Mapping Saline Groundwater in a Coastal Southern California Aquifer System

Robert Anders[1], Danny A. Cronquist[1, 2], Lindsey E. White[1, 3], and Wesley R. Danskin[1]

1–U.S. Geological Survey, CaWSC, 4165 Spruance Road, Ste. 200, San Diego, CA, 92101
2–San Diego State University, 5500 Campanile Drive, San Diego, CA 92182
3–Naval Facilities Engineering Command, SW, 1220 Pacific Hwy, San Diego, CA 92132

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Abstract

Extensive data, including lithologic information, geophysical logs, and water-quality data have been collected in the San Diego, California area since 2001 to evaluate the suitability of the San Diego Formation and overlying alluvial deposits for use as a drinking-water supply. *Lithologic information was compiled from descriptions of drill cuttings collected during the installation of 9 multiple-well monitoring sites to depths of more than 700 meters and was combined with available geospatial data sets, surface geologic maps, and various literature references to wells and outcroppings to generate a three-dimensional geologic framework model of the coastal San Diego area. Natural gamma-ray and electromagnetic induction (EM) logs were obtained prior to the installation of the monitoring wells and during subsequent site visits. EM logs are sensitive to changes in lithology and water quality; because the lithology remains constant, repeated EM logs were used to show changes in water-quality due to natural recharge processes, seawater intrusion, or other processes. Water samples were collected and analyzed for selected major- and minor-ions, the stable isotopes of hydrogen, oxygen, and strontium, and the radiogenic isotope of carbon-14. Through the use of the geophysical logs, water-chemistry data, and cross sections derived from the 3D geologic framework model, it was possible to map the groundwater quality in the coastal aquifer system. In addition, by using sodium-to-calcium molar ratios, in combination with the isotopic data, the occurrence of saline groundwater as a result of seawater intrusion was distinguishable from groundwater in a previously-saline aquifer which has been "freshened" by continental recharge. These findings indicate multiple groundwater flow paths exist in the coastal aquifer system.*

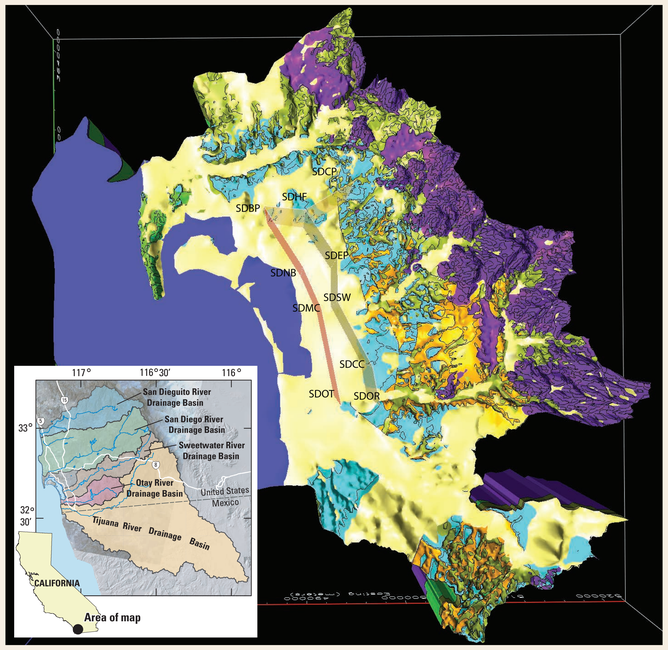
Background

Over the past decade, the USGS has been conducting a regional assessment of the groundwater resources in the San Diego area. The regional assessment of groundwater resources in the San Diego area was designed as an integrated set of five drainage-basin investigations to evaluate the suitability of the San Diego Formation and overlying alluvial deposits for use as a drinking water supply. The San Diego Formation is composed of thinly bedded sandstone and conglomerate, which originated as marine and non-marine sediment during the late Pliocene and early Pleistocene, ranges in thickness from about 30 meters to more than 250 meters, and is overlain by unconsolidated Quaternary alluvium of the Linda Vista and Bay Point Formations. An integral part of the regional assessment has been the installation of 9 multiple-well monitoring sites, each with as many as 6 monitoring wells, to depths of more than 700 meters.

Additionally, the multiple-depth monitoring-well sites have been equipped with real-time, water-level recording equipment and the data is available via the project website. (For more information see-*http://ca.water.usgs.gov/sandiego*)

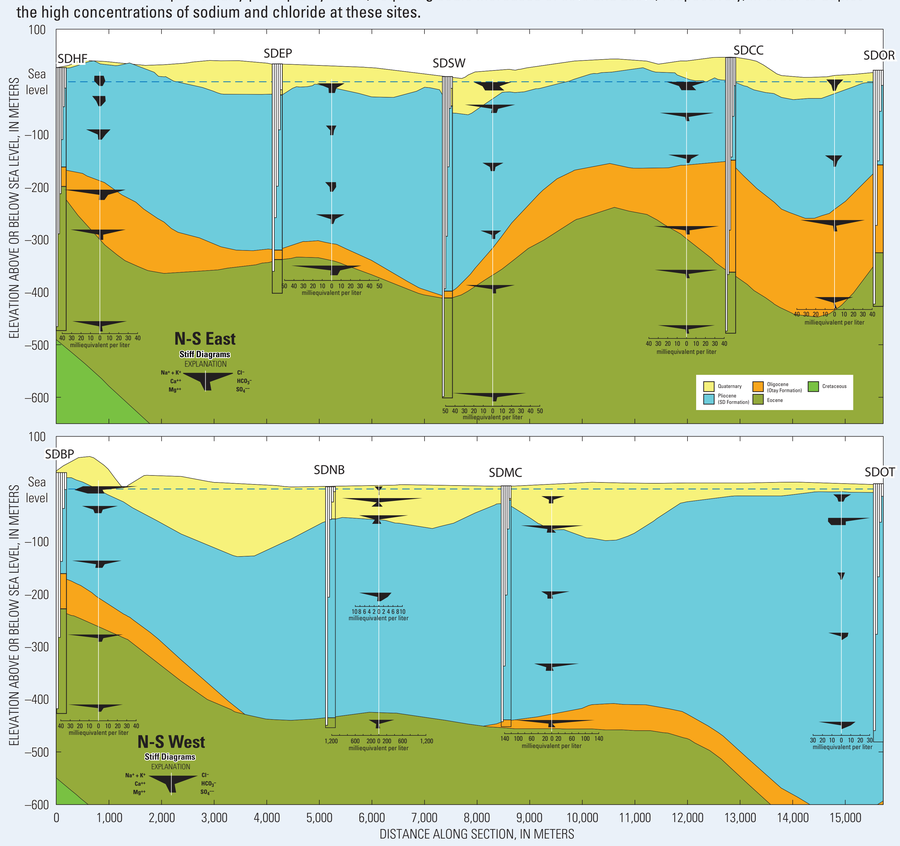
3D Geologic Framework Model

Lithologic information was compiled from descriptions of drill cuttings collected at each borehole and from observations recorded during drilling. These observations provided direct, reliable data for the geologic boundaries of the subsurface. Additional data from wells, borings and seismic shot points provided age and depth information. These values were coupled with pre-existing GIS data sets, surface geologic maps, drilling and well logs, the aforementioned direct observations of lithology, and various literature references to wells and outcroppings to provide the input data used by RockWorks modeling software to generate a three-dimensional geologic framework model. Two north-south cross-sections were derived from the 3D geologic framework model, one located along the San Diego Bay (West) and the other one located along the coastal plain away from the bay (East). The East and West cross sections were used to map the groundwater quality in the coastal southern California aquifer system.



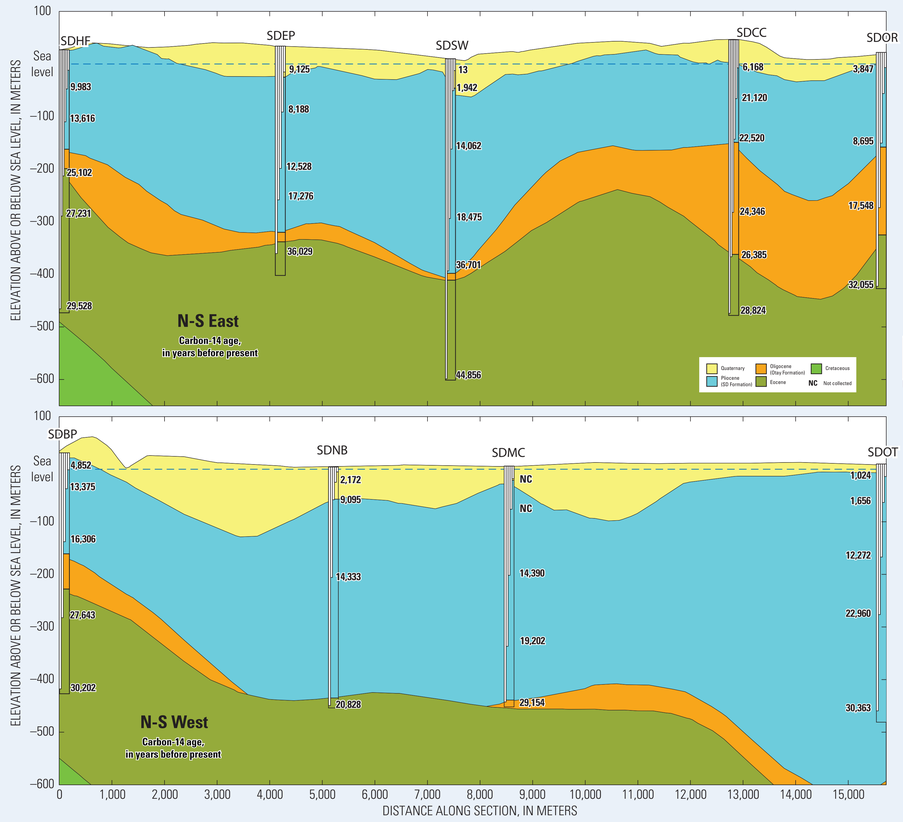
Major-ion Chemistry

Major-ion composition of groundwater samples collected from 9 multiple-well monitoring sites located in coastal San Diego County are presented here using Stiff diagrams. As seen in both the West and East cross sections, much of the groundwater in the coastal southern California aquifer system is of poor quality, having high sodium and chloride concentrations. SDMC and SDNB have particularly poor quality water, requiring scale increases of 50% and 200%, respectively, in order to depict the high concentrations of sodium and chloride at these sites.



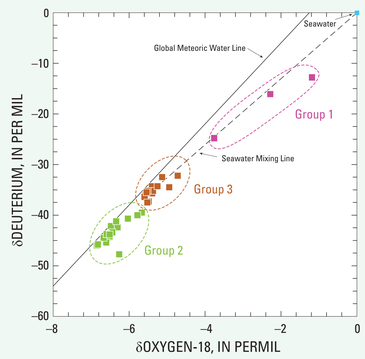
Uncorrected Groundwater Age

Carbon-14 was used to derive the uncorrected groundwater ages from calculations using the percent modern carbon measured in the various samples. The cross sections show a general trend which depicts groundwater in the Quaternary alluvium as less than 10,000 years before present, groundwater in the San Diego Formation as generally less than 20,000 years before present, and groundwater in the Otay Formation and the Eocene layer as between 25,000 and 45,000 years before present. The presence of modern groundwater in only the shallowest monitoring wells indicates most of the groundwater in the coastal aquifer system was recharged many thousands of years ago.



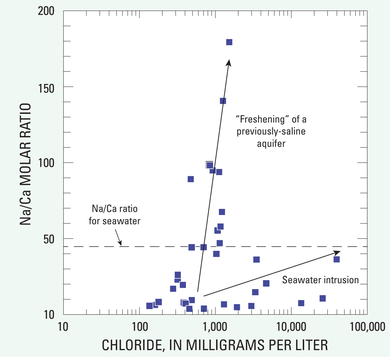
Stable Isotopes of H and O

The stable isotopes of hydrogen and oxygen can be used to identify the different sources of recharge throughout the region. These different sources are distinguishable by: (1) isotopic values comprised of a mixture of groundwater and seawater: (2) lighter (more negative) isotopic values that are characteristic of recharge originating in the fractured crystalline rock more than 20 km east and upgradient from the coastline; and (3) intermediate isotopic values that are characteristic of precipitation originating in the coastal plain as the source of recharge.



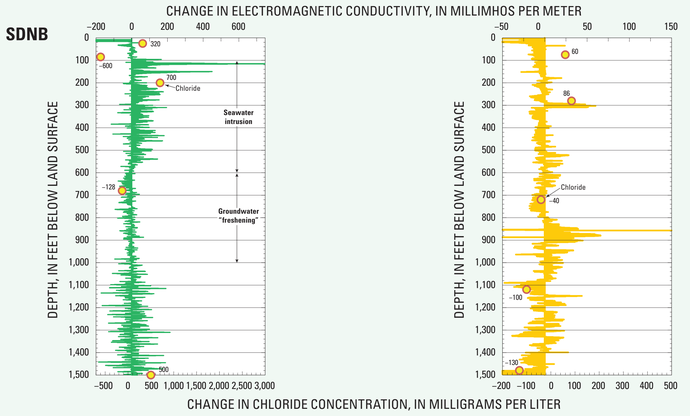
Na/Ca Molar Ratios

The relationship between Na/Ca molar ratios and Cl concentrations can be used to distinguish between the processes responsible for the occurrence of saline groundwater in a coastal aquifer system. For the San Diego area, the composition of fresh groundwater is represented by low Na/Ca molar ratios with low to intermediate Cl concentrations. In contrast, increasing Na/Ca molar ratios without a corresponding increase in Cl concentrations indicate "freshening" of a previously-saline aquifer by continental recharge. Finally, Na/Ca ratios approaching seawater with increasing chloride concentrations indicate the source of saline groundwater to these wells is the result of seawater intrusion.



Changes in Geophysical Logs and Cl Concentrations

Gamma and electromagnetic induction (EM) logs were obtained prior to the installation of the monitoring wells, and during subsequent site visits. A natural gamma tool is designed to measure the total intensity of gamma-ray emissions from the formation. EM logs are sensitive to changes in lithology and water quality; because the lithology remains constant repeated EM logs show changes in water-quality due to natural recharge processes, seawater intrusion, or other processes. Recent increases in EM conductivity and Cl concentrations for two multiple-well monitoring sites (SDNB and SDMC) located along the coast indicate seawater intrusion is occurring within these zones. In contrast, decreases in EM conductivity and Cl concentrations indicate zones of "freshening" of a previously-saline aquifer by recently recharged water.



Significant Findings

1. A three-dimensional geologic framework model was generated and used to map the groundwater quality in the coastal southern California aquifer system.

2. Stiff diagrams are used to depict the water quality of groundwater samples collected from 9 multiple-well monitoring sites located in coastal San Diego County. As seen in both the West and East cross sections, much of the groundwater in the coastal southern California aquifer system is of poor quality.

3. The uncorrected C-14 ages of groundwater in the coastal aquifer system generally correlates with depth and indicates that most of the groundwater was recharged many thousands of years ago.

4. The stable isotopes of hydrogen and oxygen indicate the different sources of recharge for the groundwater in the San Diego area are distinguishable with more locally recharged groundwater being found at shallower depths and more distantly recharged groundwater found at greater depths.

5. The relationship between Na/Ca molar ratios and Cl concentrations can be used to distinguish between the presence of saline groundwater as a result of seawater intrusion and "freshening" of a previously-saline aquifer by continental recharge.

6. Changes in EM conductivities provide evidence for the occurrence of seawater intrusion and "freshening" of a previously-saline aquifer by recently recharged water.