City of Redwood City
Redwood City, California

Feasibility of Supplemental Groundwater Resources Development

Redwood City, California

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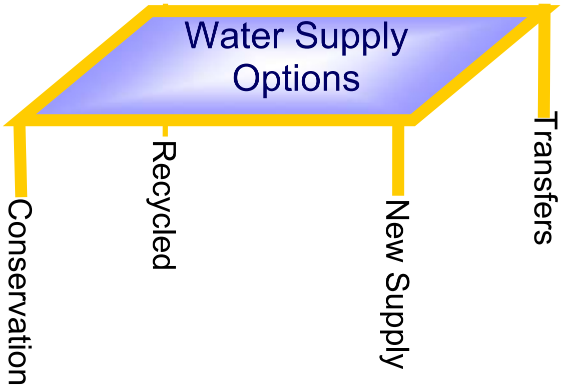
1 Introduction

The City of Redwood City (City) currently obtains 100 percent of its water supply from the City of San Francisco Water Department through its Hetch Hetchy Aqueduct water allocation. The City currently exceeds its supply assurance level by about 1,100 acre-feet per year (AFY). The capacity of this existing water supply to meet future demand is limited and drought conditions could reduce the City's allocation in the future. The City is considering four of the most viable options to reduce current demands on the Hetch Hetchy supply, to comply with the supply assurance level, and to provide supply for future growth. These four options are:

1. Negotiating water transfers from other agencies that use the Hetch Hetchy regional system
2. Negotiating a new source of potable water supply via the regional system ("wheeling")
3. Implementing water conservation measures
4. Implementing a water recycling program for landscape irrigation and industrial uses

Redwood City Water Supply Options



To further explore the use of recycled water, the City completed the *Water Recycling Feasibility Study for the Redwood Shores Area* (Kennedy/Jenks, January 22, 2002) and the *Water Recycling Study for Redwood City* (Kennedy/Jenks, August 7, 2002). The latter of the two feasibility studies recommended implementing a 1,955 AFY recycled water system in conjunction with water conservation programs to reduce existing demands on the San Francisco Hetch Hetchy regional water system to be within the City's contractual supply assurance and to provide a source of future water supply for potential new developments within the City. The City Council subsequently made a policy decision that "Redwood City will not make the use of recycled water mandatory to existing residences or homeowners' associations". This decision required that the recycled water project be modified to account for the loss of planned irrigation customers, and the refined project (Alternative E) was presented in a Technical Memorandum (Kennedy/Jenks, February 21, 2003).

Recent public discussions about the recommended recycled water project have resulted in the City wanting to re-explore and confirm information related to other possible “new water supply” options. One possibility for new supply could be local groundwater sources. Historically, groundwater has not been a source of supply for the City because of water quality, reliability, and long-term production capacity concerns. Local groundwater does exist, and this memorandum provides a preliminary feasibility level evaluation of the potential groundwater supply, groundwater quality and cost considerations associated with possibly developing groundwater resources in Redwood City that could be comparable to the proposed recycled water project under Alternative E.

The study area encompasses the area within the City limits (Figure 1). For this study, existing data were compiled and evaluated. Study results are summarized and conclusions are presented regarding the feasibility of developing local groundwater resources to supplement water supply.

2 Geology

Regionally, Redwood City is located in the Coast Range Physiographic Province. The region is characterized by northwest-trending faults, mountain ranges, and valley depressions. Movement along the San Andreas, Hayward, and Calaveras faults and down warping of the area in between the fault zones has formed the depression whose axis is along the San Francisco Bay (DWR, August 1967).

Redwood City is located in the South Bay Drainage Unit, which is characterized by a broad alluvial valley sloping toward the San Francisco Bay and flanked on the east and west by alluvial fans deposited at the foot of the Diablo Range in the East Bay and the Santa Cruz Mountains in the west (DWR, August 1967). Surface streams have flowed out from the elevated areas to the east and west of the San Francisco Bay area and deposited debris as alluvial fans and flood plains. These alluvial deposits comprise the major aquifers of the region.

The near surface geologic materials beneath the City can be divided into three areas. The area in the northeast part of the City near the San Francisco Bay (Bay) is underlain by unconsolidated Bay Muds and Artificial Fill (see Figure 2). Review of water well logs indicates that the thickness of the Bay Muds in the vicinity of Redwood City is from 15 to 100 feet. In the area southwest of Highway 101, the central area of the City is underlain by fine- to coarse-grained unconsolidated alluvial deposits. On the southwestern edge of the City near Highway 280, the City is underlain by bedrock units comprised predominantly of the Butano and Franciscan Formations (SEEHRL, December 1987).

The alluvial deposits form a wedge that thins near the bedrock hills and thickens toward the Bay. Review of water well logs indicates the thickness of the alluvial deposits in the vicinity of the City range from zero where bedrock crops out to approximately 500 feet near the Bay. Alluvial deposits underlie the Bay Muds and Artificial Fill. Bedrock units are the underlying basement complex beneath the alluvial deposits.

Alluvial deposits are of most interest to this study since they comprise the water-bearing deposits in the study area. Alluvial deposits tend to be more fine-grained near the Bay and more coarse-grained near the bedrock units and along stream channels. The percentage of coarse-grained sediments in the study area is relatively less than in surrounding areas to the south and north along the Peninsula. This is because local streams are small, drain relatively small watersheds, and thus have less capacity for transporting significant volumes of coarse-grained sediment (Fio and Leighton, 1995). Relatively coarse-grained deposits are found on the southeast edge of the City near Atherton associated with San Francisquito Creek (Fio and Leighton, 1995). San Francisquito Creek has a large watershed (40 square miles) and as a result alluvial deposits associated with the creek are permeable and the alluvial deposition area of the creek is large (DWR, August 1967).

3 Hydrogeology

Redwood City is located in the south San Mateo Bay Plain Groundwater Basin, which is part of the Santa Clara Valley Groundwater Basin (DWR, August 1967; SEEHRL, December 1987). Numerous aquifers make up the water-bearing units of the Santa Clara Valley Groundwater Basin. The aquifers are composed of unconsolidated permeable alluvial deposits separated by lower permeability units that act as aquitards or barriers to groundwater flow. The bedrock formations in the southwest of the study area are considered non-water-bearing, except for local small water supplies (SEEHRL, December 1987).

The Department of Water Resources (DWR, August 1967) has defined three hydrogeologic subareas in the Redwood City area, which are based on the sources of the alluvial deposits found in each. These subareas include the San Francisquito Subarea, the Belmont Subarea, and the Niles Subarea (Figure 1).

The City is underlain by the San Francisquito Subarea south of Brewster Avenue. The San Francisquito Subarea is the most important groundwater producing area on the Peninsula and for many years during the early half of the twentieth century supplied the municipal needs of Stanford University and the City of Palo Alto. The water-bearing sands and gravels of the San Francisquito Subarea are discontinuous and cannot be correlated into distinct aquifers across the area. The thickness of water-bearing sediments in the San Francisquito Subarea range from more than 1,000 feet south of Palo Alto thinning to approximately 500 at the northern end of the subarea beneath Redwood City (Fio and Leighton, 1995; DWR well logs). These alluvial deposits form a wedge; thin near the base of the Santa Cruz Mountains and thickening toward the Bay. Groundwater in the San Francisquito Subarea is recharged by infiltration along San Francisquito Creek, infiltration from Lake Lagunita, deep percolation and sub-surface inflow. Groundwater discharge is to wells and through the shallow aquifer to the Niles Subarea to the east.

The City is underlain by the Belmont Subarea from just south of Brewster Avenue. to the northern City border. Relative to the San Francisquito Subarea, the alluvial deposits become thinner and more fine-grained with distance north along the Peninsula. Groundwater recharge in the subarea is mainly by infiltration along small streams draining the adjacent uplands. Groundwater may discharge to the Niles subarea to the east (DWR, August 1967).

The City is underlain by the Niles Subarea near the Bay margin. The Niles Subarea includes the Niles Cone, which is the large alluvial fan formed by Alameda Creek in the East Bay that extends westward beneath the San Francisco Bay to the Redwood City bay front area (DWR, August 1967). With increasing distance westward from the City of Niles in the East Bay, the water-bearing units within this subarea thin and become more fine-grained. Recharge to the aquifers in this subarea occurs at its eastern edge in the

East Bay. Multiple laterally continuous aquifers have been defined in the Niles Subarea. The lateral continuity of Niles Subarea aquifers beneath the Bay was demonstrated through geologic profiling along the length of the Dumbarton Bridge and through pumping tests that showed drawdown in wells in the middle and on the east side of the Bay when a well on the west side of the Bay was pumped (DWR, August 1967).

Because of the discontinuous nature of the water-bearing units in the San Francisquito and Belmont Subareas, groundwater levels vary from well to well and groundwater may be confined, semi-confined, or unconfined depending on the location of the well and depth of the screened interval. Depths to groundwater in the Niles Subarea vary from about 5 to 50 feet below the ground surface and occur under confined conditions. A review of driller's logs in the study area indicates depths to groundwater from 3 to 155 feet below ground surface (bgs) with an average of 34 feet bgs. It should be noted that the well logs represent wells drilled at various times from the 1920s to 2001, in different subareas, and at different depths. Generally groundwater flow in the study area is from the southwest uplands area to the northeast toward the Bay.

Probable well yields in the study area have been estimated as varying from 1 to 100 gallons per minute (gpm) within the alluvial deposits (Webster, 1972). Generally, this range of well yields is thought to be adequate for single family domestic use, but inadequate to marginal for light industrial use (Webster, 1972). Most of the wells drilled in the study area are small diameter (less than 8 inches) domestic and irrigation wells, with a few larger diameter (10 to 30 inch) industrial wells. It should be noted that the limited number of wells in the study area and the lack of long-term formal pumping test data limit the ability to reliably predict well yields. The pumping rates listed on drillers' well logs compiled for the study area indicated minimum, maximum, mean, and median well yields of 0 gpm, 450 gpm, 70 gpm, and 28 gpm, respectively.

Storage capacity is an estimate of the maximum volume of groundwater stored in the aquifer. Storage capacity can be estimated based on the specific yield of the sediments in the aquifer and the thickness and areal extent of saturated permeable sediments. Simply, specific yield is a measure of the volume of water that an aquifer releases by gravity. Thus, a gravel aquifer has a higher specific yield than a clay formation. Groundwater storage in the area east of the bedrock uplands, south of Ralston Avenue, north of Atherton Avenue and west of the Bay front is estimated at approximately 800,000 acre-feet (AF). This estimate assumes an area of 27 square miles, an average alluvial thickness of 275 feet, an average depth to groundwater of 30 feet, and an average specific yield of 20 percent.

It should be noted that the total volume of subsurface storage is not available for pumping because of the potential for of subsidence and salt water intrusion. Historically, land subsidence and compaction of the aquitards occurred in areas south of the study area when groundwater levels were drawn down approximately 50 feet below sea level (Fio and Leighton, 1995). Additionally, pumping to levels below sea level has the potential to reverse the natural groundwater flow direction and induce salt water intrusion from the Bay and shallow water-bearing units with poor quality water. Thus the usable volume of groundwater is much less than 800,000 AF.

A more relevant indicator of the recoverable groundwater resource is the amount of groundwater that is recharged to the water-bearing units beneath the City on an annual basis. The data are not available to support a detailed evaluation of the water balance, including inflows, outflows, and change in storage. However, a number of assumptions can be made to calculate a reasonable range of values for groundwater recharge (see

Table 1). For this estimate, it was assumed that percolation of rainfall and return flows from landscape irrigation are the major sources of recharge. Other sources of inflow (stream percolation, subsurface groundwater inflow, and leaking water and sewer lines) were assumed to be small. Based on the assumptions in Table 1, the annual groundwater recharge in the vicinity of Redwood City is estimated between a low of 1,700 AFY and a high of 2,800 AFY.

Table 1

Estimate of Annual Groundwater Recharge Redwood City Area

Precipitation				
Watershed Area[1]	Annual Rainfall	Rainfall on Watershed Area	Rainfall Percolation to Groundwater	
			5% - low	10% - high
(acres)	(feet)	(AFY)	(AFY)	(AFY)
12,000	1.5	18,000	**900**	**1,800**
Imported Water				
Annual Importation	40% Used for Irrigation low	50% Used for Irrigation high	Irrigation Percolation to Groundwater	
			15%	15%
(AFY)	(AFY)	(AFY)	(AFY)	(AFY)
13,000	5,200	6,500	**780**	**975**
		Total	**1,680**	**2,775**

[1] The watershed was measured as the area between the drainage divide on the southwest, Stockbridge Ave. on the south, San Carlos Ave. on the north, and Highway 101 on the west.

AFY - acre-feet per year

4 Wells and Production

In the first half of the 20th century, water supplies in the Redwood City and surrounding Bay area were provided primarily by groundwater. In the second half of the century, substantial quantities of surface water were imported to supply the rapidly growing urban population of the area. A large number of wells used for residential irrigation still exist in the Atherton City area (Fio and Leighton, 1995; SEEHRL, December 1987).

Groundwater production wells have been installed by some nearby water purveyors such as the California Water Service Company and the City of Palo Alto. The City of Palo Alto wells are not currently pumping and are used as an emergency backup in case of drought or imported supply interruption. The California Water Service Company wells were used in the past but have all been abandoned.

Water well drillers reports for the Redwood City area and the areas immediately surrounding the City were collected from the Department of Water Resources (DWR) and inventoried to provide an indication of the characteristics of the aquifer beneath the Redwood City area. Just over 100 supply well logs (irrigation, domestic, and industrial) were available. Monitoring, test and cathodic protection well logs were also collected. Many of the wells were older and likely have been abandoned or destroyed.

Sixty-one wells have been constructed in the area since 1970 and it is assumed that these wells are still active. Almost all of the wells are relatively small diameter wells used for domestic supply or irrigation. Thirty-eight of the wells are located in the City of Atherton.

Transmissivity is an indication of the productivity of the aquifer. Transmissivity can be estimated by performing a constant rate, long-term pumping test. A number of irrigation wells have been drilled recently in the Pacific Shores Center area (Geoconsultants, Inc., May 17, 1991; Bohley/Maley Associates, December 16, 1993; Maggiora Bros. Drilling, Inc., October 16, 2001). These wells have larger diameter casings and more extensive pumping tests and water quality testing than most other wells in the study area. Four long-term pumping tests were conducted for Pacific Shores. During these tests the wells were pumped at rates between 40 and 250 gpm yielding a range of transmissivities from approximately 100 to 6,000 gallons per day per foot (gpd/ft) (Bohley/Maley Associates, December 16, 1993). Currently, three irrigation wells are operated in the Pacific Shores area and produce about 55 AFY (Bohley, March 5, 2003).

While a constant rate, long-term pumping test is the best method of determining transmissivity, it can also be calculated empirically based on the initial pumping rate of the well and the observed drawdown. These initial measurements are often recorded on driller’s well logs. Review of the driller’s well logs collected in the Redwood City area from the DWR indicates a range in the empirically calculated transmissivity from 22 to 60,000 gpd/ft with an average of 6,332 gpd/ft. If an aquifer has a transmissivity of less than 1,000 gpd/ft, it can supply only enough water for domestic wells or other low-yield uses. When transmissivity is 10,000 gpd/ft or more, well yields can be adequate for industrial and municipal purposes (Driscoll, 1986).

Empirical transmissivity results indicate that development of a municipal supply may be possible; however, the initial pumping rates and drawdowns recorded on driller’s logs are not highly reliable and tend to overestimate well yields. Limited actual long-term pumping test data indicate transmissivities that are marginal for municipal supply.

5 Groundwater Quality

Limited data are available on natural groundwater quality beneath the City. It appears that water quality varies by the strata from which the samples were obtained (SEEHRL, December 1987). General mineral and physical testing was available for nine wells in the study area. The water quality results for these wells are presented in Attachment A.

Elevated levels of nitrate can make groundwater unsuitable for drinking water supplies due to health concerns. Thus a primary maximum contaminant level (MCL) has been established for nitrate (45 mg/L). Sources of nitrate include septic systems, leaking sewer lines, and fertilizer application. Two wells with levels of nitrate above the primary MCL were identified north of San Francisquito Creek and just south of the study area (Leighton and Fio, 1995). Nitrate concentrations in two well samples within the study area were below the MCL (Attachment A).

Elevated levels of other parameters such as total dissolved solids (TDS), hardness, iron, manganese, and chloride make groundwater undesirable for potable use for aesthetic rather than health reasons. Aesthetic concerns include problems with soap lathering, taste, odor, and plumbing/clothing staining. Accordingly, these parameters are evaluated with reference to secondary MCLs or other criteria.

TDS is a measure of the general dissolved mineral content of groundwater. The recommended secondary MCL for TDS in drinking water is 500 milligrams per liter (mg/L). Elevated TDS and chloride can be an indication of salt water intrusion. Because of the proximity of the San Francisco Bay to Redwood City, there is potential for salt water intrusion into the groundwater beneath the City. Shallow water-bearing zones near San Francisco Bay have levels of TDS above 500 mg/l. In addition, elevated TDS and chloride has been identified in an area north of San Francisquito Creek and south of the study area. TDS was above 500 mg/l in three of three wells sampled in the study area. Specific conductance, which is related to TDS, was above 900 micromhos per centimeter in five of eight wells sampled in the study area. Chloride was above 250 mg/l in two of eight samples collected in the study area (Attachment A).

Water quality analyses available in the study area indicate hard (121 to 180 mg/l) to very hard (>180 mg/l) water in six of seven samples analyzed (Attachment A). Generally, hard water prevents soap from lathering and causes encrustation on surfaces when the water is heated.

Iron exceeded the secondary MCL of 0.3 mg/l in three of five samples collected in the study area and manganese exceeded the secondary MCL of 0.05 mg/l in six of six samples (Attachment A).

Water quality analyses performed for irrigation wells in the Pacific Shores area showed water that meets Title 22 requirements for potable supplies. However, iron, manganese, chloride, TDS, turbidity, and color exceeded secondary MCLs in individual wells.

Elevated levels of some constituents including sodium and boron make groundwater unsuitable for irrigation uses. Elevated sodium levels in groundwater used for irrigation can cause deflocculation of clays and damage to soil structure (Hem, 1989). Elevated levels of sodium have been reported in some wells near San Francisquito Creek (Fio and Leighton, 1995). Limited analyses available in the study area indicate acceptable boron levels for irrigation use.

Because Redwood City is intensively developed with residential neighborhoods and commercial and industrial sites, groundwater resources are vulnerable to releases of contaminants associated with these land uses. A large number of possible contaminating activities exist in the city and range from leaking underground storage tanks to overuse of fertilizers and pesticides in residential areas. A total of 183 leaking underground storage tank sites have been identified in the City (SWRCB, 2003). Not all leaking underground tanks impact groundwater. However, 65 of the 183 sites have an “open” status, meaning that the extent of contamination has not been characterized or fully contained and/or remediated. Most of the contamination sites are located in areas of commercial and industrial development along the Highway 101 and El Camino Real corridors. A review of monitoring well logs compiled for the study area showed 30 sites where monitoring wells had been installed indicating the potential for groundwater contamination at these sites. All of the monitoring well logs available from the DWR in the study area are less than 30 feet deep. This indicates that contamination may be limited to shallower water-bearing zones with deeper zones protected by intervening aquitards. However, the extent of anthropogenic contamination in deeper water-bearing zones has not been characterized as part this study. A thorough review of regulatory files would be necessary to characterize contamination sites as part of the process for siting a new well.

6 Supplemental Wells

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

6.1 Expected Yields

Supplemental wells could be installed by the City for local irrigation and/or to augment existing water supplies in case of emergency or drought. However, yields from wells in the vicinity of Redwood City can be expected to be low ranging from 10 to less than 500 gpm. This range of well yield has historically been considered inadequate to marginal for irrigation and municipal use. However, as water resources in California have become more stressed with ever increasing demand, what constitutes an acceptable yield has declined. Based on the existing data, a properly sited and designed, large diameter water well could potentially yield 200 gallons per minute (gpm) on a sustained basis. One well producing 200 gpm on a continuous basis, allowing for 30 days of down time and annual maintenance, would produce approximately 300 AFY.

At this time, the groundwater resources in the Redwood City area are not widely utilized with the exception of the Atherton area; therefore, existing groundwater extraction is minimal. Thus, although the annual groundwater recharge is not great, there is not currently a large demand on the resource. As discussed in Section 3 above, a preliminary estimate of annual groundwater recharge in the Redwood City area ranges from 1,700 to 2,800 AFY. The City could install supplemental wells to capture some portion of this annual recharge without mining the groundwater resource. It is estimated that a supplemental drilling program with wells distributed across the City might produce between 500 and 1,000 AFY.

6.2 Expected Water Quality

Based on the limited water quality data available, supplemental wells can be expected to have acceptable water quality for irrigation or potable uses. However, the water is hard with some wells exhibiting levels of TDS, iron, manganese, and chloride that are objectionable for aesthetic reasons. Therefore, groundwater would likely require blending and treatment prior to use for potable supplies.

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 completed prior to issuing an operation permit. A DWSAP program will define the capture zone of the well as well as 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 in Section 5 above, a number of contaminant releases have occurred in the City and many have impacted shallow groundwater supplies. These contamination sites would need to 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.

6.3 Locations

Based on the available data, it appears that supply wells located on the south side of the City in the San Francisquito Subarea and wells located near the Bay in the Niles Subarea are more likely to produce groundwater yields in the hundreds of gallons per minute range. In addition, groundwater wells located near stream channels are more likely to penetrate more coarse-grained alluvial deposits than wells located at the midpoints between stream channels and nearer to the Bay.

Water supply wells located near San Francisco Bay will be more susceptible to salt water intrusion from the Bay. Accordingly, operation of wells near the Bay would require regular monitoring to ensure that poor quality water from the Bay is not being pulled landward. As a general rule water supply wells located away from commercial and industrial areas are less susceptible to water quality degradation from the accidental release of contaminants due to leaks and spills in the near surface.

6.4 Costs

Due to the limited amount of data that exist in the study area, it would be prudent to conduct an exploration drilling program prior to drilling a production well. An exploration program would include drilling of one or more borings to the bedrock interface (~500 feet), geophysical logging in the open borehole to characterize the permeable units and other aquifer parameters, converting the boring to a test well, constructing the test well with an 8-inch diameter casing, developing the test well, collecting and analyzing groundwater quality samples, conducting a pumping test to determine aquifer transmissivity, and preparing a report. The cost of an exploration program, including engineering costs would be approximately $100,000 per test well.

Based on positive results of the exploration program, a production well could be designed and installed. The cost to design and install a 12-inch diameter, 500-foot deep production well is approximately $225,000 per well.

Significant additional costs may be associated with permitting, land acquisition, treatment, power, pumps, and piping. Assuming that each well would require purchase of a 50-foot by 100-foot lot, a soundproof building enclosure matching adjacent development appearance, power service, pumping equipment, motor, motor control center, standby power generator, disinfection treatment system, mechanical piping and controls, planning, engineering, CEQA and administrative costs, an individual well for potable water could cost from $1M to $2M to construct, without additional treatment for iron and manganese. A well for onsite irrigation would be less expensive but would still provide an in-lieu water supply.

7 Conclusions

Our hydrogeologic review indicates that while the aquifers under the Redwood City area are considered marginal as sources of municipal supplies, these water-bearing zones are adequate to provide small amounts of supplemental water. There is available groundwater storage and recharge to provide a supplemental source of water. Currently, use of groundwater in the area is minimal so there is little competition for the resource. Existing data indicate that the expected yield from a properly sited and designed production well in the area would likely be less than 500 gpm and probably would be on the order of 200 gpm. The estimated annual recharge to groundwater in the Redwood City area is between 1,700 and 2,800 AFY. With a network of properly sited and designed well, the City might feasibly recover between 500 and 1,000 AFY of supplemental water.

Groundwater quality is acceptable for potable and/or irrigation uses; however, to address aesthetic concerns, groundwater treatment and blending would be required for potable use. The existence of contamination sites would need to be evaluated and considered in the well siting process.

Groundwater resources could be developed for local irrigation applications, replacing imported water and/or for standby emergency potable use in case of drought or imported water interruption. Groundwater use for irrigation of local parks and open spaces would require less infrastructure since treatment and connection to the municipal supply would not be required. Development of supplemental groundwater for standby and emergency potable uses would involve considerable greater costs for CEQA approval, hook-up to the distribution system, groundwater treatment and transmission.

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