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Distribution of Nitrate in Ground Water Redlands, California

Geological Survey, Menlo Park, Calif Water Resources Div

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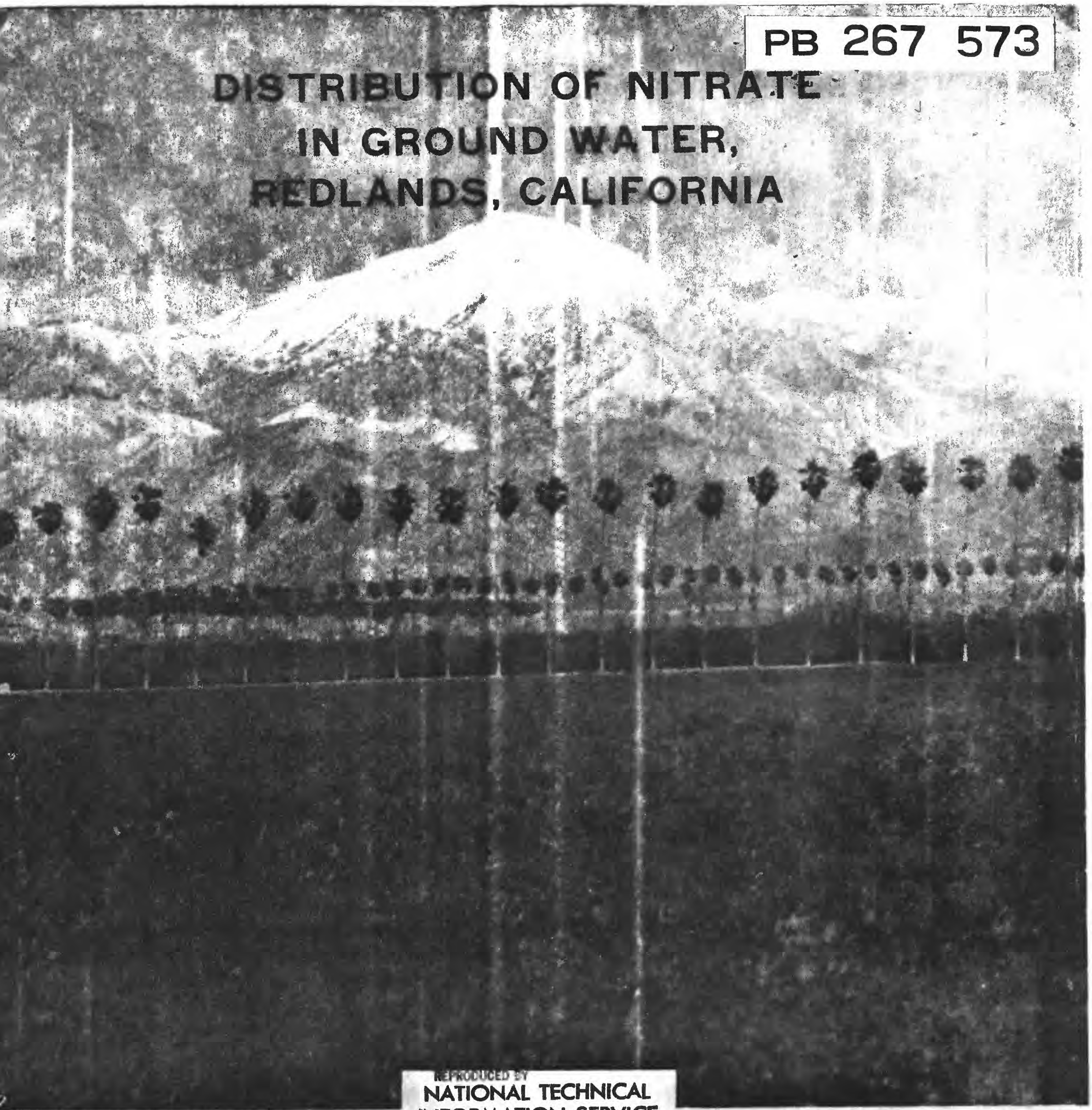
DISTRIBUTION OF NITRATE IN GROUND WATER, REDLANDS, CALIFORNIA



U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 76-117

Prepared in cooperation with the
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16. Abstracts Wells producing water with nitrate as nitrogen concentrations in excess of 10 milligrams per liter are common throughout the Redlands, Calif., area. Nitrate as nitrogen concentrations in water from the saturated part of the aquifer ranged from much greater than 20 milligrams per liter at the water table to less than 5 milligrams per liter at depths of 300 feet below the water table. This depth dependence suggests that the major source of nitrate is a generalized area-wide infiltration of high-nitrate water downward from the surface through the unsaturated zone. The nitrate concentration in water from individual wells is dependent primarily upon depth and well construction--particularly aquifer seal and aquifer penetration--and secondarily upon well location. Nitrate concentrations of water in wells are increased by heavy pumping which causes high-nitrate water near the water table to be pulled deeper. In addition, where a rising water table intercepts high-nitrate, downward infiltrating water in the unsaturated zone, increased nitrate concentrations in water from wells can result, a condition implied by the result of this study.

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CONVERSION FACTORS

For use of those readers who may prefer metric units rather than English units, the conversion factors for the terms used in this report are listed below:

Multiply English unit	*By*	*To obtain metric unit*
acres	4.047×10^{-1}	ha (hectares)
acre-ft/d (acre-feet per day)	1.233×10^{-3}	hm^3/d (cubic hectometers per day)
ft (feet)	3.048×10^{-1}	m (meters)
gal/min (gallons per minute)	6.308×10^{-2}	ℓ/s (liters per second)
in/hr (inches per hour)	2.540×10	mm/hr (millimeters per hour)
(lb/acre)/yr (pounds per acre per year)	1.123	(kg/ha)/yr (kilograms per hectare per year)
mi (miles)	1.609	km (kilometers)

The U.S. Environmental Protection Agency (1972) criteria for nitrate concentrations are expressed in terms of an equivalent weight of nitrogen (N). The equivalent value for nitrate (NO_3) can be obtained by use of the following conversion factor:

Nitrate as nitrogen (NO_3-N) in milligrams per liter (mg/ℓ) multiplied by 4.429 equals nitrate (NO_3) in mg/ℓ.

DISTRIBUTION OF NITRATE IN GROUND WATER, REDLANDS, CALIFORNIA

By Lawrence A. Eccles and Wesley L. Bradford

ABSTRACT

The distribution of nitrate in ground water in the Redlands area is dependent primarily upon depth below the water table and areal location. Concentrations of nitrate as nitrogen exceeding 10 milligrams per liter are generally found within the upper 50 feet below the water table in the study area, with the exception of the areas in and adjacent to the Santa Ana River and Mill Creek channels.[1] Concentrations of nitrate as nitrogen less than 10 milligrams per liter are found throughout most of the area at depths below the water table of 300 feet or greater. This depth dependence suggests that the major source of nitrate is a generalized area-wide infiltration of high-nitrate water downward from the surface through the unsaturated zone. The largest point source of nitrate in the study area is from the Redlands sewage-treatment facility. The high-nitrate concentrations presently found along the Santa Ana River channel, downgradient from the Redlands sewage-treatment facility, probably came from the nearby previously used facility which was abandoned in 1963.

The nitrate concentration in water from individual wells is dependent primarily upon depth and well construction--particularly aquifer seal and aquifer penetration--and secondarily upon well location. Nitrate concentrations of water in wells are increased by heavy pumping which causes localized depressions of the water table and which subsequently causes the high-nitrate water near the water table to be pulled deeper and to constitute an increasing fraction of water produced by the well. The results of this study and the data collected before and after the 1969 flood, which caused an abnormally large rise in the water table, suggest that increased nitrate concentrations in water from wells can result if a rising water table intercepts high-nitrate, downward-infiltrating water in the unsaturated zone.

[1]Nitrate concentrations are expressed in terms of an equivalent amount of nitrogen (U.S. Environmental Protection Agency, 1972).

INTRODUCTION

Statement of the Problem

Concentrations of nitrate as nitrogen (NO_3-N) in excess of 10 mg/ℓ (milligrams per liter) are frequently found in water from wells throughout the Redlands area (figs. 1 and 2). Many of these wells are used for public water supplies. The U.S. Environmental Protection Agency (1972) recommends a limit of 10 mg/ℓ nitrate as nitrogen for such water.

Agricultural and urban development in the Redlands area has relied upon multiple uses of ground-water resources. Surface-water resources alone have been inadequate to meet either irrigation or domestic water-supply requirements. Much applied irrigation water percolates to the ground-water aquifer and is used again. The reuse of ground water, the use of high-nitrogen fertilizers, and several other factors probably caused the high-nitrate concentrations in water from wells in the study area (Kearney Foundation, 1973).

Some citrus growers in the Redlands area reported that they have not applied nitrogen fertilizer for more than 5 years because of the high concentrations of nitrate in their irrigation water. Nitrate in irrigation water is generally beneficial to crops; however, excessive nitrate applied at the wrong time can cause regreening in oranges, reduce sugar content in sugar beets, and have adverse effects on fruit-set in tomatoes. For these and perhaps other crops, water low in nitrate would be advantageous (P. F. Pratt, written commun., March 1976).

High-nitrate concentrations in drinking water can be harmful. The intake of nitrates can cause a condition in infants and livestock known as methemoglobinemia or nitrate cyanosis, a condition caused by the reduction of nitrate to nitrite in the intestinal tract. The nitrite in turn reacts with the blood's hemoglobin to form methemoglobin. The altered hemoglobin can no longer carry oxygen (McKee and Wolf, 1963). The nitrite can also react with amines to produce nitrosamines, some of which may be cancer-causing agents (Universities Council on Water Resources, 1974). The U.S. Public Health Service (1962) requires that users of water with nitrate concentrations exceeding 10 mg/ℓ (as nitrogen) be warned of the dangers of giving the water to infants. Thus, high-nitrate concentrations in water supplies in the Redlands area may be beneficial to some agricultural users and detrimental to public water-supply purveyers.

The solution is to avoid high-nitrate concentrations in public water supplies. To help accomplish this, the U.S. Geological Survey, in cooperation with the San Bernardino Valley Municipal Water District (SBVMWD), began a study in 1974 to determine the distribution of nitrate in ground water in the Redlands area.

Purpose and Scope of Investigation

The purposes of this investigation were to determine the present (1975) areal and vertical distribution of nitrate in ground water in the Redlands area and ascertain the cause of the high-nitrate concentrations.

Only water from production wells currently in service was sampled for nitrate analysis. Existing data on water levels, well depths, and the perforated intervals of well casing, on file with the Geological Survey or provided by the SBVMWD and other local agencies, were used to interpret the nitrate data. In addition, important sources of nitrate as identified by the Kearney Foundation (1973) are briefly discussed.

Thanks are extended to the San Bernardino Valley Municipal Water District and the city of Redlands, Department of Public Works for their help in carrying out the investigation, to John Lemberger, the city of Redlands Water Quality Control Officer who provided unpublished data and helped acquire many of the water samples, and to Professor Parker F. Pratt of the University of California, Riverside, who reviewed this report.

Area Description

Location and Land Use

Redlands is in the Santa Ana River basin at the east end of the San Bernardino Valley near the base of the San Bernardino Mountains in southern California. The general distribution of urbanization and of citrus culture is shown in figure 1; however, figure 1 does not reflect all the new low-density housing intermixed with citrus groves. Land use for the previous half century, which is perhaps more pertinent to the present ground-water quality problems, would show more citrus groves, and citrus density would be higher. Currently, many groves are receiving minimum maintenance, and the planting of new citrus groves has practically ceased. Urban land uses are characterized by low-density residential and related uses. As urbanization progresses, home-managed turf grass will be the most significant crop replacing citrus.

The largest domestic water suppliers taking water from wells in the study area are the city of Redlands and the Gage Canal Co. The city of Redlands derives its water from wells and flow in Mill Creek. The Gage Canal Co. gets its water from wells in secs. 13 and 23, T. 1 S., R. 4 W., which are along the Santa Ana River near the west end of the study area. This water is pumped to the city of Riverside in a pipeline.

Prior to 1950, sewage disposal was primarily by septic tank; now much of the area is sewered. Many outlying areas around Redlands, including the Mentone area, are still using septic tanks.

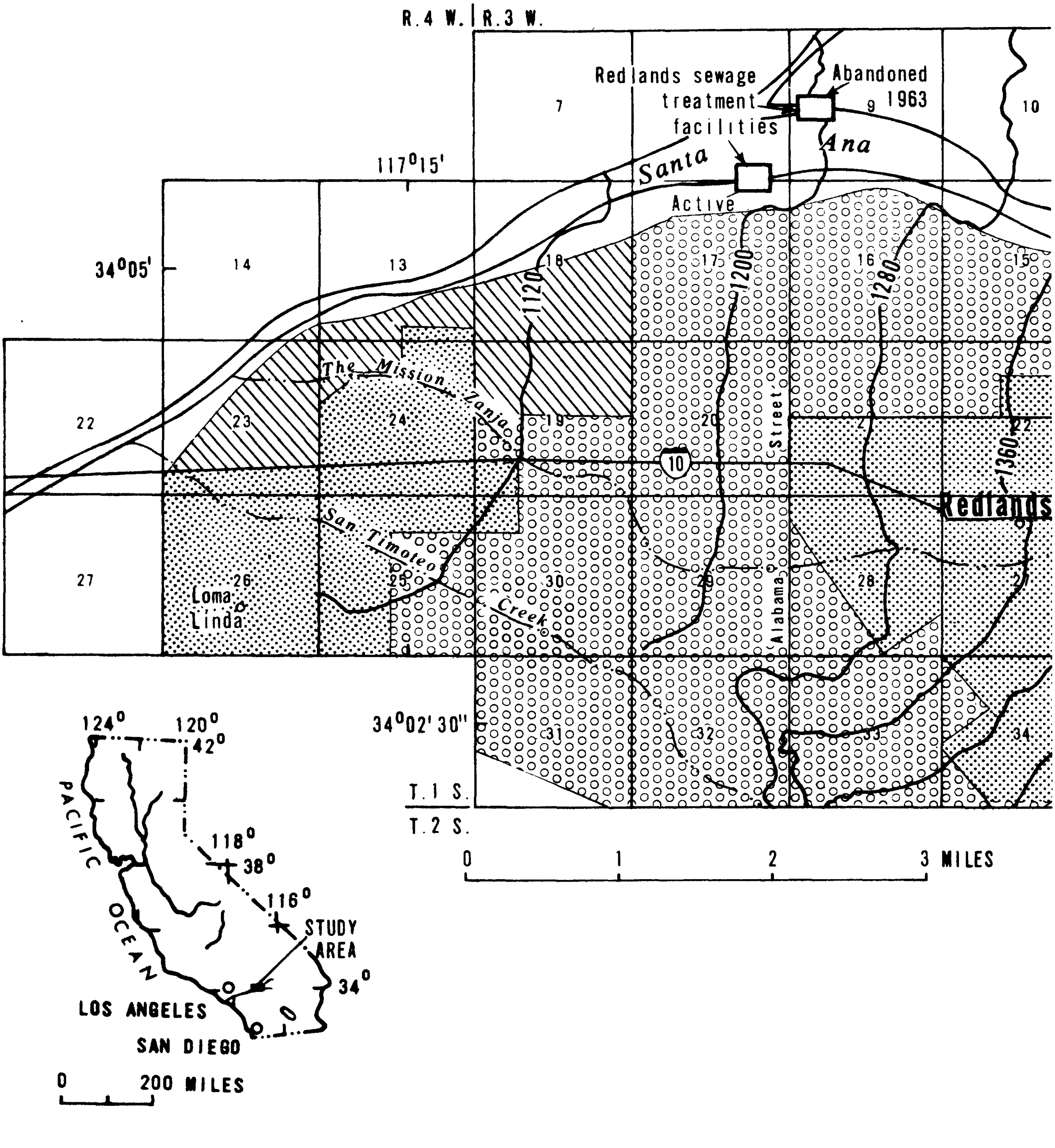
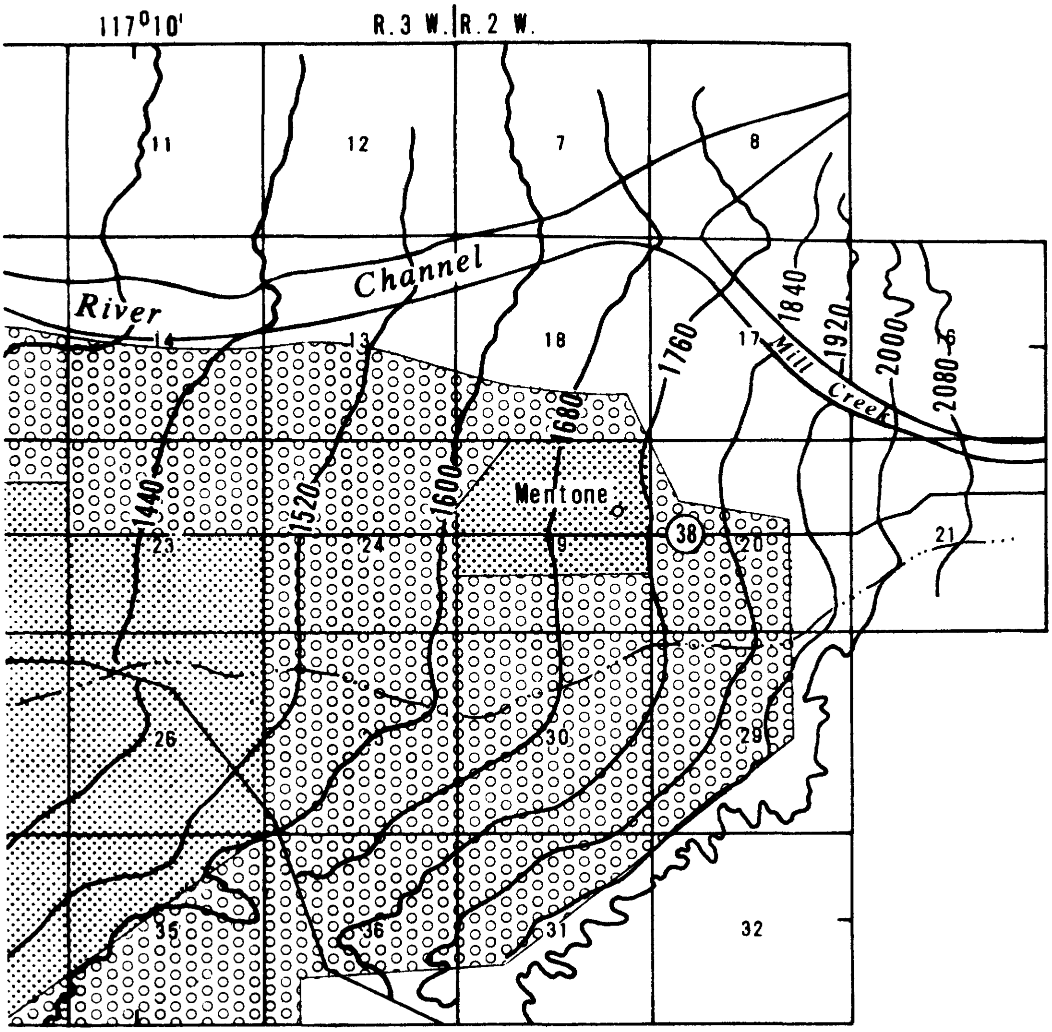


FIGURE 1.--Study area showing land use as of 1975.



EXPLANATION

CITRUS GROVES

URBAN AREA

FIELD CROPS

——1120—— ALTITUDE OF LAND SURFACE, IN FEET ABOVE MEAN SEA LEVEL--Interval 80 feet

FIGURE 1.--Continued

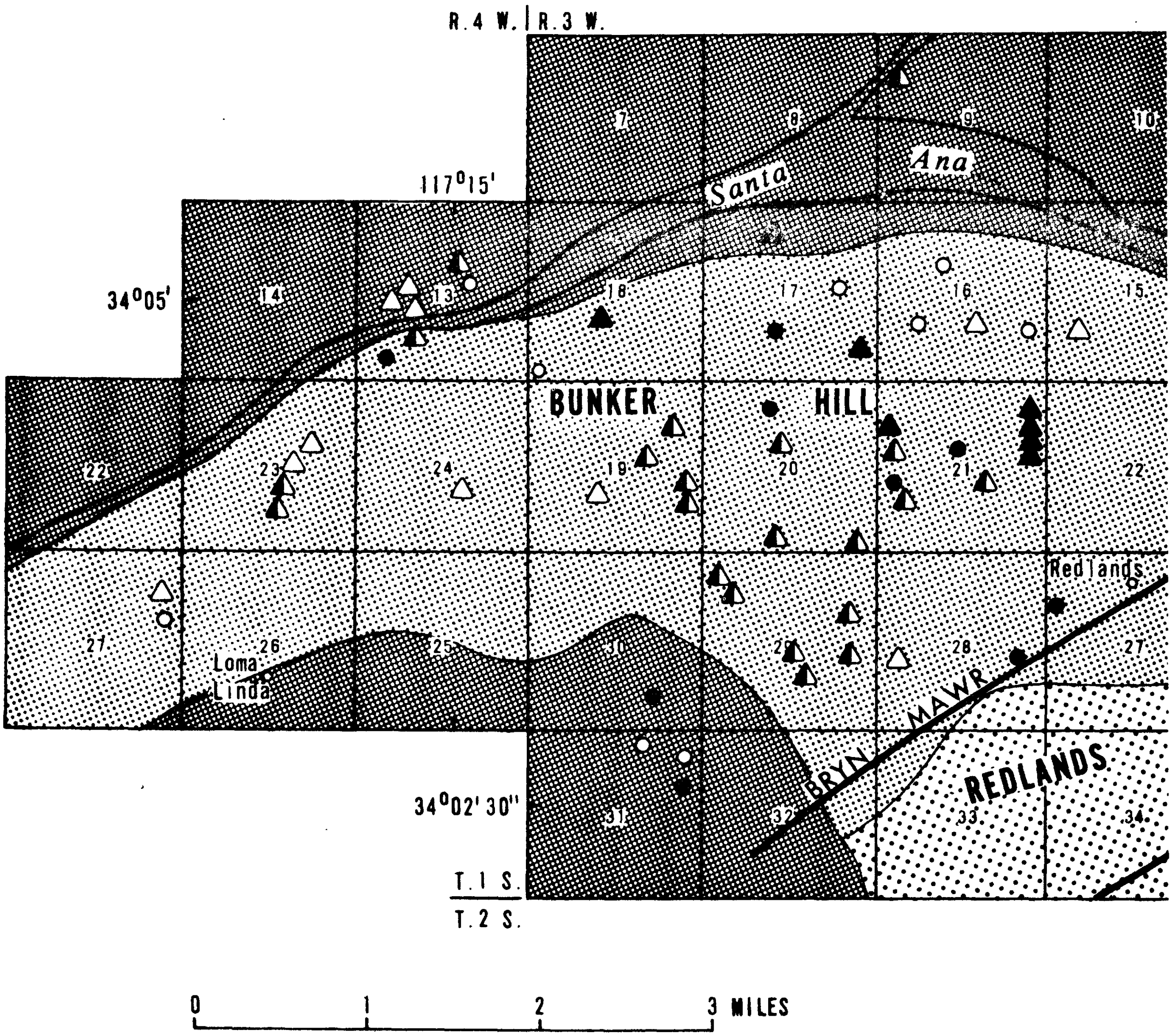
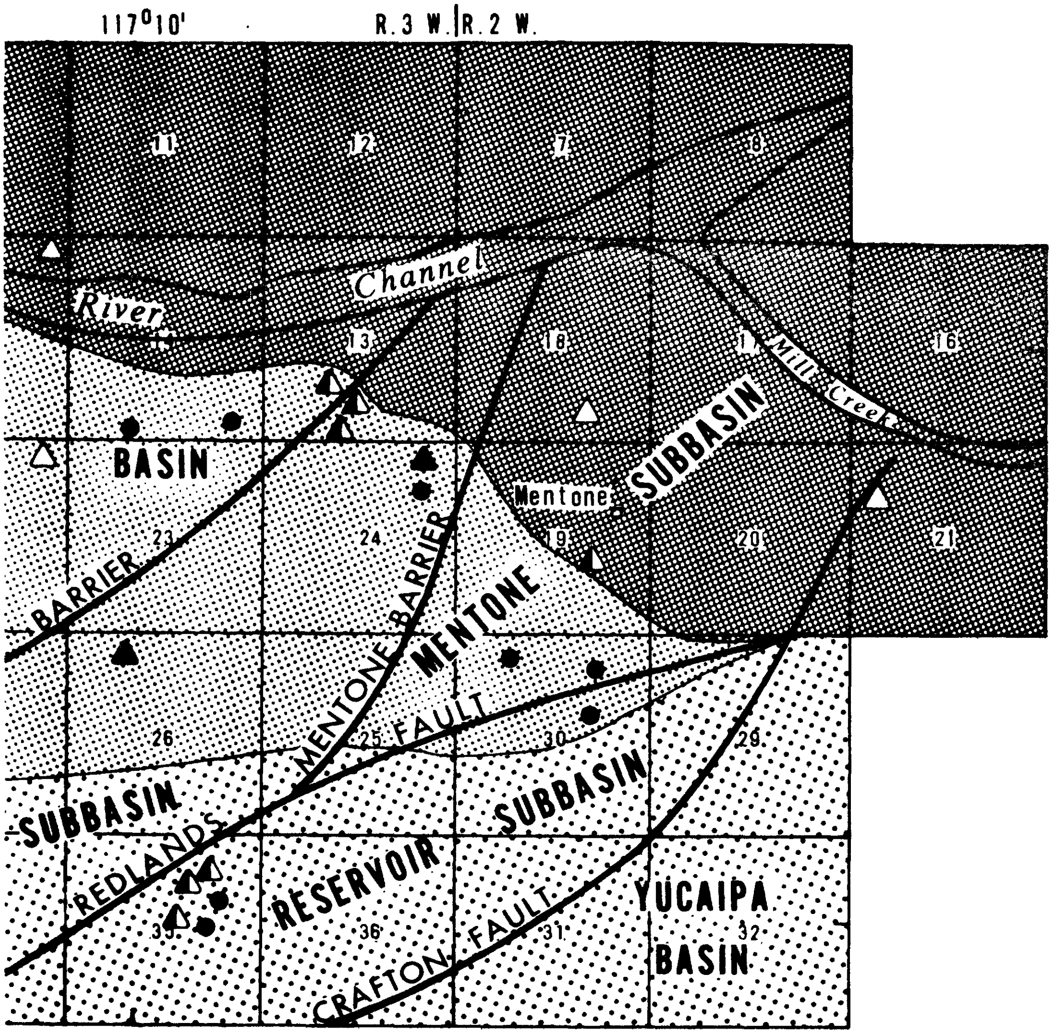


FIGURE 2.--Geohydrologic features of study area and concentration of nitrate as nitrogen in water from wells.



EXPLANATION

WATER-INFILTRATION RATES OF SOILS UNDER WETTED CONDITIONS--(After Kearney Foundation, 1973) In inches per hour

- Greater than 6
- 0.6-6
- 0.06-0.6

NITRATE AS NITROGEN IN WATER FROM WELLS, IN MILLIGRAMS PER LITER

- ▲ Greater than 20
- ● 10-20
- ◭ 5.0-9.9
- △ 1.0-4.9
- o Less than 1.0

FIGURE 2.--Continued.

Large-scale sewage disposal has been and is presently carried out in the vicinity of Alabama Street and the Santa Ana River (fig. 1).

Geohydrology

The study area encompasses all or part of the following ground-water basins and subbasins: The Bunker Hill and Yucaipa basins, and the Redlands, Reservoir, and Mentone subbasins (fig. 2). The boundaries of the study area were based on hydrologic features, discussed later, except for the southern boundary which was limited by the availability of wells that could be sampled.

Ground-water and land-surface contours in the study area indicate a gradient from east to west (figs. 1 and 3). The depth to water below land-surface datum ranges from about 20 ft on the east to about 120 ft near the west end and to nearly 300 ft along the Redlands fault.

The aquifer in the study area is alluvium consisting of sand, gravel, and boulders with small and variable clay and silt fractions. Interspersed in the alluvium are lenticular deposits of clay and silt with low permeability, but there are no lenses extensive enough to cause any perched ground-water bodies. In this study area the aquifer may be considered heterogeneous and unconfined.

Bedrock of comparatively low permeability underlies the alluvium intersecting the surface at the eastern limit of the study area. The depth to bedrock varies widely throughout the Santa Ana River basin but in this study area probably does not greatly exceed 1,000 ft (Burnham and Dutcher, 1960, fig. 10).

The aquifer is cut by faults and barriers across which the flow of ground water is generally restricted. The Redlands and Crafton faults separate the Bunker Hill basin from the Yucaipa basin. Water-level contours are discontinuous across the Redlands fault with differences exceeding 200 ft (fig. 3). The Bryn Mawr and Mentone barriers are indicated by discontinuous ground-water levels. These barriers define the Redlands and Mentone subbasins shown in figure 2 (Burnham and Dutcher, 1960).

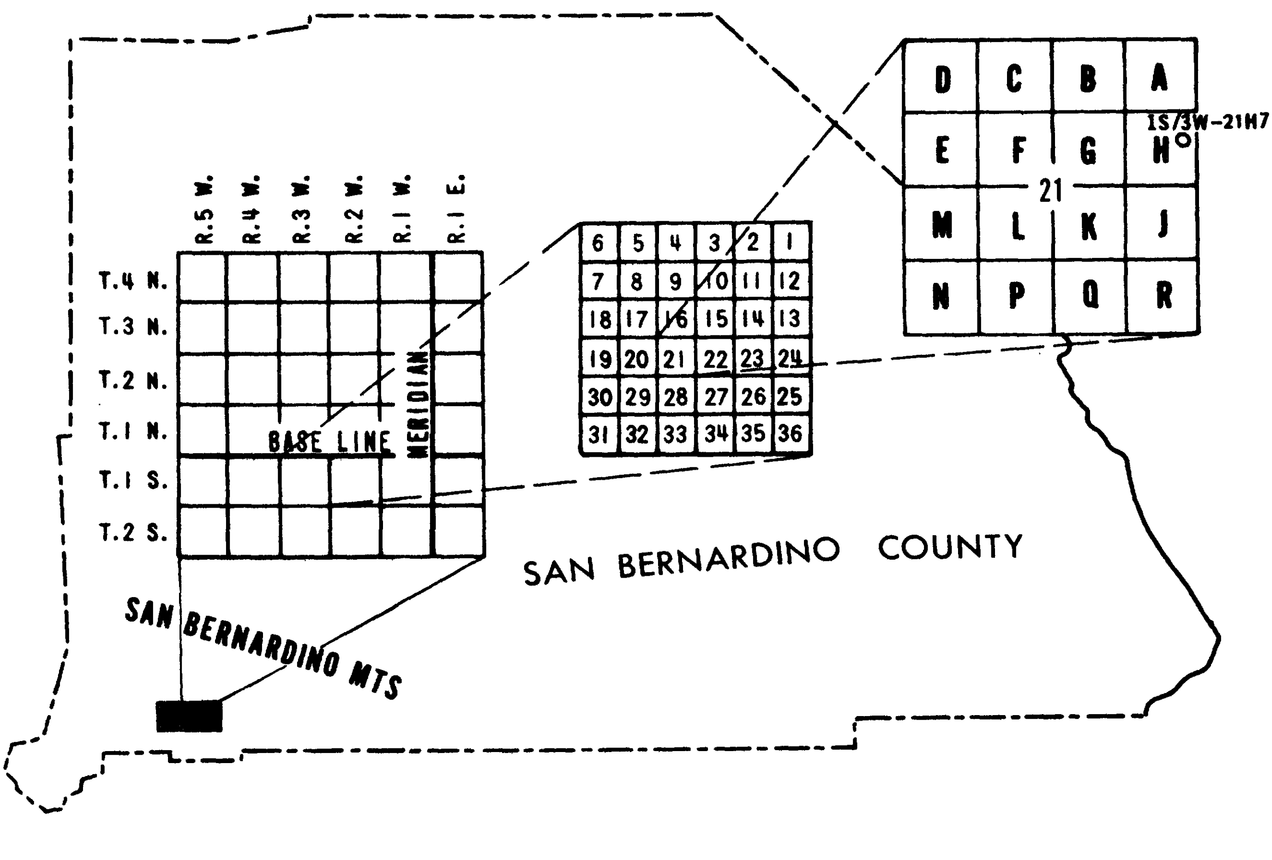
Recharge to ground water is largely from natural and artificial flow in the Santa Ana River and Mill Creek, from irrigation return, and from direct infiltration of precipitation.

The permeability of soil (fig. 2) influences the quantity and quality of water recharging the underlying aquifer. The infiltration rates for soil measured under wetted conditions vary more than two orders of magnitude across the study area. The Bunker Hill basin, overlain with moderate to highly permeable soils, is able to infiltrate more than 6 in/hr of water in some places. The Redlands subbasin is partly covered by a lens of relatively low-permeability soil, and most of the Yucaipa basin within the study area has low-permeability soils.

The western part of the Bunker Hill basin contains confined aquifers. The approximate eastern extent of the confining layers determined the western boundary of the study area. Because frequent and low-nitrate recharge takes place along the Santa Ana River channel, it was chosen as the northern limit of the study area. The eastern and southeastern limits were taken to be along the Crafton fault.

Well-Numbering System

Wells are numbered according to their location in the rectangular system for subdivision of public land. For example, in the well number 1S/3W-21H7, that part of the number preceding the slash indicates the township (T. 1 S.); the number and letter following the slash indicate the range (R. 3 W.); the number following the hyphen indicates the section (sec. 21); the letter following the section number indicates the 40-acre subdivision of the section according to the lettered diagram below. The final digit is a serial number for wells in each 40-acre subdivision. The area covered by this report lies entirely in the southwest quadrant of the San Bernardino base line and meridian.



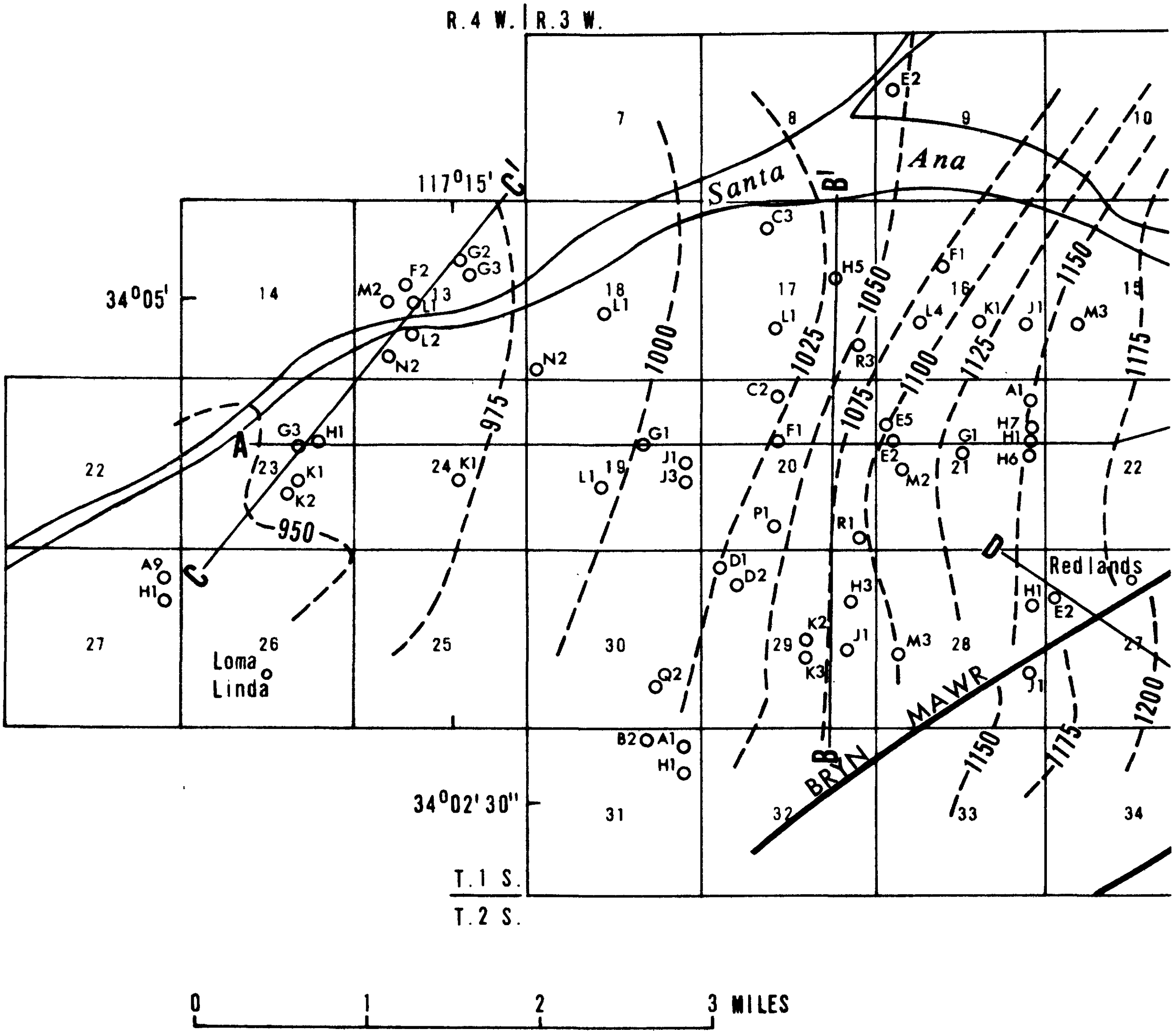
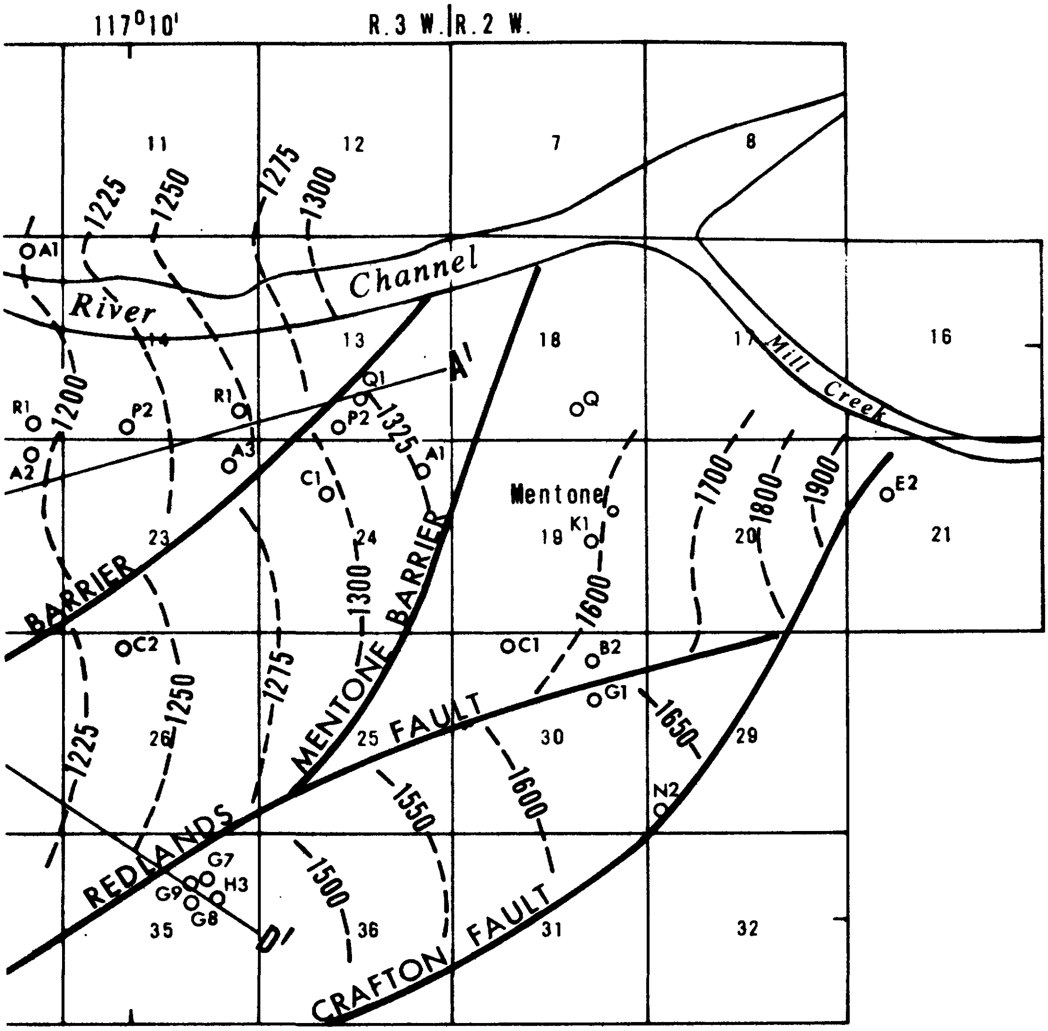


FIGURE 3.--Water-table contours and location of wells and vertical sections.



EXPLANATION

A———A' LOCATION OF VERTICAL SECTION

o C2 WELL AND NUMBER

— — 975 — — WATER-TABLE CONTOUR--(After F.B. Laverty, written commun., 1974) Shows altitude of water table April 1974. Contour interval 25, 50, and 100 feet. Datum is mean sea level

FIGURE 3.--Continued.

Background

Prior Studies

A pertinent prior study concerning nitrate in ground water in the Redlands area was that by the Kearney Foundation of the University of California (1973) concerning nitrate in relation to ground-water pollution. The study area of that report encompassed not only Redlands but also the upper Santa Ana River basin. Some important aspects covered in that study were:

1. A review of available data on nitrate in ground water in the area.

2. A history of land and water use.

3. Waste disposal and other practices related to nitrate in ground water.

4. Causes of high-nitrate concentrations.

5. Guidelines for reducing nitrate pollution.

6. Identification of problems needing further study.

An extensive description of geology and ground-water hydrology of the area was given by Burnham and Dutcher (1960). Water-bearing deposits were identified and their hydraulic characteristics given. Ground-water barriers and the basins and subbasins were described. Sources of recharge and discharge for the ground-water basins were some of the more important elements of the report.

Sources of Nitrate in Ground Water

Three sources contributing nitrate to ground water in the study area have been identified by the Kearney Foundation of the University of California (1973): (1) Nitrogen fertilizers used for citrus and field crops; (2) effluent from the Redlands sewage-treatment facility, which is discharged to the Santa Ana River channel (fig. 1); and (3) to a much lesser extent, percolation from septic tanks. The most important source is commercial nitrogen fertilizer.

Recharge by natural flow from the Santa Ana River and Mill Creek is not a source of nitrate to ground water. Chemical analyses of surface water and of water from wells in the channels upstream of the Redlands sewage-treatment plant show little or no nitrate (Coe and Florian, 1957; California Department of Water Resources, written commun., 1972).

Nitrogen fertilizers.--The area has been used intensively for agriculture during the past 75 years. Citrus has been, and still is, the dominant crop. According to the Kearney Foundation (1973), the accumulation of nitrate in ground water is due mostly to high application rates of nitrogen fertilizers to citrus crops combined with low soil denitrification potential and high infiltration rates. Except for leguminous plants, nitrogen fertilization is often necessary to obtain high-yield, high-quality crops. Commercial nitrogen fertilizers used in the study area are anhydrous ammonia gas, ammonium, sodium and calcium nitrate, ammonium sulfate, urea, and fish emulsion. Manures are no longer an important source of nitrogen but are still used as soil conditioners (Luckhardt, 1974).

Most nitrogen in applied fertilizers is converted to either nitrate or nitrogen gas by bacteria in the root zone. The nitrogen that is not utilized by plants or that is lost to the atmosphere as nitrogen gas is subject to leaching by infiltrating water. The uptake of nitrogen applied to citrus crops in the past has been less than 50 percent (Kearney Foundation, 1973, p. 25). A simplified description of the nitrogen cycle in soil is given in figure 4 (Salle, 1961).

In the past, nitrogen application on some citrus crops in the Redlands area has exceeded 600 (lb/acre)/yr (Kearney Foundation, 1973, p. 25). With the advent of the leaf analysis for crop nitrogen requirements in the 1960's, the application of nitrogen fertilizers to citrus crops has been greatly reduced. Recent research on nitrogen requirements for citrus crops indicates that further reduction of nitrogen-application rates could be effected without reducing crop yields or quality. Present application for citrus crops ranges from 0 to 300 (lb/acre)/yr, and from 100 to 300 (lb/acre)/yr for field crops. Home-managed turf grass, the most significant crop replacing citrus, receives about 40 (lb/acre)/yr (Kearney Foundation, 1973). Figures for nitrogen leached below the root zone of turf grass compared to that leached below the root zone of citrus crops are not available.

The few analyses of ground water in the study area during the 1930's show much lower nitrate concentrations than those in the 1970's (Coe and Florian, 1957; Kearney Foundation, 1973), thus suggesting a buildup of nitrate with time. Those early nitrate values could be somewhat low because of the sample-preservation techniques used at that time, but it is unlikely that they could be sufficiently in error to alter the implication that there has been a buildup of nitrate concentration in ground water.

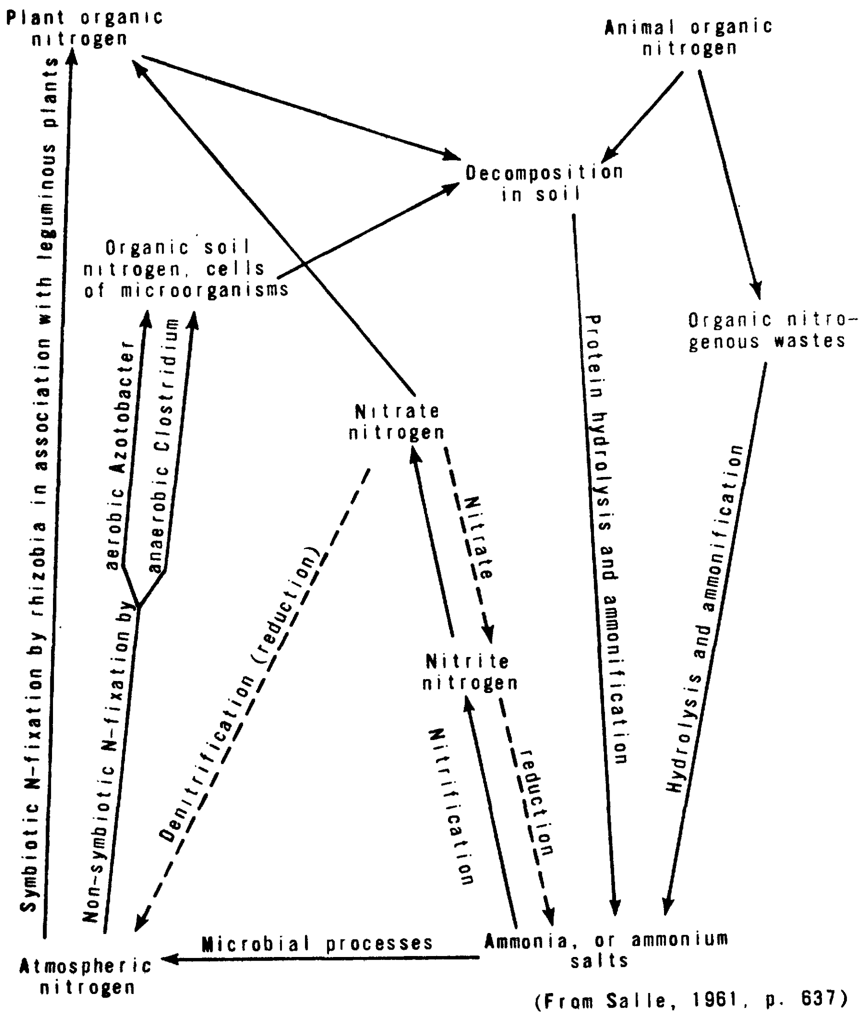


FIGURE 4.--The nitrogen cycle.

Two explanations are proposed for the observed nitrate buildup since the 1930's. First, prior to the 1930's, manure--which contains organic carbon--was used as nitrogen fertilizer rather than high-nitrogen inorganic chemical fertilizers. Organic carbon is a required energy source for denitrifying bacteria, and the rates of denitrification increase with its availability. The organic content of the manure may have caused a much larger fraction of the available nitrate to undergo denitrification (Lance, 1975). Furthermore, the rate at which nitrogen was applied to crops as manure was probably much lower than that applied as commercial chemical fertilizer. Second, it is possible that nitrate formed in and leached from the surface soil has been proceeding downward through the unsaturated zone and only recently has intercepted the water table. The nitrate now reaching the water table could be from nitrogen applied to the surface many years ago. Pratt, Jones, and Hunsaker (1972) noted that a considerable time lag, perhaps 40 years or more, may be expected between the application of nitrogen fertilizer and its appearance in ground water for areas with soil types and depth to water like that found in the Redlands area.

High-nitrate concentrations are expected in the unsaturated part of the aquifer beneath the orange groves in the Redlands area. This expectation is based on results of analysis for nitrate from soil solutions of core samples taken below the root zone of an experimental orange grove in an area of California similar to Redlands. Results from one experimental plot showed a NO_3-N concentration of 45 mg/ℓ when a controlled fertilization rate of 350 (lbs/acre)/yr and a leaching fraction[1] of 0.41 were used on this plot. The fertilization rate and irrigation practice are similar to those used by many growers in the Redlands area in the past (Kearney Foundation, 1973).

Effluent from the Redlands sewage-treatment facility.--The effluent discharged from the Redlands sewage-treatment facility (fig. 1) is the largest point source of nitrogen in the area. A discharge of 7.4 acre-ft/d containing 30-40 mg/ℓ of ammonia (equivalent to 25-33 mg/ℓ NO_3-N) is infiltrated into the Santa Ana River channel. A sewage-treatment facility discharging effluent equal to 30 mg/ℓ NO_3-N to a sandy soil in another area of California was investigated by the Kearney Foundation (1973). Analysis of soil solutions from core samples taken beneath an infiltration pond showed NO_3-N concentrations of 5,200 mg/ℓ directly beneath the pond and 100 mg/ℓ just above the saturated zone. Similar findings might be expected for the presently used Redlands sewage-treatment facility. A nearby sewage-treatment facility that was used until 1963 also discharged effluent to the Santa Ana River channel (fig. 1). The concentration of nitrogen compounds in the effluent from that now-abandoned facility was probably as high as that in the effluent from the presently used sewage-treatment facility. The high-nitrate concentrations presently found along the Santa Ana River channel, downgradient from the Redlands sewage-treatment facility, most likely came from the previously used facility.

Percolation from septic tanks.--Because much of the area investigated is presently (1975) serviced by sewers, infiltration from septic tanks is a diffuse and minor source of nitrate compared with previous high-application rates of nitrogen fertilizer. Septic tanks, still numerous in the Mentone area, could be a localized source of nitrate.

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[1]Leaching fraction--water applied in excess of crop requirements to reduce soil salinity.

Movement of Nitrate from the Surface to the Saturated Zone

The inferred mechanism for nitrate transport from the surface to the saturated zone is based on two major assumptions. Both are reasonable within limits. First, it is assumed that once nitrate passes through the root zone to the unsaturated and saturated zones it moves with the infiltrating water and undergoes little or no chemical change (Pratt and others, 1972). Second, it is assumed that flow through the unsaturated zone is vertical (Todd, 1960). Thus, nitrate slowly percolates vertically through the unsaturated zone and eventually reaches the saturated zone contributing to increased nitrate concentrations.

Mixing of Nitrate in the Saturated Zone

In semiarid areas such as Redlands, with a wet and a dry season, water levels decline during the pumping season and recover during the wet season with recharge. Water rising in the saturated zone during recharge mixes with water in the unsaturated zone. This cycle is repeated annually and is exaggerated by exceptionally wet or dry years. Layers of nitrate of different concentrations, related to periods and rates of fertilizer application, infiltrate downward and are intercepted by the fluctuating water table. Thus no rigid layer of high nitrate is established in the saturated zone. Also, a significant period of recharge does not necessarily cause lower nitrate concentration in wells, because a rise of the water table would result in mixing with the high-nitrate water in the unsaturated zone. Based on the results of the study concerning nitrate concentrations below the root zone of a citrus grove (Kearney Foundation, 1973), high-nitrate concentrations below the root zone would be expected in Redlands. Analyses for nitrate from several wells in the Redlands area for the period before and after the 1969 flood indicate higher nitrate concentrations in some wells following the recharge (table 1).

TABLE 1.--*Concentration of nitrate as nitrogen (NO_3-N) in selected wells before and after the 1969 flood*

[After California Department of Water Resources unpublished data]

Well No.	Before 1969 flood		After 1969 flood	
	Date	NO_3-N (mg/ℓ)	Date	NO_3-N (mg/ℓ)
1S/3W-15R1	5-03-67	9.1	9-17-71	30
1S/3W-17L1	5-28-68	15	5-15-69	17
1S/3W-19G1	8-29-68	4.1	9-10-70	6.4
1S/3W-28H1	5-28-68	8.6	5-14-69	13
1S/3W-35H3	8-29-67	8.2	6-23-71	15

METHODS

Drawbacks in Sampling Production Wells

Vertical mixing of water of different chemical types may be severely restricted in an unconfined alluvial aquifer (Hughes, 1975, p. 15-20) because of intermittent recharge of water of different quality to the saturated zone through the unsaturated zone. A vertical stratification often results with each recharge event retaining its general chemical identity. Infiltration of good-quality surface flow in the Santa Ana River alternating with poor-quality water from seasonal irrigation return is an example of intermittent recharge. The areal distribution of each zone of different water quality is also often discontinuous and difficult to locate. An ideal monitoring network would be designed to describe both the vertical and the areal distribution of the constituent of interest. This is best done by constructing test wells perforated at specific depth zones, a method used successfully by Hughes (1975) in a sampling network for an unconfined aquifer at Barstow, Calif.

Two serious drawbacks to interpreting ground-water-quality data in terms of vertical and areal distribution result from sampling only production wells. First, because a production well is designed to provide a high volume and economical water supply, the perforated interval of casing usually intercepts a large depth interval in the aquifer. Furthermore, because various zones in the aquifer may have differing hydraulic conductivity, the mixture of water in the well at the time of sampling cannot be a proportional mixture from all depth zones intercepted. Also, not all screened zones in a well will have the same efficiency. Thus a highly permeable zone may produce less water than a poorly permeable zone. In short, the composition of water in the well is an undefinable mixture of water from all zones that are perforated. If the perforated interval is large, vertical detail in the quality distribution is masked.

Second, the composition of water from production wells in unconfined systems is not only gradually variable throughout the pumping season (Taylor and Bigbee, 1973), but also abruptly variable from the instant the pump is started to the time that drawdown and the cone of depression have stabilized. At first only water in the well and in storage in the immediate vicinity of the well is discharged. As the water removed from storage is replaced, the quality rapidly changes to that of the ground-water body under influence of the well as pumping continues. Heavy pumping tends to pull water deeper by localized depression of the water table (Schmidt, 1972). As the pumping season progresses, the composition of the water would be expected to change as water originally in the upper saturated zone is drawn deeper and constitutes a larger portion of the water produced from the well. This is illustrated by nitrate data collected at the city of Redlands well 31-A (1S/3W-21H7) shown in table 2. The nitrate concentrations in the well water increased 2.3 times as the pumping season progressed. Pumping could also be one explanation for deep mixing of nitrate in the immediate vicinity of the well.

Ground-water flow to the well could be short-circuiting flow paths by being pulled down through the gravel outside the casing, thus permitting slugs of nitrate-rich water to descend to deeper zones in the aquifer. Also, flow induced in adjacent wells with multiple-perforated zones could allow water to circulate from shallow to deeper zones (J. H. Feth, written commun., 1976).

TABLE 2.--*Nitrate as nitrogen* (NO_3-N) *analyses for well 1S/3W-21H7*[1] *(Redlands 31-A), spring-summer 1975*

[Sample collected by city of Redlands and analyzed by the Clinical Laboratory of San Bernardino, Inc.]

Date of sample	NO_3-N in mg/ℓ (rounded)
May 14, 1975	9
June 16, 1975	11
July 2, 1975	13
Aug. 20, 1975	21
Sept. 11, 1975	19

[1]Well characteristics given in table 3. Well pumped continually from May through October 1975. Drawdown is variable because of effects from nearby wells. This well alone has a drawdown in excess of 16 ft; in concert with other wells, drawdown exceeds this figure.

Attempts to isolate water samples to specific zones of the aquifer using inflatable packers seem to have had little success to date in the Redlands area. This technique was tried on at least one production well located in coarse material near the Santa Ana River channel (California Department of Water Resources, 1972). The vertical variation detected in nitrate concentrations was small.

Recognizing the possibility that low-nitrate water may exist at depth, the city of Redlands installed an inflatable packer in 1973 in supply well 31-A (1S/3W-21H7) at a depth of about 260 ft to exclude production from the upper part of the aquifer. The concentration of nitrate was reduced for a time but has since risen to previous levels (City of Redlands, Dept. of Public Works, oral commun., 1975). This high-yield well (capable of producing more than 4,000 gal/min) was also drilled in predominantly coarse material, suggesting the possibility that the shallower, high-nitrate water moved downward through the gravel around the packer. Alternatively, the packer may have been initially installed too high in the well, permitting excessive inflow from the shallower zones. During spring 1976, the packer was moved to a depth of 480 ft. This reduced the nitrate concentration in the water produced by the well from about 20 mg/ℓ to about 5 mg/ℓ.

Well Selection

In selecting production wells for sampling, the following criteria were adhered to:

1. The number of wells, subject to availability, was chosen to provide as even a distribution as possible both areally and with depth in the aquifer.

2. The wells had to be accessible and in operation.

3. The depth had to be known and the perforated interval was desired.

Water-level data by Finley B. Laverty, Consulting Engineer (written commun., 1974) were supplied by the SBVMWD.

Sampling and Chemical Analysis

Water samples were taken in autumn 1974 near the end of the pumping season, and in late spring and early summer 1975 at the beginning of the pumping season. Several wells were sampled more than once to check variations in nitrate concentration.

Samples were filtered through a 0.45 micrometer filter at the time of collection and then chilled at 4°C in polyethylene bottles. Nitrate analyses were done at the Geological Survey Central Laboratory in Salt Lake City. The analytical method for the determination of nitrate used by the U.S. Geological Survey is a conversion of nitrate to nitrite using a cadmium-reduction column as described in American Public Health Association, "Standard Methods for the Examination of Water and Wastewater" (1971), followed by an analysis for nitrite using the diazotization method described by Brown, Skougstad, and Fishman (1970). Because nitrate is subject to consumption or alteration by bacterial activity, preservation techniques for samples sent to the Central Laboratory were usually confirmed by a field nitrate test apparatus that was calibrated with standard nitrate solution. If the difference between the field test and the Central Laboratory results was substantial, a new sample was submitted or a rerun of the submitted sample was requested in some cases.

Water from wells sampled by the city of Redlands was analyzed by the Clinical Laboratory of San Bernardino, Inc., which is certified by the State of California. Since few of the nitrate data provided by the city of Redlands were used for this study, the method by which it was analyzed was not determined.

RESULTS

Areal Distribution of Nitrate in Wells

The locations of wells sampled in this study are given in figure 3. Also shown are the locations of four vertical sections, to be discussed later. Table 3 lists the results of nitrate analyses and physical characteristics of the wells sampled. Almost all results are for samples collected during this investigation. A few nitrate values for samples collected previously appear in table 3 because those wells could not be pumped, were abandoned, or were destroyed.

The distribution of nitrate in water from selected wells irrespective of depth in the aquifer shows no consistent pattern of nitrate values (fig. 2). Generally, there are lower concentrations near the Santa Ana River and higher concentrations away from the river; however, numerous exceptions to these generalizations exist.

TABLE 3.--*Concentration of nitrate as nitrogen (NO_3-N) in water from wells with estimated aquifer penetration and seal*

[Terminology for well characteristics shown in figure 5 and defined on p. 24-25]

State well No.	Date of sample	NO_3-N (mg/ℓ)	Aquifer penetration (ft)	Aquifer seal (ft)	$\frac{\text{Penetration + seal}}{2}$	Remarks
1S/2W-18Q	5-29-75	[1]1.7	390	173	282	
1S/2W-19K1	10-17-74	[1]8.5	184	70	127	
	6-11-75	[1]9.8	--	--	--	
1S/2W-21E2	10-01-74	1.4	100	--	--	Perforations unknown.
1S/2W-29N2	10-01-74	12	--	--	--	Perforations and depth to water unknown.
1S/2W-30B2	10-17-74	[1]12	150	45	98	
1S/2W-30C1	10-17-74	[1]17	150	0	75	
1S/2W-30G1	10-17-74	[1]18	208	45	126	
1S/3W-9E2	10-03-74	[1] [2]2.0	310	120	215	In river wash.
1S/3W-13P2	10-16-74	[1]5.7	264	41	152	
	5-29-75	[1]7.0	--	--	--	
1S/3W-13Q1	5-29-75	[1]6.6	364	0	182	Close to river.
1S/3W-14P2	6-11-75	[1]16	316	111	214	
	6-11-75	[1]19	--	--	--	
1S/3W-14R1	10-17-74	[1]12	268	27	148	
1S/3W-15A1	10-16-74	1.9	--	--	--	
1S/3W-15M3	10-16-74	[1] [2]4.5	207	0	104	Close to river.
1S/3W-16F1	5-28-75	.90	223	--	--	Perforations unknown.
1S/3W-16J1	6-12-75	[1].47	225	0	112	Close to river.
1S/3W-16K1	6-12-75	3.5	174	--	--	Perforations unknown.
1S/3W-16L4	10-01-74	.94	--	--	--	Close to river.
1S/3W-17C3	10-03-74	[1]28	99	0	50	Just downgradient from sewage plant.
1S/3W-17H5	6-12-75	[1]2.8	405	106	256	

See footnotes at end of table.

TABLE 3.--*Concentration of nitrate as nitrogen (NO_3-N) in water from wells with estimated aquifer penetration and seal*--Continued

State well No.	Date of sample	NO_3-N (mg/ℓ)	Aquifer penetration (ft)	Aquifer seal (ft)	$\frac{\text{Penetration + seal}}{2}$	Remarks
1S/3W-17L1	10-03-74	[1]15	290	90	190	
	5-28-75	[1]15	--	--	--	
1S/3W-17R3	6-12-75	[1]21	295	0	148	
1S/3W-18L1	10-03-74	25	370	--	--	Perforations unknown.
	5-27-75	26	--	--	--	
	6-26-75	24	--	--	--	
1S/3W-18N2	10-03-74	[1].29	861	666	764	
1S/3W-19G1	10-03-74	5.0	515	--	--	Perforations unknown.
	5-27-75	5.6	--	--	--	
1S/3W-19J1	10-03-74	[1]11	327	225	276	
	5-27-75	[1]6.5	--	--	--	
1S/3W-19J3	10-03-74	[1]8.1	335	305	320	
1S/3W-19L1	6-11-75	[1]4.6	420	340	380	
1S/3W-20C2	5-28-75	16	180	--	--	Perforations unknown.
1S/3W-20F1	5-28-75	[1]8.3	195	165	180	
1S/3W-20P1	5-28-75	[1]7.9	310	150	230	
1S/3W-20R1	5-28-75	[1]8.5	167	43	105	
1S/3W-21A1	6-12-75	[1]21	168	0	84	
1S/3W-21E2	6-04-75	1.4	--	--	--	
	7-15-75	5.2	--	--	--	
1S/3W-21E5	11-03-74	22	180	--	--	Perforations unknown.
1S/3W-21G1	6-04-75	[1]12	110	0	55	
1S/3W-21H1	5-20-75	31	260	--	--	Perforations unknown.
	9-10-75	27	--	--	--	
1S/3W-21H6	10-01-74	[1]26	317	35	176	
1S/3W-21H7	5-14-75	[1 3]8.9	535	75	305	
	6-16-75	[1 3]11	--	--	--	
	7-02-75	[1 3]13	--	--	--	
	8-20-75	[1 3]21	--	--	--	
	9-11-75	[1 3]19	--	--	--	
1S/3W-21M2	6-11-75	[1]14	132	0	66	
1S/3W-22A2	10-16-74	[1]4.4	619	310	464	
	6-26-75	[1]4.1	--	--	--	
1S/3W-23A3	10-18-72	[4]14	338	65	202	

See footnotes at end of table.

TABLE 3.--*Concentration of nitrate as nitrogen* (NO_3-N) *in water from wells with estimated aquifer penetration and seal*--Continued

State well No.	Date of sample	NO_3-N (mg/ℓ)	Aquifer penetration (ft)	Aquifer seal (ft)	$\frac{\text{Penetration + seal}}{2}$	Remarks
1S/3W-24A1	10-17-74	[1]26	144	16	80	
1S/3W-24C1	10-18-72	[3]5.7	330	30	180	
1S/3W-26C2	9-14-72	[3]15	425	85	255	
	11-18-73	[3]12	--	--	--	
	11-18-74	[1,3]24	--	--	--	
1S/3W-27E2	10-01-74	[1]11	214	0	107	
1S/3W-28H1	10-01-74	13	295	--	--	Perforations unknown.
1S/3W-28J1	9-10-74	[1,3]9.5	710	245	478	Located at Bryn Mawr barrier.
	5-07-75	[1,3]10	--	--	--	
	5-20-75	[3]13	--	--	--	
	6-16-75	[1,3]9.1	--	--	--	
	7-02-75	[1,3]10	--	--	--	
1S/3W-28M3	5-29-75	[1]2.9	505	479	492	
1S/3W-29D	5-30-75	9.5	330	--	--	Perforations unknown.
1S/3W-29D2	6-12-75	[1]7.2	183	146	164	
1S/3W-29H3	5-28-75	8.5	150	--	--	Perforations unknown.
1S/3W-29J1	6-03-75	[1]5.0	505	479	492	
1S/3W-29K2	5-30-75	9.1	105	--	--	Perforations unknown.
1S/3W-29K3	5-30-75	[1]6.2	284	35	160	
1S/3W-30Q2	6-26-75	16	587	--	--	Perforations unknown.
1S/3W-31A1	5-22-75	.36	308	--	--	Perforations unknown.
1S/3W-31B2	5-22-75	[1].67	675	155	415	
1S/3W-31H1	5-22-75	[1]20	284	35	160	
1S/3W-35G7	11-04-72	[3]5.0	210	104	157	
1S/3W-35G8	11-07-72	[3]5.0	430	--	--	
1S/3W-35G9	9-10-74	[1,3]9.3	573	0	286	
1S/3W-35H3	6-26-75	[1]17	253	52	152	
1S/4W-13F2	10-02-74	[1]3.9	313	175	244	

See footnotes at end of table.

TABLE 3.--*Concentration of nitrate as nitrogen* (NO_3-N) *in water from wells with estimated aquifer penetration and seal*--Continued

State well No.	Date of sample	NO_3-N (mg/ℓ)	Aquifer penetration (ft)	Aquifer seal (ft)	Penetration + seal / 2	Remarks
1S/4W-13G2	10-02-74	5.8	395	--	--	Perforations unknown.
1S/4W-13G3	10-02-74	[1].75	1,110	470	790	
1S/4W-13L1	10-02-74	[1]3.6	410	360	385	
1S/4W-13L2	10-02-74	8.2	195	--	--	Perforations unknown.
1S/4W-13M2	10-02-74	[1]1.3	821	0	410	
1S/4W-13N2	10-02-74	13	265	--	--	Perforations unknown.
1S/4W-23G3	10-02-74	4.0	715	--	--	Perforations unknown.
1S/4W-23H1	10-02-74	4.9	215	--	--	Perforations unknown.
1S/4W-23K1	10-02-74	6.5	210	--	--	Perforations unknown.
1S/4W-23K2	10-02-74	[1]9.4	190	0	95	
1S/4W-24K1	10-01-74	[1]4.9	338	185	262	
1S/4W-27A9	10-02-74	[1]2.6	463	311	387	
1S/4W-27H1	10-02-74	.05	761	--	--	Perforations unknown.

[1]Data used for statistical summaries presented in table 4 and figure 6.
[2]Data used for statistical summary presented in figure 6, but excluded from table 4.
[3]City of Redlands data.
[4]California Department of Water Resources data.

Statistical Approach to Interpretation of Nitrate Data

To describe the occurrence of nitrate in the aquifer, particularly with depth, several statistical and graphical techniques were employed. Isolation of water samples to particular depth intervals was generally not possible because most wells are perforated over large intervals. Each well was, therefore, evaluated in terms of aquifer seal (*S*), aquifer penetration (*P*) (fig. 5), and midpoint of perforated interval $(S + P) \div 2$. The aquifer seal

(S) is the distance from the water table to the top of the perforated interval; the aquifer penetration (P) is the distance from the water table to the bottom of the perforated interval; the midpoint of the perforated interval is $(S + P) \div 2$. If the uppermost perforations are above the water table, S is taken to be zero.

Inspection of the data in table 3 suggests a rough inverse relation between nitrate concentration and depth of the aquifer seal and the midpoint of the perforated interval with respect to the water table. It is suspected that depth in the aquifer is the major independent variable influencing the observed nitrate concentration.

The frequency distribution of nitrate data for wells with known depth and perforated intervals is shown in figure 6. Where more than one value had been determined, the average was incorporated into these statistics. This treatment does not take into account the physical characteristics or location of the wells.

The histogram (fig. 6) of the nitrate concentrations is skewed toward low values, with the median concentration (having equal numbers of concentrations above and below) being 8.3 mg/ℓ and with a range of concentrations from 0.3 to 28 mg/ℓ. The arithmetic mean is 10 mg/ℓ and the logarithmic mean 6.6 mg/ℓ, suggesting that the distribution is neither normal nor logarithmic and may be two separate distributions.

Occurrence of Nitrate with Depth

Statistical Distribution and Relation to Land Use

Factors that may affect nitrate distribution are (1) the various land uses that contribute different quantities of nitrate from the surface, (2) point sources of wastewater, and (3) recharge from the Santa Ana River and Mill Creek. Generally, nitrate in ground water decreases with depth.

The relation of aquifer seal, land use, and sources of wastewater or recharge water to the concentration-distribution of NO_3-N is illustrated in figure 7. That figure clearly indicates that the nitrate concentration in water from wells decreases with seal depth, although this is certainly not the only factor influencing the concentration. The upper limit of observed nitrate concentrations as a function of seal depth is defined by the curve.

Nitrate values in wells located in urban and agricultural areas are intermixed, and most wells are used for irrigation purposes. The impact of either land use on present nitrate concentrations could not be determined with

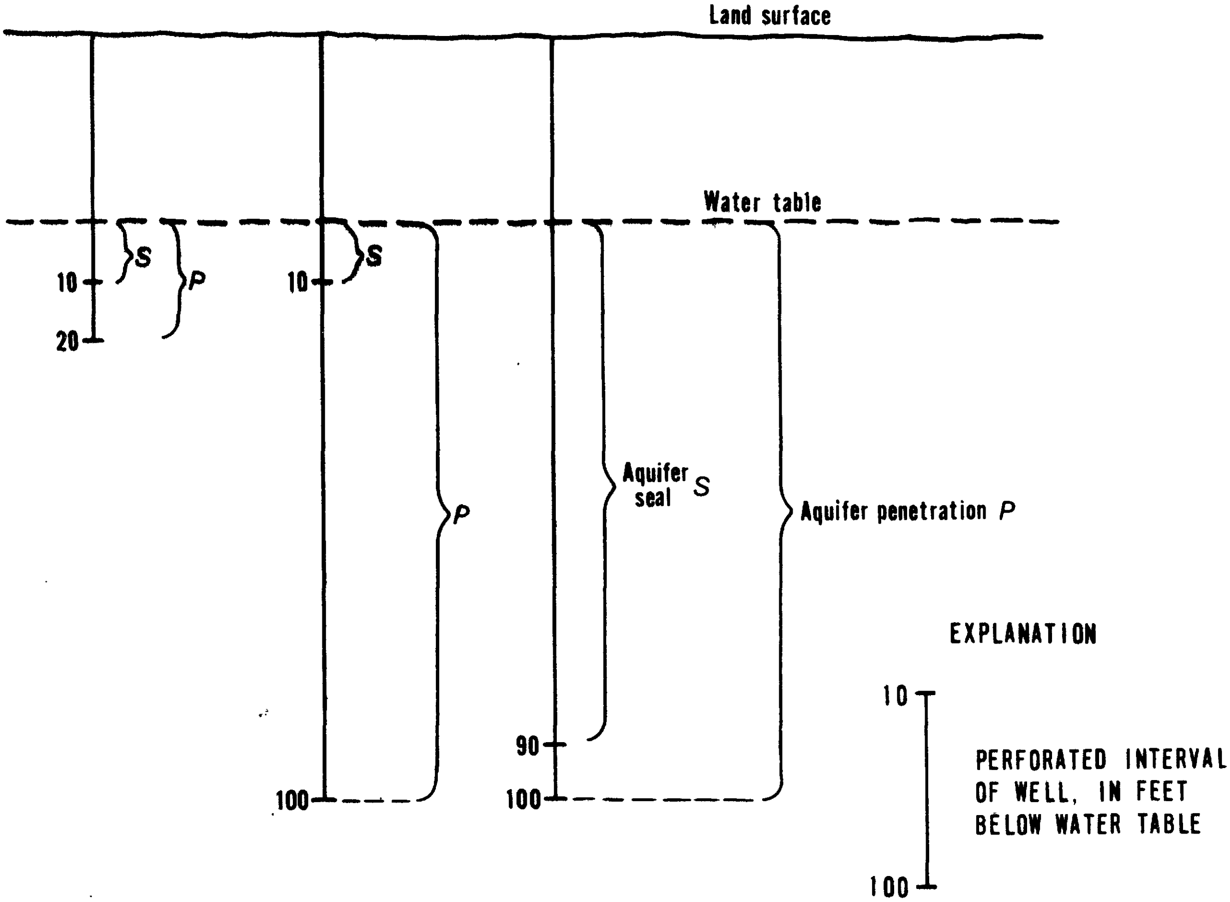

FIGURE 5.--Definition of aquifer seal (*S*) and aquifer penetration (*P*).

data available. Well 1S/3W-17C3, which has a nitrate concentration of 28 mg/ℓ, may be affected by discharge from the Redlands sewage-treatment plant. Wells close to the Santa Ana River and upstream from the Redlands sewage-treatment plant have uniformly low-nitrate concentrations, especially those wells with shallow aquifer seals.

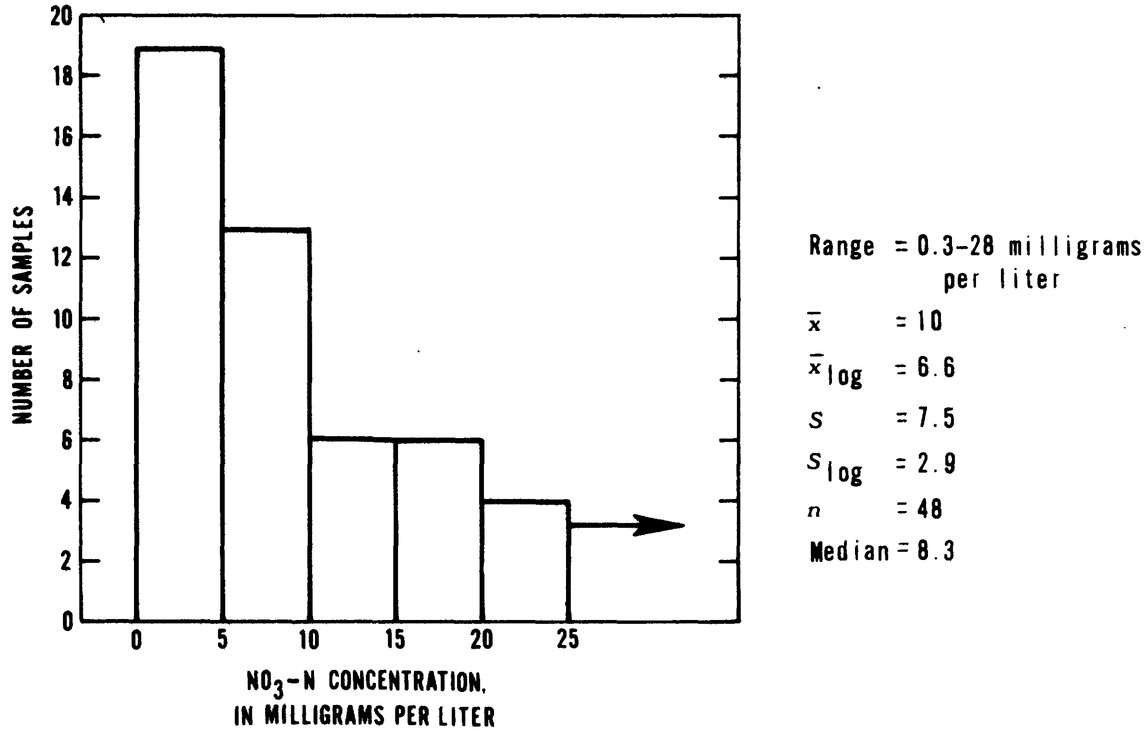

FIGURE 6.--Statistical distribution for the occurrence of nitrate as nitrogen in wells sampled, irrespective of depth.

A group of three wells with low-nitrate concentrations and shallow seals that are clearly affected by the river is anomalous and not representative of the bulk of the data set. Those wells have been excluded from the treatment that follows.

Figure 8 schematically illustrates the combined effects of the aquifer seal and the midpoint of the perforated-interval depths on the distribution of observed nitrate concentrations. As the aquifer seal and midpoint of perforated-interval depths increase, the distribution of observed concentrations moves lower. All NO_3-N concentrations exceeding 20 mg/ℓ and none less than 5 mg/ℓ (except those influenced by the Santa Ana River) occur in wells with aquifer-seal depths less than 50 ft. With the exception of those wells directly influenced by the Santa Ana River, all concentrations less than 5 mg/ℓ occur in wells with the midpoint of perforated interval deeper than 200 ft.

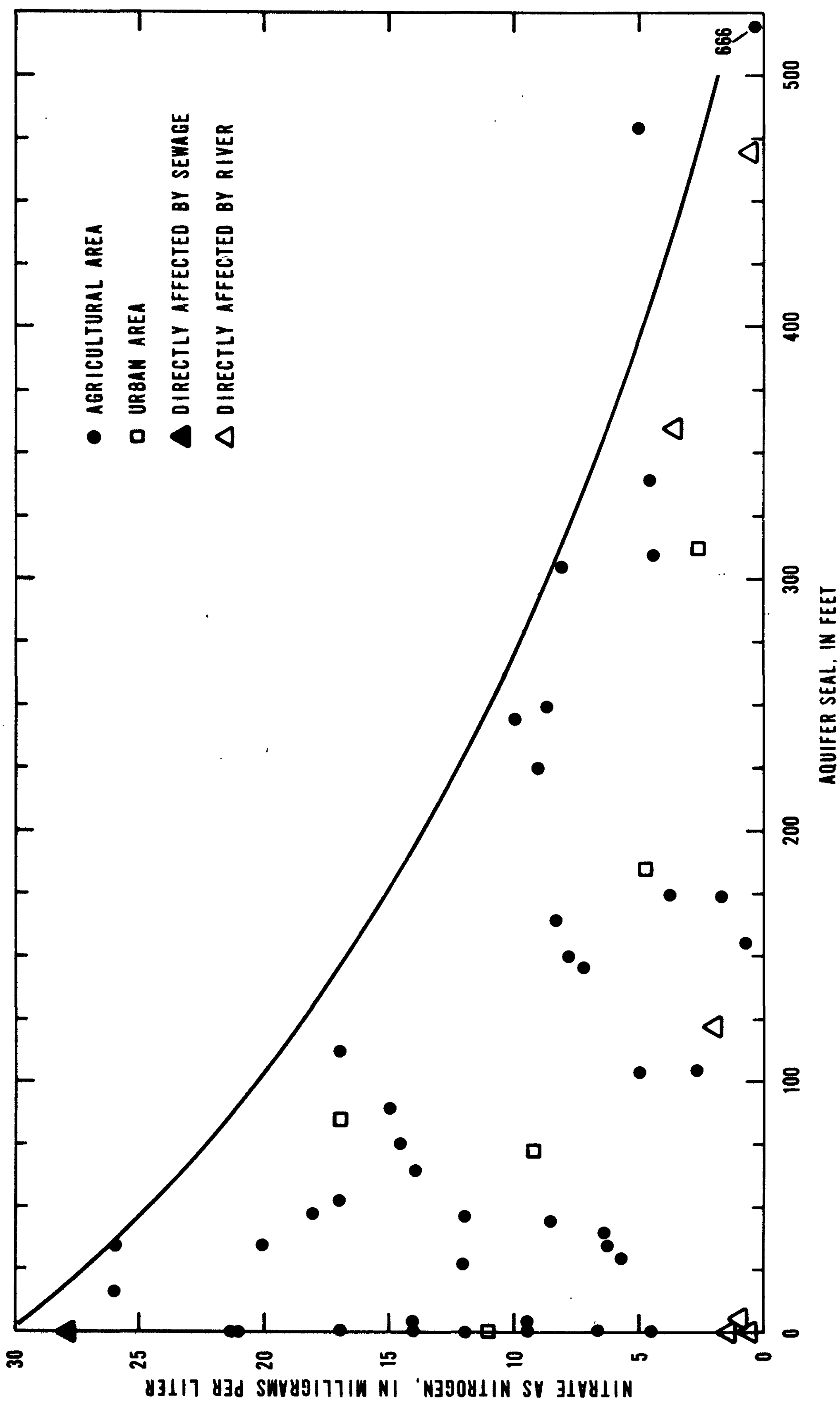

FIGURE 7.--Occurrence of nitrate as nitrogen with respect to depth of aquifer seal (where more than one analysis was performed, points represent the arithmetic mean).

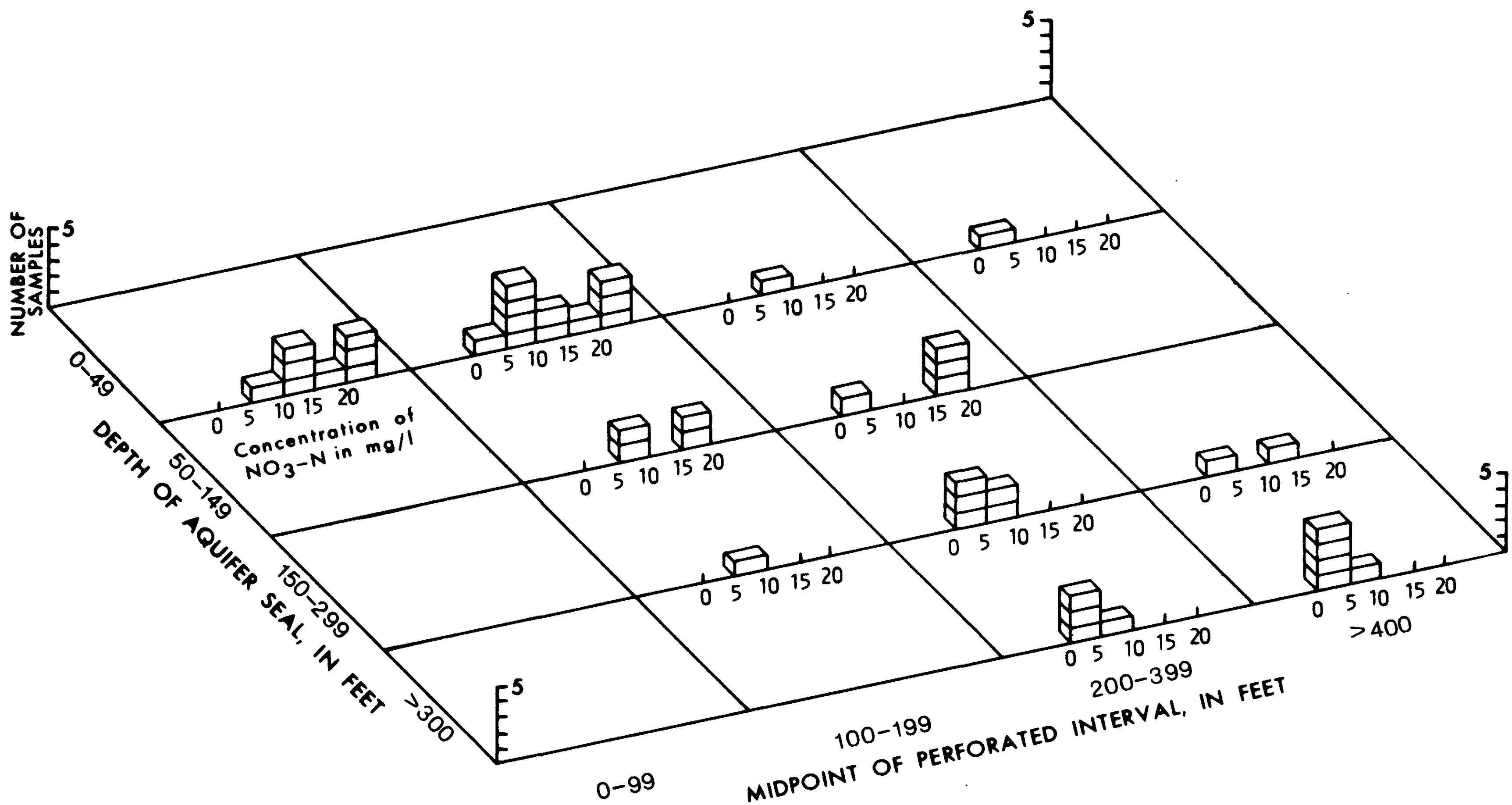

FIGURE 8.--Distribution of nitrate as nitrogen concentration with depth of aquifer seal and midpoint of perforated interval.

Table 4 summarizes the statistics of the nitrate concentrations grouped by the aquifer seal and midpoint of perforated-interval depths together. The mean concentrations decrease steadily with depth from a high of 17.0 mg/ℓ in wells with aquifer seal equal to or less than 50 ft to a low of 2.6 mg/ℓ in wells with aquifer seal exceeding 300 ft.

Nitrate Distribution Along Selected Sections

To further describe the vertical and areal distribution of nitrate, four vertical and four planar sections of the study area were prepared. The planar sections are largely derived from the vertical sections. Location of the vertical sections is shown in figure 3. Because the nitrate data are from water in wells rather than from discrete levels of the aquifer, the contours derived therefrom are subject to the qualifications discussed in detail in the section "Drawbacks in Sampling Production Wells." The location of contours is approximate.

Section A-A' (fig. 9) was taken along the ground-water gradient in the Bunker Hill basin and Redlands subbasin and crosses the most intensively pumped part of the study area. The Bryn Mawr barrier apparently causes both a nitrate and a water-level discontinuity. The apparent high nitrate near the center of the section is attributed to the extremely heavy pumping in the area, which causes a localized depression of the water table and results in the high nitrate in the upper part of the saturated zone to be pulled deeper.

Section B-B' (fig. 9) was taken across the ground-water-level gradient, again crossing an intensively pumped part of the study area. The general deepening of the 20- and 10-mg/ℓ contours from B to B' probably results from several factors: (1) Larger ground-water withdrawals toward the river; (2) the presence of coarser soils with higher infiltration rates near the river; and (3) some influence from the sewage-treatment facility near the B' extremity of the section. The apparent rise in the 5-mg/ℓ NO_3-N contour may reflect the low-nitrate recharge from the river underflowing the higher nitrate water found just off the river to the south.

Section C-C' (fig. 9) is generally parallel to the ground-water gradient and crosses the area of highest seasonal discharge. It is also downgradient from the Redlands sewage-treatment facility. All the wells sampled here are used extensively by the Gage Canal Co. Much of the nitrate found in sec. 13, T. 1 S., R. 4 W., is probably from the Redlands sewage-treatment facility. The downward bend in the nitrate contours can be attributed, in part, to the heavy pumpage in this area.

Section D-D' (fig. 9) traverses two ground-water barriers and an urbanized part of Redlands. Because of the lack of wells from which to obtain water samples, the data were not adequate to plot continuous contours in the Redlands subbasin part of figure 9.

TABLE 4.--*Statistical distribution of nitrate as nitrogen* (NO_3-N) *concentration in wells grouped by physical characteristics of the wells*

[$\bar{x}$, arithmetic mean; S, standard deviation; n, number of wells; R, range]

Depth of aquifer seal (ft)	Depth of midpoint of perforated interval (ft)			
	0-99	100-199	200-399	>400
0-49	$\bar{x}$ = 17 S = 6.9 n = 8 R = 9.4 - 28	[1]$\bar{x}$ = 14 S = 7.1 n = 9 R = 6.9 - 26	9.3 n = 1	1.3 n = 1
50-149	--	$\bar{x}$ = 12 S = 4.6 n = 4 R = 9.2 - 17	$\bar{x}$ = 15 S = 8.9 n = 4 R = 2.8 - 24	--
150-299	--	8.3 n = 1	$\bar{x}$ = 8.5 S = 5.2 n = 5 R = 1.7 - 8.9	$\bar{x}$ = 5.3 n = 2
>300	--	--	$\bar{x}$ = 4.7 S = 2.4 n = 4 R = 2.6 - 8.1	$\bar{x}$ = 2.6 S = 2.1 n = 5 R = 0.3 - 5.0

[1]The data set excluded wells clearly affected by direct surface recharge from the Santa Ana River. Including these wells results in the following statistics: $\bar{x}$ = 12, S = 8.0, n = 11, R = 0.5 - 26

Planar sections (fig. 10) show expected nitrate concentration at 50, 100, 150, and 300 ft below the water table. Concentrations of NO_3-N in excess of 10 mg/ℓ will be found at 50 ft below the water table over most of the study area. In two large areas, concentrations exceed 20 mg/ℓ at this depth. At 100 ft below the water table, three smaller areas show NO_3-N concentrations in excess of 20 mg/ℓ. At 150 ft below the estimated water table, there is only one area with NO_3-N in excess of 20 mg/ℓ. At 300 ft below the water table, concentrations less than 10 mg/ℓ can be expected throughout most of the study area.

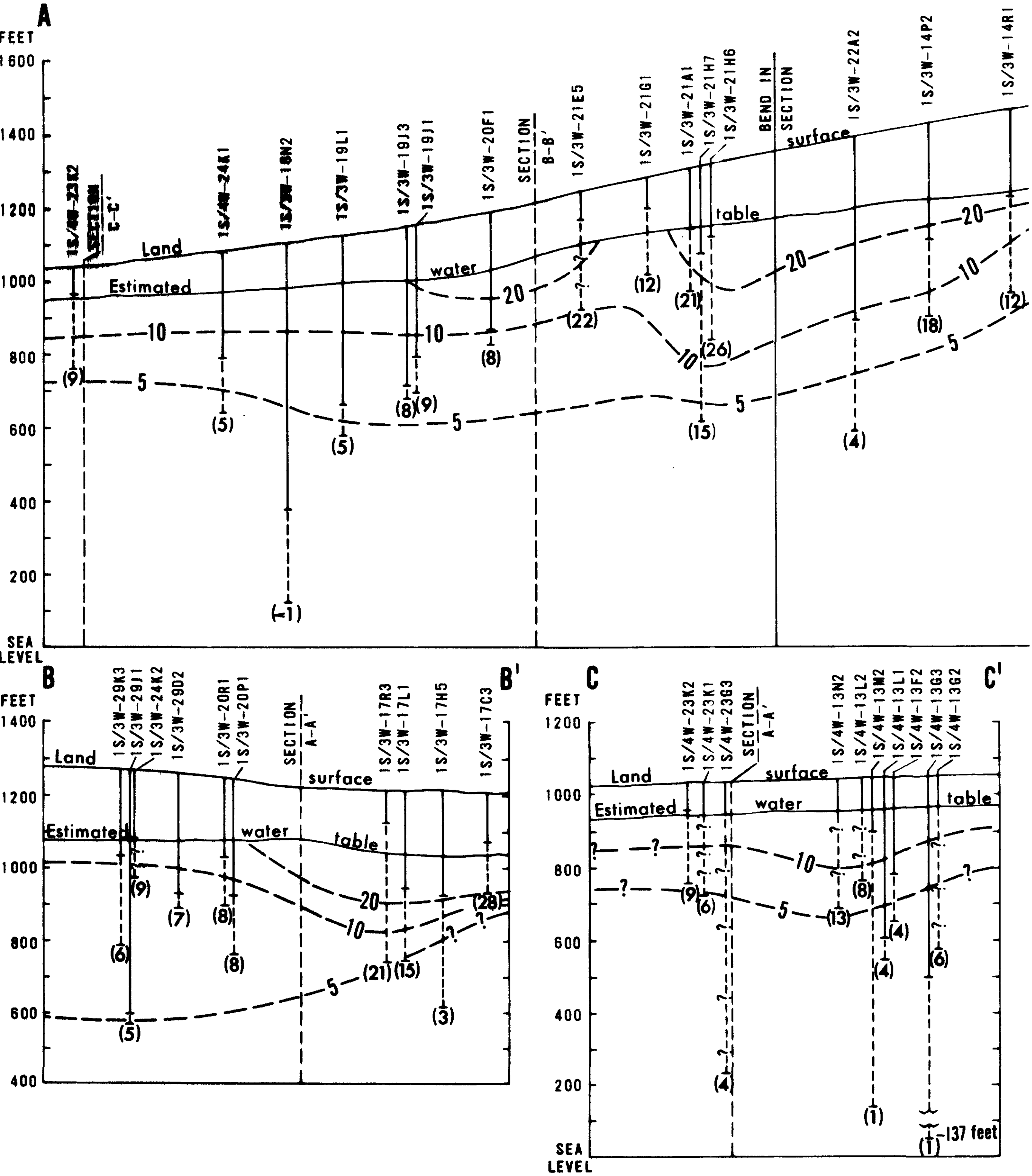

FIGURE 9.--Diagrammatic illustrations of vertical distribution of nitrate as nitrogen.

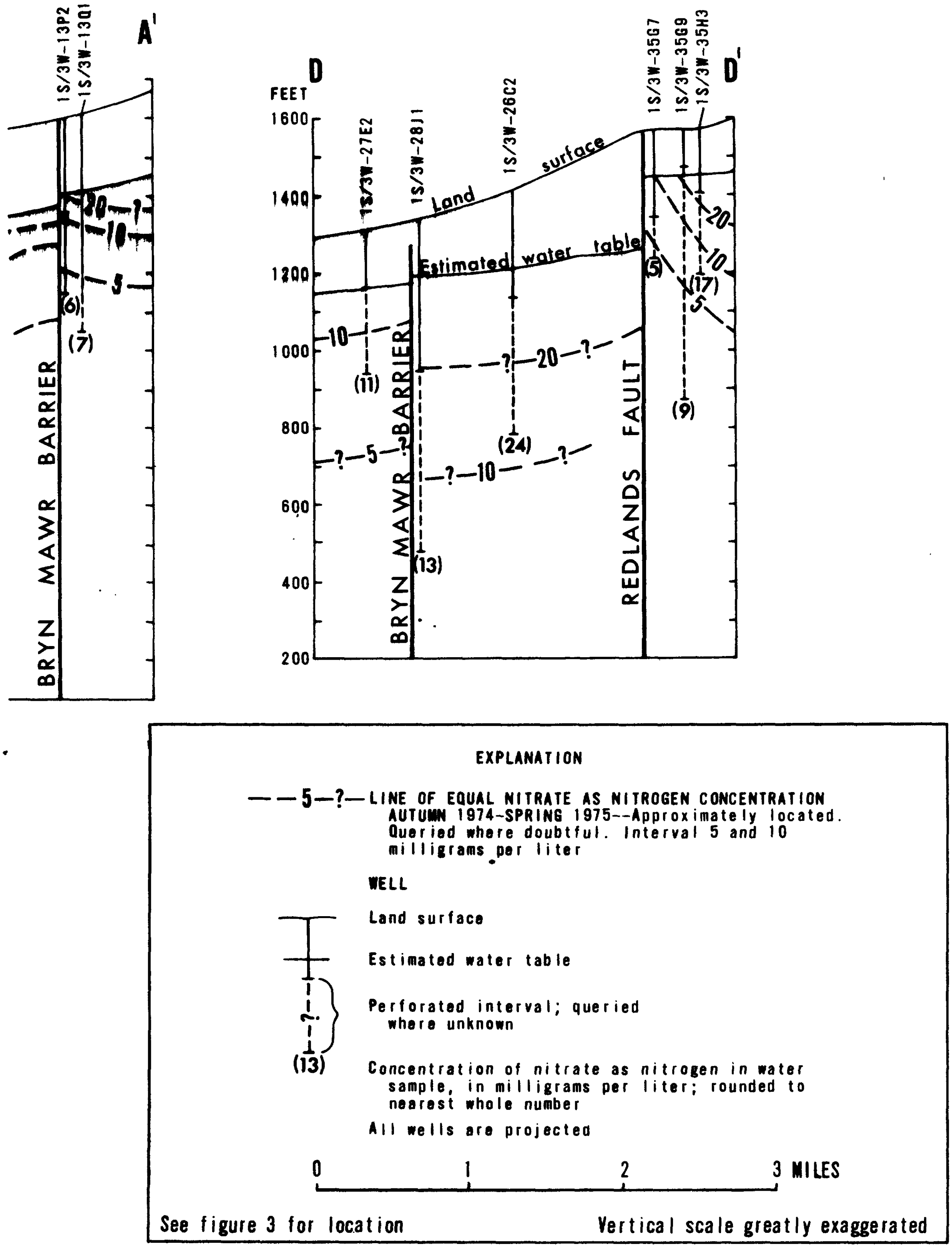

FIGURE 9.--Continued.

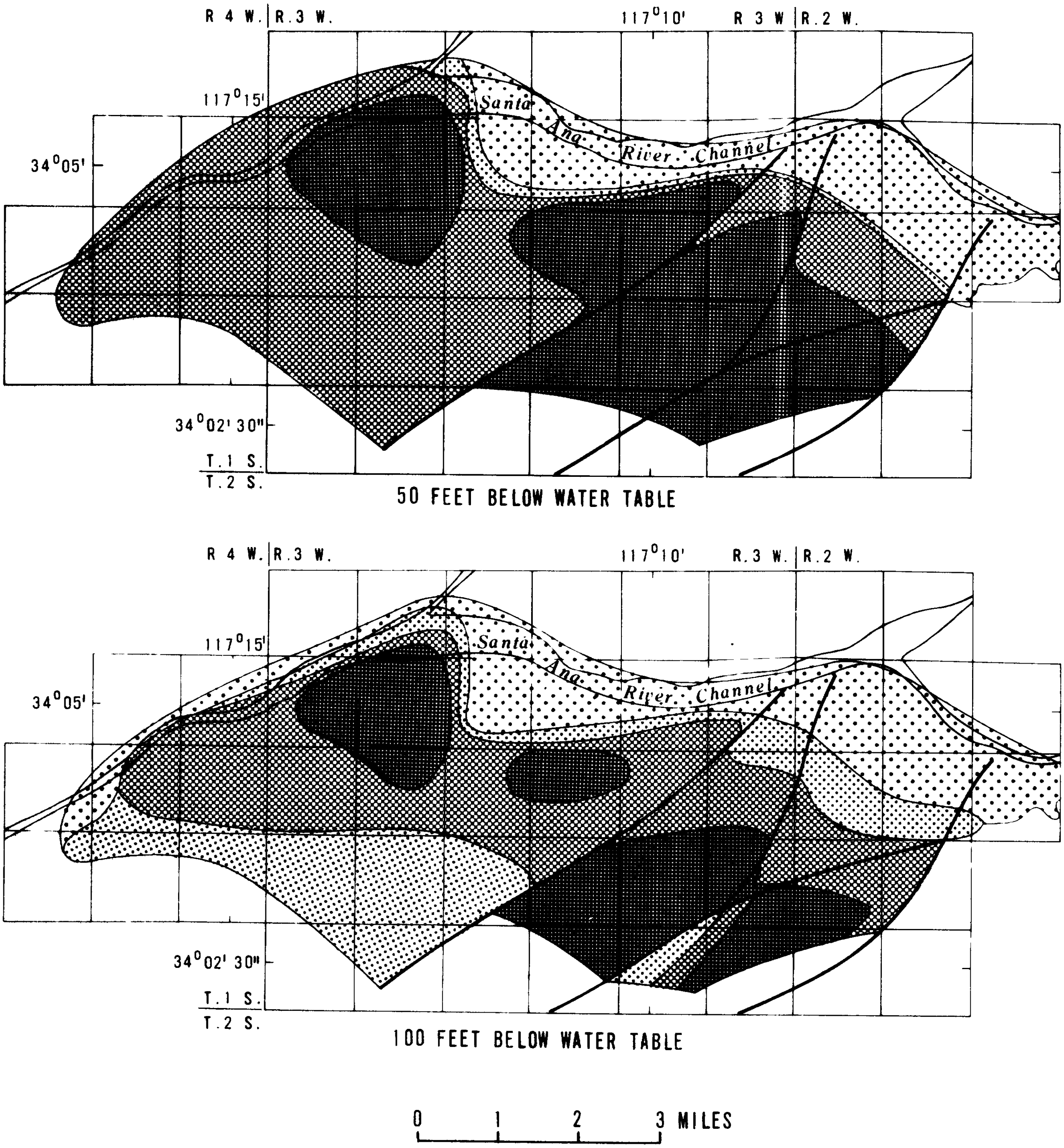

FIGURE 10.--Areal distribution of nitrate as nitrogen, autumn 1974-spring 1975.

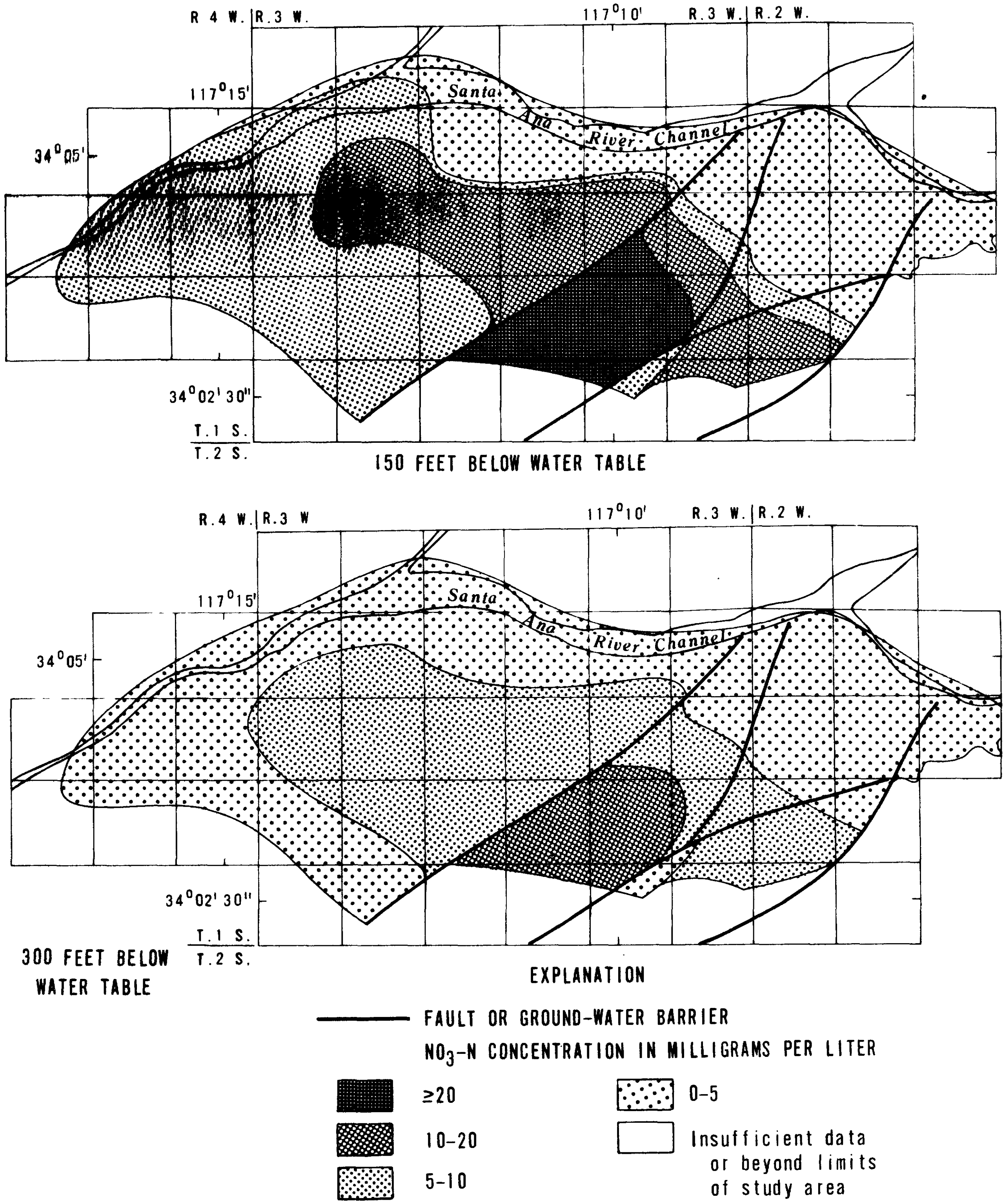

FIGURE 10.--Continued.

CONCLUSIONS

High-nitrate concentrations are found in most shallow ground water in the study area, with the exception that low-nitrate concentrations are generally found in the shallow zone adjacent to the Mill Creek and Santa Ana River channels. Low-nitrate concentrations are found almost everywhere at 300 ft or more below the water table and are probably related to good-quality, low-nitrate water in storage which has not been affected by agricultural and urban development in the area.

The distribution of nitrate in ground water is related primarily to depth below the water table. This depth dependence suggests that the major source of nitrate is a generalized area-wide percolation of high-nitrate water downward from the surface through the unsaturated zone. This nitrate may be from fertilizers added in excess of plant needs, perhaps several decades ago, which then was leached below the root zone by irrigation. Discontinuities or variations in the general increase of nitrate with depth are probably caused by domestic wastes, recharge of good-quality water, or heavy pumping. The nitrate concentration in water from wells is dependent primarily upon depth and well construction--particularly aquifer seal and aquifer penetration--and secondarily upon well location.

Nitrate concentration of water in wells is increased by heavy pumping which causes high-nitrate ground water near the water table to be pulled into the well.

Artificial recharge operations may cause additional quantities of nitrate to reach the water table. Evidence suggests that the unsaturated zone is holding large quantities of high-nitrate water in transit to the saturated zone. The unsaturated zone is a most important water-quality factor to be considered in artificial recharge operations. A rising water table will hasten the inclusion in the saturated zone of high-nitrate water which is presumably percolating downward through the unsaturated zone. Under these conditions, withdrawal of high-nitrate water to wells must be expected to continue.

In addition, the area downgradient from the Redlands sewage-treatment facility could pose a problem because discharge from this plant may be a potential source of nitrate pollution for the Gage Canal Co. well field and other downstream users.

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