

Base from U. S. Geological Survey State base map of California, south half, 1:1,000,000, 1970, and State base map of Nevada, 1:1,000,000, 1965

**EXPLANATION** 

Area shown on map

Colorado River

Santa Ana San Diego

and identification letter

#### INTRODUCTION

(RASA) area

The areal distribution of the concentrations of the stable isotopes deuterium and oxygen-18 in ground water in southeastern California is depicted and evaluated in this report. The deuterium content of about 300 ground-water samples and the oxygen-18 content of 101 of these samples are presented. Thirty-two of the samples were collected by the U.S. Geological Survey in 1977–78 as part of a study to determine the mineral and brine potential of playa lakes in selected basins in southeastern California. Most of the remaining samples were collected during the winters and springs of 1981 and 1982 as part of the Climate Change Program of the Geological Survey. Selected additional samples were collected through 1986. Stable-isotope data from three previous studies also have been included. These data are for 19 samples from the Coso thermal area east of the southern Sierra Nevada (Fournier and Thompson, 1980, tables 1, 2), 5 samples from areas in Nevada just east of Death Valley (Winograd and Friedman, 1972, table 1), and 9 samples from the Imperial Valley (Coplen, 1971, table 1). Also presented for comparison are weighted averages of deuterium content of recent precipitation collected for this report at 32 stations over the 7-year period from April 1982 to April 1989 (Irving Friedman and G.I. Smith, U.S. Geological Survey, written commun., 1989).

The compilation of stable-isotope data presented here was done as part of the Regional Aquifer-System Analysis (RASA) Program. The objectives of the southern California basins RASA study are to determine the geohydrologic framework of the coastal and desert basins in southern California excluding the Central Valley and to identify and analyze major issues and problems affecting the use of ground water in these basins (Martin, 1986). The quantity and distribution of recharge and the flow between aquifer layers are issues that have been selected for detailed investigation during this RASA study; the data on stable-isotope ratios of ground water presented in this report will be useful in addressing both issues.

Collection of the new (1981–86) samples included in this report required the assistance and cooperation of many persons, including landowners and employees of ranches and water districts who provided access to wells and well-construction and other data. Although it is not possible to cite them all, the following people, acting on behalf of themselves as well as their organizations, deserve our special thanks: J.P. Calzia, E. Carlson, J.A. Crowley, R.D. Dockter, E.N. Eldridge, G.E. Ericksen, L. Lunk, J. McConaha, G.F. Moulton, L.L. Reise, A. Romspert, and G.T. Server.

### STABLE-ISOTOPE CHEMISTRY

The ratios of the heavy isotopes of oxygen [oxygen-18 ( $^{18}O$ )] and hydrogen [deuterium (D or  $^2H$ )] in ground water, relative to the more abundant isotopes ( $^{16}O$  and  $^1H$ ), are indicators of its hydrologic history. The isotope ratios are expressed in delta notations ( $\delta$ ) as per mil (parts per thousand) differences relative to the standard known as Vienna Standard Mean Ocean Water (V-SMOW):

 $\delta^{18}O = \frac{(^{18}O^{16}O) sample - (^{18}O^{16}O) standard}{(^{18}O/^{16}O) standard} \times 1,000$ 

 $\delta D = \frac{(^{2}H/^{1}H) sample - (^{2}H/^{1}H) standard}{(^{2}H/^{1}H) standard} \times 1,0$ 

 $\delta D = \frac{(^{1}H^{1}) \, standard}{(^{2}H^{1}H) \, standard} \times 1,000.$  Oxygen-isotope values have been normalized for 0 per mil V-SMOW and –55.5 per mil Standard Light Antarctic Precipitation (SLAP); hydrogen-isotope values have been normalized for 0 per mil V-SMOW and –428 per mil SLAP. When run in duplicate, oxygen and hydrogen samples are considered to be precise to 0.1 and 0.8 per mil, respectively. The relation between  $\delta D$  and  $\delta^{18}O$  of natural water was first proposed by Friedman (1953) and later was quantified by Craig (1961), who found that plots of  $\delta^{18}O$  and  $\delta D$  in precipitation throughout the world are linearly correlated. This linear relation is referred to as the global meteoric water line and is the result of the fact that seawater is the source of most precipita-

The isotopic composition of seawater is relatively constant; therefore, the isotopic composition of vapor derived from ocean waters that have the same temperature also is constant. However, as this water vapor condenses and precipitates, the proportion of heavier isotopes removed is greater than that of the lighter isotopes. This leaves the remaining vapor relatively depleted in oxygen-18 and deuterium. This process, which is known as isotopic fractionation, is temperature dependent: The lower the temperature of condensation, the greater the fractionation. The net result of these processes is that precipitation from a given storm becomes progressively lighter isotopically as the storm moves inland, and precipitation that condenses at lower temperatures is lighter than precipitation that condenses at higher temperatures (Dansgaard, 1964; Friedman and others, 1964).

Evaporation also causes fractionation. When water is evaporated during the precipitation process or after precipitation reaches the ground, the lighter isotopes of oxygen and hydrogen are preferentially partitioned into the vapor phase, thus causing the remaining water to be isotopically heavy. After the water becomes recharged and migrates below the depth at which evaporation occurs, little further change in the isotopic composition occurs at the low temperatures of most ground-water systems, although exchange between the oxygen in water and some rocks can occur. Most changes in the isotopic composition of ground water along a flow line reflect primarily the mixing of waters within the aquifer system.

#### DATA-COLLECTION PROCEDURES AND MEASUREMENT TECHNIQUES

The collection plan and procedures for the samples collected from 1981 to 1986 were designed to provide water samples for analyses of hydrogen- and oxygen-isotope ratios from a representative selection of the perennial springs and deep wells within part of the Basin and Range Province and adjacent regions in southeastern California. To avoid collecting samples whose isotope ratios were altered by evaporation while the water was standing in storage tanks or ponds, wells were sampled at the pump while it was operating, provided that the pump had operated long enough to evacuate all water in the well casing. In general, where several wells were available, the deepest well was sampled, although in some areas, shallow wells also were sampled to test for any vertical gradients in isotope concentration. In addition, information about depths to the water table, pump or impeller, well casing, perforation zones, and so forth was compiled. Springs that were sampled, most of which are shown on Survey topographic maps, were flowing and were sampled at or close to their discharge points. For samples collected during 1977–78, field measurements of specific gravity, pH, and temperature were made. For those wells that have been assigned a State well number (table 1), corroborating and supplemental data are available in U.S. Geological Survey files.

<sup>1</sup>5735 Kearny Villa Road, Suite O, San Diego, CA 92123.

Deuterium concentrations were measured by using techniques described by Friedman (1953) and Friedman and Woodcock (1957). Oxygen-18 analyses were made by first equilibrating a small amount of each water sample with carbon dioxide. The carbon dioxide then was separated from the water and purified before being analyzed in a mass spectrometer for its oxygen-18 to oxygen-16 ratio. All brine samples were distilled to dryness and the residue heated to above 250°C to remove salts before further treatment.

### heated to above 250°C to remove salts before further treatment. DEUTERIUM CONTENT OF WATER FROM WELLS AND SPRINGS

SANTA CATALINA

All stable-isotope data are given in table 1 and plotted on the map. In general, the listing in the table is from north to south; the specific sequence is determined by the letter and number assigned by the California Department of Water Resources (1964) to the hydrologic units, which are outlined and labeled on the map, and by the sample number within each unit. The letter indicates the drainage province in which the hydrologic unit is located. Most of the data included in this study are from the Lahontan (W) and the Colorado River (X) Drainage Provinces. The boundaries of hydrologic units were drawn on the basis of surface-drainage divides. Laboratory number, State well number (where applicable), altitude of land surface, location, water-table and well depths, and other data on the sample source also are given. All data points are plotted on the map. Where more than one sample was collected from the same spring or well, average  $\delta D$  values were plotted. Several samples were collected outside the western boundary of the study area; deuterium data from these samples are given in table 1 and are assigned to the hydrologic unit nearest the sample site.

To portray regional patterns in deuterium concentration in the water of deep wells, lines of equal  $\delta D$  values (interval 10 per mil) were drawn on the map on the basis of plotted data points. A few individual data points (whose values are enclosed by parentheses) were ignored in drawing the lines because their values clearly are anomalous with respect to the range indicated by the enclosing lines. Deuterium content in water from springs was not considered in plotting these lines, but the  $\delta D$  values of water from springs can be compared with those of ground water from wells in nearby areas.

The δD values are negative because all waters are isotopically lighter (depleted in deuterium) than seawater. This is because the area is 75 km or more inland from the Pacific Ocean and the Gulf of California, which are the sources of virtually all atmospheric moisture that falls as precipitation in the area. Some of the deuterium originally in the airmasses that were in nominal equilibrium with seawater ( $\delta D=0$  per mil) was fractionated into the precipitation that condensed before reaching this area of study. This process produces a detectable easterly gradient in deuterium content, but the effect of mountains in the paths of storms is more pronounced. As airmasses are forced over high mountains, adiabatic cooling occurs in proportion to the altitude of the mountains. This cooling causes condensation and results in increased deuterium loss from easterly moving airmasses over short horizontal distances (see Smith and others, 1979, p. 173–175). The notably light (more negative) values from east of the highest segments of the Sierra Nevada and northeast of the high peaks in the San Bernardino Mountains are attributed to this process. Conversely, heavy (less negative) values are noted inland from low passes in mountainous terrain, particularly in the westernmost part of the Antelope Hydrologic Unit (W26), which is rimmed along its western border by relatively low ranges; heavy values also are present along the west edge of the southernmost part of the Imperial Hydrologic Unit (X23), which is bounded by low mountains and is close to the Pacific Ocean and the Gulf of California. The trends of the lines of equal δD values are relatively uninfluenced by the position and trends of areally small or topographically low mountain ranges of the Lahontan and the Colorado River Drainage Provinces. The lines of equal  $\delta D$  cross moderate-sized mountain masses, which indicates that either the mountains had minimal influence on the deuterium content of moist airmasses

or interbasin ground-water leakage has been extensive since recharge. The  $\delta D$  values shown on the map range from -130 per mil in the north to near -60 per mil in the south. As noted above, most of this variation can be attributed to the effect of high mountains. In addition, other north-south  $\delta D$  gradients are produced by the temperature gradients relative to latitude and the statistically greater likelihood of high-latitude storms bringing moisture to the northern areas and low-latitude storms bringing moisture to areas in the south. Both factors, therefore, combine to assure that the more northerly areas commonly receive precipitation that is condensed at lower temperatures than is precipitation falling in the southern areas; this situation results in greater fractionation and isotopically lighter pre-

Many of the  $\delta D$  values from deep wells and some springs shown on the map are depleted from 20 to 30 per mil relative to the weighted average of recent precipitation collected at 32 stations in the study area by Friedman and others (Irving Friedman and G.I. Smith, U.S. Geological Survey, written commun., 1989). The mean  $\delta D$  values ( $\delta D_m$ ) for the precipitation-collection stations shown on the map represent 14 semiannual samplings of precipitated rain and snow made between April 1982 and April 1989; the  $\delta D$  values are weighted by the amount of precipitation in each 6-month sample. These data indicate that the isotopically lighter ground-water samples were products of other climatic regimes or abnormal precipitation years when the amounts of precipitation were well above present norms and the isotopic fractionation was more extreme than at present. Examples of these contrasts between values for ground water and recent precipitation are found near the following pre-

cipitation stations:

Darwin	-87	W20	-100 and -110
Death Valley	-75	W09	-100 and $-110$
Goldstone	-64	W17	−90 and −100
Twentynine Palms	-64	X09	-90 and -80
Chiriaco Summit	-58	X18	-80 and -90
Mount San Jacinto	-84	X19	-60 and -70
r; for example:			s of surrounding groun
***	some station $\delta D_m$	s are similar to δD value Hydrologic unit	s of surrounding groun  Enclosing δD lines
r; for example:	δD		

Inspection of the map reveals several areas that are isotopically anomalous relative to

the regional trends. Many of the anomalously heavy  $\delta D$  values for those areas represent

samples that were collected from wells or springs associated with one of the many playa lakes

Hydrologic unit Enclosing δD lines

found in southeastern California. Some of these lakes are regional discharge areas (Moyle, 1974), which means that ground water flowing toward these areas has approached the surface and evaporated, thus becoming isotopically enriched in deuterium in comparison with the surrounding ground water in that region. The most extensively sampled of these discharge areas is Searles Lake (Hydrologic Unit W21). Samples collected from wells within the boundary of the dry lake have isotopic values that are at least 50 per mil heavier than those from the surrounding alluvial and bedrock areas. A more complete description of the isotopic character of the brines and salts beneath Searles Lake is given by Friedman and others (1982). Water samples from wells in Bristol, Cadiz, and Danby Lakes (Hydrologic Units X10, X11, X12, respectively), which are discharge areas, also show the results of evaporation. A single isotopic data point from the playa lake in the middle of the Panamint Hydrologic Unit (W20) suggests that this lake also is a discharge area. In contrast, well samples from beneath the following eight dry lakes show no isotopic evidence of evaporative discharge:

Soggy and Melville (X02), Means (X04), and Emerson (X05).

Three other areas that contain anomalous  $\delta D$  values are in the Mojave, Imperial, and Coachella Hydrologic Units. The  $\delta D$  values of water samples from 8 of 11 wells within 5 km of the Mojave River (Mojave Hydrologic Unit W28) range from -60 to -70 per mil, whereas wells more than 5 km away from the river yield water with  $\delta D$  values that are 20 per mil or more lighter. Three samples of Mojave River water collected in December 1984 and January and June 1985 have  $\delta D$  values of -57, -61, and -70 per mil, respectively. In most years, the Mojave River flows intermittently along this strip underlain by isotopically heavy water and well beyond it in flood years (Woolfenden, 1984, p. 8–9). The similarities between the isotopic character of the river-water samples and samples from ground water that underlies the river clearly show that the river is the main source of recharge to the alluvium along both sides of its flood plain. Thus,  $\delta D$  values can be helpful in ascertaining the extent of recent

Superior (in Hydrologic Unit W19), Cuddeback (W27), El Mirage (W28), Lucerne (X01),

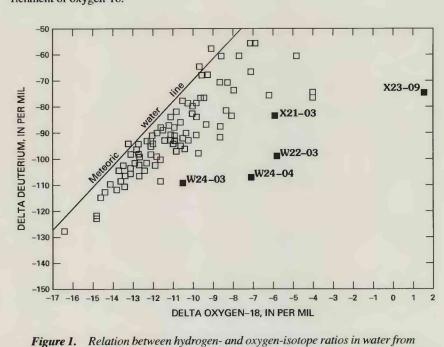
recharge and the relation between surface water and ground water. The Imperial Hydrologic Unit (X23) also contains anomalous  $\delta D$  values in the area southeast of the Salton Sea. Most wells in the nonirrigated parts of the Imperial Hydrologic Unit (the areas west of the New River and east of East Highline Canal) yield water with  $\delta D$  values that ranged from -62 to -77 per mil. In the area that is irrigated with water from the Colorado River,  $\delta D$  values average about -90 per mil. In June 1984, river water near Yuma had a  $\delta D$  value of -108, and water samples collected from the All American and the East Highline Canals had  $\delta D$  values of -107 and -106 per mil, respectively. Wells adjacent to the Colorado River and the All American Canal in the Yuma Hydrologic Unit (X27) and the southern part of the Amos–Ogilby Hydrologic Unit (X26) had  $\delta D$  values that ranged from -104 to -114 per mil, which indicated that these wells are deriving water predominantly from the modern Colorado River, its prehistoric floodings of this area, or leakage of the 20th century irrigation canals. Coplen (1971, p. 115) concluded that recharge by partially evaporated Colorado River water explains the light  $\delta D$  values (average about -90 per mil) of most

The Coachella Hydrologic Unit (X19) contains two distinct zones of  $\delta D$  values that appear to be separated by the San Andreas Fault system. Water samples from wells northeast of the fault system have  $\delta D$  values that range from -84 to -94 per mil, whereas samples from southwest of the fault system range from -65 to -79 per mil. The  $\delta D$  data indicate that ground-water flow in the unconsolidated deposits of the area is interrupted by the San Andreas Fault system, thus demonstrating how  $\delta D$  values can be used to identify barriers to

of the water that underlies the below-sea-level southern Imperial Hydrologic Unit.

## the movement of ground water within an individual hydrologic unit. OXYGEN-18 ANALYSES

The delta oxygen-18 ( $\delta^{18}$ O) analyses of samples from 73 wells and springs that were analyzed for this study, plus 28  $\delta^{18}$ O analyses from other studies, are given in table 1 and are plotted against  $\delta$ D in figure 1. The samples chosen for  $\delta^{18}$ O analysis were selected to represent the entire study area and possibly explain some anomalous values. Almost all the samples plot to the right of the meteoric water line in figure 1. Samples that plot the farthest from the meteoric water line are from geothermal wells (W22–03, W24–04, W21–03, and X23–09) in which temperatures range from 57°C to 232°C. The water from those wells apparently has reacted with the minerals in the enclosing rocks, which has resulted in an enrichment of oxygen-18.



CONCLUSIONS

Values of  $\delta D$  in samples from wells and springs in southeastern California range from -130 per mil in the north to -60 per mil in the south. The observed distribution is the result of orographic and meteorologic processes. The high altitude of the Sierra Nevada in the northern part of the area causes the  $\delta D$  values in samples from east and southeast of the range to

be much lighter (more negative) than would be produced from latitude effects alone. Heavy

δD values in the south, with the exception of the Imperial Valley, are the result of lower

latitudes and the increasing amounts of precipitation derived from low-latitude storms.

selected wells and springs. Solid symbols represent samples from geothermal wells.

In general, the trends of the  $\delta D$  lines do not change significantly as they cross the

Geology from G. E. Walker and T. E. Eakin (1963), W. R. Moyle (1974).

J. H. Stewart and J. E. Carlson (1974), and T. J. Durbin (1978)

medium to low mountain regions of the Lahontan and the Colorado River Drainage Provinces. This implies that because of their low altitudes, those ranges have little meteorological effect on the storms that pass through the regions. In many areas, the  $\delta D$  values of sampled ground water are significantly different from those of precipitation collected over a recent 7-year period. This difference suggests that recent recharge from local precipitation is relatively insignificant in these areas. More data and research are needed to determine the age and meteorological character of the climatic periods that recharged the ground water that is isotopically light in comparison with present precipi-

Many of the  $\delta D$  values for samples collected from wells or springs associated with playa lakes in the study area are anomalously heavy relative to regional trends. Most of these playa lakes are regional discharge areas. Therefore, ground water in these areas has approached the surface and evaporated, thus becoming isotopically enriched in deuterium in comparison with the surrounding ground water in the region.

The  $\delta D$  values of water in some samples from the Mojave, Imperial, and Coachella Hydrologic Units also are anomalous relative to regional trends. The  $\delta D$  of samples from wells near the Mojave River (Mojave Hydrologic Unit) are 20 per mil or more lighter than samples from wells 5 km away from the river. The  $\delta D$  values of samples from the Mojave River water are similar to those of the underlying ground water, which indicates that the river is the main source of recharge to the alluvium along its flood plain. The Imperial Hydrologic Unit contains anomalous  $\delta D$  values in the area southeast of the Salton Sea. Samples from wells in the irrigated parts of the hydrologic unit are from about 10 to 20 per mil lighter than samples from wells in the unirrigated parts. Light  $\delta D$  values in the irrigated parts of the Imperial Hydrologic Unit have been attributed to recharge by partially evaporated Colorado River water. The Coachella Hydrologic Unit contains two distinct zones of dissimilar  $\delta D$  values that appear to be separated by the San Andreas Fault system. Water samples from wells northeast of the fault system have  $\delta D$  values that are about 10 per mil lighter than samples from wells southwest of the fault system. The  $\delta D$  data indicate that ground-water flow in the

# unconsolidated deposits of the area is interrupted by the San Andreas Fault system. REFERENCES CITED

California Department of Water Resources, 1964, Names and areal code numbers of hydrologic areas in the Southern District: California Department of Water Resources Office Report, 57 p.
 1975, California's ground water: California Department of Water Resources Bulletin 118, 135 p.
 Coplen, T.B., 1971, Isotopic geochemistry of water from the Imperial Valley, *in* Rex, R.W.,

and others, Cooperative geological-geophysical-geochemical investigations of geothermal resources in the Imperial Valley area of California: Riverside, University of California, p. 113–119.
Craig, H., 1961, Isotopic variation in meteoric waters: Science, v. 133, p. 1,702–1,703.
Dansgaard, W., 1964, Stable isotopes in precipitation: Tellus, v. 16, p. 436–468.
Durbin, T.J., 1978, Calibration of a mathematical model of the Antelope Valley ground-water basin, California: U.S. Geological Survey Water-Supply Paper 2046, 51 p.
Fournier, R.O., and Thompson, J.M., 1980, The recharge area for the Coso, California, geothermal system deduced from δD and δ 18 O in thermal and non-thermal waters in the region: U.S. Geological Survey Open-File Report 80–454, 27 p.
Friedman, Irving, 1953, Deuterium content of natural waters and other substances: Geochimica

et Cosmochimica Acta, v. 4, p. 89–103.

Friedman, Irving, Redfield, A.C., Schoen, B., and Harris, J., 1964, The variation of the deuterium content of natural waters in the hydrologic cycle: Reviews of Geophysics, 2, p. 177–224.

Friedman, Irving, Smith, G.I., and Matsuo, S., 1982, Economic implications of the deuterium anomaly in the brine and salts in Searles Lake, California: Economic Geology, v. 77, no. 3, p. 294–702.

Friedman, Irving, and Woodcock, A.H., 1957, Determination of deuterium-hydrogen ratios in Hawaiian waters: Tellus, v. 9, p. 553–556.

and thermal wells: California Division of Mines and Geology, California Geologic Data Map Series, Map no. 1.

Martin, Peter, 1986, Southern California alluvial basins regional aquifer-system study, *in* Sun, R.J., ed., Regional Aquifer System-Analysis Program of the U.S. Geological Survey—Summary of projects, 1978–84: U.S. Geological Survey Circular 1002, p. 245–247.

Moyle, W.R., Jr., 1974, Geohydrologic map of southern California: U.S. Geological Survey Water-Resources Investigations Report 48–73, 1 sheet, scale 1:500,000.

Smith, G.I., Friedman, Irving, Klieforth, H., and Hardcastle, K., 1979, Areal distribution of

deuterium in eastern California precipitation, 1968-1969: Journal of Applied Meteor-

Jennings, C.W., 1975, Fault map of California with locations of volcanoes, thermal springs

Stewart, J.H., and Carlson, J.E., 1974, Preliminary geologic map of Nevada: U.S. Geological Survey Miscellaneous Field Studies Map MF-609, 4 sheets.
Walker, G.E., and Eakin, T.E., 1963, Geology and ground water of Amargosa Desert, Nevada-California: Nevada Department of Conservation and Natural Resources, Reconnaissance Series Report 14, 53 p.
Winograd, I.J., and Friedman, Irving, 1972, Deuterium as a tracer of regional ground-water flow, southern Great Basin, California and Nevada: Geological Society of America Bulletin, v. 83, p. 3,691–3,708.
Woolfenden, L.R., 1984, A ground-water-quality monitoring network for the lower Mojave

River valley, California: U.S. Geological Survey Water-Resources Investigations

ology, v. 18, no. 2, p. 173-188.

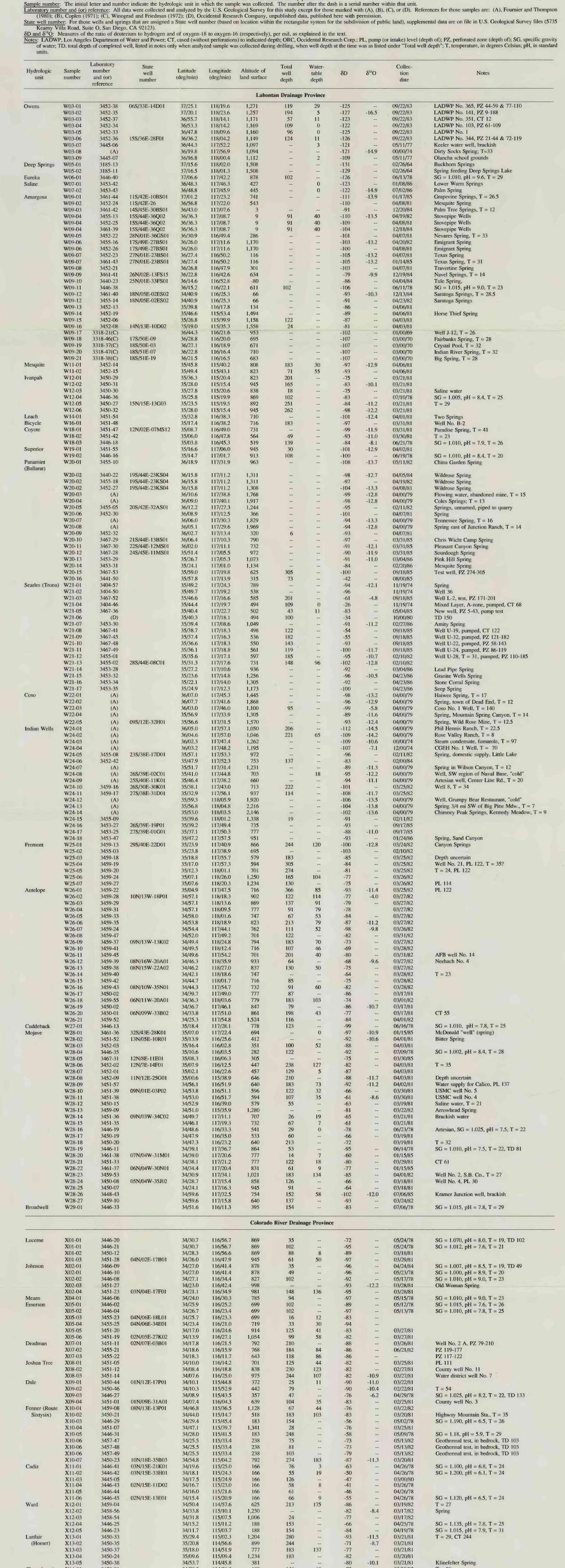
Report 83-4148, 58 p.

Table 1. Deuterium and oxygen-18 contents of water from wells and springs

Hydrologic unit: From a classification developed by the California Department of Water Resources (1964). Names of drainage provinces and hydrologic units were assigned by California Department of Water Resources (1964) except

[Altitude of land surface is in meters above or below (-) sea level. Total well depth and water-table depth are in meters below land surface. --, no data]

nint, Searles, Fenner, Lanfair, and Coachella units. The State-assigned name for these units is indicated by parenthese



X14-01 X14-02 3459-06 34/26.6 3450-42 34/11.5 Colorado X15-01 3458-24 X15-02 33/13.1 114/51.7 34/05.0 X16-01 3450-43 114/51.0 Chuckwalla 3451-52 115/25 1 X17-02 3450-49 33/51.4 115/23 0 115/14.3 3450-48 115/24.8 X17-05 X19-01 3451-16 34/03.4 Coachella 116/34.6 X19-02 3467-01 116/39.3 X19-03 33/58.0 3467-05 116/30.0 X19-04 3467-14 33/57.0 116/47.8 X19-05 3467-02 02S/04E-36D01 33/57.2 116/32.1 X19-06 3467-07 33/55.1 116/25.3 X19-08 33/50.3 33/50.3 X19-09 116/27.9 X19-10 33/39.0 116/23.9 3467-23 33/42.1 X19-11 116/17.1 X19-12 3467-16 33/37.7 116/13.4 X19-14 3467-18 33/25.8 X19-15 33/25.4 116/04.7 X19-16 3458-44 11S/10E-32R01 33/10.0 115/56.7 West Salton X21-01 X21-02 3458-38 33/23.1 116/01.4 X21-03 3458-40 33/18.3 115/55.4 X22-01 3457-05 33/29.0 116/37.9 3457-08 10S/06E-05F01 33/19 9 116/23.7 X22-03 3457-07 10S/05E-36A01 33/16.3 116/24.4 X22-04 3457-09 11S/06E-07K03 33/14.7 116/23.2 X22-05 3457-13 12S/08E-10Q02 33/08.2 116/08.0 33/07.3 116/07.7 X22-07 32/58.8 116/26.9 32/57.0 X22-08 3457-22 116/19.2 X22-08 3457-23 32/57.0 116/19.2 X22-08 3457-24 32/57.0 116/19.2 X22-09 3457-26 32/52.4 116/11.5 X22-10 3467-27 32/51.7 116/25.2 1,805 X22-11 3461-48 32/37.3 116/11.1 X22-12 3461-47 32/37.0 3458-50 X23-02 33/23.9 115/39.8 X23-03 3458-49 115/39.0 X23-04 3458-48 33/22.3 115/38.2 X23-05 33/15.2 3458-16 115/15.3 X23-06 33/13.4 115/36.1 3457-39 X23-07 33/11.2 115/22.3 X23-08 3458-28 33/12.7 115/15.7 X23-09 3458-46 33/09.9 115/28.1 X23-10 33/07.7 X23-11 33/04.5 3458-13 115/21.3 X23-12 3458-11 33/02.9 115/22.5 32/58.5 X23-13 115/29.3 X23-14 32/55.9 115/29.0 32/52.2 X23-15 115/29 3 X23-16 32/47.9 115/27.7 X23-17 3457-43 32/48.3 115/46.0 X23-18 3457-44 32/47.8 115/45.9 X23-19 32/46.2 X23-20 3457-27 32/45.4 115/57.4 X23-21 3457-28 32/43.8 115/59.3 X23-22 3457-29 32/43.8 115/59.8

32/43.1

32/42.8

33/05.8

33/05.3

32/59.8

32/44.12

32/57.9

32/52.8

32/44.2

32/44.7

32/44.5

115/57.2

115/04 0

115/15.2

115/14.4

115/04.2

115/02.8

114/55.3

114/51.8

114/53.4

114/45.9

114/38.2

X23-23

X23-24

X26-01

X26-02

X26-03

X26-04

X26-05

X26-06

X26-07

X27-01

X27-02

Z02-01

3457-30

3458-09

3458-35

3458-21

3458-22

3458-08

3457-01

3458-18 13S/18E-33A0

03/19/82 03/22/81 T = 26, CT 117 04/01/81 03/24/81 03/25/81 T = 2803/24/81 PZ 34-43 04/25/84 T = 4304/26/84 04/26/84 Well 22, T = 20, PZ 120-230 04/25/84 04/25/84 Well 4562, PZ 121-246 Well 5624, PZ 198-280 Well 574, PZ 152-274 Well 6782, PZ 122-183 Well 7991, PZ 121-274 Well 8993, PZ 70-107 Sampled from end of 1.5-km pipeline, PZ 71-106 03/08/82 Artesian well 03/07/82 Spring, T = 3703/07/82 02/20/82 PL 87 Borrego Water Co. 02/20/82 Well at park housing 02/20/82 Borrego Water Co. 02/21/82 02/21/82

-9.9

-4.0

-5.9

-8.3

+1.6

-8.7

-9.9

-9.4

-8.0

-9.7

-12.8

-6.9

-12.5

-14.7

03/01/82

-104

-114

San Diego Drainage Province

33/33.4 116/38.5 1,219 30 6 -64 -- 02/20/82 PL 24

-11.1

-10.6

02/21/82 Spring, cold 02/21/82 Spring, cold 02/21/82 Spring, cold 02/21/82 11/02/84 Depth uncertain 11/22/85 Jacumba Hot Spring, T = 40 09/16/70 03/10/82 Artesian, T = 5803/10/82 Artesian, T = 2403/10/82 Frink Spring 02/28/82 Flowing well near Niland Well ED-13, PZ 30-49 Geothermal well, T = 23202/27/82 T = 4109/16/70 Magnolia Union School Kendalls' Plunge No. 1, Hart Rd. & Hwy. 115 09/17/70 Schnaffner Dairy 11/29/70 Holtville Iceplant Geothermal well, T = 174Artesian well 02/22/82 02/22/82 T = 3302/22/82 02/22/82 09/17/70 Gordon's well Well No. 6-RC, PZ 42-48 & 60-72 02/26/82 Well No. ED-2, PZ 59-83 08/17/70 Erma Mine area well 03/04/82 T = 38T = 36, PL 157 03/01/82 09/17/70 Rest Stop, Sand Hills

DEUTERIUM CONTENT OF WATER FROM WELLS AND PERENNIAL SPRINGS, SOUTHEASTERN CALIFORNIA

1994