Ground-Water Outflow From Chino Basin, Upper Santa Ana Valley, Southern California

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1999-G

Prepared in cooperation with the San Bernardino County Flood Control District

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By J. J. FRENCH

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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GROUND-WATER OUTFLOW FROM CHINO BASIN, UPPER SANTA ANA VALLEY, SOUTHERN CALIFORNIA

By J. J. French

ABSTRACT

Ground-water outflow from Chino basin was calculated by a direct method using the equation $Q = PIA$, in which Q is the quantity of ground-water outflow, P is the average coefficient of permeability of the sediments through which the flow occurs, I is the average hydraulic gradient, and A is the cross-sectional area of the sediments through which the flow occurs. The period selected for the calculation was 1930–66.

Permeability of the water-bearing sediments was calculated from aquifer-test data and from computations involving specific-capacity data from 200 wells in the outflow area. Permeability ranged from less than 100 to more than 5,000 gallons per day per square foot.

The annual hydraulic gradient was derived from contour maps of average water levels in wells for each water year for the period 1930–66.

The cross-sectional area used to calculate ground-water outflow from Chino basin extends southwestward from Pedley Hills to Puente Hills. The area of the outflow section is the saturated thickness of permeable materials measured along the line of section. Part of the lower boundary is the interface between the alluvium and the underlying basement complex, and part is a change in permeability within sedimentary rocks. Geological methods were combined with geophysical methods to determine the cross-sectional area of the water-bearing sediments. Gravity and seismic traverses, drill-hole logs, and data from more than 600 drill holes, including eight test holes drilled as a part of this investigation, were used to delineate the size and the shape of the outflow area. For the period of calculation, 1930–66, the total area of the outflow section varied from about 16 to 22 million square feet. The fluctuation in total area is caused by changes in the altitude of the water table.

Annual ground-water outflow from Chino basin calculated by the direct method for the period 1930–66 ranged from 38,000 acre-feet in the 1941 water year to 9,400 acre-feet in the 1966 water year.

Two indirect methods of calculating ground-water outflow were studied as a part of this project: the chemical method and the water-budget method. The chemical method was found to be unsatisfactory. Although the ground-water discharge into the Santa Ana River from Chino basin is quite different in chemical composition from the discharge from Temescal basin, there is no known way to quantitatively separate the total discharge with respect to source. In the water-budget method direct runoff and evapotranspiration were reevaluated, and the ground-water outflow from Temescal basin was calculated by the same direct method employed for Chino basin. Annual ground-water outflow from Temescal basin calculated by the direct method for the period 1930–66 ranged from 11,000 acre-feet in the 1940 and 1945 water years to 3,000 acre-feet in the 1965 water year. Annual ground-water outflow from Chino basin computed by the water-budget method for the period 1933–63 ranged from 45,000 acre-feet in the 1941 water year to 10,000 acre-feet in the 1963 water year.

PURPOSE AND SCOPE

In 1963 the San Bernardino County Flood Control District, in behalf of its constituent agencies, requested the U.S. Geological Survey to make a new estimate of annual ground-water outflow from Chino basin (fig. 1) into the Santa Ana River between Riverside Narrows and Prado Dam (pl. 1).

Previous estimates of outflow were derived indirectly by water-budget methods. Gleason (1947) estimated outflow as the difference between the estimated values for recharge from all sources and the estimated values of discharge from all sources. Garrett and Thomasson (1949) calculated outflow from Chino basin as the difference between total inflow to the valley floor and the estimated outflow from Temescal basin. Garrett and Thomasson (1949, p. 46–48) also described a chemical method for determining outflow, but they concluded that the method was unsatisfactory.

Using the indirect method of Garrett and Thomasson, with some revision, outflow calculations were extended through 1962 by the Engineering Coordinating Committee of the Water Defense Office. This organization is composed of rêpresentatives of agencies involved in common in litigation of water rights in the Santa Ana River drainage basin.

For this report a direct method was used by the Geological Survey to calculate the basin outflow. The base period originally selected was 1930–60; it was later extended to 1966.

Eight test holes were drilled to obtain data on water levels, lithology, and water-bearing properties of the sediments along and adjacent to the outflow sections. Gravity and seismic traverses were made to determine the geologic structure beneath the alluvial cover.

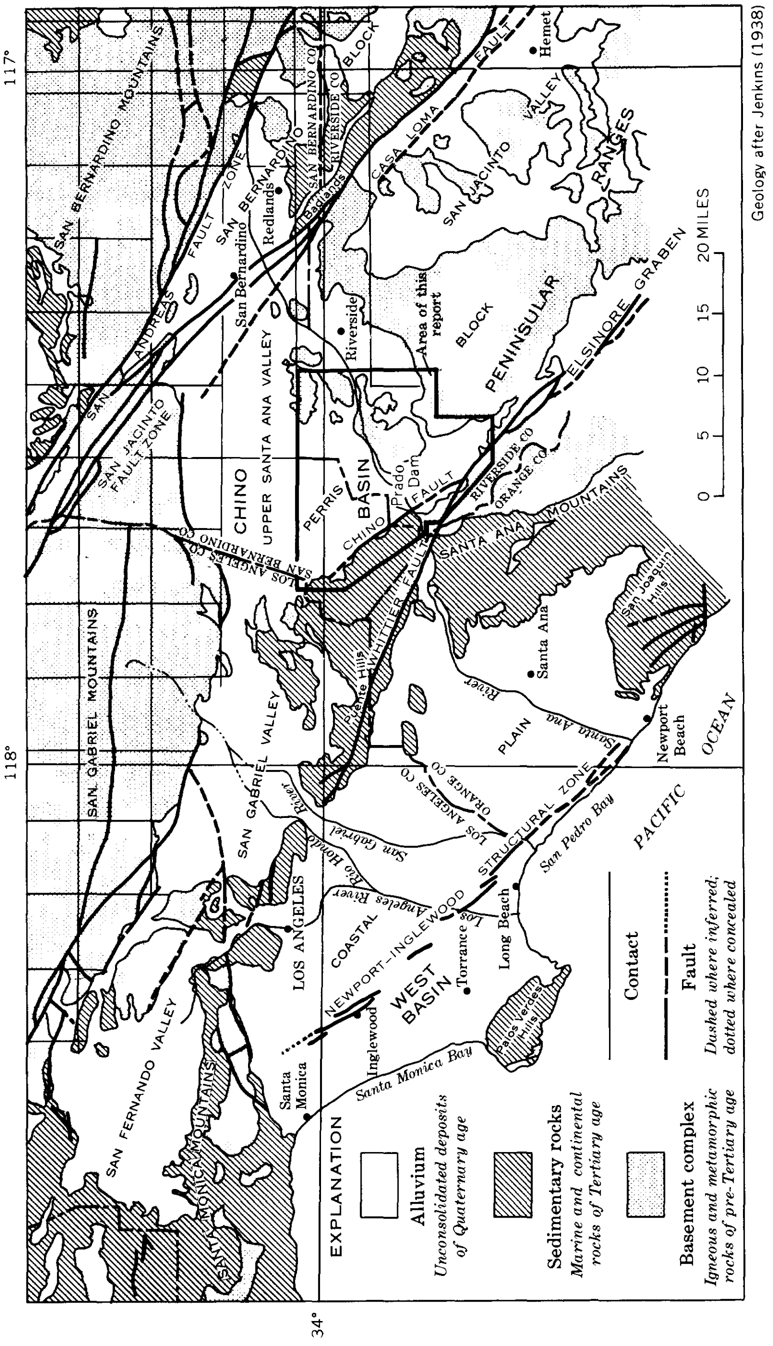

FIGURE 1.—Generalized geologic map of part of the south coastal basin, southern California.

To compare the results of the outflow calculations with the results of the indirect methods used by Garrett and Thomasson (1949) certain parameters were reestimated by using a longer base period and others by different techniques. The principal elements reevaluated were base flow in the Santa Ana River between Riverside Narrows and Prado Dam, evapotranspiration from the flood plain along the same reach, and ground-water outflow from Temescal basin. The use of the chemical method was also reevaluated.

In both the direct method and the water-budget method, the water year was used as a time increment. A water year is the 12-month period ending September 30 each year; it is designated by the calendar year in which it ends.

This report was prepared in cooperation with the San Bernardino County Flood Control District as one of a series of investigations of the water resources of the upper Santa Ana Valley.

Mr. E. R. Hedman, research hydrologist, U.S. Geological Survey, computed the water budget, and Mr. D. M. Stewart, hydrologist, U.S. Geological Survey, did much of the chemical evaluation. The gravity traverses were made by Dr. S. W. Dana, professor of geology and geophysics, University of Redlands, Redlands, Calif.

CHINO BASIN

Chino basin is in the upper Santa Ana Valley in southern California (fig. 1). This report mainly concerns the southern part of Chino basin south of the latitude of the Jurupa Mountains but also includes parts of Temescal and Arlington basins (pl. 1). The investigation area covers nearly 200 square miles, about half in San Bernardino County and half in Riverside County.

The surface of Chino basin is a broad smooth plain that slopes from the San Gabriel Mountains on the north to the Santa Ana River on the south. In the study area the plain is bounded by the Puente Hills on the west and by low hills on the east. The southeastern part of the plain is bounded by the Santa Ana River.

Temescal basin, which is south of the Santa Ana River, is bounded by the foothills of the Peninsular Ranges to the southeast and by the Santa Ana Mountains to the southwest. Arlington basin, which is also south of the river, is nearly surrounded by bedrock foothills of the Peninsular Ranges.

The alluvium and the sedimentary rocks in Chino basin overlie a basement complex of pre-Tertiary age composed of granodiorite and associated plutonic rocks of the southern California batholith (Larsen, 1948). The buried surface of the basement complex is irregular (pl. 1, geologic sections) and probably represents the extension of the foothills of the Peninsular Ranges. On the east side of Chino basin, the basement complex is exposed almost continuously from the Jurupa Mountains to the Santa Ana River, but immediately to the west, it is overlain by alluvial debris as much as 400 feet thick. West of Sumner Avenue, the surface of the basement complex is depressed sharply to more than 5,000 feet below sea level (Durham and Yerkes, 1964, p. 35).

The basement complex does not transmit water except for small quantities in cracks and fissures or where the rock is deeply weathered. For the purpose of this investigation, it is considered impermeable to water.

A sequence of consolidated marine and continental conglomerate, sandstone, and siltstone beds overlies the basement complex in the southern and western parts of the area. Those sedimentary rocks range in age from Paleocene to late Miocene and possibly Pliocene. The sequence is nearly 5,000 feet thick in the western part of the area (Durham and Yerkes, 1964, p. 35) but thins abruptly to zero eastward (pl. 1).

The sedimentary rocks for the most part do not contain or transmit fresh water. Some of the poorly consolidated conglomerate and sandstone in the upper part of the sequence may transmit fresh water, but if they do, they are indistinguishable from the overlying alluvium and are included with the alluvium in the outflow study.

Overlying both the sedimentary rocks and the basement complex is a sequence of poorly sorted gravel, sand, silt, and clay that contain and transmit the principal body of fresh water. In this report the sequence is called alluvium, although it is made up of lake, terrace, flood-plain, and alluvial-fan sediments. The sequence ranges in age from Pleistocene to Holocene, although in the lower part it probably includes, as just noted, some poorly consolidated sedimentary rocks of Tertiary age.

Water enters the basin by infiltration of surface-water runoff from the highlands, by deep penetration of rain on the valley floor, and by artificial means such as irrigation return or induced recharge. Ground water moves generally in alluvium south from the mountains and west from adjacent basins through Chino basin (fig. 2); it rises to the surface along the Santa Ana River between Riverside Narrows and Prado Dam. Subsurface flow past Prado Dam has been stopped by means of a sheet-steel wall driven to the base of the water-bearing sediments. All surface outflow at Prado Dam is gaged.

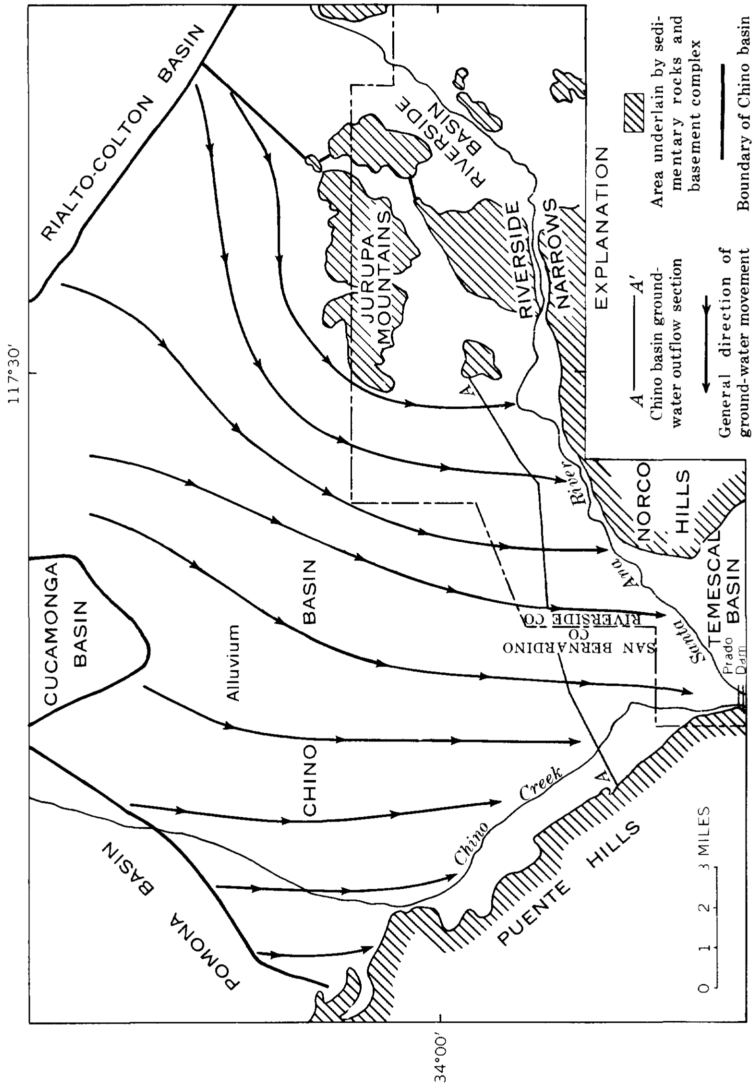

Figure 2.—General direction of ground-water movement.

DIRECT METHOD OF OUTFLOW CALCULATION

The quantity of ground water that flows through water-bearing sediments can be calculated by a modification of Darcy's equation of flow,

$$Q = PIA,$$

in which

Q is the volume rate of ground-water outflow,
P is the permeability of the water-bearing sediments through which the flow occurs,
I is the hydraulic gradient or slope of the water table, and
A is the cross-sectional area of the saturated water-bearing sediments through which the flow occurs.

In Chino basin, ground-water outflow, Q, includes water from the zone of saturation that (1) appears at land surface as effluent seepage, (2) is evaporated, or (3) is consumed by native vegetation (Garrett and Thomasson, 1949, p. 40). These processes occur in the lowland area along the Santa Ana River between Riverside Narrows and Prado Dam.

PERMEABILITY

The permeability is calculated from aquifer-test data and from computations involving the specific capacity, depth, perforation interval, and water-level history of wells in the outflow area.

Specific capacity is the ratio of the yield of a well to the drawdown. (Drawdown is the difference between the pumping water level and the static water level.) The ratio is dependent on the construction and the development of the well and on the hydraulic properties of the aquifer. A poorly constructed or poorly developed well will not take in water as fast as the aquifer is capable of yielding it without additional loss of head. As a result of this entrance loss, as the water passes from the aquifer through the perforations into the well, the water level immediately outside a poorly constructed or poorly developed well may be several feet higher than the pumping level inside the well. The specific capacity computed on the basis of the drawdown within such a well will be considerably lower than in a well with small entrance loss. Conversely, a properly constructed and properly developed well will take in water about as fast as the aquifer will yield it without an additional loss of head. Therefore, the specific capacity of a properly constructed and developed well is very nearly a measure of the water-yielding properties of the aquifer.

When the water level in a well is drawn down below the water level in the aquifer, the pressure gradient developed drives water into the well. As the gradient increases in response to lowering the water level in the well, water drains into the well at a faster rate. As pumping continues at a uniform rate from an extensive aquifer, the rate of decline of the water level within the well diminishes until it virtually stabilizes (assuming that the aquifer boundaries are not intercepted by the drawdown cone). At this point in time, the water level in the well will continue to decline but at a very slow rate. The time required for drawdown to virtually stabilize may vary from a few minutes to more than a day.

Specific capacity is expressed in gallons per minute per foot of drawdown. The specific capacity of a well may vary somewhat depending on the well's efficiency, the rate of pumping, and the length of time pumped; it is a useful number if calculated after stabilization of the pumping water level.

The specific capacity of any well cannot be an exact criterion of the water-yielding properties of the aquifer because of the many other factors which affect the well production per foot of drawdown. The depth of penetration into the aquifer, the diameter of the well, the type, number, and condition of the perforations, the gravel pack, and the state of development of the well could be the major factors influencing the drawdown and, consequently, the specific capacity. However, even a rough approximation of the water-yielding properties of an aquifer is useful. If there are many such approximations in an area and these approximations can be related to more elaborate determinations of these properties, then the approximations can be used with a fair degree of confidence.

In Chino basin more than 300 specific-capacity values were computed from data on more than 200 wells. Most of the data were reported by owners or by well drillers. Values ranged from less than 1 gpm per ft (gallons per minute per foot) of drawdown to more than 300 gpm per ft.

To minimize the effect of differences in well construction and development, all specific-capacity values were compared with drillers' logs of the wells, if they were available. If a log indicated the specific capacity of a well was probably too low compared with wells of similar construction and lithology, then the specific-capacity value was not used. If a single well did not have a log available but had an unusually low specific capacity compared with other wells in the immediate area, the low value was not used. To minimize the effect of deterioration of a well, only the highest value computed for each well was used.

About half the original specific-capacity values were discarded by these processes. The more than 150 retained are considered to be reasonably representative of the water-yielding properties of the aquifer.

Thiem (1906) published an equation that determined permeability on the basis of the flow of water into a discharging well. The Thiem equation required measurements of water level in observation wells. Wenzel (1942, p. 81) modified this equation by expressing it in terms commonly used in the United States. Theis, Brown, and Meyer (1963, p. 331–340) further modified the equation to apply only to the pumped well. In analyzing aquifer tests, they found an empirical relation between specific capacity and transmissibility—that an approximate value of transmissibility of the water-bearing sediments can be obtained by multiplying the average specific-capacity values for wells distributed over an area by a factor.

Transmissibility data from 13 aquifer tests in the upper Santa Ana Valley (McClelland, 1964) indicate an average factor of 2,300, but individual factors ranged from 1,140 to 3,300. In the Chino basin project area the transmissibility data from four aquifer tests compared with selected specific-capacity tests gave a factor of 1,950. Thus, in the outflow section the average transmissibility was estimated by multiplying the specific capacity by a factor of 2,000. On the basis of this factor the areal pattern of average transmissibility of the water-bearing sediments in the project area is that shown in figure 3.

Similarly, an approximate value of permeability was obtained from specific capacity by a method devised by Poland (1959, p. 32) and implemented by others (Back, 1957, p. 16; Thomasson and others, 1960, p. 60–61, 207–208; Olmstead and Davis, 1961, p. 139; Wood and Dale, 1964, p. 48, 53–54). Poland introduced the term "yield factor" as an approximate relative measure of the permeability of the water-bearing material tapped by a well. He described the yield factor as the specific capacity, divided by the thickness of the saturated material. To eliminate decimal fractions, the quotient is multiplied by 100. For this report saturated thickness is the depth of the well below static water level.

Most of the wells used in the computations are perforated throughout most or all of their length and are gravel packed. Therefore the yield factor computed by using the depth of the well below the static water level affords a comparative measure of the average permeability of all the saturated material penetrated by wells. Doubtless some wells obtain water from permeable sediments above and below the perforated intervals.

If it is assumed that the average coefficient of transmissibility is 2,000 times the specific capacity, then the permeability is 20 times the yield factor, since

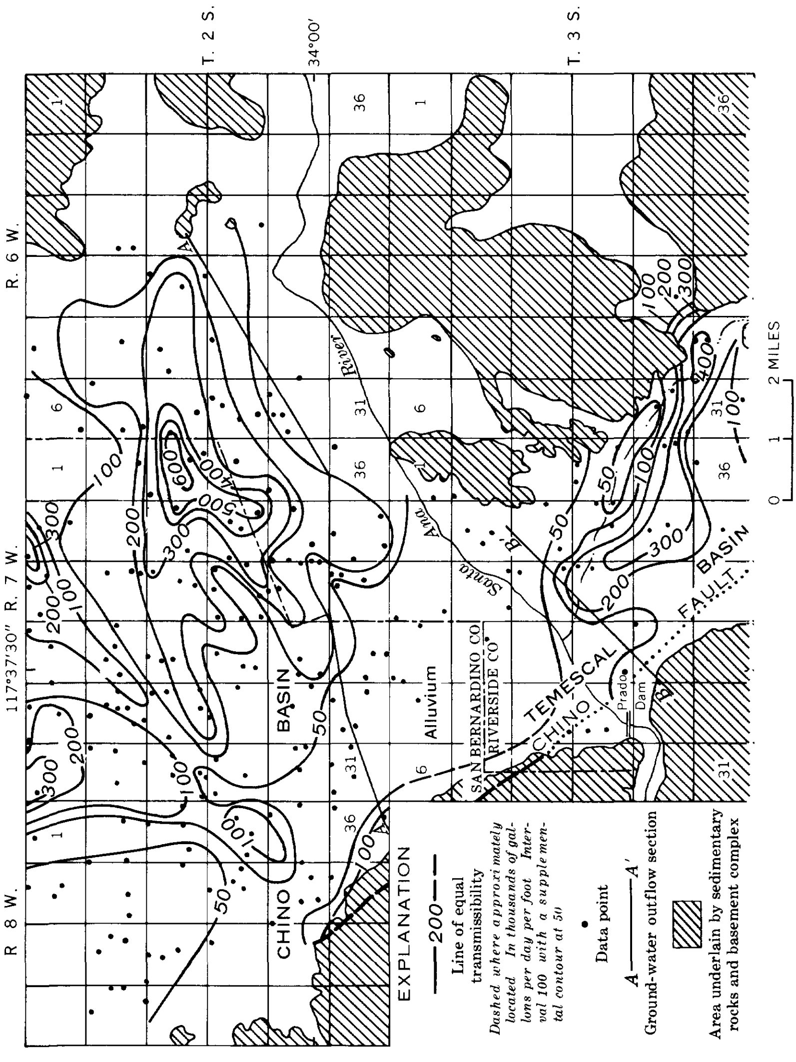

FIGURE 3.—Aquifer transmissibility.

$$P = \frac{T}{m}$$

and

$$T = 2{,}000s$$

then

$$P = \frac{2{,}000s}{m}$$

or

$$P = 20\left(\frac{s}{m} \times 100\right) = 20y$$

in which

P is the permeability (gallons per day per square foot),
T is the transmissibility (gallons per day per foot),
m is the saturated thickness (feet),
s is the specific capacity (gallons per minute per foot of drawdown), and
y is the yield factor (gallons per minute per foot of drawdown per foot of saturated thickness).

The average permeability of the water-bearing sediments in the report area, computed as 20 times the yield factor, ranged from less than 100 gpd per ft^2 (gallons per day per square foot) to more than 5,000 gpd per ft^2 (fig. 4). To account for the general increase in fine-grained sediments with depth, as indicated by drillers' logs, the lower parts of some of the segments of the outflow section were assigned permeability values somewhat lower than the indicated average.

WATER-LEVEL GRADIENT

The water-level or hydraulic gradient is calculated from hydrographs and historical records of water levels in many wells throughout the area. Because the water-level gradient varies both in time and in space, any solution of the equation $Q = PIA$ would be valid for only one point in time. Therefore, the long-term approximation of the equation would have to reflect the average water-level gradient during a selected time period. The time period selected for this report is a water year.

To derive the average water level for each water year for the period 1930–66, water-level hydrographs (not shown) were drawn for all wells along or near the outflow section for which data were available for 10 or more years. In all, 26 hydrographs were drawn. From the hydrographs the average water level for each month was obtained, and those averages were averaged for each water year. Where enough data were available, supplemental water levels from other wells were used to augment the yearly averages.

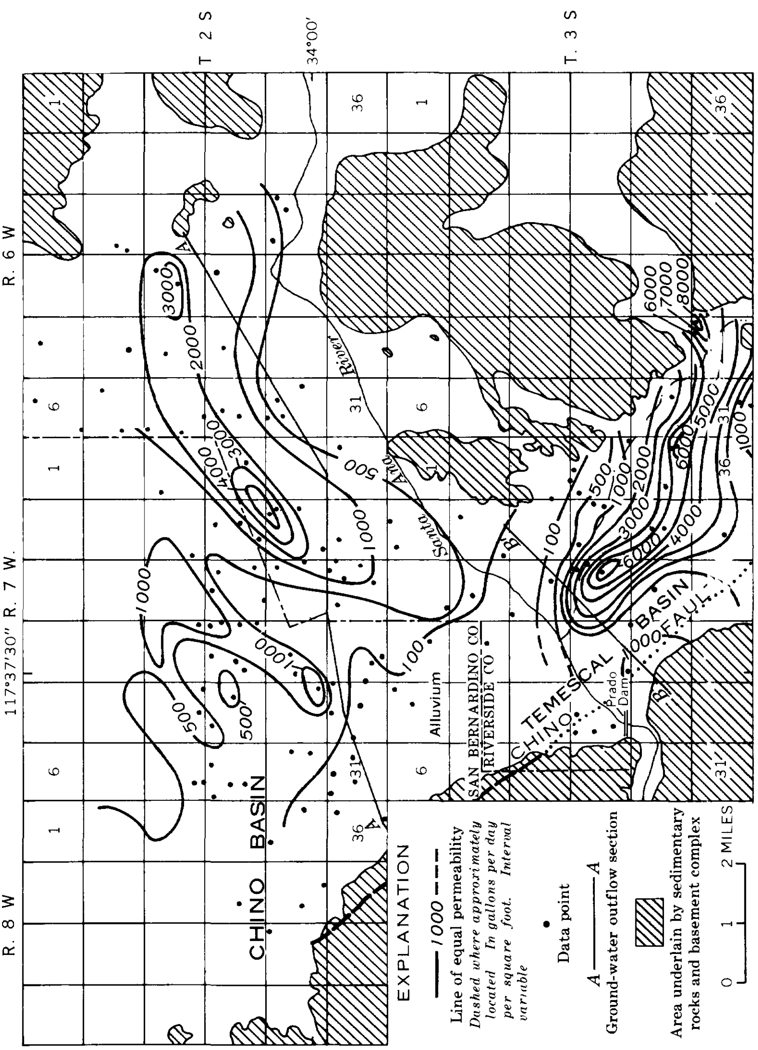

FIGURE 4.—Aquifer permeability.

The annual average water levels were plotted on maps (not shown), and water-level contours were drawn. From the maps, annual average water-level gradients were obtained for each segment of the outflow section. The process of determining an average water level yields only an approximate result; therefore, the equation $Q = PIA$, which uses a gradient derived from the average water levels, is itself an approximation, not a solution. In the triangular-shaped subsegments (pl. 1), water-level gradients were weighted toward the part of the subsegment that had the greatest vertical length. Where the contours intersected the ground-water outflow section at an angle (which they usually did), the gradient was multiplied by the cosine of the angle to obtain the gradient perpendicular to the outflow section.

In segments 2 and 3 the gradient was reversed during some years in the 1960's. That is, ground water was moving from south to north across the outflow section, then back across, north to south in segment 4. For those years no outflow actually came from Chino basin across those segments, and the resulting outflow calculations reflect this fact.

The water-level gradient is the most sensitive element of the outflow equation. For example, a 10-percent error in the average water-level gradient would mean a 3-feet-per-mile error when the average gradient is 30 feet per mile or a 2-feet-per-mile error when the average gradient is 20 feet per mile. Errors of this degree are possible; in fact, the sparsity of data for some years could introduce an even greater error in calculations. Also, the water-level gradient is the only element that varies significantly with time. The average permeability values, once determined, will not change appreciably from year to year. The cross-sectional area values, once determined, will vary only slightly with rise or fall of the water table. However, the water-level gradient changes continuously in both amount and direction.

CROSS-SECTIONAL AREA OF THE PERMEABLE DEPOSITS

The cross-sectional area is determined by geologic, geophysical, and hydrological studies. To account for the variations in permeability and in water-level gradient along the entire length, the outflow section was divided into nine segments (pl. 1), each fairly consistent within itself but unlike the adjacent segments. To account for variations in permeability at depth, most segments were further divided into an upper and lower part.

Cross-section A–A', along which ground-water outflow from Chino basin was calculated, extends southwestward from a western outlier of the Pedley Hills to Puente Hills (pl. 1). The area of the outflow section is the length along the line of section times the vertical distance between the water table and the lower limit of permeable materials. Because the upper boundary is the water table, the area of the outflow section varies as the water table rises or falls.

The lower limit of permeable sediments is irregular, but does not vary with time. East of Sumner Avenue (see pl. 1) most of the lower boundary is the interface between alluvium and the underlying basement complex. West of Sumner Avenue the boundary is a change in permeability within the sedimentary rocks.

The general shape of the basin is known from previous work (Eckis, 1934; Woodford and others, 1944; Garrett and Thomasson, 1949; and others) and from oil-well data. To calculate the groundwater outflow from Chino basin by the direct method, a more accurate determination of cross-sectional area is required. A combination of interrelated geological and geophysical methods was used.

Most of the information about the thickness and the character of the water-bearing sediments is known only from test holes and wells, for the area is covered by alluvium. Drillers' logs and electric logs from more than 600 drill holes within the area of investigation were studied. Along the outflow section, logs from 42 drill holes were used, including four of the eight test holes drilled as a part of this investigation.

The configuration of the basement surface east of Archibald Avenue is known from many holes drilled along the section and from many others drilled nearby. There the basement complex is overlain only by alluvium, and the surface of the basement complex is the base of the outflow section. Test hole 5, drilled as a part of this investigation, penetrated 185 feet of alluvium, 110 feet of poorly permeable decomposed granitic material, and entered basement complex at a depth of 295 feet.

West of Archibald Avenue the basement complex is reported in only a few deep oil wells. There the configuration of the basement surface is less important, because the base of the outflow section is defined as the bottom of the permeable deposits in the overlying sedimentary sequence.

Of all the water wells drilled along the outflow section between Archibald Avenue and Puente Hills, only a few exceed a depth of 400 feet. The deeper wells penetrate most of the water-bearing sediments. Test holes 2, 3, 4, and 6 (pl. 1) were drilled to determine if the sediments below those tapped by existing wells are water bearing. Test holes 2 and 4 were cased as observation wells. The logs of test holes 2, 3, and 4 and bailing tests on test holes 2 and 4 indicate low permeability below the 400-foot depth and very tight, or impermeable, sediments below about a 550-foot depth. Test holes 2 and 3 were drilled to 800- and 1,000-foot depths, respectively. Comparison of the logs of those holes with logs from nearby oil wells indicates no fresh-water-bearing sediments below those penetrated in the test holes.

Test hole 4 penetrated a tight blue sandy clay at 568 feet. This depth corresponds with a refracting horizon (discussed in a later paragraph) indicated by seismic survey. The character of the drill cuttings and the velocity of the refracted waves indicate that the top of the blue sandy clay is probably at the base of water-bearing sediments.

Test hole 6 drilled in Prado flood control basin about 3 miles south of the outflow section penetrated tight blue clay from 276 to 622 feet and a very hard, tight blue siltstone from 622 feet to the total depth of 942 feet. Comparison of the log of this test hole with logs of nearby deep oil-test wells indicates that fresh water probably is not transmitted from Chino basin through sediments below those penetrated by the test hole.

As reconstructed from drill-hole data, the base of the water-bearing sediments is a remarkably smooth surface sloping westward from an altitude of 40 feet above sea level in test hole 4 to about sea level in test hole 3 and to 30 feet below sea level in test hole 2. West of test hole 2, correlation of surface geology with oil-well logs shows that the base of water-bearing sediments rises sharply to intersect the water table along the base of the Puente Hills.

Correlation of lithologic units between test holes as far apart as test holes 2, 3, and 4 is tenuous unless supported by corroborating evidence. Part of the gap in data was filled by data from oil wells. Further corroboration was obtained by the geophysical methods of gravimetry and refraction and reflection seismic surveying. The determination of the structure of the underlying impermeable rocks by geophysical methods aided in delineating the base of the outflow section.

Gravimetry, the gravity method, measures differences in the attraction of gravity at the earth's surface caused by differences in density of the material beneath the surface. The differences in density may be used in conjunction with other data to indicate geologic structure. The general shape of the surface of the basement complex was determined by gravity measurements.

More than 500 gravity measurements were made at 1,000-foot intervals, or less, along straight traverses, using a Worden gravity meter (Model W–111). Supplemental measurements were made to complete the data for a gravity anomaly map (fig. 5). All measurements were corrected for meter drift, altitude, topography, and latitude.

The gravity data are consistent with the interpretation that a troughlike structure exists beneath the alluvial cover of the Chino

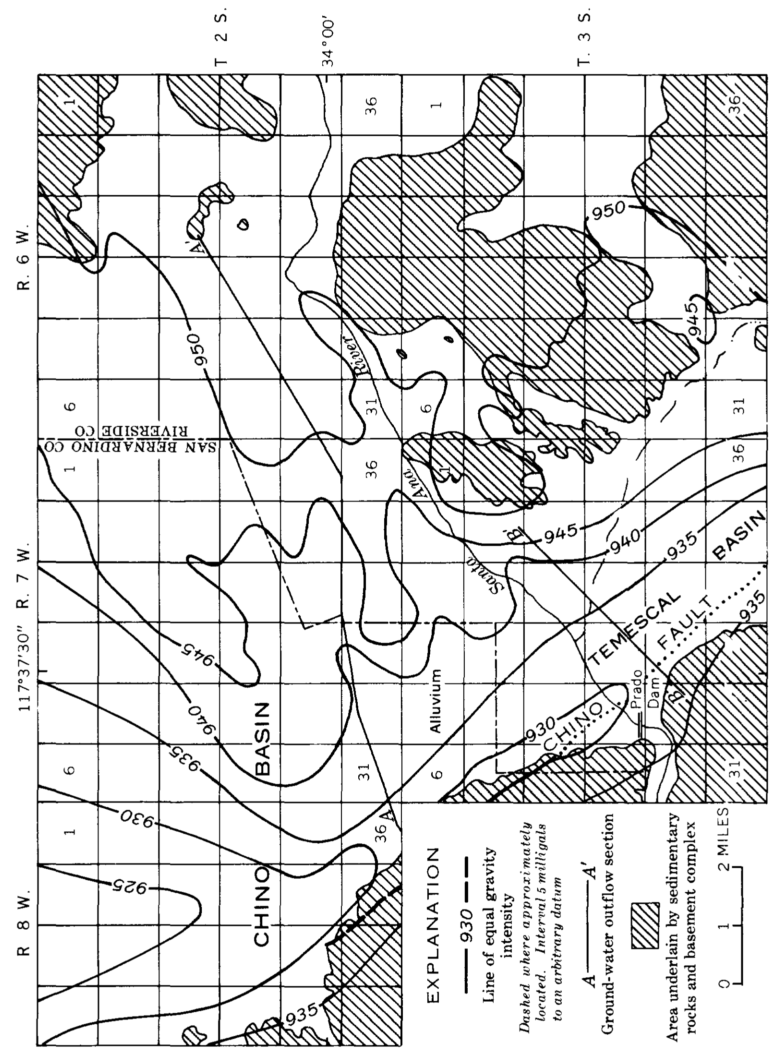

FIGURE 5.—Gravity intensity.

basin. The northwest trend of the minimum gravity values (925–935 milligals) indicates that the trough is deep, if one assumes that all the basement rocks are of the same density. Apparently this trough is an extension of the Elsinore graben (fig. 1). The steep gravity gradient on the northeast side of the trough suggests a major zone of faulting that is approximately parallel to the Chino fault. Plots of the gravity traverses (not shown) suggest that there are other faults throughout the basin. Although the gravity data indicate the general shape of the basin and suggest a fault pattern, they do not measure the actual depth to the basement complex or the amount of offset along faults.

The seismic method utilizes artificially generated elastic waves that are transmitted through the ground. The speed of transmission of the waves varies with the type of material and, in general, is a function of the degree of consolidation of the material. Heiland (1940, p. 468–472) reported velocity ranges of 1,900 to 6,400 fps (feet per second) in alluvium; 3,000 to 12,000 fps in conglomerate, sandstone, and shale; and 13,000 to 25,000 fps in igneous and metamorphic rocks.

Four seismic traverses were made adjacent to the outflow section (pl. 1). Traverse *A*, which coincides with the western two-thirds of the outflow section, shows the configuration of the basement complex westward from near Sumner Avenue to near Euclid Avenue. West of Euclid Avenue the basement complex is depressed along a series of faults to more than 2,000 feet below sea level. The basement surface was not detected on the western part of the traverse, probably because it is too deeply buried.

An intermediate refracting horizon (11,000–13,500 fps) detected from seismic station 435 to 470 correlates with a tight blue sandy clay penetrated in test hole 4. This horizon is interpreted as an unconformity overlying older sedimentary rocks, which are probably Tertiary in age; the horizon is projected eastward from test hole 4 to the basement complex as the base of the water-bearing sediments.

Except near the east end of seismic traverse *A* (stations 480–500), the seismic surveys did not indicate the depth of the base of the water-bearing sediments. Apparently the vertical change from permeable to impermeable sediments was either too gradual or too erratic for detection. All the reflecting or refracting horizons detected west of test hole 4 were below the base of the water-bearing sediments indicated by data from test holes and wells. The final determination of the base of the outflow section was made on the basis of bore-hole data.

In summary, the base of water-bearing sediments along the outflow section is the buried irregular surface of the basement complex in the east and a somewhat smooth regular interface within sedimentary rocks in the west. The depth of the base of the water-bearing sediments below land surface ranges from zero at both ends of the basin to as much as 600 feet near the western margin.

From Pedley Hills westward the outflow section thickens from zero to a maximum of about 300 feet in an asymmetrically shaped channel, thinning to less than 200 feet in sec. 30, T. 2 S., R. 6 W.

At Sumner Avenue the base slopes abruptly downward from a depth of less than 200 feet to about 600 feet. From there westward to test hole 2 the base is nearly flat at about the altitude of sea level. From test hole 2, the base rises abruptly to land surface at the foot of Puente Hills.

The area of the outflow section or the area of any part of it can be computed by choosing the water table as the datum plane for the upper boundary. For the period of calculation, 1930–66, the total area of the outflow section varied from about 16 to 22 million square feet (3,100–4,100 mile-feet).

Because of the differences in permeability along the outflow section, the section was divided into segments, and the average permeability was calculated for each segment. In turn, most segments were divided into an upper part and a lower part according to the relative permeability at depth of each, as discussed in the section on permeability.

To facilitate computation, the shape of each segment or part of segment was approximated by a regular triangle or rectangle (pl. 1). The upper boundary of the idealized outflow section of plate 1 is a horizontal line 600 feet above sea level. For the computations where the water table was above 600 feet altitude, the additional saturated area was added to the area of the appropriate segment by using the permeability value of that segment. Where the water table was below 600 feet altitude, the unwatered area of each segment was subtracted from the total area of that segment.

OUTFLOW CALCULATIONS

The annual ground-water outflow from Chino basin for the period 1930–66, calculated by the direct method, ranged from 38,000 acre-feet in the 1941 water year to 9,400 acre-feet in the 1966 water year. Table 1 shows the quantity for each year, and figures 6 and 7 show comparisons of these outflow calculations with those of a water-budget method.

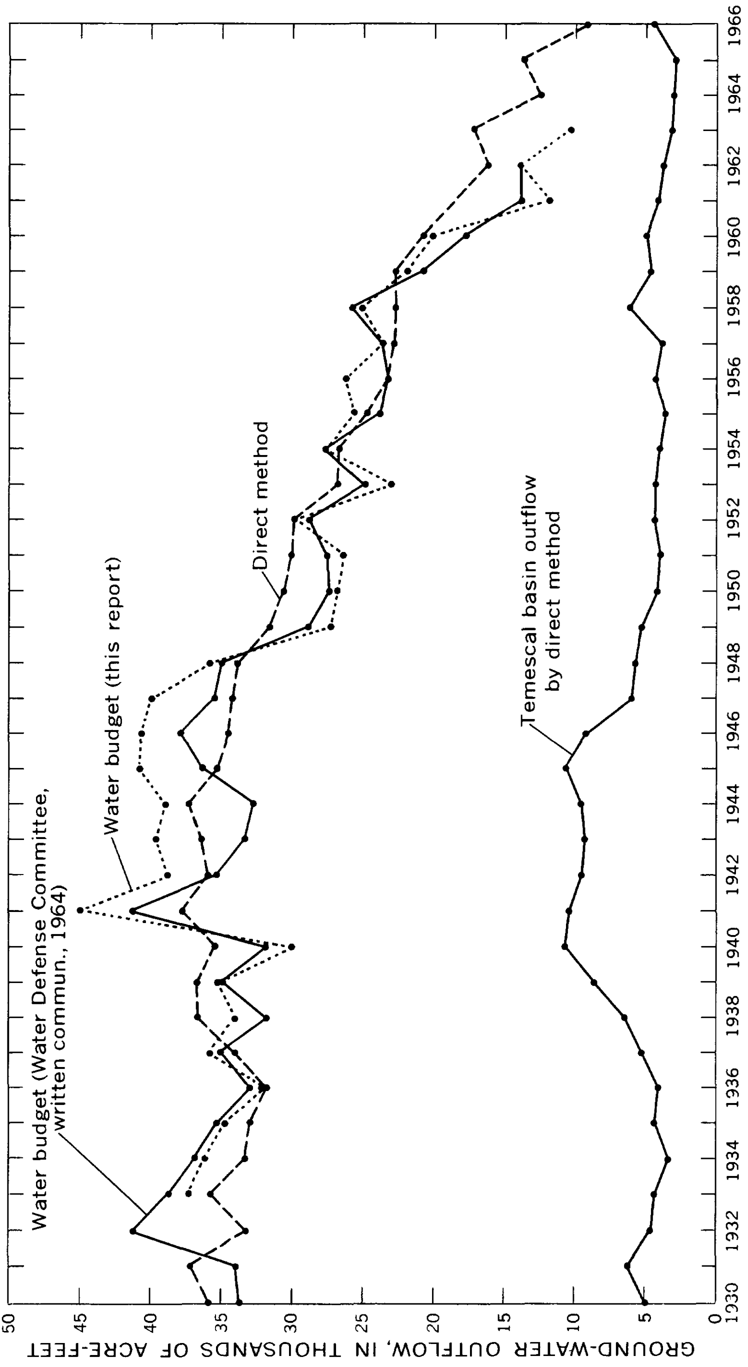

FIGURE 6.—Ground-water outflow, 1930–66, calculated by direct method and by water-budget method.

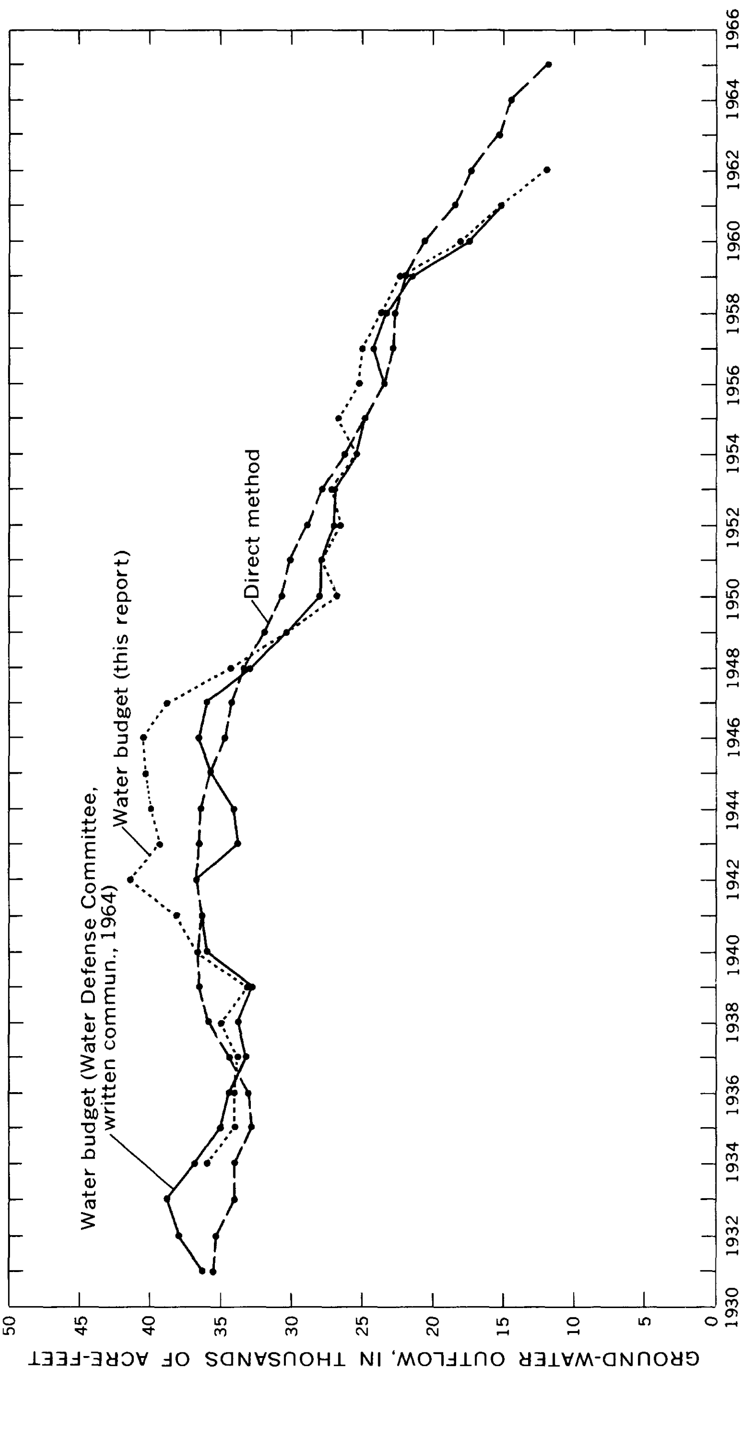

FIGURE 7.—Comparison of ground-water outflow calculations using 3-year moving averages.

TABLE 1.—*Ground-water outflow from Chino basin, 1930–66, calculated by direct method*
[Acre-feet rounded to two significant figures]

Water year	Outflow (thousands of acre-feet)	Water year	Outflow (thousands of acre-feet)	Water year	Outflow (thousands of acre-feet)
1930	36	1943	36	1956	23
1931	37	1944	37	1957	23
1932	33	1945	35	1958	23
1933	36	1946	34	1959	23
1934	33	1947	34	1960	21
1935	33	1948	34	1961	18
1936	32	1949	32	1962	16
1937	34	1950	31	1963	17
1938	37	1951	30	1964	12
1939	37	1952	30	1965	14
1940	36	1953	27	1966	9
1941	38	1954	27		
1942	36	1955	25		

INDIRECT METHODS OF OUTFLOW CALCULATION

Two indirect methods of calculating ground-water outflow were studied as a part of this investigation: a water-budget method and a chemical method. The water-budget method is similar to that used by Garrett and Thomasson (1949, p. 50–102), except that direct runoff and evapotranspiration were reevaluated and the ground-water outflow from Temescal basin was calculated by the same direct method employed in Chino basin. The chemical method, also investigated by Garrett and Thomasson (1949, p. 46–48), was reevaluated.

WATER-BUDGET METHOD

The ground-water outflow for the Santa Ana River between Riverside Narrows and Prado Dam was calculated by a water-budget method. The measured discharge for the gaging stations at Riverside Narrows and below Prado Dam was adjusted by subtracting the estimated direct runoff and measured releases to the river by the Metropolitan Water District of Southern California. The direct runoff was estimated for each gaging station by separating the direct runoff from base flow on a daily hydrograph for each station.

Estimates of the water pumped from the reach and the water removed by evapotranspiration were added to the adjusted discharge below Prado Dam, and estimates of the discharge for Sheehan and Arlanza ditches were added to the adjusted discharge for Riverside Narrows. The net gain in the reach was then calculated as the ground-water outflow. Ground-water outflow from Temescal basin was subtracted from the net gain to determine ground-water outflow from Chino basin.

A sample calculation of the water budget for the water year of 1941 is as follows:

	Thousands of acre-feet (rounded to thousands)
Discharge of Prado	174
Minus direct runoff	109
Minus Metropolitan Water District releases	0
Plus water pumped	0
Plus evapotranspiration	14
Net 1	79
Discharge at Riverside Narrows	101
Minus direct runoff	77
Plus discharge from Sheehan ditch	0
Plus discharge from Arlanza ditch	0
Net 2	24
Net 1	79
Minus net 2	24
Minus ground-water outflow from Temescal basin	10
Ground-water outflow from Chino basin	45

The evapotranspiration losses were computed by the Blaney-Criddle method (1945). In this method, consumptive use is assumed to vary according to a factor determined by multiplying mean monthly temperature, t, by monthly percentage of annual daylight hours, p. Unit consumptive-use values were based on those derived by Muckel and Blaney (1946). The values by Muckel and Blaney were calculated for a normal year and consequently could be adjusted according to the annual indices. U.S. Weather Bureau temperatures and values of percentage of daylight hours at Corona were used. Annual $t \times p$ values were obtained by summing the monthly figures. The ratio of each annual value to the long-time average (or normal), expressed as a percentage, indicated whether the year was below normal or above with respect to consumptive-use indices. The monthly adjusted unit consumptive use for each area was determined from each month's percentage of annual $t \times p$ total, and then the water volume was computed for the area affected by evapotranspiration losses.

CALCULATION OF OUTFLOW FROM TEMESCAL BASIN

For this report the average annual ground-water outflow from Temescal basin was calculated directly by the equation $Q = PIA$. The elements of the equation were determined by the same methods that were used for Chino basin.

Permeability values were computed by using specific-capacity data from about 50 wells (pl. 1). Water-level gradients were obtained from average annual water-level-contour maps (not shown) compiled from 35 well hydrographs and many supplemental measurements. The vertical cross-section *B–B′*, along which ground-water outflow from Temescal basin was calculated, extends across the mouth of the basin between Norco Hills and the foothills of the Santa Ana Mountains. The section follows Corydon Road in the eastern part and extends in a straight line projection of Corydon Road across part of the Prado flood control basin. Drillers' logs and electric logs from about 100 drill holes, including three of the eight test holes drilled as a part of this investigation, were used to determine the thickness and character of the sediments and rocks that make up the Temescal basin outflow section.

The rocks that bound the section and the permeable sediments that constitute it are similar to those in Chino basin (pl. 1). The rock units consist of the crystalline basement complex of pre-Tertiary age and the consolidated marine and continental rocks of Tertiary age. The basement complex crops out near the northeast end of the outflow section at about 600 feet above sea level. The surface of the basement complex, traced by a refraction seismic traverse as a horizon with a refracting velocity of 17,000 fps, slopes steeply southwestward to about 1,000 feet below sea level near River Street. Between River Street and the south side of the Prado flood control basin, the basement surface slopes gently downward to about 1,500 feet below sea level. Westward the basement surface was not detected by seismic methods. Gravity and oil-well data indicate that the basement may be more than 4,000 feet below sea level at the southwest end of the outflow section.

Consolidated marine and continental sedimentary rocks of Tertiary age overlie the basement complex and are in turn covered by alluvium. The base of the permeable sediments, which may coincide with the contact between the sedimentary rocks and the overlying alluvium, was delineated by refraction of seismic waves as a well-defined interface between beds with a refracting velocity of 6,400 fps and beds with a velocity of 7,900 fps. These velocities represent, respectively, water-saturated alluvium and consolidated rocks of low permeability. The depth of the refracting interface agrees very well with electric-log analyses from three deep oil wells drilled near Temescal Wash.

The outflow section is shown in plate 1. The Chino fault apparently does not inhibit the flow of ground water from Temescal basin, because the fault is nearly parallel to the ground-water flow lines.

The sedimentary rocks which underlie and bound Temescal basin on the west consist of sandy siltstone and silty shale. The low permeability of these rocks is suggested by their makeup and by their comparatively high water-level gradient, which is about 50 feet per mile between Temescal basin and the Santa Ana River below Prado Dam. Very little water probably moves westward through these sedimentary rocks to the Santa Ana River below the dam.

Within the permeable sediments, well data indicate great contrasts in water-bearing properties. Drillers' logs of wells show a distinct sequence of coarse material about 100 feet thick and about 1 mile wide extending from Arlington basin northwest beneath Corona to the Santa Ana River. The shape of this coarse-grained sequence leads one to infer that it represents a buried river channel.

The elongate, sinuous pattern of the contours of transmissibility and of permeability (figs. 3, 4) also suggest a buried channel. Permeability values, from specific-capacity data, locally exceed 6,000 gpd per ft^2 in the postulated channel but are generally less than 1,000 gpd per ft^2 along its flanks. Test hole 1, drilled as a part of this investigation, penetrated a coarse-grained sequence nearly 150 feet thick which apparently represents the channel. Most wells that tap this sequence are not drilled entirely through it. The few deeper wells that do penetrate it enter beds of clay, sandy clay, or siltstone. Test hole 1 penetrated more than 100 feet of hard tight clay and siltstone beneath the coarse-grained sequence.

This interpretation is corroborated by a plume of high-nitrate concentration in the ground water, apparently originating in the Arlington basin, which follows the zone of highest transmissibility mapped in figure 3.

To facilitate computation of the irregular shape of the outflow section and the extreme variations in permeability within it, the section was divided into four segments, and the average permeability (pl. 1) was calculated for each segment. Two of the segments were redivided into an upper and a lower part according to the relative permeability of the parts. To facilitate calculation of outflow, the shape of each segment or part of segment was idealized into a regular geometric figure, as were the segments in the Chino basin outflow section. The upper boundary of the outflow section, as illustrated in plate 1, is a horizontal line 500 feet above sea level. For the computations, if the water table was above 500 feet altitude, the additional saturated area was added to the area of the appropriate segment by using the permeability value of that segment.

The annual ground-water outflow from Temescal basin during the period 1930–66 ranged from 11,000 acre-feet in the 1940 and 1945 water years to 3,000 acre-feet in the 1965 water year. Annual figures are given in table 2.

TABLE 2.—*Ground-water outflow from Temescal basin, 1930–66, calculated by direct method*

[Acre-feet, rounded to two significant figures]

Water year	Outflow	Water year	Outflow
1930	5,000	1949	5,200
1931	6,400	1950	4,100
1932	4,600	1951	4,000
1933	4,300	1952	4,300
1934	3,400	1953	4,300
1935	4,300	1954	4,000
1936	4,000	1955	3,700
1937	5,400	1956	4,300
1938	6,400	1957	3,900
1939	8,600	1958	6,200
1940	11,000	1959	4,700
1941	10,000	1960	5,000
1942	9,500	1961	4,100
1943	9,400	1962	3,800
1944	9,500	1963	3,200
1945	11,000	1964	3,100
1946	9,200	1965	3,000
1947	6,000	1966	4,300
1948	5,700		

CHEMICAL METHOD

Garrett and Thomasson (1949, p. 46–48) examined a chemical method by which the outflow to the valley floor would be prorated according to source on the basis of chemical quality of the water. They found that the water escaping from Chino basin was considerably different in chemical composition from the water escaping from Temescal basin. However, they concluded that the method was unsatisfactory because of the increase in salt content of the escaping water caused by evapotranspiration in the flood plain. During the present investigation, this method was reevaluated and was found inadequate.

All available chemical analyses of water from wells in Chino basin, in Temescal basin, and from the Santa Ana River between Riverside Narrows and Prado Dam were studied. More than 250 analyses were plotted on maps to show the areal variation in concentration of dissolved solids, chloride, and nitrate. Ionic-concentration diagrams (Stiff, 1951) of water from 262 wells and three sites in the Santa Ana River were also plotted on a map. Percentage-reactance values of chemical constituents of water samples from more than 80 wells, Chino Creek, and the Santa Ana River were plotted on trilinear diagrams. Well depths and perforation intervals were plotted on a map and compared to water-quality variations. A series of maps (not shown) at 5-year intervals depicting the dissolved-solids content of ground water were drawn.

Those procedures clearly show the contrast in water quality between Chino basin and Temescal basin, the progressive deterioration of ground-water quality in both basins, the areas of high-nitrate concentration, and water-quality degradation in many individual wells. However, even with the abundance of chemical-quality data and the distinct water-quality difference between the two basins, there is no known satisfactory way to quantitatively separate the net gain in the reach of the river with respect to source.

OUTFLOW CALCULATIONS

The ground-water outflow from Chino basin for 1933–63, calculated by the water-budget method, was obtained by subtracting the

TABLE 3.—*Ground-water outflow, in thousands of acre-feet, from Chino basin, 1930–63, calculated by water-budget methods*

[Acre-feet rounded to two significant figures]

Water year	Garrett and Thomasson (1949)	Water Defense Committee (written commun., 1964)	This report
1930	40	34	----------
1931	38	34	----------
1932	41	41	----------
1933	38	39	37
1934	35	37	36
1935	35	35	35
1936	31	33	32
1937	40	35	36
1938	39	32	34
1939	34	35	35
1940	32	32	30
1941	61	41	45
1942	37	35	39
1943	36	33	40
1944	36	33	39
1945	39	36	41
1946	37	38	41
1947	----------	35	40
1948	----------	35	36
1949	----------	29	27
1950	----------	27	27
1951	----------	28	26
1952	----------	29	30
1953	----------	25	23
1954	----------	28	28
1955	----------	24	26
1956	----------	23	26
1957	----------	24	24
1958	----------	26	25
1959	----------	21	22
1960	----------	18	20
1961	----------	14	12
1962	----------	14	14
1963	----------	----------	10

calculated ground-water outflow from Temescal basin from the net gain in the reach of the Santa Ana River between Riverside Narrows and Prado Dam. The quantity ranged from 45,000 acre-feet in the 1941 water year to 10,100 acre-feet in the 1963 water year. Table 3 shows the quantity of outflow for each year, and figures 6 and 7 show comparisons of outflow calculated by the direct method and by the water-budget method. For further comparison, calculations by Garrett and Thomasson (1949) (table 3) and by the Water Defense Committee (written commun., 1964) (table 3; figs. 6, 7) are shown.

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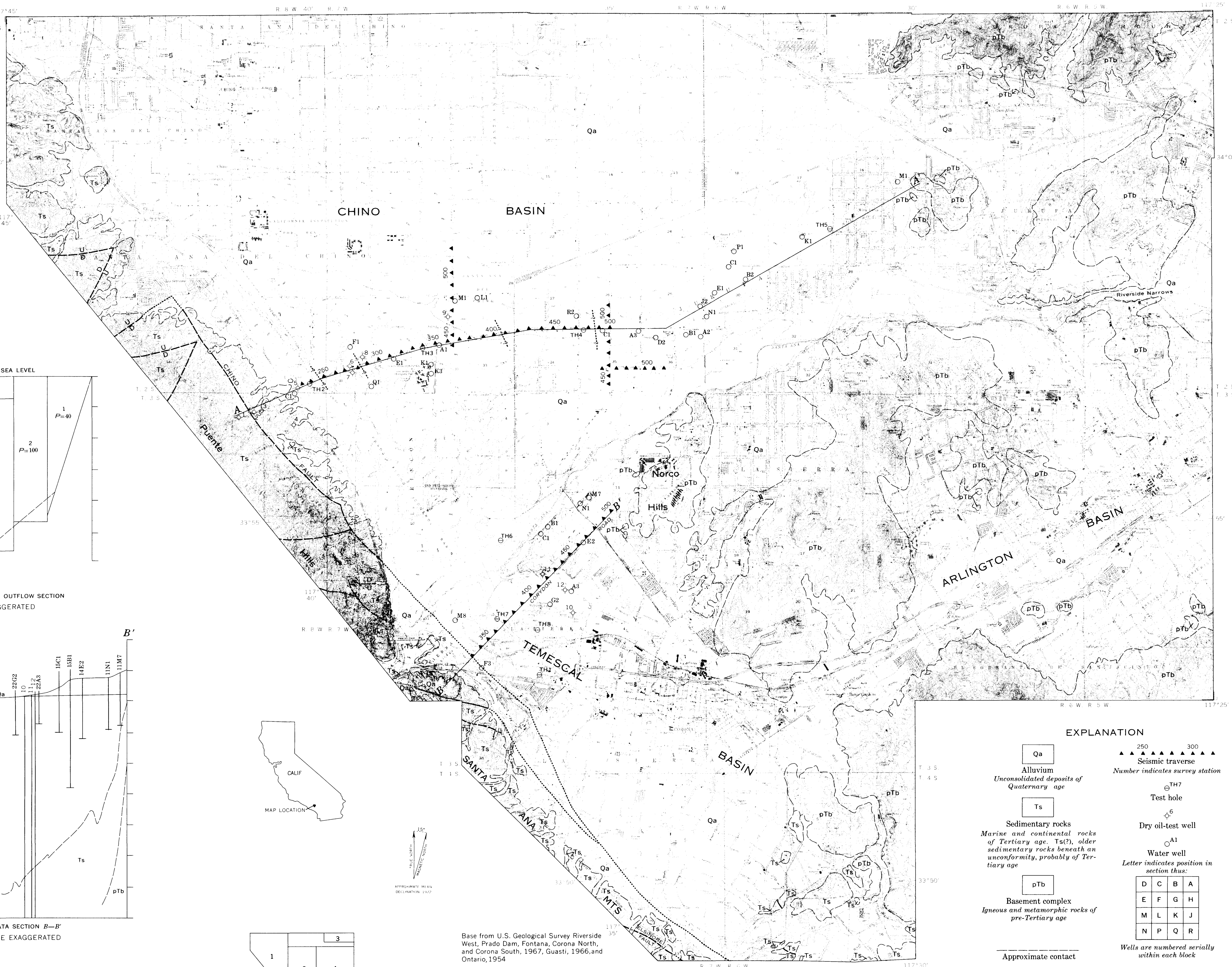
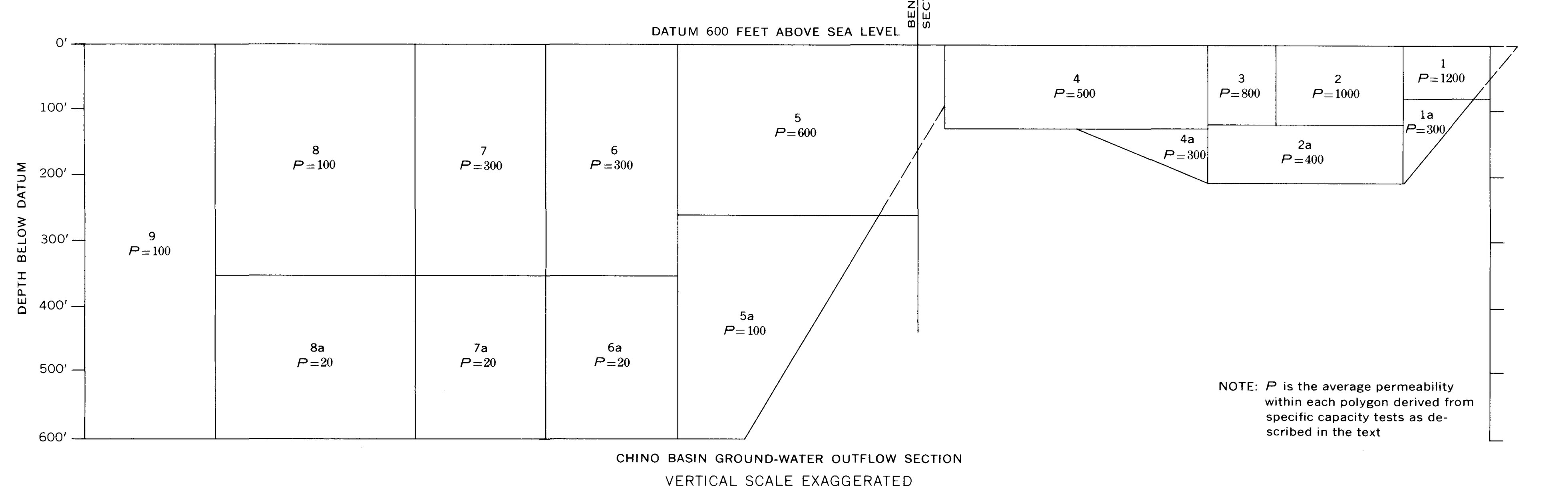
UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

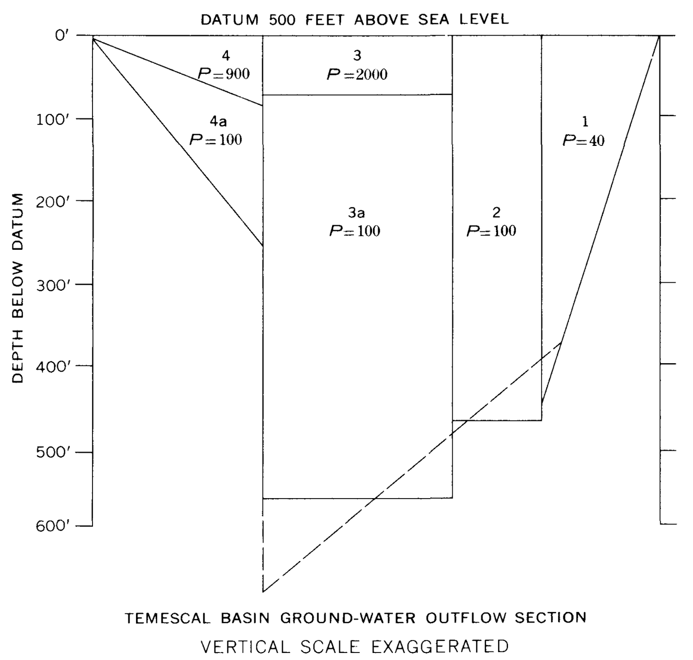
PREPARED IN COOPERATION WITH THE
SAN BERNARDINO COUNTY FLOOD CONTROL DISTRICT

WATER-SUPPLY PAPER 1999-G
PLATE 1





CHINO BASIN GROUND-WATER OUTFLOW SECTION
VERTICAL SCALE EXAGGERATED



TEMESCAL BASIN GROUND-WATER OUTFLOW SECTION
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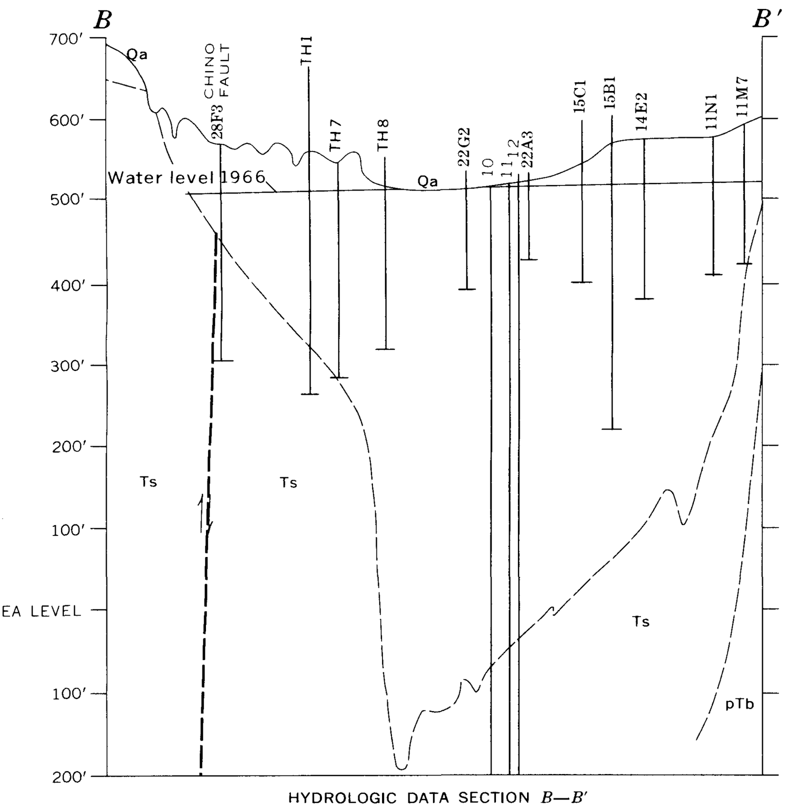

HYDROLOGIC DATA SECTION B—B′
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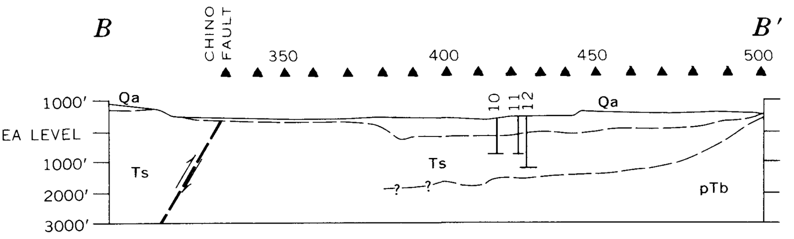
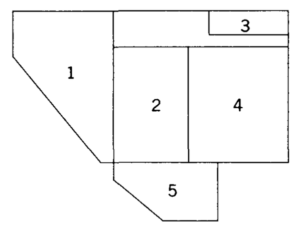


GEOLOGIC SECTION B—B′
NO VERTICAL SCALE EXAGGERATION



INDEX TO GEOLOGIC MAPPING
1. Durham and Yerkes (1964)
2. Garrett and Thomasson (1949)
3. MacKevett (1951)
4. Larsen (1948)
5. Gray (1961)

Base from U.S. Geological Survey Riverside West, Prado Dam, Fontana, Corona North, and Corona South, 1967, Guasti, 1966, and Ontario, 1954

SCALE 1:62 500

CONTOUR INTERVALS 5, 10, 20, 25, AND 40 FEET
DOTTED LINES REPRESENT 5, 10, AND 20-FOOT CONTOURS
DATUM IS MEAN SEA LEVEL

EXPLANATION

Qa — Alluvium
Unconsolidated deposits of Quaternary age

Ts — Sedimentary rocks
Marine and continental rocks of Tertiary age. Ts(?), older sedimentary rocks beneath an unconformity, probably of Tertiary age

pTb — Basement complex
Igneous and metamorphic rocks of pre-Tertiary age

Approximate contact

Fault
Dashed where approximately located, dotted where concealed, queried where doubtful. U, upthrown side; D, downthrown side. On geologic sections arrows indicate direction of relative movement

Seismic traverse
Number indicates survey station

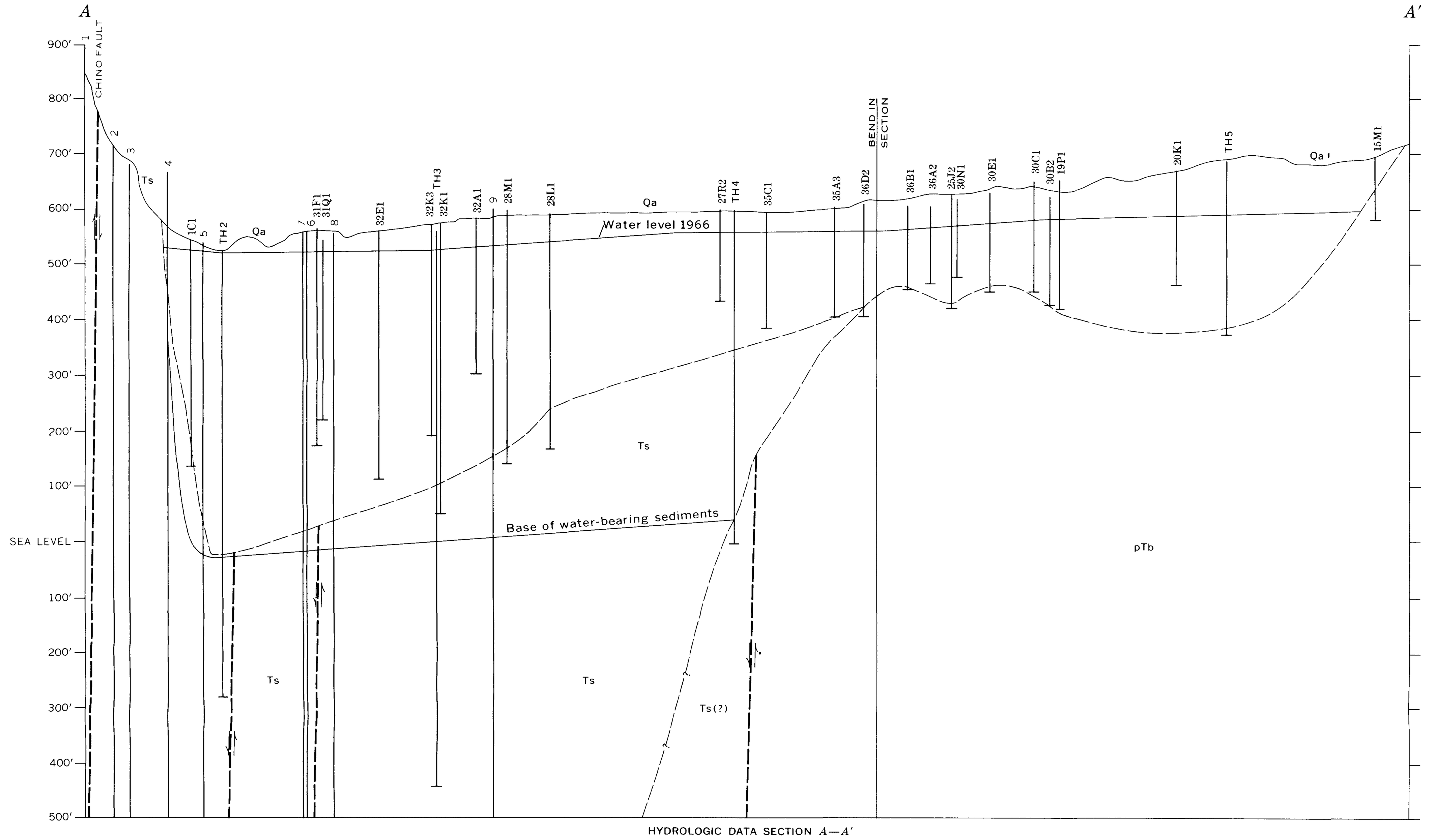
Test hole

Dry oil-test well

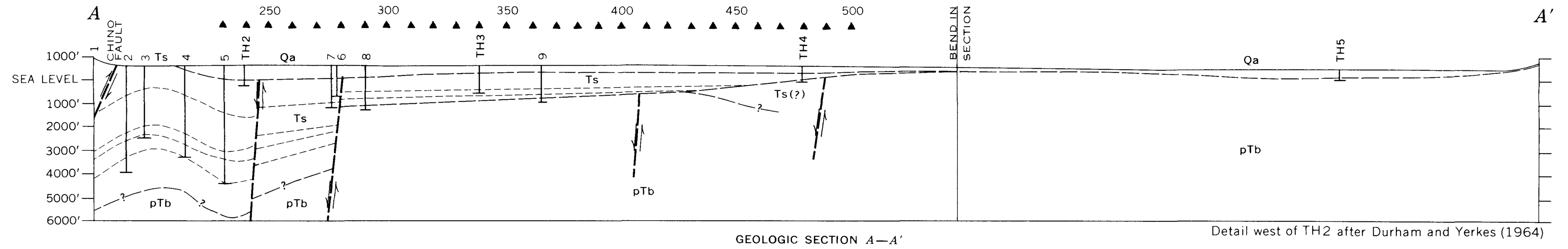
Water well
Letter indicates position in section thus:

D	C	B	A
E	F	G	H
M	L	K	J
N	P	Q	R

Wells are numbered serially within each block



HYDROLOGIC DATA SECTION A—A′
VERTICAL SCALE EXAGGERATED



GEOLOGIC SECTION A—A′
NO VERTICAL SCALE EXAGGERATION

Detail west of TH2 after Durham and Yerkes (1964)

GEOLOGIC MAP AND SECTIONS AND GROUND-WATER OUTFLOW SECTIONS OF THE CHINO BASIN AND TEMESCAL BASIN OUTFLOW AREAS, SOUTHERN CALIFORNIA