U.S. Department of the Interior
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Source, Movement, and Age of Ground Water in a Coastal California Aquifer

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This report is a summary of isotopic studies of ground-water source, movement, and age in aquifers underlying the Santa Clara-Calleguas basin, Ventura County, California. It is part of a series summarizing the results of the U.S. Geological Survey's Southern California Regional Aquifer-System Analysis (RASA) study of a southern California coastal ground-water basin. The geologic setting and hydrologic processes described in this report are similar to those in other coastal basins in southern California.

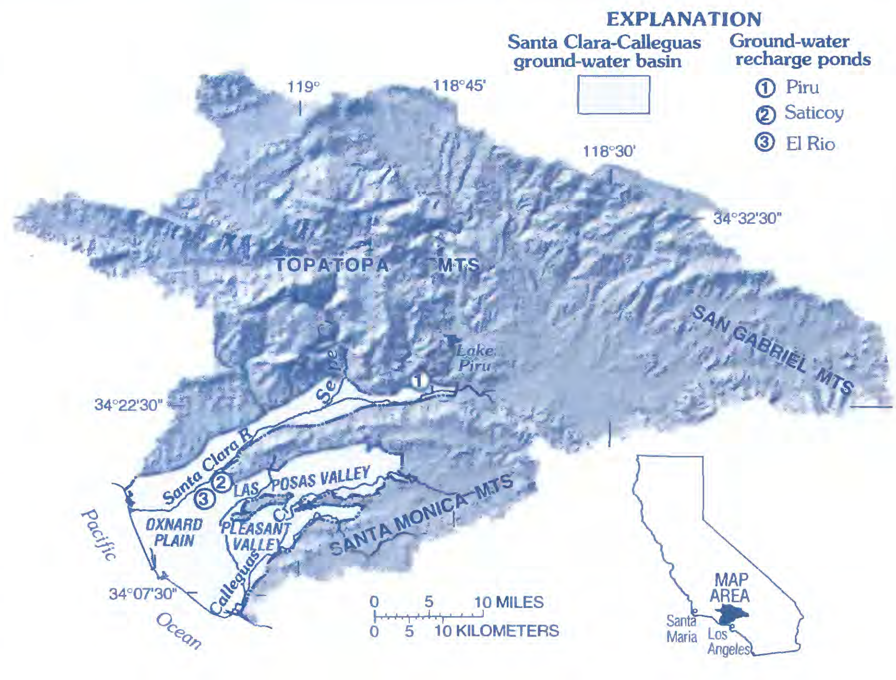

Figure 1. Santa Clara-Calleguas Hydrologic Unit.

Introduction

Understanding the contribution of recharge from different sources is important to the management of ground-water supply in coastal aquifers in California—especially where water-supply or water-quality problems have developed as a result of ground-water pumping. In areas where water levels have changed greatly as a result of pumping and no longer reflect predevelopment conditions, an analysis of isotopic data can provide information about the source, movement, and age of ground water that is not readily obtained from a more traditional analysis of ground-water data. This information can be used to develop management strategies that incorporate the availability of natural and artificial recharge to control water-level declines and water-quality degradation.

In this study, the ratios of the stable isotopes of oxygen and hydrogen were used to determine the source and trace the movement of ground water in the Santa Clara-Calleguas basin, Ventura County, California. Tritium and carbon-14 data were used to estimate the age (time since recharge) of ground water.

Hydrogeology

The 2,010-square-mile (mi^2) Santa Clara-Calleguas Hydrologic Unit, about 60 miles northwest of Los Angeles, has a Mediterranean climate characterized by warm, dry summers and cool, wet winters. Precipitation ranges from 14 inches near the coast to more than 40 inches at higher altitudes in the Topatopa and San Gabriel Mountains. Surface drainage is toward the Pacific Ocean through the Santa Clara River, which drains about 1,600 mi^2, and Calleguas Creek, which drains about 400 mi^2 (fig. 1). In most areas streamflow is intermittent and occurs only for brief periods after storms. However, streamflow is perennial in the larger tributaries to the Santa Clara River and in parts of the Santa Clara River where ground water discharges at land surface. In recent years, perennial flow has been maintained in some reaches within the Calleguas Creek drainage by the discharge of treated municipal sewage and irrigation return water.

The Santa Clara-Calleguas Hydrologic Unit includes the Santa Clara-Calleguas ground-water basin. The 310-mi^2 basin contains a complex system of aquifers that can be divided into an upper aquifer system and a lower aquifer system (see fig. 6, later in this report). The upper aquifer system consists of alluvial deposits and is generally about 400 feet thick. The lower aquifer system consists of alluvial deposits, which grade to marine deposits near the coast and with increasing depth, and is more than 1,000 feet thick in places. The deposits of the lower aquifer system are folded and faulted and crop out in some places along the flanks of the mountains and hills that surround the basin.

Previous researchers believed that natural recharge to both the upper and lower aquifer systems occurred primarily as infiltration of surface water from larger, perennial streams and that in areas where these streams are not present aquifers were readily recharged by infiltration of precipitation or infiltration of runoff in smaller, intermittent streams. Natural recharge is supplemented by diversion of surface water from Piru Creek near Piru and the Santa Clara River near Saticoy and El Rio (fig. 1). In other areas, natural recharge is supplemented (intentionally and unintentionally) by irrigation return water, discharge of treated municipal wastewater, and use of imported water.

The upper and lower aquifer systems are extensively developed for water supply. In many areas, ground-water pumping in excess of ground-water recharge has resulted in water-level declines greater than 200 feet. As a result, water supply and water-quality problems, such as seawater intrusion and brine invasion, are important concerns. Because of the large variability in seasonal and annual precipitation, runoff, and streamflow—and the geologic complexity of the aquifer system—there is uncertainty about the sources and amount of ground-water recharge, and about the movement of water within the aquifer systems.

Source and Movement of Ground Water

Oxygen-18 and deuterium are naturally occurring stable isotopes of oxygen and hydrogen. Oxygen-18 and deuterium abundances are expressed as ratios in delta notation (δ) as per mil (parts per thousand) differences relative to the standard known as Vienna Standard Mean Ocean Water (VSMOW). By convention the value of VSMOW is 0 per mil.

Most of the world's precipitation originates from the evaporation of seawater. As a result, the oxygen-18 ($\delta^{18}O$) and deuterium (δD) composition of precipitation throughout the world are linearly correlated and distributed along a line known as the meteoric water line (fig. 2). The $\delta^{18}O$ and δD composition of a water sample relative to the meteoric water line and relative to the composition of water from other areas provides a record of the source and evaporative history of the water and can be used as a tracer of the movement of the water.

The $\delta^{18}O$ and δD composition of water from almost 240 wells in the basin ranged from -8.85 to -1.75 and -62.5 to -9.5, respectively (Izbicki and others, 1995). The isotopically heavier (less negative) waters result from the mixing of freshwater with seawater or other saline water. The source of these waters has been discussed by Izbicki (1996) and will not be discussed further in this report. Many of

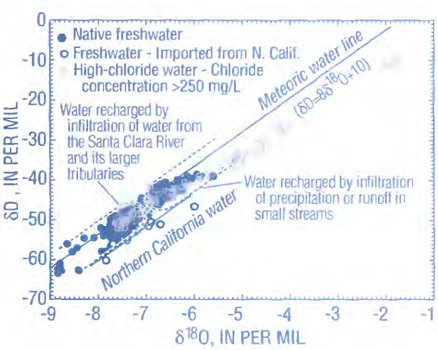

Figure 2. Delta deuterium (δD) as a function of delta oxygen-18 ($\delta^{18}O$) in water from wells.

the remaining differences in the isotopic composition of ground water are the result of differences in the temperature of condensation (dew point) of precipitation in different parts of the basin. Water recharged from precipitation (or resulting runoff and streamflow) that condensed at higher altitudes and lower temperatures is isotopically lighter (more negative) than water recharged from precipitation that condensed at lower altitudes and higher temperatures. Most other observed differences in the isotopic composition of sampled waters are the result of evaporation, the use of imported water, or (for water recharged many thousands of years ago) long-term changes in climate.

Water from most wells in the Santa Clara River valley and the upper and lower aquifer systems underlying the Oxnard Plain had δD values less than -50 per mil (fig. 3). (The δD composition of water resulting from the mixing of freshwater with seawater or other saline water is not shown in figure 3.) Water in these areas was recharged by infiltration of surface water from the Santa Clara River that originated largely as runoff from the higher altitudes of the Topatopa and San Gabriel Mountains.

Water from wells in Las Posas Valley, Pleasant Valley, and near the flanks of the mountains north of the Santa Clara River had δD values greater than -45 per mil and was isotopically heavier than water from most wells in the Santa Clara River valley or Oxnard Plain. Water in these areas was recharged by direct infiltration of precipitation or infiltration of runoff in small streams that drain the area.

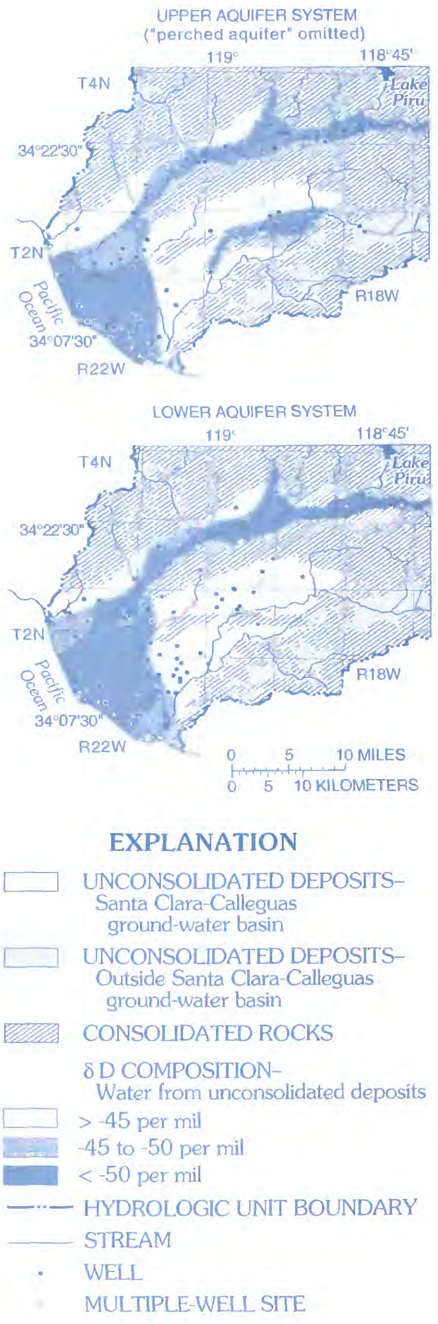

Figure 3. Delta deuterium (δD) composition of water from selected wells.

No large areas of isotopically heavy water were present in the upper or lower aquifer systems underlying the Oxnard Plain. These data suggest that the amount of ground-water movement from Las Posas Valley, Pleasant Valley, and near the flanks of the mountains to aquifers underlying the Oxnard Plain is small.

Water from some wells in the upper aquifer system near the northeast corner of the Oxnard Plain have an intermediate isotopic composition (δD values between -45 and -50 per mil) (fig. 3). As a group, water samples from wells in this area were affected by evaporation and plot to the right of the meteoric water line. These samples were collected near the end of an extended drought when recharge from the Santa Clara River was scant. In this area, there are no thick clay layers separating the upper aquifer system from the surface; and, therefore, irrigation return water can infiltrate to the water table. Isotopically heavier water is not present in the upper aquifer system farther away from the recharge area because low-permeability clay deposits underlying the Oxnard Plain isolate the aquifers from land surface.

Isotopically light water (less than -50 per mil) in the upper aquifer system in parts of Las Posas and Pleasant Valleys near streams (fig. 3) is the result of recharge by treated municipal wastewater. The wastewater originated as water imported from northern California for public supply. This water is isotopically lighter than water from local precipitation and plots along a line parallel to but below the meteoric water line (fig. 2). Northern California water also was present in parts of the Santa Clara River valley, but its presence is less obvious because native water in the Santa Clara River valley is lighter than water in other parts of the basin.

The lightest water (less than -60 per mil) in the basin is from deep wells at the end of long flow paths in aquifers underlying the Oxnard Plain. The isotopic composition of this water reflects a cooler temperature of condensation and cooler climatic conditions than those found in the basin today. It is possible that these waters are very old and were recharged many thousands of years ago.

Age of Ground Water

Naturally occurring radioactive isotopes of hydrogen (tritium) and carbon (carbon-14) were used to determine the age (time since recharge) of ground water. Tritium was used to identify recently recharged (post 1952) ground water and carbon-14 was used to estimate the age of older ground water.

Recently Recharged Water

Tritium (^3H) has a half-life about 12.4 years and is measured in tritium units (TU)—each tritium unit equals one tritium atom in 10^{18} atoms of hydrogen. Prior to 1952, the tritium concentration of precipitation in coastal southern California was about 2 TU. Beginning in 1952, tritium was released to the atmosphere as a result of the atmospheric testing of nuclear weapons, and the tritium concentration of precipitation increased (fig. 4). Because tritium is part of the water molecule, tritium concentrations are not affected significantly by reactions other than radioactive decay. Tritium is an excellent tracer of the movement of water on time scales ranging from 10 to less than 100 years before present. In this report, ground water having tritium concentrations less than the detection limit of 0.3 TU is interpreted as water recharged prior to 1952. Ground water having measurable tritium is interpreted as water recharged after 1952.

Tritium concentrations in water from almost 150 wells sampled as part of this study ranged from 9.4 TU to less than the detection limit of 0.3 TU (Izbicki and others, 1995). Ground water containing tritium was present throughout large areas of the upper aquifer system underlying the Santa Clara River valley and parts of the Oxnard Plain near the Santa Clara River (fig. 5). Between 1952 and 1993 about 1.8 million acre-feet of water was recharged in ponds at Saticoy and El Rio. By 1991, this water was present throughout much of the upper aquifer system underlying the Oxnard Plain and had moved more than 6 miles downgradient from the recharge area but had not yet reached the coast. Ground water containing tritium was present only in small areas of the lower aquifer system near Saticoy and El Rio (fig. 6). These data suggest that infiltration of surface water in ponds at these locations is more effective at recharging the upper aquifer system than the lower aquifer system. However, water levels throughout the upper and lower aquifer systems are raised by hydraulic pressure from this recharge water.

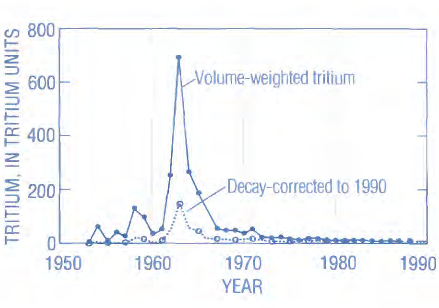

Figure 4. Volume-weighted tritium levels in precipitation at Santa Maria, California. (Data from International Atomic Energy Agency.)

Tritium was present in the upper aquifer system near streams in Las Posas Valley. On the basis of the $\delta^{18}O$ and δD isotopic composition, this water was identified as water imported from northern California for public supply and discharged as treated municipal wastewater. Small amounts of tritium also were present in water from wells in the upper aquifer system near the coast as a result of seawater intrusion in those areas (Michel and others, in press).

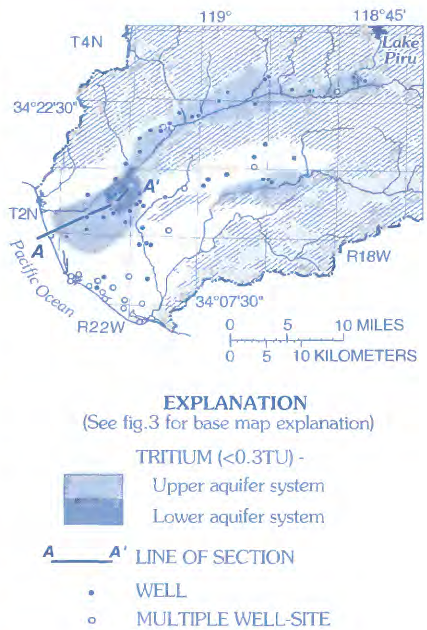

Figure 5. Tritium in water from selected wells.

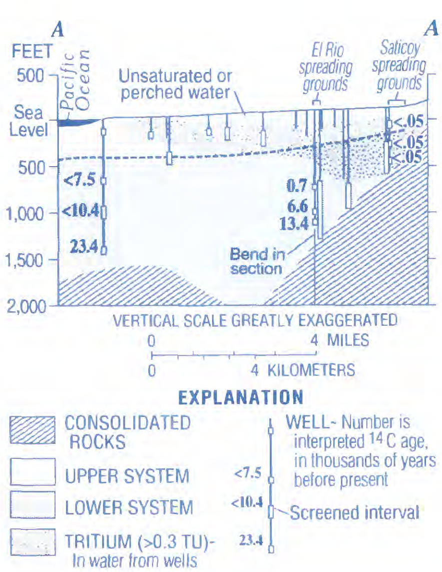

Figure 6. Geologic section *A-A'*.

Tritium was not present in water from most wells in Las Posas Valley and Pleasant Valley, in deep wells at multiple-well sites in the Santa Clara River valley, and in deep wells in most parts of the Oxnard Plain. These data show that water in these areas was recharged prior to 1952. Carbon-14 data were used to determine the age of this older water.

Older Water

Carbon-14 (^{14}C) has a half-life of about 5,730 years and is measured as percent modern carbon by comparing carbon-14 activities to the radioactivity of National Bureau of Standards oxalic acid prepared in 1950—12.88 disintegrations per minute per gram of carbon equals 100 percent modern carbon. Carbon-14 is a tracer of the movement and relative age of ground water on time scales ranging from recent to more than 20,000 years before present.

Carbon-14 activities for water from 34 wells in the study area ranged from 89.4 to less than the detection limit of 1 percent modern carbon (Izbicki and others, 1995). Carbon-14 activities were higher in areas where ground water contained tritium and lower near the downgradient ends of long flow paths through the lower aquifer system.

Carbon-14 is not part of the water molecule, and in addition to radioactive decay, carbon-14 activities are affected by chemical reactions that occur between dissolved constituents and the material that composes the aquifer. For example, in the Santa Clara-Calleguas basin, oxidation of organic material (that does not contain carbon-14) within the aquifer deposits during the reduction of sulfate to hydrogen sulfide can reduce the carbon-14 activity of water from wells. Izbicki and others (1992) and Izbicki and Martin (written commun., 1996) evaluated the mass transfer of carbon, sulfur, and other elements between the solid and dissolved phases—and the subsequent changes in carbon-13 ($\delta^{13}C$), sulfur-34 ($\delta^{34}S$), and carbon-14 composition of ground water—using the computer program NETPATH (Plummer, and others, 1994). Interpreted carbon-14 ages ranged from recent (less than 50 years before present) for water from wells near sources of ground-water recharge along the Santa Clara River to more than 20,000 years before present (fig. 7).

Changes in ground-water ages with depth (figs. 6 and 7) were evaluated on the basis of samples collected from 19 wells at 8 sites that were screened in individual aquifers (Densmore, 1996). Interpreted carbon-14 ages increased with increasing depth and increasing distance downgradient from recharge areas. The oldest water was from deep wells at the end of long flowpaths through the lower aquifer system underlying the Oxnard Plain (fig. 6). Large changes in ground-water ages with

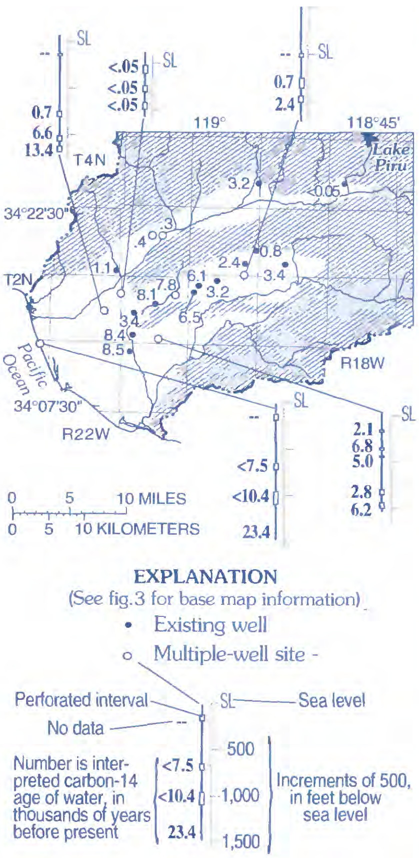

Figure 7. Age of water from selected wells.

depth confirm that the deeper aquifers of the lower aquifer system are largely isolated from overlying aquifers and surface sources of ground-water recharge.

Water from most wells sampled in the Pleasant Valley and Las Posas areas also is relatively old, reflecting the smaller quantities of recharge available to aquifers underlying these areas in comparison with aquifers underlying the Santa Clara River valley or the Oxnard Plain. However, water from the wells sampled in Pleasant Valley is not as old (and not as isolated from sources of recharge) as water from wells sampled in the western part of Las Posas Valley or from some of the deeper wells sampled in the Oxnard Plain.

Management Strategies

Isotopic data show that recent recharge occurs primarily as infiltration of surface water from large streams. Water from these sources does not effectively recharge the lower aquifer system or aquifers in parts of the basin that are distant from these large streams. In some areas recharge occurs as infiltration of precipitation or as infiltration of runoff in smaller, intermittent streams (especially in areas where flow in these streams has been increased by discharge of treated municipal wastewater). However, in most areas where aquifers are distant from large streams ground water does not contain tritium and, on the basis of carbon-14 data, is very old.

Results of a recently completed U.S. Geological Survey simulation-optimization study of alternative management strategies (Reichard, 1995) showed that ground-water resources in the Santa Clara-Calleguas basin could be used more efficiently by increasing artificial recharge programs and reducing pumping from the lower aquifer system. Local agencies responsible for ground water management are increasing recharge to the upper aquifer system by releasing water for ground-water recharge to the Santa Clara River from Lake Piru (Densmore and others, 1992), increasing the capacity of facilities used to supplement natural recharge through the diversion of surface water, and injecting water in the lower aquifer system and other parts of the basin where present day recharge is scant (Ventura County Public Works Agency, 1995). Local agencies also are proposing to reduce pumping from the lower aquifer system through a combination of water conservation measures, a shift in pumping to the upper aquifer system, and delivery of surface water for agricultural supply to replace ground-water pumping (Ventura County Public Works Agency, 1995). Information obtained from the U.S. Geological Survey RASA study of southern California coastal basins will aid in the development of those projects and in the effective management of the ground-water resources of the Santa Clara-Calleguas basin.

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