U.S. Department of the Interior
U.S. Geological Survey

Seawater Intrusion in a Coastal California Aquifer

This report is a summary of recent work on seawater intrusion in aquifers underlying the Oxnard Plain, Ventura County, California. It is part of a series of reports describing 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 that affect seawater intrusion in aquifers underlying the Oxnard Plain are similar to those in other coastal basins in southern California.

Introduction

Seawater intrusion in aquifers underlying the Oxnard Plain, Ventura County, California, was first observed in the early 1930's and became a serious problem in the mid-1950's (California Department of Water Resources, 1965) (fig. 1). Historically, local agencies responsible for the management of ground water used a criterion of 100 milligrams per liter (mg/L) chloride to define the leading edge of the seawater front. It was assumed that all high-chloride water from wells behind the front originated from seawater that entered aquifers through outcrop areas in submarine canyons. Recent work (Izbicki, 1991; Stamos and others, 1992) showed that other sources of high-chloride water to wells are present and that the areal extent of seawater intrusion in the upper aquifer system is smaller than previously believed.

Hydrogeology

The Oxnard Plain, 60 miles northwest of Los Angeles, has an area of 120-square miles (mi^2) and is underlain by a complex system of aquifers more than 1,400 feet thick. These aquifers (like many similar coastal aquifers in southern California) can be divided into an upper and a lower aquifer system (fig. 2).

The upper aquifer system consists of relatively flat-lying alluvial deposits about 400 feet thick and contains two aquifers that have been developed for water supply—the Oxnard and Mugu aquifers. The Oxnard aquifer, about 180 feet below land surface, is the primary water-yielding zone. The Oxnard aquifer is underlain by the Mugu aquifer and overlain by a thick, areally extensive clay deposit. This clay deposit separates the Oxnard aquifer from a shallow unconfined aquifer that previous researchers have referred to as the 'perched aquifer.' (Use of this name in this report does not imply that perched conditions exist in the Oxnard Plain.) The Oxnard and Mugu aquifers crop out in Hueneme and Mugu submarine

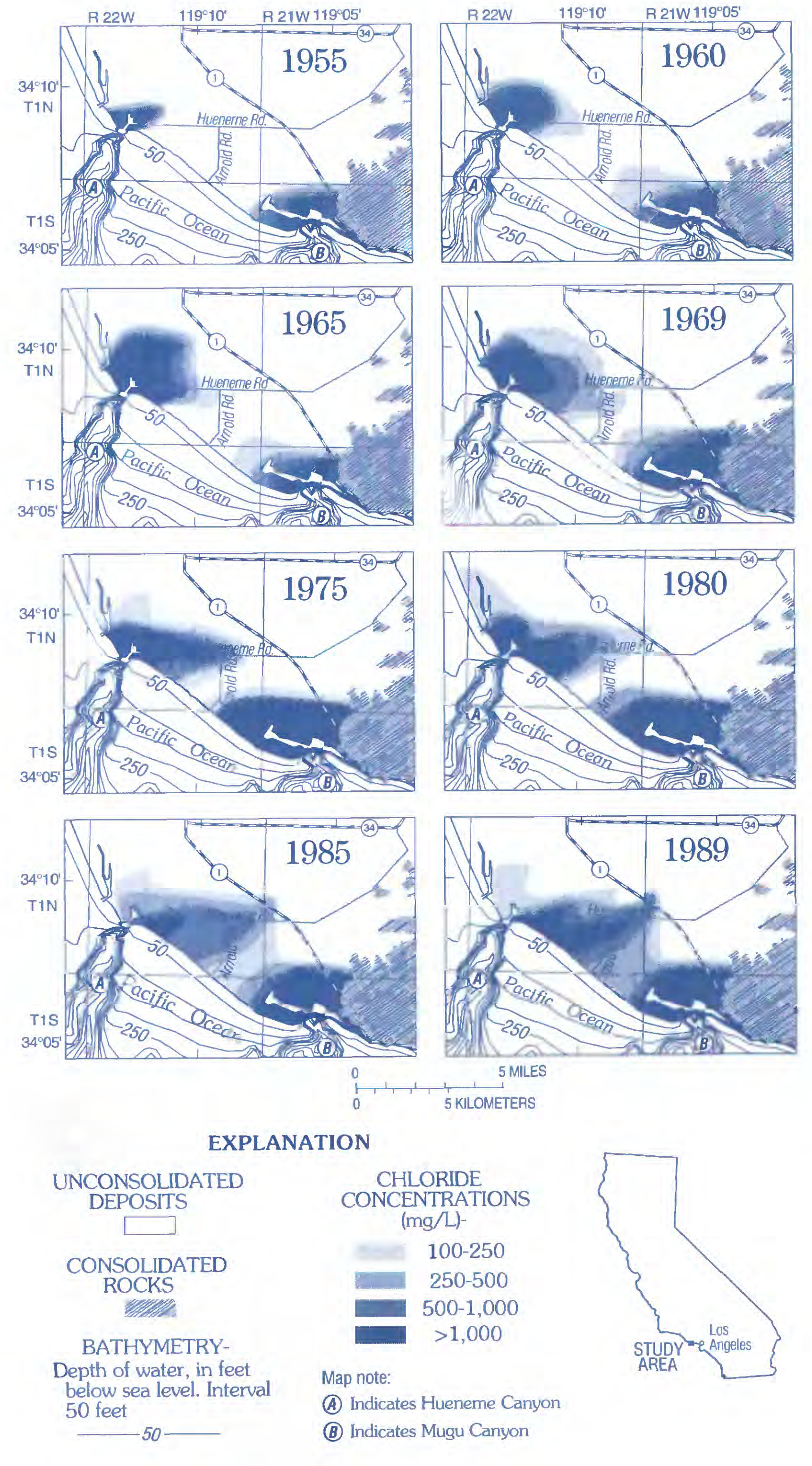

Figure 1. Chloride concentrations in water from wells in the upper aquifer system in the Oxnard Plain, 1955-89. (Data from California Department of Water Resources and County of Ventura Public Works Agency.)

canyons less than one-quarter mile offshore (fig. 2). The perched aquifer crops out immediately offshore all along the coast in the study area.

Native water in the Oxnard and Mugu aquifers is generally fresh and has chloride concentrations about 40 mg/L. However, in some areas (especially near Mugu submarine canyon) interbedded fine-grained deposits in the Oxnard and Mugu aquifers contain saline water. Prior to the onset of seawater intrusion, the Oxnard and Mugu aquifers were extensively pumped for water supply. The perched aquifer contains fresh and saline water, but it is not used as a source of water supply. Saline water in the perched aquifer results from a combination of (1) seawater that recharged the aquifer through offshore outcrops or infiltrated into the aquifer through coastal wetlands or during coastal flooding [in some cases this water was partly evaporated prior to recharge], (2) concentration of dissolved minerals resulting from the evaporative discharge of ground water, (3) infiltration of irrigation return water.

The lower aquifer system consists of alternating layers of alluvial sand and clay about 5 to 50 feet thick. These deposits grade to marine near the coast and overlie fine-grained marine sands that are more than 100 feet thick and are separated by marine silt and clay interbeds as much as 50 feet thick. The deposits of the lower aquifer system have been folded and faulted. Marine seismic-reflection data (Greene and others, 1978) and test-drilling data show that the lower aquifer system crops out in Hueneme submarine canyon, but it does not crop out in Mugu submarine canyon because of offshore faults and uplift of partly consolidated marine and volcanic rocks (fig. 2).

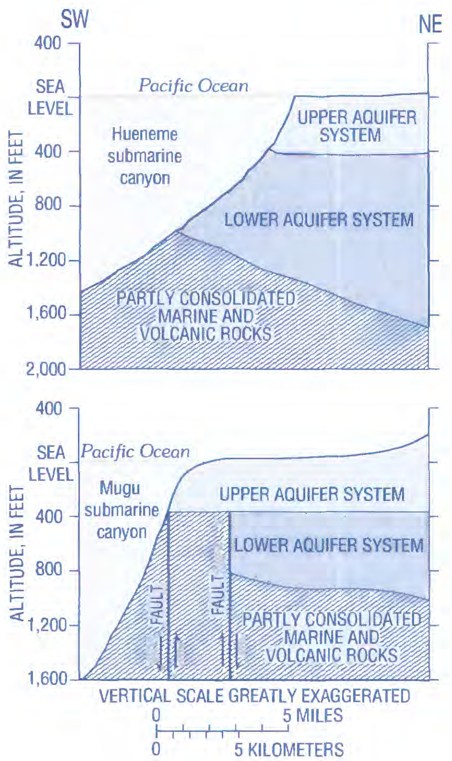

Figure 2. Generalized geologic sections through Hueneme (A in figure 1) and Mugu submarine canyons (B in figure 1).

Native water in the lower aquifer system generally is fresh and has chloride concentrations that range from 40 to 100 mg/L. The lower aquifer system is surrounded and underlain by partly consolidated marine and volcanic rocks that contain saline water. Chloride concentrations are as high as 3,400 mg/L in the partly consolidated marine rocks and can exceed 1,000 mg/L in the volcanic rocks.

Ground-water pumping has caused water levels in parts of the Oxnard and Mugu aquifers to decline below sea level and below the water level in the perched aquifer. Seawater entered aquifers through outcrop areas in Hueneme and Mugu submarine canyons in the mid-1950's and advanced inland in response to changes in the amount and distribution of pumping (fig. 1). By 1989, about 23 mi^2 of the upper aquifer system was believed to be intruded by seawater. Because of increasing chloride concentrations, pumping was shifted from the upper system to the lower system; subsequently, water levels in the lower aquifer system declined to below sea level. Increasing chloride concentrations were observed in the lower aquifer system near Mugu submarine canyon as early as 1985, and high-chloride water in the lower aquifer system near Hueneme submarine canyon was discovered as part of this study in 1989 (Izbicki, 1991).

After 1993, a combination of ground-water management strategies and increased availability of water from the Santa Clara River for ground-water recharge caused water levels in wells near the coast to rise above sea level and above water levels in the perched aquifer. Water levels in parts of the lower aquifer system near Hueneme submarine canyon also rose above sea level at that time, but water levels in the lower aquifer system near Mugu submarine canyon were still below sea level as late as 1996.

Seawater Intrusion in the Upper Aquifer System

Prior to 1989, most of the wells used to monitor chloride concentrations in the upper aquifer system were abandoned (unused) agricultural supply wells, and many of these wells were screened in more than one aquifer. As part of this study, 32 monitoring wells were installed in the upper aquifer system at 14 multiple-well sites within the area believed to be intruded by seawater (Densmore, 1996). These wells are screened in individual aquifers (the Oxnard, Mugu, or perched aquifer) to enable collection of aquifer-specific water-level and water-quality data.

Chloride concentrations in water from most wells completed as part of this study were less than 250 mg/L (fig. 3)—and in water from many wells, chloride concentrations were not much higher than that of native (fresh) ground water. However, chloride concentrations in water from some wells near Hueneme and Mugu submarine canyons were

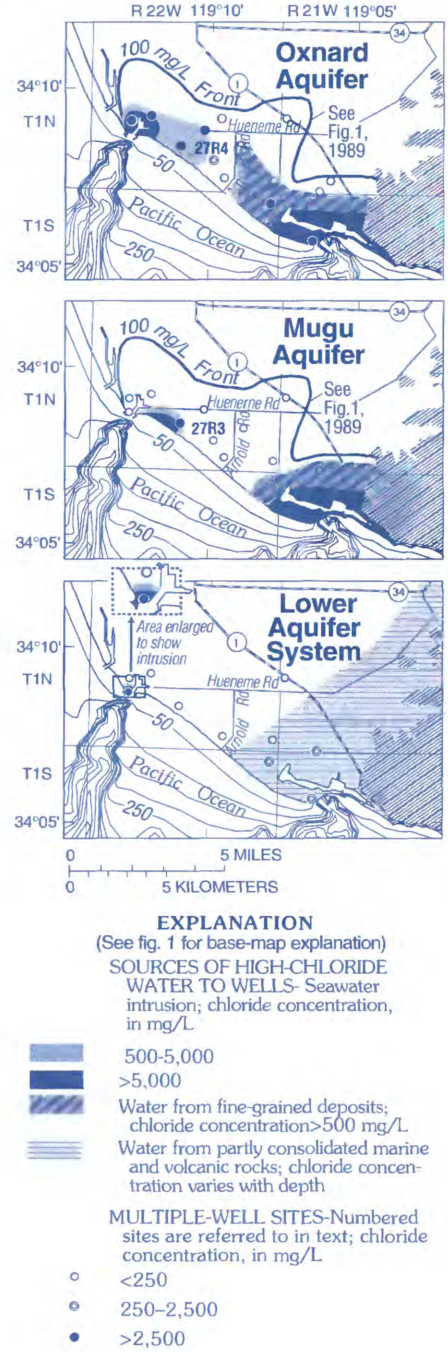

Figure 3. Areal extent of seawater intrusion and high-chloride water from other sources in aquifers underlying the Oxnard Plain, 1993.

as high as 17,000 mg/L in the Oxnard aquifer, and as high as 6,300 mg/L in the Mugu aquifer (Izbicki and others, 1995). Chloride concentrations in the perched aquifer near the coast were as high as 23,000 mg/L. For comparisons, seawater has a chloride concentration of 19,000 mg/L; the EPA Maximum Contaminant Level (MCL) for chloride in a public water supply is 250 mg/L; and salt-sensitive crops common in the study area, such as strawberries, are adversely affected by chloride concentrations as low as 100 mg/L.

Results of sample analyses showed that water from abandoned agricultural wells was not representative of ground water in the Oxnard or Mugu aquifers. This is because these wells have (1) large diameter casings and are difficult to purge of stagnant water prior to sample collection, (2) screened intervals that may be open to more than one aquifer (as a result, chloride concentrations in individual aquifers cannot be defined), and (3) steel casings that are subject to corrosion and failure—especially in areas where water in the perched aquifer is saline.

Corrosion and failure of abandoned wells may result in leakage of water from the perched aquifer into underlying aquifers. For example, chloride concentrations in water from well 27R1, located in what was believed to be a highly intruded part of the upper aquifer system, increased from less than 70 mg/L in the early 1960's to 1,900 mg/L in 1990 (fig. 4). The increase in chloride concentrations was used as evidence of increasing seawater intrusion in the Oxnard aquifer. However, less than 150 feet away, water from well 27R4 (screened in the Oxnard aquifer) had a chloride concentration in 1990 of 180 mg/L. At the same time, water in well 27R5, screened in the perched aquifer, had a chloride concentration of 23,000 mg/L. The water level in well 27R5 was higher than the water level in wells 27R1 or 27R4 (fig. 4), suggesting that water could move from the overlying perched aquifer into the Oxnard aquifer through the failed casing of well 27R1. Leakage of water at a rate of 9 gal/min was confirmed on the basis of a heat-pulse velocity log (R.T. Hanson, U.S. Geological Survey, written commun., 1994). Similar results were obtained at two additional locations where multiple-well sites were located near abandoned wells. Predmore (1993) identified more than 160 abandoned, and potentially failed, wells in the area believed to be intruded by seawater.

Results of a direct-current surface-resistivity survey in the area believed to be intruded by seawater (Zohdy and others, 1993) agreed with water-quality data from multiple-well sites and showed that the areal extent of seawater intrusion in the upper aquifer system was smaller than previously believed. Interpretation of geologic, water-quality, and surface-resistivity data by Stamos and others (1992) suggested that poor-quality water from

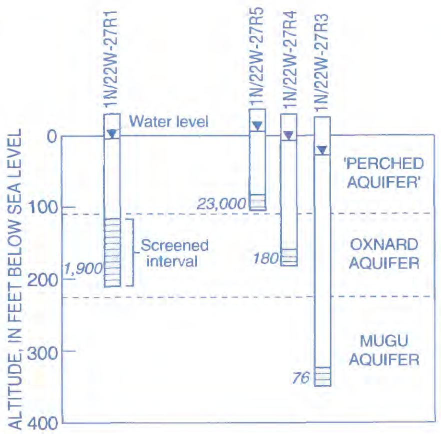

Figure 4. Water levels and chloride concentrations in wells 1N/22W-27R1,3-5 (Number is chloride concentration, in mg/L.)

fine-grained deposits may be an additional source of high-chloride water to wells. The presence of poor-quality water in the fine-grained, lagoonal deposits near Point Mugu was confirmed using test-drilling data and electromagnetic logs (R.T. Hanson, U.S. Geological Survey, written commun., 1994).

Major-ion data (Izbicki, 1991) and oxygen and deuterium ($\delta^{18}O$ and δD) isotopic data (Izbicki, 1996) were used to identify the source of high-chloride water to wells and to redefine the areal extent of seawater intrusion in the Oxnard and Mugu aquifers. Using this approach, seawater cannot be positively identified from other sources of high-chloride water at chloride concentrations less than 500 mg/L. The redefined areal extent of seawater intrusion in 1993 was 5.5 mi^2 in the Oxnard aquifer and 3.3 mi^2 in the Mugu aquifer (fig. 3)—considerably less than the 23 mi^2 (of the upper aquifer system) mapped in previous studies. Much of the apparent reduction in the areal extent of seawater intrusion results from the identification of additional sources of high-chloride water to wells in the Oxnard and Mugu aquifers. For example, near Mugu submarine canyon the seawater front is preceded by water from fine-grained lagoonal deposits that has chloride concentrations greater than 500 mg/L in both the Oxnard (4.5 mi^2 of high-chloride water) and Mugu (3.1 mi^2) aquifers.

On the basis of the redefined areal extent of seawater intrusion, seawater in the Oxnard and Mugu aquifers advanced only 2.7 and 1.9 miles, respectively, from aquifer outcrops in the submarine canyons between 1955 and 1992 (fig. 3). As a consequence, the seawater must be moving slower than previously believed. This is consistent with estimates of the rate of movement of the seawater front made on the basis of tritium and chlorofluorocarbon data (Michel and others, in press).

Seawater Intrusion in the Lower Aquifer System

The lower aquifer system also contains multiple sources of high-chloride water to wells. These sources include seawater intrusion and movement of high-chloride water from partly consolidated marine and volcanic rocks that surround and underlie the basin. Although not discussed specifically in this report, leakage of water through the corroded and failed casings of abandoned wells also is a source of high-chloride water to wells in the lower aquifer system. As part of this study, 25 monitoring wells (some as deep as 1,500 feet) were installed in the lower aquifer system and underlying marine rocks at 10 sites near Hueneme and Mugu submarine canyons (Densmore, 1996).

Chloride concentrations in water from wells installed in the lower aquifer system as part of this study were as high as 2,500 mg/L near Mugu submarine canyon and 7,100 mg/L near Hueneme submarine canyon. Chloride concentrations in water from wells installed in the surrounding and underlying marine rocks were as high as 3,400 mg/L (Izbicki and others, 1995).

High-chloride water from wells in the lower aquifer system near Mugu submarine canyon is enriched in iodide relative to a mixture of native water with seawater (fig. 5). These data suggest that high-chloride water in the lower aquifer system near Mugu submarine canyon is not the result of seawater intrusion. This interpretation was confirmed by $\delta^{18}O$ and δD data, which show that high-chloride water near Mugu submarine canyon is meteoric, rather than oceanic, in origin (Izbicki, 1991). The chemical and isotopic composition of high-chloride water from wells near Mugu submarine canyon is similar to that of high-chloride water from wells as far as 15 miles inland. These inland wells have been invaded by high-chloride water from the marine and volcanic rocks that surround and underlie the lower aquifer system. Analyses of water-quality data suggest that the source of

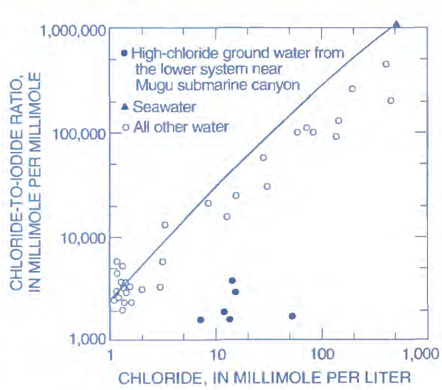

Figure 5. Chloride-to-iodide ratio as a function of chloride in water from wells in the Oxnard Plain.

most of the high-chloride water to wells in the lower aquifer system near Mugu submarine canyon is the partly consolidated marine rocks, although the volcanic rocks are a locally important source.

The $\delta^{18}O$ and δD data confirm that high-chloride water near Hueneme submarine canyon is a mixture of native water and seawater. Seawater intrusion in the lower aquifer system was first identified in November 1989 in water from a well near Hueneme submarine canyon (fig. 3). This well is screened between 720 and 760 feet below land surface. By May 1991, water from a well at the same site, but screened between 500 and 520 feet, also was intruded by seawater. In August 1993, no increase in chloride concentration and no evidence of seawater intrusion was found in water from a well at the site screened at a depth of 830 to 870 feet or in water from other multiple-well monitoring sites inland from Port Hueneme.

Electromagnetic logs show that seawater intrudes the lower aquifer system through relatively thin layers within the aquifer (R.T. Hanson, U.S. Geological Survey, written commun., 1994). Intruded layers are presumably areally extensive and more permeable than the unintruded layers. Clay deposits having low permeability restrict the vertical movement of seawater between more permeable layers. The layered nature of seawater intrusion within the lower aquifer system was simulated using a solute-transport model developed by the U.S. Geological Survey (Tracy Nishikawa, written commun., 1996).

Strategies for Controlling Seawater Intrusion

In previous studies, the areal extent of seawater intrusion in aquifers underlying the Oxnard Plain was overestimated because other sources of high-chloride water to wells were not recognized. Control of these other sources may require new solutions, such as the destruction of abandoned (unused) wells (Ventura County Public Works Agency, 1995). More accurate understanding of the areal extent of seawater intrusion also may allow increased pumping from the upper aquifer system, or the use of management solutions such as injection barriers, which had previously been rejected as impractical for control of the widespread seawater intrusion believed to exist in the upper aquifer system underlying the Oxnard Plain (Ventura County Public Works Agency, 1995).

Results of a recently completed U.S. Geological Survey simulation-optimization study of alternative water-resource management strategies (Reichard, 1995) showed that a significant reduction in pumping, particularly in the lower aquifer system, and a large quantity of additional water (either recharged to aquifers or used in place of ground-water pumping) would be required to control seawater intrusion. Numerous projects to reduce water demand and develop supplemental water sources through the expansion of existing ground-water recharge facilities, expansion of existing water-distribution facilities, use of reclaimed water, and injection of imported or reclaimed water into aquifers underlying the Oxnard Plain are planned by local water agencies and municipalities (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 aid in the effective management of the ground-water resources of the basin.

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