Coastside County Water District
Half Moon Bay, California

Lower Pilarcitos Creek Groundwater Basin Study

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Executive Summary

This report summarizes a study of the technical and economic feasibility of a proposed Lower Pilarcitos Creek groundwater project for Coastside County Water District (CCWD) in Half Moon Bay, California. The purpose of this study is threefold:

- To evaluate the safe or perennial yield of the Lower Pilarcitos Creek groundwater basin,
- To assess the potential for production from a proposed CCWD wellfield in the basin, and
- To prepare a cost estimate to construct the infrastructure for groundwater production.

In addition, this study responds to seven questions posed in the July 2002 request for proposal for the Lower Pilarcitos Creek Groundwater Basin Project, which are listed and addressed at the end of this executive summary.

This report describes the hydrogeologic framework of the groundwater basin. In brief, marine terrace deposits form the main aquifer in the Lower Pilarcitos Creek groundwater basin. The predominantly-confined aquifer is about 30 feet thick in the vicinity of the proposed wellfield and is underlain by Purisima Formation. Relatively fine-grained alluvial deposits overlie the aquifer.

Groundwater flows from east to west, discharging into the Pacific Ocean. Along the shoreline, an interface exists between fresh groundwater and saltwater. The position of the fresh-salt water interface is dynamic and migrates depending upon the aquifer discharge. Reducing this discharge will move the interface inland.

The total groundwater storage of the marine terrace aquifer averages 10,600 acre-feet (AF). Assuming that only one-third of the stored water can be used, then the usable storage is 3,533 AF. However, groundwater levels fluctuate on a seasonal basis by 10 to 20 feet, which is significant relative to an aquifer thickness of only about 30 feet near the proposed wellfield.

The water balance equation for the groundwater basin addresses inflow, outflow, and change in storage. Change in storage is considered zero. While a small net error exists, the average annual inflows and outflows balance at about 2,200 acre-feet per year (AFY).

Rainfall recharge and subsurface inflow from the upper Pilarcitos Creek valley are significant. The water balance equation indicates that stream recharge is an important inflow; however data are lacking. Of the outflows, subsurface outflow to the ocean is predominant, accounting for 77 percent of outflows, while groundwater pumping, export, and consumption account for the remainder. Although many wells have been drilled in the groundwater basin, many also have been abandoned. The major existing groundwater use involves pumping and export of groundwater for golf course irrigation to the south of the basin.

The perennial yield (safe yield) for the Lower Pilarcitos Creek groundwater basin is defined by the amount of groundwater that can be pumped while minimizing saltwater intrusion from the ocean. A total pumping of 1,300 AFY can be sustained on a long-term perennial yield basis without inducing significant adverse impacts (i.e., saltwater intrusion into the basin). This perennial yield value amounts to 60 percent of the estimated 2,200 AFY of total inflow to the groundwater basin, reflecting the unlikelihood that all of the inflow to the groundwater basin can be safely captured without incurring adverse impacts.

Groundwater quality is a concern in the Lower Pilarcitos Creek groundwater basin, especially for iron and manganese. Excessive iron and manganese likely reflects a combination of pumping from the Purisima Formation, mixing with Marine Terrace aquifer water, and inadequate well development. These problems can be minimized with thorough well development and design of production wells with screens placed solely in the marine terrace aquifer. Based on available information, water from a proposed Pilarcitos Creek wellfield would be treated for iron and manganese and blended with Crystal Springs water at an approximate ratio of 3:1 to provide acceptable water for floriculture irrigation.

For evaluation of economic feasibility, plans for wellhead, conveyance, and treatment facilities are provided for the proposed wellfield. The yield of the five wells is variable throughout the year (reflecting changing groundwater levels), with higher yields during the winter-spring season (November-March) and low yields during the summer-autumn dry season. Key criteria for operating the wellfield are to manage pumping rates to avoid dewatering of the aquifer and exposure of well screens. Application of these criteria to a monthly evaluation of well yields results in estimated total annual yields ranging from 129 to 259 million gallons per year (MGY) for drought and normal years. To provide a conservative estimate of water costs, an annual yield of 194 MGY (595 AFY) is assumed. Cost projections of economic feasibility are based upon that quantity of water.

Construction, operations, and maintenance costs are estimated and compared to the current cost of Crystal Springs supply. Comparatively, the Lower Pilarcitos Creek groundwater cost is about the same as current surface water purchase and treatment costs. The expected life of the wells would be 25 to 30 years.

Should CCWD decide to proceed with evaluation of the proposed Lower Pilarcitos Creek wellfield, the recommended next step is installation of a pilot production well; specific recommendations for well design, construction, developing, testing, and reporting are included. In addition, stream flow monitoring is recommended, including stream flow surveys on the lower reaches of Pilarcitos Creek to document changes in streamflow along the channel and assess potential groundwater recharge from the creek.

The July 2002 request for proposal posed the following seven questions, which are summarized below with brief responses.

1. *What is the estimated total annual safe yield of the basin during both normal precipitation periods and drought periods?*

The estimated total annual perennial yield (safe yield) of the Lower Pilarcitos Groundwater Basin is 1,300 AFY. This estimate is based on analysis of the amount of groundwater that can be captured without inducing seawater intrusion. It is about 60 percent of annual recharge to the basin. During severe drought, the recharge to the basin is effectively halved, resulting in groundwater level declines and reduced well yields. For more information, see *Groundwater Basin Water Balance, Perennial Yield.*

2. *How do the safe yield estimates developed in Item No. 1 compare to estimates contained in other studies of the basin? What are the reasons for the differences, if any, in the estimates?*

The estimate of perennial or safe yield in this report is similar to, but lower than previous estimates. Geoconsultants (1987 and 1991) estimated safe yield at 1,813 and 1,507 AFY in 1987 and 1991, respectively. These estimates are based on use of two-thirds of groundwater recharge and one-third of groundwater storage capacity as guidelines for safe yield. For more information, see *Groundwater Basin Water Balance, Previous Work.*

3. *What is the estimated annual amount of groundwater currently being withdrawn from the basin? How does this estimate compare with other available estimates*

for recent years and for prior years? What are the reasons for the difference, if any, in the estimates? What changes in total annual withdrawals have occurred in the last ten years? What changes in total annual withdrawals by current well owners (other than the District) are anticipated in the next 10 years?

The most important groundwater pumping in the basin is the Ocean Colony Partners Balboa wellfield, which provides irrigation water for two golf courses south of the basin. This groundwater pumping and export is 347 AFY. Groundwater pumping and consumption within the basin is estimated at 163 AFY. The latter value accounts for return flows to the basin. No previous estimates of total pumping are known. Groundwater pumping amounts have changed little over the past years. While pumping for landscaping has increased since the mid-1980s, pumping for crops in the groundwater basin has declined. There are no known plans to increase golf course pumping. For more information, see *Hydrogeologic Setting, Groundwater Development and Wells,* and *Groundwater Basin Water Balance.*

4. What is the estimated total annual amount of groundwater currently potentially available from the entire groundwater basin on a safe yield basis to the District during normal precipitation periods and during drought periods? Can these same total amounts of groundwater be safely withdrawn during a portion of the year, rather than evenly throughout a 12-month period? Can the average annual rate of withdrawal be safely increased by a factor of 50% or 100% for a short period of time?

The estimated total annual perennial yield (safe yield) of the Lower Pilarcitos Groundwater Basin of 1,300 AFY takes into account long-term existing pumping including agriculture and pumping from the Balboa wellfield for one golf course. Relatively recent increases in pumping from the Balboa wellfield for a second golf course (140 AFY) should be included in the 1,300 AFY. The remainder, 1,160 AFY, is sufficient for the potential Lower Pilarcitos wellfield and additional development by CCWD. Maximization of overall yield from the wellfield would involve seasonal operation with greatest withdrawal during the winter and spring. Summer and autumn pumping will be limited by lower groundwater levels and recommended operating criteria that avoid dewatering of the aquifer and exposure of well screens. For more information, see *Groundwater Basin Water Balance, Perennial Yield,* and *Lower Pilarcitos Creek Test Well Analysis, Wellfield Operation and Life Expectancy.*

5. What is the total estimated annual amount of groundwater currently potentially available on a safe yield basis from the District's five existing test on a safe yield basis during both normal precipitation periods and drought periods? Can these same annual total amounts be safely withdrawn during a portion of the year? Can the average annual rate of withdrawal be safely increased by a factor of 50% or 100% for a short period of time such as five days to meet customer demands during a hot weather period?

The estimated total yield of the five wells of the proposed Lower Pilarcitos wellfield ranges between 129 and 259 MGY for drought and normal years. For costing purposes, an average value of 194 MGY (595 AFY) is assumed. This total yield assumes seasonal variation in pumping, with greater pumping during the winter and spring. Pumping rates are limited by groundwater levels relative to the elevations of the top of the aquifer and top of well screens. Pumping at higher rates, lowering the water levels below the top of the aquifer, and exposing the well screen are not recommended as that will result in decreased yields and reduced life of the well and well pump. Interference would occur among wells in the wellfield area, varying according to pumping rate and season. Wellfield pumping would not affect Pilarcitos Creek, which is situated above the water table. For more information, see *Lower Pilarcitos Creek Test Well Analysis, Wellfield Operation and Life Expectancy.*

6. *For each of the District's proposed wells at the maximum safe pumping rate, what is the estimated water level drawdown and what is the diameter of the cone of depression?*

The available water level drawdown estimates (documented for each test well in Table 6) range from 16.54 to 24.17 feet and average about 20 feet. The shape of the cone of depression depends on the transmissivity and storativity of the aquifer, the length of pumping, and the discharge of the wells. For an average well in winter, computations indicate well interference of five feet at a distance of 1,000 feet after 100 days of continuous pumping.

7. For the District's test wells, what water well development is recommended prior to the installation of production well pumps, or will a new well need to be drilled? What are the recommended operation and maintenance procedures for maintaining the optimum production rate? What decline in production from the initial production rate should be anticipated over a period of years of operation? What is the estimated life of these wells? What is the closest recommended distance for a replacement well on the same parcel?

New wells need to be designed and installed for production purposes. The section, *Lower Pilarcitos Creek Test Well Analysis, Wellfield Operation and Life Expectancy,* outlines a pilot and production well construction program. The key recommendations for operation and maintenance in the wellfield are to avoid lowering the water levels below the top of the aquifer and exposing the well screen. Declines in production typically are small over most of the life of a properly maintained well, and with appropriate operation and maintenance, the expected life of the wells is 25 to 30 years. A replacement well should be within 10 feet of the initial well. For more information, see *Lower Pilarcitos Creek Test Well Analysis, Wellfield Operation and Life Expectancy.*

Introduction

This report summarizes a study of the technical and economic feasibility of a proposed Lower Pilarcitos Creek groundwater project in Half Moon Bay, California. This study is based on available data and focuses on three telescoping study areas: the Pilarcitos Creek watershed, Lower Pilarcitos Creek groundwater basin, and proposed Lower Pilarcitos wellfield.

Background and Purpose

Coastside County Water District (CCWD) is responsible for provision of water supply to customers within its service area, including the City of Half Moon Bay and several unincorporated coastal communities. Currently, CCWD provides water from several sources, including the Pilarcitos Creek wellfield in Pilarcitos Canyon, City of San Francisco sources (Pilarcitos Lake and Crystal Springs Reservoir), and the Denniston project (surface water diversions and wells north of the City). Moderate demand for additional water service connections exists in the service area, and in light of expected increased costs for water from City of San Francisco system, CCWD is considering supplemental water supply sources, including the Lower Pilarcitos Creek groundwater basin.

The purpose of this study is threefold:

- To evaluate the safe or perennial yield of the Lower Pilarcitos Creek groundwater basin,
- To assess the potential for production from the five existing test wells in the basin, and
- To prepare a cost estimate to construct the infrastructure for groundwater production.

In addition, if the project is deemed feasible, this study is intended to provide the basis for subsequent environmental review and application for a coastal development permit.

Scope and Study Area

CCWD has explored the feasibility of a Lower Pilarcitos Creek groundwater project through previous efforts, including evaluation of existing wells for possible CCWD acquisition during the 1991 drought relief program and an exploratory drilling program in

1997 (Nelson, 1997 and 1998). This report builds on and integrates previous work done for the CCWD and City of Half Moon Bay, and other existing information.

Figure 1 defines three, telescoping study areas: the entire Pilarcitos Creek watershed, the Lower Pilarcitos Creek groundwater basin, and the vicinity of the planned wellfield. The Pilarcitos Creek watershed study area, encompassing 20,761 acres (or 32.44 square miles [mi^2]) above Half Moon Bay, allows accounting of all water that enters the Lower Pilarcitos Creek groundwater basin. The groundwater basin, encompassing 1,765 acres (or 2.76 mi^2) is the study area for a focused water balance in which water inflows, outflows, and groundwater storage change are defined. The vicinity of the proposed wellfield allows detailed consideration of wellfield operation and potential impacts.

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Hydrogeologic Setting

The hydrogeologic setting provides the context for understanding the three study areas of the watershed, groundwater basin, and proposed wellfield. The setting includes climate, historic land use and land use planning, groundwater development and wells, soils, streamflow, geology, and hydrogeology. Three hydrogeologic cross sections are presented, two roughly parallel to the shoreline and one parallel to Pilarcitos Creek. These cross sections show the lower groundwater basin aquifer and its relationship to underlying and overlying geologic units, groundwater levels, and selected wells.

Location

The Pilarcitos Creek watershed is located on the San Mateo County coast, encompassing 22,524 acres (35.19 mi^2) and draining westward into Half Moon Bay. Elevations range from sea level to over 2,000 feet along Skyline Boulevard near Kings Mountain and near 2,000 feet at the crest of Montara Mountain. The Lower Pilarcitos Creek groundwater basin is situated along the coastal plain of Half Moon Bay, extending from the vicinity of Frenchmans Creek on the north to just south of the City of Half Moon Bay (see Figure 1).

Climate

Half Moon Bay is characterized by a coastal fog-belt Mediterranean climate with cool, rainy winters and mild, foggy summers. Prevailing onshore winds often result in winter low clouds and mist and in summer fog, including noticeable fog drip from trees. As a result, temperatures are generally moderate year-round and evapotranspiration is relatively low. The climate is ideal for cool-weather truck crops (e.g., brussel sprouts), Christmas tree farms, and floriculture.

Rainfall. Figure 2 shows annual rainfall at the Half Moon Bay airport over the period of record, extending from 1939 through 2002 (see Appendix 1). As indicated, the record in some years is marked by missing data. Annual rainfall totals are expressed in terms of the water year, October 1 through September 30. Annual rainfall averages 26.40 inches and has ranged from 13.03 inches in 1972 to 52.62 inches in 1983.

Figure 3 shows the monthly distribution of rainfall throughout the year. As shown, January has the highest average rainfall (5.41 inches), but measurable precipitation has occurred in all months.

Figure 4 illustrates the areal distribution of rainfall in the Half Moon Bay area (SCVWD, 1989). The pattern of precipitation is complex, with significant variations depending on elevation and topographic setting. In general, rainfall increases from a low of about 26 inches at the coast to highs of 42 inches near Pilarcitos Lake on the northeast and 40 inches along the Kings Mountain crest on the southeast. The intervening area (crossed by Highway 92) has lower rainfall, averaging 30 inches.

Evapotranspiration. Evapotranspiration (ET), the loss of water to the atmosphere through evaporation and plant transpiration, is relatively low in the study area. The California Department of Water Resources (DWR) includes the Half Moon Bay area within its Coastal Plains Heavy Fog Belt zone (DWR, no date). Reference evapotranspiration is approximately 33 inches. This ET rate refers to a well-watered turf and is applied to an individual crop type through use of a coefficient that accounts for the typical growing season of the crop and crop water consumption. Actual evapotranspiration rates from a field also are influenced by cropping and irrigation practices. The study area is marked by a variety of crops (for example, brussel sprouts, daisies, and pumpkins) and differences in cropping and irrigation practices, all of which have changed over time. Accordingly, the water balance for this report applies the reference ET rate to all crops and landscaping. This results in some overestimation of groundwater consumption.

The Lower Pilarcitos Creek groundwater basin also includes extensive areas of natural vegetation, including areas of grass and shrubs along the coastal bluffs and a corridor of water-loving trees and shrubs (phreatophytes) along Pilarcitos Creek. Evapotranspiration for the natural grass and shrubs was estimated by applying monthly ET coefficients for sagebrush-grass (Stephens, 1996), which reduced the ET rate to about 22 inches per year. Phreatophytes are assumed to consume the full potential ET (Stephens, 1996).

Land Use

Land use in the Half Moon Bay area was mapped by the California DWR in 1977 and 1987 (DWR, 1977 and 1987). For this study, the 1987 land use map was updated to current conditions (autumn 2002) through field reconnaissance. DWR land use maps provide information on the full range of land uses including natural vegetation, recreation areas, urban land uses (e.g., urban, urban residential, schools, and vacant lands), and agricultural land uses (specific crop types, irrigation status, fallow and idle lands).

Specific crop types indicated in the local land use maps include flowers, truck crops (notably brussel sprouts and artichokes), Christmas trees, grains, and pasture.

Pilarcitos Creek Watershed. The Pilarcitos Creek watershed consists primarily of relatively rugged uplands characterized by shrubs and grasslands. Significant portions of the watershed are protected by the City of San Francisco Public Utilities Commission within their Peninsula Watershed lands including the upper Pilarcitos Creek watershed (from just below Stone Dam). Substantial portions of the watershed area between Pilarcitos Creek and Arroyo Leon are protected from urban development by the Peninsula Open Space Trust (POST).

Historically, upland portions of the watershed were cultivated for dryland crops including small grains. Currently, developed lands within the watershed are primarily along the stream valleys, including Pilarcitos Creek, Arroyo Leon, Apanolio Creek (Digges Canyon), Corinda Los Trancos, and Nuff Creek. Most of these lands are developed for agriculture, primarily flowers with some truck crops, Christmas trees, and irrigated pasture. Review of the DWR land use maps show a decline in cropland from about 470 acres in 1977 to about 385 acres in 1987, while reconnaissance of cropland for this study indicated a stabilization in cropland along Pilarcitos Creek and Arroyo Leon at about 400 acres. It should be noted that in any given year, specific agricultural fields may be cropped or fallowed. In addition, agricultural land use along Pilarcitos Creek and Highway 92 has shifted in recent years from traditional cropping toward more commercial, public-oriented agricultural land uses such as commercial nurseries, pick-your-own Christmas tree farms, and stables.

Residential land uses also are present in the watershed, for example along Highway 92 and Pilarcitos Creek and along Higgins Canyon Road and Arroyo Leon. Major non-agricultural facilities in the watershed include Skylawn Memorial Gardens cemetery on Highway 92 at Skyline Boulevard, the Ox Mountain Sanitary Landfill in upper Corinda Los Trancos Canyon, and a quarry in Nuff Creek Canyon.

Lower Pilarcitos Creek Groundwater Basin. Land uses in the Lower Pilarcitos Creek groundwater basin have included a variety of urban land uses, agricultural land (including irrigated, non-irrigated, and fallow lands), recreation areas and natural vegetation. Crops in the groundwater basin area have included flowers, truck crops (primarily artichokes and brussel sprouts), with some field crops (e.g., dry beans), irrigated pasture, and non-irrigated grain (DWR, 1977 and 1987). For this study, DWR land use types were grouped into three broad categories:

- Urban: urban, urban residential, and schools
- Open space: natural vegetation, recreation, idle agriculture, and urban vacant lands
- Irrigated agriculture: flowers, field crops, and truck crops.

Figure 5 illustrates land use in the groundwater basin, while Table 1 summarizes the extent of the land use categories based on the DWR land use maps for 1977 and 1987 and the field reconnaissance for 2002. The areal extent of the groundwater basin is 1,765 acres or about 8 percent of the Pilarcitos Creek watershed. As indicated, urban areas have increased over the period 1977 to present, with the greatest increase since 1987. As shown in Figure 5, lands undergoing urbanization generally have been urban infill and have changed from open space (specifically, idled agricultural land) in 1977 to urban in 2002. Irrigated agriculture acreage declined slightly between 1977 and 2002.

The open space area includes phreatophytic vegetation along the riparian corridor of lower Pilarcitos Creek; this area is estimated at 28 acres (6,000 linear feet along the creek and 200 feet wide on average).

Figure 6 shows the City of Half Moon Bay land use plan map developed for the City's general plan update (EMC Planning, June 2000). Comparison of Figures 5 and 6 reveal the following:

- Current agriculture areas within the groundwater basin are urban reserve
- Medium-density residential land uses account for nearly half the urban area within the groundwater basin; the remaining area is primarily mixed commercial and residential uses and public services areas (e.g., schools)
- Areas along the coast now mapped as open space are shown to continue as open space, in some cases protected by transfers of development rights
- Natural vegetation open space areas east of Highway 1 are planned for urban uses, primarily medium-density residential.

Impervious Areas. An important land use characteristic for a water balance is the proportion of impervious area (paved areas and buildings) within a land use category. Representative proportions of impervious areas for selected land use categories in the San Francisco Bay area and Santa Clara Valley are shown in Table 2.

For this study, the urban area within the groundwater basin was estimated to be half medium-density residential and half a mixture of commercial, public service, and medium- to high-density residential. The medium-density residential area was assigned a value of 15 percent impervious, and the remaining mixed land uses were assigned an overall value of 50 percent impervious.

Overall, the urban area was computed to be 32 percent impervious. Agricultural areas are estimated to be 4 percent impervious. In impervious areas, zero recharge to groundwater is assumed to occur and, assuming relatively rapid drainage to the ocean, all rainfall on impervious areas becomes runoff. The small impervious areas in open space areas (2 percent) are assumed insignificant.

Groundwater Development and Wells

Data Sources. Two primary sources of information exist on wells drilled in the area: DWR Water Well Drillers Reports and San Mateo County Department of Health Services (Environmental Health Division) files.

DWR Water Well Drillers Reports were collected for the Lower Pilarcitos Creek groundwater basin and watershed and adjacent areas, including Princeton, El Granada, Miramar, and Half Moon Bay Golf Links. Appendix 2 summarizes information for 614 wells located in the Pilarcitos Creek watershed and groundwater basin, including information on location, drilling and construction, discharge, drawdown, and water levels. Well records were collected from Range 5 West, Township 5 South (5W/5S), 6W/5S, and 5W/6S; and portions of 6W/4S, 4W/6S, 5W/7S, 4W/5S,and 5S/5W related only to the Pilarcitos Creek watershed and groundwater basin.

The San Mateo County Department of Health Services is the permitting agency for well drilling and construction in the county. The San Mateo County well files include copies of DWR reports, and information on well permits, operating permits, informal pumping tests, water quality, and well abandonment. San Mateo County well files were used as a secondary source, largely because the records are organized by Assessor Parcel Number (APN). Although APNs provide very specific location data, they do not provide a consistent or unique well numbering system. For example, subdivision of parcels results in multiple APNs, more than one well can be installed on a parcel, and different APNs can be assigned for the same well’s construction and abandonment. Accordingly, County files were acquired for selected areas to aid in evaluation of particular issues (e.g., water quality).

In addition to the above primary sources, a water well inventory was previously compiled for the area from Miramar to Cañada Verde (Geoconsultants, June 1987 and August 1991). This inventory was useful because it included a well location map. It should be noted that Geoconsultants developed a different grid system than the traditional township and range grid.

Groundwater Development. Figure 7 shows the number of wells drilled annually since 1952 (from Appendix 2) and number of CCWD new connections since 1971 (CCWD, March 2002). As shown, water wells generally have been drilled at a relatively consistent rate of less than ten wells per year (average of six wells per year). It should be noted that this drilling includes some replacement of older existing wells. In 1987, 1988, and 1989, well construction soared to over 130 wells per year. Many of these wells were drilled for single family domestic homes. This was the result of significant demand for residential housing in the Half Moon Bay area coupled with limitations on CCWD water connections.

As indicated on Figure 7, new CCWD connections generally numbered less than 100 from 1978 through 1992. Subsequently, Crystal Springs Reservoir supply was developed and the number of new CCWD connections soared to a peak of 601 new connections in 1994. While some of these new connections undoubtedly represented new homes, many were replacements for previously drilled domestic wells that were subsequently abandoned. Domestic wells were abandoned for a variety of reasons, including the locally poor quality of groundwater relative to the high quality of CCWD water and the low well yields during drought (e.g., 1988 through 1993) in contrast to reliable CCWD supplies.

The number of existing, active domestic wells in the area was assessed through a process of elimination from the well database (Appendix 2) as follows:

1. Of the total 614 wells, 422 are identified as domestic wells.
2. A partial review of portions of the County files revealed 73 known abandoned wells, leaving 349 wells.
3. During 1985 through 1991, 265 wells were drilled, many apparently as alternatives to CCWD connections. It is assumed that most of these were abandoned when CCWD connections became available. During the periods 1952-1984 and 1992-2002, drilling averaged six wells per year. Assuming six wells per year would have been drilled and maintained regardless of the availability of CCWD connections, then only 42 wells were drilled and maintained, and the remaining 223 were abandoned, leaving 126 wells.

Accordingly, it is estimated that 126 domestic wells are active in the groundwater basin.

In addition, 128 wells have been drilled in the Half Moon Bay area for crop and landscape irrigation. Within the groundwater basin, the cropland relying on wells for irrigation supply is clustered along lower Pilarcitos Creek and near the confluence of Arroyo Leon and Pilarcitos Creek. About 10 agricultural irrigation wells are still active in the groundwater basin. Wells for landscaping irrigation include Ocean Colony Partners' wells located along Balboa Boulevard near Pilarcitos Creek.

The Ocean Colony Partners Balboa wellfield is the most important groundwater user in the basin. The wellfield consists of four, relatively low-capacity wells that are pumped to provide water supply for two golf courses, the Half Moon Bay Golf Links located south of the groundwater basin. The wellfield initially was developed in the early 1980s as the supply for one golf course, pumping an average of 207 acre-feet per year (AFY), while current pumping for the two golf courses averages 347 AFY (Luhdorff & Scalmanini, 2000). This pumping represents an export of water from the groundwater basin.

Since the mid-1980's the total amount of groundwater pumping has changed little. Although numerous wells were drilled in the 1980s for domestic use, most of these were subsequently abandoned. While the pumping for the Balboa wellfield has increased since the mid-1980s, the cropland irrigated with local groundwater has declined since 1987.

Figure 8 shows the areal distribution according to township/range section of the 614 wells listed in Appendix 2. Note that 432 or about 70 percent of the wells have been drilled in the southwest quadrant of township 5W/5S, or in other words, in the Lower Pilarcitos Creek groundwater basin. However, as noted above, many of these wells are not currently in use.

Soils

Soils in the Pilarcitos Creek watershed and groundwater basin are generally divided into upland soils and soils of the marine terraces, alluvial fans, and floodplains (USDA SCS, 1961).

The Pilarcitos Creek watershed is marked by two major upland soil associations. The Miramar-Sheridan soil association occurs generally north of Pilarcitos Creek and includes soils developed on granitic rocks with shrub- or forest-covered steep slopes. The Lobitos-Santa Lucia-Gazos soil association occurs generally south of the creek. These soils are developed on sedimentary rocks with grass- or shrub-covered steep slopes. In addition, the Pilarcitos Creek and Mills Creek alluvial valleys are characterized by the Tunitas-Lockwood soil association.

The Lower Pilarcitos Creek groundwater basin includes the Tierra-Colma soils on high marine terraces, Watsonville-Elkhorn soils on low marine terraces, and Tunitas-Lockwood soils on floodplains along lower Pilarcitos Creek and Arroyo Leon. Specific soil types with significant areal extent across the groundwater basin include the Botella clay loam, Denison clay loam and loam, Farallone loam, Soquel loam, Tierra loam, and Watsonville clay loam and loam.

An important characteristic of soils for the local water balance is the soil moisture holding capacity, or the maximum amount of water that is stored in a soil and available to plants for evapotranspiration. Soil moisture holding capacity is estimated for each vertical soil zone and expressed in terms of inch/inch. For this study, the entire thickness and soil moisture holding capacity of each soil was assumed to be available to plants. Soils in the area are relatively thick, ranging from 48 inches (Farallone loam) to 67 inches (Denison loam). Soil moisture holding capacities range from 2.94 inches (Tierra loam) to 10.80 inches (Botella clay loam); these were averaged according to the relative areal extent of the soils across the basin, resulting in an average soil moisture holding capacity of 6.70 inches.

Streamflow

Streamflow for Pilarcitos Creek has been recorded by the United States Geological Survey (USGS) at two gauges in the study area (see Figure 1). In addition, one gauge exists in the upper portions of Purisima Creek located south of and adjacent to the Pilarcitos Creek watershed. Because the Purisima Creek station is located in a relatively undisturbed watershed, surface water flow characteristics, ET, and groundwater recharge estimates from the Purisima Creek watershed help confirm watershed characteristics of the upper Pilarcitos Creek watershed.

A summary of streamflow records for the creeks are shown in Table 3a. Pilarcitos Creek at Half Moon Bay has been measured since 1966, while Pilarcitos Creek below Stone Dam and Purisima Creek near Half Moon Bay have been measured for relatively short intervals of time. Note that the Pilarcitos Creek below Stone Dam and Purisima Creek stations have similar watershed basin areas. In addition, the two stations are similar in terms of hydrogeologic controls; both are situated below relatively undeveloped watersheds in narrow, bedrock-exposed canyons that provide for little opportunity for groundwater recharge or underflow. Monthly discharge data for the three gauge stations listed in Table 3a appear in Appendix 3 and are summarized as water year totals.

Figure 9 depicts the streamflow hydrograph for the entire record (1966 to current) of Pilarcitos Creek near Half Moon Bay, for Purisima Creek (1959 to 1969), and for Pilarcitos Creek below Stone Dam (1998 to 2001). The average monthly discharge for Purisima Creek (201 acre-feet [AF]) and upper Pilarcitos Creek (195 AF) are comparable, while the average monthly discharge for Pilarcitos Creek near Half Moon Bay is nine times greater, reflecting its larger drainage area.

Figures 10 and 11 compare monthly discharge for the records of coincidence of Pilarcitos Creek near Half Moon Bay with Pilarcitos Creek below Stone Dam and Purisima Creek, respectively. Note that for the period of coincidence (Figure 10) the baseflow (about 100 AF per month) measured for Pilarcitos Creek at the Half Moon Bay is about ten times the baseflow for Pilarcitos Creek below Stone Dam (about 10 AF per month). The baseflow indicated at the Half Moon Bay gauge reflects the inflow of surface water and groundwater into Pilarcitos Creek in its upper canyon and into its major tributaries above the gauge.

Table 3b summarizes the average discharges for the entire streamflow record and for the period of coincidence for Pilarcitos Creek below Stone Dam (1997 to 2001) and Purisima Creek (1966 to 1969).

Figure 12 shows average monthly discharge for all three stations. As shown, January, February, and March are the months with the highest streamflow, contributing more than 60 percent of the total yearly discharge. In contrast, less than 10 percent of the streamflow is contributed during September, October, and November.

Geologic Setting

The upper Pilarcitos Creek watershed is composed primarily of igneous, metamorphic, and sedimentary rocks, recent alluvium, and colluvium (Figure 13). The Lower Pilarcitos Creek groundwater basin, situated on a westward sloping marine terrace incised by Pilarcitos Creek (Lajoie et al., 1979), is composed of four important hydrogeologic units. These are consolidated sedimentary rocks (Purisima Formation), marine terrace, alluvial fan, and recent surficial deposits. The recent deposits include recent alluvium deposited by Pilarcitos Creek, beach and dune sands, colluvium, and artificial fill.

The bedrock has been affected by folding and faulting but the overlying unconsolidated formations have experienced only minor deformation (Geoconsultants, June 1987). Geoconsultants (June 1987) compiled a geologic map of the coastal plain area between El Granada and Cañada Verde based on Brabb and Pampeyan (1983) and Lajoie et al. (1974).

Purisima Formation. The Lower Pilarcitos Creek groundwater basin is underlain by a thick section of Tertiary age Purisima Formation. In 1984, an exploration boring (5S/5W-30H) drilled by Half Moon Bay Properties near Balboa Boulevard revealed that the Purisima Formation occurs to depths of at least 1,031 feet (elevation of 1,011 feet below mean sea level [msl]).

Figure 14 shows a generalized east-west cross section of the Half Moon Bay terrace. Note that the vertical exaggeration is only five times. The top of the Purisima Formation ranges between about 45 feet below msl beneath the coastline to about 60 feet above msl in the low foothills east of Half Moon Bay and along Highway 92. The overlying unconsolidated sediments form a relatively thin veneer on top of the Purisima Formation.

The undivided Purisima Formation is of Pliocene and upper Miocene age and is predominantly gray and greenish-gray to buff fine-grained sandstone, siltstone, and mudstone (Brabb and Pampeyan, 1983). The Purisima Formation is considered non-water bearing and is readily recognized by drilling contractors. Where groundwater has been encountered in the Purisima Formation, water quality is usually poor with elevated concentrations of chloride, iron, manganese, and total dissolved solids (TDS) (Kleinfelder, April 1988).

Marine Terrace Deposits. The marine terrace deposits overlying the Purisima Formation form the main aquifer in the Lower Pilarcitos Creek groundwater basin. The sediments were deposited in shallow water on old wave-cut marine terraces that are now slightly warped and elevated above sea level (Lajoie et al., 1979). The marine terrace deposits are weakly consolidated, moderately weathered, well-sorted to poorly-sorted sand and gravel and range from 30 to 60 feet thick (Brabb and Pampeyan, 1983). Surface outcrops of marine terraces occur east of Half Moon Bay and onlap the Purisima Formation. The hydrologic properties of the Marine Terrace deposits are described in detail in the subsequent section, *Marine Terrace Hydrologic Properties*.

Alluvial Fans. Two generations of alluvial fans were deposited on top of the marine terraces. The older fan deposits, consisting of inter-bedded clays, silts, fine sands, and clayey silts, extend from the foothills to the coastline. The younger fan deposits, consisting of unconsolidated silts, fine- to coarse-grained sands, and gravels, have been eroded and are discontinuous across the Lower Pilarcitos Creek groundwater basin. The older fan deposits tend to be finer-grained than the younger fan deposits. In general, the alluvial fan deposits are above the regional water table and therefore are not significant aquifers.

Geologic logs reported by drillers and corroborated with geophysical logs indicate that the alluvial fan deposits are predominantly silts and clays in the lower reaches of the Pilarcitos Creek groundwater basin. Commonly occurring in the distal portion of an alluvial fan (Reading, 1981; Walker, 1981), these fine-grained deposits reduce any hydraulic connection between Pilarcitos Creek and associated overlying alluvium and the underlying marine terrace aquifer. In addition, these alluvial fan deposits provide a relatively impermeable cap to the marine terrace aquifer resulting in confined groundwater conditions.

Alluvium. Unconsolidated surficial materials include recent alluvium deposited by and adjacent to Pilarcitos Creek, colluvium in the upper reaches of Pilarcitos Creek and its small tributaries, beach and dune sand along the coastline, and artificial fill. In general, these unconsolidated materials consist of mixtures of silt, sand, and gravel. Because these surficial materials are limited in extent, thin and usually above the water table, they are not significant aquifers in the Lower Pilarcitos Creek groundwater basin.

Hydrogeologic Cross Sections

Three cross sections were constructed for the Lower Pilarcitos Creek groundwater basin. Two are roughly north-south and perpendicular to Pilarcitos Creek and one is parallel to the creek. Figure 15 shows the location of the cross sections. Appendix 4 contains summaries of the wells used for the cross sections. The geologic framework for the north-south cross sections was based on downhole geophysical logs collected from six test wells and five irrigation wells installed by the CCWD and Half Moon Bay Properties, respectively. Review of DWR Water Well Drillers Reports and CCWD files provided additional well data and geophysical logs that supported and extended the cross sections north and south.

Cross section A-A’ (Figure 16) was developed from borings and test wells installed by CCWD (Nelson, 1997 and 1998). As a result of the 1991-1992 drought relief program, CCWD files provided good documentation on the Corporation Yard (ESA, February 17, 1992), Cunha 2 (ESA, December 6, 1991), and Holiday Inn (ESA, March 5, 1992) wells. This documentation includes well location, geology, geophysical logs, construction details, hydraulic testing, and groundwater quality. Cross Section A-A’ is based on six geophysical logs: TW1, TW2, TW3, and TW5; Cunha 2; and Corporation Yard.

The marine terrace aquifer (sands and gravels on Figure 16) is underlain by the Purisima Formation and overlain by the alluvial fan deposits (predominantly silts and clays as shown on Figure 16). The marine terrace aquifer is about 30 feet thick beneath and adjacent to Pilarcitos Creek ranging between an elevation of about six feet above msl to 24 feet below msl. The marine terrace aquifer is about 25 feet below Pilarcitos Creek. South of the test well locations, the aquifer tends to be thicker (40 to 60 feet) and at higher elevations ranging between 40 feet above msl for the top to 10 feet below msl for the bottom of the aquifer. These higher elevations reduce the well depths, but also decrease the available drawdown in wells, and thus yields.

Two water levels are shown on Figure 16; the higher water levels (to the left) were measured in the test wells in winter 1997, while the lower water levels were measured during the early 1990’s drought. This change in groundwater levels is about 20 feet and reflects drought and seasonal conditions. This change is large relative to the thickness of the aquifer and overlying sediments and significantly impacts the potential well yields from the marine terrace aquifer. The groundwater levels are below the bottom of the Pilarcitos Creek channel indicating that the creek and groundwater in the regional aquifer are not in direct hydraulic connection. Furthermore, a downward hydraulic gradient exists that indicates that the creek is a source of recharge to groundwater.

Cross section B-B’ (Figure 17) is based on data from borings, irrigation wells, and domestic well data collected from the DWR Water Well Drillers Reports, geophysical logs provided by Maggiora Brothers Drilling, Inc. (December 23, 2002), and a technical report prepared for Half Moon Bay Properties (Luhdorff & Scalmanini, 2000). The geologic framework for cross section B-B’ is based on eight geophysical logs.

Similar to cross section A-A’, the marine terrace aquifer is underlain by the Purisima Formation and overlain by the fine-grained alluvial fan deposits. The marine terrace aquifer is about 50 feet thick beneath and adjacent to Pilarcitos Creek and ranges between an elevation of about 6 feet above msl to 42 feet below msl. The marine terrace aquifer is about 5 feet beneath Pilarcitos Creek. South of the test well locations, the aquifer tends to be thicker (up to 60 feet) and the top of the aquifer is at higher elevations ranging between 10 and 20 feet above msl.

Comparisons between cross sections A-A’ and B-B’ indicate that the marine terrace aquifer is relatively uniform and consistent at these two locations. Because many of the wells used for cross section B-B’ were installed at various times, no consistent water level is shown. Nevertheless, the variations in water levels suggest a groundwater fluctuation of about 20 feet.

The geologic framework for cross section C-C’ (Figure 18) is based on geophysical logs (two from Stone Pine Center), borings, irrigation wells, and domestic well data collected from the DWR Water Well Drillers Reports, and data analyzed for cross sections A-A’ and B-B’.

Cross section C-C’ shows the marine terrace aquifer is underlain by the Purisima Formation and overlain by the fine-grained alluvial fan deposits. The Purisima Formation crops out to the east at an elevation of about 60 feet above msl (Geoconsultants, June 1987) and gradually changes in elevation from about 10 feet above msl near Stone Pine Road Center to 42 feet below msl near the coastline. The marine terrace aquifer thins towards the east and is about 50 feet thick in the vicinity of the Balboa wellfield and 30 feet thick in the vicinity of the CCWD test wells. Review of the geology reported by the drillers indicates a general coarsening of grain size from west to east.

As illustrated in cross section C-C’, water levels fluctuate seasonally by about 20 feet, rising in response to winter recharge and falling in summer as a result of drainage to the ocean. These naturally fluctuating water levels limit the amount of water that can be pumped during the summer and fall.

The marine terrace aquifer is bounded on the east by bedrock and on the west by the Pacific Ocean. The approximate position of the fresh-salt water interface is shown on cross section C-C’. Because fresh groundwater is lighter than saltwater, the fresh water upwells at the interface and is discharged as seepage along the shoreline. The position of the fresh-salt water interface is dynamic and will move depending upon the amount of aquifer discharge. Reducing the aquifer discharge (e.g., through pumping) will move the interface inland.

Lower Pilarcitos Creek Test Well Analysis

In the autumn of 1997, CCWD conducted a two-phase investigation of the Lower Pilarcitos Creek groundwater basin to determine the thickness, permeability, and lateral extent of aquifers beneath and adjacent to Pilarcitos Creek and west of the Highway 1 bridge crossing. Phase One included the drilling of six test borings while the follow-on study, Phase Two, completed the project with the installation and aquifer testing of five test wells. This section summarizes the investigation and provides an analysis of available pumping test data.

Drilling and Construction

Figure 15 shows the location of the test borings/wells. Three test borings were installed north of Pilarcitos Creek and three south of Pilarcitos Creek. Ground surface elevations range from 60 feet near Kelly Avenue and Highway 1 to 30 feet on Chesterfield Avenue near Pilarcitos Creek. Table 4 summarizes the construction details for the test borings/wells.

Phase One. The test borings were installed by Pitcher Drilling Company from East Palo Alto, California using a Failing 1500 direct mud rotary drilling rig. The six test borings were drilled between September 2 and 9, 1997 using a combination of 5-inch diameter tricone and fish-tail drill bits. Discrete formation samples were collected generally every ten feet using a split-spoon sampler providing a 1-inch diameter by 18-inches long core sample. These cores were used to describe the subsurface materials and were supplemented with examination of returned formation cuttings mixed with bentonite drilling fluid. The borings were drilled to depths ranging between about 64 and 75 feet below ground surface.

A suite of geophysical logs were conducted by Welenco (September 11, 1997) on four of the test borings (TB1, TB2, TB3, and TB5) on September 8, 1997. The suite of geophysical logs included spontaneous potential (SP), short (16-inch) and long (64-inch) normal resisitivity, and single point resisitivity. Two (TB1 and TB2) of the four test borings were drilled, left as open holes, and logged 142 and 120 hours, respectively, after mud circulation had stopped. This non-standard logging procedure can impact the interpretation of the geophysical logs. Nelson (1997) provides the geologic and geophysical logs.

Based on the geologic logs and geophysical logs of the test borings, the area is underlain by a thin and uniform aquifer (see Figure 16). The top of the sand and gravel aquifer is defined primarily by a distinct geophysical signature while interpretation of the bottom of the aquifer has been based on the geologic logs. Ground surface elevations are provided by Nelson (1998). The Phase One test borings indicate that the aquifer thickness ranges between 27 and 33 feet. The aquifer is underlain by the consolidated Purisima Formation and overlain by about 30 feet of silts and clays. The base of the aquifer ranges between 23 and 31 feet below msl while the top of the aquifer ranges between 10 feet above and 4 feet below msl. The aquifer was absent from TB4 (Nelson 1997), which is located approximately 600 feet northeast of TB3 where the underlying Purisima Formation was encountered at an elevation of about 24 feet below msl.

Phase Two. All test borings except TB4 were selected for follow-on test well construction. The purpose of Phase Two was to determine the long-term yields for the test wells near the Phase One borings. The test wells were installed, constructed, and developed by Pitcher Drilling Company using a Failing 1500 direct mud rotary drilling rig. The five test wells were drilled and reamed (?), constructed, and developed between November and December 1997 using a 14-inch diameter tricone and drag drill bits. The test wells were drilled to depths between 82 and 85 feet, providing 10 to 15 feet of additional hole beneath the aquifer for a sump or tail pipe.

Eight-inch diameter Schedule 40 PVC (0.25-inch wall) casing and horizontal perforations were installed in each boring. The perforations consist of 43 rows of 0.060-inch (60 slot) per foot and three perforations per row (?), resulting in a relatively small open area. The estimated open area is 18.576 square inches (in^2) or 6 percent open area. In contrast, the open area of similar diameter and slot wirewrap well screen is 123.840 in^2 or 40 percent open area.

AMC Lonestar medium aquarium sand (6 X 16) was installed as a filter pack envelop surrounding the screen. The depth to the top of the filter pack ranges between 25 and 37 feet. A concrete grout surface seal was installed in the annular space between the 14-inch diameter hole and the 8-inch diameter PVC casing from ground surface to the top of the filter pack. The length of the perforations range between 40 and 45 feet. These are between 30 percent to 105 percent longer than the aquifer thickness. This placement of perforations opposite other geologic formations (especially the Purisima Formation with potentially poor water quality) may significantly impact the measured water quality parameters from the test wells.

Well development consisted of thinning the drilling fluid and partially removing the fluids prior to well screen installation and then completely removing the fluids after well construction. The drilling fluids were transported by tank truck and transferred to the wastewater treatment plant. Approximately 20 pounds of Barafos, a chemical dispersant, were used to break down the mud to enhance removal. Additional development was conducted during the pumping test activities.

After well development, a small submersible pump was installed in the test wells. Initially, a variable discharge (step-drawdown) pumping test was conducted to complete well development and to assess the long-term yield and performance of the test well.

Five long-duration pumping tests (720 minutes) were conducted on each test well between December 22, 1997 and January 20, 1998. Recovery water levels were collected on the test wells for 30 minutes. Table 5 summarizes these tests. The non-pumping or static water level from the top of casing for the wells ranged between 15.83 feet (TW1) and 20.46 feet (TW5) below ground surface. The pumping tests were conducted with discharge rates ranging between 135 gallons per minute (gpm) for TW3 and 203 gpm for TW1. Total drawdowns observed in the pumping wells varied from 22 feet for TW2 to 31 feet for TW1. During the pumping tests, water levels were measured in available wells located approximately 500 feet from the pumping wells. Drawdowns in these wells ranged between 2 feet and 6 feet (Nelson, 1998).

Hydraulic Analysis

Hydraulic analysis of the pumping test data was conducted to estimate well performance and aquifer parameters. Table 5 shows a summary of these parameters. In general, the pumping test data indicate that the permeability of the aquifer is consistent throughout the wellfield. Small variations in well performance and aquifer parameters are probably due to differing well inefficiencies and hydraulic conductivities, respectively.

Drawdown. The drawdown in a well is the vertical distance between the static water level and the pumping water level. When a well is pumped, the maximum drawdown in the aquifer occurs at the pumping well allowing groundwater to flow toward the well. The drawdown systematically decreases away from the pumping well to form an inverted cone; thus a cone of depression. Drawdown continues to increase with elapsed time of pumping unless a recharge boundary is encountered.

Specific Capacity. The specific capacity is a measure of the productivity of the well, and is computed as the discharge of a well divided by the measured drawdown in the pumping well at a specified elapsed time. As the drawdown increases with elapsed time of pumping, the specific capacity decreases. Large specific capacities (greater than ten gallons per minute per foot [gpm/ft] of drawdown) indicate prolific aquifers; small specific capacities indicate poor aquifers or inefficient wells. The specific capacity is directly proportional to the aquifer permeability. The proportionality constant is 1,500 for unconfined aquifers and 2,000 for confined aquifers (Driscoll, 1986; AWWA, 2003).

The specific capacity for the test wells ranges from 4.64 (TW3) to 8.62 (TW5) gpm/ft of drawdown after 720 minutes of pumping (Table 5). This means that for every foot of drawdown the test wells can be pumped between 4.64 and 8.62 gpm. The aquifer permeability should range between 9,000 and 17,000 gallons per day per foot (gpd/ft).

Transmissivity. The transmissivity (T-value) or field permeability represents the ease at which groundwater flows through the aquifer. High T-values (greater than 10,000 gpd/ft) indicate prolific aquifers; small T-values indicate poor aquifers. Transmissivity is estimated using time drawdown data collected from the pumping well and any nearby observation wells. Table 5 summarizes the transmissivity data calculated for both drawdown and recovery data. Average T-values for the test wells range from 9,960 (TW6) to 20,150 (TW5) gpd/ft. This is consistent with the specific capacity data.

Hydraulic Conductivity. The hydraulic conductivity (K-value) or intrinsic permeability of the aquifer is a fundamental property of the aquifer. The K-value is directly proportional to the transmissivity and inversely proportional to the aquifer thickness. Like T-values, high K-values indicate prolific aquifers, while small K-values indicate poor aquifers. Table 5 summarizes the K-values. The K-values range from 302 to 713 gallons per day per square foot (gpd/ft^2). These K-values represent moderate to high values.

Storativity. The storativity (S-value) or storage coefficient is a measure of the confinement of the aquifer and is unit-less. High S-values (greater than 0.005) indicate water table conditions or unconfined aquifers, while low S-values (less than 0.005) indicate confined or artesian aquifers. In unconfined aquifers, the S-value is the specific yield of the aquifer.

Storativity can only be measured in observation wells. Insufficient data were collected during the test boring/well program to estimate the S-value. Based on literature review and the hydrogeologic framework, the S-value for the aquifer in the vicinity of the test wells is about 0.0005.

Estimated Well Yields. In summary, the average T-value of the aquifer is 16,000 gpd/ft while the average available drawdown is 20.13 feet. Here, the available drawdown is defined as the distance between the static water level and the top of the aquifer. Using only two-thirds of the available drawdown (which allows for seasonal and water level fluctuations as well as pump and well inefficiencies) results in an expected average well yield of about 107 gpm.

Estimated discharges for each test well are summarized on Table 6, which is divided into two parts to illustrate the seasonality of well yields. Table 6a summarizes well yields for the winter rainy season, while Table 6b summarizes yields for the summer dry season.

It is not uncommon for seasonal water level fluctuations to be in excess of 20 feet in the Lower Pilarcitos Creek groundwater basin. Two long-term water level hydrographs of Wells 5S/5W-29F04 and 5S/5W-32K (discussed below) clearly demonstrate the significant water level fluctuations. During the winter, the static water level ranges between 16 and 21 feet below ground surface providing an available drawdown ranging between 17 and 24 feet. The average yield for the test wells is 88 gpm per well.

Table 6b is similar to Table 6a. However, the static water levels have been adjusted by 20 feet to account for the seasonal water level fluctuation. Note that the 20-foot drop in water level in the summer or during drought results in water levels near or below the top of the aquifer. Therefore, under these criteria, the wells will produce little, if any water. Calculations show that TW1 (18 gpm) and TW6 (1 gpm) can meet the available drawdown criteria.

Although not recommended, pumping water levels could be lowered to below the top of the aquifer. However, in no instance should the wells utilize more than 50 percent of the aquifer for drawdown (Driscoll, 1986). If the wellfield were to operate in this manner, calculations show that the average well yield would be reduced to about 37 gpm.

Well Interference. For an average well in winter, the shape of the cone of depression and resulting interference between wells depends on the T-value (16,000 gpd/ft), the S-value (0.0005), the length of pumping, and the discharge (107 gpm). Calculations show that at distances of 100, 500, and 1,000 feet after one day of pumping will result in interference of 4.92, 2.51, and 1.62 feet respectively. After 100 days of continuous pumping, interference would be 8.22, 5.91, and 4.92 feet, respectively. These interference effects at various distances will lower the static water level resulting in decreased available drawdowns and reduced well yields.

Well Construction Program

The test wells provided valuable information on the feasibility of a Lower Pilarcitos wellfield. However, estimated well efficiencies of the Lower Pilarcitos Creek test wells range between 45 and 85 percent. For a newly installed well, typical well efficiencies are greater than 80 percent.

In addition, the test wells were characterized by turbid discharge. This indicates that the wells were not fully developed to remove drilling fluids introduced during drilling and fine-grained sands adjacent to the screen, and to remedy the damage to the borehole. The wells were not rigorously developed because of their construction with PVC casing materials, which are a much weaker material than steel casing and provide a much lower open area than wirewrap screen. Lower well screen open areas limit the effectiveness of well development procedures and may restrict efficient flow of groundwater into the well. As a result, the test wells do not adequately reflect the potential capability of wells in that location, the local water quality, or the aquifer response to pumping.

Should CCWD decide to proceed with evaluation of a Lower Pilarcitos wellfield, the recommended next step is installation of a pilot production well immediately adjacent to TW2. This pilot production well would provide the following:

- Better definition of the composition of aquifer materials,
- Water quality information with depth and geologic formation, allowing isolation of the water quality of the alluvial aquifer,
- Assessment of the aquifer response during formal pumping tests using an observation well, and
- Optimization of well efficiency.

The pilot well (and any subsequent production wells) should be installed approximately 10 feet from the existing test wells. This distance will allow measurement of water levels during pumping tests not only in the pumping well but also in the existing test well, which would serve as an observation well. These measurements would provide a better understanding of aquifer parameters (transmissivity and, especially, storativity). This better hydraulic understanding is necessary to predict well interference and well spacing in the well field.

Because drilling depths are shallow (about 65 to 85 feet deep), the production wells should be drilled with cable tool methods. Cable tool methods have several advantages in comparison to rotary drilling methods including the following:

- No drilling fluid (bentonite) is introduced to the borehole,
- Minimal borehole damage as the casing is advanced as drilling proceeds,
- Design of the well can accommodate either natural filter pack (preferred) or filter pack designs,
- Aquifer soil samples can be properly classified resulting in custom-made well design screens (aperture size and screen lengths) suited for each site, and
- Groundwater samples can be collected during drilling to determine if groundwater quality is stratified with depth.

The pilot well and subsequent production wells should have a pump chamber of at least 12-inch diameter and be constructed of steel. A surface seal should be installed to about 20 feet; a County Health Department variance will be needed for this seal. The wells should be drilled to bedrock. The well screen should be 12-inch telescope (natural filter pack) or 6-inch diameter pipe size (filter pack) continuous wirewrap stainless steel screen. The well screen should be placed at least three feet above the bedrock. The aperture size of the screen should be designed from particle size analysis of representative formation samples. After installation and construction, the well should be developed with swab and bail methods for at least 30 hours. Mechanical well development should be followed with development using the test pump. Detailed and formal pumping tests (step-drawdown and constant discharge) should be conducted on the well. A well construction report should be prepared to document the drilling, construction, development, and testing of the production wells.

A phased approach to the wellfield would involve installation of wells on the north side of the creek and construction of water conveyance and treatment facilities, followed by extension of conveyance facilities to the south side of the creek.

Wellfield Operation and Life Expectancy

Yields from proposed production wells will be limited by seasonal water level fluctuations and the relatively shallow depth of the aquifer. To assess the impact of groundwater fluctuations at the test wells, water levels in nearby well 29F04 (see Figure 19) were assumed representative. Groundwater fluctuations at well 29F04 range from elevations of about 8 feet above msl in November to 47 feet above msl in March. The elevation of the top of the aquifer near the lower Pilarcitos Creek wellfield is about 10 feet above msl (Figure 16). Therefore, drought and summer/autumn water levels are near the elevation of the top of the aquifer.

Operation of the wellfield should maintain water levels above the top of the aquifer. Pumping at higher rates and lowering the water levels below the top of the aquifer will reduce the transmissivity of the aquifer and thereby lessen the yield. To optimize well yields, the well screen should be installed opposite the full thickness of the aquifer. However, lowered water levels exposing the well screen will have negative impacts to the operation and life of the well. Exposing the screen during pumping will result in cascading water, air entrainment, potential water quality changes, and reduced life of the well pump and well itself.

Assuming operation as outlined above, pumping and yield from the test wells would vary systematically through the months of the year. Accordingly, pumping and well yield were analyzed on a monthly basis for average, dry, and wet year conditions.

For a year with average precipitation, pumping from the test wells systematically changes from a low of 53 AF in September and November to 88 AF in March; the average monthly yield from the test wells would be 66 AF or about 800 AFY.

For a drought year, the pumping from the test wells systematically changes from a low of 4 AF in November to 56 AF in February, with an average monthly yield from the test wells of 33 AF or about 396 AFY. For a year with above average precipitation, the monthly yields would range from 70 AF in September to 118 AF in March; averaging about 88 AF or 1,053 AFY.

Pumping of the test wells can occur throughout the year but at reduced rates during the summer and autumn. These calculations have not been adjusted for test well inefficiencies and probable interference from neighboring wells or other test wells.

The expected life of the production wells would be 25 to 30 years (Gass et al, undated), assuming appropriate operation and maintenance. Factors affecting the life of the wells would include specific subsurface conditions, construction materials, well development, operational procedures, pumping rates, and well maintenance schedules. Declines in production typically are small over most of the life of a properly designed, constructed, and maintained well. When replacement wells need to be drilled, we recommend siting within about ten feet of the original well on the same parcel.

Marine Terrace Hydraulic Properties

The marine terrace deposits form the main aquifer of the Lower Pilarcitos Creek groundwater basin. Available pumping test data from wells in the basin provide information on hydraulic properties of the marine terrace aquifer, including conductivity, transmissivity, and storativity. Groundwater flow is generally toward the shoreline, where an interface exists between the onshore fresh water and offshore salt water. Substantial discharge of groundwater occurs to the ocean. Groundwater storage is affected significantly by seasonal fluctuations in groundwater levels.

Pumping Tests

A handful of formal pumping tests conducted with the supervision of a hydrogeologist and many informal tests conducted without supervision have been performed and recorded in the Half Moon Bay and Lower Pilarcitos Creek areas. The formal pumping tests are analyzed and discussed by ESA (December 6, 1991, February 27, 1992, and March 5, 1992) and by Luhdorff & Scalmanini (2000). Nelson (1998) did not analyze the five 12-hour pumping tests collected during the Lower Pilarcitos Creek test well installation and groundwater investigation but noted the data were available in the CCWD files. Todd Engineers reviewed and analyzed the pumping test data for the current investigation (see previous section).

Table 5 summarizes eight formal single well pumping tests conducted by CCWD. These tests were conducted in the vicinity of the proposed Pilarcitos Creek wellfield (cross section A-A', Figure 16). The T-value ranges between 10,000 and 20,000 gpd/ft for the test wells and the Holiday Inn well while the wells in the southern portion of the cross section (Cunha and Corporation Yard) show a range between 1,500 and 7,000 gpd/ft. Nevertheless, these are similar values considering that the transmissivity can vary by 12 orders of magnitude (Freeze and Cherry, 1979) and suggest that the aquifer is slightly less permeable south of the proposed wellfield. The K-value averages about 160 gpd/ft^2 south of the proposed wellfield and 537 gpd/ft^2 near the proposed wellfield.

Aquifer testing was conducted at the Balboa wellfield by Luhdorff & Scalmanini (2000). The aquifer test consisted of pumping one well at 66 gpm for eight hours and measuring the drawdown at three observation wells. Table 7 summarizes these data. The T-values estimated for the three observation wells range between 8,000 and 10,000 gpd/ft; equivalent to an average K-value of 354 gpd/ft^2. Because observation wells were used for this aquifer test, calculations can be conducted to determine the S-value of the aquifer. The S-value ranges between 0.00071 and 0.0013, indicating that the marine terrace aquifer is confined near the Balboa wellfield.

The informal pumping tests performed by drilling contractors are usually recorded on the DWR Water Well Drillers reports and provide basic hydraulic information including static water level (SWL), pumping water level (PWL), length of pumping test, and the approximate discharge. These are reported in Appendix 2, well inventory information.

The well inventory lists 380 wells (62 percent) with hydraulic information. Because the T-value (and, by inference, the specific capacity) varies with geologic materials, the well inventory was sorted by aquifer type (alluvium, marine terrace, and bedrock) and summarized to determine the minimum, maximum, and average specific capacities. The specific capacity for these wells varies by at least three orders of magnitude and ranges between 0.006 (bedrock) to 7.06 gpm/ft of drawdown (alluvium and marine terrace). The alluvium and marine terrace aquifers are similar in hydraulic properties, averaging 2.82 and 2.64 gpm/ft of drawdown, respectively; the average for bedrock is 0.66 gpm/ft of drawdown. This suggests that the T-values of the geologic units range between 1,000 gpd/ft for bedrock and 5,500 gpd/ft for the alluvium and marine terrace units.

In summary, the marine terrace aquifer near the proposed Lower Pilarcitos Creek wellfield has a T-value of about 16,000 gpd/ft, an aquifer thickness of about 32 feet, a K-value of 500 gpd/ft^2, and is a confined aquifer. The marine terrace aquifer near the Balboa wellfield has a T-value of about 9,400 gpd/ft, an aquifer thickness of about 42 feet, a K-value of about 224 gpd/ft^2, and an S-value of 0.0011 (confined aquifer). In regions south of the proposed Lower Pilarcitos Creek wellfield, the T-value is lower ranging between 1,500 and 7,000 gpd/ft. Regional informal pumping tests and empirical analysis of the data suggest that the T-value may range between 1,000 and 5,500 gpd/ft for bedrock and marine terrace aquifers, respectively. In general, the informal pumping test data are consistent with formal aquifer and well testing.

Groundwater Elevation Maps

Geoconsultants (June 1987, August 1991, and September 1993) constructed four groundwater elevation or potentiometric maps for the Lower Pilarcitos Creek coastal plain between Arroyo de en Medio and Cañada Verde. The four maps include (1) a composite map for 1978 to 1987, (2) winter 1990-91, (3) summer 1991, and (4) summer

1993. Review of these maps indicates that groundwater flows consistently from east to west discharging into the Pacific Ocean.

Three hydraulic (groundwater) gradients were estimated from each map at approximately the same location from the foothills to the coastline. These locations are parallel to and south of Frenchmans Creek, along Pilarcitos Creek, and in the vicinity of Higgins Canyon. Hydraulic gradients ranged between 0.0048 to 0.016 feet per foot (ft/ft). The average hydraulic gradients for the Higgins Canyon (0.011 ft/ft) and Frenchmans Creek (0.0083 ft/ft) areas tend to be similar to but steeper than gradients along Pilarcitos Creek (0.0077 ft/ft). In general, winter hydraulic gradients (0.0085 to 0.010 ft/ft) tend to be steeper than summer gradients (0.0048 to 0.011 ft/ft) reflecting the effect of groundwater recharge during the winter.

Groundwater Fluctuations

Since the 1960's groundwater levels have been collected from two wells in the Lower Pilarcitos Creek groundwater basin for varying durations. Wells 5S/5W32K and 5S/5W29F04 have been measured by DWR and USGS, respectively. Figure 15 shows the location of these wells while Figure 19 shows the hydrograph record for the wells.

Well 32K is located south of Pilarcitos Creek near the intersection of Highway 1 and Purisima Avenue, at a ground surface elevation of 90 feet, and is screened opposite the Purisima Formation. The groundwater elevation ranges between 45 and 75 feet above msl and averages about 62 feet above msl. Annual groundwater fluctuations are about 5 feet.

Well 29F4 is located north of Pilarcitos Creek near the intersection of Highway 1 and Highway 92, at an elevation of about 50 feet, and is screened opposite the terrace marine aquifer. The groundwater elevation ranges between 9 and 48 feet above msl, averaging about 35 feet above msl. Groundwater fluctuations over the period of record span about 30 feet. In contrast to 32K, the annual groundwater fluctuations are between about 10 and 20 feet. This suggests that the marine terrace aquifer is significantly affected by winter recharge that raises groundwater levels and by the persistent discharge of groundwater to the Pacific Ocean that lowers groundwater levels.

Between October 1986 and May 1991, Geoconsultants (August 1991) collected water levels for a network of 42 wells between Miramar and Cañada Verde. The duration of the water level records ranges between 14 and 55 months (4.5 years). In general, review of these hydrographs indicates that water levels fluctuate between 1 and 19 feet on a seasonal basis. Those wells located adjacent to Pilarcitos Creek and screened opposite the terrace marine aquifer show the greatest fluctuations, ranging between 10 and 15 feet and comparable to those observed at Well 29F4. This suggests significant stream recharge in the winter.

Aquifer Storage and Usable Storage

Aquifer storage can be estimated for the marine terrace aquifer beneath the coastal plain of Half Moon Bay. The areal extent of the aquifer (1,765 acres) is assumed to be coincident with the area of the Lower Pilarcitos Creek groundwater basin. The thickness of the aquifer ranges between 20 and 60 feet, while the specific yield of the aquifer is about 15 percent (0.15). Therefore the total groundwater storage of the marine terrace aquifer ranges from 5,290 to 15,870 AF, averaging 10,600 AF. Assuming that only one-third of the stored water can be used, then the average usable storage is 3,533 AF. The seasonal water level changes result in significant changes in usable storage; summer declines result in summer/autumn usable storage of about 1,763 AF.

Groundwater Discharge

Groundwater discharge to the Pacific Ocean in the Lower Pilarcitos Creek groundwater basin can be estimated using a modification of Darcy's law which states that groundwater flow is proportional to the T-value (K-value times aquifer thickness), the hydraulic gradient, and the width of the aquifer. The width of the aquifer from Frenchmans Creek to Higgins Canyon is about 14,000 feet. The average summer and winter hydraulic gradients are 0.0079 and 0.0093 ft/ft, respectively, and the T-value ranges from 9,400 gpd/ft near the Balboa wellfield to 16,000 gpd/ft near the proposed Lower Pilarcitos Creek wellfield. Groundwater flow ranges between 74.26 gallons per day per unit width (gpd/unit width) of aquifer in the summer to 148.80 gpd/unit width of aquifer in the winter. Calculations show that groundwater outflow to the ocean ranges between 1,175 AFY under summer conditions to 2,334 AFY under winter conditions.

Saltwater Intrusion

The geologic units comprising the Lower Pilarcitos Creek groundwater basin extend to the west underneath Half Moon Bay. Near the shoreline, an interface exists between the onshore fresh water and saltwater beneath the ocean. The density of saltwater (1.025 grams per cubic centimeter [g/cm^3]) is greater than that of fresh water

($1.000\ g/cm^3$), allowing the fresh water to float on top of the saltwater (Todd, 1980) and to seep directly into the ocean. The fresh-salt water interface is a broad zone of mixing rather than a sharp boundary. The ground surface expression of the interface usually is defined by mean sea level along the coastline.

The shape of the interface is defined by a non-linear polynomial equation (Todd, 1980). The equation relates the width of the seepage face along the coastline, the depth below sea level of the interface, the density contrast between saltwater and fresh water (40), the hydraulic conductivity of the aquifer (224 to 500 gpd/ft^2; averaging 362 gpd/ft^2), and the unit discharge of groundwater per unit length of shoreline (11,500 feet). The fresh-salt water equilibrium requires that the water table or groundwater elevation (potentiometric surface) be above sea level and slope toward the ocean, otherwise seawater will advance directly inland (Todd, 1980).

Calculations show that the dynamic location of the toe of the fresh-salt water interface changes with the amount of groundwater discharge from the aquifer. Between an average winter discharge (2,334 AFY) and summer discharge (1,175 AFY), the toe of the fresh-salt water interface moves inland from 34 feet in winter to 83 feet in summer while the seepage faces decreases from 10 feet in winter to 5 feet in summer. Additional pumpage from the marine terrace aquifer would reduce the aquifer discharge and result in additional inland migration of the fresh-salt water interface. If 80 percent of the summer discharge (940 AFY) is pumped from the aquifer, then the groundwater discharge to the Pacific Ocean would be 235 AFY. The toe of the fresh-salt water interface would move inland by 437 feet to a new dynamic position. The submarine seepage face would decrease to one foot in width.

Land Subsidence

Land subsidence is the lowering of the natural ground surface, which can result in damage to structures and disrupt the gradient of streams and canals (Todd, 1980). It has been documented in areas of intensive groundwater pumping and groundwater level decline, including portions of the San Joaquin and Santa Clara valleys. Such subsidence occurs in groundwater basins with a significant thickness of saturated fine-grained sediments and significant lowering of the water table. It results from loss of hydrostatic pressure and subsequent compaction of clay layers. Coarse-grained sediments are subject to smaller amounts of compaction (Borchers, 1998). Subsidence is not an issue for the Lower Pilarcitos Creek groundwater basin, which is characterized by a relatively thin sequence of alluvial sediments and shallow fine-grained sediments.

Watershed Water Balance

Two water balance approaches are provided for the Pilarcitos Creek drainage basin. One approach is regional, and accounts for the entire surface watershed area (17,069 acres) above the Pilarcitos Creek at Half Moon Bay gauge station. The second approach, summarized in the next section, applies the soil moisture balance methodology to the Lower Pilarcitos Creek groundwater basin (1,765 acres) below the Pilarcitos Creek at Half Moon Bay gauge.

Methodology and Data

A water balance study for a watershed accounts for all water (surface water, evapotranspiration [ET], and groundwater) that occurs in a watershed. If the estimates and calculations are realistic, then the final water balance should be zero (i.e., Inflow – Outflow ± Change in Storage = 0). The first methodology determines the regional water balance based on a lumped sum parameter approach, average annual rainfall, and streamflow measurements. The second methodology determines the local water balance for the Lower Pilarcitos Creek groundwater basin based on monthly soil moisture, ET, and water yield calculations during a selected time interval (1986 to 2001). For comparison, the first methodology determines the relative volume or magnitude of key water balance components (e.g., ET), while the second methodology provides estimates of specific components for the groundwater basin.

The following summarizes pertinent data from previous sections for the water balance calculations. Figure 1 shows the watershed areas, divided into sub-basins based on the location of stream gauge stations, while Table 3a summarizes the acreage of each area contributing to the stream gauge station and average record discharges. Table 8 summarizes the stream gauge station and precipitation data for each watershed. The drainage areas reported in Tables 3 and 8 differ by about two percent, reflecting differences in measurement by the USGS and Todd Engineers, respectively.

Table 8 also shows the estimated average precipitation upstream and contributory to each streamflow gauge station. Precipitation ranges from 32.53 to 38.98 inches in the Pilarcitos Creek watershed above the Half Moon Bay gauge and 36.66 inches above the Purisima Creek gauge. These average values were estimated by measuring the area between isohyets (Figure 4) for each area and then calculating a weighted rainfall average for the drainage area.

Area above the Purisima Creek Gauge

A water balance for the Purisima Creek gauge was conducted to verify and compare values estimated for the Pilarcitos Creek watershed. Unlike the Pilarcitos Creek watershed, the Purisima Creek watershed is a nearly native and non-urbanized watershed. Table 9 (Column A) shows an accounting of the water in the upper Purisima Creek. Note that the altitude of the Purisima Creek gauge (about 380 feet above msl) and the average annual precipitation (36.66 inches) are similar to the altitude of the Pilarcitos Creek below Stone Dam gauge (500 feet above msl) and precipitation in the Pilarcitos Creek watershed (34.08 to 38.98 inches). Both watersheds experience the same basic weather patterns.

Based on the isohyetal map (Figure 4), approximately 36.66 inches (about 3 feet) of precipitation falls on the 3,168 acres during an average year. The area for the Purisima Creek watershed is approximately 25 percent smaller than the area for the Pilarcitos Creek below Stone Dam drainage basin.

For all regional watershed analyses presented, it can be assumed that the surface water drainage divides also represent the groundwater divides. This reasonable assumption implies that surface water and groundwater inflow to the watershed does not occur. In addition, no water is imported into the Purisima Creek watershed. Therefore, the total inflow to the Purisima Creek watershed is 9,678 AFY.

Precipitation that falls on the Purisima Creek watershed drains toward the Pacific Ocean and passes the gauge station on Purisima Creek as surface water or groundwater, or is consumed by plants and evaporation. ET cannot be directly or easily measured. Therefore, ET becomes an unknown quantity to be estimated as the residual or remaining quantity of water after all other water balance components are itemized and accounted. Change in storage is assumed to be zero.

Average streamflow for the Purisima Creek gauge station is about 2,418 AFY for the record between 1959 and 1969. Subsurface outflow cannot be readily measured but can be assumed to be about 1 percent of the surface water discharge in the upper reaches of a watershed. Subsurface flow can also be estimated, where appropriate, using Darcy's Law. The undetected subsurface outflow for the upper Purisima Creek watershed is about 24 AFY (1 percent). Exported water to the Purisima Creek watershed is zero. Therefore, the difference between the inflow (9,678 AFY) and outflow (2,442 AFY) suggests that ET consumes 7,236 AFY.

ET can be expressed in terms of percent precipitation. For the Purisima Creek watershed, 74.8 percent of the precipitation on the upper Purisima Creek watershed is removed from the watershed by ET. The surface water runoff coefficient for the Purisima Creek watershed is 0.76 AF/acre, consistent with the bedrock geology of the watershed.

Area above the Pilarcitos Creek below Stone Dam Gauge

A second regional water balance was conducted for the watershed above the Pilarcitos Creek below Stone Dam gauge (Table 9, Column B). The results of the water balance for this area are similar to the results estimated for the Purisima Creek watershed.

The average annual precipitation on the 4,090 acre watershed is 38.98 inches (about 3.25 feet). No surface or subsurface inflow occurs in the watershed and no water is imported into the watershed. Therefore, the total inflow to the upper Pilarcitos Creek watershed is about 13,284 AFY or approximately 27 percent greater than the upper Purisima Creek watershed, comparable to the difference in areas (23 percent).

Precipitation that falls on the upper Pilarcitos Creek watershed drains toward the Pacific Ocean and eventually passes the gauge stations on Pilarcitos Creek as surface water or groundwater. ET becomes an unknown quantity to be derived as the residual or remaining quantity of water after all other water balance components are itemized and accounted. Change in storage is assumed to be zero.

Average streamflow for the Pilarcitos Creek below Stone Dam gauge station is about 2,339 AFY for the record between 1997 and 2001. The undetected subsurface outflow for the upper Pilarcitos Creek watershed is about 23 AFY (1 percent). Based on records provided by the City of San Francisco (see Appendix 5), diversions from Pilarcitos Creek amount to about 760 AFY. Therefore, the difference between the inflow (13,284 AFY) and outflow (3,122 AFY) suggests that 10,162 AFY is removed by ET and deep percolation.

ET as a percent of precipitation is 76.5 percent, similar to the 74.8 percent ET estimated for the upper Purisima Creek watershed. The surface water runoff coefficient for the upper Pilarcitos Creek watershed is 0.76 AF/acre, consistent with the bedrock geology of the watershed.

Area above Pilarcitos Creek at Half Moon Bay Gauge

A water balance was conducted for the area above the Pilarcitos Creek at Half Moon Bay gauge (Table 9, Column C). This balance includes the upper Pilarcitos Creek watershed and provides an estimate of the groundwater outflow to the Lower Pilarcitos Creek groundwater basin.

Based on the isohyetal map (Figure 4), the average annual rainfall on the 17,069 acre watershed is 34.08 inches (about 2.84 feet). No surface or subsurface inflow occurs in the watershed. After treatment at the Nunes Water Treatment Plant (WTP), minor amounts of imported water (77 AFY) are brought into the watershed from Crystal Springs Reservoir (see Appendix 6). Therefore, the total inflow to the Pilarcitos Creek watershed is about 48,552 AFY or approximately 365 percent greater than the upper Pilarcitos Creek watershed.

Because of the proximity to the coast (fog belt), the ET for the entire Pilarcitos Creek watershed was assumed to be approximately five percent less than the average ET of the upper Pilarcitos Creek (76.5 percent) and Purisima Creek (74.8 percent) watersheds or about 71.5 percent. Accordingly, ET is estimated to be 34,660 AFY.

Average streamflow for the Pilarcitos Creek at Half Moon Bay gauge station is 11,543 AFY for the record between 1967 and 2001. Subsurface outflow cannot be readily measured and is estimated from the residual of the water balance. Based on records provided by the City of San Francisco (see Appendix 5), exported water from the watershed amounts to about 760 AFY. Other diversions include the Pilarcitos Creek wellfield operated by CCWD (155 AFY) and Pilarcitos Lake diversions (913 AFY) (see Appendix 6). Therefore, the difference between the inflow (48,552 AFY) and outflow (48,031 AFY) suggests that 521 AFY is groundwater outflow. The undetected subsurface outflow for the Pilarcitos Creek watershed can also be estimated using Darcy's Law (254 to 508 AFY). In terms of the surface water runoff coefficient for the Pilarcitos Creek watershed, calculations show that 0.68 AF/acre of water drains from the watershed.

Precipitation at the Half Moon Bay Station ranges between 13.03 inches in 1972 to 52.92 inches in 1983; the long-term average is 26.40 inches. Therefore, total inflow to the Pilarcitos Creek watershed could range between 23,985 (49.4 percent of average) in dry years to 97,347 (200.5 percent of average) in wet years. The total estimated groundwater inflow to the Lower Pilarcitos Creek groundwater basin ranges between 257 AFY in dry years to 1,107 AFY in wet years.

Groundwater Basin Water Balance

This section describes the water balance (inflows, outflows, and change of storage) for the Lower Pilarcitos Creek groundwater basin. Trends over the study period (1986-2001) and previous evaluations also are discussed. In brief, inflows and outflows are balanced over the study period at about 2,200 AFY. Perennial yield, however, is defined by the amount of subsurface discharge that can be captured without inducing harmful saltwater intrusion. Consideration of saltwater intrusion indicates that a total pumping of about 940 AFY can be sustained without inducing significant saltwater intrusion into wells. Use of such a value for perennial yield is a management decision.

Inflows

Inflows to the Lower Pilarcitos Creek groundwater basin (1,765 acres) include rainfall recharge, deep percolation from irrigation water, subsurface inflow, stream recharge, and leakage from pipelines. Other small inflows include septic tank return flows and subsurface inflow from bedrock; however, these are likely insignificant.

Rainfall Recharge. Rainfall recharge to the groundwater basin was evaluated based on application of a soil moisture balance methodology to local rainfall, evapotranspiration, and land use characteristics. For this water balance, a representative study period of 15 years was selected, extending from October 1986 through September 2001. This period includes drought (1987 through 1991) and very wet years such as 1998, when rainfall exceeded 50 inches. The average rainfall over the period is 26.87 inches, close to the long-term average of 26.40 inches.

The soil moisture balance methodology takes into account rainfall, runoff, soil moisture holding capacity, and ET to compute rainfall recharge. In brief, monthly water balances are developed to account for rainfall occurring on a representative volume of soil. First, runoff is estimated to account for 20 percent of rainfall, comparable but slightly lower than the runoff/rainfall ratio for the upper watershed.

The remaining water infiltrates into the soil. At the beginning of the rainfall season, water infiltrating into the soil is subject to ET. Over each month of the rainfall season, if the amount of rainfall exceeds the ET demands, then an amount is stored as soil moisture. Infiltrating rainfall accumulates in soil moisture throughout the season until it exceeds soil moisture holding capacity. At this point, the surplus water becomes available for groundwater recharge.

This is a simplified accounting of what happens to rainfall. However, it can be tailored to a specific area by taking into account local rainfall amounts, soil conditions, and ET for different land use conditions (e.g., native vegetation, crops, or landscaping). This method also can yield insights into the variability of groundwater recharge in average, wet, and dry years.

Land uses in 1987 and 2002 (representing conditions at the beginning and the end of the study period) were subdivided into three major categories: urban, open space, and irrigated agriculture. As described in the Land Use section of this report, urban areas are estimated to be 32 percent impervious. For the purposes of the water balance, the remaining 68 percent of the area is assumed to be irrigated landscaping. Similarly, agricultural areas are estimated to be 96 percent irrigated cropland and 4 percent impervious. Open space is considered to have no effective impervious area and to be entirely non-irrigated native vegetation (grass and shrubs). As shown in Table 10, the land uses can be subdivided according to these percentages and then regrouped relative to their impervious, irrigated or non-irrigated condition.

Impervious areas provide no significant recharge, so water balance spreadsheets (see Appendix 7) were developed for two land use conditions: open space/native vegetation and irrigated landscaping/cropland. Water balances were computed monthly for the 15-year study period, water years 1987 through 2001. The water balances used monthly rainfall values from the Half Moon Bay airport climate station, average monthly ET values for the coastal fog belt zone, and a soil water holding capacity of 6.7 inches. Full potential ET was applied both to cropland and landscaping, while ET from natural vegetation was reduced using a coefficient for grassland/sagebrush. Phreatophyte consumption (estimated as the full potential ET) is addressed separately as a water balance outflow item.

Table 11 summarizes rainfall and recharge for each year in the study period. As indicated, the average rainfall recharge rate is greater on the natural vegetation/open space areas (7.98 inches/year) than on landscaping/cropland areas (5.32 inches/year), reflecting the lower ET of natural vegetation. For both land use types, annual recharge ranged from a low of zero in the drought year of 1990 to more than 20 inches in 1998.

Table 12 applies the recharge rates from Table 11 to total acreage values from Table 10 for 1987 and 2002 land use conditions. As indicated, average recharge from rainfall amounts to 885 AFY with 1987 land use conditions and 822 AFY given 2002 land uses. The computed decline in recharge is the result of increased impervious surfaces in the groundwater basin over the study period.

Deep Percolation from Irrigation. Irrigation in the groundwater basin includes irrigation of crops and irrigation of landscaping. A portion of the water applied for irrigation of crops or landscaping percolates through the soil downward to recharge the groundwater basin. If the source of the irrigation is water imported from beyond the limits of the groundwater basin, then the deep percolation represents an inflow to the groundwater basin. If the irrigation source is local groundwater, then the deep percolation is not an inflow, but rather a return flow that simply recycles groundwater back into the basin.

Two areas of cropland are irrigated primarily with sources of water beyond the groundwater basin. These include fields irrigated by diversions from Frenchmans Creek on the north edge of the basin and fields that have been irrigated from Arroyo Leon on the south edge of the basin. These fields encompass an estimated 180 acres. Review of the soil moisture balance for landscaping and cropland (Appendix 7) indicates that the irrigation water required to supplement rainfall and fulfill the full potential ET is 16.70 inches or 1.39 feet/year. It is assumed that irrigation efficiency is 85 percent; in other words, more water is applied than is actually needed by the crops. In addition, it is assumed that the surplus water percolates downward and does not run off the fields as surface water. Accordingly, the applied water amounts to 1.64 feet/year and the amount of deep percolation is 0.25 feet/year (1.64 -1.39). Application of this deep percolation rate to the 180 acres of irrigated cropland results in a deep percolation of 45 AFY.

Landscape irrigation in the groundwater basin includes the irrigation of parks, playing fields, and landscaping around public buildings, businesses, apartment complexes, and homes. Some of this irrigation is provided by local groundwater; however, most of the landscape irrigation currently is supplied through the importation of CCWD water (primarily its Crystal Springs, Pilarcitos Lake, and upper Pilarcitos Creek wellfield supplies).

Information on the amount of water imported to the groundwater basin per se is not readily available. Accordingly, water imported to the groundwater basin has been estimated using available information on housing and water sales. First, the United States Census 2000 reports the existence of 4,004 occupied housing units in the City of Half Moon Bay, which extends to the north and south beyond the basin. With an estimated 1,000 homes beyond the groundwater basin boundaries, then approximately

3,000 homes exist within the basin. Most of these are single-family homes. The average water usage of a single family home within the service area as of 2001 is 244 gallons/day (244 gpd or 0.273 AFY; see CCWD, March 2002, Table 6). Accordingly, water imported for residential purposes in the basin amounted to 820 AF in 2001 (3,000 x 0.273).

These amounts do not account for the various commercial, multiple-unit residential, and public service water users. Review of water sales data for the entire service area (Table 5 in CCWD, March 2002) indicate that urban water sales (not including floriculture and irrigation sales) are mostly residential (67 percent in both 1987 and 2001). The remaining water sales are for various recreational, commercial, school, and multiple-unit residential customers. Applying this ratio to the groundwater basin indicates that total water import for residential, commercial, and public service uses amounted to 1,224 AF in 2001 (820 AF for residential and 404 AF for commercial, multiple unit, and public service uses).

Of this water, some is used indoors, where it is either consumed by evaporation or discharged as wastewater. The City of Half Moon Bay, including the groundwater basin area, is predominately sewered and the collected wastewater is discharged to the ocean.

The remaining portion of the imported water is used outdoors for landscape irrigation. This irrigation water is consumed by evapotranspiration or percolates downward to recharge groundwater. The amount of water used outdoors in Half Moon Bay is estimated at 40 percent. This proportion is relatively low, reflecting the locally low water use rates (CCWD, 2000) and the cool climate. Accordingly, the estimated amount of water used outdoors is 490 AF (1,224 x 0.4). Of this amount, 15 percent or 73 AF is assumed to percolate to groundwater.

In sum, estimated deep percolation of water from agriculture is 45 AF and from landscape irrigation is estimated at 73 AF. The total deep percolation, 118 AFY under current conditions, represents a small but significant inflow.

Subsurface Inflow. Groundwater flows into the groundwater basin along its eastern boundary with the bedrock uplands and through the alluvium that underlies the upper Pilarcitos Creek valley. The amount of inflow from bedrock is small and not quantified for this study.

The amount of subsurface inflow from the upper Pilarcitos Creek valley has been quantified using two methodologies. First, Darcy's Law was applied to the cross section where the Pilarcitos Creek valley enters the coastal plain. As a result of variable water table gradients, the resulting subsurface flow varies between about 254 and 508 AFY.

Second, the subsurface flow was computed as the residual of the water balance at the groundwater basin boundary. This accounting of the difference between inflows (48,475 AFY) and outflows (48,026 AFY) over the 35-year period of record indicates an average subsurface flow of 449 AFY.

Stream Recharge. Available hydrogeologic information show that the Pilarcitos Creek channel is situated above the regional water table over much of its 6,000-foot length across the Lower Pilarcitos Creek groundwater basin. Accordingly, a downward hydraulic gradient exists to the water table, indicating that streamflow percolates downward. This downward percolation may be slow and subject to temporary storage in perched water bodies, but eventually provides inflow to the underlying aquifer.

No data exist to demonstrate what happens to streamflow that passes the gauge station at Highway 1. Such data could be obtained through a synoptic survey of the stream. A synoptic survey involves measurement of streamflow at several stations along the channel, accounting for any inflows (e.g., from storm drains) and any discharges (e.g., diversions). The increase or decrease in streamflow along the channel length then would reflect inflow from groundwater or outflow (recharge) to groundwater, respectively. For example, a survey of Denniston Creek on March 16, 1998 indicated recharge of 29 AF per day (14.60 cubic feet per second [cfs]) along the 6,000-foot-long reach crossing the coastal plain (Balance Hydrologics, April 2002, p. A-28).

Although data are lacking, anecdotal information suggests that the lower reach of the creek provides flow to groundwater recharge. For example, a survey on July 25, 1985 noted streamflow of 0.65 cfs at Highway 1 and zero flow at the mouth of the stream (Zatkin, 2002). However, assessment of the amount of recharge is complicated by irrigation diversions from the creek and riparian vegetation consumption.

For this study, no adequate data are available to provide a firm estimate of stream recharge. However, this source of inflow is probably significant. In the absence of data, recharge often is estimated as a percentage of rainfall or runoff. For example, estimates of the El Granada area (Kleinfelder, April 1988) suggested recharge at five percent of runoff. Previous estimates for the Lower Pilarcitos Creek groundwater basin

(Geoconsultants, June 1987 and August 1991) estimated recharge as 15 percent of runoff. Application of the assumed recharge rates of 5 and 15 percent to the average annual Pilarcitos Creek flow at Half Moon Bay (11,543 AFY) yields a range from 587 to 1,730 AFY. For this study, an assumed average annual recharge rate of 1.0 cfs per day on a year-round basis results in recharge of 723 AFY.

The recharge/runoff ratios also can be applied to evaluation of wet periods and drought. For example, application of a 15 percent recharge rate to total streamflow in the drought year of 1990 (1,725 AF, see Table 3.1) would result in estimated recharge of only 259 AFY. Assuming a less efficient recharge rate of 5 percent in a very wet year like 1998 (36,783 AFY) results in an estimated recharge of 1,839 AFY.

Leakage from Pipelines. The CCWD's most recent *Water Supply Evaluation* (Table 4 in CCWD, March 2002) includes a discussion of leakage from pipelines, which represent an inadvertent inflow of imported water to the groundwater basin. According to CCWD, unmetered water includes authorized uses such as pipeline flushing and firefighting. It also includes unauthorized uses, such as meter inaccuracy and pipeline leaks. Annual unmetered water has ranged between 13.4 and 95.4 million gallons (MG) over the study period and has averaged 50.4 MG per year. The CCWD's review of unmetered water in 2002 indicated that 18 MG of unmetered water were the result of authorized uses and meter inaccuracy, and the remainder was the result of leaks.

For this study, it is assumed that an average of 20 MG per year of unmetered water are the result of authorized uses and meter inaccuracy, and that the remainder, about 30 MG per year (or 95 AFY) is the results of leaks. Of this service area-wide amount, 50 AFY is assumed to occur within the groundwater basin, representing a small inflow.

Outflows

Outflows from the Lower Pilarcitos Creek groundwater basin include subsurface outflow to the ocean, groundwater pumping and export, and groundwater pumping and consumption. Phreatophyte water consumption is very small, but significant to supporting the riparian corridor along lower Pilarcitos Creek.

Subsurface Outflow. As described previously in the *Hydrogeologic Setting* section, the marine terrace aquifer is a relatively thin (30 to 50 feet thick) aquifer that slopes from east to west, extending under the Pacific Ocean. Similarly, groundwater levels decline from east to west, indicating groundwater flow toward the ocean. As detailed in the section, *Hydraulic Properties of the Marine Terrace Aquifer,* this groundwater outflow was estimated using Darcy's Law. The amount of groundwater outflow varies seasonally and is estimated at 1,175 AFY in summer and 2,334 AFY in winter. For the overall water balance, an average value of 1,755 AFY is used.

Groundwater Pumping and Export. The only known groundwater pumping and export from the basin is that of Ocean Colony Partners, operating four wells at the north end of Balboa Boulevard near Kelly Avenue (Ocean Colony, August 27, 2002). The water is pumped to irrigate 210 acres of the Half Moon Bay golf links, located south of the groundwater basin. Annual water usage is 347 AFY; this represents an export from the basin.

Groundwater Pumping and Consumption. Groundwater is pumped from the groundwater basin and used for cropping, landscape irrigation, and domestic use.

Approximately 94 acres of cropland in the groundwater basin are irrigated primarily with groundwater. Review of the soil moisture balance (Appendix 7) for landscaping and cropland indicates that the irrigation water needed to supplement rainfall and fulfill the full potential ET is 1.39 feet/year. It is assumed that all water applied in excess of this amount percolates downward and returns to groundwater. Accordingly, the amount of consumed water is the full potential ET, 1.39 feet/year. Application of this rate to the 94 acres of irrigated cropland results in a groundwater consumption of 131 AFY.

Most of the landscaping irrigation demand is supplied by the CCWD, which serves local schools, parks, and multiple-unit housing developments with extensive commons. Possible exceptions include wells operated by the Amesport Landing Homeowners Association and Holiday Inn. This commercial groundwater pumping and consumption for landscape irrigation is assumed insignificant.

Numerous domestic wells have been drilled in the groundwater basin. As described in the previous section on *Groundwater Development and Wells*, 265 wells were drilled during 1985 through 1991, most because CCWD connections were not available. It is assumed that almost all of these were abandoned when CCWD connections became available. As a result, it is estimated that 126 wells serve households in the groundwater basin.

Assuming that these households use 0.273 AFY (the CCWD average water usage for a single family home), then pumping from the 126 wells amounts to 34 AFY.

To estimate consumption of this water, it is assumed that 60 percent is used indoors and is lost to evaporation or sewage discharge to the ocean. Of the 40 percent used outdoors, only 15 percent returns to groundwater and 85 percent is lost to evapotranspiration. Accordingly, of the 34 AFY that is pumped, only 2 AFY is returned and the remaining 32 AFY is consumed. This is a very small outflow.

In summary, groundwater pumping and consumption for irrigation (131 AFY) and domestic uses (32 AFY) amounts to 163 AFY.

Phreatophyte Consumption. Lower Pilarcitos Creek is characterized by a corridor of riparian vegetation along most of its length across the groundwater basin. This riparian zone, estimated to encompass about 28 acres (6,000 feet long by 200 feet wide), is included in the open space/natural vegetation land use area described in the previous section concerning inflow from rainfall recharge. However, it is recognized that phreatophytes consume more water than other native vegetation types. Review of the water balance (Appendix 7) for native vegetation indicates that the amount of water needed for this increased consumption (potential ET minus actual ET) averages 8.2 inches/year. Accordingly, the water needed to support the riparian vegetation in addition to rainfall is about 19 AFY. This outflow is very small relative to other water balance components.

Change in Storage

Change in storage is represented by change in groundwater elevations; for this study, with specific reference to the period 1987 through 2001. In the Lower Pilarcitos Creek groundwater basin, water level data have been gathered consistently over the study period for only one well, 5S/5W29F04. This well, located near Pilarcitos Creek and Highway 1 in the center of the basin, has been monitored by the DWR since 1960 (see Figure 19). Water elevations in this well in the mid-1980s generally varied between 30 and 40 feet MSL on a seasonal basis, then gradually declined during the drought from 1988 through 1993. The relatively wet period after 1994 resulted in a recovery of groundwater levels to between 30 and 40 feet MSL after 2000. Over the study period specifically, water levels changed from 29 feet MSL (November 5, 1986) to between 35 and 39 feet MSL in 2000-2002 (no measurements were taken in 2001).

For the purpose of this water balance, change in groundwater storage is deemed to be zero. This assumption is based not only on the record of one well, 29F04, but also recognizes the relative lack of change in groundwater pumping over the study period.

Although numerous wells were drilled in the 1980s for domestic use, most of these were subsequently abandoned. While the pumping for the Balboa wellfield has increased since the mid-1980s, the cropland irrigated with local groundwater has declined slightly since 1987.

Water Balance Equation

The water balance equation combines the components of inflow, outflow, and change in storage. In this water balance evaluation, each component of inflow, outflow, and change in storage has been evaluated independently. Over a representative period of time, the equation should balance; any residual represents the net error inherent in estimations and assumptions.

Table 13 summarizes the water balance for the Lower Pilarcitos Creek groundwater basin. Inflows amount to an estimated 2,162 AFY, outflows total 2,284 AFY, and change in storage is zero. Combining the components results in a residual of -122 AFY, which represents a net error of about 5 percent. For discussion purposes, the average annual inflows and outflows are balanced over the study period at 2,200 AFY.

With regard to inflows, rainfall recharge and stream recharge apparently are the most significant inflows, each accounting for about one-third of inflows. Subsurface inflow from the upper Pilarcitos Creek valley also is significant. Pipeline leakage, although known to occur, is a very small component.

Stream recharge is an important component of the water balance equation. As noted in the section on stream recharge, no data exist to evaluate the amount of stream recharge. However, the independent evaluation of all the other components and their subsequent combination indicate that stream recharge is a substantial source of inflow to the groundwater basin.

Of the outflows, subsurface outflow to the ocean is predominant, accounting for an estimated 77 percent of the outflows. Groundwater export and consumption account for the remaining outflows. Phreatophyte consumption, while crucial to the maintenance of the riparian corridor, is not a significant part of the water balance equation.

Change in storage has been deemed zero, although available data (i.e., water levels in well 29F04) suggest a slight increase in groundwater storage over the study period. The increased groundwater storage and the net residual error of –122 AFY suggests that inflows are underestimated and/or outflows are overestimated. Stream recharge is one of the largest single components and the least known, and warrants further investigation.

Drought Conditions

Drought results in significantly reduced recharge to the groundwater basin. Impacts of drought were assessed through examination of conditions during the recent severe drought of 1987 through 1991. Over the five years, annual rainfall averaged about 20 inches or 75 percent of the average rainfall over the water balance study period. Inflow components assumed to decrease significantly during drought are rainfall recharge, subsurface inflow, and stream recharge. Deep percolation of irrigation water and pipeline leakage would also decline, particularly in response to drought-time conservation, but these changes are assumed to be small and are not included here.

Rainfall Recharge. Rainfall recharge declines significantly during drought. As documented in Table 11 (and Appendix 7, Water Balance Spread Sheets), annual rainfall recharge averages 5.32 inches on landscaping/crop areas and 7.98 inches on native vegetation. Examination of Appendix 7 for the drought years reveals that annual rainfall recharge rates decline to averages of 1.1 and 3.2 inches for landscaping/crop and native vegetation areas, respectively. This assumes that potential ET rates do not change, neither increasing because of hot, dry conditions nor decreasing as plants die back. Applying these recharge rates to the estimated 2002 acreage in the groundwater basin for landscaping/crop areas (465 acres) and native vegetation areas (356 acres) results in rainfall recharge of 32 AFY for landscaping crop areas and 126 AFY for native vegetation areas, for a total of 158 AFY. This drought-time average rainfall recharge of 158 AFY is significantly less than the 822 AFY of rainfall recharge under average conditions (see Table 13, Summary of Water Balance).

Subsurface Inflow. Similarly, subsurface inflow would decline. Estimated from water table gradients, subsurface inflow under historical conditions is estimated as varying between about 254 and 508 AFY. The lower value, 254 AFY, is assumed here to be representative of drought conditions.

Stream Recharge. As noted previously, stream recharge probably is the least known inflow component. It has been assessed in the past as 5 to 15 percent of runoff. Runoff during the five drought years ranged from 1,725 AF in 1990 to 5,889 AF in 1989 and averaged 3,395 AFY (see Appendix 3). For this analysis, it is assumed that dry conditions would result in relatively high stream recharge of 15 percent. Applying this rate to annual runoff during the five drought years results in an estimated stream recharge of 509 AFY.

Drought Recharge. To summarize, drought conditions, like those of 1987 through 1991, would result in a decline in recharge to the groundwater basin. Estimated recharge amounts under drought conditions are as follows:

Rainfall recharge	158 AFY
Deep percolation	118 AFY (not changed)
Subsurface inflow	254 AFY
Pipeline leakage	50 AFY (not changed)
Stream recharge	509 AFY
Total	1,089 AFY

This is approximately half the recharge experienced during average rainfall years. This decrease would result in a decline in groundwater levels, available drawdown in wells, and well yields similar to summer conditions.

Trends

The Lower Pilarcitos Creek hydrogeologic analysis and water balance evaluation show that the Lower Pilarcitos Creek groundwater basin is characterized by substantial groundwater outflow to the ocean. Because of this large outflow, groundwater storage that accumulates during the winter wet season drains relatively quickly to the ocean during the summer. As a result, seasonal groundwater level changes are relatively large in comparison to long-term changes.

The hydrograph (Figure 19) of Well 29F04, located near the proposed Lower Pilarcitos Creek wellfield, shows a gradual rise in groundwater levels through the 1960s and relatively stable levels until about 1985. The severe, prolonged drought of 1988 through 1993 is marked by a decline of groundwater levels. Groundwater levels since 1995 have varied widely; however, no net change is apparent between the mid-1980s and present.

Changes in land use can affect the water balance of a groundwater basin. In Half Moon Bay, the most significant land use changes since the 1970's have involved conversion of open space (mostly urban vacant land) to urban uses. This conversion results in loss of permeable land for rainfall recharge (unless mitigated). As described in the section on rainfall recharge, estimated rainfall recharge declined from 885 AFY with

1987 land use conditions to 822 AFY with 2002 land uses. This loss of recharge is offset somewhat by increased return flows of imported water used for landscaping irrigation.

Conversion of irrigated cropland to urban uses has been limited in recent years. If such conversion occurs, the impact on the water balance would involve loss of rainfall recharge, which might be offset in part by decreased pumping for agricultural irrigation and return flows of water imported for landscaping.

Previous Work

Water balances were evaluated previously for the Lower Pilarcitos Creek groundwater basin by Geoconsultants (June 1987 and August 1991). The Geoconsultants' water balances are similar to the water balance in this study in two major respects:

- The study areas are similarly defined; while the Geoconsultants area includes 1,720 acres, the study area in this report includes 1,765 acres.
- The total recharge or inflow values are comparable. Geoconsultants estimated total recharge at 2,719 AFY (1987) and 2,261 AFY (1991), while this report provides an estimate of 2,200 AFY.

The water balances differ in overall methodology. Geoconsultants focused on evaluation of two major sources of recharge, rainfall recharge and runoff recharge. This study includes independent evaluation of all major inflow and outflow components and change in storage.

Both studies include evaluation of rainfall recharge, taking into account rainfall, soil moisture holding capacity, ET, and land use. While the values and computations differ, the conceptual approach taken by Geoconsultants and this report is similar. In addition, the rainfall recharge results are similar for the Geoconsultants' 1987 study (871 AFY) and this report (822 AFY). Geoconsultants' 1991 study, addressing drought conditions, estimated rainfall recharge at 599 AFY.

Geoconsultants estimated runoff recharge as 15 percent of runoff, resulting in estimates of 1,848 AFY (1987) and 1,662 AFY (1991). This study estimates stream recharge conservatively at 723 AFY.

In considering perennial yield, Geoconsultants offers two approaches. One is to use one-third of the storage capacity in one year and the second is to use two-thirds of the annual recharge. This results in perennial yield estimates of 1,813 AFY and 1,507 AFY in 1987 and 1991, respectively.

Perennial (Safe) Yield

The perennial yield of a groundwater basin is defined as the rate at which water can be withdrawn perennially under specified operating conditions without incurring adverse impacts (Todd, 1980). The term “perennial yield” is used here instead of safe yield, which has been widely misinterpreted to be a fixed quantity of water (often equated to recharge) that could be extracted. Perennial yield embodies the concepts and intent of City of Half Moon Bay Local Coastal Plan policies (Policy 10-14) which state that new or increased well production shall be limited to a safe yield factor that will not impact water-dependent sensitive habitat, riparian habitats, marshes, and agricultural water use. Perennial yield also accounts for adverse impacts of saltwater intrusion, land subsidence, and decreased creek flow.

Perennial Yield and Recharge. Perennial yield and safe yield have been equated with the total amount of recharge entering a groundwater system. For the Lower Pilarcitos Creek Groundwater Basin, the total average annual recharge is about 2,200 AFY. However, the total recharge can far exceed the amount of water that can be withdrawn without undesirable impacts. Accordingly, the total amount of recharge may provide little if any guidance in developing a groundwater basin. This is the situation in the Lower Pilarcitos Creek Groundwater Basin. Instead, the amount of groundwater that can be safely developed is defined by the hydrologic impacts that can be tolerated and generally depends on the amount of natural *discharge* that can be captured (Bredehoeft, 1982).

Perennial Yield and Discharge. For the Lower Pilarcitos Creek groundwater basin, the single most important feature of the water balance is the predominance of subsurface discharge to the ocean. Unlike some groundwater basins, the aquifer of the Lower Pilarcitos Creek groundwater basin does not discharge significantly to a stream. Accordingly, development of the proposed Lower Pilarcitos wellfield would not capture groundwater that would have supported stream baseflow and riparian habitat. Instead, future wells must capture a portion of the subsurface discharge to the ocean.

The most significant potential adverse impact of such capture would be saltwater intrusion from the ocean. As explained in the section on saltwater intrusion, additional pumping of groundwater would result in inland migration of the fresh-salt water interface.

An example was provided involving pumping of 80 percent of the summer discharge or 940 AFY. This amount of pumping, based on long-term average groundwater gradients, results in an estimated inland migration of the toe of the fresh-salt water interface of 437 feet. This estimated new dynamic position is very close to the shoreline and unlikely to affect any existing wells. The Balboa wellfield, for example, is located about 1,000 feet from the shore. This pumping also would result in maintenance of groundwater discharge to the ocean of 235 AFY.

Existing Pumpage. The value of 940 AFY is based on average groundwater gradients and subsurface outflows that already have been affected by long-term agricultural and domestic groundwater use (amounting to an estimated 163 AFY) and by pumping of the Balboa wellfield to irrigate one golf course (207 AFY). This long-term pumping of 370 AFY has already impacted groundwater gradients, subsurface outflow and seawater intrusion. Accordingly, it is additive to the 940 AFY of additional potential pumping to result in a total potential perennial yield of about 1,300 AFY (940+370=1,310, rounded to 1,300 AFY). This value is lower than, but similar to Geoconsultants' previous perennial yield estimates of 1,813 AFY and 1,507 AFY in 1987 and 1991, respectively. However, a perennial yield of 1,300 AFY is considerably greater than the sum of the long-term groundwater use, recent increase in Balboa export, and pumping from the proposed Lower Pilarcitos wellfield (which totals 817 AFY or 370+147+300 AFY).

Perennial Yield Value. A total pumping of 1,300 AFY can be sustained on a long-term perennial yield basis without inducing significant adverse impacts (i.e., saltwater intrusion into wells). For overall planning purposes, we recommend use of the 1,300 AFY value as the perennial yield (safe yield) for the Lower Pilarcitos Creek groundwater basin.

The perennial yield value of 1,300 AFY is smaller than the estimated 2,200 AFY of total inflow to the groundwater basin, amounting to about 60 percent of inflow. This reflects the unlikelihood that all of the inflow to the groundwater basin can be safely captured without incurring adverse impacts (seawater intrusion). This approach is similar to that of Geoconsultants, who recommended use of two-thirds of the annual recharge as a perennial yield value.

Use of such a value for perennial yield (or safe yield) is a management decision. For example, cities in the Arroyo Grande Groundwater Basin on the San Luis Obispo coast entered into a "Gentlemen's Agreement" in which the estimated safe yield of the basin (9,500 AFY) was allocated among municipal and agricultural pumpers (Cities of Arroyo Grande, et al., 2002). This agreement, based on a previous groundwater basin assessment, specifies an allocation of 200 AFY to subsurface outflow to the ocean, similar to the 235 AFY indicated by the above example.

Water Quality

Groundwater quality is a concern in the Lower Pilarcitos Creek groundwater basin, because many wells yield water with excessive iron and manganese, and locally high chloride concentrations. Accordingly, groundwater quality data are reviewed for CCWD test wells and other wells investigated by CCWD for their 1991 drought relief program. In addition, quality data are reviewed from selected private wells as recorded in selected San Mateo County Department of Health Services records. Potential sources of anthropogenic (human-caused) contamination are identified in the study area.

CCWD Test Wells and Drought Relief Wells

Figure 20 shows the locations of the CCWD Lower Pilarcitos Creek test wells and other wells investigated by CCWD for the drought relief program. The latter wells include the Nerhan, Holiday Inn, Corporate Yard, Amesport 1 and 2, Nurserymens 1 and 3, and Stone Pine Center 1, 4, and 6 wells. Table 14 summarizes the water quality for the CCWD test wells and drought relief wells. Appendix 8 contains water quality data for all the wells and an explanation of the major and minor cations and anions and trace elements in water.

Diagnostic Analysis. Figure 21 shows three selected water quality diagnostic diagrams that were applied to water quality data from test wells and drought relief wells.

The water differentiation diagram (Figure 21a) compares gypsum and sodium chloride contents and is used to indicate the source of salts in an aquifer. The diagram indicates that the CCWD test wells are characterized by low sodium chloride relative to the other wells. The diagram also suggests that the slightly elevated salt contents in the other wells probably were derived from salt spray incorporated into the aquifer during its formation. The elevated chlorides are not from saltwater intrusion.

The calcium-sulfate diagram (Figure 21b) shows how much gypsum is in the water. Gypsum is a somewhat soluble evaporite mineral that can accumulate in an aquifer generally during its formation and therefore, it also indicates the influence of salt spray, which can be a significant source of salts. Accumulation of gypsum also is indicative of relatively low permeability sediments and a relative lack of flow (flushing) through the aquifer.

The calcium sulfate diagram indicates that the test well water has only moderate amounts of gypsum, indicating a fairly permeable aquifer flushed with recharge, presumably from Pilarcitos Creek. Of the drought relief wells, eight of the nine drought relief wells have higher gypsum contents than the test wells, suggesting lower permeability aquifers in those areas.

The groundwater source diagram (Figure 21c) shows the relative concentration of the major ions. If the individual well plots show similar shapes, then the groundwater has similar characteristics and, probably, similar origins. The groundwater source diagram indicates that groundwater from all the wells is derived from similar sources.

Total Dissolved Solids, Iron, and Manganese. As shown in Table 14, total dissolved solids (TDS) concentrations in the test wells range from 330 to 610 milligrams per liter (mg/l); the highest TDS level (from TW3) exceeds the secondary (aesthetic) drinking water standard of 500 mg/l. Similarly, TDS concentrations in the drought relief wells range from 300 mg/l to 710 mg/l. In addition, the water is hard.

Most notably, the analyzed water samples from all the test wells show iron, manganese, and turbidity concentrations in excess of drinking water standards. Similarly, the drought relief wells are characterized by excessive iron, manganese, and turbidity.

The excessive iron and manganese may originate from the underlying Purisima Formation, which is characterized regionally with high iron and manganese. The test wells were completed not only in the marine terrace aquifer, but also in the Purisima Formation with overlapping screens.

However, the excessive iron and manganese may also reflect inadequate test well development and removal of suspended sediment. The water sample analyses showed excessive turbidity, a typical indicator of inadequate well development. In addition, the reported color concentrations (Table 14) for TW2, TW3, TW5, and TW6 and several drought relief wells reflects the high turbidity conditions of the water sample. Turbidity is the amount of light scattered by particulate or suspended particles in water (e.g., muddy water) while color is the absorption of selected wavelengths of light (e.g., by tannins in tea).

As shown in Table 14, aluminum was detected in all of the test well samples and in the drought relief wells samples (where analyzed), which is unusual. Aluminum generally is not present in groundwater in dissolved form except under very acidic ($pH < 4.0$) or alkaline ($pH > 10$) conditions (Borg, 1995, p.193). Under typical surface water and groundwater environments, aluminum occurs as either suspended sediment or in colloidal form. Accordingly, the aluminum detected in test well water samples indicates inadequate well development and the presence in the water samples of suspended sediment (i.e., turbidity).

Problems with excessive turbidity can be minimized with thorough development of wells and proper well screen design. Minimization of turbidity will reduce aluminum, iron, and manganese concentrations. In addition, design of production wells with screens placed solely in the marine terrace aquifer would minimize excessive iron and manganese concentrations.

Groundwater Quality in AP Book 56 Area

Groundwater quality in the Assessor's Parcel (AP) Book 56 area (see Figure 20) was examined to better understand local concerns with groundwater quality. AP Book 56 includes Highland, Silver, and Terrace avenues located north of the CCWD test wells. Wells for domestic water supply were installed in this area from about February 1987 through July 1992. These were generally shallow wells with depths not exceeding 40 to 50 feet below the ground surface.

Table 15 summarizes the groundwater quality data for wells located in the AP Book 56 area. Most of the wells were sampled and tested only for coliform bacteria, iron, manganese, chloride, nitrate, bicarbonate, TDS, and specific conductance (electrical conductivity). In general, groundwater quality after well installation was initially poor, with iron, manganese, and chloride exceeding the drinking water standard, requiring installation of filter systems. For some wells, coliform bacteria exceeded drinking water standards requiring the installation of chlorination systems.

In some cases, well water quality improved after pumping tests, suggesting that many wells were improperly developed. The removal of suspended sediment during extensive pumping probably cleaned these wells. Review of the well records also indicates that most of the local domestic wells were completed in the Purisima Formation, which has lower quality groundwater characterized by high iron and manganese.

Possible Anthropogenic Contamination Sources

As shown in Figure 20, a GeoTracker search identified a number of Leaking Underground Fuel Tank (LUFT) sites within the study area. Most LUFT sites involve diesel and gasoline fuel releases from underground storage tanks. Associated with these releases are aromatic volatile organic compounds (VOCs) such as benzene, toluene, ethyl benzene, total xylenes (BTEX) and methyl-tertiary butyl ether (MTBE). LUFT sites have the potential of contaminating shallow groundwater. In general, gasoline and diesel will float on the water table, but because BTEX and MTBE have significantly high water solubilities, they can impact deeper groundwater sources; therefore, they pose a greater threat to groundwater sources and supplies.

Figure 20 also shows the location of the Ox Mountain Sanitary Landfill along Corinda Los Trancos Canyon, which is a tributary to Pilarcitos Creek. The landfill has been used as a solid waste disposal site since 1976 (Harding Lawson, May 1988) and currently serves as the major disposal site for San Mateo County. The major water quality concern with any landfill is the potential for migration of leachate. Accordingly, the landfill is operated and monitored in accordance with Regional Water Quality Control Board (RWQCB) waste discharge requirements. Monitoring includes sampling of leachate from the landfill's leachate containment systems, in addition to surface water and groundwater sites.

During the Lower Pilarcitos Creek test well program (Nelson, 1998), groundwater samples were collected from the five test wells and analyzed for a variety of organic chemicals including VOCs, both aromatic and chlorinated; chlorinated pesticides and herbicides; and nitrogen/phosphorous-containing pesticides. No anthropogenic chemicals were detected in any of the test wells.

In the event that the Lower Pilarcitos Creek wellfield is developed, a Drinking Water Source Assessment will be required after well installation but prior to acquiring operating permits. Such an assessment includes determination of the capture zone for water around a well, evaluation of the sensitivity of the well to surface contamination, and identification of potential sources of contamination to the well within the capture zone.

Economic Feasibility

This section assesses the economic feasibility of the proposed Lower Pilarcitos Creek wellfield as a source of supplemental water for CCWD.

Background

CCWD acquired options to purchase six potential well sites, installed six test borings, and constructed five test wells on those sites in 1997 (Nelson, 1997 and 1998). In the summer of 2002, the District Engineer prepared a preliminary report on cost estimates for water production from the proposed Lower Pilarcitos Creek Groundwater Project (Teter, July 2002). This report stated:

1) Each of the five wells produced a substantial quantity of water when tested, and

2) The quality of the water produced from the test wells was suitable for potable water use when blended at the Nunes Water Treatment Plant (WTP) with water from the existing supply sources.

This preliminary report indicated a relatively favorable cost for development and use of this groundwater supply compared to existing costs of water supplied from the San Francisco Water Department's Pilarcitos Lake and Crystal Springs sources that are treated at the Nunes WTP. The report further cautioned that "Project feasibility cannot be determined until a groundwater geotechnical study is completed to determine how water may be withdrawn safely without resulting in a significant adverse impact."

The locations of the five test wells and estimates of winter (441 gpm) and summer-autumn (19 gpm) well capacities are based upon an analysis of the 1998 pumping tests (see Table 6), the water quality of those wells, and a hydrogeologic analysis (Todd Engineers, January 31, 2003).

The marine terrace aquifer in the lower Pilarcitos Creek groundwater basin recharges from winter rain and streamflow while groundwater discharges to the ocean year-round. Accordingly, the non-pumping water levels fluctuate by as much as 20 feet. The result is a seasonal supply that can yield a total of nearly 441 gpm in the winter and as low as 19 gpm in the summer-autumn (see Table 6).

An estimate of average total annual yield from this wellfield ranges from 396 AFY (245 gpm; 0.35 million gallons per day [MGD]; 129 million gallons per year [MGY]) during droughts and 799 AFY (495 gpm; 0.71 MGD; 259 MGY) during an average water year. For an average precipitation year, wet-season yields occurring from November through March (5 months) are about 351 AF (527 gpm; 0.76 MGD); while dry-season yields occur during the balance of the year (7 months) are 448 AF (476 gpm, 0.69 MGD). The wet- and dry-seasons are based on the precipitation patterns shown on Figure 3. For drought years, wet-season yields are about 175 AF (261 gpm; 0.38 MGD); while dry-season yields are 221 AFY (235 gpm; 0.34 MGD). However, the lowest monthly yields may range between 4 and 53 AF (3 gpm to 33 gpm; 0.004 to 0.048 MGD).

In summary, well yields could vary between 129 and 259 MGY. Additional wells could be installed to increase the capacity of the wellfield during the dry-season. However, to provide a conservative estimate of water costs, an annual yield of 194 MGY (average of 129 and 259 MGY) is used in this economic analysis in order to reduce the water produced during this period at the Nunes WTP to meet water quality goals for floriculture irrigation in the Coastside area.

The locations of these wells, together with that of the proposed pipelines connecting to the Nunes WTP, are shown in Figure 22. Photographs of the well sites and of the pipeline route are shown in Appendix 9. These photographs were obtained at the time of the site visit to observe field conditions related to access and location in order to estimate the construction cost of the facility including pipelines, electrical service, and related features.

Water Quality and Treatment

The water quality obtained in January 1998 (Nelson, 1998) during the pumping tests are summarized in Table 16 for the five wells. Also shown in Table 16 are (1) the average of the groundwater quality for the wells, (2) the average for the current Nunes WTP, (3) a blend of the Lower Pilarcitos Creek groundwater and surface water in December through February with increasing amounts of Crystal Springs Reservoir water in other months of the year, (4) comparison to CCWD’s other source of supply at the Denniston Creek WTP, and (5) agricultural water quality objectives. Water quality of individual “raw” water sources (i.e., Crystal Springs Reservoir, Pilarcitos Lake, and upper Pilarcitos water wells) were not provided by CCWD. In addition, seasonal variations of the water quality may occur for these raw water sources.

Overall, groundwater is characterized as moderately mineralized, hard (Todd, 1980), neutral pH, and very high in iron and manganese. The predominant cation is sodium, while the predominant anions are bicarbonate and chloride. The groundwater will require treatment for iron and manganese removal, and should be blended with other Nunes WTP supply sources at an approximate ratio of 3:1 to provide an acceptable water for floriculture irrigation (Kennedy/Jenks, 1995). Floriculture irrigation has much lower criteria for minerals than drinking water (i.e., TDS [<350 mg/l], alkalinity [<80 mg/l], chloride [<20 mg/l], sulfate [<40 mg/l], fluoride [<0.1 mg/l], and boron [<0.1 mg/l]). Considering that the preservation of the floriculture activities is of importance to the Half Moon Bay area, it is desirable to produce a blended water quality that meets their goals and is of no worse quality than as produced by the Denniston WTP (CCWD, 2001). If drinking water criteria were used, the blending ratio may change to 2:1 or less.

Water Treatment. The water treatment proposed for groundwater delivered to the Nunes WTP will include aeration for increasing pH and oxidation for reducing the high iron concentration. Addition of potassium permanganate will oxidize manganese. The water will then be blended with surface water and flocculated to remove the particulates by settling. The water will be filtered to remove the iron and manganese precipitates together with reducing the turbidity of surface water.

A plan of the facilities and a schematic diagram of the proposed and existing Nunes WTP are shown on Figures 23 and 24.

Corrosivity. An evaluation was also made of the corrosivity-scaling characteristics of the water and its probable effect on materials of pipe, well and appurtenances construction. These data are summarized in Table 17.

In general, due primarily to the low pH, high carbon dioxide, and high proportion of the strong acidic anions (chloride and sulfate), groundwater is highly corrosive to steel, ductile and cast iron, copper, and zinc. The treated water from the Nunes WTP will be much less corrosive as a result of blending, carbon dioxide stripping, and pH increases due to aeration and caustic soda.

The relative corrosivity of the soils at the well sites and along the pipeline (tested for resisitivity at the time of the site inspection) and typical soil chemistry for pH (USDA SCS, 1961) are shown in Table 18. These data indicate moderate corrosivity to unprotected steel or cast iron.

The expected water and soil corrosivity are utilized to select proposed materials and to estimate costs for well construction, pumps, pipelines, and accessories. The well casings and well pumps should be corrosion resistant Type 316 stainless steel. The wellhead piping, accessories and fittings at the wells should be fusion lined and coated epoxy steel or ductile iron. The buried transmission pipeline should be Class 350 ductile iron pipe, with flexible compression joints, polyethylene exterior sleeve, double thickness Type II cement lining, with asphalt dip coating of interior and exterior.

All concrete should be made with Type II cement and a low water-cement ratio to minimize permeability. All small and accessory piping components should be stainless steel.

Economic Feasibility

Pump and Well Facilities. Pumps were selected for each well based upon the projected capacity provided for wet-season maximum aquifer elevation and drawdown projections provided by Todd Engineers (January 31, 2003). These capacities are shown for each well and an expected total dynamic head ranging from 470 to 485 feet, as shown on Table 19. The depth of the production wells will range from 65 to 85 feet. Submersible stainless steel multi-stage turbine pumps have been selected for capacities, horsepower and pump, and well sizes. The proposed installation of the pumps is shown in Figure 25.

The submerged pump installation will minimize noise. All valves, meters and accessories will be in vaults, and the electrical station and controls in NEMA 4X enclosures located on pads. These components would be fenced to provide security. The use of below ground components with controls in small freestanding enclosures of types already in these predominately residential neighborhoods will minimize noise and visual impacts caused by pump houses.

Each pump will be provided with a variable speed drive to adjust pumping capacity seasonally, based on local available drawdown and blend ratios as selected by an adjustable computer control program from the Nunes WTP. A flow meter, water level sensor, and SCADA telemetry system are provided together with hand-off-automatic control for remote operation and status display at the Nunes WTP and at the CCWD’s Operations Center. This system will allow maximum utilization of the wellfield water throughout the year, and provide for relatively continuous rather than intermittent pumping.

The overall capacity of the five well pumps is 441 gpm (0.64 MGD). It is expected that the average annual flow from the wellfield will be a slightly less than half of the maximum quantity (194 gpm [102 MGY]); but may be reduced to 75 MGY (0.21 MGD; 143 gpm) to maintain a 3:1 blend ratio since a review of the current wet-season flows produced by the Nunes WTP are about one MGD (700 gpm). Cost projections of economic feasibility are based upon that quantity of water (75 MGY).

The estimated well construction cost is $71,000, based upon a recent bid received by Todd Engineers for a well of similar depth capacity, design, and size at Stinson Beach, Marin County. The cost of the pump units for 460-volt, 3-phase motors varies from $3,700 to $4,200. Electrical service to the wells would be obtained from nearby PG&E 3-phase power poles and was estimated at about $29,000 for each well. An additional 40 percent ($42,000) is included for well construction and design services, wellhead piping and appurtenances, and pump design.

Transmission Pipeline. The proposed transmission pipeline between the wells and Nunes WTP is shown in Figure 22. All buried pipe would be ductile iron Pressure Class 350 pipe, suitable for 350 pounds per square inch (psi) working pressure. Four-inch diameter pipe would be used to connect individual wells to the main transmission pipelines to be located in the paved streets west of Highway 1. Those south of Pilarcitos Creek would connect into a 6-inch diameter pipeline and bore and jack pipeline crossing beneath Pilarcitos Creek north of Pilarcitos Avenue, while wells north of Pilarcitos Creek would be routed southeasterly on St. James Avenue. A bore and jack pipeline would be provided north of Main Street. This pipeline would proceed up Foster Drive past the high school to the access road, where it would proceed up the hill to the Carter Hill Water Storage Tanks to the Nunes WTP.

The cost of this pipeline is based in part upon recent water distribution pipeline costs in the area (Teter, January 2003). The Engineer's Estimate of probable construction cost of the transmission pipeline is $693,000, which is adjusted to $832,000 in the Final Estimate to provide for a 20 percent contractor overhead, profit, and construction contingency.

Water Treatment. The proposed water treatment for the well water is to aerate the water to oxidize the iron, strip carbon dioxide, and increase pH to about 7.8 (Summerfield, 1999). The aerated water will be (1) treated with potassium permanganate to oxidize and precipitate the remaining iron and manganese, (2) blended with surface water for removal of the solids by coagulation, flocculation, sedimentation and titration, and finally (3) disinfected and pH adjustment by caustic soda for corrosion control.

Two types of aeration have been considered: one would be stripping through a packed tower, the other by providing a tank of 10,000 gallons resulting in about 20-minute retention at peak flow, and diffused air stripping and oxidation. Costs are based on the latter approach as either double pumping from a packed tower aerator or locating the bottom of its 20 plus feet height above the level of the flash mixers (Kennedy/Jenks, 1988). The latter approach is not considered to be as feasible or cost effective.

The construction costs of the aeration facilities are estimated at $105,500, and of the chemical storage feed facilities, $39,000. An additional $15,000 is estimated for contractor’s contingency for water treatment plant disruption, which provide for a total construction cost of $159,000 at the WTP

Capital Costs. The capital costs of the various project elements are summarized as follows:

Land Purchase, five lots at $100,000		$ 500,000
Construction Wells, five wells at $146,000		730,000
Transmission Pipeline		832,000
Water Treatment		159,000
SCADA		87,000
	Construction Subtotal	$2,308,000
Engineering Design & Construction Management at 15 percent		$ 346,000
	Construction Total	$2,654,000
Other Costs:		
Environmental – CEQA – 5 percent Construction		115,000
Coastal Development Permits & Acquisition		50,000
CCWD Staff Costs, Legal, Administrative & Engineering		50,000
	Subtotal	$ 215,000
Total Current Budget Cost Estimate		$2,869,000
Escalation at 3 percent per year – 3 years (9 percent)		$ 258,000
	Budget Total	$3,127,000

Operations and Maintenance Costs. The operations and maintenance costs are based upon the cost of an annual supply from the Lower Pilarcitos Creek groundwater basin of 75 MGY (146 gpm; 0.21 MGD). Energy costs are based upon the current average cost of 10.1¢ per kilowatt-hour (KWH) and Nunes WTP costs of 7.1¢ per 100 cubic feet (ft^3) of treated water (Mier, February 2003). Labor costs are estimated to be 5 hours per week additional at the Nunes WTP, and 2 hours per week at the wells.

Maintenance costs are estimated to be 2 percent of construction costs. The average life spans of facilities are 40 years, and are depreciated on the basis of 4 percent interest on the capital investment. The annual costs projected are:

Capital Costs	$3,127,000 per 40 Years at 4 percent	$78,200/year
Maintenance Costs	$2,308,000 x 2 percent	46,200
Operations Costs	7 hours/week x 20 weeks at $40/hour	5,600
Energy: Pumping	95 horsepower (hp) motor 95 hp x .746 kw/hp x 1.11 = 78.7 kw	
Water Treatment	Blower 5 hp x .746 x 1.11 = 4.2 kw	
	82.9 kw x 3,600 hrs/year x 10.1¢ per kwh	30,100
Chemical Costs:		
Potassium Permanganate	13 lbs per day at $1.50 per lb x 150 days	2,900
Existing WTP Costs	At 7.1¢ per 100 ft^3 = $94.92 per MG 75 MG x $94.92	7,100
Laboratory & Reporting	At $500 per month for 5 months	2,500
	Total Annual Cost	**$172,600/year**

Water Costs. The unit cost of the Lower Pilarcitos Creek groundwater supply on the basis of an annual average use of 75 MGY:

Annual Production = 75 MGY ÷ 748 (per 100 ft^3)	100,267 units/year
$172,600 per year per 100,267 units per year	$1.721/unit

A comparative cost of Crystal Springs water treated at the Nunes WTP, based on the 2002 Preliminary Report (Teter, July 2002) and the cost of treating water at the Nunes WTP (Mier, February 2003) is:

Nunes WTP Water	Winter Cost/100 ft^3	Summer Cost/100 ft^3
Purchase from San Francisco Water Department	--	$0.87
Energy Cost	0.87	0.35
Water Treatment Cost	0.071	0.071
Unit Cost	**$0.961**	**$1.291**

The cost of water treated at the Nunes WTP is less expensive during the winter months since the water supply is entirely from Pilarcitos Lake and the upper Pilarcitos Creek wells. These sources do not have the associated energy costs, due to pumping across Sweeny Ridge from the Crystal Springs Reservoir to the Nunes WTP. In the future, as water consumption increases and/or a smaller than 3:1 blending ratio is needed to maintain acceptable water quality, then the unit costs of the Lower Pilarcitos Creek groundwater supply will be reduced.

Comparatively, the Lower Pilarcitos Creek groundwater appear to cost about the same as the current surface water purchase and treatment costs. These costs may fluctuate from year to year based upon the length of time that the aquifer will sustain a reasonable pumping rate and may vary by as much as a third, either more or less, than the $1.721 estimated unit cost.

Conclusions

This study indicates that a Lower Pilarcitos Creek groundwater project is technically and economically feasible. The following key conclusions have been developed:

- The perennial or safe yield is 1,300 AFY and is defined here by the amount of groundwater that can be pumped without inducing significant adverse impacts, primarily saltwater intrusion from the ocean. This perennial yield value amounts to 60 percent of the estimated 2,200 AFY of total inflow to the groundwater basin, reflecting the unlikelihood that all of the basin inflow can be safely captured without incurring adverse impacts.
- The estimated total annual perennial yield of 1,300 AFY takes into account long-term pumping. Relatively recent increases in pumping from the Balboa wellfield (140 AFY) should be included in the 1,300 AFY. The remainder (1,160 AFY) is sufficient for the potential Lower Pilarcitos wellfield and additional development by CCWD.
- The estimated total yield of the five wells of the proposed Lower Pilarcitos wellfield ranges between 129 and 259 MGY for drought and normal years. For costing purposes, an average value of 194 MGY (595 AFY) is assumed. Pumping rates are limited by groundwater level changes, particularly in the dry season.
- Estimated construction, operations and maintenance cost for the proposed Lower Pilarcitos Creek groundwater project are comparable to the current costs of surface water purchase and treatment.
- Groundwater in the marine terrace aquifer is confined and not in direct hydraulic connection with Pilarcitos Creek; accordingly, pumping of the proposed wells would not deplete creek flows.
- Should CCWD decide to proceed with evaluation of the proposed Lower Pilarcitos Creek wellfield, the recommended next step is installation and testing of a pilot production well. In addition, stream flow monitoring is recommended.

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