southeast. Groundwater in the part of the Lakeside Subarea north of Nevada Avenue was flowing to the southwest. The water-level elevations were near mean sea level near the northeast corner of the Lakeside Subarea. In the part of the Lakeside Subarea south of

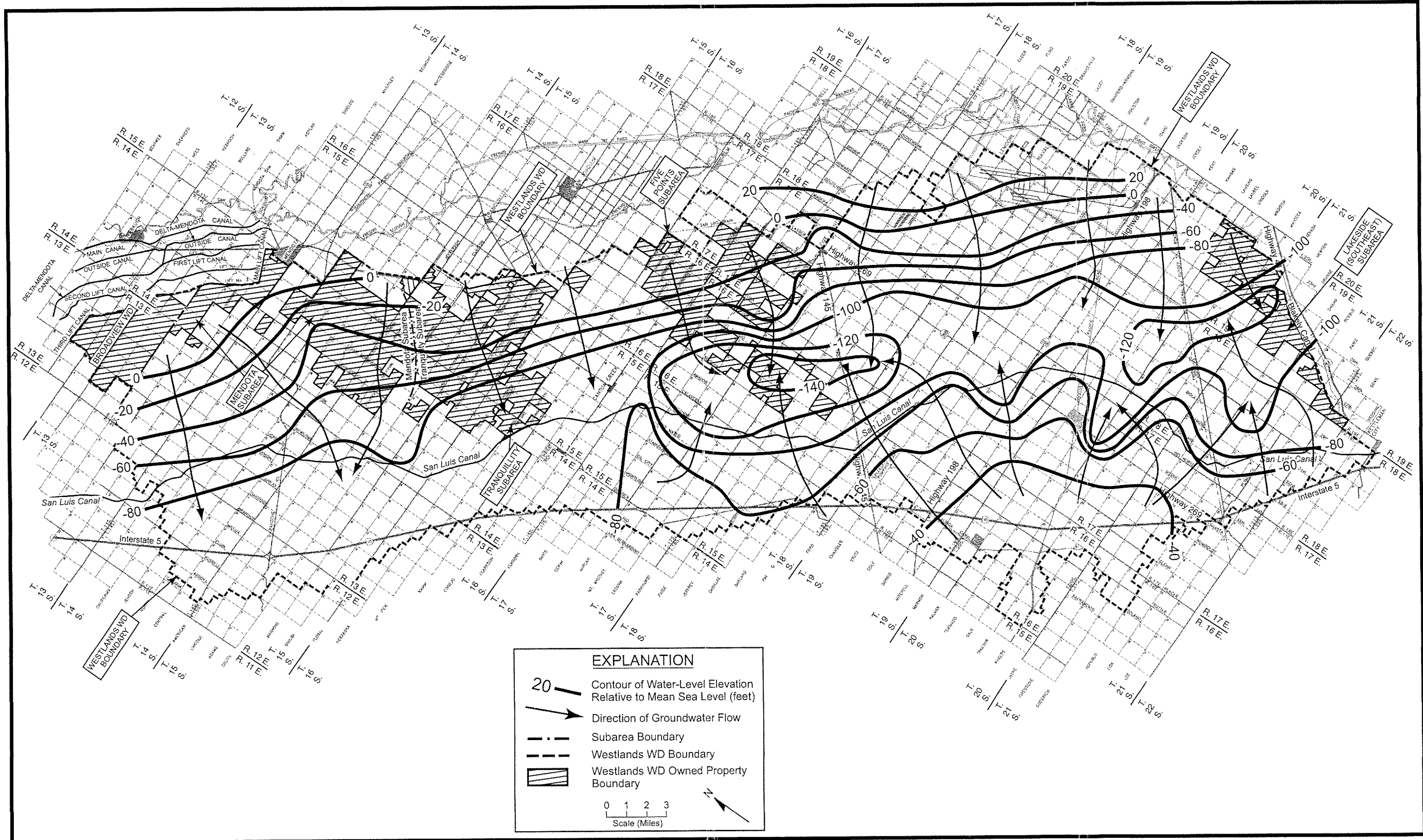


FIGURE 20 - WATER-LEVEL ELEVATIONS IN LOWER AQUIFER WELLS IN NOVEMBER-DECEMBER 1993

Nevada Avenue, water-level elevations were between 80 and 120 feet below mean sea level, and the direction of groundwater flow was to the northeast. There was a pumping depression between Madison and Newton Avenues, due to pumping of lower aquifer wells in and southeast of the subarea.

There was a cone of depression in the area between the San Luis Canal and Five Points (south of Elkhorn Avenue and north of Packard Avenue), where water-level elevations were less than 120 feet. There was another depression southeast of Huron, where water-level elevations were also less than 120 feet. Groundwater in the area west and southwest of Huron was moving to the northeast towards these depressions. These depressions were due to pumping of many wells in these areas in 1993.

Water-Level Trends

Water-level hydrographs for wells in or near the Westlands WD were obtained from a California Department of Water Resources (DWR) website. The DWR doesn't provide an indication the depth or perforated intervals for the measured wells. However, the aquifer tapped by most of these wells can be determined based on available well construction data and consideration of depth to water. Water levels in lower aquifer wells are commonly 100 feet or more deeper than the corresponding water levels in upper aquifer wells. Following is the number of lower aquifer wells with hydrographs that

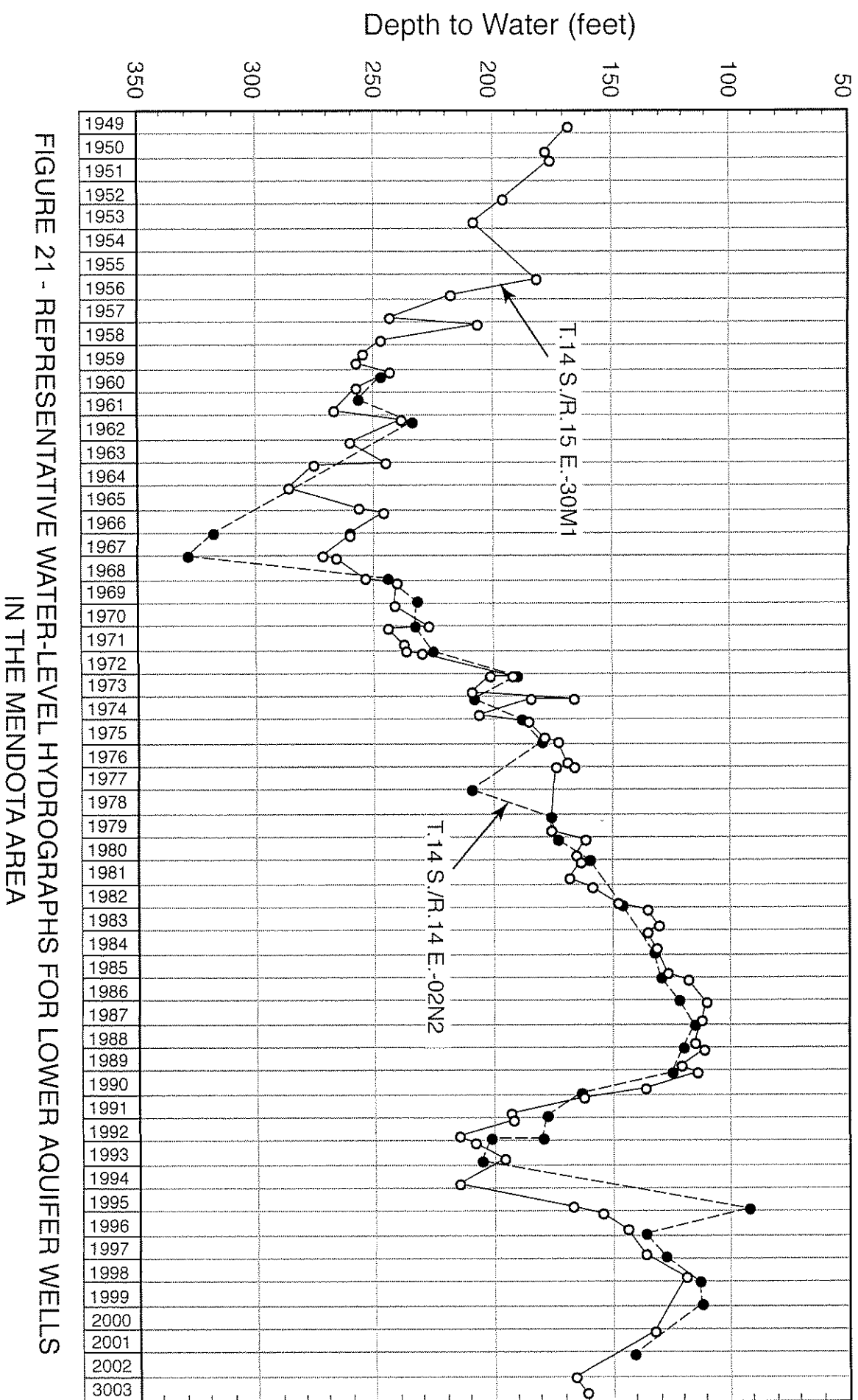
were evaluated:

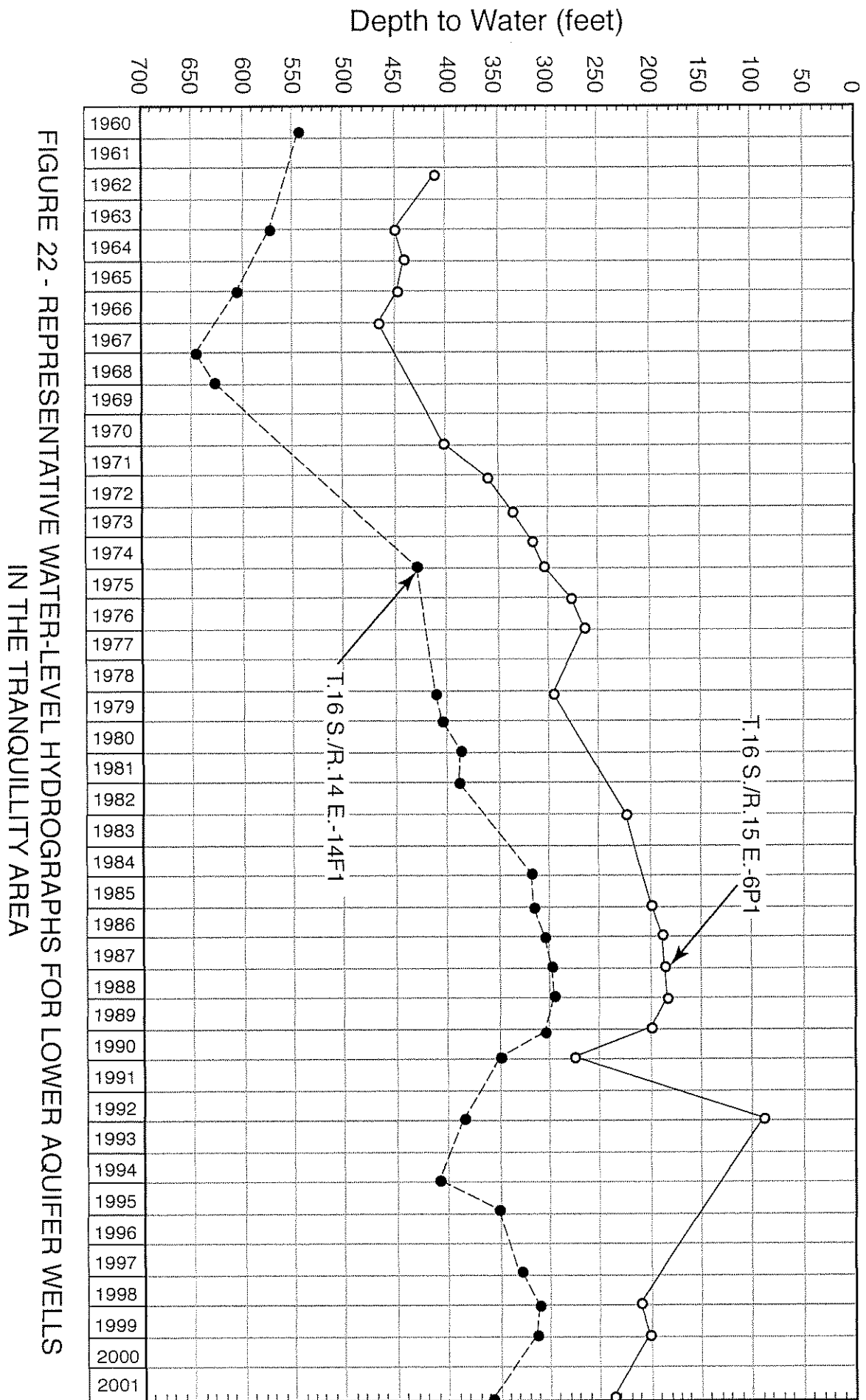
<u>Subarea</u>	<u>No. of Wells</u>
Mendota	17
Tranquillity	9
Five Points	12
Lakeside	6

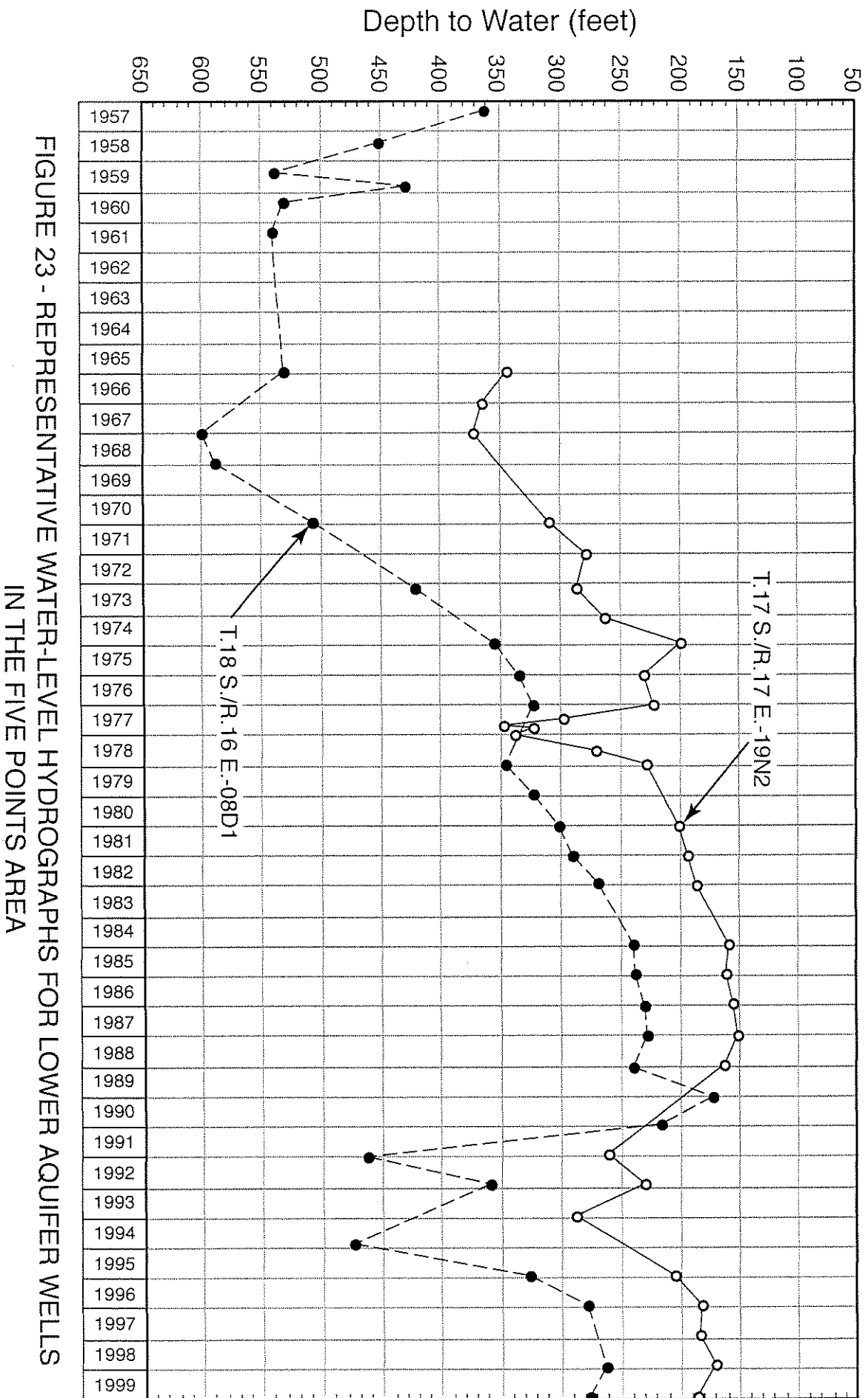
Figure 21 shows two representative water-level hydrographs for the lower aquifer in the Mendota Subarea. Well T14S/R15E-30M1 has records extending from 1950 to 2004 and Well T14S/R14E-2N2 has records extending from 1960 to 2002. Water levels in both of these wells fell until 1968, then rose through 1976, and then continued to rise after the 1977-78 drought through the late 1980's. The water levels then fell during 1990-94, and then recovered after 1994.

Figure 22 shows two representative water-level hydrographs for the lower aquifer in the Tranquillity Subarea. Well T16S/R14E-14F1 has records extending from 1960 to 2002 and Well T16S/R15E-6P1 has records extending from 1962 to 2002. Water level trends for these wells were similar to those for lower aquifer wells in the Mendota Subarea.

Figure 23 shows two representative water-level hydrographs for the lower aquifer in the Five Points Subarea. Well T17S/R17E-19N2 has records extending from 1966 to 2000 and Well T18S/R16E-8D1 has







records extending from 1957 to 2000. These wells had generally similar water-level trends as for the Mendota and Tranquillity Sub-areas. However, water levels in Well 19N2 drew down more during 1977-78 than during the early 1990's, apparently due to more pump-age in the vicinity of this well during the earlier period.

Figure 24 shows two representative water-level hydrographs for the lower aquifer in the Lakeside Subarea. Well T20S/R20E-30J1 has records extending from 1965 to 2007 and Well T21S/R19E-2B1 has records extending from 1958 to 2002. Records are not available to show rates of water-level decline in this subarea prior to 1960. Water levels were deeper in Well 30J1 during the 1992-93 period than any levels prior to that time.

Based on interpretation of the water-level hydrographs, five time periods were evaluated in order to summarize rates of water-level change. Water-level declines prior to 1967 and during 1988-94 were selected for evaluation. Water-level rises for 1967-76, 1978-88, and 1993-98 were also selected for evaluation.

Table 1 summarizes water-level changes in the subareas for these five periods. Water-level declines for the lower aquifer ranged from 10 to 19 feet per year and averaged 14 feet per year prior to 1967. Water levels rose from 18 to 24 feet per year, or an average of 20 feet per year, during 1967-76, and rose from 12 to 20 feet per year, or an average of 16 feet per year, during 1978-88. The rises were associated with increased use of imported water

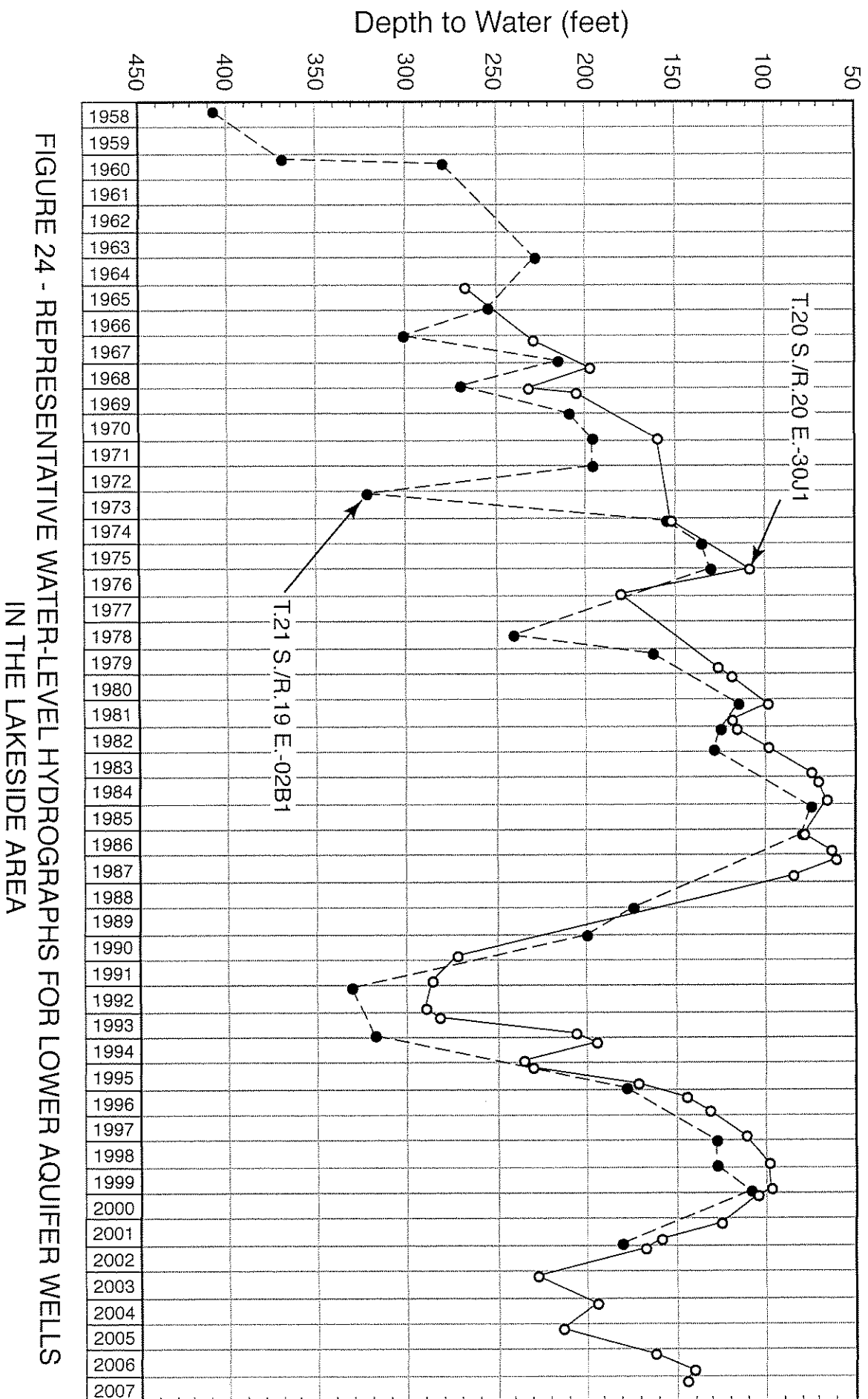


TABLE 1-HISTORICAL AVERAGE WATER-LEVEL CHANGES
IN SUBAREAS (FEET PER YEAR)

<u>Subarea</u>	<u>LOWER AQUIFER</u>				
	<u>Decline</u> <u>Prior to 1967</u>	<u>Rise</u> <u>1967-76</u>	<u>Rise</u> <u>1978-88</u>	<u>Decline</u> <u>1988-94</u>	<u>Rise</u> <u>1993-98</u>
Mendota	14	18	12	22	19
Tranquillity	19	24	20	22	28
Five Points	10	19	17	31	36
Lakeside	-	18	16	37	35
Ave	14	20	16	28	29

<u>Subarea</u>	<u>UPPER AQUIFER</u>				
	<u>Decline</u> <u>Prior to 1967</u>	<u>Rise</u> <u>1967-76</u>	<u>Rise</u> <u>1978-88</u>	<u>Decline</u> <u>1988-94</u>	<u>Rise</u> <u>1993-98</u>
Mendota	8	7	6	12	7
Tranquillity	6	6	4	10	10
Five Points	5	-	4	10	9

for irrigation and less deep well pumpage in and near the Westlands WD. Water levels temporarily fell between these two periods, due to pumping during the 1976-78 drought. Water levels fell between 1988 and 1994 from 22 to 37 feet per year, or an average of 28 feet per year, associated with more pumping during the prolonged drought. Water levels then rose from 19 to 36 feet per year, or an average of 29 feet per year, during 1993-98, following the prolonged drought. The relatively large water-level fluctuations for wells tapping the lower aquifer are expected for a confined aquifer. The highest rates (exceeding 25 feet per year) are likely indicative of the lowest transmissivity and the most confined conditions, and possibly the most concentrated lower aquifer pumpage. The smaller rates of water-level declines and rises in each subarea are likely due to less pumpage during the periods of water-level decline. Water-level declines during 1988-94 were greater than prior to 1969 in all of the subareas evaluated, indicating that lower aquifer pumping in and near the subarea was greater in 1988-94 than prior to 1967. However, the compaction of clay layers may be responsible for part of this difference.

For comparison purposes, water-level changes in the upper aquifer are also provided in Table 1. These changes were about one-third of those for the lower aquifer. This was due to the lower confinement and higher transmissivity of the upper aquifer in most subareas, and also that there has been less pumping from the

upper aquifer than from the lower aquifer.

PUMPAGE

Davis and Poland (1957) estimated that groundwater pumpage in the Dos Palos-Kettleman City area as of 1951 was about one million acre-feet per year, and as of 1953 was 1,240,000-feet per year. They indicated that about 80 percent of this pumpage was from the lower aquifer. Figure 25, taken from the Westlands WD, shows the relation between pumpage in the lower aquifer in the District and the average water-level elevation in wells tapping the lower aquifer since 1976. The greatest annual pumpage from the lower aquifer (about 600,000 acre-feet per year) was in 1991 and 1992. The next highest pumpage was about 472,000 acre-feet per year in 1977. The average annual pumpage from the lower aquifer in the District was about 405,000 acre-feet per year during 1990-94.

Average water levels in lower aquifer wells were about the same in December 2005 as in December 1986. An average of 205,000 acre-feet per year was pumped from the lower aquifer in the District during that period. This pumpage is probably close to the historical sustainable average pumpage from the lower aquifer in the District, in order to have stable water levels over the long-term.

WELL PRODUCTION

Pump test results for wells were obtained from the Westlands WD, files of KDSA, and from well completion reports. Pump tests

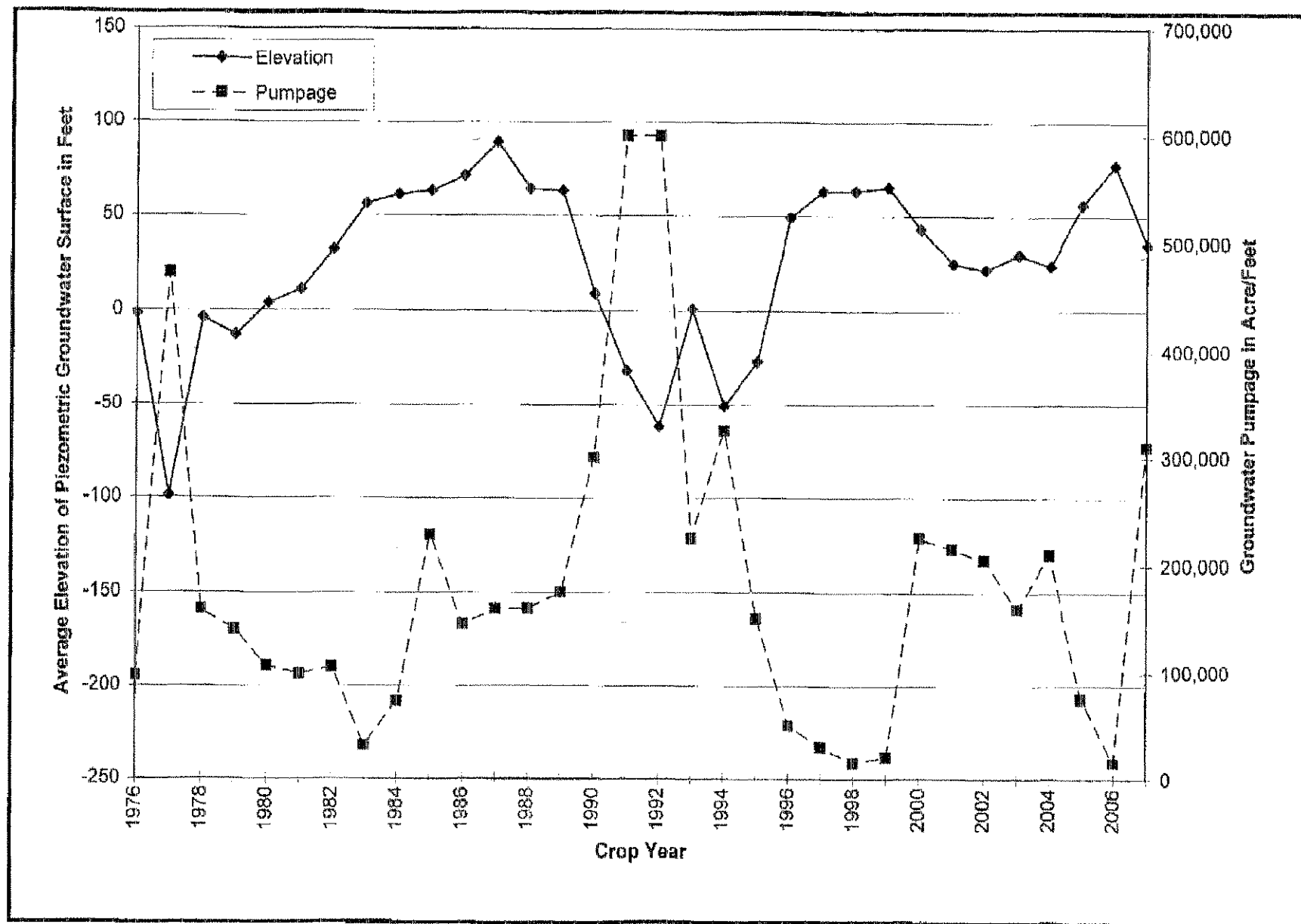


FIGURE 25-RELATION BETWEEN AVERAGE WATER-LEVEL ELEVATION FOR LOWER AQUIFER AND GROUNDWATER PUMPAGE IN WESTLANDS WATER DISTRICT

for wells tapping the upper aquifer are briefly discussed, and this is followed by a more detailed discussion of pump tests for lower aquifer wells.

Upper Aquifer

A substantial amount of information on well production for the upper aquifer is available in and near the east parts of the Mendota, Tranquillity, and Five Points Subareas. Pumping rates for many upper aquifer irrigation wells in these areas range from about 1,000 to 2,500 gpm, and specific capacities commonly range from about 30 to over 100 gpm per foot. Most of these wells tap highly permeable Sierran Sands of the upper aquifer. Belitz and Heimes (1990, Figure 3) showed the thickness of the Sierran sands in the Westlands WD. These sands are about 300 feet thick near Mendota and Five Points and more than 500 feet thick near Tranquillity. These sands thin and pinch out to the southwest and are generally not present near the San Luis Canal.

Lower Aquifer

Mendota Subarea

Table 2 provides pump test results for a lower aquifer well in or near the Mendota Subarea. The pumping rate was 2,015 gpm and the specific capacity was 38 gpm per foot.

TABLE 2-PUMP TEST RESULTS FOR A LOWER
AQUIFER WELLS IN THE MENDOTA SUBAREA

<u>Well Location</u>	<u>Date</u>	<u>Pumping Rate</u> <u>(gpm)</u>	<u>Static Level</u> <u>(feet)</u>	<u>Pumping Level</u> <u>(feet)</u>	<u>Drawdown</u> <u>(feet)</u>	<u>Specific Capacity</u> <u>(gpm/ft)</u>
T15S/R14E-20D	5/08	2,015				38

Tranquillity Subarea

Table 3 provide pump test results for two lower aquifer wells in or near the Tranquillity Subarea. Pumping rates ranged from 1,425 to 1,995 gpm and specific capacities from 6 to 13 gpm per foot. Higher specific capacities are considered obtainable in much of the area, if proper well construction and development techniques are used.

Five Points Subarea

Table 4 provides pump test results for lower aquifer wells in the Five Points Subarea. Pumping rates ranged from about 1,500 to 3,500 gpm. Specific capacities for most of these wells ranged from about 20 to 80 gpm per foot, and averaged about 40 gpm per foot. Most of these wells tap highly productive deposits within the upper 500 to 700 feet of the lower aquifer that are derived from the Sierra Nevada.

Lakeside Subarea

Table 5 provides pump test results for a number of irrigation wells in or near the north part of the Lakeside Subarea that tap the lower aquifer. Most of these wells are about 2,000 feet deep. Pumping rates ranged from about 2,000 to 3,500 gpm and most specific capacities ranged from about 30 to 45 gpm per foot.

TABLE 3-PUMP TEST RESULTS FOR LOWER AQUIFER
WELLS IN THE TRANQUILLITY SUBAREA

<u>Well Location</u>	<u>Date</u>	<u>Pumping Rate</u> <u>(gpm)</u>	<u>Static Level</u> <u>(feet)</u>	<u>Pumping Level</u> <u>(feet)</u>	<u>Drawdown</u> <u>(feet)</u>	<u>Specific Capacity</u> <u>(gpm/ft)</u>
T15S/R14E-29M	4/08	1,995				13
T16S/R14E-13B1	7/77	1,425	393	620	227	6

TABLE 4-PUMP TEST RESULTS FOR LOWER AQUIFER
WELLS IN THE FIVE POINTS SUBAREA

<u>Well Location</u>	<u>Date</u>	<u>Pumping Rate (gpm)</u>	<u>Static Level (feet)</u>	<u>Pumping Level (feet)</u>	<u>Drawdown (feet)</u>	<u>Specific Capacity (gpm/ft)</u>
T17S/R16E-3Q1	6/91	1,975	430	525	95	25
-17A	3/92	3,000	383	428	45	67
-23M	7/91	2,560	345	374	29	87
T17S/R17E-14Q	7/92	2,740	375	437	63	44
-32SW1/4	3/93	3,475	346	409	62	56
-33N	6/91	2,000			266	8
T17S/R18E-19D	5/92	2,045	239	319	80	26
T18S/R16E-3N	9/00	3,425				62
-5N	10/90	3,050	348	388	40	77
T18S/R16E-6A	5/91	3,000	397	499	102	29
-9R	8/90	2,750	305	372	67	40
-17R	10/90	2,445	349	527	178	14
-21S1/4	5/93	3,000	406	612	206	15
-23L	2/95	3,120	384	547	163	19
T18S/R17E-4N	6/91	2,700	318	383	65	40
-7E	4/92	1,745			54	32
-7G	4/92	1,540			46	34
-8Q	4/92	1,510			69	22

TABLE 5-PUMP TEST RESULTS FOR LOWER AQUIFER
WELLS IN OR NEAR THE LAKESIDE SUBAREA

<u>Well Location</u>	<u>Date</u>	<u>Pumping Rate (gpm)</u>	<u>Static Level (feet)</u>	<u>Pumping Level (feet)</u>	<u>Drawdown (feet)</u>	<u>Specific Capacity (gpm/ft)</u>
T20S/R18E-26NW	7/91	2,170			214	10
T20S/R19E-6D	7/93	2,515			65	39
-7Center	6/93	2,035	312	360	48	42
-14E	12/77	3,250	385	462	77	42
-14F	11/76	3,000	201	305	104	29
-14H	11/76	3,000	181	285	104	29
-15E	7/77	3,100	311	385	74	42
-23F	4/77	3,000	203	361	98	31
-25J	4/77	3,500	250	349	99	35
-25L	4/77	3,100	293	365	72	43
-35C	5/77	3,550	234	356	122	29
-36E	1/78	3,400	344	420	76	45

AQUIFER CHARACTERISTICS

Upper Aquifer

Results of aquifer tests are available for about a dozen wells tapping the upper aquifer, primarily in or near the Mendota Sub-area. Transmissivity values ranged widely, and most values ranged from about 60,000 to 280,000 gpd per foot. The average value was about 125,000 gpd per foot. Hydraulic conductivity values for the coarse-grained deposits alone for most of the tests ranged from about 500 to 2,000 gpd per square foot, although values for several tests ranged from 3,600 to 5,700 gpd per square foot. The average hydraulic conductivity for all of the tests is about 1,900 gpd per square foot, consistent with the coarse-grained, highly permeable nature of the Sierran sands in the area.

Lower Aquifer

Davis and Poland (1957), reported on a three-month long "mega" aquifer test that was conducted during August-October, 1926. All 54 wells of the Boston Land Co. were shut down for three months after prolonged pumping, and the water-level recovery was measured. A transmissivity of 120,000 gpd per foot was calculated from water-level recovery data. The average hydraulic conductivity for the lower zone (1,100 feet thick in the test vicinity), was 110 gpd per square foot (this value is for both sand and clay layers). Based on specific capacities for wells further north and along the east

edge of the Mendota-Huron area, Davis and Poland (1957) determined that this transmissivity was applicable along the entire easterly inflow boundary in the Dos Palos-Westhaven area.

Transmissivity values from pump tests on wells in the Mendota and Tranquillity subareas were not available for this report.

Five Points Subarea

Aquifer test results are available for 17 lower aquifer wells in the Five Points Subarea. Transmissivity values for most of these tests ranged from 50,000 to 160,000 gpd per foot, and averaged about 100,000 gpd per foot. This value is considered reasonable, and is somewhat lower than indicated near the east edge of the subarea by Davis and Poland (1957). This difference is consistent with the trend in texture for the lower aquifer deposits, which generally become finer-grained to the southwest in the area. Hydraulic conductivities for these tests have been determined for the sand strata alone. These values ranged from 230 to 810 gpd per square foot and averaged 340 gpd per square foot.

Lakeside Subarea

Aquifer tests results are available for three lower aquifer wells near the Lakeside Subarea. Transmissivities ranged from 59,000 to 84,000 gpd per foot. Hydraulic conductivities of the sand layers ranged from 260 to 300 gpd per square foot and averaged 280 gpd per square foot.

Storage Coefficient

The only known aquifer test for a well tapping the lower aquifer where the storage coefficient was determined in the vicinity of the District was conducted for one week along the DMC at the Hamburg Farms (KDSA, 1997), as part of a Leaky Aquifer Test. The site was about two miles northwest of the Fresno County-Merced County line. The transmissivity was 160,000 gpd per foot and the storage coefficient was 0.001. The vertical hydraulic conductivity of the Corcoran Clay was determined to be less than 0.001 gpd per square foot at the site. The storage coefficient for the lower aquifer in the subareas evaluated is expected to range from 0.001 to 0.0001.

ESTIMATED GROUNDWATER INFLOW TO LOWER AQUIFER

Davis and Poland (1957) estimated that as of 1951, the groundwater inflow into the lower aquifer from the northeast beneath a segment extending from south Dos Palos to Highway 41, along the northeast edge of the District, was about 175,000 acre-feet per year. The average southwesterly hydraulic gradient along the 71-mile long inflow boundary in 1951 was estimated to be about 18 feet per mile. As of 1951, about 1,000,000 acre-feet of groundwater were being pumped in the area to the west of this boundary, and an estimated 800,000 acre-feet per year was from the lower aquifer.

As part of this evaluation, water-level gradients near the inflow boundaries of the subareas were evaluated for four periods:

December 1965, December 1986, November 1993, and December 2007. The smallest gradients were in December 1986, and were about 5 feet per mile for the Mendota and Tranquillity Subareas, 14 feet per mile for the Five Points Subarea, and 11 feet per mile for the Lakeside Subarea. These measurements are representative of wet periods and minimal pumping from the lower aquifer. The steepest gradients were for November 1993, except for the Lakeside Subarea. In this subarea, there was no significant inflow through the southeast boundary of the subarea as of November 1963. The gradients in November 1993 were 31 feet per mile for the Mendota Subarea and 19 feet per mile for the Tranquillity Subarea. For the Five Points Subarea, the gradient was only three feet per mile north of Elkhorn Avenue and was 15 feet per mile south of Elkhorn Avenue.

These gradients along with transmissivity values indicate that the groundwater inflow into the lower aquifer in the Mendota Subarea (width of inflow of 12.5 miles) was about 52,000 acre-feet per year in November 1993. The inflow into the Tranquillity Subarea (width of inflow of 8.5 miles) was about 22,000 acre-feet per year in November 1993. Inflow to the Five Points Subarea was significantly less in 1993 than in the early 1950's. The estimated groundwater inflow into the Five Points Subarea (width of inflow of 7.8 miles) was about 9,500 acre-feet per year in November 2003. This is apparently because of increased lower aquifer pumping in the area northeast of this subarea (primarily east of the Fresno

Slough Bypass). There was essentially no groundwater inflow into the Lakeside Subarea from the southeast in November 1993, apparently due to pumpage southeast of this subarea.

LAND SUBSIDENCE

Shallow Subsidence

Bull (1964) reported on near-surface or shallow subsidence in western Fresno County. His evaluation indicated that mudflow deposits are common in the areas between alluvial fans on the west side of the valley. These deposits can be compacted when first irrigated, resulting in significant land subsidence. Extensive studies of this were done prior to construction of the San Luis Canal. The shallow subsidence has been most important for newly irrigated areas lands west of the canal. For the subareas evaluated, shallow subsidence has been insignificant, because the mudflow deposits don't extend this far east.

Subsidence Due to Groundwater Pumping

Most of the significant land subsidence in or near the subareas that were evaluated has been due to groundwater pumping. Decreases in hydraulic head beneath clay layers resulted in expulsion of water from these layers and compaction. A number of USGS Professional Papers (the 437 Series) focused on land subsidence due to groundwater pumping in the Los Banos-Kettleman City area. Ireland, Poland, and Riley (1984) reported on land subsidence in the Los

Banos-Kettleman City area of 1980. Figure 26, taken from Figure 4 of the reference, shows land subsidence in the area between 1926 and 1972. No up-to-date contour maps of land subsidence in the District are available. In most of the area south of Panoche Road, the greatest subsidence was near the San Luis Canal alignment. Farther north, the greatest subsidence was east of the canal alignment. Subsidence ranged from about four feet near the northeast edge of the subareas to more than 20 feet in the areas of greatest subsidence near the southwest parts of some of the subareas.

In the 1950's, the USGS and USBR installed a number of compaction recorders in or near the Westlands WD as part of their studies on land subsidence. These recorders allowed a determination of the amount of compaction of clay layers in various depth intervals. As of the late 1960's, there were 15 compaction recorders in or near the Westland WD, and six of these were along the San Luis Canal. The compaction recorders along the canal continued to be operated by DWR through 1989. There are three operating compaction recorders in the vicinity of the District. Two of these (Yearout and Fordel) are near the Mendota Pool. They are operated by the Central California Irrigation District and the Mendota Pool Group, respectively. The third is near the Delta-Mendota Canal and Russell Avenue, and is operated by the Delta-Mendota Water Users Association. As of the late 1960's, the elevations of benchmarks along

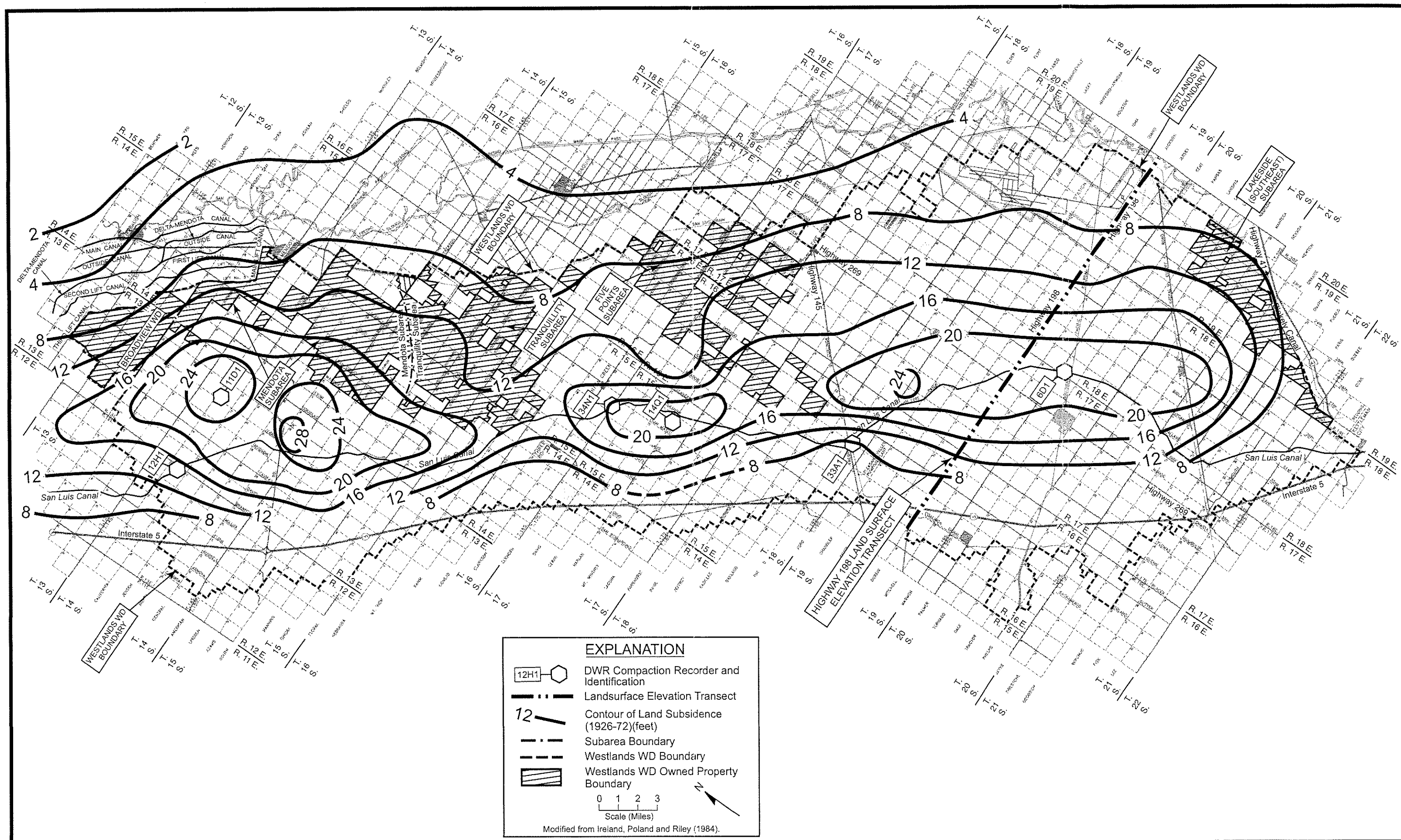


FIGURE 26 - LAND SUBSIDENCE IN THE WESTLANDS WATER DISTRICT (1926-72)

major roads were periodically surveyed, which allowed subsidence contours to be prepared (such as shown in Figure 26). Most of the subsidence monitoring program was dismantled after imported water became available in 1967. It was thought at the time that land subsidence would stop once the pumpage decreased. The only transects still being surveyed at present are the San Luis Canal (by the DWR), Highway 198 (by the National Geodetic Survey), and the Delta-Mendota Canal (by the DMWUA).

Historical records indicate that one foot of subsidence in the various subareas was caused by water-level declines ranging from about 20 to 45 feet. The least subsidence per foot of water-level decline was in the Lakeside Subarea, and the greatest was in the Mendota Subarea. Substantial pumping during the 1987-93 drought resulted in renewed land subsidence, even in cases when water levels remained above the historical low levels. Future rates of land subsidence are expected to be less until the historical deep water levels are reached.

GROUNDWATER QUALITY

Davis and Poland (1957) discussed the chemical quality of groundwater in the upper and lower aquifers as of the early 1950's and provided some interpretation, particularly of lateral and vertical differences.

The USGS collected water samples from 361 wells in the Dos

Palos-Kettleman City area during July-September, 1968. Bertoldi and Le Blanc (1969) presented tables with the results of analyses, including the perforated intervals for almost all of the wells that were sampled. Bertoldi (1971) provided a series of water quality maps for the upper and lower aquifers, including TDS, chloride, sulfate, and boron. The results of the 1968 sampling and more recent sampling, particularly since the late 1980's, were the primary information used in this evaluation.

Upper Aquifer

Davis and Poland (1957) indicated that groundwater in the upper aquifer in the Mendota-Huron area generally contained high concentrations of calcium, magnesium, and sulfate in the early 1950's. Groundwater in approximately the upper half of the upper aquifer had TDS concentrations averaging about 3,000 mg/l and a sodium percentage of about 35. The quality of this shallow groundwater had been affected by deep percolation of irrigation water. Groundwater in the lower half of the upper aquifer had lower TDS concentrations in the early 1950's, averaging about 1,500 mg/l and a higher sodium percentage (about 55). This groundwater was less influenced by irrigation practices than the shallower groundwater. In areas where permeable sands were present just above the Corcoran Clay near the east edge of the subareas, such as near Five Points, TDS concentrations in the lower part of the upper aquifer were low-

er (averaging about 850 mg/l). In an area west and southwest of Mendota, high TDS groundwater was present in the upper aquifer (the average TDS concentration was about 5,000 mg/l). This water had high sulfate and chloride concentrations. Table 6 summarizes the results of the USGS 1968 sampling for wells in the various subareas. Average TDS concentrations in the upper aquifer decreased to the south in the subareas, from greater than 4,000 mg/l in the Broadview WD to less than 1,000 mg/l in the Lakeside Subarea. Average boron concentrations also decreased to the south, from greater than 3.0 mg/l in the Broadview WD to less than 1.0 mg/l in the Lakeside Subarea.

Lower Aquifer

Davis and Poland (1957) indicated that the TDS of groundwater in the lower aquifer in the Mendota-Huron area averaged about 800 mg/l and the percent sodium averaged about 75 in the early 1950's. The lower aquifer water was primarily sodium sulfate in type, and bicarbonate concentrations were greater than in the upper aquifer. Carbon dioxide and hydrogen sulfide were reported to the present in water from deep wells in the Westhaven area.

Table 6 summarizes the results of the USGS 1968 sampling of lower aquifer wells in or near the various subareas. Average TDS concentrations ranged from about 2,200 mg/l in the Broadview WD to about 700 mg/l in the Lakeside Subarea. In the Tranquillity and

TABLE 6-SUMMARY OF 1968 WELL SAMPLING
RESULTS FOR SUBAREAS

Ave. TDS Concentration (mg/l)

<u>Subarea</u>	<u>Upper Aquifer</u>	<u>Lower Aquifer</u>
Broadview WD	>4,000	2,170
Mendota	>3,000	1,260
Tranquillity	2,560	980
Five Points	1,960	950
Lakeside	<1,000	710

Ave. Boron Concentration (mg/l)

<u>Subarea</u>	<u>Upper Aquifer</u>	<u>Lower Aquifer</u>
Broadview WD	>3.0	2.0
Mendota	>2.0	1.5
Tranquillity	1.7	1.8
Five Points	1.5	1.6
Lakeside	<1.0	1.1

Five Points Subareas, average TDS concentrations in water from lower aquifer wells in 1968 were about 950 to 980 mg/l. Average TDS concentrations in water from lower aquifer wells appeared to be slightly greater than in the early 1950's. Average boron concentrations in water from lower aquifer wells also decreased to the south, from 2.0 mg/l near the Broadview WD to 1.1 mg/l in the Lakeside Subarea.

Mendota Subarea

Table 7 contains the results of chemical analyses of water from six lower aquifer wells in or near the Mendota Subarea. TDS concentrations ranged from about 750 to 1,420 mg/l. TDS concentrations in the lower aquifer were generally lower to the south and southwest, and higher to the northwest. The waters were of the sodium sulfate type. Wells with high TDS concentrations had chloride concentrations exceeding 200 mg/l. Boron concentrations ranged from 1.2 to 1.8 mg/l.

Tranquillity Subarea

Table 8 contains the results of chemical analyses of water from six lower aquifer wells in or near the Tranquillity Subarea. TDS concentrations ranged from 720 to 1,100 mg/l and were generally lowest in the south part of the area and near Tranquillity. The waters were of the sodium sulfate type. Chloride concentrations ranged from about 40 to 100 mg/l, and boron concentrations ranged from 1.2 to 1.8 mg/l.

TABLE 7-CHEMICAL QUALITY OF WATER FROM
LOWER AQUIFER WELLS IN MENDOTA SUBAREA

Constituent (mg/l)	T14S/R14E			T15S/R14E		
	10N4	26D1	29M	7E1	15B1	20D
Calcium	56	28	33	-	25	34
Magnesium	17	4	4	-	2	1
Sodium	393	329	370	-	320	285
Potassium	-	-	3	-	-	2
Carbonate	<10	<10	<10	-	152	130
Bicarbonate	196	184	180	-	<10	<10
Sulfate	610	445	330	340	496	540
Chloride	215	130	410	44	80	70
Nitrate	5	1	<1	<1	1	<1
Boron	1.7	1.3	1.4	1.2	1.6	1.8
pH	8.1	7.8	8.1	7.1	7.8	8.2
Electrical Conductivity (micromhos/cm @ 25°C)	2,190	1,360	2,310	1,126	1,610	1,630
Total Dissolved Solids	1,420	1,110	1,330	748	1,100	1,060
Sodium Adsorption Ratio	-	-	16.2			13.1
Date	7/17/68	9/11/68	4/26/08	7/28/08	7/17/68	5/16/08
Laboratory	DWR	DWR	FGL	BSK	DWR	FGL
Perforated Interval (ft)	602-1,073	595-1,108	760-1,410		740-1,409	810-1,460

DWR water samples analyzed by California Department of Water Resources laboratory in Bryte.

TABLE 8-CHEMICAL QUALITY OF WATER FROM LOWER
AQUIFER WELLS IN TRANQUILLITY SUBAREA

Constituent (mg/l)	T15S/R14E	T15S/R16E	T16S/R14E	T16S/R15E		
	35B1	8H	3H1	6P1	9E1	18P4
Calcium	-	-	12	45	45	-
Magnesium	-	-	2	7	5	-
Sodium	280	223	355	297	247	-
Potassium	-	-	3	-	-	-
Carbonate	-	-	<10	<10	<10	-
Bicarbonate	-	-	200	108	98	-
Sulfate	510	280	500	555	500	510
Chloride	39	-	100	72	43	45
Nitrate	<1	-	1	<1	<1	<1
Boron	1.5	-	2.6	2.2	2.0	1.9
pH	-	-	8.0	7.7	8.3	-
Electrical Conductivity (micromhos/cm @ 25°C)	1,300	1,120	1,660	1,580	1,370	1,300
Total Dissolved Solids	860	720	1,100	1,090	942	830
Date	8/31/94	1/23/02	7/15/08	7/15/68	7/17/68	7/10/08
Laboratory	BSK	BSK	DWR	DWR	DWR	BSK
Perforated Interval (ft)	700-1,130	682-852	718-2,018	734-1,890	656-1,380	-

DWR analyses by Bryte Laboratory.

Five Points Subarea

Table 9 contains the results of chemical analyses of water from seven wells in or near the Five Points Subarea. TDS concentrations ranged from about 570 to 1,470 mg/l. At least two relatively deep wells (T17S/R16E-5K1 and T18S/R16E-3N1) produced water with chloride concentrations of 250 mg/l or more. The first of these wells is located about half a mile west of the Five Points Subarea, in the central part. The second of these wells is located in the southwest part of the subarea. Well T16S/R16E-20R1 produced water with a very high sulfate concentration (770 mg/l). This well is located about a mile west of the northwest part of the Five Points Subarea. Wells that produced TDS concentrations greater than 1,350 mg/l apparently tapped some of the brackish groundwater at depth, as described by the USGS. The lowest TDS concentration (568 mg/l) was found in water from a well near Five Points that was perforated only between 1,040 and 1,100 feet in depth. TDS concentrations from many other lower aquifer wells in the Five Points Subarea ranged from about 800 to 1,000 mg/l and averaged about 950 mg/l. Boron concentrations in water from most lower aquifer wells ranged from about 1.5 to 1.8 mg/l.

Lakeside Subarea

Table 10 contains the results of chemical analyses of water from four wells in or near the Lakeside Subarea. TDS concentra-

TABLE 9-CHEMICAL QUALITY OF WATER FROM LOWER
AQUIFER WELLS IN FIVE POINTS SUBAREA

Constituent (mg/l)	T14S/R14E	T17S/R16E		T17S/R17E		T18S/R16E	
	20R1	5K1	26N4	26E3	33N	3N1	15N2
Calcium	131	29	60	29	-	73	-
Magnesium	50	2	8	7	-	5	-
Sodium	220	320	249	157	180	453	-
Potassium	-	-	-	2	-	2	-
Carbonate	6	<10	<10	<10	-	<10	-
Bicarbonate	112	132	104	184	-	100	-
Sulfate	770	294	446	255	420	340	478
Chloride	76	250	110	25	48	500	118
Nitrate	1	1	2	1	29	<1	<1
Boron	1.5	1.7	1.5	0.8	0.9	1.8	1.6
pH	8.4	7.8	7.8	7.6		8.2	8.2
Electrical Conductivity (micromhos/cm @ 25°C)	1,820	1,640	1,470	897	1,200	2,520	1,550
Total Dissolved Solids	1,370	928	940	568	800	1,470	1,020
Sodium Adsorption Ratio	-	-	-	-	-	13.8	-
Date	7/17/68	6/17/68	7/16/68	7/15/68	8/21/91	9/6/08	7/14/08
Laboratory	DWR	DWR	DWR	DWR	BSK	FGL	BSK
Perforated Interval (ft)	639-1,469	642-1,621	581-1,591	1,040-1,110	510-1,190	880-1,480	-

DWR analyses are by Bryte Laboratory.

TABLE 10-CHEMICAL QUALITY OF WATER FROM LOWER
AQUIFER WELLS IN OR NEAR LAKESIDE SUBAREA

Constituent (mg/l)	T20S/R19E			T21S/R15E
	23J1	26H1	35M1	19E2
Calcium	9	11	19	25
Magnesium	2	4	8	2
Sodium	210	228	270	147
Potassium	-	-	-	-
Carbonate	<10	<10	<10	<10
Bicarbonate	364	328	308	80
Sulfate	5	29	2	255
Chloride	108	142	268	34
Nitrate	61	22	11	2
Boron	0.8	0.9	0.8	0.5
pH	8.2	7.8	7.2	8.1
Electrical Conductivity (micromhos/cm @ 25°C)	970	1,090	1,420	840
Total Dissolved Solids	572	648	786	542
Date	9/17/68	9/17/68	9/17/68	7/15/68
Laboratory	DWR	DWR	DWR	DWR
Perforated Interval (ft)	1,027-2,027	1,041-2,048	987-2,014	625-1,413

DWR analyses are by Bryte Laboratory.

tions ranged from about 540 to 790 mg/l. Water from wells in or near the northeast part of the subarea of the sodium bicarbonate or sodium bicarbonate-chloride type, with relatively low sulfate concentrations (less than 30 mg/l). Chloride concentrations in water from these wells ranged from 108 to 268 mg/l, and generally increased to the south. This water is of a different type than most westside lower aquifer water, which is sodium sulfate in type. The quality of groundwater in the lower aquifer in the northeast part of the area is apparently more related to recharge from the east side of the valley. In contrast, water from wells west of the south part of the subarea produce water of the sodium sulfate type, characteristic of lower aquifer water in most of the other subareas. Boron concentrations ranged from 0.5 to 0.9 mg/l.

POSSIBLE PUMPAGE FROM WELLS ON DISTRICT OWNED LANDS

Broadview Water District

Because of poor quality groundwater in the upper aquifer, new supply wells in the Broadview WD would tap strata below the Corcoran Clay and above a depth of about 1,200 feet. Perforations would likely extend from about 600 to 1,150 feet in depth, and annular seals would be placed above a depth of about 550 feet. Well yields are expected to average about 1,500 gpm. Sites in the south part of the subarea are expected to produce better quality water. Locations of new wells in the southwest part of the area would min-

imize adverse impacts of land subsidence on canals located northeast of the Broadview WD. Because of the chemical nature of the groundwater, corrosion resistant casing is advisable.

Mendota Subarea

Because of high TDS concentrations in most of the upper aquifer, new supply wells in the Mendota Subarea would be constructed to tap the lower aquifer. There are five known lower aquifer wells and two composite wells tapping the lower aquifer in the area between California and Central Avenues and west of Ohio Avenue. There are three other composite wells near or south of American Avenue. The chemical quality of lower aquifer water is expected to be better in the south part of the area (south of North Avenue). There are large parts of this subarea that have no known lower aquifer wells (north of California and east of San Bernardino Avenue). Land subsidence at the Mendota Pool and along canals is an issue, and sites in the northwest or south parts of this subarea would minimize adverse impacts of lower aquifer pumping.

New lower aquifer wells would be about 1,000 feet deep north of California Avenue and up to 1,500 feet deep south of California Avenue. Because of the chemical quality of the groundwater, corrosion resistant casing should be evaluated. Well yields are expected to range from about 1,500 to 2,000 gpm.

Tranquillity Subarea

There are many lower aquifer wells in the southwest part of this subarea (south of Floral Avenue and west of Monterey Avenue). Most wells in the part of the subarea east of Stanislaus Avenue tap the upper aquifer. The quality of groundwater in the lower aquifer improves to the south in the subarea. There are few lower aquifer wells in the part of the subarea north of Nebraska Avenue and east of Ohio Avenue. Depths of new lower aquifer wells would likely range from about 1,000 feet in the north part of the area to about 1,800 feet in the south part (near Nebraska Avenue). Land subsidence is an issue along the San Luis Canal. Well sites located at least several miles northeast of the canal would minimize subsidence impacts. Well yields are expected to range from about 2,000 to 3,000 gpm.

Five Points Subarea

Most wells in the part of the subarea north of Elkhorn Avenue, and east of Yuba Avenue tap the upper aquifer. Most lower aquifer wells or composite wells are south of Elkhorn and west of Colusa Avenue. There are large parts of the subarea where there are no known active wells tapping the lower aquifer. Depths of new lower aquifer wells would range from about 1,000 feet in the north and east parts of the subarea to about 1,700 feet in the southwest part. TDS concentrations appear to be relatively low in the area

south of Elkhorn Avenue. There are relatively large parts of the subarea where new lower aquifer wells could be constructed. Well yields are expected to range from about 2,000 to 3,500 gpm.

Lakeside Subarea

New wells would be located north of Newton Avenue, because of a lack of of adequate water-producing strata farther south. Well depths would be about 2,000 feet and perforated intervals would be from about 900 to 2,000 feet in depth. Expected production is about 3,000 to 3,500 gpm per well. A number of existing deep well are located in the area east of the north part of the subarea. Drawdowns could be minimized by using a well spacing of at least one mile. The area south of Lincoln Avenue, west of 24th Avenue , and north of Nevada Avenue would be the best location for new wells.

Well Spacing and Amounts of Pumpage

Well interference (drawdowns in nearby wells) can best be minimized by well spacing. Considering both aquifer characteristics and historical water-level declines, a spacing for new wells from existing lower aquifer or composite wells of at least one mile is recommended. Year to year water-level declines in the lower aquifer are directly proportional to pumpage in the lower aquifer. Thus future water-level declines will be about 20 percent greater than historical declines, if the total pumpage is increased by 20

percent.

Information presented earlier in this report indicates that recharge to the lower aquifer in the Westlands WD has averaged about 200,000 acre-feet per year. This is primarily from groundwater inflow from areas to the northeast of the subareas, and secondarily from downward flow through the Corcoran Clay. The District-owned lands portion of the recharge on a per acre basis would average about 34,000 acre-feet per year on the long term. Peak pumpage could be about 100,000 acre-feet per year. At 2,500 gpm, a new lower aquifer well could pump about 2,600 acre-feet in an eight-month period. In order to pump about 100,000 acre-feet per year, about 40 high capacity wells would be needed.

MITIGATING MEASURES

The sustainable pumpage in the District could be increased significantly by recharging water in wet years. It is recommended that injection of treated water be considered down existing lower aquifer wells and possibly new injection wells. The technology apparently already exists to do this. The three most important items for successful injection of water are:

1. The injected water has to be sediment free (i.e., filtered).
2. The injected water has to be sterilized.
3. The injected water needs to be free of air and introduced

into the well several hundred feet below the water level.

The present questions are primarily:

1. To what extent can irrigation wells be used for injection?
2. To what extent can unused wells in the area be used for injection?
3. Will existing on the farm filtering and sterilization equipment be effective?

It is recommended that pilot projects be undertaken to evaluate these issues.

RECOMMENDED ENHANCED MONITORING

An enhanced groundwater monitoring program is recommended for water levels, pumpage, and land subsidence. Present data gaps include:

1. Inadequate water-level measurements to prepare suitable water-level maps for hydrogeologic evaluations.
2. Lack of frequent measurements in at least a group of wells.
3. Lack of periodic land surface elevation surveys, so that up-to-date subsidence contour maps can be prepared.

Water-Level Measurements

A number of deep wells that have been constructed during the past two decades have been equipped with sounding tubes or other devices to allow the water level to be measured. The existing

water-level measurement grid needs to be carefully examined, and a number of new wells incorporated. There is a paucity of lower aquifer wells being measured in the northeast parts of the Mendota, Tranquillity, and Five Points Subareas. Since this area is generally close to the areas of groundwater inflow, more water-level monitoring is needed to keep track of water-level slopes and changes during pumping. Continuous water-level measurements are normally made by installing float recorders or transducers. Frequent water-level measurements are especially valuable in determining influences of pumping and recharge. Such continuous measurements have been successfully used in a number of water-banking projects in Kern County and elsewhere.

It is recommended that at least two continuous recorders be installed in new observation wells tapping the lower aquifer in the Mendota, Tranquillity, and Five Points Subareas. At least one recorder should be placed in a new lower aquifer observation well in the Broadview WD. In the Lakeside Subarea, it may be possible to equip an existing unused well with a water-level recorder.

Land Subsidence

Periodic surveys of the land surface should be reinstituted along some major roads to supplement data for the San Luis Canal, Highway 198, the DMC, and subsidence monitoring near the Mendota Pool. In the Mendota and Tranquillity Subareas, these would

include Derrick Avenue between California Avenue and the San Luis Canal, and Adams and Floral Avenues, between Lyon Avenue and the east edge of the subarea. In the Five Points Subarea, this would include Colusa Avenue, between Kamm and Jeffrey Avenues, and Elkhorn and Mt. Whitney Avenues, between Sonoma and Lassen Avenues. In the Lakeside Subarea, Highway 41 between Madison and Orange Avenues would be included. No additional compaction recorders are considered necessary.

SUMMARY AND CONCLUSIONS

A two-aquifer system is present beneath the part of the Westlands Water District east of the San Luis Canal. Primarily because of groundwater quality issues, most of the groundwater pumpage has been from the lower aquifer (below the Corcoran Clay). Depth to water in lower aquifer wells generally increases to the southwest in the area. The direction of groundwater flow has generally been to the southwest, and into the District from lands to the northeast. Water levels in lower aquifer wells have risen since importation of canal water began in the 1960's, except during drought periods. Almost 600,000 acre-feet per year were pumped from the lower aquifer in the early 1990's, and water levels temporarily fell.

Land subsidence has been a problem due to pumping from the lower aquifer. By 1972, from 6 to 20 feet of subsidence had oc-

curred beneath the lands now owned by the district. The subsidence has been the least toward the northeast, and the greatest to the southwest towards the San Luis Canal. There was some additional subsidence during the 1976-77 and 1988-94 drought. Additional subsidence is expected in the future if substantial pumping continues.

The chemical quality of groundwater in the District is generally better below the Corcoran Clay and toward the south. Problems have been encountered in some areas where perforations have been placed too shallow or wells have been drilled too deep. Overall, TDS concentrations in groundwater in the lower aquifer range from about 700 mg/l in the Lakeside subarea to over 1,200 mg/l in the Mendota subarea. In or near the Broadview Water District, TDS concentrations in the lower aquifer commonly exceed 2,000 mg/l.

Sustainable pumpage on District land is constrained by recharge, which is primarily due to groundwater inflow from the northeast.

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