GROUND WATER IN THE REDDING BASIN,

SHASTA AND TEHAMA COUNTIES, CALIFORNIA

By Michael J. Pierce

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CONVERSION FACTORS

For those readers who prefer to use the International System of units (SI) rather than inch-pound units, the conversion factors for the terms used in this report are listed below:

Inch-pound	Multiply by	SI
acres	0.4047	hectares
acre-ft (acre-feet)	1233.	m^3 (cubic meters)
ft (feet)	0.3048	m (meters)
gal/min (gallons per minute)	0.06309	L/s (liters per second)
inches	25.4	mm (millimeters)
mi (miles)	1.609	km (kilometers)
mi^2 (square miles)	2.590	km^2 (square kilometers)
μmho/cm (micromhos per centimeter)	1.000	μS/cm (microsiemens per centimeter)

Degree Fahrenheit is converted to degrees Celsius by using the formula:

Temp °C=(°F-32)/1.8

Abbreviations used

MG/L or mg/L - milligrams per liter.
UG/L or μg/L - micrograms per liter.

National Geodetic Vertical Datum

National Geodetic Vertical Datum (NGVD) of 1929--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level.

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ABSTRACT

The Redding Basin covers about 510 square miles in the northern part of the Central Valley of California and is surrounded by the Cascade Range, Klamath Mountains, and Coast Ranges. It is separated from the main part of the valley by the Red Bluff Arch, a subsurface geologic structure.

Ground water in the Redding Basin is obtained principally from wells tapping continental deposits of Tertiary and (or) Quaternary age. These deposits are arranged in a synclinal structure that trends and plunges southward. They are deposited on the Chico Formation, a marine sedimentary unit, and a basement complex composed of older igneous, metamorphic, and sedimentary rocks.

Recharge to the Redding ground-water basin is from subsurface inflow; infiltration of precipitation and applied irrigation water; and percolation from streams and creeks. Ground-water movement is generally from the periphery of the basin towards the Sacramento River and then southward, where at the Red Bluff Arch, the water in the sedimentary rocks of Tertiary and Quaternary age is probably discharging into the Sacramento River. Hydrographs show only a slight (1 to 10 feet) water-level decline for the period 1956 to 1970 and virtually no change (1 to 2 feet) for the period 1970 to 1979.

Ground water in the Redding Basin is mostly used for irrigation, which was estimated at 42,100 and 45,000 acre-feet, respectively, for 1969 and 1976. The total estimated pumpage for 1976 was 82,000 acre-feet. Estimated storage capacity in the uppermost 200 feet of saturated rock in the basin is 5.5 million acre-feet.

Chemical quality of ground water in the main water-bearing formations is rated good to excellent (dissolved solids range from 95 to 424 milligrams per liter) for most uses, and is of a magnesium-calcium bicarbonate type. The underlying Chico Formation contains saline water that contains constituents that are above the recommended limits for drinking water.

INTRODUCTION

Purpose and Scope

In October 1978, the U.S. Geological Survey and California Department of Water Resources began a cooperative study to appraise the ground-water conditions in the Redding Basin. The impact of the 1976-77 drought in California and a growing population have intensified the need for reliable and up-to-date ground-water information for use in managing the ground-water resources of the study area.

This report includes a description of the geohydrologic features of the different aquifers; a definition of source, occurrence, movement, and quality of the ground water; and an estimation of the current pumpage and ground-water storage. The description of the geohydrology in this report relies heavily on previous investigations, namely, California Department of Water Resources (1960, 1964, and 1968) and Olmsted and Davis (1961). Most of the effort in the present study was given to determining ground-water levels, storage capacity, chemical quality, and water use. The older geologic units that underlie the Redding Basin and are not utilized as a source of water, are not discussed in detail in this report.

The fieldwork was done in spring and summer 1979 and spring 1980. A well canvass was made to obtain new data on water levels, water use, and distributions and character of the water-bearing units. Water levels were measured in summer 1979 and spring 1980. Water samples for chemical analysis were collected in summer 1979 from 85 new wells.

Location and Description of Study Area

The Redding Basin includes about 510 mi^2 within the northernmost part of the Central Valley of California, in parts of Shasta and Tehama Counties (fig. 1). The "Redding Basin," as used herein is that area described in California Department of Water Resources Bulletin 118 (1975b). The basin is bounded on the east by the foothills of the Cascade Range, on the north and northwest by the Klamath Mountains, on the southwest by the northern Coast Ranges, and on the south by the Red Bluff Arch, a subsurface structural uplift trending east-northeast and located just north of the city of Red Bluff. This structural uplift separates the Redding ground-water basin from the Sacramento ground-water basin. The Redding Basin ranges in altitude from about 400 to 800 ft. The area is an interior dissected plain, crossed by the valleys of the Sacramento River and of Churn, Clear, Cottonwood, Cow, and Stillwater Creeks.

The climate of the Redding Basin is hot and dry during the summer months, with temperatures reaching over 100°F; winters are cool and rainy. The average annual maximum daily air temperature is 76°F (National Oceanic and Atmospheric Administration, 1975-80). Precipitation is about 37 inches per year and occurs mostly from November through April. Vegetation commonly found in the Redding Basin includes annual grasses, live and blue oaks, digger pines, manzanita, and poison oak.

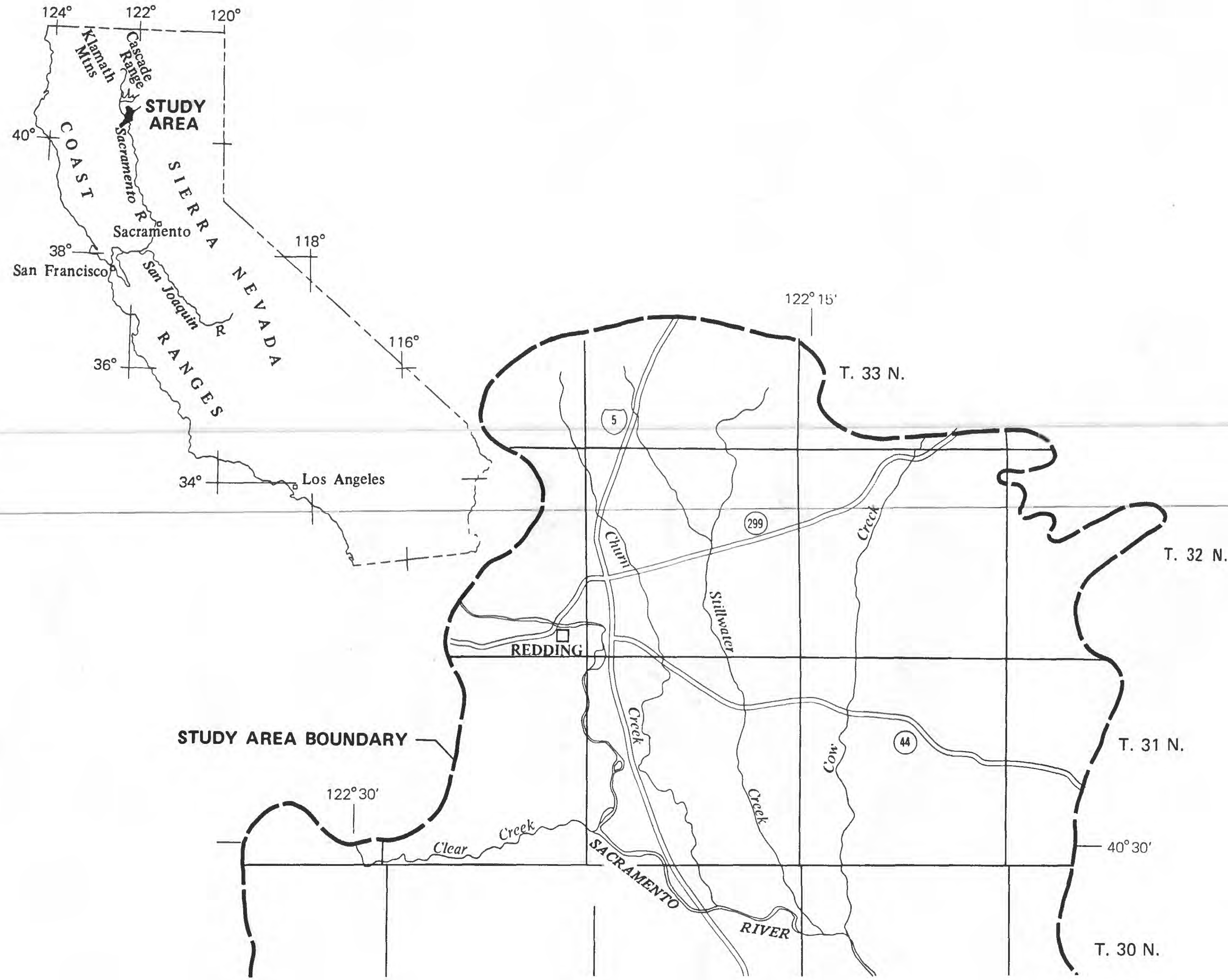
Approximately 84 percent of the population of Shasta County lives in the Redding Basin (CH2M-Hill, written commun., 1976). During this investigation, the population of the Redding Basin increased from about 88,500 in January 1978 to 104,300 in July 1981; the July 1985 population projection is about 118,800 (California Population Research Unit, May 1979, January 1980, and May 1980). The mainstays of the economy are agriculture, lumber industry, and the medical center of the northern Sacramento Valley (California Department of Water Resources, 1968).

Ground water in the Redding Basin is used for domestic, irrigation, stock, municipal, and industrial purposes. Most of the ground water pumped is used for irrigation; however, several of the towns and most rural homes depend on ground water for domestic supplies.

Currently, water from the Sacramento River is being diverted for use by the city of Redding, Bella Vista Water District, and Anderson-Cottonwood Irrigation District. The Anderson-Cottonwood Irrigation District has a diversion dam for gravity flow into their canal system, which begins in the city of Redding and ends at Cottonwood Creek in the southern part of the basin. The quality of water from the Sacramento River is considered acceptable for all uses (CH2M-Hill, 1975). The drainage pattern is generally towards the Sacramento River, then southward into the Central Valley.

Acknowledgments

The compilation of data used in the report has been made possible by the cooperation of local well and property owners, well drillers, and the California Department of Water Resources.



124°
122°
120°
118°
116°
40°
38°
36°
34°
Klamath Mtns
Cascade Range
STUDY AREA
COAST
RANGES
SIERRA NEVADA
Sacramento R
Sacramento
San Francisco
San Joaquin R
Los Angeles
122° 15'
122° 30'
40° 30'
T. 33 N.
T. 32 N.
T. 31 N.
T. 30 N.
5
299
44
Churn Creek
Stillwater Creek
Cow Creek
Clear Creek
SACRAMENTO RIVER
REDDING
STUDY AREA BOUNDARY

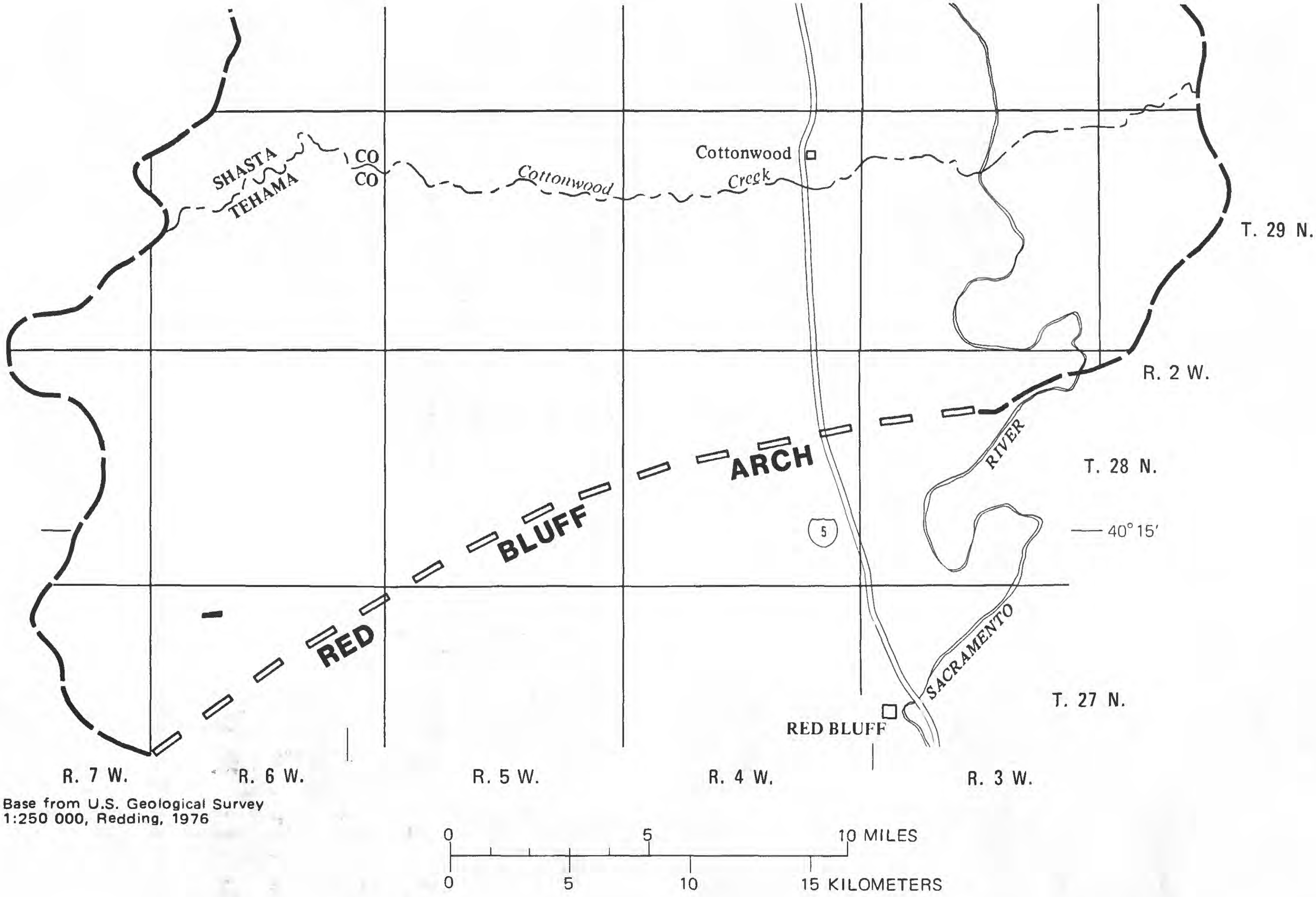


FIGURE 1. — Location of the Redding ground–water basin.

Well-Numbering System

Wells are identified according to their location in the rectangular system for the subdivision of public lands. Their identification consists of the township number, north or south; the range number, east or west; and the section numbers. Each section is further divided into sixteen 40-acre tracts lettered consecutively (except I and O), beginning with A in the northeast corner of the section and progressing in a sinusoidal manner to R in the southeast corner. Within the 40-acre tract, wells are sequentially numbered in the order they are inventoried. The final letter in a well identification number refers to the base line and meridian. All wells in the study area are referenced to the Mount Diablo base line and meridian (M). This final letter will sometimes be omitted in this report. Figure 2 shows how the well number 30N/3W-12E1 is derived. For computer storage and retrieval reasons, the number 30N/3W-12E1 appears in computer printouts as 030N003W12E01M.

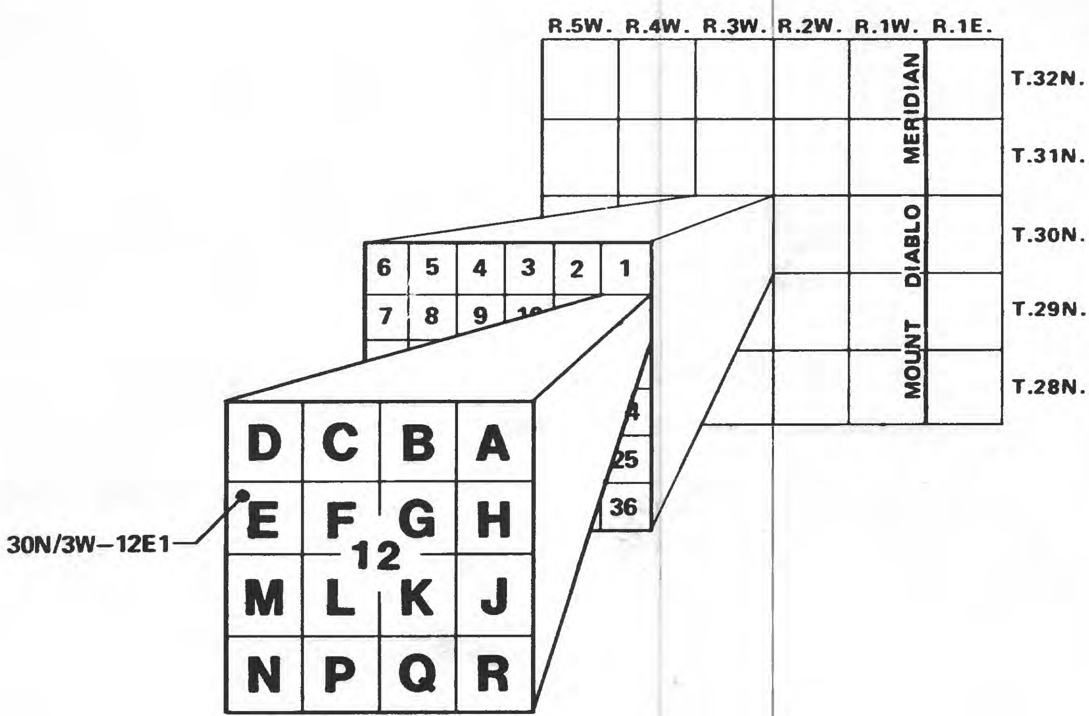


FIGURE 2. — Standard well-numbering diagram.

GEOHYDROLOGY

The Redding Basin is the northern part of the Sacramento Valley, but it is hydrologically separated from the rest of the Sacramento Valley by the Red Bluff Arch. The general structure of the Redding Basin is a southerly plunging syncline (California Department of Water Resources, 1964). However, the southward plunge is interrupted at the Red Bluff Arch, which trends northeasterly to form the southern boundary of the Redding Basin (fig. 3). Dips on the limbs of the syncline generally range from about 5 to 20 degrees. The thickest section of sedimentary rock, probably about 9,000 ft, in the basin is in the vicinity of the city of Cottonwood (fig. 1).

Geohydrologic Units

Geologic formations in the Redding Basin are divided into two general units--one of pre-Tertiary age and one of Tertiary and (or) Quaternary age (table 1). This division of units corresponds to that of Strand (1962), except that the pre-Tertiary formations have been consolidated into one unit that includes a basement complex and the Chico Formation, shown together in figures 3 and 4. The unit of Tertiary and (or) Quaternary age includes, in ascending order, the Nomlaki Tuff Member of the Tuscan and Tehama Formations; the Tuscan, Tehama, and Red Bluff Formations; terrace deposits; and alluvium (fig. 3; table 1). The main discussion of hydrology in this report concerns ground water occurring in strata of the unit of Tertiary and (or) Quaternary age.

The formations of pre-Tertiary age contain water of poor quality (dissolved solids range upward to 22,000 mg/L) or have low yield and are not considered an important source of water for agriculture or other uses. The Tertiary and (or) Quaternary formations, except for the Nomlaki Tuff Member, which is explained later in more detail, are aquifers that contain water of useful quality and quantity. The geohydrologic units and their water-bearing characteristics are summarized in table 1. Yields of wells tapping the main aquifers range from 20 to over 4,000 gal/min. Forty gal/min is typical of domestic wells, and for irrigation wells, 1,000 gal/min is fairly common (California Department of Water Resources, 1968).

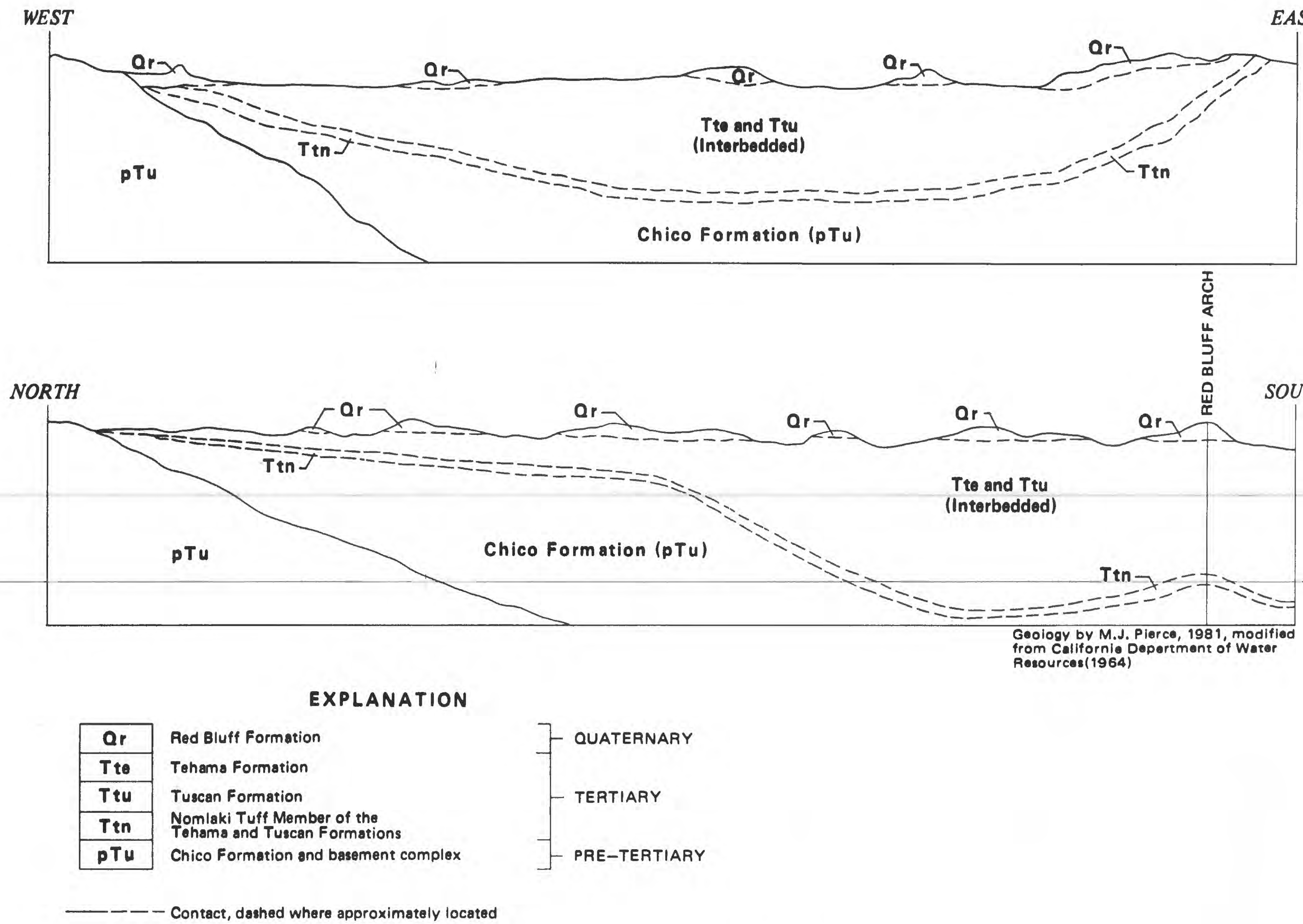


FIGURE 3. — Diagrammatic sections across center of the Redding Basin area.

TABLE 1.--Geohydrologic units in the Redding Basin area

[Modified from California Dept. of Water Resources, 1964 and 1968]

Unit	Period	Epoch	Formation name and map symbol	Approximate thickness (feet)	Lithologic character	Water-bearing properties
Tertiary and (or) Quaternary unit	Quaternary	Holocene	Alluvium (Qal)	<1-50	Unconsolidated gravel, sand, silt, and clay; includes stream-channel and flood-plain deposits and dredged gravels.	Moderately permeable. Locally, near stream channels, well yields are good for domestic and limited irrigation.
		Holocene and Pleistocene	Terrace deposits (Qt)	<1-50	Poorly consolidated gravels with some sand and silt along Cow and Cottonwood Creeks.	Moderately to highly permeable. Yields moderate quantities of water to wells from perched water tables.
		Pleistocene	Red Bluff Formation (Qr)	<1-100	Coarse gravels, commonly with large boulders in red sandy clay matrix. Layers of partially consolidated sand present.	Poorly to moderately permeable. Locally, contains perched water tables. Yields are generally of small to moderate quantities for domestic use (5-40 gal/min).
	Tertiary	Pliocene	Tehama Formation (Tte)	<1-2,500	Silts, sand, gravel, and clay of fluviatile origin derived from the Klamath Mountains and Coast Range. Sediments are locally cemented.	Moderately to highly permeable. One of the principal water-bearing formations in the Redding ground-water basin. Yields are moderate to high (100 to 1,000 gal/min).
			Tuscan Formation (Ttu)	<1-1,000	Volcanic gravels and tuff-breccia, volcanic sandstone and conglomerate, coarse- to fine-grained tuff, tuffaceous silt and clay; predominantly andesitic and basaltic.	Moderately to highly permeable except for beds of tuff-breccia. One of the principal water-bearing formations in the Redding ground-water basin. Yields are moderate to high (100 to 1,000 gal/min).
			Nomlaki Tuff Member of Tehama and Tuscan Formations (Ttn)	<1-80	Underlies both the interbedded Tehama and Tuscan Formations. Poorly consolidated dacite pumice in a matrix of glass and crystal fragments.	Poorly permeable. Water quality is degraded due to the underlying Chico Formation. Wells yield as much as 40 gal/min.
Pre-Tertiary unit	Pre-Tertiary		Chico Formation (pTu)	<1-6,000	Marine clastic sedimentary rocks consisting mostly of siltstone, sandstone, and shale.	Practically impermeable; the few relatively permeable beds contain saline water. In some areas, contains water under artesian pressure.
			Basement complex (pTu)		Igneous, metamorphic, and sedimentary rocks.	Yield minor quantities of water from joints, fractures, and weathered zones.

CORRELATION OF MAP UNITS

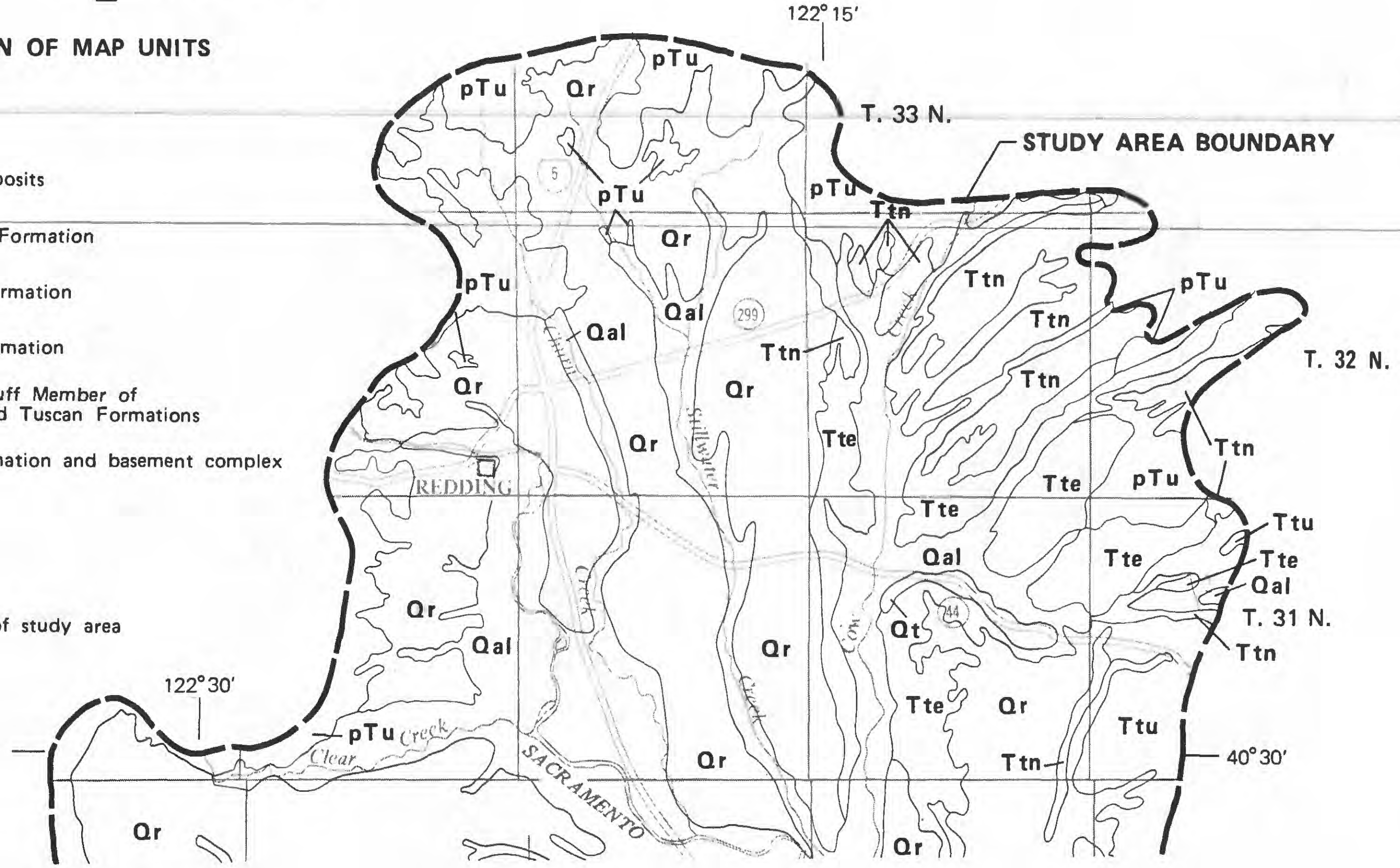
Unit	Epoch	Period
Qal	Holocene	QUATERNARY
Qt	Pleistocene	QUATERNARY
Qr	Pleistocene	QUATERNARY
Tte	Pliocene	TERTIARY
Ttu	Pliocene	TERTIARY
Ttn	Pliocene	TERTIARY
pTu		PRE-TERTIARY

DESCRIPTION OF MAP UNITS

Qal	Alluvium
Qt	Terrace deposits
Qr	Red Bluff Formation
Tte	Tehama Formation
Ttu	Tuscan Formation
Ttn	Nomlaki Tuff Member of Tehama and Tuscan Formations
pTu	Chico Formation and basement complex

——— Contact

▬ ▬ Boundary of study area



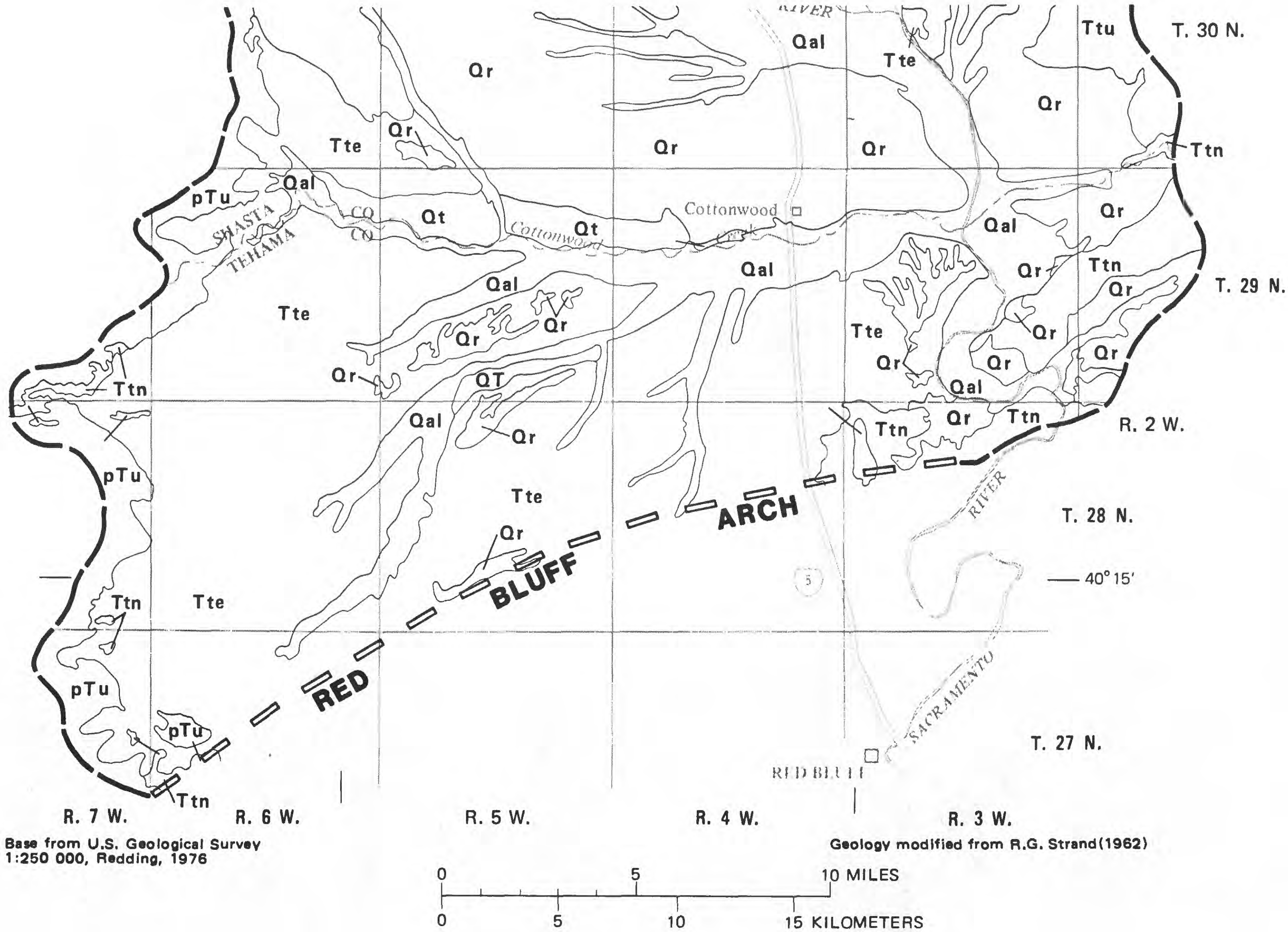


FIGURE 4. — Generalized geology.

Pre-Tertiary Unit

The pre-Tertiary rocks which underlie the Redding Basin consist of mostly non-water-bearing formations of the northern Coast Ranges province, the Klamath Mountain province, and some volcanic rocks of the Cascade province; and the Chico Formation. The age of these formations ranges from the Devonian through the Cretaceous Periods (California Department of Water Resources, 1964). The rocks of the basement complex crop out mostly in the steep terrain on the periphery of the Redding Basin and underlie the central part of the area (figs.3 and 4). These rocks have little significance as they relate to the water resources of the Redding Basin. They are considered non-water-bearing, although in some areas the basement complex may yield enough water for domestic use.

The Chico Formation, which underlies the main water-bearing formations of the Redding Basin, consists of marine clastic sedimentary rocks, mostly of siltstone, sandstone, and shale which are practically impermeable (fig. 4); however, the Chico contains a few relatively permeable beds that contain saline water. This saline water, in some places where the shaley beds are extensive, may be under artesian pressure. The Chico Formation crops out in the northern part of the Redding Basin and ranges in thickness from less than 1 ft in the north to about 6,000 ft near the south end of the basin at the Red Bluff Arch. In the Redding Basin, the top of the Chico Formation defines the base of fresh water.

Tertiary and (or) Quaternary Units

Nomlaki Tuff Member of the Tuscan and Tehama Formations

The Nomlaki Tuff Member of Pliocene age occurs as a basal member of both the Tuscan and Tehama Formations (fig. 4, table 1). It lies directly and unconformably on the Chico Formation. The Nomlaki Tuff Member is one massive bed varying in color. It is poorly consolidated and composed of white pumice fragments in a matrix of volcanic glass and crystal fragments. Gradual thickening in an eastward direction indicates that the formation had an eastern source. The Nomlaki is of little importance as a source of ground water because of its low permeability and its stratigraphic position. Wells in the Nomlaki yield an average of 40 gal/min, but the contained water is degraded locally by upward migration of saline water from the underlying Chico (California Department of Water Resources, 1964).

Tuscan Formation

The Tuscan Formation of Pliocene age consists of tuff breccia, tuffaceous sandstone and conglomerate, and tuffaceous silt and clay (Anderson, 1933). It ranges from less than 1 ft to 1,000 ft in thickness and is interbedded with the Tehama Formation in the Redding Basin.

The Tuscan Formation is one of the principal water-bearing units in the Redding Basin. It contains moderately permeable beds at various depths, and the lenticular clayey beds result in local confinement. Yields of wells range from 100 to 1,000 gal/min.

Tehama Formation

The Tehama Formation of Pliocene age is composed of silt, sand, gravel, and clays of fluviatile origin and lies unconformably on the Chico Formation of marine origin. Sediments are locally cemented (Russell, 1931). The formation ranges from less than 1 ft to 2,500 ft in thickness and is generally flat-lying throughout most of the basin. In the central part of the Redding Basin, the Tehama Formation interfingers with the Tuscan Formation. The Tehama Formation crops out principally in the west and southwest periphery of the basin.

The Tehama Formation is one of the principal water-bearing formations in the Redding Basin and contains ground water under both confined and unconfined conditions. The confined conditions are due to beds of fine-grained sediments which are low in permeability. The Tehama generally has moderate to high permeability, and yields to wells are moderate to high (100 to 1,000 gal/min).

Red Bluff Formation

The Red Bluff Formation unconformably overlies most of the interbedded Tehama and Tuscan Formations. It is composed of coarse gravels and boulders in a reddish sand, silt, and clay matrix. It ranges from less than 1 ft to as much as 100 ft in thickness. The Red Bluff Formation is poorly to moderately permeable, and, in general, areas of outcrop are above the zone of saturation but contain small bodies of perched water. Yields are small to moderate (5 to 40 gal/min) for domestic wells (California Department of Water Resources, 1968).

Terrace Deposits

Terrace deposits occur in narrow bands along the channels of Cow and Cottonwood Creeks (fig. 4). The terrace deposits, composed of poorly consolidated gravels, sand, and silt, range from less than 1 ft to about 50 ft in thickness. The permeability of the deposits is moderate to high, and well yields are moderate. However, most wells tapping the terrace deposits generally are also perforated adjacent to the Pliocene sediments below the terrace deposits, so the yield from the terrace deposits is not well known.

Alluvium

Most alluvium is in flood plains and channels adjacent to the Sacramento River, and Cottonwood, Cow, and Stillwater Creeks. The alluvium is primarily interbedded gravel, sand, silt, and clay and is as thick as 50 ft (California Department of Water Resources, 1968). The deposit is unconsolidated and the permeability is generally moderate but locally, where gravels predominate, may be very high. Many wells in the alluvium have moderate yields; however, some have produced as much as 2,000 gal/min, and others produce only enough for domestic use (California Department of Water Resources, 1964).

GROUND WATER

Source

Recharge of the aquifers in the Redding Basin area is from subsurface inflow from adjacent uplands; direct penetration of local precipitation; seepage from canals and channels of rivers and streams; and penetration below the root zone of crop irrigation water derived from imported surface water and locally pumped ground water. Recharge of the ground-water basin differs from year to year depending on the amount of precipitation and the amount of irrigation water applied. Recharge to the principal aquifer formations (Tuscan and Tehama Formations) in the Redding Basin is mostly by infiltration of streamflow on the margin of the basin. Infiltration of applied irrigation water and streamflow, and direct infiltration of precipitation are the main sources of recharge into the alluvium. Perched ground-water bodies contained in the Red Bluff Formation are mainly recharged by the infiltration of precipitation (California Department of Water Resources, 1964).

Water Levels and Ground-Water Movement

Water-level contours, based on spring 1980 measurements, indicate the direction of ground-water movement in the Redding Basin (fig. 5). Under natural conditions, ground water in the Redding Basin generally follows the topographic gradients.

Water-level measurements were made at approximately 200 wells during summer 1979 and spring 1980 (fig. 5). Most of these wells are open to all water-bearing units penetrated. The water levels were contoured without regard to aquifer or well depth, although some artesian head affects the water levels in deep wells. Because the clayey beds are lenticular in the Pliocene and younger sediments, the confinements are localized and not readily apparent (California Department of Water Resources, 1964). Perched ground water occurs in T. 30 N., R. 5 W. in the Red Bluff Formation. Water levels in these areas of perched water do not reflect the same water body as in the rest of the area. The dashed 500-ft contour in that township reflects water levels in the main water body.

Because the spring and summer measurements were virtually the same, only the spring 1980 measurements are presented in figure 5. Water levels ranged from below 400 ft to more than 600 ft above NGVD, and ground water moves generally toward the Sacramento River and then generally south-southeast. The data are insufficient to determine the ground-water - streamflow relationship in the vicinity of the Red Bluff Arch. However, the effect of the arch probably is to force ground water toward the surface so that the streams also are probably gaining in that area.

The hydrographs in figure 6 show seasonal fluctuations and long-term trends in water levels in the Redding Basin. Between 1956 and 1970, the average water levels declined slightly in most wells, but remained virtually constant or rose slightly in others. Between 1970 and 1979, the average water levels showed virtually no change.

Ground-Water Storage Capacity

Storage capacity is the volume of water that would drain by gravity from a given saturated thickness of the deposits underlying a designated ground-water storage area. Storage coefficient is the volume of water an aquifer releases from or takes into storage per unit area per unit change in head. Specific yield is the ratio of the volume of water drained from a sample of saturated material to the total volume of the sample. Under water table conditions, the storage coefficient and specific yield of a given sample of material may be considered virtually equal.

Table 2 shows the specific yield (percent) assigned to the materials of the Redding Basin as described by Olmsted and Davis (1961) in their report on the Sacramento Valley. The estimated average specific yield for the Redding Basin as determined from this table and drillers logs of 269 wells in the area is 8.5 percent. Assuming that an average of 200 ft of saturated water table aquifer is present throughout the 510 mi^2 area of the Redding Basin, and that the specific yield is 8.5 percent, storage capacity in the 200 ft saturated interval is about 5.5 million acre-ft. Because there was no significant change in water levels between 1970 and 1979, there has been no significant change in ground-water storage in that same period.

TABLE 2.--Specific yield of materials in the Redding Basin

[From Olmsted and Davis, 1961]

Material	Specific yield (percent)
Gravel	25
Sand, including sand and gravel, and gravel and sand	20
Tight sand, hard sand, fine sand, sandstone, and related deposits	10
Clay and gravel, gravel and clay, cemented gravel, and related deposits	5
"Clay," silt, sandy clay, lava rock, and related fine-grained deposits	3

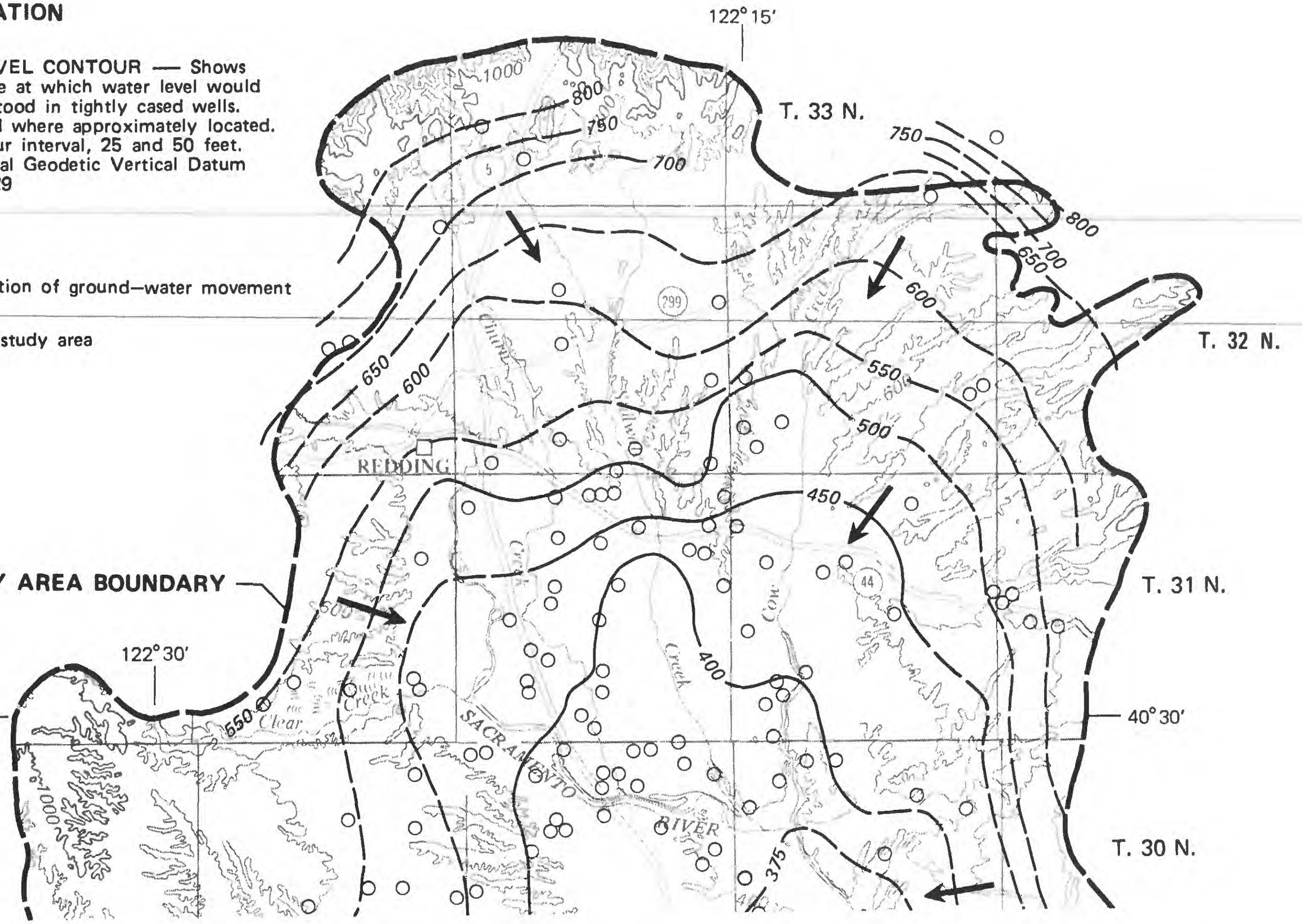
EXPLANATION

550 — — WATER–LEVEL CONTOUR — Shows altitude at which water level would have stood in tightly cased wells. Dashed where approximately located. Contour interval, 25 and 50 feet. National Geodetic Vertical Datum of 1929

○ Water well

→ General direction of ground–water movement

— — Boundary of study area



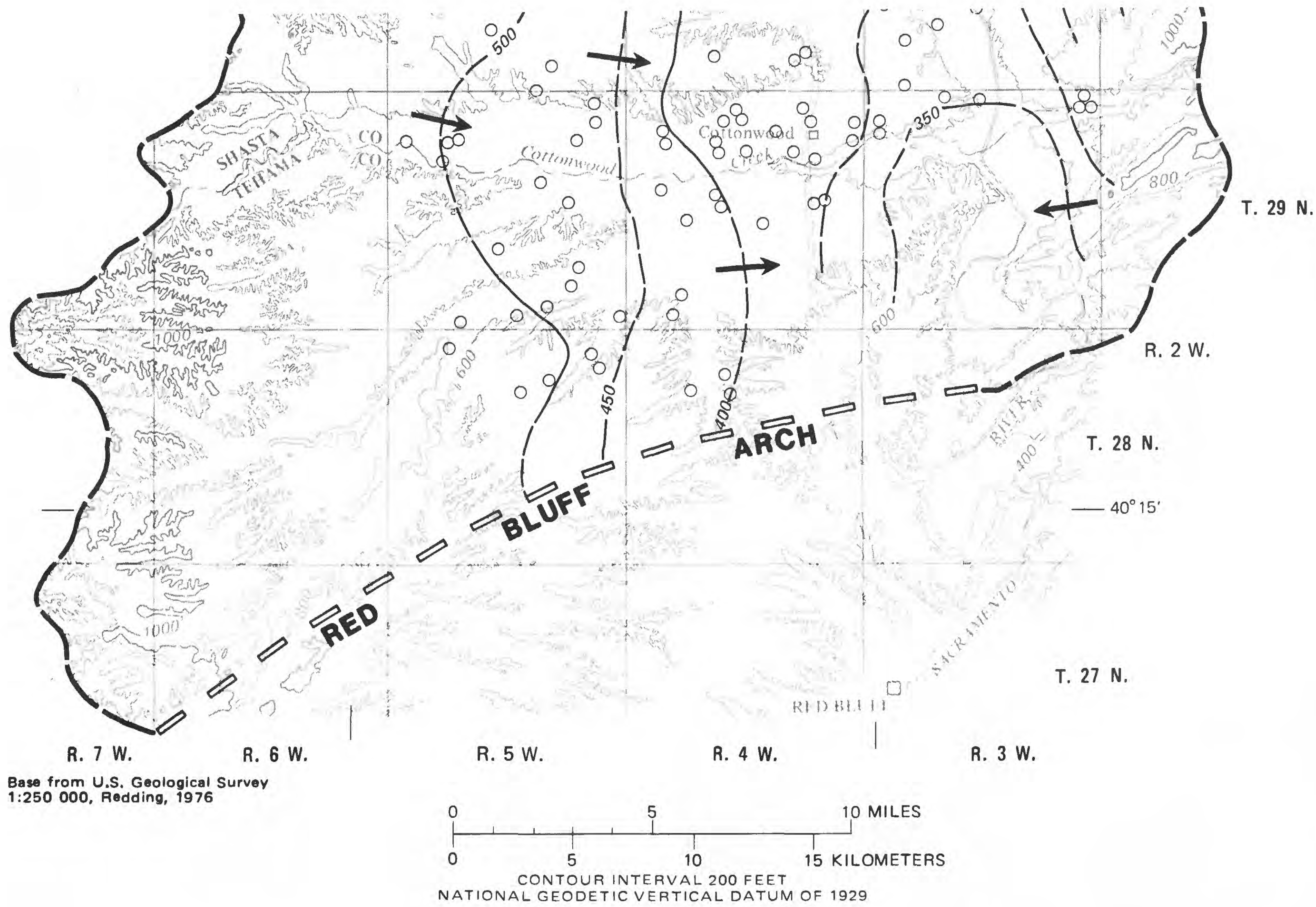


FIGURE 5. — Water–level contours and direction of ground–water movement, spring 1980.

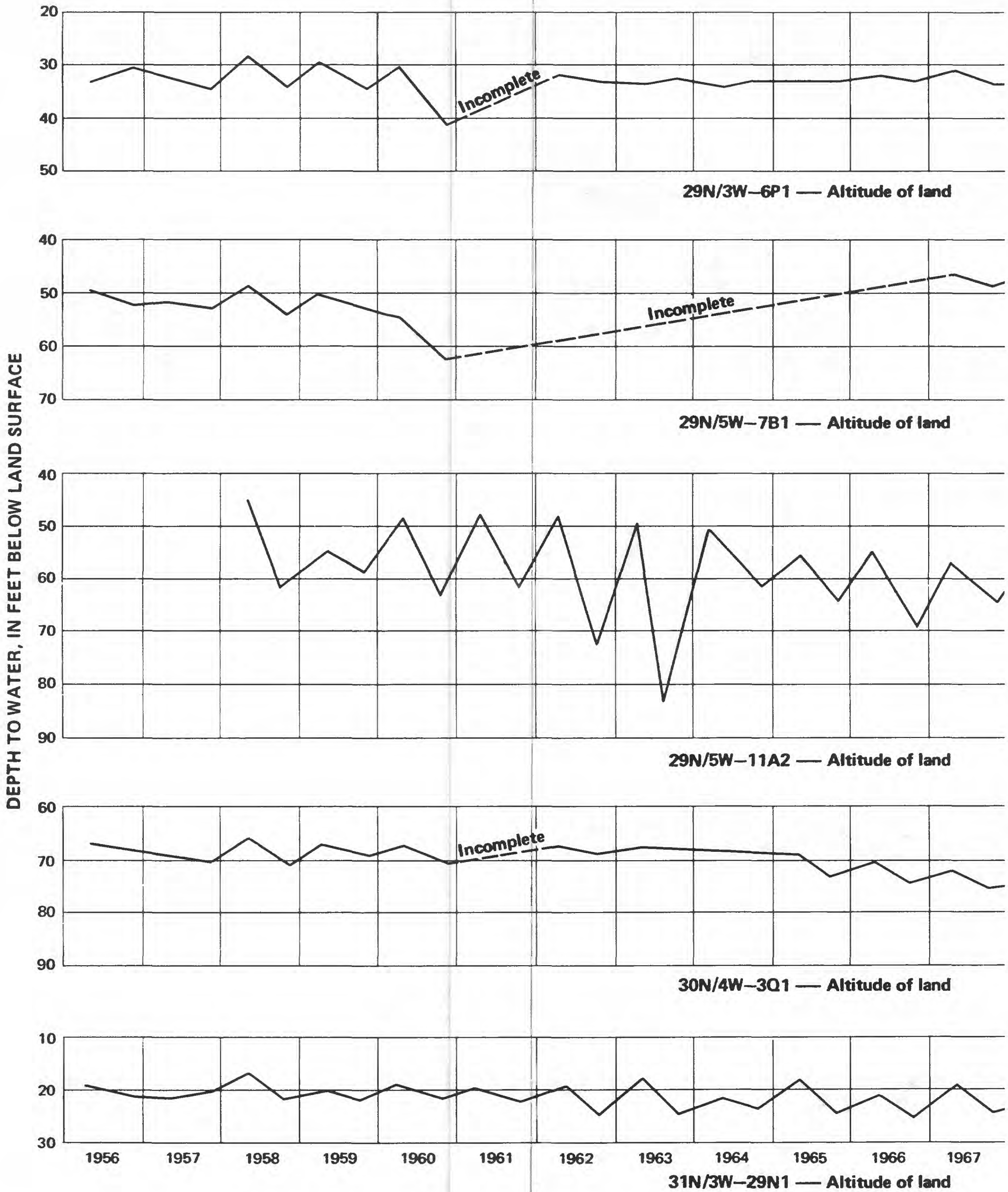
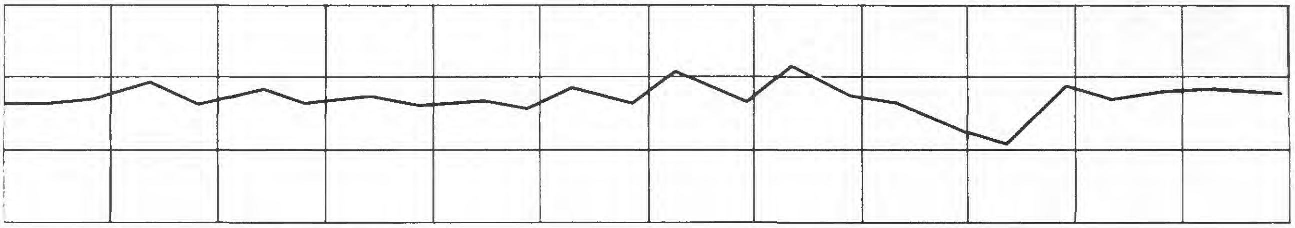
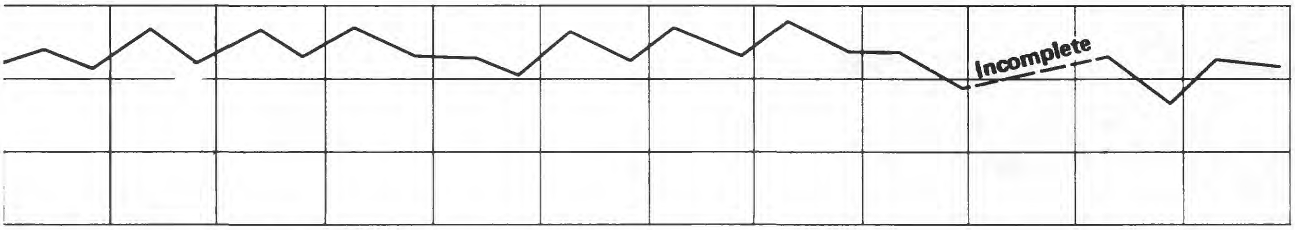


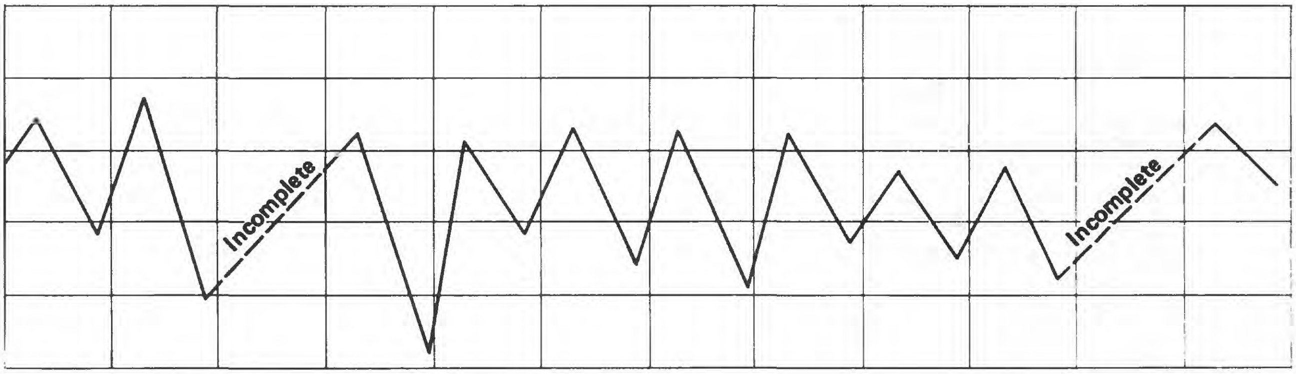
FIGURE 6. — Fluctuation of water



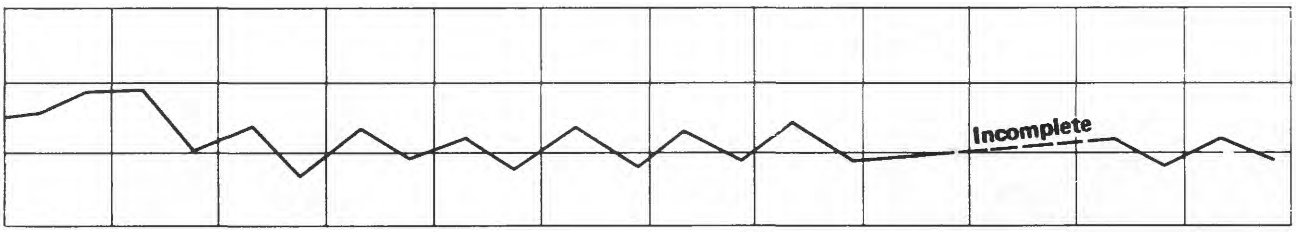
surface, 412 feet; depth of well, 69 feet



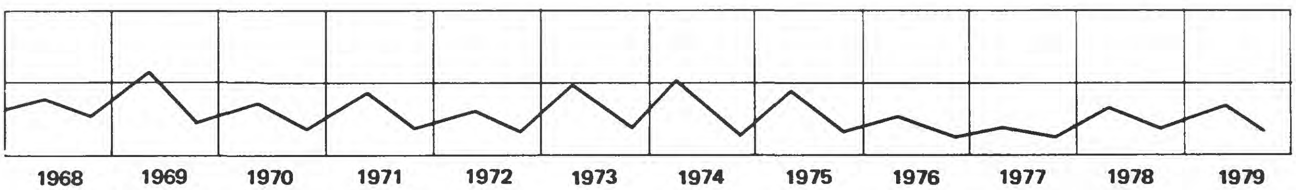
surface, 562 feet; depth of well, 450 feet



surface, 517 feet; depth of well, 360 feet



surface, 473 feet; depth of well, 140 feet



surface, 417 feet; depth of well, 130 feet

levels in five wells, 1956–79.

Water Use

About 30 percent of the water used in the Redding Basin in 1976 for agriculture was ground water (California Department of Water Resources, Land-Use Survey, 1969, 1976, by quadrangle summary). There are no more recent data, but because there was virtually no change in water levels for the period 1976-79 (fig. 6), it is assumed that ground-water use is about the same for 1980. Even during the drought period 1976-77, very little change was reflected in the ground-water use. Tables 3 through 5 provide information for the estimated 42,100 acre-ft in 1969 and 45,000 acre-ft in 1976 of ground water pumped for irrigation. Most of the pumpage for irrigation is in the Stillwater Creek, Cow Creek, Cottonwood Creek, and the Anderson-Cottonwood areas.

Ground water is also used for industrial, municipal, and domestic purposes; in 1975 an estimated 38,000 acre-ft was pumped for these uses (CH2M-Hill, consultants, Redding, Calif., written commun., 1980). The main ground-water suppliers are Anderson-Cottonwood Irrigation District, Bella Vista Water District, and Clear Creek Community Service District. The highest demand for ground water occurs during the period June through September.

The quantity of water used for irrigation was estimated by the land-use method in which the applied-water required, in acre-feet, for each major crop type is multiplied by the acreage of that crop type (table 3). The sum of the applied-water requirements for all crop types is considered equal to the irrigation water used. The unit applied-water requirement includes all transpiration, evaporation, and other losses from vegetation, land, and water surfaces (McClelland, 1963). Errors (probably less than 5 percent) in estimating irrigation water use by this method may result because of inaccurate delineation of the major crop types and (or) estimated volumes of applied water used on the major crop types.

There was about a 5 percent increase, based on estimates given in table 5, in ground-water pumpage for irrigation from 1969 to 1976. Crop acreage increased but water usage per acre decreased. The decrease in usage per acre was owing largely to the change in major crop type during those years. The California Department of Water Resources (written commun., 1980) suggests that with conservation of water, increasing irrigation efficiency, and encroachment on agricultural land by industry and urban development in the Redding Basin area, ground-water pumpage for irrigation in the future probably will remain the same or decline.

TABLE 3.--Estimated applied water for irrigation, both surface and ground water, in the Redding Basin

Crop type	Unit applied water requirements[2] (acre-ft/acre)	Total acreage[1] for crop type 1969	Estimated applied water (acre-ft) 1969	Total acreage[1] for crop type 1976	Estimated applied water (acre-ft) 1976
Olives	3.1	909	2,818	925	2,868
Misc. subtropical fruit	3.1	0	0	8	25
Apricots	3.8	2	8	0	0
Peaches and nectarines	3.8	43	163	0	0
Prunes	3.8	394	1,497	570	2,166
Miscellaneous deciduous	3.8	78	296	123	467
Almonds	3.8	141	536	178	676
Walnuts	3.8	1,415	5,377	1,455	5,529
Corn	3.1	55	170	240	744
Grain sorghums	3.1	75	232	65	202
Sudan	3.1	142	440	32	99
Beans (dry)	3.1	0	0	359	1,113
Grain	.9	0	0	3,082	2,774
Pasture	6.0	7	42	0	0
Alfalfa	5.3	1,731	9,174	729	3,864
Clover	6.0	0	0	15	90
Mixed pasture	6.0	19,390	116,340	20,547	123,282
Native pasture	6.0	139	834	0	0
Marshgrass (manmade)	6.0	376	2,256	0	0
Sudan grass	6.0	208	1,248	0	0
Lawns	6.0	30	180	275	1,650
Cemeteries	6.0	7	42	74	444
Beans (green)	2.2	86	189	0	0
Melons	2.2	36	79	12	26
Onions and garlic	2.2	0	0	238	524
Miscellaneous truck	2.2	9	20	12	26
Strawberries	2.2	301	662	537	1,181
Vineyard	3.3	3	10	11	36
Totals[3]		25,000	142,000	29,500	148,000

[1]California Department of Water Resources, Land-Use Survey 1969, 1976, by quadrangle summary.

[2]Oral communication with Robert R. McGill and Eugene M. Pixley, California Department of Water Resources.

[3]Totals have been rounded to three significant figures.

TABLE 4.--Estimated applied surface water for irrigation in Anderson-Cottonwood Irrigation District, Bella Vista Water District, and Clear Creek Community Service District

Crop type	Unit applied water requirements[1] (acre-ft/acre)	Total acreage for crop type[2] 1969	Estimated applied water (acre-ft) 1969	Total acreage for crop type[2] 1976	Estimated applied water (acre-ft) 1976
Anderson-Cottonwood Irrigation District					
Prunes	3.8	230	874	178	676
Miscellaneous deciduous	3.8	70	266	59	224
Almonds	3.8	128	486	99	376
Walnuts	3.8	985	3,743	1,019	3,872
Corn	3.1	48	149	224	694
Grain sorghums	3.1	0	0	24	74
Sudan	3.1	142	440	0	0
Grain	.9	0	0	1,104	994
Alfalfa	5.3	1,253	6,641	288	1,526
Mixed pasture	6.0	12,441	74,646	12,756	76,536
Native pasture	6.0	90	540	0	0
Marshgrass (manmade)	6.0	275	1,650	0	0
Cemeteries	6.0	4	24	18	108
Beans (green)	2.2	86	189	0	0
Melons	2.2	36	79	0	0
Miscellaneous truck	2.2	9	20	0	0
Strawberries	2.2	0	0	51	112
Totals[3]		15,800	89,700	15,800	85,200
Bella Vista Water District					
Miscellaneous deciduous	3.8	4	15	5	19
Walnuts	3.8	13	49	2	8
Grain sorghums	3.1	64	198	0	0
Grain	.9	0	0	477	429
Alfalfa	5.3	149	790	56	297
Mixed pasture	6.0	534	3,204	1,136	6,816
Onion	2.2	0	0	105	231
Strawberries	2.2	136	299	128	282
Totals[3]		900	4,560	1,910	8,080
Clear Creek Community Service District					
Family garden	3.0			78	234
Olives	3.1	(Estimated from growth	percentage of Bella	662	2,052
Vineyard	3.3	Vista Water	District)	4	13
Miscellaneous truck	2.2			12	26
Melons	2.2			12	26
Corn	3.1			16	50
Mixed pasture	6.0			1,250	7,500
Alfalfa	5.3			20	106
Totals[3]		1,000	5,600	2,000	10,000

[1]Oral communication with Robert R. McGill and Eugene M. Pixley, California Department of Water Resources.

[2]California Department of Water Resources, Water Purveyor Survey, with Anderson-Cottonwood Irrigation District, Sept. 28, 1978; Bella Vista Water District, Nov. 2, 1978; Clear Creek Community Service District, May 5, 1980.

[3]Totals have been rounded to three significant figures.

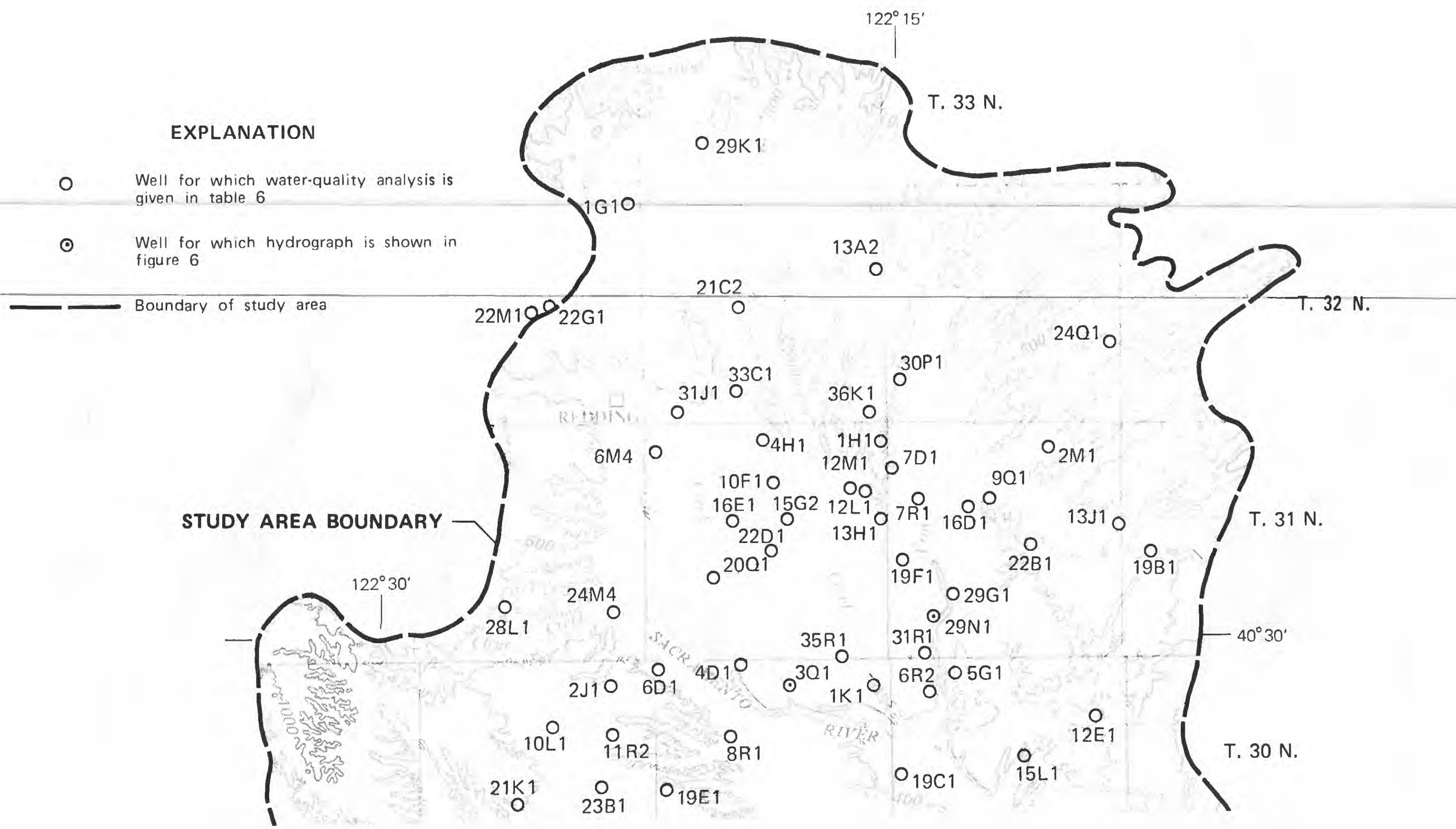
TABLE 5.--Estimated ground-water pumpage for irrigation in the Redding Basin

Water source	Annual volume of water (acre-feet)			
	1969		1976	
Redding Basin applied water (surface and ground)		142,000		148,000
Anderson-Cottonwood Irrigation District applied water (surface)	89,700		85,200	
Bella Vista Water District applied water (surface)	4,560		8,080	
Clear Creek Community Service District applied water (surface)	5,600		10,000	
Total applied (surface)		99,900		103,000
Estimated pumpage for irrigation (ground)		42,100		45,000

CHEMICAL QUALITY OF GROUND WATER

During October 1979, samples of ground water from 85 wells (fig. 7) in the Redding Basin were collected. Samples were taken mainly from domestic wells which were pumped long enough before sampling to assure that water was coming from the aquifer as opposed to coming from storage in the casing or pressure tank.

Water temperature, pH, alkalinity, and specific conductance were measured immediately after sampling in the field. Temperature of the sample was taken with a hand-held thermometer. The pH was determined by a portable pH meter. Alkalinity was determined by the electrometric titration process described by Brown and others (1970, p. 42). Specific conductance was measured on a direct-reading conductivity-temperature meter. After proper treatment in the field, the samples were shipped to the California Department of Water Resources, Bryte laboratory for major ions analysis, and to the U.S. Geological Survey Central Laboratory in Arvada, Colo., for trace elements analysis. All samples were packed in ice until delivery to the appropriate laboratories. The analytical results are given in table 6.


EXPLANATION
Well for which water-quality analysis is given in table 6
Well for which hydrograph is shown in figure 6
Boundary of study area
STUDY AREA BOUNDARY
122° 15'
122° 30'
40° 30'
T. 33 N.
T. 32 N.
T. 31 N.
T. 30 N.
29K1
1G1
13A2
21C2
22M1
22G1
24Q1
30P1
33C1
31J1
36K1
4H1
1H1
6M4
12M1
7D1
2M1
10F1
9Q1
16E1
15G2
12L1
7R1
16D1
13J1
22D1
13H1
22B1
19B1
20Q1
19F1
29G1
24M4
28L1
29N1
35R1
31R1
4D1
3Q1
6R2
5G1
2J1
6D1
1K1
12E1
10L1
11R2
8R1
15L1
19C1
21K1
23B1
19E1
SACRAMENTO
RIVER

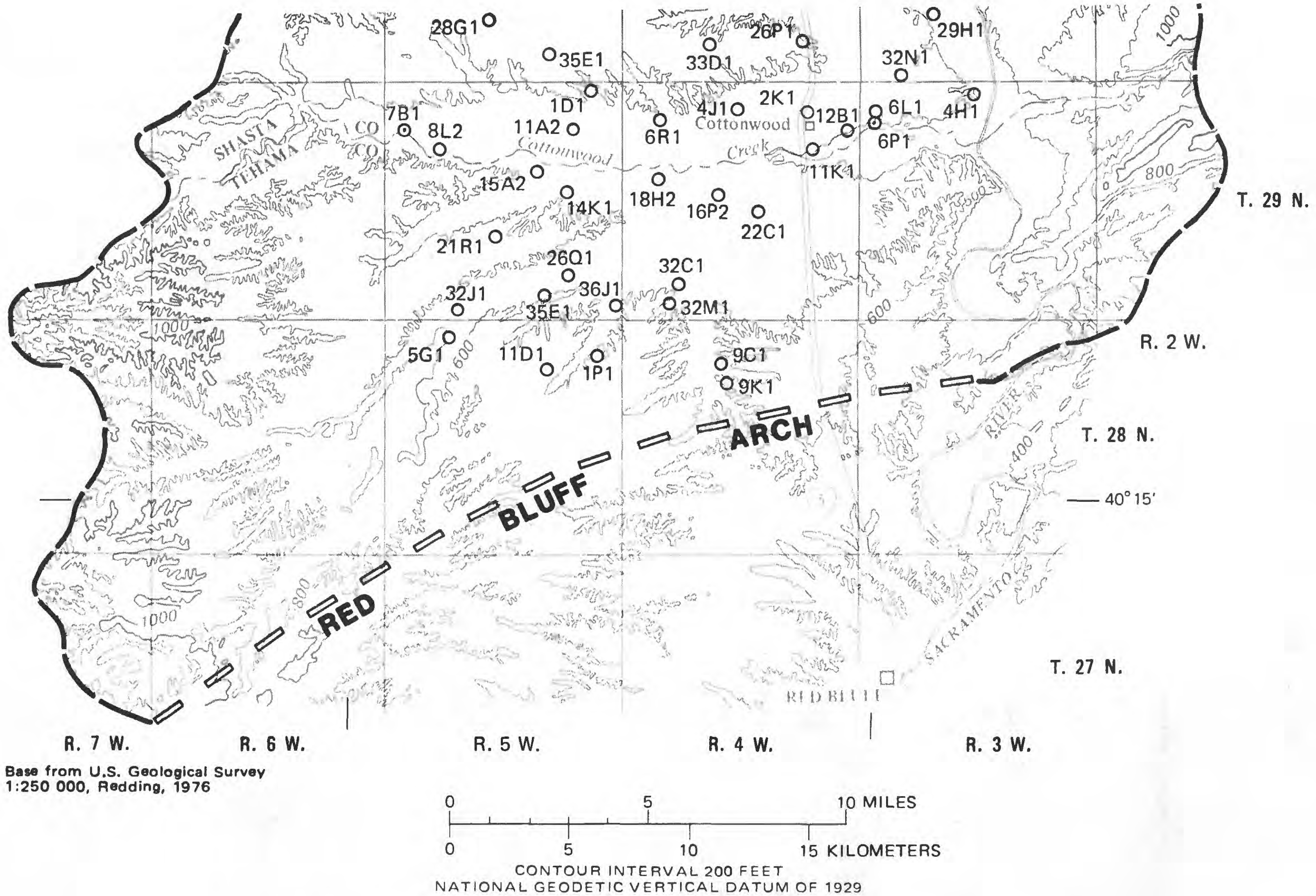


FIGURE 7. — Location of wells for which water–quality analyses have been made and hydrographs prepared.

TABLE 6.--Ground-water quality data

[Analyses by California Department of Water Resources and U.S. Geological Survey]

STATE WELL NUMBER	DATE OF SAMPLE	SPE-CIFIC CON-DUCT-ANCE (MICRO-MHOS)	PH FIELD (UNITS)	TEMPER-ATURE, WATER (DEG C)	HARD-NESS (MG/L AS CACO3)	CALCIUM DIS-SOLVED (MG/L AS CA)	MAGNE-SIUM, DIS-SOLVED (MG/L AS MG)	SODIUM, DIS-SOLVED (MG/L AS NA)	SODIUM PERCENT	SODIUM AD-SORP-TION RATIO
028N004W09C01M	79-10-12	212	7.4	19.5	81	16	10	18	32	.9
028N004W09K01M	79-10-12	274	7.6	20.5	100	26	9.0	20	29	.9
028N005W01P01M	79-10-17	251	7.3	20.5	110	22	14	12	19	.5
028N005W05G01M	79-10-17	340	7.3	20.5	140	28	18	18	21	.7
028N005W11D01M	79-10-17	316	7.8	21.0	130	29	15	18	22	.7
029N003W04H01M	79-10-17	138	7.6	19.0	47	9.0	6.0	12	34	.8
029N003W06L01M	79-10-17	151	7.1	17.5	58	10	8.0	12	31	.7
029N004W02K01M	79-10-10	160	7.2	18.5	30	7.0	3.0	51	77	4.1
029N004W04J01M	79-10-10	175	6.9	21.0	60	11	8.0	14	33	.8
029N004W06R01M	79-10-10	176	7.1	23.5	56	11	7.0	16	38	.9
029N004W11K01M	79-10-10	181	7.4	18.5	70	13	9.0	11	25	.6
029N004W12B01M	79-10-10	252	7.0	18.0	100	18	14	12	20	.5
029N004W16P02M	79-10-12	592	6.6	17.5	240	42	32	35	24	1.0
029N004W18H02M	79-10-18	216	6.8	18.5	98	16	14	10	18	.4
029N004W22C01M	79-10-12	167	7.0	17.5	70	13	9.0	10	24	.5
029N004W32C01M	79-10-17	189	7.1	20.5	73	16	8.0	14	29	.7
029N004W32M01M	79-10-17	192	7.3	20.0	73	16	8.0	13	28	.7
029N005W01D01M	79-10-10	171	6.8	19.5	50	10	6.0	17	40	1.0
029N005W08L02M	79-10-10	268	6.8	18.5	130	22	17	10	15	.4
029N005W14K01M	79-10-18	231	7.1	17.5	100	19	13	12	20	.5
029N005W15A02M	79-10-18	204	6.8	18.5	90	16	12	11	21	.5
029N005W21R01M	79-10-17	205	7.4	21.0	85	16	11	13	25	.6
029N005W26Q01M	79-10-17	239	7.0	18.5	98	23	10	14	23	.6
029N005W32J01M	79-10-17	429	7.5	19.0	190	38	23	20	19	.6
029N005W35E01M	79-10-17	234	7.3	19.5	94	21	10	15	26	.7
029N105W36J01M	79-10-17	180	6.9	18.5	74	15	9.0	10	22	.5
030N003W05G01M	79-10-16	173	7.2	20.5	66	10	10	10	24	.5
030N003W06H02M	79-10-16	168	7.2	22.0	60	11	8.0	13	31	.7
030N003W12E01M	79-10-16	327	6.5	20.0	140	27	18	12	15	.4
030N003W15L01M	79-10-16	275	7.3	20.0	120	19	18	12	17	.5
030N003W19C01M	79-10-17	156	7.0	16.5	64	11	9.0	9.0	23	.5
030N003W29H01M	79-10-17	236	7.0	16.5	100	17	15	11	18	.5
030N003W32N01M	79-10-17	178	7.1	18.0	71	12	10	10	23	.5
030N004W01K01M	79-10-16	142	7.0	19.0	54	10	7.0	9.0	26	.5
030N004W04D01M	79-10-16	299	6.9	18.0	120	24	15	10	15	.4
030N004W06D01M	79-10-10	135	6.5	19.0	44	8.0	6.0	13	38	.8
030N004W03H01M	79-10-10	118	7.3	21.5	42	7.0	6.0	9.0	31	.6
030N004W19E01M	79-10-10	117	6.2	22.0	36	8.0	4.0	11	39	.8
030N004W26P01M	79-10-10	217	7.4	23.0	74	13	10	18	34	.9
030N004W33D01M	79-10-10	200	7.0	22.0	70	13	9.0	17	34	.9
030N005W02J01M	79-10-11	99	6.3	18.0	28	6.0	3.0	12	48	1.0
030N005W10L01M	79-10-10	133	7.0	19.0	38	7.0	5.0	13	42	.9
030N005W11R02M	79-10-10	136	6.6	18.5	42	7.0	6.0	12	38	.8
030N005W21K01M	79-10-10	131	7.0	20.5	40	8.0	5.0	13	41	.9
030N005W23B01M	79-10-10	170	7.4	20.5	44	8.0	6.0	20	49	1.3
030N005W28G01M	79-10-10	118	6.7	20.5	34	7.0	4.0	12	43	.9
030N005W35F01M	79-10-11	175	6.8	21.0	60	11	8.0	17	38	1.0
031N002W19B01M	79-10-01	301	7.0	24.0	140	26	17	17	21	.6
031N003W02M01M	79-10-02	167	7.5	20.0	59	12	7.0	10	26	.6
031N003W07D01M	79-10-02	175	6.7	21.0	58	10	8.0	15	35	.9
031N003W07R01M	79-10-02	157	7.2	21.0	56	11	7.0	9.0	25	.5
031N003W09Q01M	79-10-01	180	7.3	25.0	74	15	9.0	9.0	20	.5
031N003W13J01M	79-10-01	220	6.8	25.0	90	21	9.0	9.0	17	.4
031N003W16D01M	79-10-01	173	7.2	24.0	72	14	9.0	9.0	21	.5
031N003W19F01M	79-10-02	214	6.8	20.0	77	11	12	15	29	.7

TABLE 6.--Ground-water quality data--Continued

STATE WELL NUMBER	DATE OF SAMPLE	POTASSIUM, DISSOLVED (MG/L AS K)	ALKALINITY (MG/L AS CACO3)	SULFATE DISSOLVED (MG/L AS SO4)	CHLORIDE, DISSOLVED (MG/L AS CL)	FLUORIDE, DISSOLVED (MG/L AS F)	SILICA, DISSOLVED (MG/L AS SIO2)	SOLIDS, RESIDUE AT 180 DEG. C DISSOLVED (MG/L)	NITROGEN, NITRATE DISSOLVED (MG/L AS N)	ARSENIC DISSOLVED (UG/L AS AS)
028N004W09C01M	79-10-12	1.1	110	1.0	3.0	.1	44	153	1.2	--
028N004W09K01M	79-10-12	3.2	140	2.0	4.0	.1	57	209	.70	--
028N005W01P01M	79-10-17	.6	130	3.0	3.0	.3	40	169	.90	--
028N005W05G01M	79-10-17	.7	140	16	19	.2	38	217	.90	--
028N005W11D01M	79-10-17	1.0	150	8.0	12	.1	37	201	.29	--
029N003W04H01M	79-10-17	2.0	64	4.0	2.0	.1	64	157	1.2	--
029N003W06L01M	79-10-17	.9	74	5.0	2.0	.1	44	136	.59	2
029N004W02K01M	79-10-10	2.4	140	1.0	5.0	.0	26	176	.20	--
029N004W04J01M	79-10-10	.9	84	2.0	3.0	.1	66	156	.70	--
029N004W06H01M	79-10-10	.7	84	.0	3.0	.1	63	152	.90	--
029N004W11K01M	79-10-10	.7	79	3.0	5.0	.1	42	128	.90	--
029N004W12B01M	79-10-10	.6	120	7.0	4.0	.1	39	163	.79	--
029N004W16P02M	79-10-12	.9	180	36	46	.0	34	367	10	1
029N004W18H02M	79-10-18	.7	110	5.0	2.0	.1	47	168	1.5	--
029N004W22C01M	79-10-12	.6	76	4.0	4.0	.1	42	132	1.1	--
029N004W32C01M	79-10-17	.6	100	3.0	3.0	.2	46	170	1.2	--
029N004W32M01M	79-10-17	.8	92	3.0	2.0	.2	46	164	.59	--
029N005W01D01M	79-10-10	5.0	84	.0	3.0	.1	59	143	.50	1
029N005W08L02M	79-10-10	.7	130	6.0	3.0	.1	51	--	.79	--
029N005W14K01M	79-10-18	.8	120	6.0	4.0	.1	50	182	.79	--
029N005W15A02M	79-10-18	.7	100	6.0	4.0	.1	50	173	1.6	--
029N005W21R01M	79-10-17	.7	110	3.0	3.0	.1	48	168	.70	2
029N005W26Q01M	79-10-17	.8	110	6.0	6.0	.1	30	154	1.1	--
029N005W32J01M	79-10-17	.9	160	25	28	.1	41	275	.90	--
029N005W35E01M	79-10-17	.7	110	5.0	4.0	.2	36	174	1.4	--
029N105W36J01M	79-10-17	.6	83	5.0	3.0	.1	40	151	1.7	1
030N003W05G01M	79-10-16	1.8	83	4.0	2.0	.1	89	201	1.2	--
030N003W06R02M	79-10-16	1.5	73	4.0	6.0	.1	60	162	.41	--
030N003W12E01M	79-10-16	1.5	110	10	16	.1	73	266	7.0	1
030N003W15L01M	79-10-16	1.9	140	3.0	3.0	.1	78	211	.50	--
030N003W19C01M	79-10-17	1.4	73	5.0	3.0	.1	53	149	1.2	--
030N003W29H01M	79-10-17	1.6	120	6.0	3.0	.1	60	182	.50	--
030N003W32N01M	79-10-17	1.6	85	7.0	3.0	.1	68	176	.59	--
030N004W01K01M	79-10-16	.9	62	4.0	3.0	.1	48	137	1.6	1
030N004W04D01M	79-10-16	.9	130	9.0	6.0	.1	36	186	2.3	--
030N004W06D01M	79-10-10	.5	55	1.0	3.0	.1	43	126	.50	1
030N004W08R01M	79-10-10	.9	50	2.0	2.0	.1	34	95	.59	--
030N004W19E01M	79-10-10	.5	40	5.0	6.0	.0	57	122	1.3	--
030N004W26P01M	79-10-10	.8	100	6.0	2.0	.1	46	149	.29	1
030N004W33D01M	79-10-10	.9	96	2.0	3.0	.1	53	151	.41	--
030N005W02J01M	79-10-11	.5	47	1.0	2.0	.2	69	124	.50	--
030N005W10L01M	79-10-10	.5	62	3.0	2.0	.2	47	114	.00	--
030N005W11R02M	79-10-10	.6	62	3.0	3.0	.1	71	142	.29	--
030N005W21K01M	79-10-10	.3	64	3.0	2.0	.1	53	119	.29	--
030N005W23B01M	79-10-10	.8	79	9.0	3.0	.2	41	144	.00	--
030N005W28G01M	79-10-10	.3	56	2.0	2.0	.1	58	133	.41	1
030N005W35E01M	79-10-11	.5	85	3.0	4.0	.1	58	164	.79	--
031N002W19B01M	79-10-01	1.1	160	2.0	3.0	.1	85	246	1.2	--
031N003W02M01M	79-10-02	1.3	74	1.0	3.0	.1	76	163	.09	--
031N003W07D01M	79-10-02	1.6	81	1.0	4.0	.1	93	196	.41	--
031N003W07R01M	79-10-02	1.8	62	3.0	4.0	.1	64	152	1.6	--
031N003W09Q01M	79-10-01	1.6	90	1.0	2.0	--	79	172	.29	--
031N003W13J01M	79-10-01	2.3	110	2.0	4.0	.0	63	186	.00	--
031N003W16D01M	79-10-01	1.7	86	1.0	2.0	.1	79	177	.20	--
031N003W19F01M	79-10-02	1.3	93	3.0	11	.2	76	188	.29	--

TABLE 6.--Ground-water quality data--Continued

STATE WELL NUMBER	DATE OF SAMPLE	BARIUM, DIS-SOLVED (UG/L AS BA)	BORON, DIS-SOLVED (UG/L AS B)	CADMIUM DIS-SOLVED (UG/L AS CD)	CHRO-MIUM, DIS-SOLVED (UG/L AS CR)	COPPER, DIS-SOLVED (UG/L AS CU)	IRON, DIS-SOLVED (UG/L AS FE)	LEAD, DIS-SOLVED (UG/L AS PB)	MANGA-NESE, DIS-SOLVED (UG/L AS MN)
028N004W09C01M	79-10-12	--	100	--	--	--	--	--	--
028N004W09K01M	79-10-12	--	0	--	--	--	--	--	--
028N005W01P01M	79-10-17	--	0	--	--	--	--	--	--
028N005W05G01M	79-10-17	--	0	--	--	--	--	--	--
028N005W11D01M	79-10-17	--	0	--	--	--	--	--	--
029N003W04H01M	79-10-17	--	0	--	--	--	--	--	--
029N003W06L01M	79-10-17	20	0	<1	0	0	<10	0	2
029N004W02K01M	79-10-10	--	300	--	--	--	--	--	--
029N004W04J01M	79-10-10	--	0	--	--	--	--	--	--
029N004W06R01M	79-10-10	--	0	--	--	--	--	--	--
029N004W11K01M	79-10-10	--	100	--	--	--	--	--	--
029N004W12R01M	79-10-10	--	0	--	--	--	--	--	--
029N004W16P02M	79-10-12	100	100	<1	0	3	<10	0	1
029N004W16H02M	79-10-18	--	0	--	--	--	--	--	--
029N004W22C01M	79-10-12	--	0	--	--	--	--	--	--
029N004W32C01M	79-10-17	--	0	--	--	--	--	--	--
029N004W32M01M	79-10-17	--	0	--	--	--	--	--	--
029N005W01D01M	79-10-10	30	0	<1	0	2	<10	2	4
029N005W08L02M	79-10-10	--	0	--	--	--	--	--	--
029N005W14K01M	79-10-18	--	0	--	--	--	--	--	--
029N005W15A02M	79-10-18	--	0	--	--	--	--	--	--
029N005W21P01M	79-10-17	40	0	<1	0	0	<10	0	<1
029N005W26Q01M	79-10-17	--	0	--	--	--	--	--	--
029N005W32J01M	79-10-17	--	0	--	--	--	--	--	--
029N005W35E01M	79-10-17	--	0	--	--	--	--	--	--
029N105W36J01M	79-10-17	50	0	2	0	14	<10	0	3
030N003W05G01M	79-10-16	--	0	--	--	--	--	--	--
030N003W06R02M	79-10-16	--	0	--	--	--	--	--	--
030N003W12E01M	79-10-16	30	0	2	0	0	<10	1	6
030N003W15L01M	79-10-16	--	0	--	--	--	--	--	--
030N003W19C01M	79-10-17	--	0	--	--	--	--	--	--
030N003W29H01M	79-10-17	--	0	--	--	--	--	--	--
030N003W32N01M	79-10-17	--	0	--	--	--	--	--	--
030N004W01K01M	79-10-16	20	0	<1	0	0	20	0	3
030N004W04D01M	79-10-16	--	0	--	--	--	--	--	--
030N004W06D01M	79-10-10	40	0	<1	0	1	<10	0	10
030N004W08R01M	79-10-10	--	0	--	--	--	--	--	--
030N004W19E01M	79-10-10	--	0	--	--	--	--	--	--
030N004W26P01M	79-10-10	30	0	<1	0	7	<10	0	3
030N004W33D01M	79-10-10	--	0	--	--	--	--	--	--
030N005W02J01M	79-10-11	--	0	--	--	--	--	--	--
030N005W10L01M	79-10-10	--	0	--	--	--	--	--	--
030N005W11R02M	79-10-10	--	0	--	--	--	--	--	--
030N005W21K01M	79-10-10	--	0	--	--	--	--	--	--
030N005W23B01M	79-10-10	--	0	--	--	--	--	--	--
030N005W28G01M	79-10-10	30	0	<1	0	5	<10	0	2
030N005W35E01M	79-10-11	--	0	--	--	--	--	--	--
031N002W19H01M	79-10-01	--	0	--	--	--	--	--	--
031N003W02M01M	79-10-02	--	0	--	--	--	--	--	--
031N003W07D01M	79-10-02	--	0	--	--	--	--	--	--
031N003W07R01M	79-10-02	--	0	--	--	--	--	--	--
031N003W09Q01M	79-10-01	--	0	--	--	--	--	--	--
031N003W13J01M	79-10-01	--	0	--	--	--	--	--	--
031N003W16D01M	79-10-01	--	0	--	--	--	--	--	--
031N003W19F01M	79-10-02	--	0	--	--	--	--	--	--

TABLE 6.--Ground-water quality data--Continued

STATE WELL NUMBER	DATE OF SAMPLE	MERCURY DIS- SOLVED (UG/L AS HG)	SELE- NIUM, DIS- SOLVED (UG/L AS SE)	SILVER, DIS- SOLVED (UG/L AS AG)	ZINC, DIS- SOLVED (UG/L AS ZN)
028N004W09C01M	79-10-12	--	--	--	--
028N004W09K01M	79-10-12	--	--	--	--
028N005W01P01M	79-10-17	--	--	--	--
028N005W05G01M	79-10-17	--	--	--	--
028N005W11D01M	79-10-17	--	--	--	--
029N003W04H01M	79-10-17	--	--	--	--
029N003W06L01M	79-10-17	.0	0	0	130
029N004W02K01M	79-10-10	--	--	--	--
029N004W04J01M	79-10-10	--	--	--	--
029N004W06H01M	79-10-10	--	--	--	--
029N004W11K01M	79-10-10	--	--	--	--
029N004W12H01M	79-10-10	--	--	--	--
029N004W16P02M	79-10-12	.1	0	0	30
029N004W18H02M	79-10-18	--	--	--	--
029N004W22C01M	79-10-12	--	--	--	--
029N004W32C01M	79-10-17	--	--	--	--
029N004W32M01M	79-10-17	--	--	--	--
029N005W01D01M	79-10-10	.0	0	0	1300
029N005W08L02M	79-10-10	--	--	--	--
029N005W14K01M	79-10-18	--	--	--	--
029N005W15A02M	79-10-18	--	--	--	--
029N005W21R01M	79-10-17	.0	0	0	360
029N005W26Q01M	79-10-17	--	--	--	--
029N005W32J01M	79-10-17	--	--	--	--
029N005W35E01M	79-10-17	--	--	--	--
029N105W36J01M	79-10-17	.0	0	0	180
030N003W05G01M	79-10-16	--	--	--	--
030N003W06R02M	79-10-16	--	--	--	--
030N003W12E01M	79-10-16	.0	0	0	1700
030N003W15L01M	79-10-16	--	--	--	--
030N003W19C01M	79-10-17	--	--	--	--
030N003W29H01M	79-10-17	--	--	--	--
030N003W32N01M	79-10-17	--	--	--	--
030N004W01K01M	79-10-16	.0	0	0	540
030N004W04D01M	79-10-16	--	--	--	--
030N004W06D01M	79-10-10	.0	0	0	40
030N004W08R01M	79-10-10	--	--	--	--
030N004W19E01M	79-10-10	--	--	--	--
030N004W26P01M	79-10-10	.0	1	0	1600
030N004W33D01M	79-10-10	--	--	--	--
030N005W02J01M	79-10-11	--	--	--	--
030N005W10L01M	79-10-10	--	--	--	--
030N005W11R02M	79-10-10	--	--	--	--
030N005W21K01M	79-10-10	--	--	--	--
030N005W23R01M	79-10-10	--	--	--	--
030N005W28G01M	79-10-10	.0	0	0	1000
030N005W35E01M	79-10-11	--	--	--	--
031N002W19H01M	79-10-01	--	--	--	--
031N003W02M01M	79-10-02	--	--	--	--
031N003W07D01M	79-10-02	--	--	--	--
031N003W07R01M	79-10-02	--	--	--	--
031N003W09Q01M	79-10-01	--	--	--	--
031N003W13J01M	79-10-01	--	--	--	--
031N003W16D01M	79-10-01	--	--	--	--
031N003W19F01M	79-10-02	--	--	--	--

TABLE 6.--Ground-water quality data--Continued

STATE WELL NUMBER	DATE OF SAMPLE	SPE-CIFIC CON-DUCT-ANCE (MICRO-MHOS)	PH FIELD (UNITS)	TEMPER-ATURE, WATER (DEG C)	HARD-NESS (MG/L AS CACO3)	CALCIUM DIS-SOLVED (MG/L AS CA)	MAGNE-SIUM, DIS-SOLVED (MG/L AS MG)	SODIUM, DIS-SOLVED (MG/L AS NA)	SODIUM PERCENT	SODIUM AD-SORP-TION RATIO
031N003W22B01M	79-10-01	125	7.2	23.0	46	10	5.0	7.0	24	.5
031N003W29G01M	79-10-01	268	6.7	19.5	120	19	17	11	17	.4
031N003W31R01M	79-10-17	167	6.8	20.0	67	12	9.0	10	24	.5
031N004W01H01M	79-10-02	147	6.4	22.0	49	8.0	7.0	13	36	.8
031N004W04H01M	79-10-03	235	7.5	21.0	64	14	7.0	30	50	1.6
031N004W06M04M	79-10-10	265	7.2	18.0	44	8.0	6.0	24	53	1.6
031N004W10F01M	79-10-03	181	6.9	21.0	64	9.0	10	14	32	.8
031N004W12L01M	79-10-02	220	7.9	21.5	42	10	4.0	35	63	2.4
031N004W12M01M	79-10-02	184	6.8	20.5	62	10	9.0	12	29	.7
031N004W13H01M	79-10-02	244	7.4	22.5	74	15	9.0	24	41	1.2
031N004W15G02M	79-10-03	203	7.1	20.5	74	10	12	15	30	.8
031N004W16E01M	79-10-10	385	6.6	18.5	170	24	27	12	13	.4
031N004W20Q01M	79-10-10	165	6.3	17.0	66	13	8.0	9.0	23	.5
031N004W22D01M	79-10-03	202	7.1	20.5	80	12	12	12	25	.6
031N004W35R01M	79-10-16	97	7.3	20.5	29	5.0	4.0	8.0	37	.6
031N005W25M04M	79-10-10	135	7.7	18.5	5	2.0	.0	30	92	5.8
031N005W28L01M	79-10-10	196	6.6	17.5	50	12	5.0	14	37	.9
032N003W24G01M	79-10-02	327	7.1	19.5	88	17	11	40	49	1.9
032N003W30P01M	79-10-02	211	7.7	22.5	67	12	9.0	20	38	1.1
032N004W13A02M	79-10-10	263	6.8	19.5	29	5.0	4.0	55	80	4.4
032N004W21C02M	79-10-03	659	8.2	21.0	5	2.0	.0	150	98	29
032N004W31J01M	79-10-10	236	7.0	18.5	110	14	17	8.0	14	.3
032N004W33C01M	79-10-03	246	7.2	21.0	98	16	14	20	31	.9
032N004W36K01M	79-10-02	214	6.8	21.0	75	12	11	17	32	.9
032N005W01G01M	79-10-09	266	7.3	17.5	110	34	6.0	12	19	.5
032N005W22G01M	79-10-09	318	7.7	22.0	140	23	20	14	18	.5
032N005W22M01M	79-10-09	423	7.5	20.5	190	64	8.0	16	15	.5
033N003W25H01M	79-10-02	416	7.0	21.0	210	69	8.0	6.0	6	.2
033N004W29K01M	79-10-09	193	7.1	19.5	76	19	7.0	10	22	.5
033N005W21E01M	79-10-09	514	8.7	19.0	250	55	28	14	11	.4

TABLE 6.--Ground-water quality data--Continued

STATE WELL NUMBER	DATE OF SAMPLE	POTASSIUM, DISSOLVED (MG/L AS K)	ALKALINITY (MG/L AS CACO3)	SULFATE DISSOLVED (MG/L AS SO4)	CHLORIDE, DISSOLVED (MG/L AS CL)	FLUORIDE, DISSOLVED (MG/L AS F)	SILICA, DISSOLVED (MG/L AS SIO2)	SOLIDS, RESIDUE AT 180 DEG. C DISSOLVED (MG/L)	NITROGEN, NITRATE DISSOLVED (MG/L AS N)	ARSENIC DISSOLVED (UG/L AS AS)
031N003W22B01M	79-10-01	2.0	51	1.0	2.0	.2	80	153	1.4	1
031N003W29G01M	79-10-01	2.5	120	6.0	6.0	.0	86	224	.70	--
031N003W31R01M	79-10-17	1.4	74	5.0	3.0	.1	67	185	2.2	--
031N004W01H01M	79-10-02	1.3	67	.0	3.0	.2	86	167	.20	1
031N004W04H01M	79-10-03	.8	110	3.0	9.0	.1	27	159	.00	--
031N004W06M04M	79-10-10	1.1	76	1.0	3.0	.1	31	125	.50	2
031N004W10F01M	79-10-03	.5	76	1.0	9.0	.2	54	151	1.1	--
031N004W12L01M	79-10-02	1.9	100	1.0	6.0	.2	52	178	.00	5
031N004W12M01M	79-10-02	.9	73	4.0	5.0	.2	62	150	.79	--
031N004W13H01M	79-10-02	1.7	100	2.0	19	.1	50	168	.00	--
031N004W15G02M	79-10-03	.5	83	1.0	6.0	.2	54	163	3.6	--
031N004W16E01M	79-10-10	.6	110	6.0	42	.0	48	246	5.2	--
031N004W20G01M	79-10-10	.4	64	6.0	6.0	.0	31	121	1.2	--
031N004W22D01M	79-10-03	.6	78	5.0	6.0	.1	43	150	3.4	1
031N004W35H01M	79-10-16	.8	36	4.0	1.0	.1	51	120	2.3	--
031N005W25M04M	79-10-10	.4	66	.0	4.0	.2	31	110	.00	1
031N005W28L01M	79-10-10	1.9	69	4.0	6.0	.0	60	142	.00	--
032N003W24G01M	79-10-02	2.4	150	1.0	19	.1	83	258	.09	--
032N003W30P01M	79-10-02	2.4	110	3.0	2.0	.1	64	171	.09	--
032N004W13A02M	79-10-10	.6	140	.0	5.0	.1	76	227	1.2	--
032N004W21C02M	79-10-03	1.3	130	.0	140	.2	40	424	.00	48
032N004W31J01M	79-10-10	.5	89	23	7.0	.0	34	160	.09	--
032N004W33C01M	79-10-03	.6	130	2.0	4.0	.2	48	173	.20	--
032N004W36K01M	79-10-02	2.3	100	1.0	3.0	.1	90	195	.50	--
032N005W01G01M	79-10-09	.3	110	18	4.0	.1	18	166	.00	--
032N005W22G01M	79-10-09	.4	140	19	8.0	.2	57	221	.00	--
032N005W22M01M	79-10-09	.3	180	45	2.0	.1	29	277	.00	--
033N003W25H01M	79-10-02	.4	120	90	2.0	.3	34	302	.00	--
033N004W29K01M	79-10-09	.1	79	8.0	7.0	.1	23	125	.20	--
033N005W21E01M	79-10-09	.4	110	170	.0	.1	24	376	.59	--

TABLE 6.--Ground-water quality data--Continued

STATE WELL NUMBER	DATE OF SAMPLE	BARIUM, DIS-SOLVED (UG/L AS BA)	BORON, DIS-SOLVED (UG/L AS B)	CADMIUM DIS-SOLVED (UG/L AS CD)	CHRO-MIUM, DIS-SOLVED (UG/L AS CR)	COPPER, DIS-SOLVED (UG/L AS CU)	IRON, DIS-SOLVED (UG/L AS FE)	LEAD, DIS-SOLVED (UG/L AS PB)	MANGA-NESE, DIS-SOLVED (UG/L AS MN)
031N003W22B01M	79-10-01	20	0	<1	10	5	<10	0	<1
031N003W29G01M	79-10-01	--	0	--	--	--	--	--	--
031N003W31R01M	79-10-17	--	0	--	--	--	--	--	--
031N004W01H01M	79-10-02	40	0	<1	10	2	10	0	10
031N004W04H01M	79-10-03	--	--	--	--	--	--	--	--
031N004W06M04M	79-10-10	60	0	<1	0	0	<10	2	20
031N004W10F01M	79-10-03	--	0	--	--	--	--	--	--
031N004W12L01M	79-10-02	40	400	<1	0	1	<10	0	--
031N004W12M01M	79-10-02	--	0	--	--	--	--	--	--
031N004W13H01M	79-10-02	--	200	--	--	--	--	--	--
031N004W15G02M	79-10-03	--	0	--	--	--	--	--	--
031N004W16E01M	79-10-10	--	0	--	--	--	--	--	--
031N004W20Q01M	79-10-10	--	100	--	--	--	--	--	--
031N004W22D01M	79-10-03	30	0	<1	10	1	<10	0	1
031N004W35R01M	79-10-16	--	0	--	--	--	--	--	--
031N005W25M04M	79-10-10	10	200	<1	0	2	20	0	50
031N005W28L01M	79-10-10	--	0	--	--	--	--	--	--
032N003W24Q01M	79-10-02	--	100	--	--	--	--	--	--
032N003W30P01M	79-10-02	--	0	--	--	--	--	--	--
032N004W13A02M	79-10-10	--	200	--	--	--	--	--	--
032N004W21C02M	79-10-03	40	2700	<1	0	1	40	0	10
032N004W31J01M	79-10-10	--	0	--	--	--	--	--	--
032N004W33C01M	79-10-03	--	0	--	--	--	--	--	--
032N004W36K01M	79-10-02	--	0	--	--	--	--	--	--
032N005W01G01M	79-10-09	--	200	--	--	--	--	--	--
032N005W22G01M	79-10-09	--	0	--	--	--	--	--	--
032N005W22M01M	79-10-09	--	0	--	--	--	--	--	--
033N003W25H01M	79-10-02	--	0	--	--	--	--	--	--
033N004W29K01M	79-10-09	--	100	--	--	--	--	--	--
033N005W21E01M	79-10-09	--	0	--	--	--	--	--	--

TABLE 6.--Ground-water quality data--Continued

STATE WELL NUMBER	DATE OF SAMPLE	MERCURY DIS-SOLVED (UG/L AS HG)	SELE-NIUM, DIS-SOLVED (UG/L AS SE)	SILVER, DIS-SOLVED (UG/L AS AG)	ZINC, DIS-SOLVED (UG/L AS ZN)
031N003W22B01M	79-10-01	.0	0	0	80
031N003W29G01M	79-10-01	--	--	--	--
031N003W31R01M	79-10-17	--	--	--	--
031N004W01H01M	79-10-02	.0	0	0	2400
031N004W04H01M	79-10-03	--	--	--	--
031N004W06M04M	79-10-10	.0	0	0	40
031N004W10F01M	79-10-03	--	--	--	--
031N004W12L01M	79-10-02	.0	0	0	70
031N004W12M01M	79-10-02	--	--	--	--
031N004W13H01M	79-10-02	--	--	--	--
031N004W15G02M	79-10-03	--	--	--	--
031N004W16E01M	79-10-10	--	--	--	--
031N004W20Q01M	79-10-10	--	--	--	--
031N004W22D01M	79-10-03	.0	0	0	320
031N004W35R01M	79-10-16	--	--	--	--
031N005W25M04M	79-10-10	.0	0	0	5
031N005W28L01M	79-10-10	--	--	--	--
032N003W24Q01M	79-10-02	--	--	--	--
032N003W30P01M	79-10-02	--	--	--	--
032N004W13A02M	79-10-10	--	--	--	--
032N004W21C02M	79-10-03	.0	0	0	<3
032N004W31J01M	79-10-10	--	--	--	--
032N004W33C01M	79-10-03	--	--	--	--
032N004W36K01M	79-10-02	--	--	--	--
032N005W01G01M	79-10-09	--	--	--	--
032N005W22G01M	79-10-09	--	--	--	--
032N005W22M01M	79-10-09	--	--	--	--
033N003W25H01M	79-10-02	--	--	--	--
033N004W29K01M	79-10-09	--	--	--	--
033N005W21E01M	79-10-09	--	--	--	--

The general quality of ground water in the Redding Basin is considered good to excellent (dissolved solids between 95 to 424 mg/L) for most uses (table 6), except for that water from shallow depths along the margins of the basin where pre-Tertiary formations may be tapped. Some wells in those areas yield water with constituents that are above the recommended limits for drinking (table 7). This water probably is derived from the Chico Formation.

Hardness may be objectionable to some consumers, especially when the hardness as $CaCO_3$ is above 180 mg/L. Increased use of soap products, incrustation in water pipes, and scum or scaling left on clothing or utensils are associated with increased hardness. Eighty-six percent of the water analyzed is classified as moderately hard or soft (table 8).

TABLE 7.--Summary of chemical constituents subject to drinking water standards

Constituent	Concentrations			
	Range	Mean	Median	Recommended limits[1]
Arsenic (µg/L)	1-48	4.2	1	50
Barium (µg/L)	10-100	37	30	1,000
Cadmium (µg/L)	1-2	1.1	1	10
Chromium (µg/L)	0-10	1.8	0	50
Lead (µg/L)	0-2	0.29	0	50
Mercury (µg/L)	0-0.1	0.005	0	2
Nitrate (as N)(mg/L)	0-10	0.97	0.59	[2]10
Selenium (µg/L)	0-1	0.06	0	10
Silver (µg/L)	0	0	0	50
Fluoride (mg/L)	0-0.3	0.1	0.1	1.6 (at 24.4°C)
Copper (µg/L)	0-14	2.6	1	1,000
Iron (µg/L)	10-40	13	10	300
Manganese (µg/L)	1-50	8	3	50
Dissolved solids (mg/L)	95-424	178	166	500
Chloride (mg/L)	0-140	7.4	3	250
Sulfate (mg/L)	0-170	8.2	3	250

[1]California Department of Health, 1977, Domestic Water Quality and Monitoring Regulations.

[2]Nitrate (as NO_3) is converted to nitrate (as N) by using the formula: Nitrate (NO_3) x (0.2259) = nitrate (N).

TABLE 8.--Hardness classes among wells sampled in the Redding Basin

[Modified from Hem, 1970]

Hardness range, in milligrams per liter	Classification	Distribution, in percent
<60	Soft	31.8
60-120	Moderately hard	54.1
121-180	Hard	8.2
>180	Very hard	5.9

The general chemical character of water is determined by the relative concentration of major ions in terms of their chemical milliequivalents per liter. The name of a water type is classified as in the following examples: a "sodium bicarbonate" type water designates water in which sodium amounts to 50 percent or more of the cations and bicarbonate to 50 percent or more of the anions, in chemical milliequivalents. In the case where neither cations nor anions amounts to 50 percent or more, hyphenated water types can be used. A "magnesium-calcium bicarbonate" type water designates water in which the magnesium and calcium are first and second, respectively, in order of abundance among the cations but neither amounts to 50 percent of the cations; "calcium sulfate-bicarbonate" designates water in which the sulfate and bicarbonate are first and second, respectively, in order of abundance among the anions but neither amounts to 50 percent of the anions (Piper and others, 1953).

The ground water pumped in the study area is generally of magnesium-calcium bicarbonate type (table 6).

There has been no significant change in water quality in the Redding Basin since earlier studies (California Department of Water Resources, 1968). However, there is a potential to induce the saline water in the Chico Formation to move upward if pumpage from the Tuscan and Tehama Formations is increased significantly.

SUMMARY

Ground water in the Redding Basin is obtained principally from wells tapping the continental deposits of Quaternary and (or) Tertiary age, which include alluvium, terrace deposits, Red Bluff Formation, Tehama and Tuscan Formations, and Nomlaki Tuff Member of the Tehama and Tuscan Formations. The formations are arranged in a synclinal structure that trends and plunges southward towards the Red Bluff Arch, which separates the Redding and Sacramento ground-water basins.

The Chico Formation contains saline water which is under artesian pressure in some places. Fresh water occurs in formations deposited on the Chico Formation. The Nomlaki Tuff Member is a poor source of ground water because of its low permeability and its content of saline water derived from the underlying Chico. The Tehama and Tuscan Formations are the principal water-bearing units in the Redding Basin. The Red Bluff Formation, terrace deposits, and generally the alluvium yields are only small to moderate at a sufficient rate for domestic water needs.

Recharge of the Redding ground-water basin is from subsurface inflow, infiltration of precipitation and applied irrigation water, and percolation of certain reaches of streams and creeks. Ground-water movement generally follows the topographic gradients toward the Sacramento River and then in a general south-southeast direction. At the Red Bluff Arch, the Redding ground-water basin is probably losing to the Sacramento River.

Hydrographs show only a slight water-level decline for the period 1956 to 1970 and virtually no change for the period 1970 to 1979.

The principal use of ground water in the Redding Basin is for irrigation. Estimated ground-water pumpage for irrigation for 1969 is 42,100 acre-ft and for 1976 is 45,000 acre-ft. Estimated storage capacity of the Redding ground-water basin is about 5.5 million acre-ft.

Ground-water supplies from the continental deposits of Quaternary and (or) Tertiary age in the Redding Basin are rated good to excellent in quality (dissolved solids between 95 and 424 mg/L). The water is generally a magnesium-calcium bicarbonate type.

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