City of Menlo Park
City of East Palo Alto
California

FINAL

Feasibility of Supplemental Groundwater Resources Development

Menlo Park and East Palo Alto, California

August 2005

Todd Engineers
Emeryville, California

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December 2003

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Executive Summary

The Cities of Menlo Park and East Palo Alto (Cities) currently obtain 100 percent of their water supply from the City of San Francisco Water Department through their Hetch Hetchy Aqueduct water allocation. The Cities are evaluating the feasibility of augmenting water supplies with additional sources such as reclaimed water and/or groundwater.

The Cities are located in the San Francisquito Creek Groundwater Subbasin, which is part of the Santa Clara Valley Groundwater Subbasin The San Francisquito Creek Subbasin is composed of coarse- and fine-grained alluvial deposits of San Francisquito Creek. The groundwater system includes a shallow aquifer and a deep aquifer beneath a laterally extensive confining clay layer. The deep aquifer consists of an upper and lower zone. The groundwater subbasin is as much as 1,000 feet thick in places. Pumping test and empirical transmissivity data indicate that development of a municipal supply in the study area is feasible. Storativity values indicate the shallow aquifer is unconfined and the deeper aquifer system is semi-confined.

Under natural conditions, groundwater flow is from the edge of the basin near the bedrock uplands toward San Francisco Bay to the northeast. In the early 1900s this natural groundwater flow pattern was reversed when pumping and periodic drought reduced groundwater elevations to below sea level in the area. Lowered groundwater levels induced saline water from the San Francisco Bay inland into the aquifer system and also resulted in ground subsidence as the result of dewatering and compaction of clay layers within the aquifer.

Groundwater extraction from the area declined significantly after the importation of Hetch Hetchy water supplies in the 1960s. As a result, groundwater elevations have been steadily increasing over much of the area. Currently, the groundwater gradient is toward the Bay. If groundwater gradients toward the Bay are maintained, intrusion of saline water from the Bay can be prevented under future development scenarios.

Review of water well drillers logs and other data in the area indicate that a properly designed and sited municipal well in the Cities can be expected to yield between 300 and 1,800 gallons per minute (gpm). Although, recommended pumping rates over the long-term may be less if pumping water levels are significantly below sea level. Currently, groundwater use in the area is not extensive and is estimated to be approximately 1,100 acre feet per year (AFY). Water demand in the study area is projected to increase and it is anticipated that during a drought or emergency reduction in Hetch Hetchy allocations, groundwater use will increase. It is estimated that future municipal and private groundwater use in the San Francisquito Subbasin in the year 2020 during a drought or emergency Hetch Hetchy system-wide reduction of 20 percent could increase to approximately 4,700 AFY.

In order to estimate the quantity of groundwater that can be sustainably developed from the San Francisquito Subbasin, a basic water balance under current pumping conditions was performed. It is estimated that annual recharge to the San Francisquito Groundwater Subbasin ranges from approximately 4,000 to 8,000 AFY. The total basin discharge under current conditions is estimated to be approximately 8,000 AFY. The water balance calculations show a balance between basin discharge and the higher end estimate of groundwater recharge. Additional groundwater resources can be developed. If additional groundwater resources are developed, groundwater levels will decline and less groundwater will discharge in the subsurface to the Bay. Regional management of groundwater extraction is recommended to prevent saline intrusion and subsidence.

The Cites could install supplemental wells to capture some portion of the estimated annual recharge without mining the groundwater resource. The amount of recharge that can be safely recovered without inducing saline water intrusion from the Bay and subsidence will be dependent on the volume extracted by all users in the basin. Therefore, any development of groundwater resources within the Cities should consider regional conditions.

Supplemental wells can be expected to have acceptable water quality for irrigation or potable uses. However, the water is hard with some wells exhibiting elevated concentrations of total dissolved solids, iron, manganese, and chloride that are objectionable for aesthetic reasons. Therefore, groundwater would likely require blending with Hetch Hetchy water and/or treatment prior to use for potable supplies in order to be acceptable to customers. Groundwater for irrigation supplies is not likely to require treatment or blending.

1 Introduction

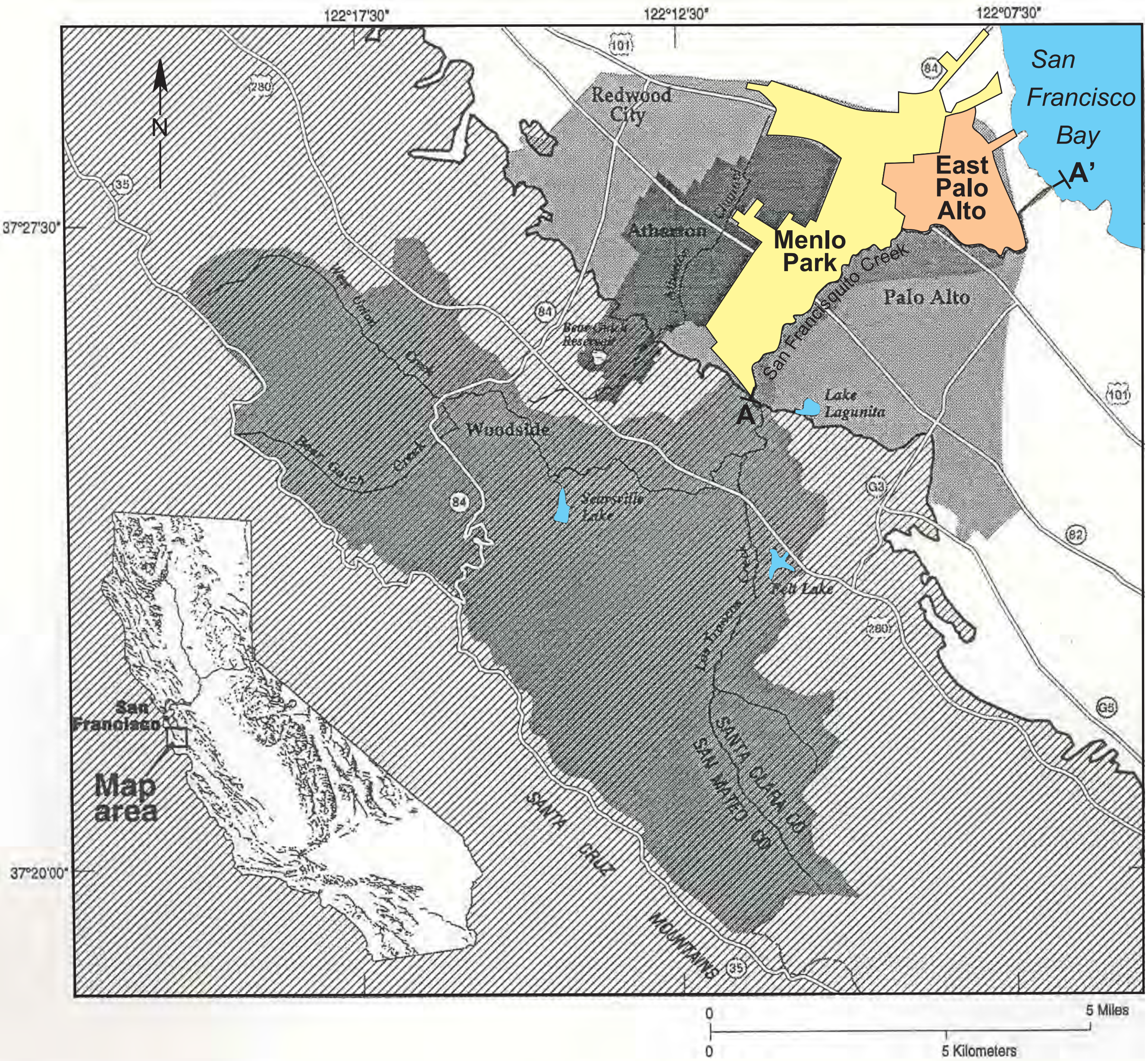
The Cities of Menlo Park and East Palo Alto (Cities) currently obtain 100 percent of their water supply from the City of San Francisco Water Department through their Hetch Hetchy Aqueduct water allocation. The Cities are evaluating the feasibility of augmenting water supplies with additional sources such as reclaimed water and/or groundwater.

Figure 1 shows the location of Menlo Park and East Palo Alto and surrounding communities. The cities are situated in the San Francisquito Creek Groundwater Subbasin, which is roughly coincident with the alluvial fan deposits of San Francisquito Creek. The drainage basin for San Francisquito Creek is also shown in the figure. The study area encompasses the area within the city boundaries of Menlo Park and East Palo Alto. In order to understand the regional hydrogeology, reports and information on the surrounding basin have also been collected, reviewed, and summarized.

This report provides a preliminary feasibility level evaluation of the potential supply and quality of groundwater resources in Menlo Park and East Palo Alto. Study results are summarized and conclusions are presented regarding the feasibility of developing local groundwater resources to supplement water supply.

2 Historical Background

Water demand and sources of water supply for Menlo Park and East Palo Alto and surrounding areas have changed dramatically. The demand for water has shown a steady increase since 1900 as the region has changed from sparsely populated agricultural land to a densely populated residential and commercial area. Before 1900, water needs in the area were met primarily with diversions from local creeks. In the early 1900s, development of groundwater began due to the lack of a dependable year-round surface water supply (Metzger and Fio, 1997). Beginning in the 1920s, the City of San Francisco began augmenting local groundwater supplies in the area with deliveries of Hetch Hetchy Aqueduct water (Metzger and Fio, 1997; Carollo, April 2003). However, up to the 1960s, groundwater was the primary source of water supply for the City of Palo Alto and Stanford University and for surrounding communities. Groundwater pumping during this period caused groundwater levels to drop below sea level. In turn, lowered water levels caused land subsidence and saline water intrusion from the San Francisco Bay (Fio and Leighton, 1995).



LEGEND

- Alluvium outside of San Francisquito Creek Alluvial Cone
- San Francisquito Creek Alluvial Cone
- San Francisquito Creek drainage basin
- Study Area
- Consolidated Rock

A – A' Line of Geologic Cross Section A to A' runs along the bed of San Francisquito Creek and extends into the Bay

Modified from: Metzger, 2002.

Figure 1
Study Area and Surrounding Hydrogeologic Features

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By the early to mid 1960s, surface water from the Hetch Hetchy Aqueduct became the dominant source of water for the area. While groundwater still provides a portion of the water supply for the area, groundwater levels have been rising and are now at levels comparable to those of the early 1900s (Carollo, April 2003).

3 Geology

The study area is located in the Coast Range Physiographic Province, a region characterized by northwest-trending faults, mountain ranges, and valleys. Movement along the San Andreas, Hayward, and Calaveras faults and down warping of the area in between the fault zones has formed the physiography of the San Francisco Bay area (California Department of Water Resources [DWR], August 1967).

The Cities are located in the South Bay Drainage Unit, which is characterized by a broad alluvial valley sloping toward the San Francisco Bay and flanked by the Diablo Range in the East Bay and the Santa Cruz Mountains in the west (DWR, August 1967). Surface streams flowing from the mountains toward the Bay have deposited debris as alluvial fans and flood plains. These alluvial deposits comprise the major aquifers of the region.

The study area is underlain by unconsolidated and semi-consolidated deposits of the San Francisquito Creek alluvial fan. The alluvial fan is composed of deposits from the Santa Cruz Mountains and from San Francisco Bay. Fine-grained silts and clays were deposited during periods of rising sea levels when the area was inundated. When sea levels declined, streams eroded the fine-grained deposits and deposited coarse-grained sand and gravel near the foothills and in the stream channels. The fan deposits vary in composition with distance from the head of San Francisquito Creek. The alluvial fan can be divided into proximal, medial, and distal fan deposits. Proximal deposits near the head of the fan at the foothills are characterized as poorly sorted clays and gravels. Medial deposits near the central portion of the fan and the active stream course are generally cleaner sands and gravels. The distal deposits near the terminal portion of the fan at the Bay consist of fine-grained silts, clays and fine sands (CH2MHill, July 1992). Relatively finer-grained materials were deposited laterally away from the stream channel course as overbank materials.

The alluvial deposits of the San Francisquito fan form a wedge that thins near the bedrock hills and thickens toward the Bay. Review of water well drillers logs and other references indicate that the thickness of the alluvial deposits in the vicinity of the Cities range from zero where bedrock crops out to approximately 1,000 feet near the Bay at the border between the Cities and Palo Alto. The alluvial deposits tend to be thickest near and south of San Francisquito Creek and thin to the northwest. (Oliver, 1990; Fio and Leighton, 1995). Bedrock units comprising the underlying basement complex define the base of the alluvial deposits. The top of bedrock is not a smooth dipping surface, but rather exhibits undulations and changes in dip. There are two valleys or depressions in the bedrock surface thought to be the result of erosion from the ancestral San Francisquito Creek and another unnamed modern-day creek southwest of Atherton (Oliver, 1990). High bedrock elevations have been interpreted from a gravity survey to exist in the Lindenwood area east of Atherton where bedrock rises to within 300 feet of the ground surface and in an area centered near the intersection of Willow Road and Ravenswood Slough in east Menlo Park (Oliver, 1990).

The Pulgas Fault is a southwest dipping reverse fault that separates bedrock deposits of the foothills of the Santa Cruz Mountains on the southwest from younger alluvial deposits of the San Francisquito fan on the northeast. The fault may impede the subsurface inflow of groundwater from the bedrock uplands (Metzger, 2002). Other smaller faults exist in the area, but are not thought to displace alluvial deposits and affect groundwater flow.

4 Hydrogeology

San Francisquito Creek is the major stream crossing the study area. The creek has a watershed area of 45 square miles (mi^2) encompassing mountainous bedrock terrain and relatively flat alluvial fan deposits (Figure 1). The alluvial deposits associated with the creek are permeable and the alluvial deposition area of the creek is large (DWR, August 1967). As a result San Francisquito Creek is an important source of groundwater recharge. However, the creek is usually dry during the dry summer months from May to October.

Precipitation in the Cities averages 15 inches per year. Rainfall is greater in the higher elevations of the San Francisquito Creek drainage basin where it averages more than 40 inches per year at the highest elevations.

Menlo Park and East Palo Alto are located in the San Francisquito Creek Groundwater Subbasin, which is part of the Santa Clara Valley Groundwater Subbasin (DWR, August 1967; Metzger, 2002). The San Francisquito Creek fan encompasses approximately 22 mi^2. The fan extends under the southern portion of Redwood City to the northern portion of Palo Alto, and also underlies Atherton, Menlo Park, East Palo Alto, and Stanford University. The subbasin boundaries roughly correspond to the extent of the San Francisquito Creek alluvial fan (Figure 1). With the exception of the southwestern boundary where faulting between bedrock and alluvial deposits may impede groundwater inflow, the subbasin boundaries do not represent hydrogeologic barriers. Accordingly, the San Francisquito Subbasin is continuous with Belmont Subbarea on the northwest and the Santa Clara Valley Subbasin on the southeast.

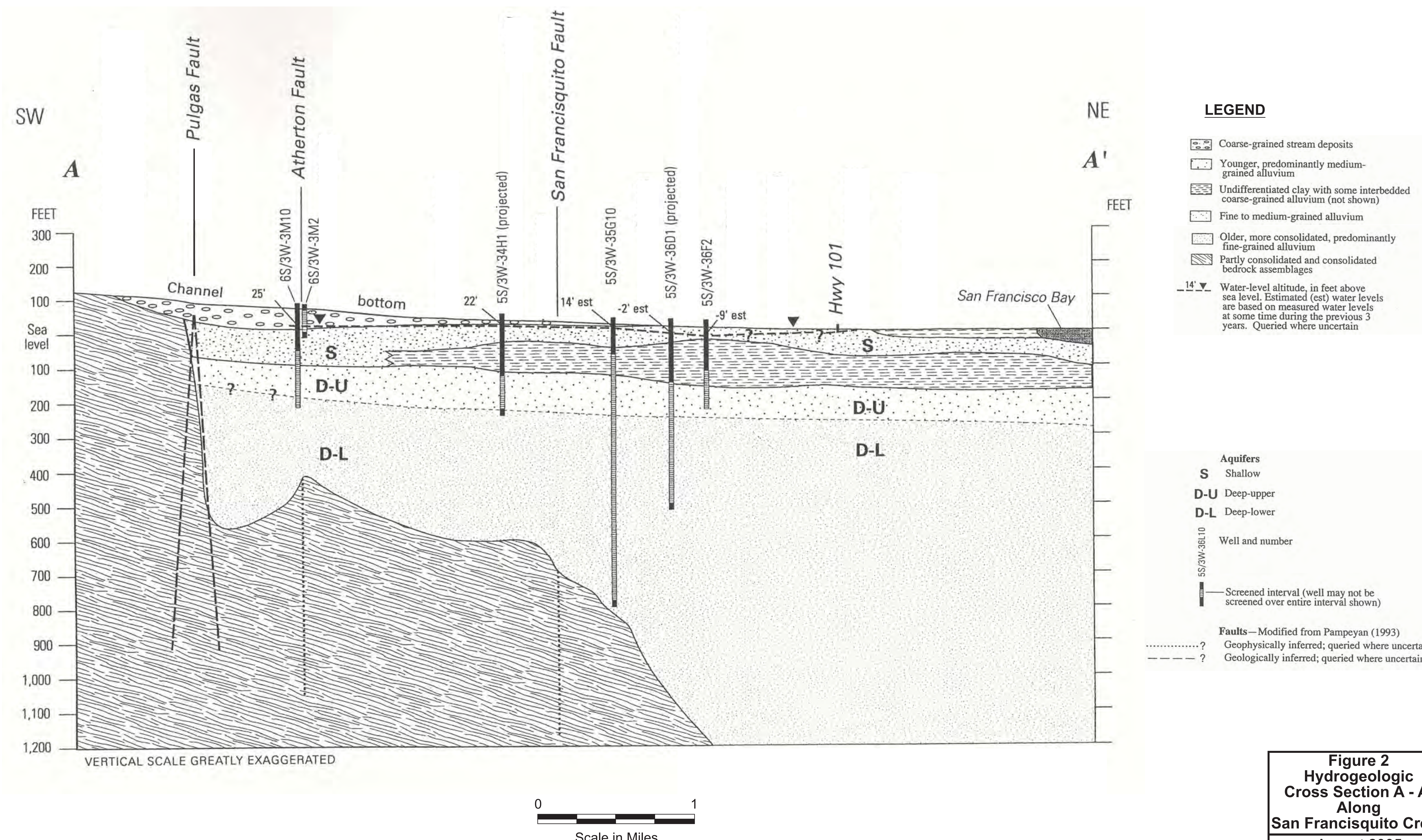
Groundwater in the Subbasin is unconfined to semi-confined. On average, the thickness of water-bearing sediments in the San Francisquito Subbasin range from more than 1,000 feet south of Palo Alto thinning to less than 400 feet at the northern end of the subbasin beneath Redwood City (Fio and Leighton, 1995; Water well drillers logs).

The San Francisquito Creek Subbasin is composed of coarse- and fine-grained alluvial deposits of San Francisquito Creek. Thick laterally extensive fine-grained materials (deposited when the area was below sea level) form an aquitard or confining layer, thereby producing a multiple aquifer system, as illustrated in Figure 2. Figure 2 shows a cross section prepared by the USGS (Metzger, 2002) that trends from southwest to northeast along the bed of San Francisquito Creek. As shown, the groundwater system includes a shallow aquifer that extends from the ground surface to about 15 to 100 feet below ground surface (bgs) and a deep aquifer beneath the confining layer that has two water-bearing zones. The upper zone is between 200 and 300 feet bgs and the lower zone extends to depths greater than 300 feet bgs.

The shallow aquifer consists of predominantly medium-grained alluvium. The unit is more coarse-grained near the southwest edge of the subbasin (Metzger, 2002). As shown in Figure 2, the shallow aquifer is thicker in the southwest and thinner near the Bay. Fine-grained Bay Mud overlies the shallow aquifer near San Francisco Bay.

Beneath the shallow aquifer in most of the study area is a thick laterally extensive fine-grained layer. This confining layer separates the shallow aquifer from the deeper aquifer system. The confining layer pinches out near the mountain front where the shallow and deeper aquifers are in hydraulic connection.

The deeper aquifer is separated into an upper and lower zone. The upper zone has a greater proportion of coarse–grained sediments as compared with the lower zone



Modified from: Metzger, 2002.

Figure 2
Hydrogeologic Cross Section A - A' Along San Francisquito Creek

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(Metzger, 2002). Partly consolidated and consolidated igneous and sedimentary rocks underlie the alluvial basin. The Pulgas Fault, which runs along the base of the mountain front, may impede subsurface inflow of groundwater from bedrock uplands to the alluvial basin.

4.1 Aquifer Parameters

Two key parameters, transmissivity and storativity, are used to quantify the potential productivity and storage characteristics of water-bearing units. Transmissivity is an indication of the productivity of an aquifer and can be estimated by performing a constant rate pumping test. Transmissivity and storativity values available from pumping tests in the area are provided in Table 1.

Table 1

Summary of Transmissivity and Storativity Data

Well	Transmissivity	Storativity	Reference
6S/3W-1B2	34,400		Fio and Leighton, 1995
6S/3W-1D1	7,387		Fio and Leighton, 1995
6S/3W-1M1	2,690		Fio and Leighton, 1995
6S/3W-10L1	20,000	0.05	Sokol, 1964
6S/3W-11B1	118,000	0.00126	Sokol, 1964
6S/3W-12D1	48,800	0.000186	Sokol, 1964
Average	38,546		
Geometric Mean	20,702		

While a constant rate pumping test is the best method of determining transmissivity, it can also be calculated empirically based on the pumping rate of the well and the observed drawdown. These initial measurements are often recorded on driller's water well logs. Review of the driller's water well logs collected in the San Francisquito fan area indicate a range in the empirically calculated transmissivity from 28 to 480,000 gpd/ft with an average of 22,850 gpd/ft. This value compares well with the average and geometric mean of transmissivity values available from pumping tests 38,546 and 20,702 gpd/ft, respectively. If an aquifer has a transmissivity less than 1,000 gpd/ft, it can supply only enough water for domestic wells or other low-yield uses. With a transmissivity of 10,000 gpd/ft or more, well yields are adequate for industrial and municipal purposes (Driscoll, 1986). Pumping test and empirical transmissivity results indicate that development of a municipal supply in the study area is feasible.

Storativity is the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. It is a ratio comparing a volume of water to a volume of aquifer and therefore is unitless. In a confined aquifer, storativity ranges from 0.005 to 0.00005. Specific yield is the ratio of the volume of water that a material will yield by gravity drainage to the volume of material. In an unconfined aquifer, the storativity is equivalent to the specific yield. Specific yield usually ranges between 0.01 and 0.3. The storativity of an aquifer has implications for the zone of influence of a pumping well. Pumping wells in confined aquifers (storativity from 0.005 to 0.00005) will cause larger head change over larger areas compared with a pumping well in an unconfined aquifer. Accordingly, the lower the storativity of an aquifer, the greater the radius of influence and drawdown of a pumping well screened in that aquifer.

Storativity values from pumping tests are shown in Table 1. The storativity values indicate a range of conditions from unconfined to semi-confined. Based on pumpage and measured groundwater levels, Carollo (April 2003) estimated a storativity of 0.007 for the deeper aquifer system beneath Palo Alto. Sokol (1964) estimated the average storativity of the deeper water bearing zone to be 0.001. Based on average specific yields of classes of sediments and sediment distributions determined through review of driller's logs, Sokol estimated an average specific yield of the basin at approximately 0.08 and found higher average specific yields in the upper 100 feet of alluvial deposits as well as along the axis of San Francisquito Creek and near the foothills.

4.2 Groundwater Elevations and Flow

Under natural conditions, groundwater flow is from the edge of the basin near the bedrock uplands toward San Francisco Bay to the northeast (Fio and Leighton, 1995; Metzger and Fio, 1997).

Groundwater elevations in the San Francisquito Subbasin were near and in some areas above the ground surface (flowing artesian) in the early 1900s. Increased pumping and periodic drought in the early part of the century reduced groundwater levels to below sea level in the area. It is estimated that annual pumping from the San Francisquito Subbasin amounted to about 7,500 AF prior to 1962. Of this total, approximately 6,500 AFY was by the City of Palo Alto and Stanford University (Sokol, 1964).

These groundwater level declines caused a reversal of the normal groundwater flow toward the Bay. Lowered groundwater levels induced inland movement of saline water from the San Francisco Bay into the aquifer system. Saline water intrusion extended two to three miles inland in the area of Palo Alto, Menlo Park, and Atherton (Iwamura, 1980). Lowered water levels also resulted in subsidence of the ground surface as a result of dewatering and compaction of clay layers and the skeletal framework of the aquifer. Land subsidence of more than two feet was measured in Palo Alto and East Palo Alto between 1934 and 1967 (Poland and Ireland, 1988). Subsidence in the Atherton area during the same period was reportedly between 0.1 and 0.5 foot (Metzger and Fio, 1997).

Groundwater extraction from the area declined significantly after the importation of Hetch Hetchy water supplies in the 1960s. As a result, groundwater elevations have steadily increased over much of the area. Between 1962 and 1987, groundwater elevations in the City of Palo Alto rose more than 150 feet to levels comparable to those of the early 1900s (Carollo, April 2003). Measurements between 1993 and 1995 in the City of Atherton showed depths to groundwater ranging between 20 feet bgs near the Bay to 70 feet bgs near the bedrock uplands (Metzger and Fio, 1997).

The groundwater gradient toward the Bay in 1990 was estimated to be 0.0005 ft/ft in the shallow aquifer and 0.005 ft/ft in the deeper aquifer (Fio and Leighton, 1995, Figure 20). If groundwater gradients toward the Bay are maintained, intrusion of saline water from the Bay can be prevented.

5 Wells and Production

In order to assess current groundwater use, water well drillers logs available from the DWR were compiled for the cities of Menlo Park and East Palo Alto and for the surrounding communities of Redwood City, Atherton, Palo Alto, and Stanford University. While over 300 well logs were available, many of these wells were drilled early in the 1900s. It can be assumed that most of these wells have been abandoned or destroyed. Well logs for a total of 224 wells installed after 1962 were available from the DWR. Records on the status of wells (active, idle, or destroyed) in the area are poor. For the purpose of this study we have assumed that wells drilled after 1962 are still active. Not all wells drilled have logs on file at DWR and there are likely other wells in existence not identified by this study.

Water wells are commonly designated by use as municipal, domestic, irrigation, or industrial. Individual municipal and industrial wells would tend to have greater production than domestic or irrigation wells. In the early 1900s, most of the groundwater extraction in the area was from large capacity municipal wells such as those operated by the City of Palo Alto and Stanford University. With the importation of Hetch Hetchy water, these municipal wells were abandoned or destroyed. As the cost of imported water has increased, a number of private homeowners in the area have installed wells, primarily for irrigation, to supplement their water supply. The installation of private wells tends to correlate with periods of drought or below average rainfall (1976 -1977 and 1987 – 1992) when concerns over rationing and water costs increase.

Generally, the most productive wells are located near San Francisquito Creek in the medial portion of the alluvial fan. Wells tend to be less productive near the Bay and near the southeast and northwest edges of the subbasin (CH2MHill, July 1992; Water well drillers logs).

Well logs indicate well yields in the San Francisquito cone area vary from 1 to 1,800 gallons per minute (gpm), with an average yield of 130 gpm. Most of the wells drilled in the study area are small diameter (less than 8 inches) domestic and irrigation wells, with fewer larger diameter (10 to 30 inch) municipal and industrial wells. Generally, municipal wells with larger diameter casings yield between 100 and 1,800 gpm, with an average of 650 gpm.

Specific capacity is the yield of a well per unit of drawdown and is a measure of the productivity of the well (Todd, 1980). Well logs indicate an average specific capacity of 19 gallons per minute per foot of drawdown (gpm/ft) for wells in Menlo Park and East Palo Alto. If an aquifer has a specific capacity less than one gpm/ft, it can supply only enough water for domestic wells or other low-yield uses. With a specific capacity greater than 5 gpm/ft or more, well yields are adequate for industrial and municipal purposes. Specific capacity data indicate that development of a municipal supply in the study area is feasible.

Existing Municipal Wells. There is some existing municipal water use in the study area. The Palo Alto Mutual Park Water Company currently provides groundwater from two wells located in East Palo Alto. The Palo Alto Mutual Park Water Company has less than 500 connections (Katherine Loudd, personal communication). Assuming 400 connections using 250 gallons per day per household yields an annual production of approximately 100 AF.

The O'Connor Tract Cooperative Water Company operates two wells in Menlo Park (O'Connor, November 14, 2003). The company serves approximately 300 homes and apartments (Kelly Fergusson, personal communication). Assuming 300 connections using 350 gallons per day yields an annual production of approximately 117 AF.

Potential Future Municipal Wells. The City of Palo Alto maintains five wells for emergency standby supply. The wells were last used in 1988 during the extended drought period (Carollo, April 2003). The City of Palo Alto has proposed to rehabilitate five old wells and drill three new wells to be used for emergency supply. It has been estimated that the wells could produce 500 AFY on a continuous basis or 1,500 AFY on an intermittent basis without causing excessive declines in groundwater levels (Carollo, April 2003).

The County of San Mateo operated the East Palo Alto County Municipal Waterworks District (County District) water system until about 2000 at which time the facilities were transferred to the City of East Palo Alto. East Palo Alto has contracted with the California-American Water Company to operate the water system. East Palo Alto has one well located at Gloria Drive and Bay Road which is currently inactive that has been identified as a potential source of water supply. It is estimated that the well could produce approximately 300 AFY (Brown and Caldwell, April 1998). Previously, the County District had considered installation of additional wells to augment water supplies.

The City of Redwood City has also considered development of groundwater to augment groundwater supplies (Todd Engineers, March 2003). However, Redwood City is located near the northwestern extent of the subbasin where alluvial deposits are thinner and more fine-grained than deposits further to the south and thus the groundwater development in this area is less economically feasible and potential production would be less than in areas to the south.

Industrial Wells. Three industrial wells were identified in Redwood City. Their status is unknown.

Domestic and Irrigation Wells. DWR records indicate that a minimum of 171 private domestic and/or irrigation wells have been installed in the study area and surrounding communities since 1962. An assumption has been made that wells installed prior to 1962 are likely inactive and have been abandoned or destroyed. Of the 171 private wells, 23 are in Redwood City, 81 in Atherton, 10 in Menlo Park, 3 in East Palo Alto, and 54 in Palo Alto. DWR records are incomplete and the actual number of wells is probably higher. The USGS performed a more comprehensive survey of wells in the City of Atherton and identified at least 278 likely active wells as of 1993-1995 (Metzger and Fio, 1997). Metzger and Fio (1997) estimated that the total pumpage from these wells at approximately 710 AFY or about 19 percent of the City of Atherton's total water supply.

Estimating pumpage from domestic and irrigation wells in the remainder of the area is difficult. It is assumed that most usage is for landscape irrigation purposes. Using the average annual pumpage of 1.9 AFY per well estimated by Metzger and Fio for the Atherton area and multiplying that value by the identified domestic and irrigation wells installed since 1962 in the remaining cities (90 wells) yields approximately 170 AFY.

Table 2 shows estimated existing and potential future groundwater pumpage (in 2020) during a drought or emergency shortage condition. The total of current groundwater use is estimated at 1,100 AFY. An estimate of potential future municipal and private groundwater use during a drought or emergency Hetch Hetchy system-wide reduction of 20 percent was based on a number of assumptions.

Overall water demand in the area is projected to increase according to the Bay Area Water Users Association (BAWUA). The future groundwater use estimate provided in Table 3 is based on overall water demand estimates for the year 2020 (CSG, February 2003). It is noted that the East Palo Alto Urban Water Management Plan (UWMP) estimated a higher water demand for the City of East Palo Alto for the year 2020 than BAWUA (CSG, February 2003). The UWMP estimate is 3.6 to 4.3 million gallons per day (mgd) in 2020, while the BAWUA estimate is 2.9 mgd in 2020. For the future use estimate it was assumed that there is a 20 percent Hetch Hetchy system-wide reduction in supply due to drought or emergency. Under these conditions all of the cities and water purveyors in the study area will have a water shortage relative to their Hetch Hetchy supply. For the cities of Atherton (water provided by California Water Services Co.)

Table 2

Estimate of Annual Groundwater Pumping

San Francisquito Groundwater Subbasin

Groundwater Extraction	Estimated Existing Use (AFY)	Estimated Potential Future Use[1] (AFY)
Atherton Private and Institutional Wells	710	890
Private Wells Palo Alto, Menlo Park, East Palo Alto, and Redwood City	170	215
O'Connor Tract Cooperative Water Company	120	150
Palo Alto Mutual Park Water Company	100	125
City of Redwood City		640
City of Palo Alto		525
City of Menlo Park		350
City of East Palo Alto		780
City of Atherton (California-American Water Company)		370
Stanford University		630
Total	**1,100**	**4,675**

AFY acre feet per year

[1] Future usage in year 2020 assuming a 20 percent reduction in Hetch Hetchy allocation

Table 3

Estimated Water Shortage in 2020 Under Drought/Emergency Conditions

City	Estimated Shortage in 2020 under a 20% System-Wide Hetch Hetchy Reduction in Supply (AFY)
East Palo Alto	1,600
Menlo Park	700
Palo Alto	1,100
Redwood City	6,400
Atherton (California-American Water Company)	740
Stanford	1,300

Menlo Park, East Palo Alto, and Palo Alto, it was assumed that 50 percent of this shortfall will be supplied by groundwater. It is assumed that the remaining 50 percent of the shortfall would be made up by conservation, water restrictions, recycled water use, or other means. For Redwood City, where development of significant groundwater resources is less feasible, it is assumed that 10 percent of the shortfall is made up by groundwater extraction. For private water users and small water purveyors, it was assumed that groundwater use would increase 25 percent over current conditions. The estimated groundwater use in the San Francisquito Subbasin in 2020 under a 20 percent system-wide reduction in Hetch Hetchy supply is estimated at approximately 4,700 AFY.

6 Groundwater Quality

6.1 Native Groundwater Quality

Native groundwater quality within the San Francisquito fan varies areally and with depth. Shallow groundwater tends to be similar in composition to recharge water (surface water, precipitation, and imported water). Deeper groundwater varies in composition as a result of contact and residence time with formation sediments (Metzger, 2002).

Generally, groundwater in the study area is acceptable for both potable and irrigation uses. However, consumers would likely find untreated groundwater to be less desirable when compared with Hetch Hetchy water. Groundwater from wells operated by the O'Connor Tract Cooperative Water Company in Menlo Park and the Palo Alto Mutual Park Water Company in East Palo Alto meets all primary drinking water quality standards without additional treatment. However, many residences that are served by these private companies have in-home water softeners. Table A-1, presenting a summary of selected groundwater quality parameters, is included in Appendix A.

Groundwater in the San Francisquito Subbarea tends to be somewhat hard (i.e., high in calcium carbonate – $CaCO_3$) with elevated concentrations of chloride, iron, manganese, specific conductance, and total dissolved solids (TDS) that exceed secondary maximum contaminant levels (MCLs). Elevated concentrations of these constituents make groundwater undesirable for potable use for aesthetic rather than health reasons and thus secondary MCLs apply. Aesthetic concerns include problems with soap lathering, taste, odor, and plumbing/clothing staining. Primary MCLs are health-based water quality criteria. Two wells in the study area (Atherton) were found to exceed a primary

MCL (for nitrate plus nitrite). The detections are probably the result of a local septic system or overuse of fertilizers.

Water quality analyses available in the San Francisquito Subbasin area indicate hard (121 to 180 milligrams per liter (mg/L) of $CaCO_3$)) to very hard (>180 mg/L of $CaCO_3$) groundwater (Todd, 1980). In comparison Hetch Hetchy water was measured in 1997 at 21 mg/L (Metzger, 2002). Generally, hard water prevents soap from lathering and causes encrustation on surfaces when the water is heated.

TDS is a measure of the general dissolved mineral content of groundwater. The recommended secondary MCL for TDS in drinking water is less than 500 mg/L, but concentrations from 500 to 1,000 mg/L are acceptable, with a short-term limit of 1,500 mg/L. TDS levels in groundwater samples compiled in the San Francisquito Subbasin range from 130 to 1,170 mg/L. In comparison, Hetch Hetchy water had a TDS concentration of 48 mg/L in 1997 (Metzger, 2002). Elevated TDS may be the result of contact with and residence time in marine formations and can also be an indication of saline water intrusion. A study performed in the Atherton area found the highest TDS concentrations occur near the foothills where consolidated rocks are primarily of marine origin and near the Bay where the potential for saline intrusion exists.

Chloride concentrations in groundwater ranged from 4.5 to 460 mg/L. The secondary MCL for chloride is 250 mg/L. In comparison, the chloride level in Hetch Hetchy water measured in 1997 was 3.7 mg/L. Elevated chloride can be an indication of saline water. Saline water intrusion was documented in studies done in the area due to overpumping of the groundwater basin in the first half of the century (Iwamura, 1980). A recent USGS study concluded that modern Bay water intrusion is not the source of high chloride concentrations (greater than 100 mg/L) in water from wells sampled in East Palo Alto, Menlo Park, and Palo Alto in 1997. Rather the elevated chloride was the result of mineral dissolution of marine sediments in the subsurface (Metzger, 2002).

Iron concentrations ranged from not detected to 25 mg/L, although most samples were less than 1 mg/L. The secondary MCL for iron is 0.3 mg/L. In comparison, Hetch Hetchy water sampled in 1997 had an iron concentration of 0.02 mg/L.

Manganese concentrations in groundwater quality samples ranged from not detected to 0.6 mg/L. Groundwater samples frequently exceed the secondary MCL for manganese of 0.05 mg/L. In comparison, a Hetch Hetchy water sample contained 0.001 mg/L of manganese. Manganese is an undesirable impurity in water supplies because of its tendency to deposit black oxide stains.

Elevated concentrations of some constituents such as sodium and boron make groundwater unsuitable for irrigation uses. Elevated sodium concentrations in groundwater used for irrigation can cause deflocculation of clays and damage to soil structure (Hem, 1989). Elevated concentrations of sodium have been reported in some wells near San Francisquito Creek (Fio and Leighton, 1995). Boron concentrations in wells sampled in the San Francisquito Subbasin ranged from 0.11 to 0.78 mg/L. These levels of boron are acceptable for irrigation purposes even for sensitive plants such as fruit trees (Hem, 1989).

6.2 Environmental Contamination

Some contaminants detected in groundwater are the result of human activity rather than naturally-occurring conditions. Groundwater contamination related to human activity is commonly related to leaking underground storage tanks in commercial/industrial areas. Agricultural activities such as application of fertilizer and pesticides can also result in groundwater contamination as can discharges from densely sited septic systems or exfiltration from sanitary sewer systems. Some human-caused contaminants are carcinogenic and many are hazardous to human health at elevated concentrations. Thus primary MCLs are the water quality standards applied to these contaminants.

Elevated levels of nitrate are related to septic systems, leaking sewer lines, and fertilizer application and can make groundwater unsuitable for drinking water supplies due to health concerns. The primary MCL for nitrate is 45 mg/L and for nitrate plus nitrite is 10 mg/L. Two wells with levels of nitrate above the primary MCL were identified in the Atherton area (Fio and Leighton, 1995; Metzger and Fio, 1997). Nitrate concentrations in other wells in the San Francisquito Subbasin were below the MCL (Appendix Table A-1).

Because Menlo Park and East Palo Alto are intensively developed with residential neighborhoods and commercial and industrial sites, groundwater resources are vulnerable to releases of contaminants associated with these land uses. Environmental contamination sites are regulated by a number of different agencies under a number of different programs.

While a comprehensive inventory of contaminant release sites is beyond the scope of this report, a review of site lists available on regulatory websites indicates a number of release sites in Menlo Park and East Palo Alto as well as in surrounding communities. A total of 24 leaking underground storage tank (LUST) sites in Menlo Park and 8 sites in East Palo Alto have been identified (SWRCB, 2003; RWQCB, November 2003). Not all leaking underground tanks impact groundwater; although those that do may be impacting shallow groundwater. The regional aquitard will provide some protection from the downward migration of contaminants to the deeper aquifer system. However, wells such as old irrigation or domestic wells that have not been properly constructed or abandoned can provide a vertical conduit for migration between shallow and deep aquifers providing a continuing threat to water quality.

Of the 32 sites identified, only 9 of the sites have a “closed” status, meaning that the extent of contamination has been characterized or fully contained and/or remediated at these “closed” sites. Ten of the sites are identified as having methyl tertiary butyl ether (MtBE) in groundwater. MtBE is a gasoline additive known to be very mobile in groundwater.

The Regional Water Quality Control Board, San Francisco Bay Region (RWQCB) monitors some contaminant releases under its Spills, Leaks, Investigations, and Cleanup (SLIC) Program. A review of SLIC sites found 11 sites in Menlo Park and 9 sites in East Palo Alto. Of these sites, only two have a “closed” status.

Most of the contamination sites are located in areas of commercial and industrial development along the Highway 101, El Camino Real, and Willow Road corridors. A thorough review of regulatory files is recommended to characterize contamination sites as part of the process for siting a new well.

7 Water Balance

Estimating the quantity of groundwater that can be sustainably developed from the San Francisquito Subbasin requires evaluation of all the significant inflows and outflows of water from the basin. For a particular groundwater basin, a balance should exist between the quantity of water recharged to the basin, the quantity of water leaving the basin, and the change in storage.

The major components of groundwater recharge in the San Francisquito Subbasin are:

- Imported water infiltration including percolation from landscape irrigation and leaking pipelines
- Surface water inflow including infiltration from streams and lakes

- Precipitation infiltration
- Subsurface inflow

The major components of groundwater discharge in the San Francisquito Subbasin are:

- Groundwater pumping and consumptive use
- Subsurface outflow
- Stream outflow

When discharge exceeds recharge, groundwater levels fall and there is a decrease in groundwater storage. This occurred in the first half of the 1900s when groundwater elevations were drawn down below sea level. The physical impacts of excessive declines in groundwater storage were land subsidence and saline water intrusion. Therefore, good groundwater management policies attempt to balance discharge (especially pumping) with recharge over the long-term. When recharge exceeds discharge groundwater levels rise and there is an increase in storage. This occurred in the basin between the 1960s and the present.

The data are not available for the San Francisquito Subbasin to support a detailed evaluation of the water balance, including inflows, outflows, and change in storage. Data on groundwater extraction and groundwater levels are limited. However, a number of assumptions can be made to provide an estimate of groundwater recharge and discharge.

7.1 Basin Recharge

An estimate of annual groundwater recharge is presented in Table 4. For this estimate, sources of recharge include percolation from landscape irrigation, leakage of water and sewer lines, infiltration from San Francisquito Creek, percolation of rainfall on the alluvial fan, and subsurface groundwater inflow from the upland drainage basin. Due to the considerable uncertainties, low and high estimates are provided. The results indicate a low value of annual recharge to the San Francisquito Groundwater Subbasin of 4,072 AFY and a high value of 7,880 AFY.

To estimate percolation from irrigation, the estimated volume of water supplied to each of the major water users within the subbasin was multiplied by a low (30 percent) and high (50 percent) irrigation usage percentage (CSG, February 2003; Metzger and Fio, 1997). These two values were in turn multiplied by a low (10 percent) and high (15

Table 4
Estimate of Annual Groundwater Recharge San Francisquito Groundwater Subbasin

Irrigation Percolation		LOW	HIGH		Percolation to Groundwater	
Estimated	Annual Water Importation (AFY)	30% Used for Irrigation (AFY)	50% Used for Irrigation (AFY)		LOW Low x 10% (AFY)	HIGH High x 15% (AFY)
Redwood City	6,100	1,830	3,050		183	458
Atherton	3,700	1,110	1,850		111	278
Menlo Park	2,500	750	1,250		75	188
East Palo Alto	2,200	660	1,100		66	165
Palo Alto	9,500	2,850	4,750		285	713
Santford	3,400	1,020	1,700		102	255
				Irrigation Percolation Total	**822**	**2,055**
Water Pipeline Leakage					Leakage to Groundwater	
Estimated	Annual Water Importation (AFY)				LOW - 3% (AFY)	HIGH - 5% (AFY)
Redwood City	6,100				183	305
Atherton	3,700				111	185
Menlo Park	2,500				75	125
East Palo Alto	2,200				66	110
Palo Alto	9,500				285	475
Stanford	3,400				102	170
				Water Pipeline Leakage	**822**	**1,370**
Sewer Pipeline Leakage					Leakage to Groundwater	
Estimated	Annual Water Importation (AFY)				LOW - 0.5% (AFY)	HIGH - 2% (AFY)
Redwood City[1]	6,100				31	122
Atherton	3,700				19	74
Menlo Park	2,500				13	50
East Palo Alto	2,200				11	44
Palo Alto[1]	9,500				48	190
Stanford	3,400				17	68
				Sewer Leakage	**137**	**548**
Surface Water Infiltration					Recharge ot Groundwater (AFY)	(AFY)
San Francisquito Creek				Surface Water Infiltration	**950**	**950**
Precipitation Percolation	Basin Area (acres)	Annual Rainfall (feet)	Rainfall on Basin Area (AFY)		Rainfall Percolation to Groundwater LOW - 5% (AFY)	HIGH - 10% (AFY)
Alluvial Basin	14,080	1.25	17,600		**880**	**1,760**
Subsurface Inflow	Watershed Area (acres)	Annual Rainfall (feet)	Rainfall on Watershed Area (AFY)	Percolation to Upland 5% (AFY)	Subsurface Inflow to Alluvial Basin LOW - 25% (AFY)	HIGH - 50% (AFY)
Uplands	23,936	2	47,872	2,394	**598**	**1,197**
Total					**4,072**	**7,880**

AFY - acre-feet per year

[1] Hetch Hetchy supply allocation reduced by half since only approximately half of city within San Fancisquito Subbasin.

percent) percolation percentage. These estimations resulted in a range of irrigation return flow from 822 to 2,055 AFY.

A range of water supply pipeline leakage losses from 3 to 5 percent of total water supplies resulted in a range of recharge from 822 to 1,370 AFY. The range in estimated sewer line leakage losses to groundwater was estimated between 137 to 548 AFY.

The USGS has estimated average streamflow losses from San Francisquito Creek at 1,050 AFY. After accounting for evapotranspiration, recharge to groundwater from San Francisquito Creek is estimated to average approximately 950 AFY (Metzger, 2002).

Some portion of precipitation falling on the alluvial basin will percolate to groundwater. A range of 5 to 10 percent resulted in annual recharge between 880 and 1,760 AFY. Precipitation will also percolate into the subsurface in the drainage basin upland. The portion of this water that moves into the alluvial groundwater basin as subsurface flow was estimated to be between 25 and 50 percent of rainfall percolation, yielding a range of annual subsurface recharge from 598 to 1,197 AFY.

Based on these estimates, the low-range amount of annual recharge to the San Francisquito Groundwater Subbasin is 4,072 AFY and the high-range amount is 7,880 AFY.

In comparison, Sokol (1963) estimated annual groundwater recharge to the San Francisquito Creek Subbasin at about 3,000 AFY in 1962. That estimate included recharge from San Francisquito Creek, Lake Lagunita, infiltration of runoff from the foothills not drained by San Francisquito Creek, over irrigation, subsurface groundwater inflow, and precipitation. Seepage from San Francisquito Creek was estimated to be 650 AFY or 22 percent of the total recharge. Sokol's (1963) estimate was performed prior to the importation of significant quantities of Hetch Hetchy water. Thus it is expected that estimates for current conditions would be considerably higher.

An evaluation of potential groundwater use was recently conducted for a portion of the San Francisquito Subbarea (9,500 acres) in the vicinity of Palo Alto (Carollo, April 2003). Carollo estimated annual groundwater recharge to range between 38 and 3,800 AF.

Carollo (April 2003) also evaluated impacts of future groundwater pumping. Based on water level declines observed in Palo Alto city wells when the wells were pumped for five months during the 1988 drought, it was concluded that groundwater extraction of 500 AFY on a continuous basis or 1,500 AFY on a short-term basis would not result in subsidence, saline water intrusion, or migration of contamination plumes. During the 1988 drought the City of Palo Alto pumped approximately 1,505 AF of groundwater over a five month period. Groundwater level declines in pumping wells during this period ranged from 15 to 37 feet. Water levels recovered to pre-pumping water levels in 18 months.

7.2 Basin Discharge

An estimate of annual groundwater discharge is presented in Table 5. Basin discharge includes groundwater pumping and consumptive use, subsurface outflow, and outflow of stream flow.

Table 5
Estimate of Annual Groundwater Discharge
San Francisquito Groundwater Subbasin

Groundwater Pumping and Consumptive Use	Estimated Existing Use (AFY)			Consumption 95% (AFY)
Atherton Private and Institutional Wells	710			675
Private Wells Redwood City, Menlo Park, East Palo Alto, and Palo Alto	170			162
O'Connor Tract Cooperative Water Company	120			114
Palo Alto Mutual Park Water Company	100			95
			Total Consumption	**1,045**
Subsurface Outflow Q = L x T x i	Width (feet)	T (gpd/ft)	i (ft/ft)	Outflow (AFY)
Shallow Aquifer	29,800	38,000	0.0005	634
Deep Aquifer	29,800	38,000	0.005	6,342
			Total Subsurface Outflow	**6,977**
Total				**8,022**

AFY - acre-feet per year
Q - flow
W - width of the aquifer
i - hydraulic gradient
T - transmissivity in gallons per day per foot
ft/ft - foot per foot

Consumptive use is estimated as 95 percent of current groundwater extraction (Table 2) equal to approximately 1,045 AFY. Subsurface outflow will likely occur on northeastern edge of the basin. Subsurface outflow can be estimated using a modified Darcy's Law equation shown in Table 5 (Todd, 1980). Discharge from the shallow and deep aquifer systems where calculated separately given the different groundwater gradients in each. Total subsurface outflow is estimated as 6,977 AFY. Outflow from stream baseflow will include discharge by San Francisquito and other creeks to the Bay. These flows are considered minor since the San Francisquito Creek is a losing creek (i.e. the creek is losing water to the groundwater) over most of the basin. The total basin discharge is estimated to be 8,022 AFY.

The water balance calculations show basin discharge balances with the higher estimate of groundwater recharge under current conditions (Table 4). Development of additional groundwater resources will reduce groundwater levels and decrease the volume of water discharged to the Bay. Saline water intrusion can be prevented if a groundwater gradient toward the Bay is monitored and maintained.

8 Supplemental Wells

This section summarizes our evaluation of the feasibility of supplemental wells to augment the Cities' water supply.

8.1 Expected Yields

Supplemental wells could be installed by the Cities for irrigation and/or potable use to augment existing water supplies in case of emergency or drought. Yields from a properly designed and sited large diameter well installed in the Cities can be expected to range from approximately 300 to 1,800 gpm. Recommended pumping rate may be less if pumping water levels are significantly below sea level.

At this time, the groundwater resources in the area are not widely utilized with the exception of the Atherton area. As discussed above, a preliminary estimate of annual groundwater recharge in the San Francisquito Subbasin ranges from approximately 4,000 to 8,000 AFY. The Cities could install supplemental wells to capture some portion of this annual recharge without mining the groundwater resource.

The amount of recharge that can be safely recovered without inducing saline water intrusion from the Bay will be dependent on the volume extracted by all users in the basin. Therefore, any development of groundwater resources within the Cities should consider regional conditions. It is likely that during a water emergency or drought, demands will be put on the groundwater basin by entities other than the Cities. The City of Palo Alto has proposed using 500 AFY of groundwater continuously or 1,500 AFY on a short-term basis to augment its water supply. It is also likely that the installation and use of private wells would also increase during any reduction in imported water. These potential increases in groundwater use were estimated in Table 3. Development of a regional strategy among the local water purveyors is recommended to manage the common groundwater resource. Such a strategy might include the regular monitoring of groundwater levels and quality.

8.2 Expected Water Quality

Based on available water quality data, supplemental wells can be expected to have acceptable water quality for irrigation or potable uses. However, the water is hard with some wells exhibiting elevated concentrations of TDS, iron, manganese, and chloride that are objectionable for aesthetic reasons. Therefore, groundwater would likely require blending with Hetch Hetchy water and/or treatment prior to use for potable supplies in order to be acceptable to customers. Groundwater for irrigation supplies is not likely to require treatment or blending.

The Department of Health Services (DHS) requires that any new municipal drinking water supply well have a drinking water source assessment and protection (DWSAP) program inventory completed prior to issuing an operation permit. A DWSAP program is required to define the capture zone of the well and all of the potentially contaminating activities that exist within that capture zone. Ideally, the DWSAP would identify any contamination site that could potentially impact the water quality in the supply well. As discussed above, a number of contaminant releases have occurred in the Cities and some may have impacted groundwater supplies. It is recommended that contamination sites be assessed further as part of the process of siting a new well. In general, it is preferable to site wells away from commercial/industrial areas where most contaminant releases occur.

8.3 Well Locations

Siting of a new municipal supply wells should be based on evaluation of several criteria including land availability, location of existing water supply facilities, aquifer characteristics, known contamination sites and land use, and location of existing active supply wells.

Much of the aquifer under Menlo Park and East Palo Alto is suitable for municipal groundwater development. Areas near San Francisquito Creek offer some advantages over other areas. The San Francisquito Subbasin is thicker near San Francisquito Creek and alluvial materials near the creek are relatively more coarse-grained than further north of the creek. In addition, considerable recharge occurs from the creek. The creek loses water to groundwater throughout most of the alluvial basin with 58 percent of the creek recharge occurring between San Mateo Drive and Middlefield Road (Metzger, 2002). An additional consideration is proximity to the Bay since wells in close proximity to the Bay may be more prone to salt water intrusion.

As discussed in the previous section, production wells situated in commercial/industrial areas are more vulnerable to releases of contaminants.

8.4 Governance of Groundwater Pumping

The San Francisquito Groundwater Subbasin overlies portions of San Mateo and Santa Clara counties. In Santa Clara County, Santa Clara Valley Water District (SCVWD) is the primary water resources agency. Because SCVWD contributes to the management and maintenance of the groundwater basins under its purview, it requires certain well owners to pay for the well water that they use. Thus the City of Palo Alto will be required to pay SCVWD for the extraction of groundwater under future use scenarios. SCVWD also is the well permitting agency in Santa Clara County. Menlo Park and East Palo Alto are situated within San Mateo County. There is no water resources agency that actively manages the San Francisquito Groundwater Subbasin beneath the cities. Accordingly, there is no fee to extract groundwater beneath the Cities. However, the San Mateo County Environmental Health Division does require a permit and fee for the issuance of a well permit in San Mateo County.

Operation of new large capacity municipal or irrigation water supply wells may also require compliance with the California Environmental Quality Act (CEQA).

9 Conclusions

- The aquifers under Menlo Park and East Palo Alto are suitable for development of municipal groundwater supplies.
- Groundwater levels in the aquifer are currently near the ground surface and groundwater flow is toward the Bay.
- There is limited current development of groundwater resources in the area although other water purveyors have proposed additional development.

- The expected yield of a properly sited and designed production well in the area would likely be between 300 and 1,800 gpm. If pumping water levels are significantly below sea level, recommended yields may be less to limit saline intrusion problems.
- Annual groundwater recharge is estimated to range between approximately 4,000 and 8,000 AFY.
- Annual groundwater discharge is estimated to be approximately 8,000 AFY.
- Existing annual groundwater extraction is estimated to be approximately 1,000 AFY, with a projected increase to approximately 4,700 AF in the year 2020 under drought or emergency conditions.
- Groundwater quality is acceptable for potable and/or irrigation uses; however, to address aesthetic concerns, groundwater treatment and blending would likely be required for potable use.

10 Recommendations

- Development of groundwater resources should be performed with an awareness of regional conditions.
- Groundwater level monitoring is recommended to ensure that basin-wide gradients toward the Bay are maintained.
- Potential environmental contamination sites in the vicinity of any proposed well site should be thoroughly investigated and production wells should be designed to avoid contamination impacts to wells.

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Appendix A

Table A-1 Groundwater Quality Data

Table A-1
Summary of Selected Groundwater Quality Data

			Atherton	Redwood City	Menlo Park	East Palo Alto	Palo Alto	Hetch Hetchy
		Number of wells tested	21	11	18	6	21	1
		Dates of testing	1980-1993	1928-93	1988-02	1990-00	1931-97	1997
Selected Constituents	Units	MCL						
hardness ($CaCO_3$)	mg/L		145-670	120-300	104-640	87-560	36-370	21
specific conductance	umhos/cm	900*	838-1,640	860-1,040	785-1,740	660-1,550	560-1,700	77
total dissolved solids	mg/L	500	540-1,170	540-660	280-976	390-882	130-910	46
iron	mg/L	0.3		0.17-25	ND-0.16	ND-0.45	ND-2.9	0.018
manganese	mg/L	0.05		0.08-0.46	ND-0.5	ND-0.19	0.01-0.57	0.001
chloride	mg/L	250*	40-330	12-356	39-230	4.5-350	10-460	3.7
nitrate as NO_3	mg/L	45		ND-6	0.06-8	1.7	ND-7.3	
nitrate + nitrite as N	mg/L	10	0.06-12.0		ND-4.4	ND-3.3	ND-5.8	0.07
sodium	mg/L		47-200	140-180	36-130	88-210	39-160	5
boron	mg/L		0.11-0.78	0.29	0.15-0.66	0.18-0.35	0.17-0.39	0.03
sulfate	mg/L	250	43-270	2-250	42-140	29-100	18-71	5.7
Reference			1,10	2,3,4,10	5,7,9,10,11	5,6,7,8	5,7,9,10	7

MCL primary maximum contaminant level

* secondary MCL based on aesthetic considerations

ND not detected

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