DETERMINATION OF GROUNDWATER FLOW PATHS IN A COASTAL SOUTHERN CALIFORNIA AQUIFER

[1]Robert Anders and [2]Kiyoto Futa

1—USGS San Diego WSC, 4165 Spruance Rd., Ste. 200, San Diego, CA 92101

2—USGS Denver Federal Center, Box 25046, MS 963, Bldg. 21 Denver, CO, 80225

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Abstract

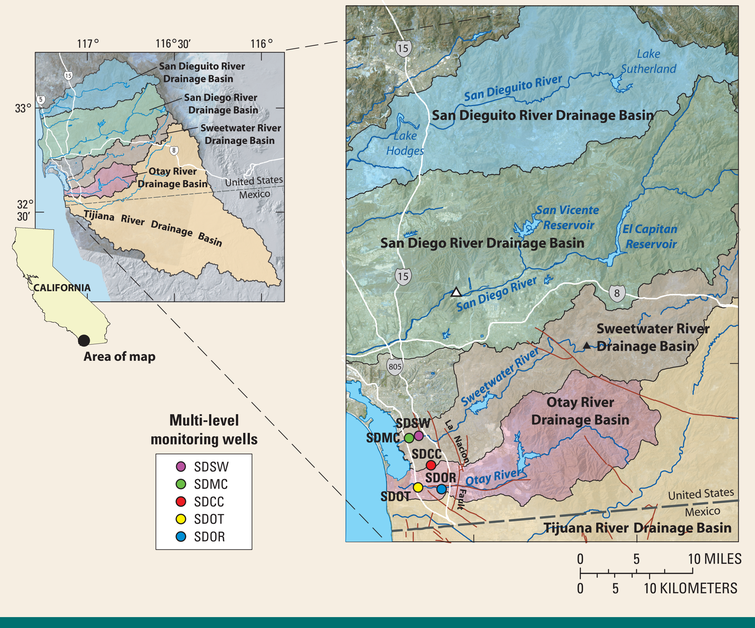
The U.S. Geological Survey (USGS) is conducting a comprehensive geologic, hydrologic, and geochemical investigation of groundwater resources in the San Diego coastal area. *The regional assessment includes five drainage basins, in order to gain a better understanding of the hydrogeology of the areally extensive San Diego Formation. An integral part of the investigation is the installation of 10 multiple-well monitoring sites to collect groundwater samples from discrete intervals and to extract pore-water fluids from selected sections of drill core. The analytical protocol includes major dissolved ions, trace metals, stable isotopes, and strontium isotopes ($^{87}Sr/^{86}Sr$). Strontium isotopes have proven to be especially useful in detecting mixing among waters of different sources and histories, as well as in characterizing the effects of water-rock interaction.*

This paper will present groundwater and pore-water data collected from two, east-west pairs of monitoring-well sites located in the Sweetwater River and the Otay River drainage basins as well, as a monitoring-well site located on a plateau between the two drainage basins. *These data indicate that the hydrogeology of the San Diego area can be characterized as alternating layers of marine and non-marine sediment lacking large-scale lateral uniformity. The dissolved strontium concentrations from these groundwater samples and pore-water fluids ranged from as low as 100 µg/L to more than 18,000 µg/L, and the $^{87}Sr/^{86}Sr$ ratios ranged from about 0.7060 to 0.7090. One potential source of groundwater in the San Diego area is modern seawater, which has an $^{87}Sr/^{86}Sr$ ratio of about 0.7092; another is recharge from the topographically higher elevations east of the study area that has $^{87}Sr/^{86}Sr$ ratios between 0.7050 and 0.7060. Finally, the similarities in $^{87}Sr/^{86}Sr$ ratios between groundwater samples and pore-water fluids provide insight into the relative hydraulic conductivity among these discontinuous aquifers.*

Background

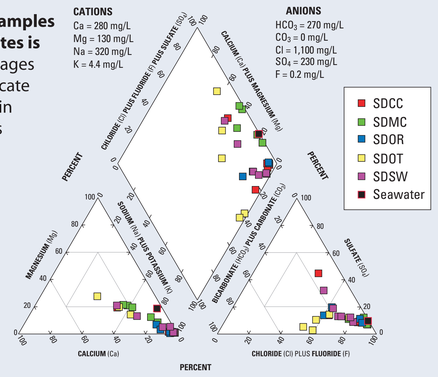
The regional assessment of groundwater resources in the San Diego area was designed as an integrated set of five drainage-basin investigations, in order to gain a better understanding of the hydrogeology of the areally extensive San Diego Formation. The San Diego Formation is composed of thinly bedded sandstone and conglomerate, which originated as marine and non-marine sediment during the late Pliocene and early Pleistocene, ranges in thickness from about 100 feet to more than 800 feet, and is overlain by about 100 feet of unconsolidated Quaternary deposits.

An integral part of the investigation is the installation of 10 multiple-well monitoring sites to depths of as much as 2,000 feet. Data includes geologic and geophysical logs, cores from selected depths, water-quality samples analyzed for a broad range of constituents including major and minor dissolved ions, trace metals, volatile organics, pesticides, wastewater indicators, and stable and radiogenic isotopes. At two multiple-well monitoring sites, pore water was extracted from numerous fresh core samples using a hydraulic press and stainless steel capsule system. The analytical protocol for the pore-water samples included major dissolved ions, trace metals, stable isotopes, and strontium isotopes ($^{87}Sr/^{86}Sr$). In addition, the multiple-well monitoring sites are equipped with real-time, water-level recording equipment and the data is available via the project website **http://ca.water.usgs.gov/sandiego**



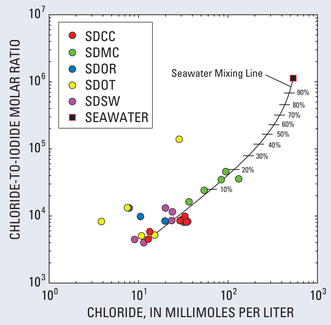
Major-ion Chemistry

Major-ion composition of 27 groundwater samples collected from 5 multiple-well monitoring sites is presented using a trilinear diagram. Percentages of major ions on a charge-equivalent basis indicate the chemical composition of the groundwater in the Sweetwater and Otay River drainage basins can be characterized as mixed cation-Cl to Na-Cl type. This chemical character results from calcite precipitation, gypsum dissolution, and cation exchange and not from sulfate-reduction reactions which are typical of other coastal groundwater systems. The percentages of major ions indicate also that the chemical character of several water samples resemble the major-ion composition of seawater.



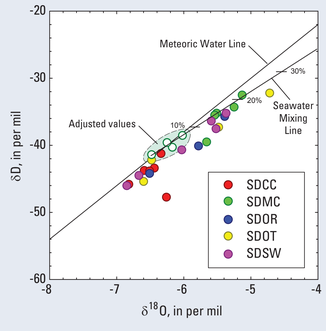
Minor-ion Chemistry

The concentration of iodide ions in water relative to Cl^- concentrations was analyzed to distinguish between high-Cl^- water from different sources. Iodide is an excellent indicator of the geologic material that water has encountered as it flows through aquifers. Also shown is a simple two-member mixing line between native freshwater and seawater. The ratio of chloride-to-iodide in water from several wells plot along the mixing line and suggests that water from these coastal wells are affected by seawater intrusion and (or) mixing with high-chloride water from fine-grained deposits.



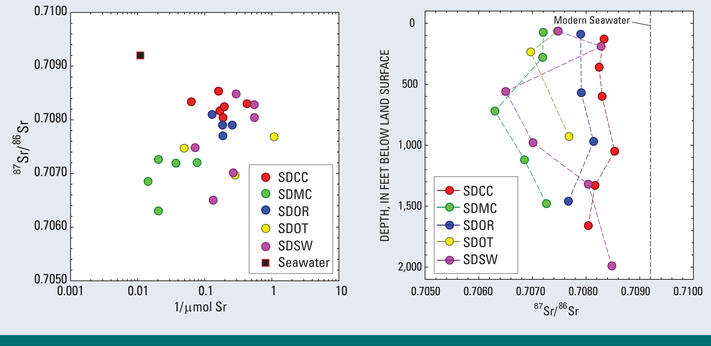
Stable Isotopes of H and O

The stable isotopes of hydrogen and oxygen can be used to identify the different sources of recharge in the Sweetwater and Otay River drainage basins. These different sources of recharge are distinguishable by: (1) isotopic values comprised of a mixture of groundwater and seawater; (2) lighter (more negative) ground-water isotopic values that are characteristic of recharge which originates in the mountains to the east of the Sweetwater and Otay River drainage basins; and (3) intermediate isotopic values which are characteristic of local precipitation as the source of recharge to the multiple-well monitoring sites. After adjusting the stable isotopic values in water from several coastal wells for the contribution of seawater, the predominant source of recharge in the Sweetwater and Otay River drainage basins appears to originate in the mountains to the east and not from local precipitation.



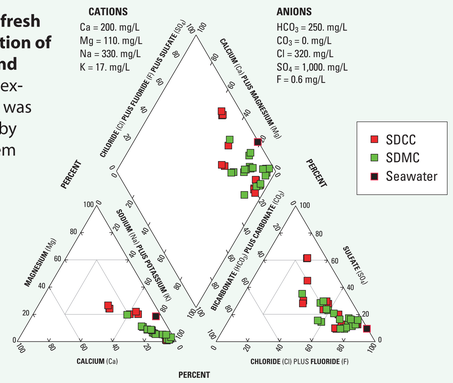
$^{87}Sr/^{86}Sr$ Isotope Ratios

Strontium isotopes are useful in detecting mixing among waters of different sources and histories, as well as in characterizing the effects of water-rock interaction. The dissolved strontium concentrations of the groundwater samples in the San Diego area ranged from as low as 100 µg/L to more than 18,000 µg/L. The highest strontium concentrations for the 27 groundwater samples in the Sweetwater and Otay River drainage basins were collected from SDMC. The $^{87}Sr/^{86}Sr$ ratios ranged from about 0.7060 to 0.7090, with the lowest values from groundwater samples collected from SDMC and the highest values from groundwater samples collected from SDCC. The greatest variation of $^{87}Sr/^{86}Sr$ ratios with depth were from groundwater samples collected from SDSW.



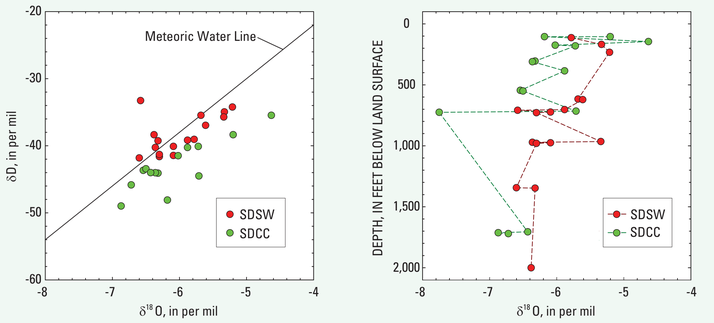
Pore Water Major-ion Chemistry

Pore water was extracted from numerous fresh core samples collected during the installation of SDSW and SDCC using a hydraulic press and stainless steel capsule system. During the extraction process, between 3 to 15 mL of fluid was squeezed from about 50 grams of sediment by applying 4,000-6,000 psi to the capsule system for a period of 15 to 45 minutes. The pore-water samples were then prepared for the analysis of major dissolved ions, trace metals, stable isotopes, and strontium isotopes. Percentages of major ions shown using a trilinear diagram indicate the chemical composition of the pore-water samples collected from SDSW and SDCC are similar to the groundwater samples.



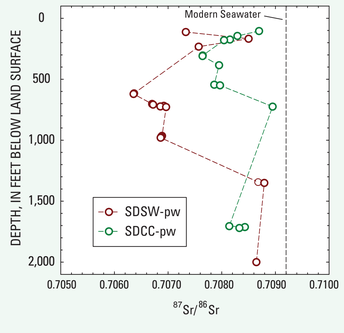
Pore Water Stable Isotopes of H and O

The lighter (more negative) isotopic values for pore-water samples collected from SDCC are characteristic of recharge which originates in the mountains to the east of the San Diego area. In contrast, the isotopic values for pore-water samples collected from SDSW are characteristic of local precipitation as the source of recharge.



Pore Water $^{87}Sr/^{86}Sr$ Isotope Ratios

The pore-water $^{87}Sr/^{86}Sr$ isotope ratios provide more hydrogeologic detail than the $^{87}Sr/^{86}Sr$ ratios from the groundwater samples. The $^{87}Sr/^{86}Sr$ ratios in the SDSW profile are highest at about the 200-ft and 1,350-ft levels and decrease to their lowest values at about the 560-ft level. The pore-water $^{87}Sr/^{86}Sr$ isotope ratios for the SDCC profile reflect a similar trend which was absent from the groundwater $^{87}Sr/^{86}Sr$ isotope ratio profile. The resulting pore-water $^{87}Sr/^{86}Sr$ profiles suggest a stratigraphic connection between the two sites. These two profiles suggest also that water flows from the mountains to the east of the Sweetwater and Otay River drainage basins, along the stratigraphic connection, and mixes with the groundwater in the coastal wells.



Significant Findings

1. **Groundwater in the Sweetwater and Otay River drainage basins is characterized as mixed cation-Cl to Na-Cl type.**

2. **Water from several coastal wells in the Sweetwater and Otay River drainage basins is affected by the presence of seawater and (or) mixing with high-chloride water from fine-grained deposits.**

3. **The predominant source of recharge in the Sweetwater and Otay River drainage basins originates in the mountains to the east and not from local precipitation.**

4. **The highest strontium concentrations are in groundwater samples collected from coastal wells and correspond to the lowest $^{87}Sr/^{86}Sr$ isotope ratios.**

5. **The pore-water $^{87}Sr/^{86}Sr$ isotope ratios identify a stratigraphic connection of relatively high hydraulic conductivity in the Sweetwater and Otay River drainage basins.**