Tracing Ground-water Movement By Using the Stable Isotopes Of Oxygen and Hydrogen, Upper Penitencia Creek Alluvial Fan, Santa Clara Valley, California

By K. S. MUIR and TYLER B. COPLEN

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 2075

U.S. DEPARTMENT OF THE INTERIOR
March 3, 1849

Prepared in cooperation with the
Santa Clara Valley Water District

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1981

UNITED STATES DEPARTMENT OF THE INTERIOR

WILLIAM P. CLARK, *Secretary*

GEOLOGICAL SURVEY

Dallas L. Peck, ***Director***

First printing 1981
Second printing 1983

For sale by the Distribution Branch, U.S. Geological Survey,
604 South Pickett Street, Alexandria, VA 22304

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CONVERSION FACTORS

The inch-pound system of units is used in this report. For those readers who prefer to use metric units, the conversion factors for the terms used in this report are listed below:

Multiply	By	To obtain
acre-ft/yr (acre-feet per year)	0.001233	hm^3/yr (cubic hectometers per year)
ft (feet)	0.3048	m (meters)
mi (miles)	1.609	km (kilometers)

National Geodetic Vertical Datum of 1929 is a geodetic datum derived from the average sea level over a period of many years at 26 tide stations along the Atlantic, Gulf of Mexico, and Pacific Coasts, and as such, it does not necessarily represent local mean sea level at any particular place. To establish a more precise nomenclature, the term "NGVD of 1929" is used in place of "Sea Level Datum of 1929" or "mean sea level."

TRACING GROUND-WATER MOVEMENT BY USING THE STABLE ISOTOPES OF OXYGEN AND HYDROGEN, UPPER PENITENCIA CREEK ALLUVIAL FAN, SANTA CLARA VALLEY, CALIFORNIA

By K. S. Muir and Tyler B. Coplen

ABSTRACT

Starting in 1965 the Santa Clara Valley Water District began importing about 100,000 acre-feet per year of northern California water. About one-half of this water was used to artificially recharge the Upper Penitencia Creek alluvial fan in Santa Clara Valley. In order to determine the relative amounts of local ground water and recharged imported water being pumped from the wells, stable isotopes of oxygen and hydrogen were used to trace the movement of the imported water in the alluvial fan. To trace the movement of imported water in the Upper Penitencia Creek alluvial fan, well samples were selected to give areal and depth coverage for the whole fan. The stable isotopes of oxygen-16, oxygen-18, and deuterium were measured in the water samples of imported water and from the wells and streams in the Santa Clara Valley. The $\delta^{18}O$ and δD compositions of the local runoff were about -6.00 o/oo (parts per thousand) and -40 o/oo, respectively; the average compositions for the local native ground-water samples were about -6.1 o/oo and -41 o/oo, respectively; and the average compositions of the imported water samples were -10.2 o/oo and -74 o/oo, respectively. (The oxygen isotopic composition of water samples is reported relative to Standard Mean Ocean Water, in parts per thousand.) The difference between local ground water and recharged imported water was about 4.1 o/oo in $\delta^{18}O$ and 33 o/oo in δL

The isotopic data indicate dilution of northern California water with local ground water in a downgradient direction. Two wells contain approximately 74 percent northern California water, six wells more than 50 percent. Data indicate that there may be a correlation between the percentage of northern California water and the depth or length of perforated intervals in wells.

INTRODUCTION

The Santa Clara Valley is an important population center that has been growing at a rapid rate. Ground-water pumping had increased so dramatically by 1950 that water levels were the lowest ever recorded. Eight conservation reservoirs had previously been constructed to capture and store runoff from winter rains for later release into streambeds and percolation ponds from which the ground-water basin could be recharged. A major program to import water began in 1952 when an extension of the Hetch Hetchy Aqueduct was opened. As demand surpassed supplies from the aqueduct and local wells, the State of California was contracted with to supply northern California water to the Santa Clara Valley through the South Bay Aqueduct of the California Water Project. Deliveries to the northern part of the Santa Clara Valley began in 1965 and have averaged about 100,000 acre-ft/yr. About one-half of this amount is used for artificial recharge.

The two primary sites for recharge of South Bay Aqueduct water are the percolation ponds and streambeds in Upper Penitencia and Los Gatos Creeks (fig. 1). Depending on the availability of local surface-water supplies, imported water is recharged at these sites. At Upper Penitencia Creek, northern California water or water from nearby Del Valle Reservoir, about 20 mi northeast of the study area, is recharged. At Los Gatos Creek, northern California water or water from Anderson, Del Valle, or Lexington Reservoirs is recharged.

One of the questions considered in such a recharge scheme is whether it is possible to determine the relative amounts of native ground water and recharged imported water in the water being pumped from wells. An earlier investigation, based on the difference in the chemical composition of imported water and local ground water, was not successful because the chemical composition of imported and local water changed shortly after percolation into the ground-water system (Averett and others, 1971, p. 7). This report presents a method based on the differences in the stable isotope ratios of waters from different sources.

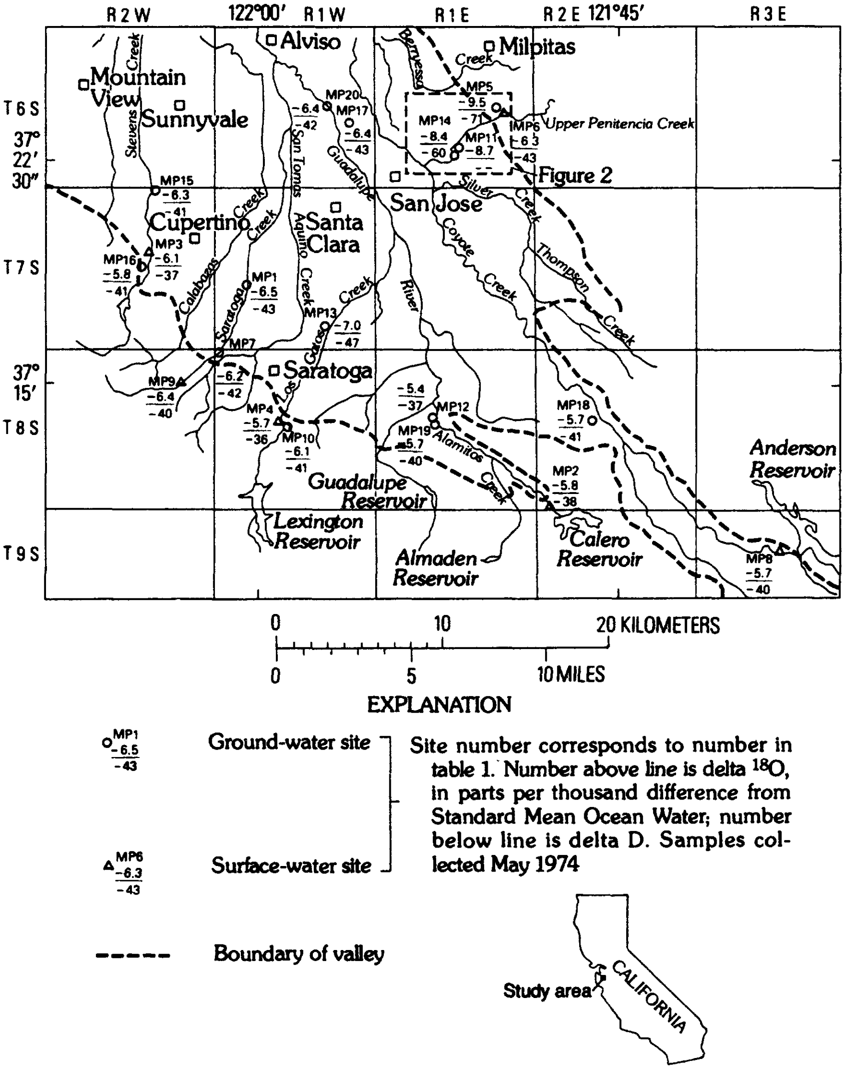


FIGURE 1.--Location of sites in Santa Clara Valley that were sampled in May 1974.

The work was started by L. C. Dutcher. Those who contributed sample collection, sample analyses, or useful scientific discussions were J. P. Akers, P. A. Emery, L. A. Eccles, Joan C. Woodward, Peter Kolesar, Candace Mooser, and Larry F. Trujillo.

The stable isotope technique involves measurement of the isotopic species oxygen-16 ($H_2{}^{16}O$), oxygen-18 ($H_2{}^{18}O$), and deuterium ($HD^{16}O$) in a water sample. The hydrogen isotopic ratio, D/H, is determined from $HD^{16}O$ and $H_2{}^{16}O$, and the oxygen isotopic ratio, $^{18}O/^{16}O$, is determined from $H_2{}^{18}O$ and $H_2{}^{16}O$. Variability in $^{18}O/^{16}O$ of natural waters is only a few parts per hundred, so it is convenient to determine the difference between $^{18}O/^{16}O$ abundance of a sample and that of a standard, in parts per thousand (o/oo), defined as delta ^{18}O ($\delta^{18}O$). Thus:

$$\delta^{18}O \text{ (in o/oo)} = \left[\frac{(^{18}O/^{16}O)_{\text{Sample}}}{(^{18}O/^{16}O)_{\text{Standard}}} - 1\right] 1000. \qquad (1)$$

The standard used for this water-resources study is SMOW (Standard Mean Ocean Water) as defined in Craig (1961b). A sample that is +10 o/oo is said to contain 10 parts per thousand or 1 percent more ^{18}O than does SMOW. In a like manner we define delta D (δD):

$$\delta D \text{ (in o/oo)} = \left[\frac{(D/H)_{\text{Sample}}}{(D/H)_{\text{SMOW}}} - 1\right] 1000. \qquad (2)$$

The importance of the stable isotope technique in water-resources investigations is that, in general, δD and $\delta^{18}O$ are different for waters of different origin. The ratios D/H and $^{18}O/^{16}O$ of precipitation are chiefly a function of the place of precipitation. Precipitation in inland areas and higher latitudes is more depleted in ^{18}O and D than precipitation near the coast and in the more temperate areas. Craig (1961a) has found a linear correlation between δD and $\delta^{18}O$ of precipitation samples from all over the world such that

$$\delta D = 8\ \delta^{18}O + 10. \qquad (3)$$

It has been observed that in certain regions the constants in this equation need some modification, as discussed by Dansgaard (1964) and Gat (1971). Consequently, the δD and $\delta^{18}O$ values of precipitation can be used to "tag" water from different sources. The two primary processes that modify the isotopic composition of water are (1) evaporation and (2) heating by rocks at high temperatures in geothermal systems. Evaporation causes an enrichment in ^{18}O and D in the residual water, but, as the isotope results show, the oxygen and hydrogen isotopic compositions of samples from the Santa Clara Valley have not been affected significantly by evaporative processes. Heating is negligible in the Santa Clara Valley ground-water system. The stable isotope technique should be excellent for the determination of relative amounts of water from isotopically different sources in well water samples. The stable isotopes have conservative properties in low-temperature ground-water systems and are virtually unaffected by chemical processes.

PURPOSE AND SCOPE

The purpose of this study, made in cooperation with the Santa Clara Valley Water District, was to trace the movement of imported water recharged into the Upper Penitencia Creek alluvial fan by using the stable isotopes of oxygen and hydrogen. The District has the responsibility for taxation of water used, and as such would like to know who is benefiting, and by how much, from their ground-water-recharge program.

The study was in two phases. The objective in the first phase was to obtain background data on the isotopic composition of water from wells and streams throughout the Santa Clara Valley. Descriptions of the sampling sites are given in table 1 and locations are shown in figure 1. Several samples of imported water (site MP5) were also collected and analyzed. Isotopic analyses of these samples, collected in May 1974, are given in table 2.

The second phase focused on the Upper Penitencia Creek alluvial fan. Wells were selected for sampling on the basis of information from well logs to give areal and depth coverage of the whole fan (fig. 2).

TABLE 1.--*Description of sampling sites*

[lsd is the altitude of land-surface datum, in feet above National Geodetic Vertical Datum of 1929; depth and perforated interval in feet below land-surface datum]

Site No.	Description
MP 1	Well, 7S/1W-20L3.
2	Alamitos Creek at gage below reservoir.
3	Stevens Creek at outlet below reservoir.
4	Los Gatos Creek at gage below Lexington Reservoir.
5	Piedmont terminal above percolation ponds.
6	Upper Penitencia Creek at gage above percolation ponds.
7	Well, 8S/1W-6B1.
8	Coyote Creek at gage near Madrone.
9	Saratoga Creek at gage.
10	Well, 8S/1W-16Q1.
11	Well, 6S/1E-27M4 (lsd, 153 ft; depth, 550 ft).
12	Well, 8S/1E-16M2.
13	Well, 7S/1W-35C1.
14	Well, 6S/1E-28J2 (lsd, 131 ft; depth, 325 ft; perforated interval, 234-247 ft).
15	Well, 7S/2W-2E2.
16	Well, 7S/2W-15Q1.
17	Well, 6S/1W-24N1.
18	Well, 8S/2E-17J2.
19	Well, 8S/1E-16N7.
20	Well, 6S/1W-23F2.
21	Well, 6S/1E-22Q1 (lsd, 186 ft; depth, 455 ft; perforated interval, 213-435 ft).
22	Well, 6S/1E-33F1 (lsd, 93 ft; depth, 340 ft).
23	Well, 6S/1E-29B1 (lsd, 65 ft; depth, 170 ft; perforated interval, 75-157 ft).
24	Well, 6S/1E-29C7 (lsd, 67 ft; depth, 500 ft; perforated interval, 220-470 ft).
25	Well, 6S/1E-27L3 (lsd, 148 ft; depth, 350 ft).
26	Well, 6S/1E-28N4 (lsd, 89 ft; depth, 156 ft; perforated interval, 133-145 ft).
27	Well, 6S/1E-29G6 (lsd, 79 ft; depth, 545 ft; perforated interval, 288-535 ft).
28	Well, 6S/1E-28A4 (lsd, 144 ft; depth, 415 ft; perforated interval, 225-415 ft).
29	Well, 6S/1E-28J4 (lsd, 127 ft; depth, 500 ft; perforated interval, 260-500 ft).
30	Well, 6S/1E-21L3 (lsd, 121 ft; depth, 202 ft; perforated interval, 172-202 ft).

TABLE 2.--*Stable isotope analyses of water samples from wells and streams in the Santa Clara Valley and from northern California water*

[Oxygen and hydrogen isotopic composition in parts per thousand difference from Standard Mean Ocean Water as defined by Craig (1961b)]

Site No.	Sample No.	$\delta^{18}O$	δD	Site No.	Sample No.	$\delta^{18}O$	δD
May 1974							
MP 1	WW- 40	-6.5	-43	MP11	WW- 50	-8.7	--
2	41	-5.8	-38	12	51	-5.4	-37
3	42	-6.1	-37	13	52	-7.0	-47
4	43	-5.7	-36	14	53	-8.4	-60
5	44	-9.5	-71	15	54	-6.3	-41
6	45	-6.3	-43	16	55	-5.8	-41
7	46	-6.2	-42	17	56	-6.4	-43
8	47	-5.7	-40	18	57	-5.7	-41
9	48	-6.4	-40	19	58	-5.7	-40
10	49	-6.1	-41	20	59	-6.4	-42
March 1975							
MP 5	WW-128	-6.8	-51	MP25	WW-130	-8.5	-61
6	126	-6.1	-40	26	131	-6.7	-45
21	124	-8.6	-63	27	132	-6.9	-46
22	125	-6.6	-46	28	133	-8.2	-60
23	127	-6.6	-46	29	134	-8.3	-60
24	129	-7.0	-48				
June 1975							
MP 5	WW-164	-9.3	-70	MP25	WW-171	-8.5	-62
6	165	-5.6	-42	26	172	-6.8	-45
11	166	-8.6	-62	27	173	-6.8	-46
21	167	-8.6	-62	28	174	-8.1	-59
22	168	-6.6	-46	29	175	-8.3	-60
23	169	-6.6	-46	30	176	-7.2	-50
24	170	-7.0	-47				
August 1975							
MP 5	WW-228	-10.8	-77				
September 1975							
MP 5	WW-238	-10.6	-77	MP25	WW-252	-8.7	-61
6	246	-5.6	-40	26	253	-6.8	-45
11	247	-8.6	-61	27	254	-6.9	-46
21	248	-8.7	-62	28	255	-8.4	-57
22	249	-6.8	-47	29	256	-8.4	-59
23	250	-6.6	-45	30	257	-7.2	-50
24	251	-7.0	-47				

TABLE 2.--*Stable isotope analyses of water samples from wells and streams in the Santa Clara Valley and from northern California water*--Continued

Site No.	Sample No.	$\delta^{18}O$	δD	Site No.	Sample No.	$\delta^{18}O$	δD
November 1975							
MP 5	WW-239	-8.8	-62	MP 5	WW-240	-10.8	-79
December 1975							
MP 5	WW-243	-11.2	-80	MP 6	WW-242	-5.2	-39
May 1976							
MP 5	WW-244	-10.0	-73	MP 6	WW-245	-5.6	-40
June 1976							
MP 5	WW-335	-9.2	-69	MP25	WW-328	-8.4	-60
6	332	-5.0	-38	26	333	-6.8	-45
21	336	-8.9	-62	27	330	-6.7	-46
22	331	-7.0	-48	28	327	-8.2	-57
23	326	-6.9	-45	29	329	-8.3	-59
24	334	-7.2	-47	30	337	-7.4	-50
September 1976							
MP 5	WW-340	-10.7	-76	MP25	WW-345	-8.0	-55
6	353	-4.5	-36	26	344	-7.0	-45
11	346	-8.6	-60	27	341	-7.2	-46
22	352	-7.0	-48	28	348	-8.4	-58
23	343	-6.9	-44	29	350	-8.7	-59
24	349	-7.4	-48	30	351	-7.5	-49
January 1977							
MP 5	WW-342	-10.6	-77	MP 6	WW-354	-5.6	-41
February 1977							
MP 5	WW-371	-11.2	-78	MP 6	WW-372	-5.4	-40
April 1977							
MP 5	WW-373	-9.6	-72	MP25	WW-378	--	-53
6	374	-5.2	-39	26	379	-6.9	-46
22	375	-7.0	-49	27	380	-7.0	-47
23	376	-6.6	-45	28	381	-8.2	-58
24	377	-7.1	-48	29	382	-8.4	-60

Because of cost restraints, no new wells were drilled. Samples of water from wells, of imported water from the Piedmont Terminal, and of local surface water from Upper Penitencia Creek were analyzed for their oxygen and hydrogen isotopic composition. Sampling started in March 1975 and continued until April 1977. Isotopic analyses of these samples are given in table 2.

ACKNOWLEDGMENTS

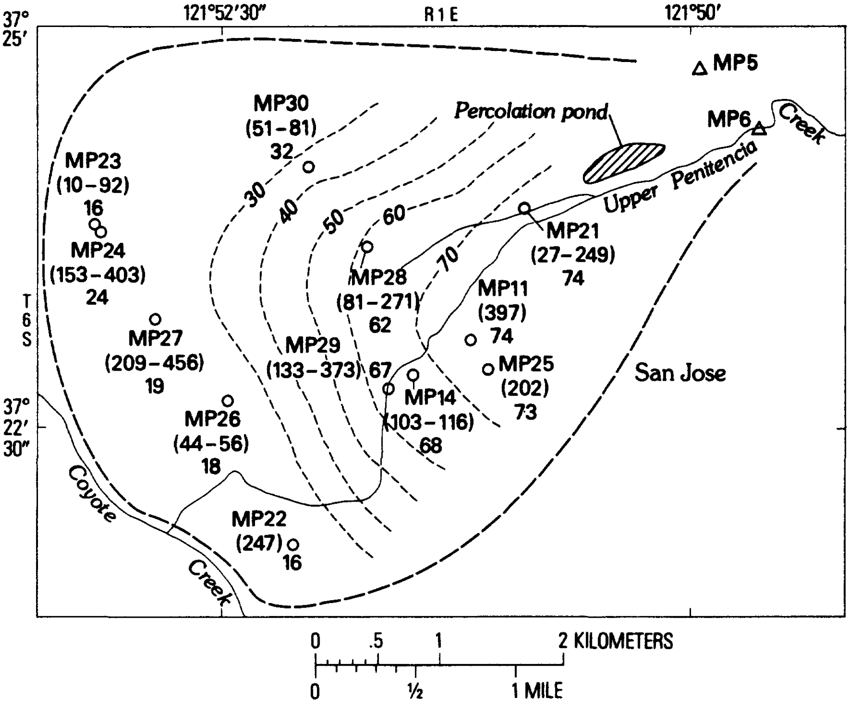
Special thanks are given to Isabel Gloege, Dimetrius Lorenzo, and Thomas Iwamura of the Santa Clara Valley Water District for their cooperation and assistance.

GEOHYDROLOGIC SETTING

Non-water-bearing rocks form the highlands bordering the Santa Clara Valley and underlie water-bearing sediments of the valley itself. The non-water-bearing rocks range in age from Jurassic to late Tertiary. Marine sandstone and shale are the most common rock types, but conglomerate, chert, marl, and several varieties of basic igneous rocks also occur.

The water-bearing sediments are of Pliocene to Holocene age. Pliocene and Pleistocene sediments crop out in hills adjacent to the valley floor and underlie most of the sediments of Pleistocene and Holocene age that compose the valley fill. The Pleistocene and Holocene sediments, comprising more than 1,000 ft of poorly sorted gravel, sand, and clay, contain most of the ground water in the Santa Clara Valley.

The Upper Penitencia Creek area (figs. 1 and 2) is underlain by Holocene alluvial fan deposits that consist of material eroded from the mountains on the east and transported by Upper Penitencia Creek to the Santa Clara Valley. These deposits are probably 400-500 ft thick and coalesce with fan deposits from Berryessa Creek to the north and Coyote Creek to the south and west (fig. 1). Underlying the Holocene fan deposits are older alluvium and the Santa Clara Formation of Pliocene and Pleistocene age, both similar



EXPLANATION

△ MP5	Surface-water site. Site number corresponds to that in table 1
○ MP30	Ground-water site. Site number corresponds to that in table 1
(51-81)	Two numbers in parentheses give altitudes of top and bottom of perforated interval, in feet below National Geodetic Vertical Datum of 1929. Single number in parentheses is altitude of well bottom, in feet, where perforated interval is unknown
32	Percentage of northern California recharge water in water pumped from wells in June 1975, except for site MP14 which is for May 1974
------*50*------	Line showing percentage of northern California recharge water in ground water of the Upper Penitencia Creek alluvial fan. Interval 10 percent
————————	Approximate boundary of the Upper Penitencia Creek alluvial fan

FIGURE 2.--Percentage of northern California recharge water in the Upper Penitencia Creek alluvial fan.

in composition to the alluvial fan deposit but more firmly consolidated and, consequently, less permeable. The older alluvium and Santa Clara Formation have a combined thickness of probably more than 500 ft. Yields of wells in the alluvial fan deposits are generally higher than those of wells producing from the older alluvium and the Santa Clara Formation.

For a more detailed discussion of geology and hydrology of the Santa Clara Valley, see reports by Tibbetts and Kieffer (1921), Clark (1924), the California State Water Resources Control Board (1955), and the California Department of Water Resources (1975). A report by the Santa Clara County Flood Control and Water Conservation District (now called Santa Clara Valley Water District) (1971) deals specifically with the geology and hydrology of the Upper Penitencia Creek alluvial fan.

ANALYTICAL METHOD

Hydrogen from water samples was quantitatively liberated from an aliquot of sample by reaction with hot uranium metal (Bigeleisen and others, 1952). Hydrogen isotopic composition was determined on a 7.5-centimeter, 60°-sector, isotope-ratio mass spectrometer (McKinney and others, 1950), with correction for $^3H^+$ (after Coplen, 1970), and correction for mixing of sample and standard gases due to glass valve leakage (after Craig, 1957). The hydrogen isotopic composition of water samples is reported in parts per thousand difference from SMOW as defined by Craig (1961b) and not as distributed by the International Atomic Energy Agency (see Coplen and Clayton, 1973). The precision of the hydrogen isotopic determination is ±1.5 o/oo.

Water samples were prepared for oxygen isotopic analysis by the method described by Epstein and Mayeda (1953). CO_2 gas was isotopically equilibrated with a water sample for 5 days in a constant-temperature bath at 25.0°C. Aliquots of the CO_2 gas were analyzed on a double-focusing, double-collecting isotope-ratio mass spectrometer (Coplen, 1973), and corrections made after Mook (1968). The oxygen isotopic composition of water samples is reported relative to SMOW in parts per thousand. The precision of the oxygen isotope determination is ±0.1 o/oo.

DISCUSSION AND RESULTS

Surface-water and ground-water samples were collected initially at sites throughout the valley. Then, because imported water was being recharged into the Upper Penitencia Creek alluvial fan, sample collection was intensified in that area (figs. 1 and 2).

Selected data from table 2 are shown in figure 1. Samples collected at surface-water sites show that the $\delta^{18}O$ and δD compositions of local runoff are about -6.00 o/oo and -40 o/oo, respectively. These values are reasonable for middle-latitude, near-ocean, lowland, meteoric precipitation (Dansgaard, 1964). The variability in the surface-water data is relatively small, in support of the fact that the sources of surface recharge are similar in elevation and temperature.

The average $\delta^{18}O$ and δD compositions of ground-water samples (excluding samples that might show a difference because of input of imported water) are about -6.1 o/oo and -41 o/oo, respectively. These data are almost identical to the surface-water results. They support the hydrologic model of this valley (California Department of Water Resources, 1975), in which the ground-water system is recharged by movement of local precipitation through permeable valley fill.

Water sampled at site MP5 is imported water recharged into the Upper Penitencia Creek alluvial fan. Fourteen analyses from this location are shown in table 2. Sample WW-128 consists primarily of water from Del Valle Reservoir. Water from this reservoir is used for recharge into the Upper Penitencia Creek alluvial fan. As expected, this sample is similar in isotopic composition to the surface-water samples analyzed in the study area. The other samples are northern California aqueduct water. They average -10.2 o/oo and -74 o/oo in $\delta^{18}O$ and δD, respectively, more depleted than any of the samples of surface water or native ground water from the study area. The difference in $\delta^{18}O$ between native ground water and northern California aqueduct water is about 4.1 o/oo. The difference in δD is 33 o/oo. These differences are at least 20 times as large as the possible error in analysis.

The consequence of these results is that one can calculate the proportions of local ground water and imported northern California recharge water in well water samples from the Santa Clara Valley. The accuracy of this calculation is within 20 percent and probably within 10 percent. A possible source of error is the unknown isotopic composition of northern California recharge water over the past decade. If one assumes that the isotopic composition has remained constant since 1965, date of completion of the aqueduct to the Upper Penitencia Creek alluvial fan, the error is probably small because the storage reservoirs between the source and study area tend to average out short-term fluctuations in isotopic composition.

The data from table 2 are shown in figure 3, a plot of δD versus $\delta^{18}O$. Only the average value for each well is plotted. All the data lie near a meteoric-water line with a slope of 8 and an intercept of slightly under 10 (see equation 3). In general, the abundance of ^{18}O and D in water increases during evaporation following a slope of 3 on a plot of δD versus $\delta^{18}O$. None of the analyses in this study lie significantly off the meteoric-water line. Therefore, none of these samples have undergone significant evaporation that would modify their oxygen and hydrogen isotopic composition. The correlation between δD and $\delta^{18}O$ is excellent. The analyses of imported-water samples from northern California, which are from the climatically coldest source area, plot nearest the lower left corner of the graph. A number of analyses plot between the northern California water analyses and analyses of samples of local native surface and ground water. Inspection of table 2 shows that these are samples from wells within several miles of and downgradient from the Upper Penitencia Creek percolation pond (fig. 2). There seems to be a linear relation between the distance downgradient and the isotopic composition of water obtained from these wells. The δD and $\delta^{18}O$ values follow:

$$MP21 \overset{-}{<} MP11 < MP25 < MP14 \overset{-}{<} MP29 < MP26$$

The isotopic data indicate dilution of northern California water with local ground water in a downgradient direction.

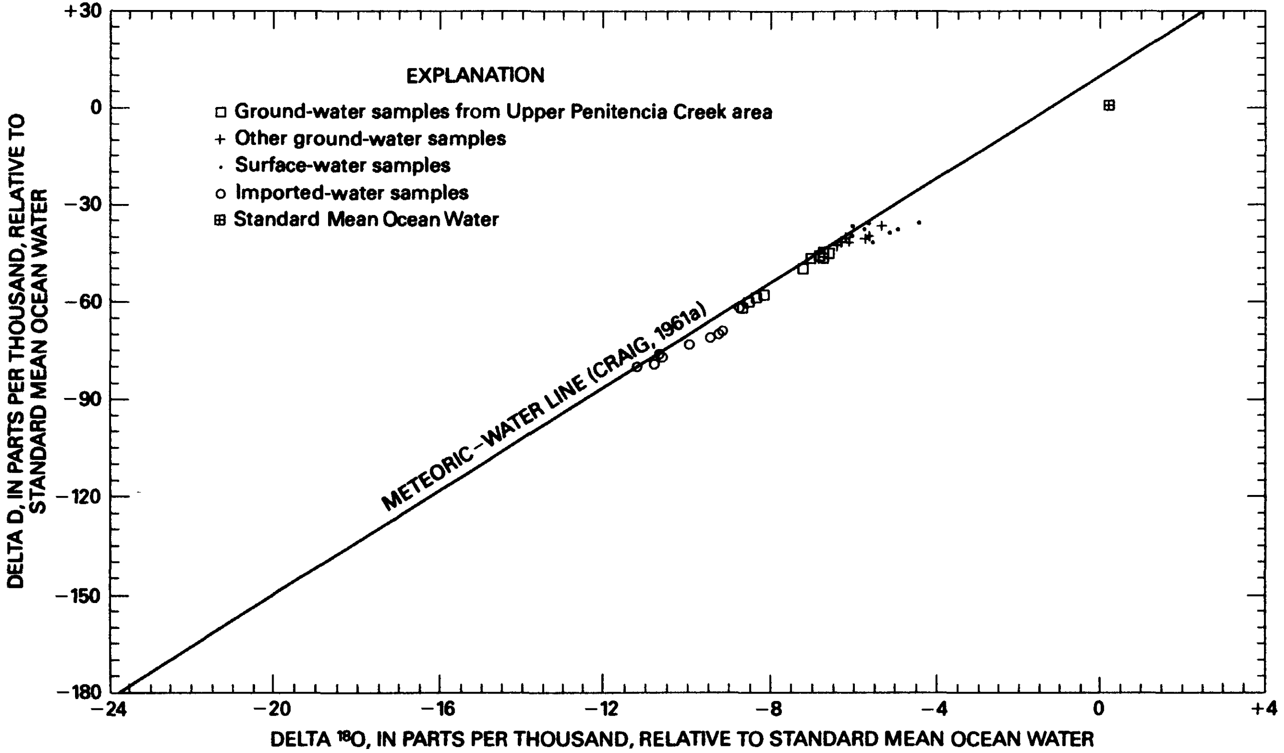


FIGURE 3.--Plot of delta ^{18}O versus delta D for water samples from wells and streams in the Santa Clara Valley and from imported northern California water, showing their relation to the meteoric-water line, to each other, and to Standard Mean Ocean Water.

Using these data, it is possible to calculate the proportions of northern California aqueduct water and local ground water in these wells. For local ground water, values of -6.1 o/oo and -41 o/oo for $\delta^{18}O$ and δD, respectively, are used. One can write for either $\delta^{18}O$ or δD that

$$\text{percentage northern California water} = \frac{\delta_n - \delta_x}{\delta_n - \delta_a} \cdot 100, \qquad (4)$$

where δ_a is the isotopic composition of northern California water, δ_n is the isotopic composition of native ground water, and δ_x is the isotopic composition of the well water sample. Percentage values were calculated from the oxygen and hydrogen isotopic analyses. Results of calculations for samples from the Upper Penitencia Creek alluvial fan area are shown in table 3. Two wells, MP11 and MP21, contained approximately 74 percent northern California water. Six wells contained more than 50 percent northern California water. The percentage values are plotted in figure 2, a map showing the percentage distribution of northern California water in the Upper Penitencia Creek alluvial fan. The map shows that northern California water has moved throughout the fan area since deliveries began in 1965.

The present study was made during the 1975-77 period of drought. How much effect the lack of local recharge had on the mixing percentages cannot be determined.

Sufficient data are not available to establish a correlation between the percentage of northern California water and the depth or length of perforated intervals in wells. Data from MP23 and MP24, however, indicate that there may be such a correlation. Water from well MP23, located about 300 ft from MP24, had 16 percent northern California water (fig. 2). MP23 is perforated from 10 to 92 ft below NGVD. A water sample taken at the same time from MP24 contained 24 percent northern California water. MP24 is perforated from 153 to 403 ft below NGVD.

For the period of record 1975-77, there was no discernible net change in the isotopic composition of the ground water in the Upper Penitencia Creek alluvial fan. This is shown graphically in figure 4, where $\delta^{18}O$ values are plotted for imported northern California water, Upper Penitencia Creek water, and water from three wells. The plots, in conjunction with figure 2, also show that, as ground water moves downgradient from the percolation ponds where imported northern California water is being recharged, the $\delta^{18}O$ composition of well water approaches that of Upper Penitencia Creek.

The results of this study indicate that the stable isotope technique can be used to calculate the relative amounts of local ground water and imported recharge water of a different isotopic composition. Therefore, it is possible to trace the movement of the imported water through the aquifer. If samples for isotope analyses were collected from the beginning of an imported-water recharge operation, the velocity of the recharge water moving through the aquifer could also be determined.

TABLE 3.--*Percentage of northern California water in wells, Upper Penitencia Creek alluvial fan*

Site No.	Contribution of northern California water based on		Average
	$\delta^{18}O$ data	δD data	
MP11	76	72	74
14	70	66	68
21	76	72	74
22	15	17	16
23	15	17	16
24	27	21	24
25	73	72	73
26	21	14	18
27	21	17	19
28	61	62	62
29	67	66	67
30	33	31	32

Note: Wells were sampled in June 1975, except MP14 which was sampled in May 1974.

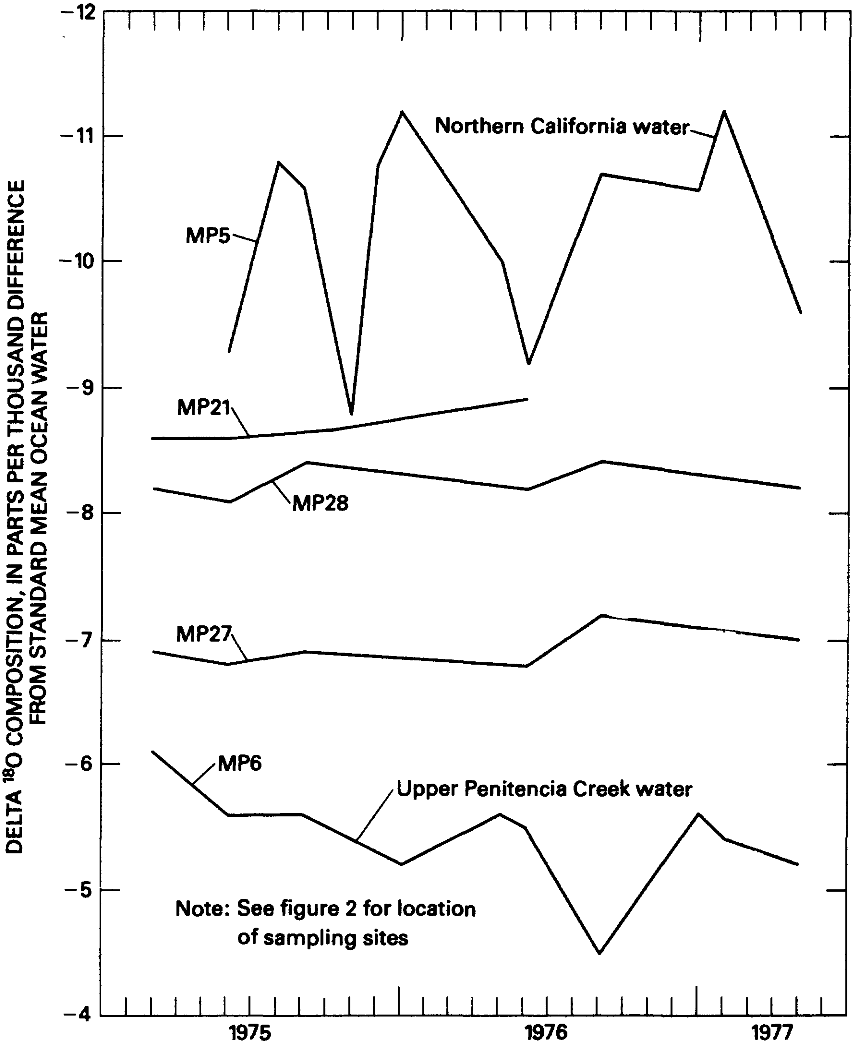


FIGURE 4.--Variation in delta ^{18}O composition of water from two surface-water sources and three wells in the Upper Penitencia Creek alluvial fan.

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