Assessment of Source Water for the Pescadero Water System - CSA 11

Prepared for:
Department of Public Works
San Mateo County, California

March 2002

TODD ENGINEERS

Department of Public Works
San Mateo County, California

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the Pescadero Water System – CSA 11

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Executive Summary

Prior to installing and operating the two County Service Area (CSA 11) water supply wells, the Town of Pescadero relied on small domestic wells, water from surface impoundments, and locally derived groundwater, from wells installed in the low-lying alluvial aquifer of Pescadero and Butano Creeks. In the 1970's and 1980's, these sources were found to contain relatively high concentrations of nitrate and other naturally occurring salts. This prompted the development of alternative groundwater sources located in the Pigeon Point Formation, about one mile west of Pescadero on the top of a northwest trending ridge, and adjacent to the Pacific Ocean. The wells have been operating since 1993. Well 1 was installed in 1983; Well 2, located 300 feet from Well 1, was installed in 1992. At the time of installation the water level elevation at the wells was about 106 feet above mean sea level. The estimated quantity of water used by CSA 11 is about 25 acre feet per year or about 16 gallons per minute.

Since well pumpage began, the depth to water in Wells 1 and 2 have dropped to 90 feet above mean sea level. This is equivalent to a drop in water level of about 1.6 feet per year. The top of the well screens for Wells 1 and 2 are at 70 and 66 feet above mean sea level, respectively. Assuming that the lowering of the water level is linear, then the current wells will fail in 8 to 15 years. The longevity of the aquifer is about 25 years. Groundwater quality has met drinking water standards for Wells 1 and 2 and water quality does not appear to deteriorate with depth.

We recommend that CSA 11 install a new production well in the vicinity of Wells 1 and 2 or at a lower elevation near the distribution tank to reduce overall drilling depth. The well should be drilled to at least 100 feet below mean sea level to take advantage of the overlying potable water. We estimate engineering costs to install a new well and above-ground facilities at about $45,000 to $55,000 and drilling contractor costs at about $150,000. Accordingly, an installed, fully equipped and functional well can be constructed for $200,000 to $250,000. Installation of such a new production well will extend the life of the CSA 11 water supply to at least 38 years.

Introduction

In April 2001, the Department of Public Works (DPW) of the County of San Mateo requested a technical proposal from Todd Engineers addressing the Town of Pescadero water system, specifically the source water. The source water consists of two wells tapping the same aquifer and installed approximately one mile west of Pescadero. The wells have been operating since 1993. Well 1 was installed in 1983; Well 2, located 300 feet from Well 1, was installed in 1992. The DPW maintains and operates the County Service Area 11 (CSA 11) system for Pescadero.

After a preliminary review of existing documents, the proposal was submitted to DPW on April 13, 2001. The proposal consisted of five general tasks: (1) review existing hydrogeologic information, (2) conduct preliminary aquifer testing, (3) conduct optional formal step-drawdown testing, (4) coordinate and conduct constant rate aquifer test, and (5) prepare a technical report. On September 7, 2001 Todd Engineers received official notice from DPW to proceed with the scope of work. This report presents our findings.

The goals of this investigation are to determine and re-assess the long-term sustainability of the aquifer pumped by the CSA 11 water supply wells and to determine the reliability of the wells. To accomplish these goals, Todd Engineers conducted a review of all available and relevant hydrogeologic information in the area to assess the long-term aquifer supply and performed pumping tests to assess well performance.

Figure 1 shows the location of the water supply wells and the geographic setting of the area. The wells are located near the top of a ridge. In general, the project area is triangular-shaped (shown on Figure 1) and is defined by Highway 1 along the west, Pescadero Road on the northwest, and Bean Hollow Road on the southeast. The project area is about 1,042 acres or 1.6 square miles and is located at the extreme north end of a northwest trending ridge. Butano Creek represents the major drainage east of the ridge while Arroyo de los Frijoles, located south of Bean Hollow Road, nearly dissects the ridge.

Topographic elevations for the area range from 0 to 285 feet above mean sea level (msl). The west-facing slopes of the ridge have shallower ground surface gradients (7 percent) than the east-facing slopes (11 percent). The east-facing slopes tend to have

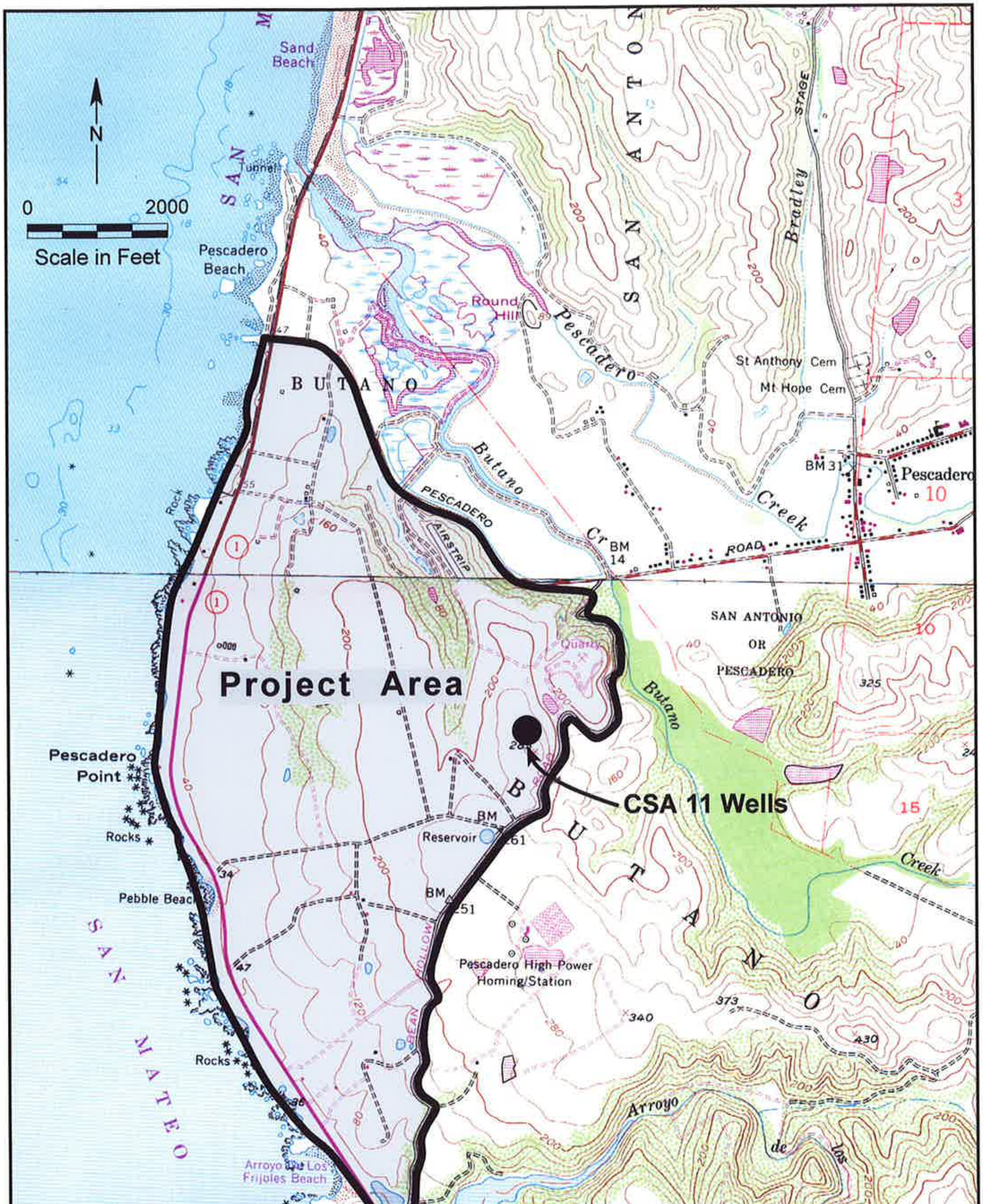

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Figure 1
Site Location Map

more pronounced drainage areas than the west-facing slopes. Pescadero Beach and the Pescadero Creek estuary are located near the northern extent of the project area. Arroyo de los Frijoles and Lucerne Lake are located south of the project area. Average annual rainfall ranges between 20 and 25 inches (Rantz, 1969; Shah and Nahn, 1989).

Prior to installing these CSA 11 water supply wells, the Town of Pescadero relied on small domestic wells, water from surface impoundments, and locally derived groundwater from wells installed in the low-lying alluvial aquifer of Pescadero and Butano Creeks. In the 1970's and 1980's, these sources were found to contain relatively high concentrations of nitrate and other naturally occurring salts. This prompted the exploration and development of alternative groundwater sources in the early and late 1980's (Wood, September 13, 1982; Geoconsultants, May 1983; Kennedy/Jenks/Chilton, September 2, 1987; Todd Engineers, July 14, 1989; and Winzler & Kelly, August 25, 1989).

Based on the history and metered usage of groundwater pumpage between 1993 and 2001, the estimated quantity of water used by CSA 11 is about 25 acre feet per year (AFY) or about 16 gallons per minute (gpm). Annual usage ranges between 17 to 29 AFY (11 to 19 gpm). Therefore, the total amount of water pumped by CSA 11 between 1993 and 2001 is about 200 acre feet (AF).

Well Information and Location

Figure 2 shows the location of all wells available for this hydrogeologic analysis. The project area is located in portions of sections 5, 8, 9, 16, and 17 of Range 5 West, Township 8 South. Forty-four wells were identified in the project area including six wells located in Pescadero Creek alluvium, and eleven wells documented from consultant reports and files. Much of the well information was compiled from the Department of Water Resources (DWR) records, County of San Mateo files and records, and Geoconsultants, Inc. and Todd Engineers files. DWR Water Well Drillers Reports could not be found for nine wells. The location of the wells shown on Figure 1 were obtained from the Drillers Reports and have not been field checked to verify the location.

Table 1 summarizes the construction details for the wells in the vicinity of CSA 11 water supply wells. The table is divided into three categories. From top to bottom they are: probable Pigeon Point Formation wells, probable marine terrace wells, and

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Figure 2
Well Location Map

Table 1

Summary of Wells in the Vicinity of the CSA 11 Wells

Name	Date	Elev.	Total Depth	CD	Csg. Diam.	Screen	Slot	SWL	Driller
Probable Pigeon Point Formation Wells									
CSA 11 Wells									
Exp Well	08/82	275	244		Abandoned			~190	Earthflow
Well 1	04/83	277	280	247	6	207 to 247	0.040	170	Earthflow
Well 2	01/92	276	260	260	10	210 to 250	0.040	170	Maggiora
SDF Well	unk	20	unk	68	8	44 to 68 ?	unk	unk	unk
Neighboring Wells									
Well 1	05/91	290	360	350	5	200 to 320	0.032	36	Digges
Well 2	05/91	270	400		Abandoned				Digges
Well 3	06/91	280	355	350	5	90 to 340	0.032	28	Digges
Well 4	01/92	260	700	635	5	228 to 628	0.040	24	Landino
Well 5	06/92	245	805	800	5	260 to 780	0.040	34	Landino
Domestic	unk	unk	unk	unk	unk	unk	unk	unk	unk
Other Wells									
62221	07/61	N/A	100	60	8	unk	unk	32	Digges
119527	02/75	N/A	220	220	5	100 to 220	unk		Maggiora
227086	04/85	N/A	100	100	4	50 to 90	unk	2	Earthflow
208314	10/85	N/A	200	200	4	40 to 180	unk	0	Earthflow
207980	12/86	N/A	100	100	5	80 to 100	unk	35	Earthflow
207981	12/86	N/A	100	100	5	80 to 100	unk	30	Earthflow
207993	06/87	N/A	160	160	5	80 to 160	unk	15	Earthflow
Probable Marine Terrace Wells									
62203	04/60	N/A	24	24	10	12 to 24	unk	6	Digges
62212	02/61	N/A	90	90	6	27 to 90	unk	24	Digges
85178	03/63	N/A	36	35	8	27 to 35	unk	23	Freedom
85178	03/63	N/A	36	35	8	27 to 35	unk	24	Freedom
107515	07/65	N/A	60	56	6	15 to 56	unk	4	Digges
122526	08/66	N/A	60	60	10	12 to 60	unk	18	Digges
122537	08/67	N/A	60	56	10	0 to 56	unk	7	Digges
122546	09/68	N/A	48	44	10	24 to 44	unk	15	Digges
13909	07/69	N/A	60	58	10	12 to 58	unk	6	Digges
13920	05/70	N/A	80	80	10	22 to 80	unk	2	Digges
13923	06/70	N/A	60	56	10	10 to 56	unk	2	Digges
13936	04/71	N/A	60	60	10	12 to 60	unk	4	Digges
13937	04/71	N/A	60	60	10	12 to 60	unk	3	Digges
13938	04/71	N/A	60	60	10	18 to 60	unk	10	Digges
20217	06/73	N/A	60	56	10	12 to 56	unk	8	Digges
20218	06/73	N/A	60	56	10	12 to 56	unk	6	Digges
110201	06/73	N/A	60	56	10	10 to 56	unk	8	Digges
38284	06/78	N/A	60	60	5	10 to 60	unk	6	Digges
38285	06/78	N/A	60	60	5	11 to 60	unk	6	Digges
227085	04/85	N/A	80	80	4	30 to 80	unk	2	Earthflow
Pescadero Creek Alluvium Wells									
107509	03/65	N/A	60	58	8	22 to 58	unk	24	Digges
91108	11/66	N/A	52	52	10	28 to 52	unk	2	Western
13915	12/69	N/A	60	56	8	20 to 56	unk	12	Digges
13925	07/70	N/A	56	56	8	18 to 56	unk	19	Digges
144907	07/76	N/A	27	27	8	12 to 27	unk	unk	Maggiora
144915	07/76	N/A	26	0	unk	unk	unk	dry	Maggiora

Name	Name of Well or State DWR Report Number	Screen	Screened interval in feet
Date	Date well drilled	Slot	Aperture size in inches
Elev.	Elevation feet mean sea level	SWL	Static Water Level in feet at well construction
CD	Completed Depth feet	unk	Unknown
Diam.	Casing (csg.) Diameter inches	N/A	not available

Pescadero Creek alluvium wells. The Pigeon Point Formation wells are further subdivided into CSA 11 wells, neighboring wells, and other wells. Each category is then arranged by date of drilling. With the exception of the State Division of Forestry (SDF) and the domestic well, information is recorded fully in reports and notes for the CSA 11 and neighboring wells. The well names for the remaining wells are the Water Well Drillers Report number.

Well depths range from 24 feet in the marine terrace wells (Well 62203) to over 800 feet (Well 5) in the Pigeon Point Formation. Most of the wells (26 wells) are located on the west-facing slope of the ridge and were drilled for domestic use. Fifteen wells exceed 100 feet in depth, while the remaining 29 wells are drilled to a relatively shallow depth and tap the Pescadero Creek alluvium or the marine terrace deposits. About twenty wells are located within 500 feet of Highway 1 and were drilled for domestic water supplies. Note that with the exception of the CSA 11 wells, the depth to water for all wells ranges between 2 and 35 feet; the CSA 11 wells have water levels of about 170 feet. In general, between 1961 and 2001, the drilled depth of wells becomes progressively deeper in the project area.

Acknowledgements

Todd Engineers acknowledges DPW staff, specifically Mr. Daniel Wang and Mr. Robert Frame, for their assistance in completing this project and coordinating contractor pre-testing activities in order to implement an acceptable pumping test. The contractor, Mr. Ron Parker of Cornerstone Pump of Morgan Hill, California, removed and re-installed the pumps in the CSA 11 wells so that reliable aquifer testing and water levels could be conducted and measured, respectively, on the pumping and the observation wells. We also appreciate the information and well construction reports (Geoconsultants, December 1991 and July 1992) provided to DPW from Geoconsultants, Inc. Discussions with Mr. Jeremy Wire of Geoconsultants, Inc. were very helpful in compiling all available information for the project area.

Hydrogeology

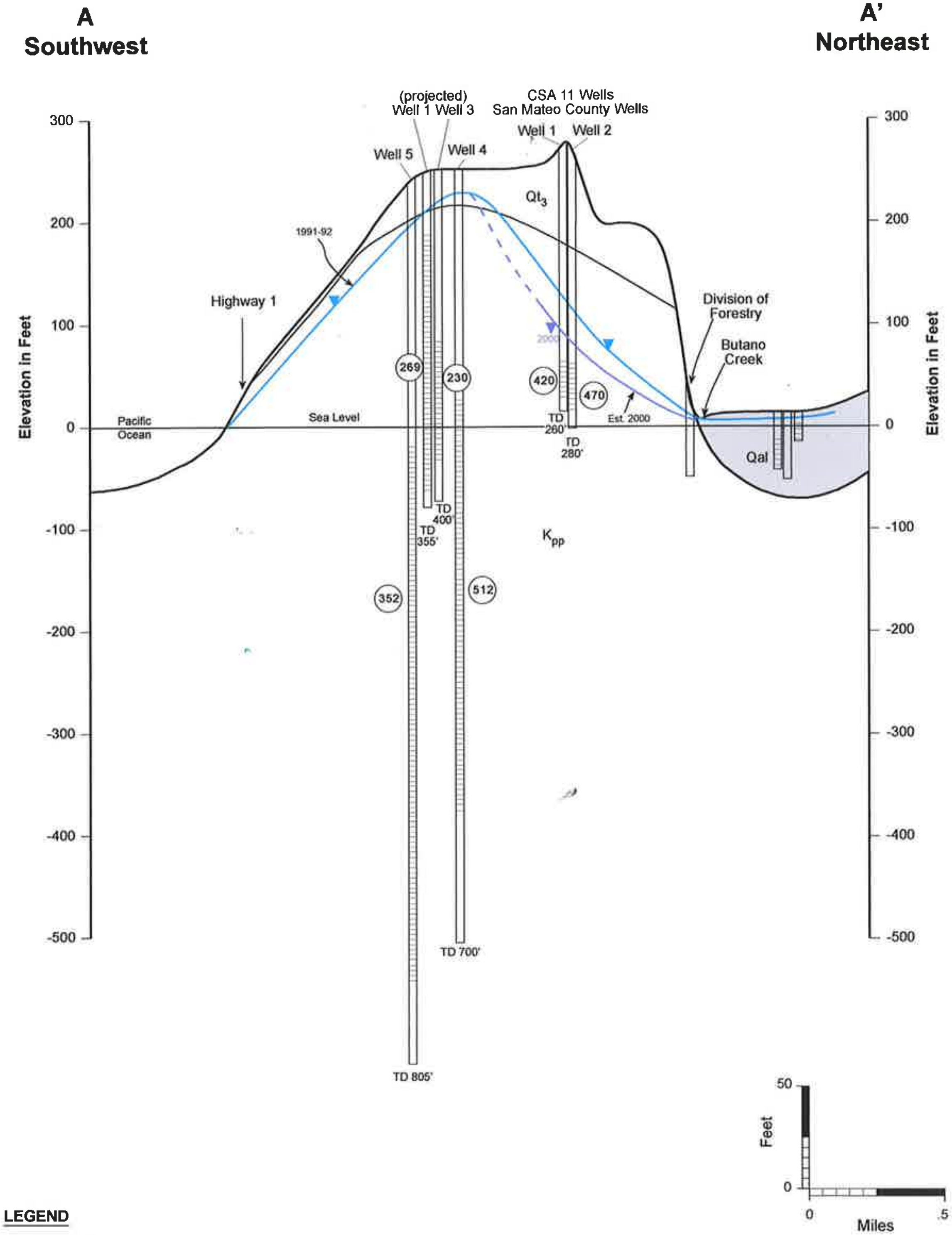
Geology

The hydrogeology of the area consists of essentially two potential moderately yielding aquifers: (1) recent unconsolidated alluvium deposited adjacent to and by Pescadero and Butano Creeks and (2) semi-consolidated to consolidated materials of the Pigeon Point Formation. A third aquifer, marine terrace deposits, exists as a thin veneer overlying the Pigeon Point Formation and is a minor water-bearing unit (low-yield). Nevertheless, these terrace deposits are suitable for domestic use. Groundwater is stored temporarily in the terrace deposits and rapidly drains from these materials.

Recent alluvium deposited by Pescadero and Butano Creeks consists of inter-bedded gravel, sand, silt, and clay. The sand and gravel units are very permeable but thin. The limited areal extent and thickness of these deposits results in a small amount of available aquifer storage. In addition, rapid percolation of surface water and septic tank return flow impacts the quality of groundwater in the alluvium (Geoconsultants, January 1981). Because aquifer storage and groundwater recharge are limited, saltwater migration or intrusion is likely to occur, also resulting in deterioration of groundwater quality.

The Pigeon Point Formation is mainly composed of jointed or fractured sandstone and conglomerate distinctly interbedded with siltstone and mudstone (Wood, September 13, 1982). Although the permeability of the Pigeon Point Formation is significantly lower than the recent alluvium, groundwater storage in the formation is much greater. The saturated portion of the Pigeon Point Formation is at least 800 feet thick. In contrast, the recent alluvium is less than 60 feet thick.

Figure 3 is a hydrogeologic cross section aligned northeast-southwest across the structural grain of the ridge and parallel to Bean Hollow Road; the location is shown on Figure 2. The cross section shows the relationship between the two main aquifers, the alluvium and the Pigeon Point Formation, and also depicts the approximate screened intervals for selected wells and measured static water levels observed in 1991 and 1992. Not much is known about the specific construction details (i.e., no Water Well Drillers Report) of the State Division of Forestry well near the Fire Station at the intersection of Bean Hollow Road and Pescadero Road.



LEGEND

Qal	Alluvium
Qt_3	Terrace Deposits
K_{pp}	Pigeon Point Formation
352	TDS
TD	Total Depth

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Figure 3
Hydrogeologic Cross Section

As shown in Figure 3 depth of wells in the alluvial aquifer range from about mean sea level to 50 feet below msl. In contrast, well depth elevations range from 30 feet above msl to 500 feet below msl for the Pigeon Point Formation. Note that the CSA 11 water supply wells are screened above mean sea level at elevations ranging between 20 and 30 feet above msl. This suggests that the CSA 11 wells are not taking complete advantage of the full saturated thickness (i.e., storage) of the Pigeon Point Formation.

Water levels are shown on the cross section for 1991 and 1992. In general, the water table surface parallels the ground surface. High elevation water levels are found near the top of the ridge, while low elevation water levels occur along the base of the ridge; this is referred to as a groundwater mound. The groundwater mound is not oriented in the middle of the ridge with respect to surface topography. This asymmetry may reflect that more groundwater recharge occurs on the west side of the ridge as a result of local precipitation patterns, leakage of surface water storage ponds south of Bean Hollow Road, and/or temporary groundwater storage in the marine terrace deposits.

Weather storms generally arrive at the project area from west to east, thereby releasing a significant portion of rainfall on the west-facing slopes. Precipitation soaks into the terrace deposits and recharges the underlying Pigeon Point Formation and also moves laterally along the terrace deposit and Pigeon Point Formation contact. A significant amount of this water drains down slope along the contact between the two units emerging as springs and seeps. Groundwater storage in the terrace deposits is temporary and may, in most years, be completely drained by mid- or late-summer. This, in part, is the reason that a proliferation of wells exists along the Highway 1 corridor as land owners have sought sustainable water supply (see Figure 2).

The water levels for the CSA 11 water supply wells and neighboring wells are significantly different indicating that groundwater flow diverges from the ridge (see Table 1). The CSA 11 water supply wells had water elevations of about 110 feet above msl compared to neighboring wells with water elevations of about 250 feet above msl. Local groundwater movement is from the neighboring wells near the top of the ridge to the CSA 11 wells.

Also shown on the cross section is an estimate of the current (2000) water table elevation at the CSA 11 water supply wells, which is 16 feet deeper than the 1991 and

1992 elevation. Recent (January 2001) water level measurements from the neighboring wells indicate water levels are at higher elevations than in 1991, suggesting that the drop in water levels at the CSA 11 wells are a local impact rather than a regional impact.

Groundwater Occurrence and Movement

Figure 4 is a water table map for 1991 and 1992. The groundwater contour interval is 25 feet. Water levels from sixteen wells were used to construct this map including three deep exploration wells in the southwest corner of the area reported to be "dry". However, it should be noted that if these "dry" exploration holes were cased and were able to stabilize, water levels would be expected to rise to the elevations shown on the contour map. The time for water to stabilize or seek it's own level in the borehole is related to the borehole/formation interface (i.e., well efficiency) and the permeability of the aquifer. High-permeable aquifers tend to stabilize to the static water level sooner than low-permeable aquifers. Furthermore, clay or drilling mud smeared along the borehole/aquifer interface will reduce the seepage into the borehole and lengthen the time for stabilization.

Diverging radial groundwater flow occurs in the project area and flows from the top to the base of the ridge. Although not shown on Figure 4, the water level contours between the study area and Arroyo de Los Frijoles wrap around to close the groundwater contours. Groundwater contours are also drawn for the alluvial aquifer in the Pescadero Creek and Butano Creek floodplains. Note the significant difference in contour spacing and groundwater gradients between the alluvial aquifer (0.0021 feet/feet) and Pigeon Point Formation (0.077 feet/feet) aquifer. This suggests that the Pigeon Point Formation has a significantly lower permeability than the alluvial aquifer. The permeability is a measure of the relative ease of fluid flow under unequal pressure (Gary et al., 1977).

The CSA 11 water supply wells are located half-way between the top and the base of the ground surface ridge and also the groundwater mound on the east-facing slopes draining to Butano Creek. This specific location and well depth does not take full advantage of the total available groundwater stored beneath the ridge. The significant drop in water levels at the CSA 11 water supply wells implies that total groundwater discharge, both from natural discharge of springs, seeps, and pumpage, exceeds groundwater recharge from rainfall. This may be a local impact caused by low

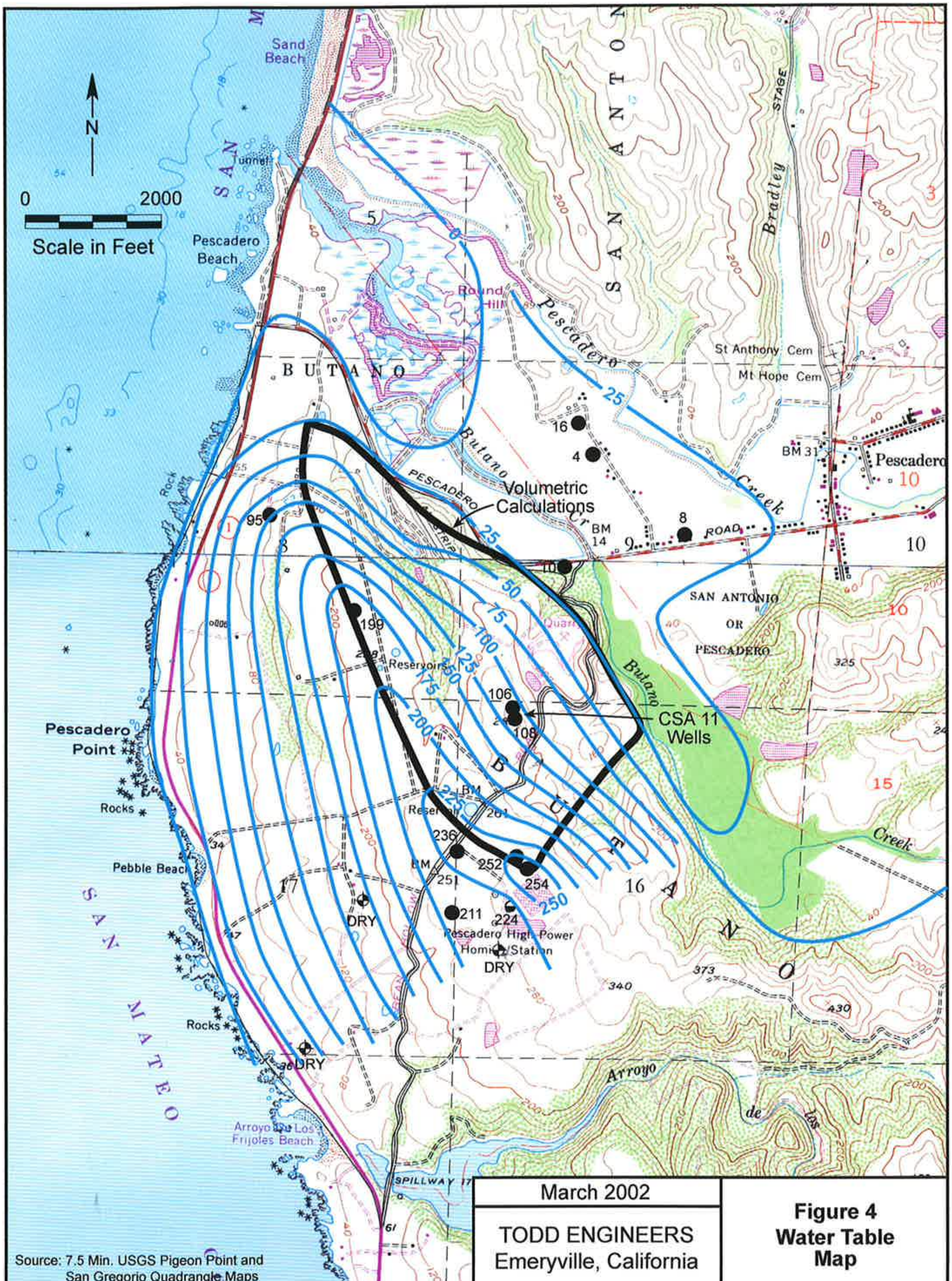

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Figure 4
Water Table Map

permeability materials in the surrounding area and consequently low recharge to the CSA 11 water supply wells or a more regional impact.

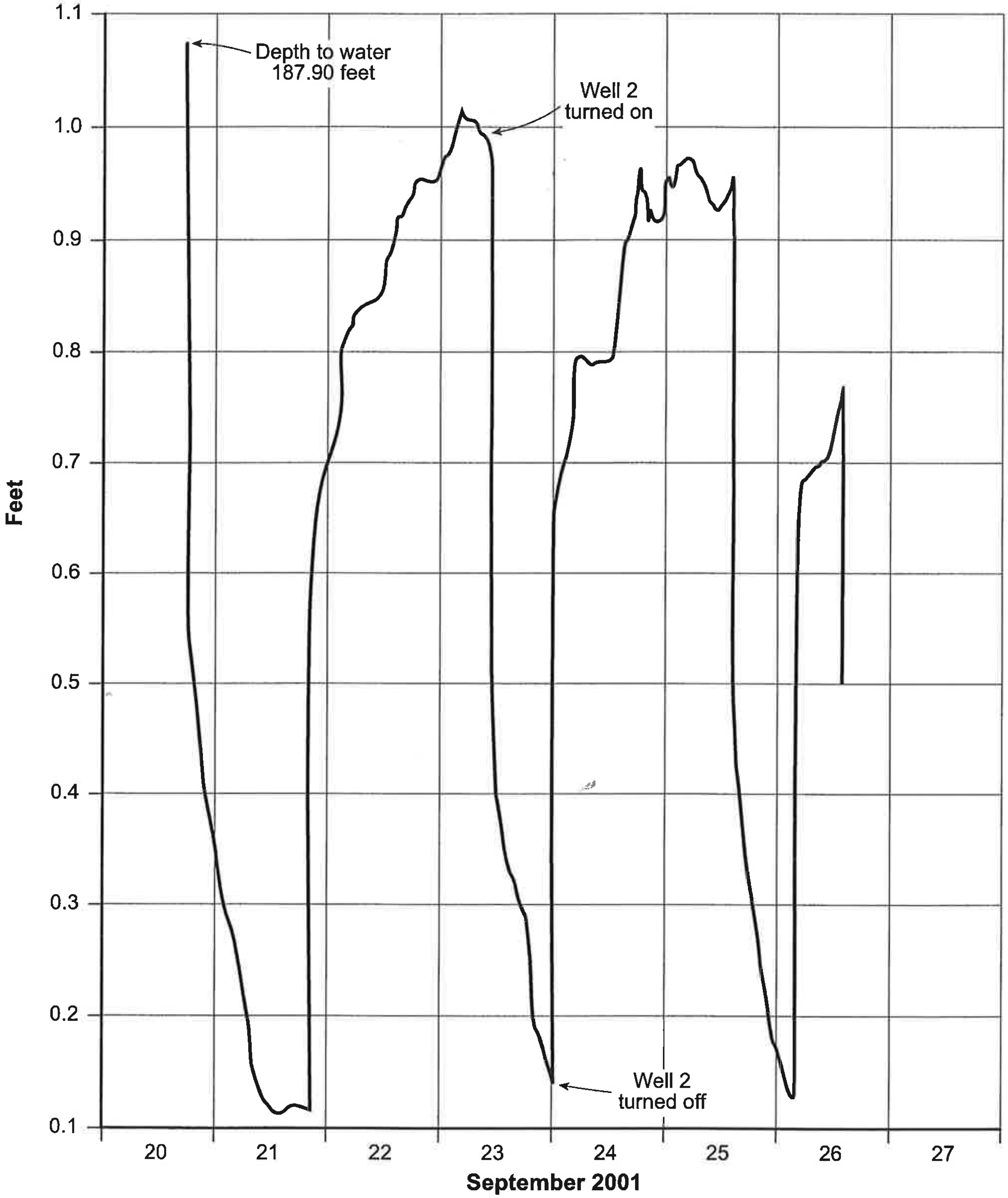
Water Level Fluctuations

Water table elevations fluctuate because aquifer recharge, discharge, and pumpage vary through time. Water level fluctuations in the Pescadero Creek alluvium would be expected to be smaller and less severe than fluctuations in the Pigeon Point Formation. Groundwater in the alluvium benefits from the Pigeon Point Formation groundwater draining to the northeast into Pescadero Creek and Butano Creek alluvium. In addition, the porosity of the Pigeon Point Formation (estimated at five percent) is probably much smaller than the porosity of the alluvium aquifer (estimated at fifteen percent) resulting in greater net groundwater fluctuation in the Pigeon Point Formation. For example, a change in volume of one foot of groundwater in alluvium would be comparable to three feet in the Pigeon Point Formation.

Prior to conducting the pumping tests, Todd Engineers installed a Leopold-Stevens Type F water level recorder in the observation well (or Well 1). The recorder consists of a clock driven mechanism with a horizontal drum covered with removable graph paper for recording water level fluctuations and a float to follow water level changes in the well.

Well 1, also referred to as the "Warheit Well", is 300 feet southwest of Well 2 and about 2,400 feet from neighboring wells. Figure 5 shows a typical response for water level changes observed at Well 1 due to pumpage from Well 2. This particular record was made between September 20 and 26, 2001 after the pumping test was completed on Well 2. The fluctuations in water levels caused by pumping Well 2 at about 25 gpm for several hours is about 0.80 feet. This indicates that the transmissivity (or field permeability) of the Pigeon Point Formation is moderate-low but sufficient for a small water system such as CSA 11. The transmissivity is the rate at which water is transmitted through a unit width under a unit hydraulic gradient (Gary et al., 1977).

The step-graph of Figure 5 shows that the water levels drop rapidly in the observation well when the pumping well is turned on. As pumping continues the water levels drop at a slower rate to drawdown stabilization. A similar, but reversed recovery response occurs when the pump is turned off. From available information, it is unclear



February 2002	**Figure 5**
TODD ENGINEERS Emeryville, California	**Groundwater Hydrograph of Well 1**

the significance of the minor groundwater fluctuations on the graph. Each successive recovery does not return fully to the previous non-pumping water level either because elapsed time of recovery is different or, alternatively, groundwater is being removed from aquifer storage. Additional aquifer testing and long-term groundwater monitoring would be needed to clarify these small fluctuations. Note that the final pumping water level for each step is the same because of mechanical pump constraints (i.e., pump rating curves and decrease in pump yields).

Regular and consistent water level monitoring has not been conducted on the CSA 11 water supply wells. Long-term records will provide the hydraulic information necessary to predict water level and aquifer behavior. Nevertheless, the static water levels in 2001 for Wells 1 and 2 are about 188 and 186 feet below ground surface, respectively, while the top of the screen intervals for the two wells are 207 and 210 feet below ground surface, respectively. Therefore, the vertical distances between the static water level and the top of the screens (referred to as the available drawdown) are 19 and 24 feet. Based on the 16-foot drop in water level over a 10-year period, calculations show that the static or non-pumping water level will reach the top of the screens in 12 years (Well 1) and 15 years (Well 2). A rule of thumb indicates that a well should utilize only two-thirds the available drawdown. This two-thirds rule provides conservatively for unforeseeable factors such as changes in well pump efficiency, seasonal and regional fluctuations in water levels, and impacts from adjacent pumping wells. Using this rule, Wells 1 and 2 can be pumped at current rates for another 8 and 10 years, respectively, before encroaching on the two-thirds rule.

Hydraulic Testing and Analysis

Pumping Tests

On September 13, 2001 a Leopold-Stevens water level recorder was installed on Well 1. Prior to recorder installation, Cornerstone Pump was contracted by DPW to remove the pump from Well 1 and to modify the wellhead of Well 2. The pump in Well 2 was removed and re-installed with a 2-inch diameter sounding tube strapped to the pump column. The pump in Well 1 was removed for the duration of the aquifer test and then re-installed with a 2-inch diameter sounding tube after aquifer testing.

The wellhead for Well 2 was modified to accommodate a tee-valve to shunt water from delivery to the nearby storage tank to open discharge near the well. A low-flow water meter that measured in cubic feet (ft^3) was also installed on the discharge pipe. The 2-inch diameter sounding tube allowed unrestricted manual access with an electric sounder to measure water levels in the well during the pumping test, and use in recommended ongoing water level monitoring.

Because aquifer testing must be conducted with stable or static groundwater conditions and water should be pumped to atmospheric pressure at the wellhead instead of the storage tank, we requested that DPW refrain from using the well for three days prior to our testing. To meet these requirements DPW, filled the storage distribution tank so that the CSA 11 system demands could be met for five days with the stored water.

A preliminary pumping test was conducted on Well 2 on September 13 to assess the general performance of the well, operation of the installed monitoring equipment, and magnitude of water fluctuations in the observation well. Unfortunately, the water level sounding probe became stuck in the pumping well at a depth of 30 feet. Instead of the probe being lowered in the 2-inch sounding tube, the sounding probe was inadvertently lowered between the 5-inch diameter casing, the 2-inch diameter sounding tube, and the pump column. No water level measurements could be collected from the pumping well at this time. Cornerstone Pump was called back to the site to correct the problem.

On September 13, 2001, the static water level for the observation well was 187.71 feet below the top of the casing. Because of the inability to measure water levels at the pumping well (Well 2), we decided to abort the pumping test activities. Since the ongoing operation of the CSA 11 system was necessary, the storage tank was re-filled and a second day of pumping was scheduled seven days later. The recorder on Well 1 was left in place to measure pre-testing water levels.

On September 20 a formal pumping test was conducted on Well 2. At 0830 hour the static water levels for Wells 1 and 2 were 187.55 and 185.81 feet below the top of casing, respectively. The pump was turned on at 0920 hour and pumped until 1520 hour (6 hours) at an average discharge of about 23.5 gpm. A five gallon bucket and stop watch was used to measure the pump discharge periodically to verify the flow meter readings. The pump was turned off and two hours of water level recovery were collected to verify drawdown measurements.

Pumping Test Analysis

Figure 6 shows the results of the constant discharge testing. The data are meaningful and internally consistent. The data are analyzed by the Cooper-Jacob semi-logarithmic method (Driscoll, 1986). Drawdown is plotted on the arithmetic scale, time is on the logarithmic scale. Both the observation well and pumping well drawdown curves are shown on Figure 6. The curves are nearly parallel. The pumping well curve is lower than the observation well. Drawdown or the water level change caused by pumping is deepest in the pumping well and systematically smaller with radial distance from the pumping well resulting in an inverted cone referred to as the cone of depression.

Based on the graphs of Figure 6, calculations show that the transmissivity or T-value of the aquifer is about 26,000 gallons per foot (gpd/ft) or 3,484 square feet per day (ft^2/day). The transmissivity of an aquifer is the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width under a unit hydraulic gradient (Gary et al., 1977). High T-values represent more prolific aquifers while low T-values indicate poorer or low-yielding aquifers. Low-yielding aquifers are suitable for domestic water supplies and are typically less than 2,000 to 3,000 gpd/ft. High-yielding aquifers can range between 8,000 to over one-million gpd/ft. The Pigeon Point Formation is a medium- to low-yielding aquifer and can be expected to yield less than 100 gpm or 19,250 cubic feet per day (ft^3/day) depending on the available drawdown.

Because Well 1 is an observation well, calculations can be made to estimate the storativity of the aquifer. The storativity of an aquifer is the volume of water released

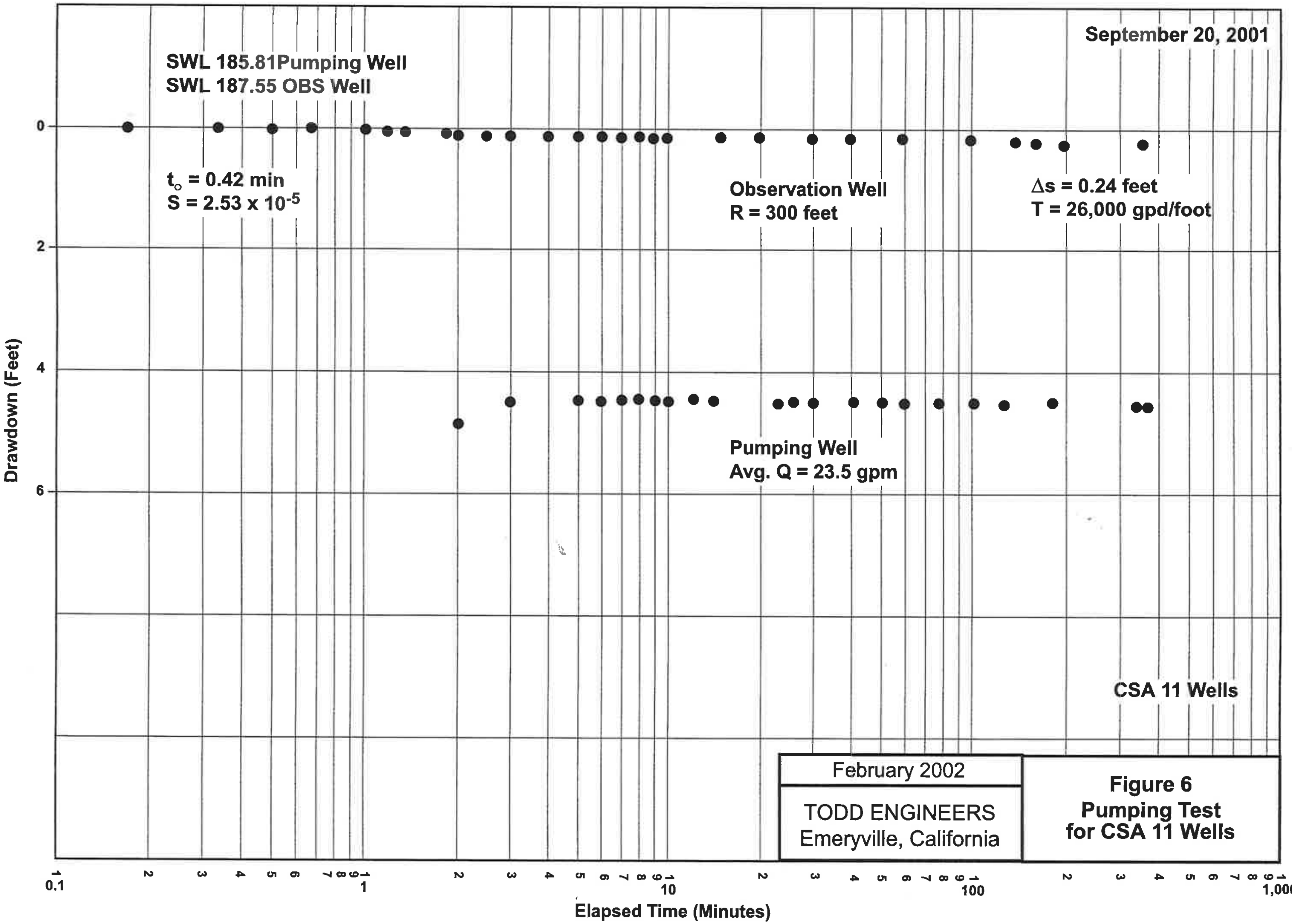


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Figure 6
Pumping Test for CSA 11 Wells

from storage in a vertical column of one square foot when the water table or potentiometric surface declines one foot (Gary et al., 1977). The storativity (S-value) indicates whether the aquifer is unconfined or confined. Large S-values (greater than 0.01) indicate water table conditions and values less than 0.005 indicate confined artesian aquifer conditions. A confined aquifer is bounded above and below by impermeable beds or beds of distinctly lower permeability than that of the aquifer itself (Gary et al., 1977). In contrast an unconfined aquifer (or water table) contains water that is not confined under pressure beneath relatively impermeable rocks (Gary et al., 1977). Calculations (Driscoll, 1986) indicate that the S-value for Well 1 is 0.000025 implying the aquifer is confined. Because the discharge for the test was only 23.5 gpm and the observation well was 300 feet from the pumping well, we believe this estimate is too low and may not reflect the true S-value for this aquifer system. The S-value should be verified with additional pumping at higher discharge rates (i.e., 75 to 100 gpm) or, alternatively, wells located closer to the pumping well (i.e., less than 30 feet).

Well Efficiency

Additional calculations indicate that Well 2 is about 40 percent efficient based on the empirical relationship between the measured transmissivity and the well specific capacity. The specific capacity is a normalized term that represents the amount of water in gallons per minute (gpm) that can be pumped from a well per foot of drawdown. The specific capacity is directly related to the T-value and well efficiency. Large specific capacities mean high-yielding aquifers, while small specific capacities mean low-yielding aquifers or low well efficiencies.

The projected 24-hour specific capacity of Well 2 is 4.94 gallons per minute per foot of drawdown (gpm/ft of dd); the theoretical specific capacity at 24 hours is about 13 gpm/ft of dd (see Driscoll, 1986). Therefore, the efficiency of Well 2 is 38 percent (4.94 ÷ 13 x 100). Current specific capacity data are not available for Well 1. Nevertheless, in 1987 the 46-hour specific capacity was 3.80 gpm/ft of dd or a well efficiency of 29 percent.

Well efficiencies are important if the pumping wells are to have optimum life expectancy and performance. Inefficient wells require greater amounts of drawdown, require more energy to lift the water from the pumping water level, and deeper well screens.

Table 2 summarizes other hydraulic information collected by consultants on the two CSA 11 wells and other neighboring wells. Note that the water table elevations of the CSA 11 and neighboring wells are significantly different even though the wells are located in the same general geologic settings; and note that the specific capacity varies by at least one order of magnitude. This implies that the neighboring wells are located in less permeable material or, alternatively, well efficiencies are lower than CSA 11 wells.

It should be noted that the estimated T-values for the neighboring wells range between 30 and 249 gpd/ft implying that the Pigeon Point Formation is less permable in that area. However, seriously inefficient wells can result in low T-values. Pumping tests on CSA 11 wells have not encountered a change in permeability (i.e., a barrier boundary) with long-term pumping tests. Additional pumping tests on these neighboring wells, especially with an observation well, would be required to verify the T-values and well efficiencies in the vicinity of the neighboring wells.

The specific capacity can be used to estimate the recommended pumping rate provided the drawdown curve shown on Figure 6 does not steepen (i.e., encounter barrier boundaries). Two-thirds of the available drawdown or 100 feet, which ever is less, is used to estimate the recommended pumping rates for Wells 1 and 2. Well 1 and Well 2 have available drawdowns of 19 and 24 feet, respectively; the specific capacity of the wells at 24 hours are about 3.85 and 4.94, respectively. Therefore, the recommended pumping rates for Wells 1 and 2 are 49 gpm and 79 gpm if sufficient drawdown is available. For contrast, the recommended discharge for the neighboring wells ranges between 2 and 17 gpm. Prior to increasing the capacity of the CSA 11 wells, additional testing should be conducted to stress the aquifer and to confirm these estimates.

The transmissivity is also directly proportional to the aquifer thickness and the hydraulic conductivity (a more fundamental measure of permeability). For example, the Pescadero alluvial aquifer is thin (about 60 feet) has a relatively high hydraulic conductivity estimated at about 450 gallons per day per square foot (gpd/ft^2) or 60 feet/day (ft/day). This results in a T-value of 27,000 gpd/ft. In contrast, the Pigeon Point

Table 2

Summary of Aquifer Testing in the Vicinity of the CSA 11 Wells

	Date	GS Elev.	Test Duration	SWL	Q	PWL	Total DD	Q/s	WL Elev.
CSA 11 Wells									
Well 1	04/83	277	24 hour	169.50	22	176.00	6.50	3.38	108
	08/87	277	30 min	168.48	27	175.38	6.90	3.91	109
	08/87	277	30 min	168.48	41	179.28	10.80	3.80	109
	08/87	277	30 min	168.48	45	179.98	11.50	3.91	109
	08/87	277	46 hour	168.54	40	178.94	10.40	3.85	108
Well 2	01/92	276	30 min	170.00	50	182.67	12.67	3.95	106
	01/92	276	30 min	170.00	100	189.00	19.00	5.26	106
	01/92	276	30 min	170.00	150	199.00	29.00	5.17	106
	09/01	276	6 hour	185.81	24	190.26	4.45	5.40	90
Neighboring Wells									
Well 1	06/91	290	8	35.60	9	120.40	84.80	0.11	254
Well 3	07/91	280	5	27.60	4	144.00	116.40	0.03	252
Well 4	01/92	260	22	24.00	35	240.00	216.00	0.16	236
Well 5	06/92	245	24	34.30	37	235.00	200.70	0.18	211
Domestic	06/91	280	3	56.00	4	129.00	73.00	0.05	224

Date	Date of aquifer test
GS Elev.	Ground surface elevation feet
SWL	Static Water Level feet
Q	Discharge gpm
PWL	Pumping Water Level feet
Total DD	Total drawdown feet
Q/s	Specific capacity gpm/ft of dd
WL Elev.	Water Level Elevation feet

Formation is relatively thick (520 feet), with a low hydraulic conductivity (50 gpd/ft^2), resulting in a T-value of 26,000 gpd/ft, the same value as the alluvium.

In summary, the yield of a well is based, in part, on the available drawdown, the specific capacity of the well, the well efficiency, and the aquifer thickness. Therefore, the CSA 11 wells would be more productive if the well screens were at deeper depths providing additional available drawdown and capture of additional regional groundwater.

Assuming that the top of the well screen is placed at mean sea level, allowing approximately 90 feet of available drawdown, and the rate in drop of the water level (1.6 feet per year) remains the same; then the longevity of the aquifer should range between 38 years (utilizing two-thirds the available drawdown) and 56 years. In addition, calculations also show that if such a well has a specific capacity ranging between 3.38 and 5.40 gpm/ft of dd, then the well should be capable of yields ranging between 200 and 300 gpm.

Groundwater Chemistry

Table 3 summarizes inorganic groundwater chemistry for CSA 11 (three samples) and the neighboring wells (five samples). Water quality of the eight samples is similar. Total dissolved solids (TDS), a measure of the total inorganic constituents and an indication of salinity, ranges between 230 and 512 milligrams per liter (mg/l). The State Department of Health Services (DHS) suggests a TDS concentration of less than 500 mg/l for a drinking water supply. Elevated TDS concentrations are not harmful to health but may require treatment to reduce scaling and soap scum. The values of TDS are shown on the cross section (Figure 3). It appears that TDS does not vary significantly with depth in contrast to Wood (September 13, 1982) who suggested that the salinity increases to non-potable saline water below sea level. Groundwater at shallower depths would tend to have lower TDS concentrations than groundwater from deeper depths because of the less time for contact with aquifer materials.

The iron and manganese concentrations for CSA 11 wells are within the suggested drinking water standards. However, elevated iron and manganese concentration in the neighboring wells, while not harmful to human health, will stain fixtures and clothing. DHS recommends that iron and manganese concentration not exceed 0.3 and 0.05 mg/l, respectively. All other inorganic constituents are within the suggested DHS drinking water standards. A groundwater sample for Well 1 of CSA 11 was analyzed for organic constituents which were found below the detection limit. The CSA 11 wells tend to have higher sodium and chloride concentrations than those from neighboring wells, but the sodium to chloride ratios are about the same ranging between 0.52 to 0.63.

We recommend that future inorganic groundwater sampling be conducted annually on the CSA 11 wells to track groundwater quality changes. This tracking will help to identify the long-term reliability of the aquifer. Constituents that should be measured annually include major cations (calcium, magnesium, sodium, and potassium), major anions (bicarbonate, sulfate, and chloride), minor ions (iron, manganese, nitrate, and fluoride), general physical (total alkalinity, total hardness, pH, TDS, electrical conductivity, turbidity, color, and odor), and trace metals (arsenic, barium, cadmium,

Table 3

Groundwater Chemistry for Wells in Vicinity of CSA 11 Wells

	CSA 11 Wells			Neighboring Wells					
	Well 1 04/83	08/87	Well 2 12/95	Well 1 06/91	07/91	Well 3 07/91	Well 4 06/92	Well 5 06/92	DHS DWS
MAJOR CATIONS									
calcium	59	24	25	29	18	20	62	24	
magnesium	18	15	19	11	11	12	52	15	
sodium	62	63	62	41	37	41	65	74	
potassium	-	3	2	-	-	-	-	-	
MAJOR ANIONS									
bicarbonate	79	55	95	130	98	116	122	140	
sulfate	11	10	13	-	7	14	9	9	250
chloride	110	110	120	-	58	66	181	116	250
MINOR IONS									
iron	*	0.12	-	-	0.8	0.6	*	*	0.3
manganese	*	*	-	-	0.1	0.1	*	*	0.05
nitrate	12	9	16	-	11	12	8	6	45
flouride	*	*	0.19	-	-	-	-	-	1.4 to 2.4
GENERAL PHYSICAL PROPERTIES									
alkalinity	-	90	-	-	-	-	-	-	
total hardness	140	120	140	-	-	-	-	-	
pH units	7.6	7.7	7.5	8	6.9	7.1	7.3	8.4	
EC umhos/cm	490	610	520	-	400	420	800	550	900
TDS	420	390	470	230	256	269	512	352	500
MBAS	*	*	*	-	-	-	-	-	0.5
turbidity NTU	-	0.07	-	-	-	-	-	-	0.5
color units	-	*	-	-	-	-	-	-	
odor units	-	1	-	-	-	-	-	-	
TRACE METALS									
arsenic	*	*	*	-	-	-	-	-	0.05
barium	*	*	*	-	-	-	-	-	1
cadmium	*	*	*	-	-	-	-	-	0.005
chromium	0.009	*	*	-	-	-	-	-	0.05
copper	*	*	*	-	0.7	0.1	*	*	1
lead	*	*	*	-	-	-	-	-	
mercury	*	*	*	-	-	-	-	-	0.002
selenium	*	*	*	-	-	-	-	-	0.05
silver	*	*	*	-	-	-	-	-	0.1
zinc	0.11	0.15	0.11	-	0.1	0.1	*	0.1	5
OTHER									
phosporous	-	*	-	-	-	-	-	-	
boron	-	-	-	0.37	*	*	0.07	*	
organic suite	-	*	-	-	-	-	-	-	
SAR	-	-	-	50	2.32	2.67	2.98	4.91	
sodium:chloride	0.56	0.57	0.52		0.64	0.62	0.36	0.64	

* Below instrument detection limit
\- Not analyzed
All concentrations in mg/l except where shown
DHS DWS Department of Health Services Drinking Water Standards

total chromium, copper, lead, mercury, selenium, silver, and zinc).

Salt Water Wedge and Intrusion

The saturated Pigeon Point Formation above sea level is unlikely to experience salt water intrusion. Apparent elevated concentrations of sodium and chloride in the CSA 11 wells are probably caused by natural recharge of sea spray and mist on the west-facing slopes and the lower recharge of groundwater on the east-facing slopes. In general, as long as the pumping water level of a well is above sea level, horizontal salt water intrusion should not be experienced at the well. Inland movement of the salt water wedge will occur if pumpage is not balanced by groundwater recharge. Horizontal movement of the salt water wedge is a balance between the dynamic groundwater head of the water level above sea level and groundwater flow through the aquifer (Todd, 1980). Increased groundwater pumpage will move the salt water wedge inland while increases to groundwater head will move the salt water wedge toward the ocean.

A second method of saltwater contamination to a well can occur from vertical movement of water or upconing. Again, as long as the pumping water level remains above sea level, upconing should not be experienced in pumping wells.

In the project area, water quality data from neighboring deep wells suggest that significant quantities of fresh water occur below sea level. This would be expected since the hydrostatic balance or equilibrium between fresh (1.000 grams/cubic centimeter [g/cm^3]) and salt water (1.025 g/cm^3) is one to forty (1:40) [1.000 ÷ (1.025 – 1.000)]. Fresh water is lighter and tends to float on salt water. This means that if sufficient groundwater storage is available, then one-foot of fresh water above sea level at a well will have 40 feet of fresh water below sea level. This relationship is experienced on ocean islands and is referred to as the Ghyben-Herzberg lens (Todd, 1980).

Volumetric Calculations

The volume of groundwater available to the CSA 11 wells was estimated based on the 1991-92 water table map (Figure 4) and an estimate of the porosity of the aquifer (0.05). Not all water is available to the CSA 11 wells in the project area. We assumed that the northeast half of the ridge (shown on Figure 4) is available to recharge the CSA 11 wells. The area delineated on Figure 4 for the volumetric calculations is 442 acres. However, without additional wells and hydraulic testing in the northern portion of the area, actual water capture would be one-half of this area or 221 acres.

The area between the groundwater contours was measured and multiplied by the average groundwater elevation or the mid-point of the contour interval. This calculation provided the total volume of saturated material beneath this portion of the ridge. The volumes were summed for each interval to provide a total volume of saturated material (43,025 acre-feet [AF]). Assuming a porosity of five percent (0.05), then the volume of groundwater available above sea level is 2,151 AF in 1992. Without additional wells to the north, it is doubtful that Wells 1 and 2 could capture more than one-half this volume or 1,075 AF.

In addition, because Wells 1 and 2 are not screened below sea level, water beneath the screened interval would not be captured. Therefore, the 1,075 AF must be corrected to reflect this unavailable water. The bottom of the wells are screened about 25 feet above sea level and the area of the contribution is 221 acres (442 acres ÷ 2). The volume of groundwater inaccessible to the wells is about 277 AF (221 acres x 25 feet x 0.05) while accessible groundwater to Wells 1 and 2 is about 798 AF (1,075 AF – 277 AF). Currently the CSA 11 water supply pumps an average of 25 AFY. Therefore, the aquifer could last between 32 (current well depth) and 43 years (well depth to sea level) based on 1992 water levels assuming no recharge.

Since 1992 water levels have dropped 16 feet. Assuming that the water levels dropped uniformly across the project area, then the 1992 longevity calculations shown above must be adjusted accordingly. A 16-foot drop is approximately equivalent to 177 AF of water (221 acres x 16 feet x 0.05). This yields a net decrease in available water to the wells of 621 AF (current well depth) or 898 AF if new wells were installed to capture groundwater to sea level. Therefore, the current estimate of the longevity of the aquifer is between 25 years (current well depth) and 36 years (well depth to sea level). It should be noted that the estimated 177 AF of water removed (18 AFY) in 10 years based on volumetric calculations is similar to the actual annual volumes removed (25 AFY).

Conclusions

Wells 1 and 2 were installed in the Pigeon Point Formation west of the Town of Pescadero for the CSA 11 water supply system in 1983 and 1992, respectively. These wells were installed to replace inadequate water supplies from domestic wells, small impoundments, and wells installed in the Pescadero Creek and Butano Creek alluvium. The wells began to operate in 1993. Average annual pumpage is 25 AFY. The water levels in both wells dropped about 16 feet in 10 years. Assuming linear declines, the wells could fail due to lack of water in 8 to 15 years.

A review of all relevant and available hydrogeologic information indicates that potable groundwater exists throughout the project area in the vicinity of the CSA 11 wells. Groundwater flows radially from the top of the groundwater mound at an elevation near 250 feet above msl to the base near sea level. Deep wells in the area suggest that fresh groundwater exists at depths of at least 400 feet below msl. Volumetric calculations indicate that the Pigeon Point Formation contains less than 621 AF of water (available to Wells 1 and 2) to 898 AF of water (available to wells tapping groundwater below sea level). These volumes correspond to potential aquifer longevity of less than 25 to greater than 36 years, respectively.

Recommendations

1. We recommend that CSA 11 install a new production well in the general vicinity of Wells 1 and 2 and the tank. The well should be drilled to at least 100 feet below msl to take advantage of the overlying potable water. A certified hydrogeologist should prepare well specifications, supervise construction, design the production well, and conduct formal aquifer testing. After well completion, a well construction report should be prepared to document site drilling and construction activities, pumping test analysis, and long-term operation and maintenance of the well. The well could be located at a lower elevation near the distribution tank to reduce overall drilling depth. Alternatively, the well could be located in the vicinity of Wells 1 and 2.

2. We recommend that CSA 11 collect annual groundwater samples for major cations and anions, minor ions, general physical, and trace metal concentrations.

3. We recommend that CSA 11 collect monthly static and pumping water levels on Wells 1 and 2. These data will be used to predict future hydrogeologic conditions.

4. Additional pumping tests to confirm aquifer parameters and aquifer response could be conducted on both Well 1 and Well 2. These tests would be conducted with larger pumps so that the Pigeon Point Formation could be fully stressed and drawdown data would be more defensible.

5. An investigation could be conducted to determine if it is economically feasible to install a storage/recharge pond in the vicinity of Wells 1 and 2. Because of the limited upstream watershed area, the water quality regulatory requirements, and unpredictable rainfall events (particularly in summer) it is doubtful that a recharge/storage pond would be successful or reliable for the CSA 11 water system.

6. With the permission of the well owner, an investigation and fieldwork could be conducted to assess if any of the existing wells in the vicinity of CSA 11 could be utilized to supplement the Town of Pescadero water system. Fieldwork would include verification of well dimensions and formal pumping tests, similar to those conducted on CSA 11 wells.

Estimated Costs

1. Todd Engineers can provide a formal proposal at a later date. Nevertheless, we estimate engineering costs to install a new well to be about $20,000 to $25,000 including technical specifications, onsite drilling, construction, and aquifer testing supervision, and inspection, and well construction report. Drilling contractor costs are estimated to be $150,000. Todd Engineers can provide above ground

engineering costs through an engineering subcontractor for between $25,000 and $30,000. Based on these estimates, an installed, fully equipped and functional well can be constructed for $200,000 to $250,000.

2. We estimate that annual groundwater sampling will cost about $2,000 per year for the laboratory.

3. We estimate that monthly water level measurements including static and non-pumping water levels will be minimal and coordinated with your daily or weekly operations site visit.

4. If additional design, coordination, supervision, analysis, and reporting of pumping tests are conducted, engineering costs may range between $5,000 and $15,000 for each aquifer test depending on the complexity of the testing. This does not include wellhead modifications and any outside contractors.

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