DIGITAL MODEL OF THE HOLLISTER VALLEY GROUND-WATER BASIN, SAN BENITO COUNTY, CALIFORNIA

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

1879 CENTENNIAL 1979

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 79-32

Prepared in cooperation with the San Benito County
Water Conservation and Flood Control District

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UNITED STATES DEPARTMENT OF THE INTERIOR
CECIL D. ANDRUS, Secretary

GEOLOGICAL SURVEY

H. William Menard, Director

OPEN-FILE REPORT

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Water Resources Division
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Menlo Park, Calif. 94025

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ILLUSTRATIONS

[Plates are in pocket]

CONVERSION FACTORS

For readers who may prefer to use metric units rather than inch-pound units, the conversion factors for the terms used in this report are listed below:

Inch-pound units	Multiply by	Metric units
acres	4.047×10^{-3}	km^2 (square kilometers)
acre-ft (acre-feet)	1.233×10^{-3}	hm^2 (cubic hectometers)
acre-ft/yr (acre-feet per year)	1.233×10^{-3}	hm^2 yr (cubic hectometers per year)
ft (feet)	3.048×10^{-1}	m (meters)
ft/d (feet per day)	3.048×10^{-1}	m/d (meters per day)
ft^2/d (feet squared per day)	9.29×10^{-2}	m^2/d (meters squared per day)
ft/mi (feet per mile)	1.894×10^{-1}	m/km (meters per kilometer)
inches	2.540×10	mm (millimeters)
in/yr (inches per year)	2.540×10	mm/yr (millimeters per year)
mi (miles)	1.609	km (kilometers)
mi^2 (square miles)	2.590	km^2 (square kilometers)

Use the following to convert degrees Fahrenheit (°F) to degrees Celsius.
Temp °C = (temp °F-32)/1.8

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ABSTRACT

A two-dimensional finite-difference digital model was constructed to simulate the effects of proposed pumping and recharge schemes on water levels in the Hollister Valley ground-water basin. The study area covers 52 square miles in San Benito County, Calif. Ground water is the principal source of irrigation water in this agricultural area, and pumping had caused water levels to decline as much as 180 feet by 1968. Agricultural development is expected to increase, and the pumping rate for the valley is expected to increase from the 1968 rate of 24,000 acre-feet per year to an ultimate rate of 38,500 acre-feet per year. Long-term average natural recharge from stream, boundary underflow, and rainfall infiltration is 16,500 acre-feet per year.

The aquifer in the study area consists of clay, silt, sand, gravel, and poorly consolidated sandstone. Both confined and unconfined conditions exist, and faults in the area act as semipermeable barriers to ground-water flow. Modifications in the initial computer program were made to better simulate flow across faults and aquifer conversion from confined to unconfined conditions.

The model was calibrated by adjusting values for hydrologic characteristics to obtain the best match between observed and computed water levels during the period 1940-51 and tested by simulating water-level changes from 1951 to 1968. For the calibration period, computed water levels were generally within 15 feet of observed water levels in areas of concentrated pumping. For the testing period, computed and observed water levels differed by as much as 35 feet in parts of the study area east of Hollister. Discrepancies in the test results can be accounted for by a 20-percent error in the pumpage data for this area. Other disagreements may result from unidentified faults or local semiconfined conditions.

Model-generated predictions of water levels to the year 2020 indicated declines as great as 170 feet in previously undeveloped parts of the study area. For developed areas near Hollister, water-level declines of 100 to 125 feet were predicted for the same period.

INTRODUCTION

Purpose and Scope

Since irrigation pumping began in the Hollister Valley in 1878, water levels have declined as much as 180 ft. Ground-water pumping has increased progressively since the mid-1940's and is expected to continue to do so. To compensate for the water-level declines, ground-water recharge plans involving imported water from the U.S. Bureau of Reclamation's Central Valley Project are being formulated. The present study was designed by the U.S. Geological Survey, in cooperation with the San Benito County Water Conservation and Flood Control District, to provide a digital model of the Hollister Valley ground-water basin capable of predicting water levels that would occur under various proposed pumping and recharge schemes.

The scope of the study is limited by a lack of definitive hydrological data for the basin. Consequently, the digital model can only predict gross regional water-level trends. By developing the model, data needs will be identified and the essentials of future work can be defined.

Location and General Features

Hollister Valley (fig. 1) is in the northeastern part of San Benito County about 40 mi southeast of San Jose. The study area, which covers 52 mi^2 and extends slightly into Santa Clara County, includes much of the valley--the part underlain by a continuous ground-water system. The study area is bordered on the north and east by the Diablo Range, on the south by the Tres Pinos fault, and on the west by the Calaveras fault (pl. 1). Topographic slope within the valley ranges from about 10 ft/mi in the vicinity of San Felipe Lake to about 200 ft/mi in the foothills in the southeastern part of the study area. Land-surface altitudes are less than 140 ft near San Felipe Lake and greater than 500 ft near the southern end of the Tres Pinos fault. The town of Hollister is near the southwest corner of the study area.

Rainfall varies considerably from year to year and, to a lesser extent, from place to place within the valley. The foothill areas and mountain slopes receive greater quantities of rain than the valley flats. Annual rainfall at Hollister, which is probably representative of the flatter parts of the valley, ranged from 10 to 20 inches during the period 1891-1968. Mean annual rainfall during this period was 13.1 inches. The climate is temperate, with average temperatures at Hollister ranging from about 49°F in the winter to about 68°F in the summer.

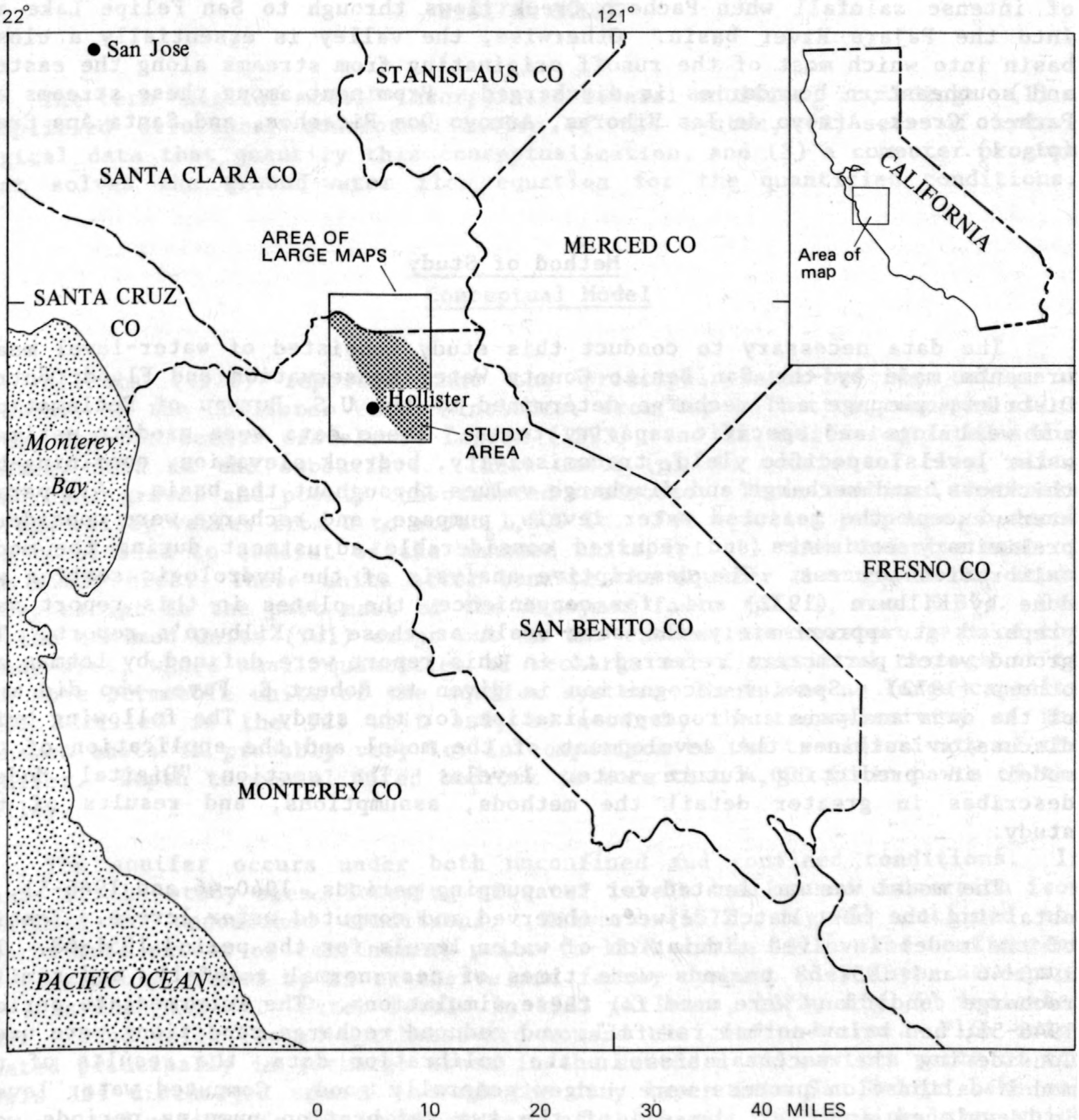

FIGURE 1.--Location of the study area.

For the most part, surface runoff leaves the valley only during periods of intense rainfall when Pacheco Creek flows through to San Felipe Lake and into the Pajaro River basin. Otherwise, the valley is essentially a closed basin into which most of the runoff originating from streams along the eastern and southeastern boundaries is discharged. Prominent among these streams are Pacheco Creek, Arroyo de las Viboras, Arroyo Dos Picachos, and Santa Ana Creek (pl. 1).

Method of Study

The data necessary to conduct this study consisted of water-level measurements made by the San Benito County Water Conservation and Flood Control District, pumpage and recharge determined by the U.S. Bureau of Reclamation, and well logs and specific capacity tests. These data were used to estimate water levels, specific yield, transmissivity, bedrock elevation, confining-bed thickness, and recharge and discharge values throughout the basin. All parameters except the measured water levels, pumpage, and recharge were considered preliminary estimates and required considerable adjustment during the model calibration process. The descriptive analysis of the hydrologic setting was done by Kilburn (1972) and, for convenience, the plates in this report were prepared at approximately the same scale as those in Kilburn's report. The ground-water parameters referred to in this report were defined by Lohman and others (1972). Special recognition is given to Robert E. Faye, who did much of the data analysis and conceptualization for the study. The following brief discussion outlines the development of the model and the application of the model in predicting future water levels. The section "Digital Model" describes in greater detail the methods, assumptions, and results of the study.

The model was calibrated for two pumping periods, 1940-46 and 1946-51, by obtaining the best match between observed and computed water levels. Testing of the model involved simulation of water levels for the period 1951-68. The 1940-46 and 1951-68 periods were times of near-normal rainfall, and similar recharge conditions were used for these simulations. The intermediate period, 1946-51, had below-normal rainfall, and reduced recharge conditions were used. Considering the uncertainties in the calibration data, the results of the model calibration process were judged generally good. Computed water levels in developed areas at the end of the two calibration pumping periods were usually within 15 ft of observed water levels.

After the model was calibrated and tested, it was used to predict future water levels to the year 2020 under proposed pumpage and recharge schemes. One scheme, described in this report, involved a 60-percent increase in the 1968 gross pumping rate by the year 2010 and distribution of imported irrigation and streambed recharge water.

DIGITAL MODEL

The term "digital model" incorporates several entities, including: (1) a simplified structural conceptualization of the system, (2) sets of hydrological data that quantify this conceptualization, and (3) a computer program that solves the ground-water flow equation for the quantified conditions.

Conceptual Model

Kilburn (1972) reported that the principal water-bearing unit, or aquifer, in the Hollister Valley includes, from top to bottom, unnamed alluvium, the San Benito Gravels of Lawson (1893), and an undifferentiated sedimentary unit in the subsurface. These units (pl. 1) consist of clay, silt, sand, and gravel and poorly consolidated sandstone. Their combined thickness in the valley varies from 0 to about 1,300 ft. For modeling purposes, bedrock was considered to consist of the unnamed units (pl. 1) that underlie most of the study area. These units occur beneath the aquifer throughout the study area, except in the part east of the Ausaymas fault (pl. 1, sec. B-B'). One of the unnamed units (Tul) crops out in the extreme southeastern part of the study area, where small quantities of recharge are transmitted through it to the more permeable units of the aquifer system. There are no large-capacity wells drilled in the Tul unit and, in general, the transmissivity of the unnamed units is probably very low in comparison to the transmissivity of the aquifer. Depth to consolidated bedrock is more than 4,000 ft in parts of the valley.

The aquifer occurs under both unconfined and confined conditions. In parts of the study area, lowering of water levels has caused conversion from confined to unconfined conditions. Kilburn (1972, fig. 5) outlined the approximate extent of confinement prior to 1878 and in 1913. The confinement is presumably caused by an extensive and fairly compact clay layer at depths of less than 100 ft. Water levels in 1913 (Kilburn, 1972, fig. 5) indicated that ground water flowed northwestward toward the confined area. Flow originated principally in recharge areas in the southern and eastern parts of the basin and discharged upward through the clay layer into San Felipe Lake and streams and marshes in the northern part of the basin. San Felipe Lake, which is currently drained by surface diversion, is evidence that this discharge still occurs in the extreme northern part of the study area.

There is little or no flow across the Calaveras or Tres Pinos faults, but there is apparently some flow across the Santa Ana Valley and Ausaymas faults (pl. 1) that originates as recharge in the foothills to the east.

South and east of the clay layer (pl. 2), the boundaries of which were designated by Kilburn (1972) as the approximate extent of artesian flow prior to 1878, the aquifer is generally unconfined. In isolated areas outside the area of artisian flow, water levels in adjacent wells drilled to different depths occasionally vary by as much as 50 ft. This indicates some degree of local confinement that is probably caused by small lenticular layers of clay or silt. For modeling purposes the area south and east of the clay layer was considered to be unconfined. The degree of vertical variation in water levels and the extent of confinement are difficult to determine because many wells are multiscreened, and the measured water level represents a composite head of two or more units.

The basin was conceptualized as a single aquifer with two-dimensional horizontal flow that is overlain in the northern part by a confining bed and an unconfined aquifer. As vertical flow in the aquifer is not accounted for, the computed water level at a node represents a composite of the actual water levels with depth. Existing water-level and pumpage data are not sufficient to develop a three-dimensional model.

Model boundaries (pl. 1) consisted of the Calaveras and Tres Pinos faults and the contact of the aquifer material with the peripheral bedrock, shown as the approximate base of the Diablo Range. These were treated as no-flow boundaries, and the Santa Ana Valley and Ausaymas faults were treated as semipermeable flow barriers.

Hydrologic and Pumping Data

Field-determined values of transmissivity and specific yield were insufficient to adequately define these parameters over the model area. Therefore, initial estimates of transmissivity were made from specific-capacity tests (Lohman, 1972). Specific yield was estimated from knowledge of the lithology of the basin. During the calibration process the distribution and magnitude of transmissivity and specific yield were revised from the initial estimates. To facilitate calibration of the model, the basin was divided into 16 subareas in which similar specific capacities were measured. These areas presumably represented areas having similar hydraulic characteristics. The aquifer hydraulic conductivity and specific yield were assumed to be uniform within each subarea. Transmissivity, which varies with changes in saturated aquifer thickness, was computed internally at each node as a function of hydraulic conductivity and saturated thickness. A detailed discussion of this computation was given by Trescott and others (1976).

Plate 2 shows the distribution of hydraulic conductivity and specific yield resulting from model calibration. Values for these aquifer parameters are highest near Pacheco Creek where hydraulic conductivity is nearly 95 ft/d and specific yield is about 0.25. In the southeastern parts of the area, hydraulic conductivity is about 0.75 ft/d and specific yield is about 0.05. The average hydraulic conductivity for the basin is 12.0 ft/d, and the average specific yield is 0.12. Plate 2 also shows transmissivity. The storage coefficient at all confined nodes determined during calibration was 0.009. Adjustments were made internally to convert confined storage coefficient values to specific yield (Trescott and others, 1976) if a node converted from confined to unconfined conditions.

Thickness and vertical hydraulic conductivity of the confining bed and altitude of the water table above the confining bed are necessary for the computation of leakage through the confining zone (Trescott and others, 1976). Data to define vertical hydraulic conductivity were sparse. Consequently, values for thickness of the confining bed and for hydraulic conductivity were determined during the model calibration process. Because leakage depends upon the ratio of hydraulic conductivity to confining-bed thickness (leakance), one of the confining-bed parameters can be defined areally and a constant value can be determined for the other parameter. This was done by defining a relative distribution of confining-bed thickness, which was not altered, and determining a constant vertical hydraulic conductivity during model calibration. Examination of drillers' logs indicated that the confining zone thickens northwestward and reaches its maximum thickness in the vicinity of San Felipe Lake. Estimates of confining-bed thickness ranged from 25 ft near San Felipe Lake to 10 ft on the southern edge of the confined zone. The value of hydraulic conductivity determined through model calibration was 0.0069 ft/d, which is representative of fairly tight clay.

Altitudes of the water table in the aquifer overlying the confining zone at the beginning of the calibration period (1940) are very uncertain. It is also evident, as discussed in the calibration section that this water table has declined due to leakage to the underlying aquifer. It is known, however, that prior to large-scale development and drainage of San Felipe Lake, the northern parts of the confined area exhibited ponded or marshy conditions which indicated a shallow water table. For the model, assumed water-table depths in 1940 ranged from less than 5 ft below land surface near San Felipe Lake to about 25 ft below land surface in the southern part of the confined zone.

Recharge to the basin occurs as infiltration from streams, boundary underflow, infiltration of rain, and return flow from irrigation. Stream infiltration occurs along most of the eastern and southeastern boundaries of the basin, principally from Pacheco Creek, Arroyo de las Viboras, Arroyo Dos Picachos, and Santa Ana Creek. Estimates of recharge by the U.S. Bureau of Reclamation (unpublished report, 1952) included a measured average annual loss from Pacheco Creek during the 1940-50 period of about 2,700 acre-ft and an estimated average annual loss from Arroyo de las Viboras during the 1942-49 period of about 400 acre-ft. Estimated annual loss from Arroyo Dos Picachos was about 650 acre-ft, and from Santa Ana Creek estimated annual loss was about 50 acre-ft. The combined contribution of the smaller streams is significant and amounts to about 40 percent of the total stream recharge for any year.

Plate 3 shows the nodal distribution of recharge from all streams and boundary underflow for the periods 1940-46 and 1951-68, and 1946-51. Figures for the periods 1940-46 and 1951-68 are representative of long-term average conditions and total about 12,500 acre-ft/yr. Stream and boundary underflow recharge for the drier period 1946-51 was estimated to be 45 percent of the long-term average, or about 5,650 acre-ft/yr.

Infiltration of rainfall, like rainfall itself, is highly variable in space and time and depends on the rate and distribution of rainfall, topography, soil permeability and porosity, vegetation, and depth to the water table. Definitive information describing the recharge contribution from rainfall does not exist. Studies in southern California (Upson, 1951) were used to obtain recharge rates from rainfall for this study. For Hollister Valley the long-term recharge rate from rainfall was estimated to be 1.5 in/yr, or about 11 percent of the average annual rainfall at Hollister. During the drier period 1946-51, the recharge rate was assumed to be about one-half the long-term average. These recharge rates were applied in the model at all unconfined nodes; the nodal rates totaled about 4,000 acre-ft/yr for the periods 1940-46 and 1951-68 and about 2,300 acre-ft/yr for the period 1946-51. Total long-term average recharge from stream losses, boundary underflow, and infiltration of precipitation was about 16,500 acre-ft/yr.

Ground-water pumping is the principal source of irrigation water in the valley, and pumping has increased significantly over the years with the growth of agriculture. Kilburn (1972) stated that the number of irrigated acres in San Benito County increased from about 900 in 1890 to about 38,000 in 1968. The U.S. Bureau of Reclamation (unpublished report, 1952), using electrical power consumption data, computed ground-water pumpage in the basin for the period 1935-50 and pumpage for various subunits for the period 1945-50. Since 1950, no comprehensive pumpage calculation has been made. However, it has been estimated (U.S. Bureau of Reclamation, unpublished report, 1973) that the gross pumping rate during the period 1958-69 averaged 23,000 acre-ft/yr. Because this quantity closely corresponds to the computed gross pumping rate for 1950, the 23,000-acre-ft/yr estimate was used for the entire simulation period 1951-68. The computed gross pumping rate for the first calibration period (1940-46) was 16,500 acre-ft/yr and for the second calibration period (1946-51) was about 26,500 acre-ft/yr.

For use in the model, gross pumping rates were distributed areally to individual wells on the basis of known irrigation pump horsepower. The distributed rates were then reduced by about 15 percent in the unconfined parts of the study area to account for irrigation return flow (U.S. Bureau of Reclamation, unpublished report, 1973). For application in the model, net pumping rates at individual wells within grid cells were summed to obtain nodal pumping rates. To illustrate the distribution of net pumpage in the valley, nodal pumping rates for two of the pumping periods, 1940-46 and 1951-68, are shown on plate 4. Annual net pumping rates for these two periods totaled 14,300 acre-ft/yr and 19,400 acre-ft/yr. Pumping for the drier period, 1946-51, totaled 22,500 acre-ft/yr and was distributed similarly to the 1951-68 pumping.

Discharge also occurs as leakage through the confining bed to the overlying unconfined aquifer. This leakage has decreased considerably in time as pumpage increased and water levels were lowered. The computed confining-bed leakage was about 3,000 acre-ft/yr in 1946 and about 200 acre-ft/yr in 1968.

Flow Equation and Computer Program

Two-dimensional flow of a noncompressible fluid in an elastic, isotropic nonhomogeneous porous medium can be described by the differential equation (Bear, 1972):

$$\frac{\partial}{\partial x} T(x,y,t)\frac{\partial h}{\partial x} + \frac{\partial}{\partial y} T(x,y,t)\frac{\partial h}{\partial y} = S(x,y)\frac{\partial h}{\partial t} + W(x,y,t),$$

where h = hydraulic head (L);
$T(x,y,t)$ = transmissivity (L^2/T);
$S(x,y)$ = storage coefficient, referred to as specific yield for unconfined portions of the aquifer (dimensionless);
$W(x,y,t)$ = flux term (L/T);
x and y = space coordinates (L); and
t = time.

The flux term, $W(x,y,t)$, may include pumpage, recharge, and leakage through a confining bed (Trescott and others, 1976).

For solution by a computer, the differential equation may be approximated by a finite-difference equation by applying Taylor's theorem (Pinder and Bredehoeft, 1968). The finite-difference equation is then solved at each node of a rectangular grid network, using any one of a number of solution techniques. For the Hollister Valley area, which involves extreme transmissivity gradients across fault zones, the strongly implicit procedure (Remson and others, 1971) was found to work satisfactorily. The computer program used for the model (Trescott and others, 1976) was chosen because it employed this procedure and was designed for areas combining both confined and unconfined conditions.

A rectangular grid with 48 rows and 27 columns representing 0.3-mile by 0.2-mile node spacing was superimposed on data maps of the study area. The centers of grid cells, or nodes, define data-input locations, as well as locations for computed water levels. The study area included 871 grid cells with each cell covering an area of 0.06 mi^2. The computed water level at a node is representative of the entire cell and is therefore higher than the actual water level in or very near a pumping well. Thus, the model computes regional rather than local water-level trends as might be computed by the Theis equation (Lohman, 1972).

For better simulation of flow across fault zones, the grid was alined as much as possible with the principal direction of faulting in the valley. Also, the original computer program was modified to accommodate fault zones, so that fault transmissivity values could be derived during the calibration process.

Treatment of Faults

There are two recognized internal faults in the Hollister Valley ground-water basin that radically affect the flow of ground water. These are the Santa Ana Valley and Ausaymas faults (pl. 1) on the eastern side of the valley. Kilburn (1972, fig. 4) indicated that considerable vertical displacement has occurred along these faults and that water levels differ by as much as 70 ft across the faults (Kilburn, 1972, fig. 6). These water-level differences are caused by extremely low transmissivities in the fault zones--much lower than transmissivities of the general aquifer material.

To better simulate ground-water flow in areas of faults and to reduce the number of nodes required in the model, the computation of intercell transmissivity in the computer program was modified. The program normally computes the transmissivity between any two grid cells as the harmonic mean of the individual cell transmissivities (Trescott and others, 1976). The modification involved specifying the transverse fault transmissivity between all nodes encompassing the simulated fault. Transverse fault transmissivities could then be adjusted during the calibration process. The calculation of the intercell transmissivities in cells adjacent to the faults, in the parallel direction to the faults, was done in the normal manner. This modification presented no computational difficulties and simulated water-level differences across the faults reasonably well.

Water-level gradients across the faults (Kilburn, 1972, fig. 6) suggest that fault transmissivities, especially for the Santa Ana Valley fault, are lowest toward the south ends of the faults. This was found to be the case through model calibration. Model-determined fault transmissivities for the Santa Ana Valley fault ranged from 0.0002 ft^2/d at the south end of the fault to 0.0015 ft^2/d at its northern contact with the Ausaymas fault. Values for the Ausaymas fault ranged from 0.0002 ft^2/d at the south end to 0.001 ft^2/d at the north extremity. In comparison, the average transmissivity of the aquifer material was about 9,100 ft^2/d.

Calibration

Calibration involved adjusting values for certain hydrologic parameters in the model to obtain the best agreement between observed and computed water levels. Two pumping periods, April 1940-March 1946 and April 1946-March 1951, were simulated.

Observed spring water levels in the late 1930's and early 1940's were used as initial conditions. The principal parameters adjusted during calibration were the hydraulic conductivity and specific yield of the aquifer and the transverse fault transmissivities across the Santa Ana Valley and Ausaymas faults.

During the first pumping period (1940-46), net discharge from the aquifer was about equal to the total recharge. Thus, the aquifer was virtually in a steady-state condition, negating the importance of specific yield and enabling the refinement of hydraulic conductivity. During the second pumping period (1946-51), pumping significantly exceeded recharge. Under this condition, water levels declined and the refinement of specific yield was accomplished. Plate 5 shows observed and computed water levels for 1946, 1951, and 1968.

Over most of the study area the agreement between observed and computed water levels was fairly good for the 1946 and 1951 pumping periods. In areas of concentrated pumping, the match was usually within 15 ft; over the area bounded by the coincident 180-ft contour (1946) or the 160-ft contour (1951) and the Ausaymas and Santa Ana Valley faults the match was within 10 ft. The greatest disagreement occurred near Arroyo Dos Picachos and in the area southeast of Hollister. In these places the computed water levels were as much as 50 ft below observed water levels. This disagreement could result from errors in the hydrologic or stress data used in the model. In an attempt to isolate the source of the problem, testing was done in which the pumpage/recharge conditions and the hydrologic parameters in the two areas of disagreement were varied within reasonable limits. The results of the tests indicated that the low computed water levels did not occur strictly from parameter errors or errors in stress rates. Other possible causes of the problems exist. There may be unidentified faults in the valley or localized confined areas that affect water levels and are unaccounted for in the model. However, with the present hydrologic understanding of the basin, the original conceptual model was retained. The model is flexible and can accommodate changes that might be warranted from additional knowledge of the hydrologic framework.

An additional problem was encountered in simulating leakage that required a minor program modification. Prior to large-scale pumping, leakage occurred upward through the confining zone to supply the overlying unconfined aquifer. After development, heads in the confined aquifer declined--causing downward leakage through the confining bed and lowered heads in the unconfined aquifer. As initially designed, the program assumed constant heads in the water-table aquifer. When used in the model, the constant-head condition resulted in exaggerated quantities of downward leakage, and, consequently, computed heads in the confined area were much higher than observed heads.

To adequately simulate the leakage conditions that exist would require either a three-dimensional model or incorporation of the transient relationship between the water table and confined heads in the present two-dimensional model. Since neither alternative was feasible, an approximation was necessary. The program was modified so that downward leakage at any node was stopped when the head declined to a certain altitude. At this altitude, the rainfall infiltration rate, assumed to be the ultimate infiltration after drainage of the unconfined aquifer, was applied. The altitude at which the transition was made was assumed, first, to be the constant water-table altitude and, second, to be the top of the confined aquifer. In the first case, however, there was still too much computed leakage, and in the second case there was not enough. A reasonable match between observed and computed water levels was achieved by allowing the transition to occur when the confined head at any node declined to an altitude three-quarters of the distance from the constant water table to the top of the confined aquifer. This process is reversible in the case that a confined head at a node rises, causing leakage to revert to an upward direction.

After the adjustments to initial parameter estimates were made during calibration, the model was tested by simulating water levels from April 1951 to March 1968. The results of this test were not as good as the results for the two calibration periods. As discussed previously, the pumpage used for the testing period was an estimated average for the entire 17-year period and was probably less reliable than pumpage for the previous periods. Computed water levels would tend to be too high if the pumpage in the latter part of the testing period was significantly greater than during the earlier part. This may have occurred in the area just east of Hollister where computed water levels were as much as 35 ft higher than observed water levels. The number of new wells in this area implies the existence of more pumpage than was used in the model. Further model tests showed that the discrepancy near Hollister could be accounted for by about a 20-percent error in pumpage data.

During the testing period (1951-68), disagreements similar to those found during the 1940-51 calibration period occurred near Arroyo Dos Picachos Creek. However, the match was fairly good in the area southeast of Hollister for the 1951-68 period. In general, the results of the calibration and testing of the model for the entire study area are compatible with the reliability of the hydrologic and stress data used in the model.

Predictions of Future Water Levels

After the model was calibrated and tested it was used to predict future water levels to 2020 for various proposed development schemes. One of these schemes and the model results are discussed in this section. The proposal involves an increase in gross pumping from the 1968 rate of 24,000 acre-ft/yr to 38,500 acre-ft/yr for 2010 and the importation of water for irrigation and recharge through streambeds. The 2010 pumping rate is presumed to be the ultimate that would occur with full agricultural development and was applied in the model from 2010 through 2020. Much of the additional development is expected to occur in the northwestern part of the study area and near the upper reaches of Pacheco Creek north of the San Benito-Santa Clara County line. Projected pumpage in these areas is considerably larger than in the past and accounts for much of the increase in gross pumpage.

Long-term average natural recharge from stream infiltration and boundary underflow, as used in the 1940-46 and 1951-68 simulations, was used throughout the prediction period. This recharge was about 12,500 acre-ft/yr. In addition to natural recharge, the model simulated return flow from pumping and imported irrigation water and induced recharge from imported water diverted to Pacheco Creek. The Pacheco Creek recharge totaled about 720 acre-ft/yr and would presumably retard water-level declines north of the county line. Rainfall recharge was about 4,000 acre-ft/yr and irrigation return flow from pumpage and imported waters ranged from about 3,200 acre-ft/yr in 1968 to about 5,800 acre-ft/yr in 2020.

Figure 2 shows gross pumping and total recharge rates used for the 1968-2020 simulation period. Pumping and recharge rates were incrementally increased as indicated on the graph. Because the projected pumping becomes progressively greater than recharge, water levels would be expected to decline continually with time. This is shown by the hydrographs in figure 3. Plate 6 shows predicted water levels for 2000 and 2020.

The amount of simulated water-level decline can be determined by comparing the predicted water levels with the computed 1968 water levels that were used as the initial condition for this simulation. Water levels declined throughout the study area except in the extreme southeastern part. The greatest declines occurred in the northwestern part of the area where past development has been minimal. Declines of 60 to 90 ft by 2000 and of 120 to 170 ft by 2020 occurred in this area. In the Pacheco Creek area, water levels declined about 25 ft by 2000 and about 85 ft by 2020. In areas just north and east of Hollister water levels declined 30 to 50 ft by 2000 and 100 to 125 ft by 2020. Water levels rose in the extreme southeastern part of the study area where the unnamed unit (Tul) crops out. This is an area of low transmissivity and, with minimal pumping, water levels rose as much as 50 ft from increased return flow of imported irrigation water.

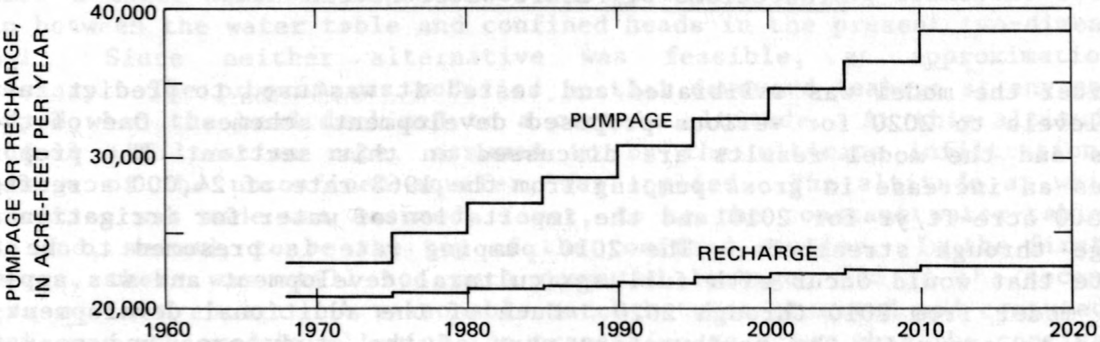

FIGURE 2.--Projected gross pumping and recharge rates, 1968-2020.

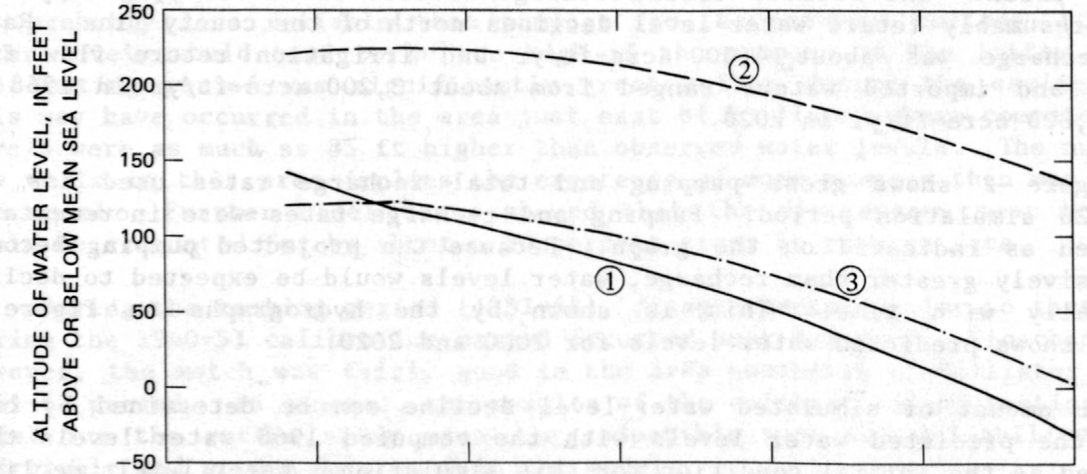

FIGURE 3.--Predicted water levels at three locations, 1968-2020. (Number in circle refers to location shown in plate 6.)

SUGGESTIONS FOR FUTURE WORK

Model analyses of the Hollister Valley ground-water basin have shown the need for additional data collection and analysis to permit an understanding of the hydrology of the basin. In particular, the existence of local confined areas and additional faults needs to be investigated. Any future work should also include a new calculation of pumpage and recharge figures. Following is a list of suggestions that should be considered for future studies.

1. The vertical and areal distribution of sand and clay should be defined from drillers' logs. This would provide a check on the present basin subdivision (pl. 2) and might isolate local confined areas. It would also improve the estimates of depth and thickness for the confining bed in the confined area.
2. Depth of screens in wells in the valley should be better defined and compared with water levels to determine the extent of water-level variations with depth.
3. The possible existence of additional faults should be investigated. Unidentified faults trending in a direction generally parallel to the Calaveras fault may exist between Hollister and Arroyo Dos Picachos.
4. Better quantification of pumpage and stream recharge rates should be made for future modeling efforts. Pumpage could be calculated and distributed from power consumption records on an annual basis; stream recharge could be computed by an analytical infiltration approach.
5. Use of a three-dimensional model is necessary for adequate simulation of water levels in the study area. Additional data and analysis, as described above, would be required for this type of model.

A project is currently underway to evaluate and revise the observation-well network in the Hollister Valley. Some of the uncertainties may be resolved through this work. As a result of this project, improved water-level data should be available in several years which, when coupled with better pumpage and recharge figures, would provide a more adequate data base for checking the validity of the model.

SUMMARY AND CONCLUSIONS

The aquifer underlying the Hollister Valley includes, from top to bottom, alluvium, the San Benito Gravels of Lawson (1893), and an undifferentiated sedimentary unit. These units vary in thickness from 0 to about 1,300 ft and consist of clay, silt, sand, gravel, and poorly consolidated sandstone. Both unconfined and confined conditions occur, with much of the northern part of the aquifer confined beneath a fairly tight and extensive clay bed. Parts of the originally confined area have converted to unconfined conditions as water levels have declined below the top of the aquifer due to pumping. Considerable faulting has occurred in the valley; faults form part of the boundary of the study area and are internal partial barriers to flow.

The valley is essentially a closed basin with recharge by stream and rainfall infiltration and discharge by pumping and leakage through the confining bed. This leakage is eventually lost to evapotranspiration or drained from San Felipe Lake by surface diversion. During a normal rainfall year the aquifer receives about 16,500 acre-ft of recharge from streams, boundary underflow, and rainfall. Average net annual pumpage during the period 1951-68 was about 19,400 acre-ft.

A two-dimensional digital model of the aquifer was constructed and calibrated by adjusting hydrologic parameters to obtain the best match of observed and computed water levels for the period 1940-51. The first part of this period, 1940-46, had near-normal rainfall conditions, and average recharge conditions were used in the model. During the latter part of the calibration period the rainfall was below normal, and reduced recharge conditions were used. Results of the calibration were generally good; computed water levels matched observed water levels within 15 ft in most developed areas. The discrepancies that did occur, principally near Arroyo Dos Picachos, probably resulted from inadequate knowledge of the geology of the aquifer rather than from errors in pumpage or recharge data. Unidentified faults or local confining layers may account for most of the discrepancies encountered during model calibration.

The model was tested by simulating water levels from 1951-68, using model parameters determined during calibration. The pumping data during this period were less reliable than for the calibration period. Computed water levels near Hollister for 1968 were as much as 35 ft higher than observed water levels. Testing indicated, however, that this discrepancy could have resulted from a 20-percent error in pumpage data.

The model was used to predict future water levels to the year 2020 for a proposed development scheme. This scheme involved increasing pumpage to an ultimate rate 60 percent greater than the 1968 pumping rate and importing water for irrigation and streambed recharge. Much of the additional pumpage was proposed for the minimally developed northwestern part of the study area. Predicted water levels in this area represent a decline of as much as 170 ft by the year 2020. Predicted declines in currently developed areas near Hollister ranged from 100 to 125 ft by 2020.

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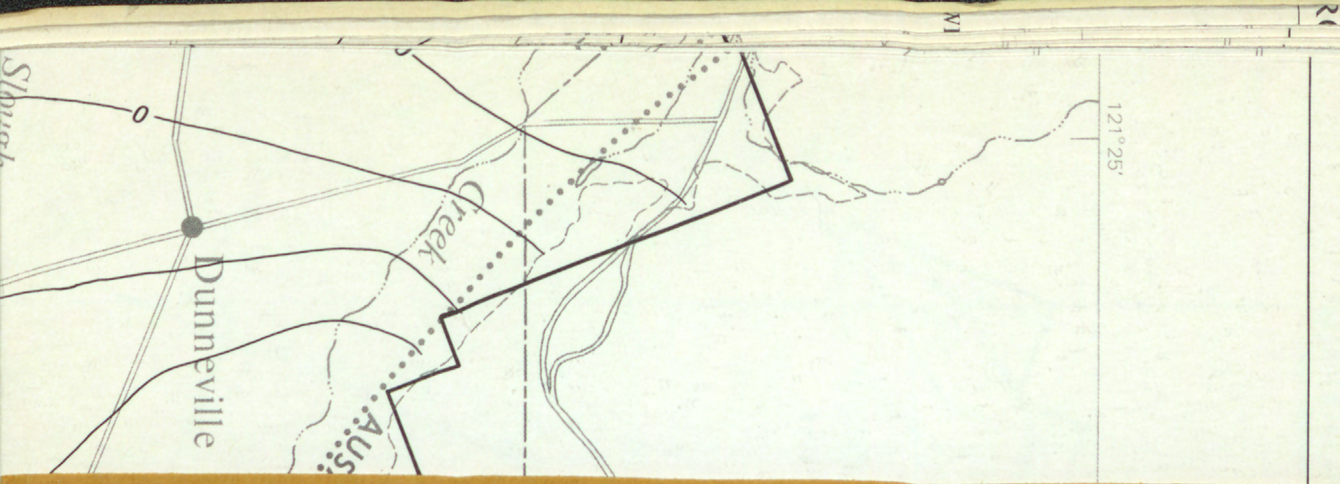
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