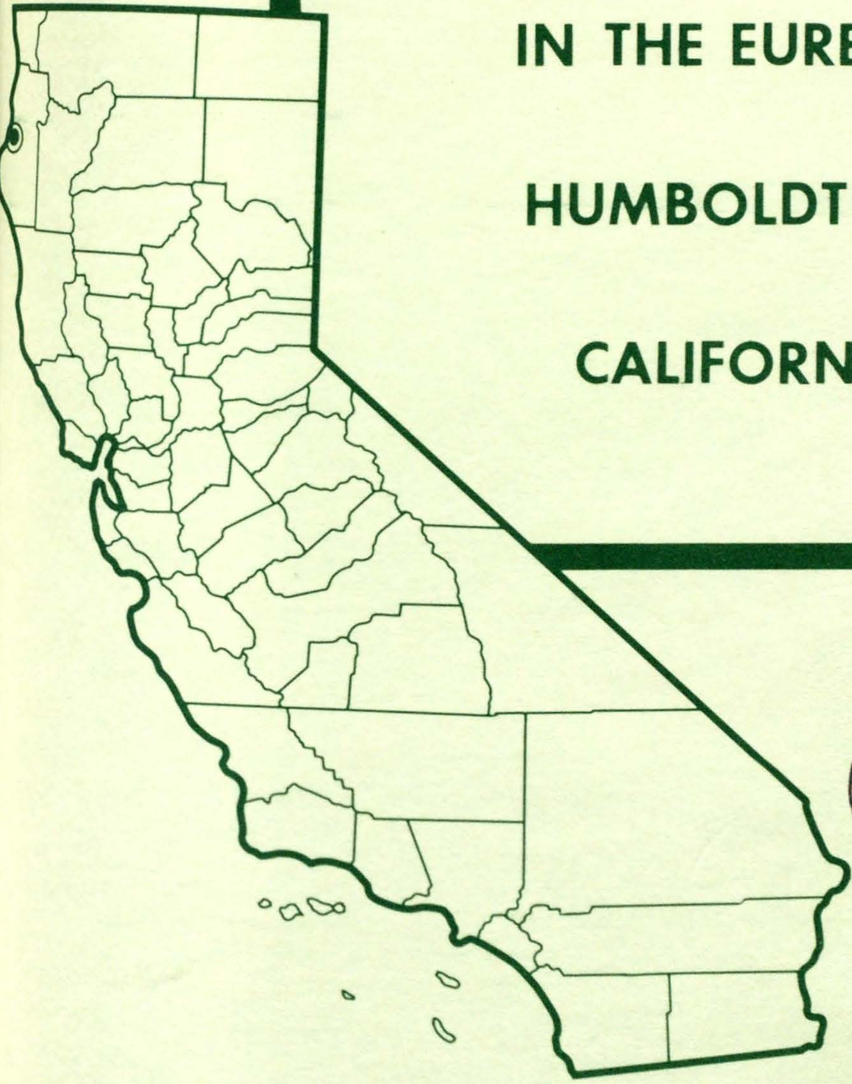
GROUND-WATER CONDITIONS IN THE EUREKA AREA, HUMBOLDT COUNTY, CALIFORNIA, 1975



U.S. Geological Survey

Water-Resources Investigations 78-127

Prepared in cooperation with the
Humboldt County Department of Public Works

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Ground-water conditions in the Eureka area were evaluated during 1975 to determine whether significant changes had occurred since 1952, when an earlier reconnaissance was made. No major changes in water levels or water quality were noted at 1975 pumping rates. Recharge to the ground-water system compensates for both artificial and natural discharge. The position of the freshwater-saltwater transition zone underlying the alluvial flood plains in the summer of 1975 were unchanged from those in 1952. Ground water continues to be used principally for irrigation on the alluvial flood plains of the Eel and Mad Rivers. In 1975, about 425 irrigation wells supplied an estimated 24,000 acre-feet of ground water to the Eureka area; half of those wells were located on the Eel River flood plain. The estimated total ground-water pumpage for irrigation, industry, public supply, domestic use, and livestock was 27,500 acre-feet. During the irrigation season, there is a higher rate of recharge from the rivers which helps to maintain ground-water storage and stabilize the freshwater-seawater transition zone.

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Groundwater, groundwater basins, groundwater recharge, pumping, California

17b. Identifiers/Open-Ended Terms

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U.S. GEOLOGICAL SURVEY

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December 1978

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UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, Secretary

GEOLOGICAL SURVEY

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CONVERSION FACTORS

The inch-pound system of units is used in this report. For those readers who prefer to use metric units 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
acre	4.047×10^{-1}	hm^2 (square hectometer)
acre-ft (acre-foot)	1.233×10^{-3}	hm^3 (cubic hectometer)
acre-ft/yr (acre-foot per year)	1.233×10^{-3}	hm^3/yr (cubic hectometer per year)
ft (foot)	3.048×10^{-1}	m (meter)
ft^3/s (cubic foot per second)	2.832×10^{-2}	m^3/s (cubic meter per second)
ft/d (foot per day)	3.048×10^{-1}	m/d (meter per day)
gal (gallon)	3.785	L (liter)
gal/d (gallon per day)	3.785	L/d (liter per day)
gal/min (gallon per minute)	6.308×10^{-2}	L/s (liter per second)
(gal/min)/ft (gallon per minute per foot)	2.070×10^{-1}	(L/s)/m (liter per second per meter)
inch	25.40	mm (millimeter)
mi (mile)	1.609	km (kilometer)

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ABSTRACT

Ground-water conditions in the Eureka area were evaluated during 1975 to determine whether significant changes had occurred since 1952, when an earlier reconnaissance was made. No major changes in water levels or water quality were noted at 1975 pumping rates. Recharge to the ground-water system compensates for both artificial and natural discharge. The position of the freshwater-saltwater transition zone underlying the alluvial flood plains in the summer of 1975 were unchanged from those in 1952.

Ground water continues to be used principally for irrigation on the alluvial flood plains of the Eel and Mad Rivers. In 1975, about 425 irrigation wells supplied an estimated 24,000 acre-feet of ground water to the Eureka area; half of those wells were located on the Eel River flood plain. The estimated total ground-water pumpage for irrigation, industry, public supply, domestic use, and livestock was 27,500 acre-feet.

During the irrigation season, when there is both natural and artificial discharge, water levels beneath the alluvial flood plains decline, and hydraulic gradients from the rivers to the alluvial flood plains are increased, thus accelerating recharge from the rivers. This accelerated recharge helps to maintain ground-water storage and to stabilize the freshwater-seawater transition zone during the irrigation season. It also results in a greater potential for future development of the ground-water resources beneath the Eel and Mad River flood plains than in cases of less rapidly recharged reservoirs. Without this recharge from the Mad River, additional ground-water development would be limited beneath the flood plain because irrigation pumpage of 4,100 acre-feet approaches the maximum one-time summer storage capacity of the alluvial aquifer. For the Eel River, a stable freshwater-seawater transition zone would not be maintained, although additional ground water could be developed because irrigation pumpage of 17,300 acre-feet is much less than the storage capacity. To better evaluate potential additional recharge induced by withdrawals for irrigation, it is recommended that more percolation tests be made along the Eel and Mad Rivers.

Significant quantities of ground water may be available in the Eel River valley from the Scotia Bluffs and Carlotta Formations. A drilling program is needed to determine the water-bearing properties, the thickness of the freshwater zone, and the quality of water.

INTRODUCTION

The Humboldt County Board of Supervisors has expressed concern that possible increased ground-water pumping since the early 1950's might be lowering water levels and inducing seawater intrusion into the aquifers underlying the Eel and Mad River flood plains. Lowered water levels over several years, with resultant seawater intrusion, would indicate that pumpage has exceeded the freshwater recharge.

The U.S. Geological Survey, in cooperation with the Humboldt County Department of Public Works, made a study to determine what changes in the position of the freshwater-seawater transition zone had occurred, and what effect these changes would have on the ability of the aquifers to supply additional ground water in the Eureka area. Additional ground-water development in the Eureka area is largely dependent on maintainence of suitable water quality in these coastal aquifers.

Purpose and Scope

The purpose of this investigation was to update the ground-water information collected by the U.S. Geological Survey in 1952 (Evenson, 1959) to identify any important changes that might have occurred in the ground-water conditions since that time.

The study was confined to evaluating the status of the freshwater-seawater transition zone in the alluvial aquifers underlying the Eel and Mad River flood plains, determining changes in ground-water levels and pumpage since 1952, evaluating the potential to develop additional ground-water supplies in the Eureka area, and identifying needs for further monitoring of ground-water conditions.

Location and Extent of Study Area

The study area borders the Pacific Ocean along 35 mi of Humboldt County's northeast-trending coastline (fig. 1). The city of Eureka is in the west-central part of the study area, about 225 mi northwest of San Francisco and 80 mi south of the Oregon border.

The hydrologic boundaries of the study area are defined principally by the limits of the Tertiary and Quaternary deposits that compose the area's aquifers. The study area includes the Eel and Mad River flood plains, the Table Bluff-Eureka Plain area between the flood plains, the Dows Prairie-McKinleyville area to the north, the Blue Lake area to the east, the upper Eel River and Van Duzen River valleys to the southeast, and adjacent hills and terraces.

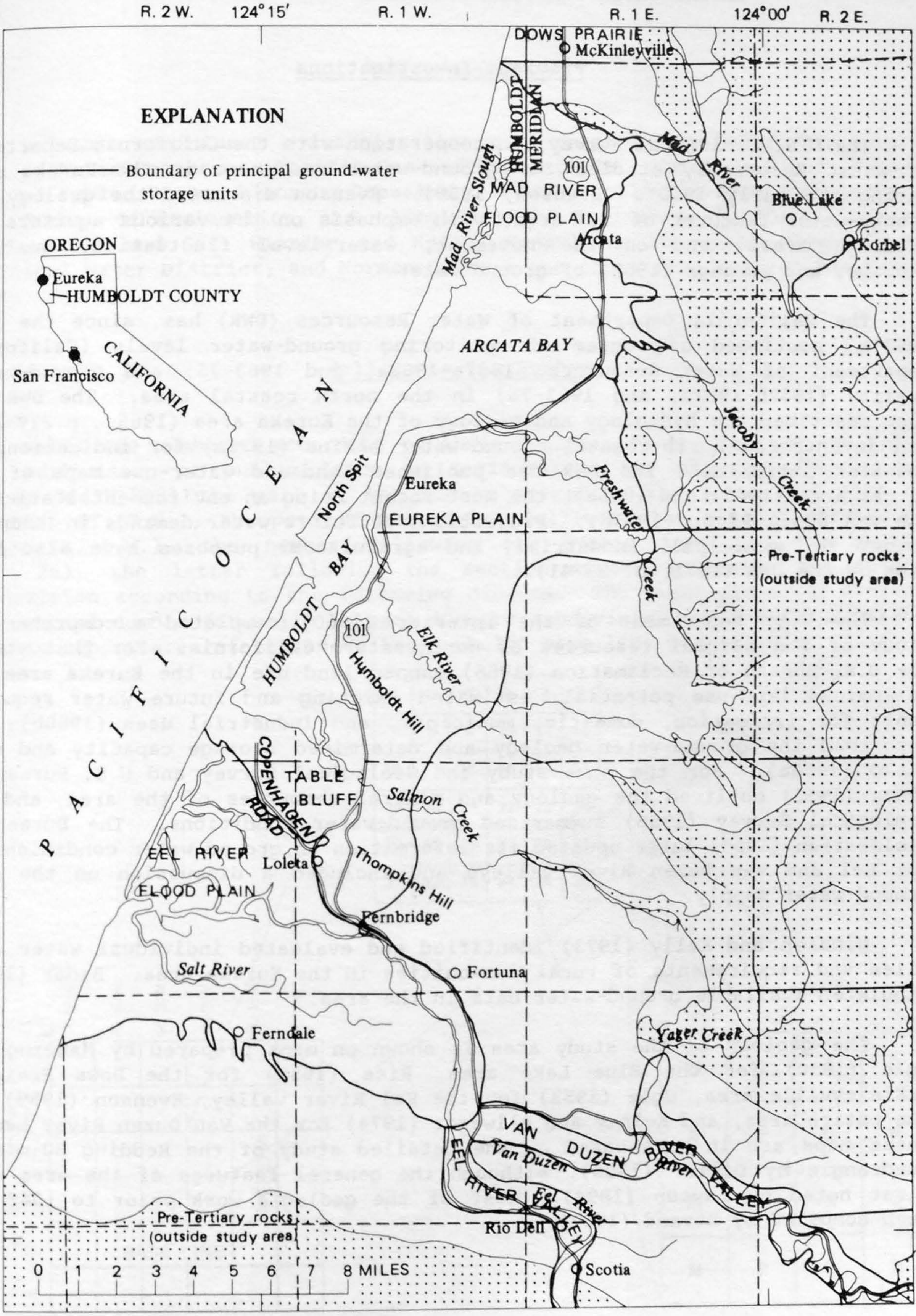


FIGURE 1.--Location of study area.

Previous Investigations

The U.S. Geological Survey, in cooperation with the California Department of Water Resources, studied the ground-water resources in the Eureka area during the early 1950's (Evenson, 1959). Evenson discussed the geology and ground-water features of the area, with emphasis on the various aquifers and recharge areas, and on the movement, water-level fluctuation, quality, storage, and pumpage (1952) of ground water.

The California Department of Water Resources (DWR) has, since the late 1950's, continued a program of monitoring ground-water levels (California Department of Water Resources, 1957a-1962a, and 1963-75) and ground-water quality (1957b-1962a, and 1963-75) in the north coastal area. The DWR has also described the hydrology and geology of the Eureka area (1965c, p.219-257) and inventoried north-coastal ground-water basins (1975a) for indications of seawater intrusion. The DWR has published land-and water-use maps of the Eureka area (1965a and 1965b), the most recent being an environmental atlas of the Van Duzen River (1975b). Projections of future water demands in Humboldt County for municipal, industrial, and agricultural purposes have also been made by the DWR (1971, p. 37-41).

The U.S. Department of the Interior (1960) completed a comprehensive study of the natural resources of northwestern California. For that study, the U.S. Bureau of Reclamation (1956) mapped land use in the Eureka area and determined land-use potential; estimated existing and future water requirements for irrigation, domestic, municipal, and industrial uses (1960b); and described the ground-water geology and determined storage capacity and safe yield (1960a). For the same study the Geological Survey and U.S. Bureau of Mines (1955) outlined the geology and mineral resources of the area, and the Geological Survey (1956) summarized ground-water conditions. The Bureau of Reclamation (1969) later updated its information on ground-water conditions in the Eel and Van Duzen River valleys and included a discussion on the safe ground-water supply.

Winzler and Kelly (1973) identified and evaluated individual water supplies and requirements of rural communities in the Eureka area. Bader (1969) tabulated available ground-water data in the area.

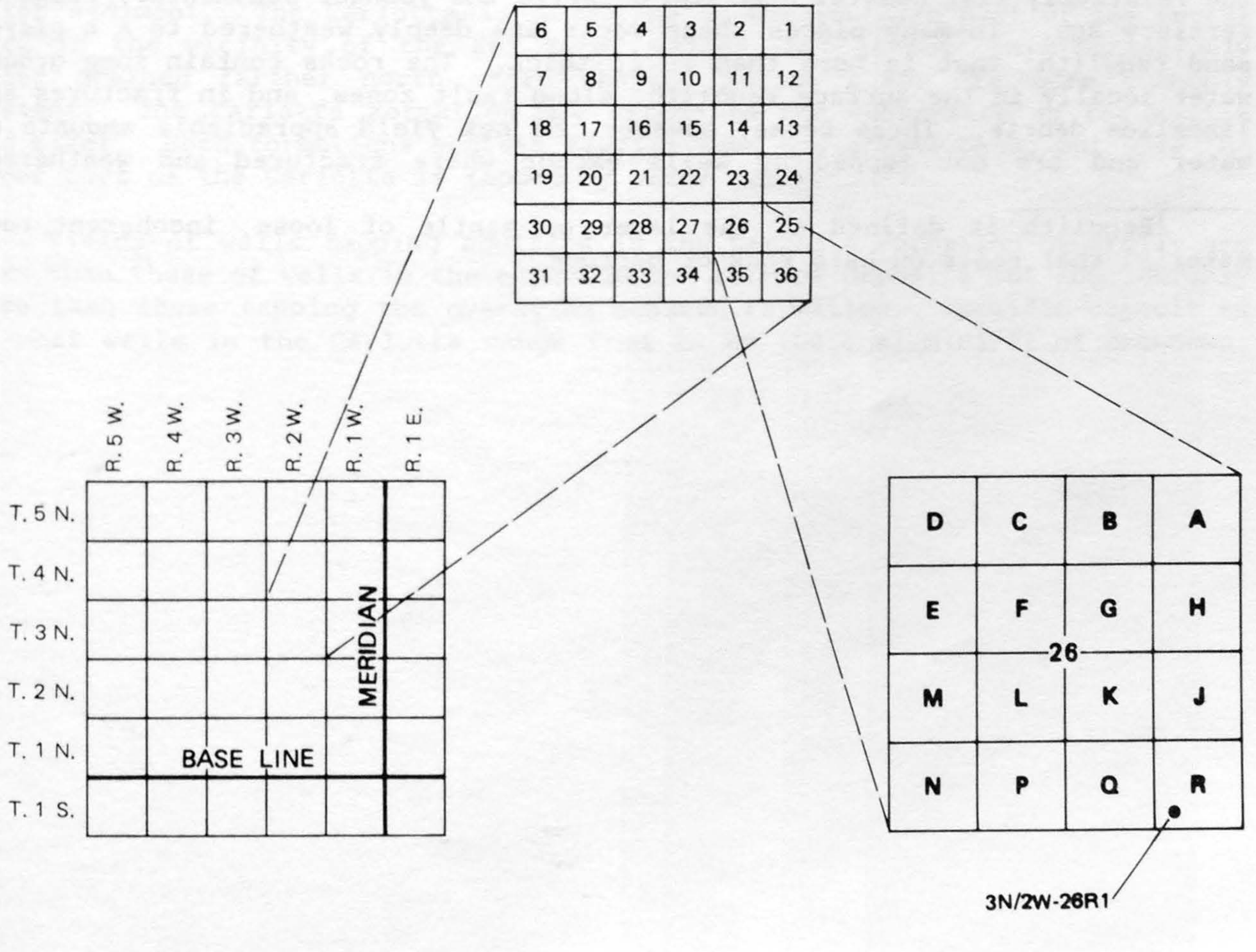
The geology of the study area is shown on maps prepared by Manning and Ogle (1950) for the Blue Lake area, Rice (1953) for the Dows Prairie-McKinleyville area, Ogle (1953) for the Eel River valley, Evenson (1959) for the entire area, and Kelsey and Allwardt (1974) for the Van Duzen River basin. These maps are in part based on the detailed study of the Redding 30-minute quadrangle by Diller (1906), although the general features of the area were first noted by Lawson (1894). Most of the geologic work prior to 1962 has been compiled by Strand (1962).

Acknowledgments

Valuable assistance and cooperation were given by the California Department of Water Resources; Pacific Gas and Electric Co.; Humboldt County Department of Public Works, Planning Department, and Agricultural Extension Service; U.S. Bureau of Reclamation; U.S. Army Corps of Engineers; California Department of Oil and Gas; Winzler and Kelly, Consulting Engineers; Humboldt Bay Municipal Water District; and Norman Grunert and other residents of the Eureka area.

Well-Numbering System

Wells are numbered according to their location in the rectangular system for subdivision of public lands in California. For example, in the well number 3N/2W-26R1 the part of the number preceding the slash indicates the township (T. 3 N.); the part of the number following the slash indicates the range (R. 2 W.); the number following the hyphen indicates the section (sec. 26); the letter following the section number indicates the 40-acre subdivision according to the following diagram. The final digit, if present, is a serial number for wells in each 40-acre subdivision. All wells mentioned in this report are referenced to the Humboldt base line and meridian.



GEOLOGY AND GROUND-WATER OCCURRENCE

The consolidated rocks and unconsolidated deposits within several thousand feet of the surface in the Eureka area are predominantly sedimentary and range in age from Jurassic to Quaternary. Their areal distribution is shown in figure 2, and their general character, stratigraphy, and water-bearing properties as described by Evenson (1959) are given in table 1.

Fresh ground water is known to occur in the Carlotta and Hookton Formations of Ogle (1953) of Pliocene and Pleistocene ages (table 1). It is also known to be present in the younger terrace deposits of Pleistocene age and in the alluvium, river-channel deposits, and dune sand of Holocene age. The coarse-grained sediments of the alluvium, river-channel deposits, dune sand, and terrace deposits at low altitudes generally contain unconfined water at depths generally less than 30 ft below the land surface. Confined water is contained in the Carlotta and Hookton Formations; perched water occurs in some of the higher terrace deposits. North of the Mad River, the Hookton Formation contains unconfined water. The principal aquifers in the study area are in the alluvium underlying the flood plains of the major rivers.

Pre-Tertiary Formations.--The basement rocks in the area comprise the Franciscan Formation and Yager Formation of Ogle (1953) of Jurassic and Cretaceous age. These rocks crop out in the hills and mountains surrounding the relatively flat coastal area and underlie the younger sedimentary rocks of Tertiary age. In many places these rocks are deeply weathered to a a clayey sand regolith[1] that is more than 20 ft thick. The rocks contain some ground water locally in the surface regolith, along fault zones, and in fractures and landslide debris. These rocks, however, do not yield appreciable amounts of water and are not tapped by wells except where fractured and weathered.

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[1]Regolith is defined as the layer or mantle of loose, incoherent rock material that rests on hard rock or bedrock.

Wildcat Group.--The Wildcat Series of Lawson (1894), called the Wildcat Group by Ogle (1953), unconformably overlies the Franciscan and Yager Formations. These rocks crop out over a large area in the eastern and southern parts of the Eureka area. The Wildcat Group is downwarped into a synclinal structure beneath the Eel and Van Duzen River valleys. It extends seaward along a northwest-trending synclinal axis and attains a thickness of more than 12,000 ft (figs. 2 and 3).

The Wildcat Group was divided by Ogle (1953) into five formations ranging in age from Miocene to Pleistocene. The three oldest units, the Pullen, Eel River, and Rio Dell Formations, consist dominantly of fine-grained, deep-marine sedimentary rocks and are poor aquifers. The two younger units, the Scotia Bluffs Sandstone and Carlotta Formation, consist dominantly of coarse-grained clastic sediments of marginal marine deposition and may be important aquifers. Water found in these two formations in the Eureka area is generally confined by interbeds of silt and clay of low permeability or by the overlying, fine-grained sediment in the Hookton Formation (of Ogle, 1953). Beneath the coastal part of the Eel River flood plain, the combined thickness of the Scotia Bluffs Sandstone and Carlotta Formation is known from oil-well logs to be about 4,000 ft, but beneath the southeastern part of the flood plain the combined thickness is less than 1,500 ft.

The contact between the two formations is gradational. Much of the Scotia Bluffs Sandstone was deposited under shallow-marine conditions; almost all the conglomeratic Carlotta Formation is composed of nonmarine or brackish-water sediment. The Carlotta is nonmarine in the southern part of the Eureka area in the vicinity of the Eel River valley, but it becomes progressively finer grained farther north where shallow marine clays are more commonly present. The Carlotta Formation may extend in the subsurface as far as the Mad River. Both formations contain fluvial sand and gravel beds, but only the upper part of the Carlotta is tapped by water wells.

Yields of wells tapping aquifers in the Carlotta Formation generally are less than those of wells in the alluvium and terrace deposits but considerably more than those tapping the overlying Hookton Formation. Specific capacities of most wells in the Carlotta range from 15 to 100 (gal/min)/ft of drawdown.

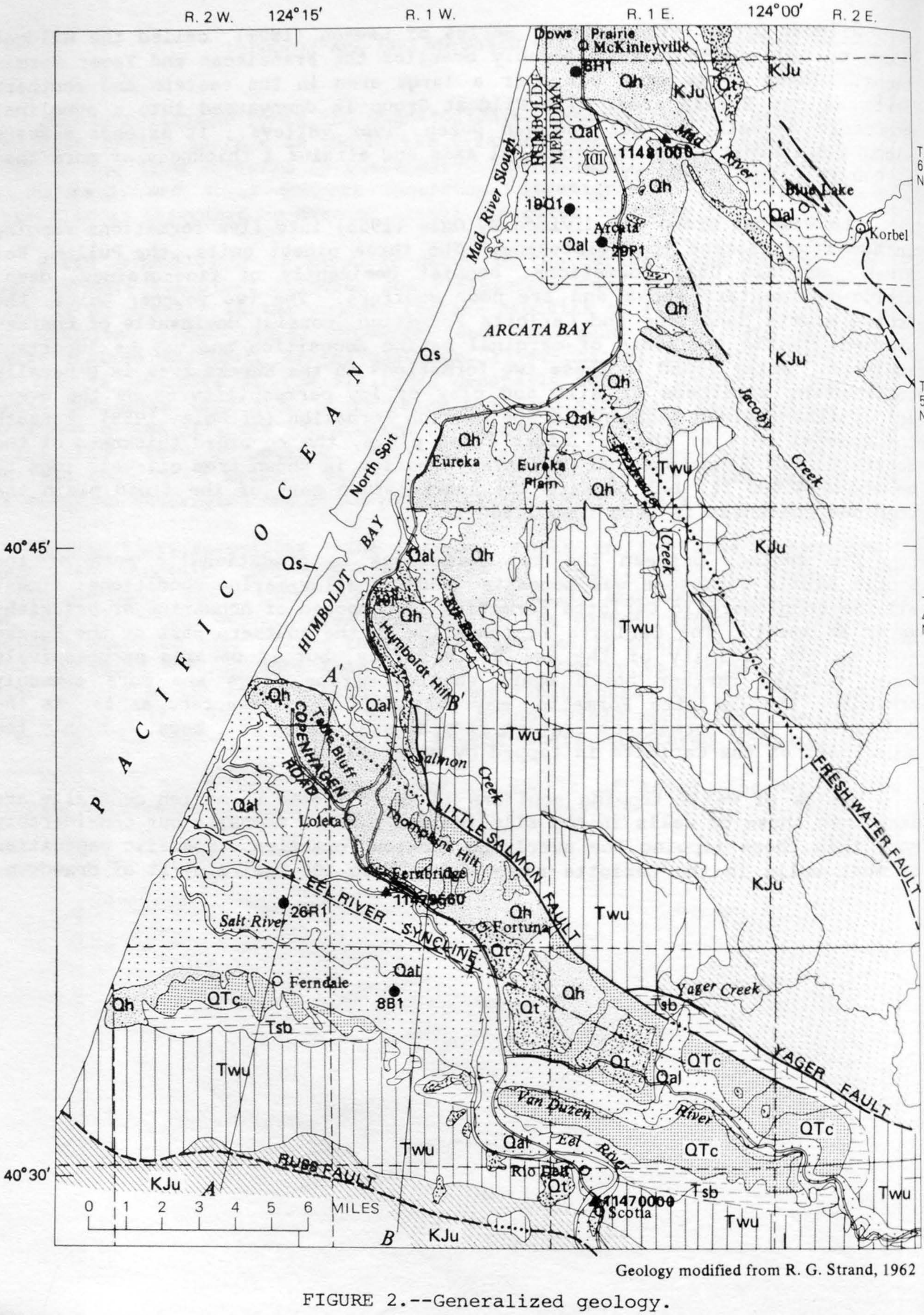
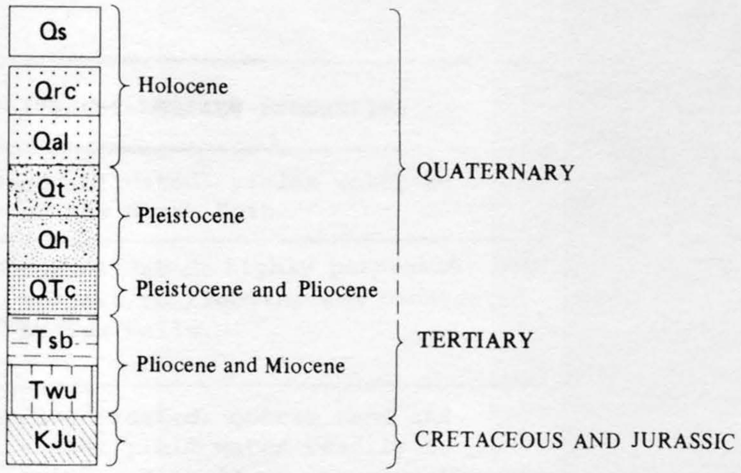


FIGURE 2.--Generalized geology.

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

Qs	Dune sand
Qrc	River-channel deposits (mapped as Qal)
Qal	Alluvium
Qt	Terrace deposits
Qh	Hookton Formation
QTc	Carlotta Formation
Tsb	Scotia Bluffs Sandstone
Twu	Rio Dell, Eel River, and Pullen Formations, undifferentiated
KJu	Yager and Franciscan Formations, undifferentiated

EXPLANATION

Contact

Fault – Dashed where approximately located, dotted where concealed

Syncline – Showing trace of trough plane. Dashed where approximately located

6H1 ● Water well and identification

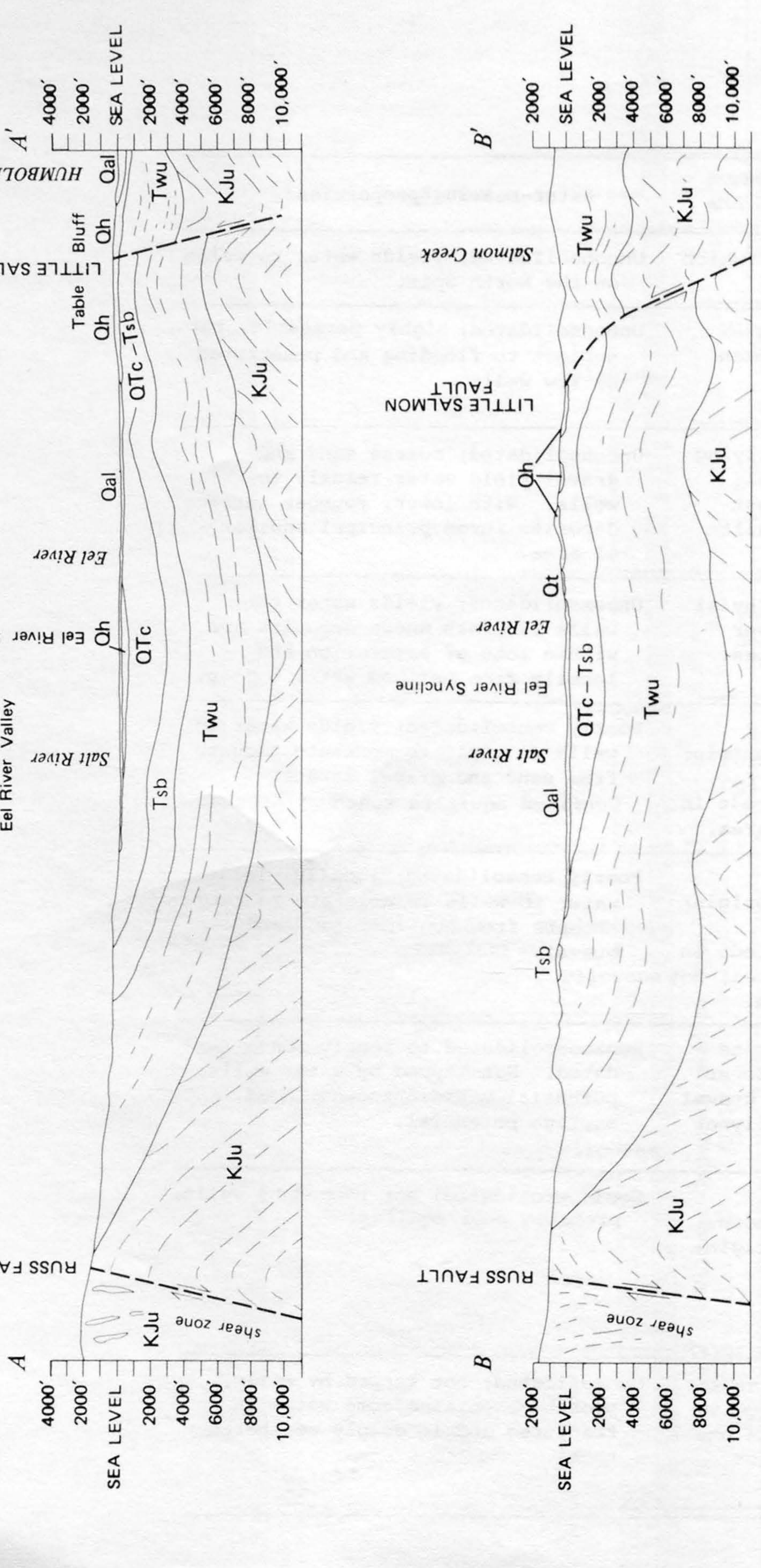
11470000▲ U.S. Geological Survey gaging station and number

A——A′ Line of geologic section shown in figure 3

TABLE 1.--*Stratigraphic* *units of the Eureka area*

[Modified from Evenson, 1959]

System	Series	Formation name and map symbol	Thickness (ft)	Lithologic character	Water-bearing properties
QUATERNARY	Holocene	Dune sand (Qs)	0-100	e to coarse sand, part of which is actively drifting.	Unconsolidated; yields water to wells on the North Spit.
		River-channel deposits (Qrc)	0-50	arse sand and gravel along channels of Eel and Van Duzen Rivers. Mapped as Qal in figure 2 because of scale.	Unconsolidated; highly permeable, but subject to flooding and penetrated by few wells.
		Alluvium (Qal)	0-200	y, sand, and gravel underlying alluvial plains; of fluvial origin except near the coast where estuarine clay and silt interfinger.	Unconsolidated; coarse sand and gravel yield water readily to wells. With lower, younger terrace deposits forms principal aquifer of area.
	?				
	Pleistocene	Terrace deposits (Qt)	0-100	y, sand, and gravel of fluvial origin; occurs beneath river benches and on higher slopes.	Unconsolidated; yields water to wells in areas where deposits are within zone of saturation and locally from perched water bodies.
		Hookton Formation of Ogle (1953) (Qh)	0-400	y, sand, and gravel predominantly of fluvial origin; becomes finer grained and interfingers with marine beds in the northern part of the area.	Poorly consolidated; yields water to wells in small to moderate amounts from sand and gravel strata. Confined aquifers south of Arcata.
?	?	Major unconformity			
QUARTERNARY AND TERTIARY	Pleistocene and Pliocene	Wildcat Group as used by Ogle (1953): Carlotta Formation of Ogle (1953) (QTc)	500-3,3	y, sand, and gravel predominantly of fluvial origin; becomes finer grained and interfingers with marine beds in the central part of the area; not recognized north of Eureka.	Poorly consolidated; locally yields water to wells in moderate to large amounts from confined sand and gravel
TERTIARY	Pliocene to Miocene	Wildcat Group as used by Ogle (1953): Scotia Bluffs Sandstone of Ogle (1953) (Tsb)	500-2,0	ssive, fine-grained sandstone with mudstone members in lower part and fluvial sand and gravel in upper part; predominantly of shallow marine origin.	Semiconsolidated to poorly consolidated. Not tapped by water wells, potential yield unknown. Good storage potential.
		Wildcat Group as used by Ogle (1953): Rio Dell, Eel River, and Pullen Formations of Ogle (1953) (Twu)	500-9,0	pact mudstone, claystone, siltstone, and some sandstone, predominantly of marine origin.	Semiconsolidated; not tapped by wells, probably poor aquifer.
		Major unconformity			
CRETACEOUS AND JURASSIC		Yager Formation of Ogle (1953) and Franciscan Formation (KJu)	20,000	aywacke, sandstone, shale, conglomerate, schist, chert, and basalt.	Consolidated; not tapped by wells, probably contains some water in fractures and in deeply weathered rocks.



See figure 2 for explanation of geologic symbols

FIGURE 3.--Geologic sections, Eel River Valley.

Hookton Formation.--The gently dipping beds of the Hookton Formation of Ogle (1953) unconformably overlie the Wildcat Group. In parts of the Eel River valley and Eureka Plain this formation consists of as much as 400 ft of continental sediments. In the northern Dows Prairie-McKinleyville area the Hookton consists of finer-grained marine sediments that underlie raised marine terraces. The Hookton Formation supplies water to many domestic wells in the Dows Prairie-McKinleyville area and on the hills and terraces of the study area. At lower altitudes and under the river valleys, water in the lower parts of the Hookton is in part confined by the overlying material. In 1975 it continued to be second only to the alluvium as a source of ground water in the Eureka area. However, yields from wells in the Hookton are small, generally less than 30 gal/min from pumping wells penetrating sand and gravel strata. Silting is a problem in many wells.

Terrace deposits.--Terrace deposits form step-like surfaces along the major river valleys and along streams of the Eureka Plain. The maximum thickness of the terrace deposits is about 100 ft. They yield water to wells locally from bodies of perched ground water and areally from deposits in the principal zone of saturation. In scattered localities, contact springs occur where saturated terrace deposits overlie relatively impermeable older formations.

Alluvium.--Alluvium underlies the flood plains of the major streams. Most of the irrigated agricultural land is alluvium. Much of the alluvium is poorly sorted sand and gravel deposits. Beneath the Eel River flood plain it is as much as 200 ft thick; most wells penetrate less than 70 ft. Beneath the Mad River flood plain the alluvium is as much as 100 ft thick, with many of the wells less than 30 ft deep. The deposits are unconsolidated and yield water readily to wells. Wells in the alluvium are the most productive in the area and have specific capacities ranging from 20 to 350 (gal/min)/ft.

River-channel deposits.--River-channel deposits composed of coarse gravel and small amounts of coarse sand lie along the present channels of the Mad and Eel Rivers. Along the Mad River the deposits are upstream from the flood plain; along the Eel River they are in the channel and on the flood plain. Although the river channel deposits in the Eel River flood plain are saturated and highly permeable, they are tapped by few wells.

Dune sand.--Beach and dune sand occur in an almost continuous strip along the coast. The dune sand is more than 100 ft thick along the North Spit between the entrance to Humboldt Bay and the mouth of the Mad River. On this spit the dune sand is locally an important aquifer. It is developed as a source of water supply for shallow wells or well points that are driven into the sand far enough to penetrate the lens of freshwater overlying the seawater.

RECHARGE, MOVEMENT, AND DISCHARGE OF GROUND WATER

Recharge to the water-bearing deposits of the Eureka area takes place in several ways. The alluvium along the major river valleys receives water from direct precipitation and by seepage from the rivers (fig. 2). Some water also moves laterally into the alluvium from adjacent formations and some moves upward from leakage due to differences in head between the alluvium and underlying formations. Aquifers in the Carlotta and Hookton Formations receive recharge from precipitation and stream seepage in their outcrop areas. The freshwater lenses in the dune sand along the coast are recharged almost wholly from local precipitation. In some areas irrigation water also returns by infiltration and is therefore a source of artificial recharge.

Water-level contours indicate the direction of ground-water movement (fig. 4) in the Eureka area. In the Eel and Van Duzen River valleys, ground water flows toward the coast and the tidal estuaries of the Eel River, generally following the topographic gradients but somewhat influenced by the geology (fig. 2). In the Table Bluff-Eureka Plain area shallow ground water drains toward stream channels; deeper ground water moves directly northwestward along southeast-northwest trending folds that underlie the area between Loleta and Eureka. On the Mad River flood plain the hydraulic gradient is seaward, with ground water in the alluvium discharging into Mad River Slough and Arcata Bay. In the Dows Prairie-McKinleyville area ground-water movement is principally toward the coast with some ground water moving southward toward the Mad River flood plain. In the alluvial deposits of the Blue Lake area, ground water moves toward the Mad River.

Ground-water discharge in the Eureka area occurs by natural and artificial means. Natural discharge takes place principally by subsurface flow to streams and tidal estuaries on the coastal plains, by evaporation and transpiration, and by discharge through springs. In the alluvium, ground-water outflow to the ocean is partly controlled by the rise and fall of the tide. In the older water-bearing deposits, outflow to the ocean probably takes place offshore, whereas outflow from the dune sand occurs near the shore. Artificial discharge is composed of pumpage and artesian flow from wells.

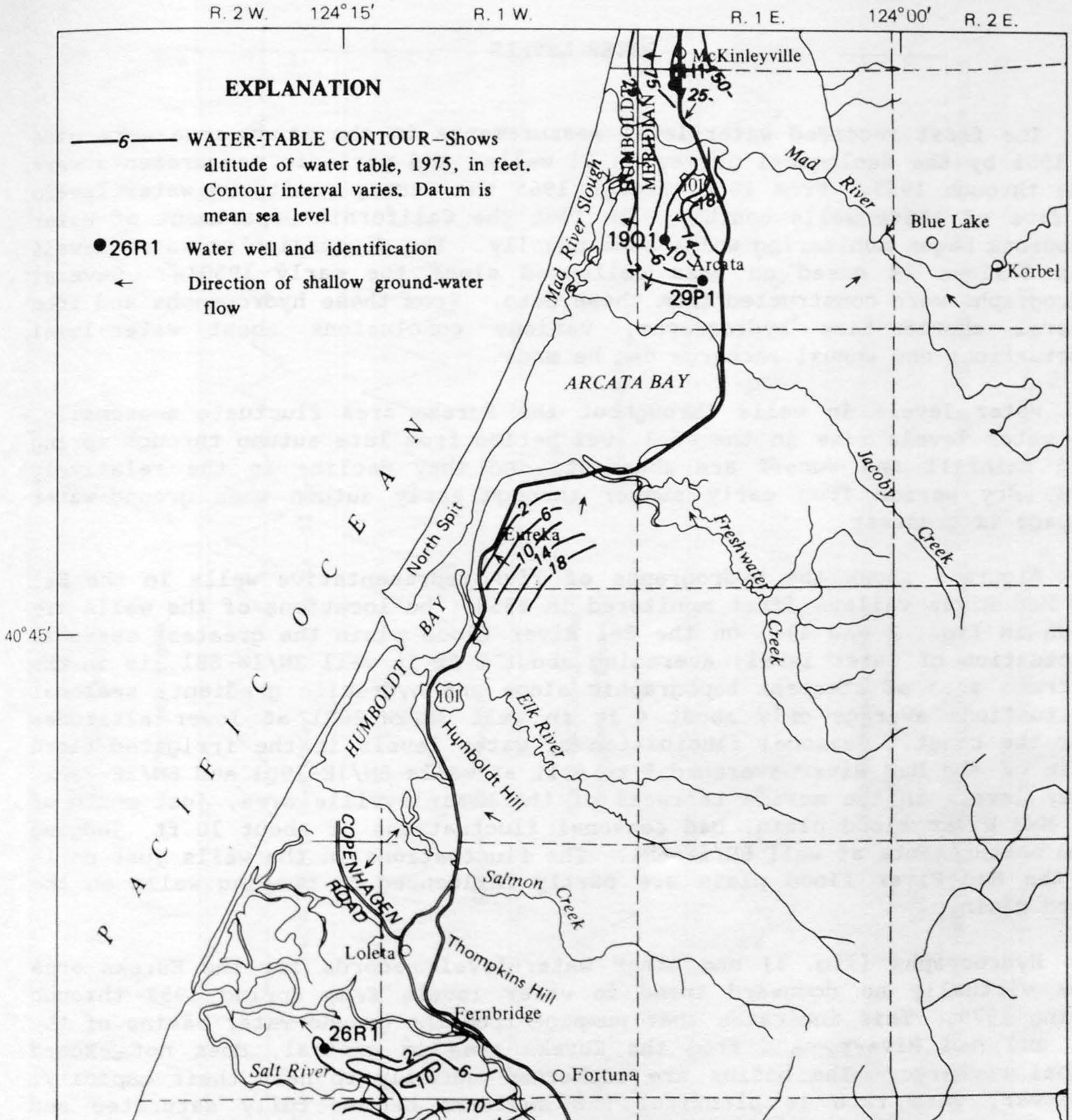


FIGURE 4.--Water-level contours, 1975.

WATER LEVELS

The first recorded water-level measurements in the study area were made in 1951 by the Geological Survey in 21 wells, and periodic measurements were made through 1955. From 1956 through 1965 the Survey monitored water levels in five of these wells monthly. In 1966 the California Department of Water Resources began monitoring wells semiannually. The discussion on water levels that follows is based on data collected since the early 1950's. Several hydrographs were constructed from these data. From these hydrographs and from several shorter-term hydrographs, various conclusions about water-level fluctuations and annual recharge can be made.

Water levels in wells throughout the Eureka area fluctuate seasonally. The water levels rise in the cool, wet period from late autumn through spring when rainfall and runoff are abundant, and they decline in the relatively warm, dry period from early summer through early autumn when ground-water pumpage is greatest.

Figure 5 shows the hydrographs of five representative wells in the Eel and Mad River valleys first monitored in 1952 (the locations of the wells are shown in figs. 2 and 4). On the Eel River flood plain the greatest seasonal fluctuation of water level, averaging about 8 ft in well 2N/1W-8B1, is in the upstream area of steepest topographic slope and hydraulic gradient; seasonal fluctuations average only about 4 ft in well 3N/2W-26R1 at lower altitudes near the coast. Seasonal fluctuation of water levels in the irrigated flood plain of the Mad River averaged 5 to 6 ft at wells 6N/1E-19Q1 and 6N/1E-29P1. Water levels in the marine terraces of the McKinleyville area, just north of the Mad River flood plain, had seasonal fluctuations of about 10 ft, judging from measurements at well 6N/1E-6H1. The fluctuations in the wells just north of the Mad River flood plain are partly influenced by pumping wells on the flood plain.

Hydrographs (fig. 5) and other water-level records for the Eureka area show virtually no downward trend in water levels from spring 1952 through spring 1975. This indicates that pumpage from the ground-water basins of the Eel and Mad Rivers, and from the Eureka area in general, does not exceed annual recharge. The basins are recharged annually to near their capacity. Moreover, when rain is plentiful the aquifers become fully saturated and reject recharge during much of the winter and spring.

Records show that, with few exceptions, water levels in wells throughout the area consistently remained above sea level even during the pumping season. On the Mad and Eel River flood plains, where most of the pumping is concentrated, water levels are maintained above sea level in the alluvial aquifers by rapid recharge from river infiltration. Recharge is rejected during the rainy season when direct infiltration of rainfall raises ground-water levels above river stage (fig. 6A). During the pumping season or during dry periods, however, water levels decline and the hydraulic gradient reverses so that water moves from the rivers toward the alluvial flood plains. As pumping progresses and the hydraulic gradient increases, river channel infiltration accelerates and maintains water levels above sea level over much of the flood plains (fig. 6B).

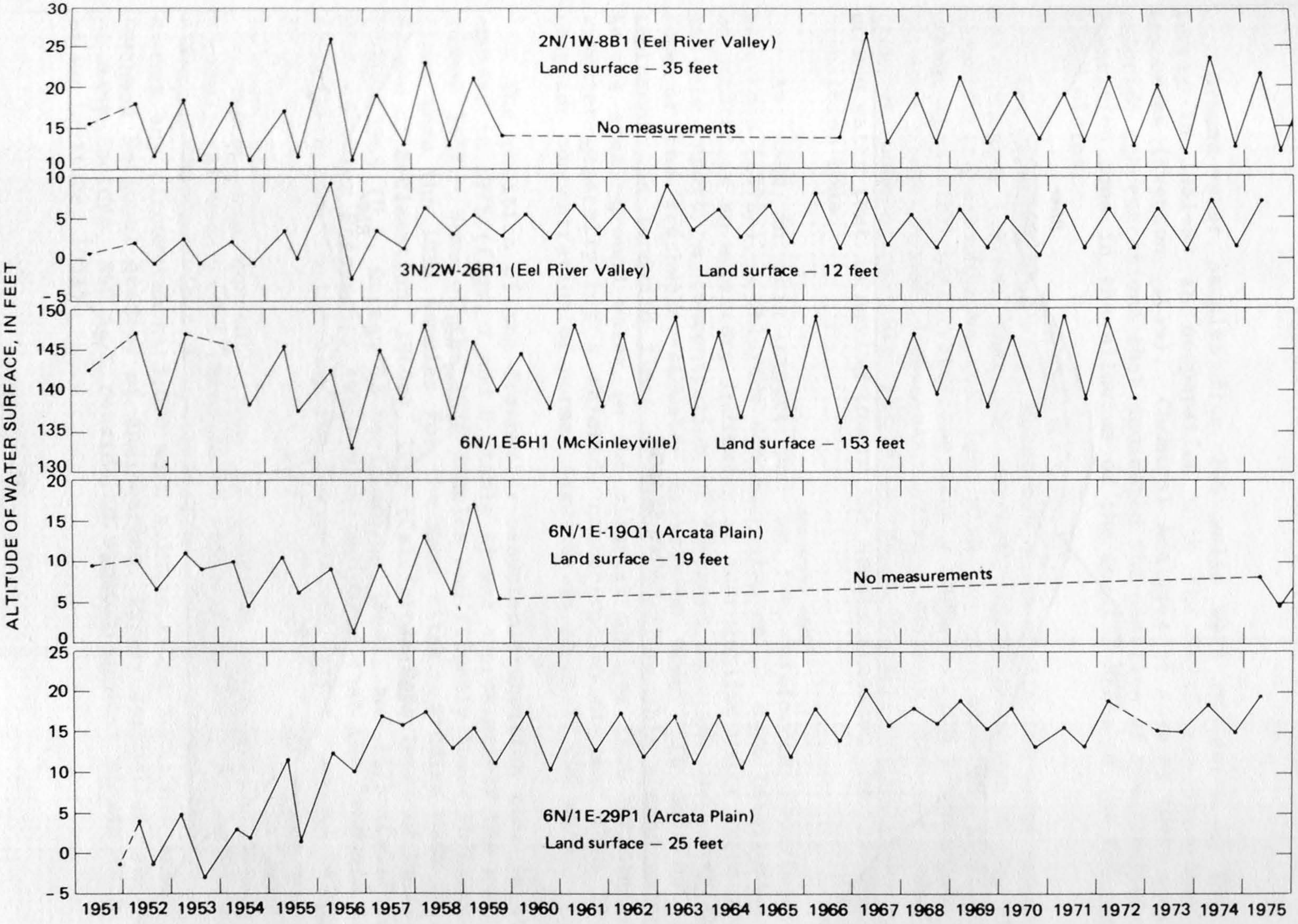


FIGURE 5.--Fluctuation of water levels in five wells, 1951-75.

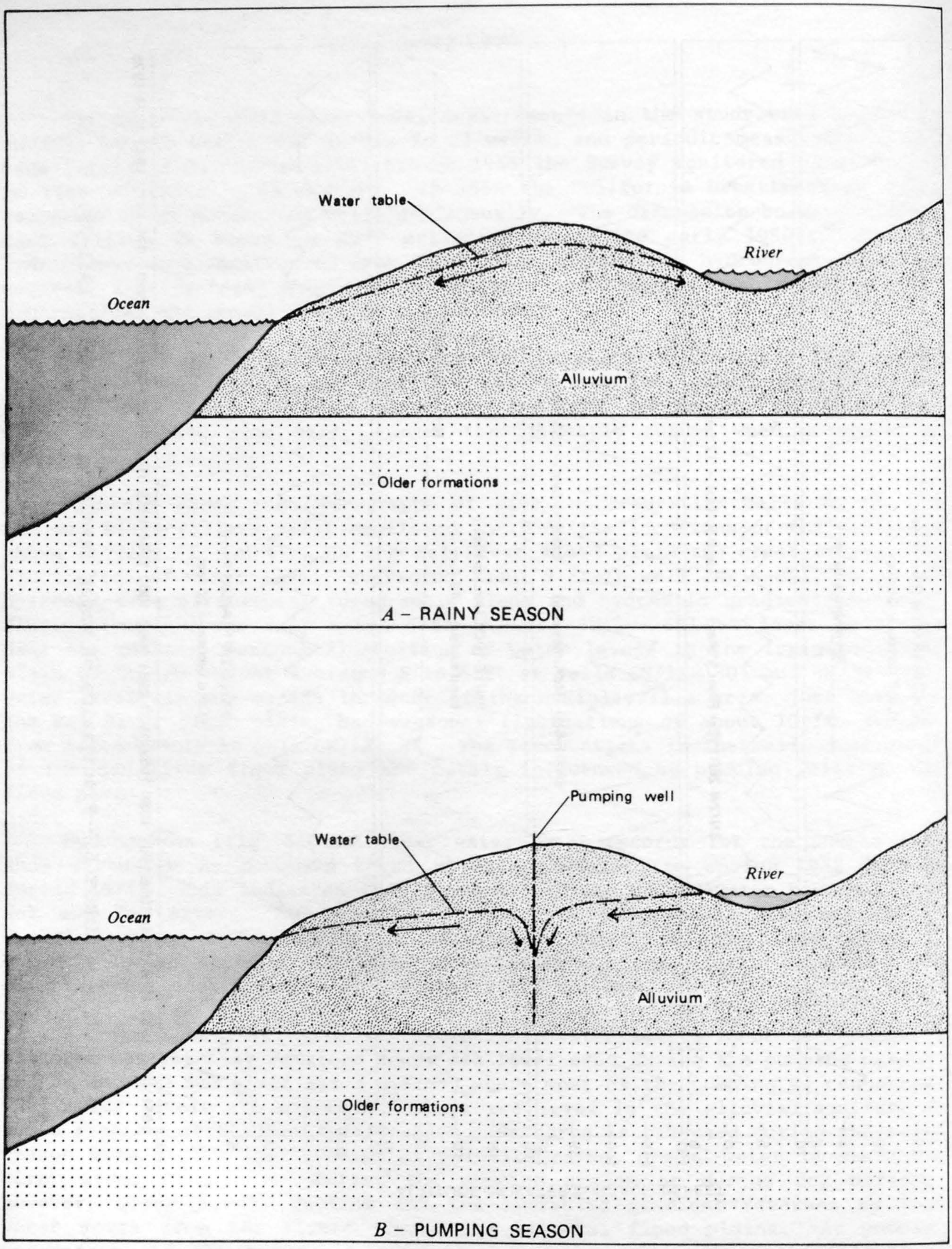


FIGURE 6.--Relation of water table to river and direction of ground-water flow during the rainy season and pumping season.

FRESHWATER-SEAWATER TRANSITION ZONE

Ground-water samples from 106 wells were collected by the Geological Survey in 1951-52 in cooperation with the California Department of Water Resources (Evenson, 1959). Chemical analyses of some of these samples showed chloride concentrations that indicated the position of the freshwater-seawater transition zone in the alluvium of the coastal areas of the Mad and Eel River flood plains.

The Department of Water Resources began monitoring water quality in 1957. It concluded (1975a) that the current (1975) position of the freshwater-seawater transition zone coincides with the zone of tidal influence near the ocean. Seawater infiltrates the highly permeable old river channel deposits. In many places these deposits underlie sloughs within the tidal zone. The seawater penetrates into the alluvial materials and diffuses through the ground water that is moving toward the coast, creating the freshwater-seawater transition zone.

As used in this report and by the California Department of Water Resources (1975a), a chloride concentration of 100 mg/L (milligrams per liter) or greater is an arbitrary indicator of poor-quality water. More specifically, in this report, a concentration of 100 mg/L chloride indicates the landward edge of the freshwater-seawater transition zone. It does not necessarily represent the landward limit of brackish or unusable ground water.[2] In the Eureka area, ground water in the alluvial aquifer that contains no diffused seawater generally has a chloride concentration of less than 30 mg/L. The chloride concentration of normal seawater is about 19,000 mg/L.

The position of the freshwater-seawater transition zone in the alluvial aquifer in 1975 (figs. 7 and 8, table 2) was approximately the same as in late summer 1952. Some of the 1975 samples had slightly lower chloride concentrations than the 1952 samples for the same sites. Studies made in 1959 (U.S. Bureau of Reclamation, 1960a), 1960 (California Department of Water Resources, 1960), 1969 (U.S. Bureau of Reclamation, 1969), and 1973 (California Department of Water Resources, 1973) also indicated that the landward limit of the transition zone in the alluvium has remained fairly constant between 1952 and 1975.

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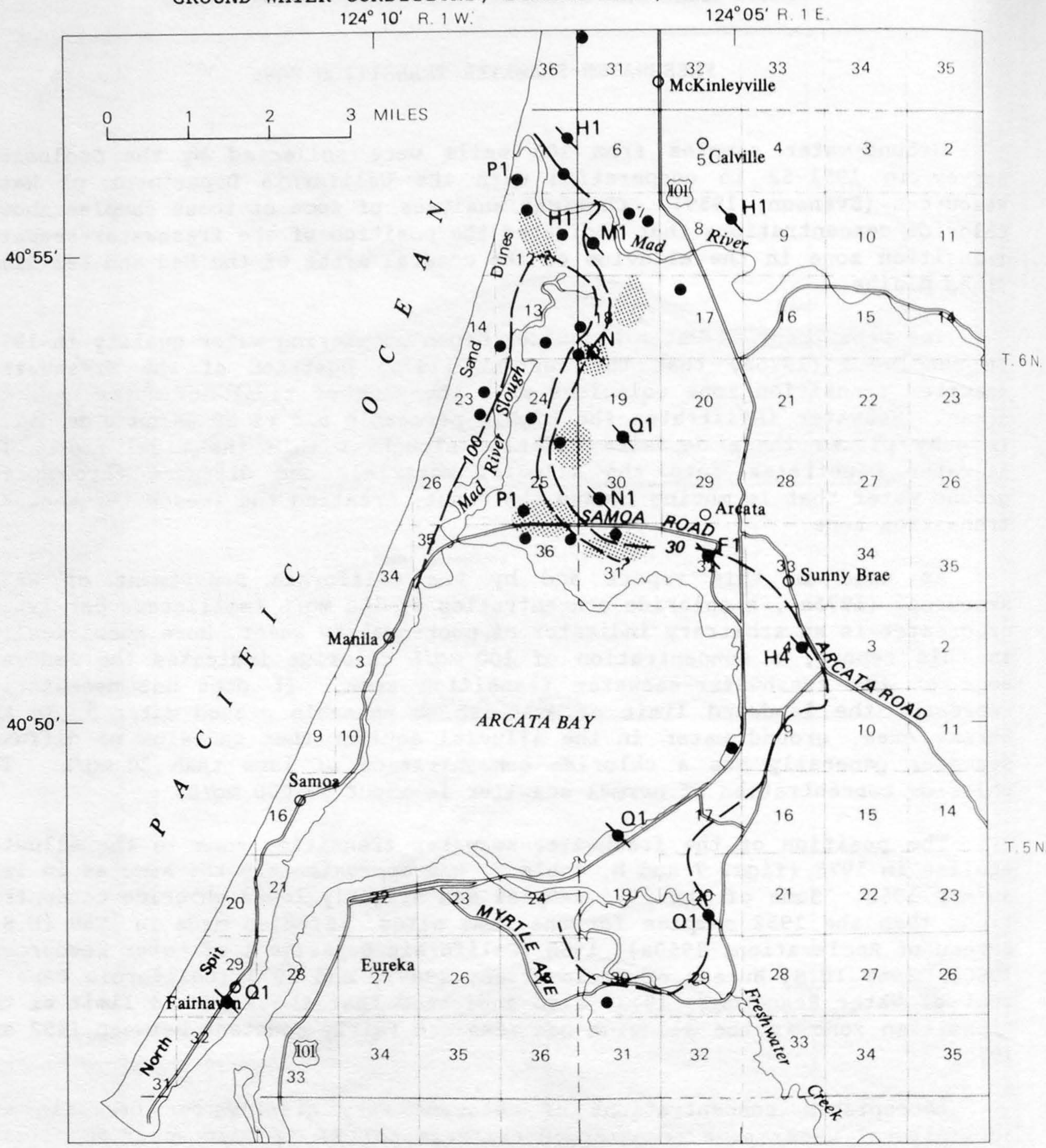
[2]Acceptable concentrations of chloride vary greatly for domestic and agricultural uses; some recommended criteria follow: public water supplies--250 mg/L chloride (based on taste preferences); livestock and poultry under almost any circumstance--3,000 mg/L soluble salts (National Academy of Sciences and National Academy of Engineering, 1972); irrigation--varies depending on many factors, 350 mg/L considered harmful to most plants (U.S. Department of Agriculture, 1954).



EXPLANATION

Area suggested for additional water-quality monitoring

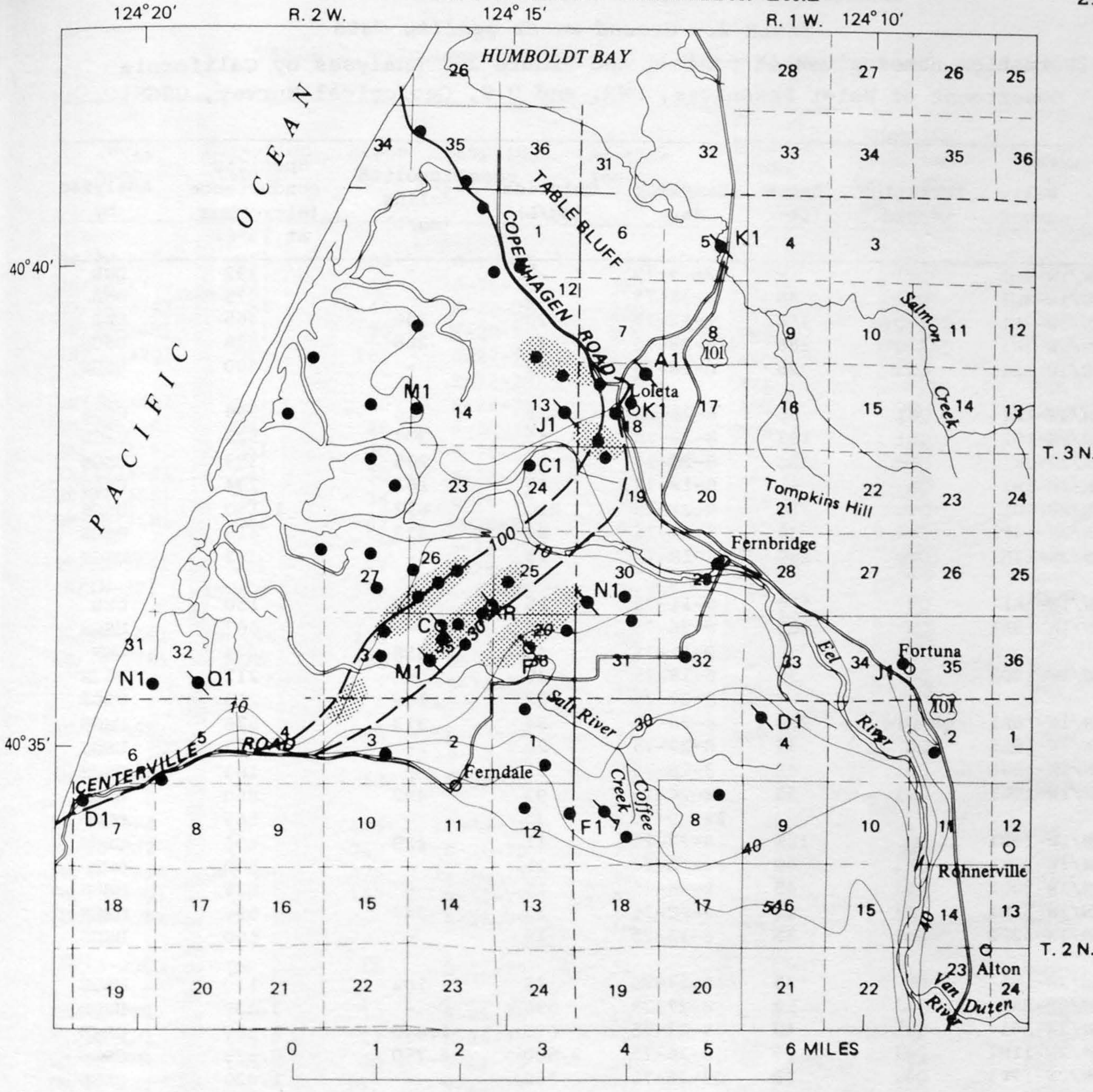
—30— LINE OF EQUAL CHLORIDE CONCENTRATION, 1975 – Dashed where approximately located. Concentration in milligrams per liter. Area within 100-milligrams-per-liter line (Mad River Slough and south to Arcata Bay) contains shallow ground water with chloride concentrations greater than 100 milligrams per liter. Area generally east of the 30-milligrams-per-liter line contains shallow ground water with chloride concentrations less than 30 milligrams per liter

P1 ● Control well and identification for well referred to in text

Q1 Well monitored by California Department of Water Resources and identification for well referred to in text

N Recommended additional monitoring well and identification for well referred to in text

FIGURE 7.--Freshwater-seawater transition zone in the alluvial aquifer, Mad River, 1975.



EXPLANATION

Area suggested for additional water-quality monitoring

—30— — LINE OF EQUAL CHLORIDE CONCENTRATION, 1975 – Dashed where approximately located. Concentration in milligrams per liter. The 100-milligrams-per-liter line indicates the landward edge of the freshwater-seawater transition zone. Area generally east of the 30-milligrams-per-liter line contains shallow ground water with chloride concentrations less than 30 milligrams per liter

D1● Control well and identification for well referred to in text

M1 Well monitored by California Department of Water Resources and identification for well referred to in text

C Recommended additional monitoring well and identification for well referred to in text

FIGURE 8.--Freshwater-seawater transition zone in the alluvial aquifer, Eel River valley, 1975.

TABLE 2.--*Ground-water quality data*

[Formation names given in table 1 and figure 2. Analyses by California Department of Water Resources, DWR, and U.S. Geological Survey, USGS]

Well number	Formation tapped	Depth (ft)	Sampling date	Chloride (mg/L)	Dissolved solids (mg/L)	Specific conductance (micromhos at 25°C)	Analyzed by
2N/1W-2L1	Qal	-	12- 9-75	9	-	392	DWR
2N/1W-4D1	Qal	48	9-11-75	10	-	575	DWR
2N/1W-7F1	Qal-QTc	154	9-12-75	20	246	465	DWR
2N/1W-7K1	Qal-QTc	155	8-28-75	22	268	458	USGS
2N/1W-8A1	Qal	25	6-18-75	12	-	400	USGS
2N/2W-1B1	Qal	56	8-28-75	21	316	559	USGS
2N/2W-1Q1	Qal	183	8-28-75	35	303	528	USGS
2N/2W-3K1	QTc	350	8-28-75	13	205	359	USGS
2N/2W-5N1	Qh	-	6-18-75	49	187	294	USGS
2N/2W-7D1	QTc	258	8-27-75	210	612	1,150	USGS
2N/2W-12F1	Qal	30	8-27-75	24	233	418	USGS
2N/2W-12H1	QTc	180	6-18-75	19	-	382	USGS
3N/1W-5K1	Qh	170	9-11-75	15	99	150	DWR
3N/1W-18A1	Qh	165	8-26-75	14	-	467	USGS
3N/1W-18D2	Qh	75	9-11-75	15	258	474	DWR
			6-18-75	30	-	212	USGS
			8-27-75	32	144	213	USGS
3N/1W-18K1	Qh-QTc	200	8-26-75	34	313	576	USGS
3N/1W-18L1	Qh	32	8-27-75	25	-	212	USGS
3N/1W-18N1	Qal	42	8-26-75	21	-	183	USGS
3N/1W-19C1	Qal	55	8-26-75	93	492	850	USGS
			12- 9-75	35	-	565	DWR
3N/1W-29G1	Qh	125	8-27-75	11	228	406	USGS
3N/1W-30N1	Qal	48	9- 6-74	15	-	580	DWR
3N/1W-30Q1	Qal	45	6-18-75	15	-	625	USGS
3N/1W-31B1	Qal	40	8-28-75	10	347	599	USGS
3N/1W-32F2	Qal	35	6-18-75	15	-	600	USGS
3N/2W-1N1	Qh	35	8-27-75	25	102	170	USGS
3N/2W-2A2	Qal	19	8-27-75	990	-	3,230	USGS
3N/2W-2R1	Qal	40	8-27-75	650	1,440	2,390	USGS
3N/2W-11M1	Qal	<15	8-26-75	2,600	4,750	8,320	USGS
3N/2W-12P1	Qal	23	8-26-75	260	-	1,020	USGS
3N/2W-13A1	Qal	55	8-26-75	1,300	2,870	4,340	USGS
3N/2W-13J1	Qal	38	6-18-75	340	-	1,500	USGS
			8-27-75	960	-	3,420	USGS
			9- 6-74	1,470	-	4,840	DWR
3N/2W-14M1	Qal	14	8-27-75	54	388	687	USGS
3N/2W-15K1	Qal	16	6-18-75	52	-	643	USGS
			8-26-75	84	-	798	USGS
3N/2W-16A1	Qal	11	8-26-75	1,500	2,920	4,980	USGS
3N/2W-16K1	Qal	-	12- 9-75	584	-	3,060	DWR
3N/2W-22B1	Qal-Qrc	12	8-26-75	110	-	957	USGS
3N/2W-22H1	Qal	12	8-26-75	140	642	1,120	USGS
3N/2W-24C1	Qrc	30	8-27-75	52	467	818	USGS
3N/2W-25M1	Qal	55	8-28-75	67	467	799	USGS
3N/2W-26E1	Qal	-	8-28-75	150	-	1,010	USGS
3N/2W-26G1	Qal	45	8-28-75	90	463	816	USGS
3N/2W-26L1	Qal	40	8-28-75	62	-	709	USGS
3N/2W-26N1	Qal	45	6-18-75	340	-	1,680	USGS
			8-28-75	220	685	1,275	USGS

TABLE 2.--*Ground-water quality data*--Continued

Well number	Formation tapped	Depth (ft)	Sampling date	Chloride (mg/L)	Dissolved solids (mg/L)	Specific conductance (micromhos at 25°C)	Analyzed by
3N/2W-26R2	Qal	32	6-18-75	33	393	677	USGS
3N/2W-27G1	Qal	18	8-28-75	300	-	1,450	USGS
3N/2W-27K1	Qal	45	8-28-75	230	699	1,270	USGS
3N/2W-28H1	Qal	20	8-28-75	870	1,880	3,420	USGS
3N/2W-32Q1	QTc	268	8-27-75	230	490	841	USGS
			9-12-75	225	471	855	DWR
3N/2W-34A1	Qal	30	8-28-75	75	407	719	USGS
3N/2W-34K1	Qal	26	8-28-75	40	335	585	USGS
3N/2W-35B1	Qal	30	8-28-75	40	-	621	USGS
3N/2W-35C1	Qal	30	8-28-75	22	-	586	USGS
3N/2W-35G1	Qal	34	8-28-75	21	326	561	USGS
3N/2W-35M1	Qal	47	8-28-75	47	-	657	USGS
			9-11-75	46	387	700	DWR
3N/2W-36A1	Qal	27	8-28-75	14	344	589	USGS
4N/1W-8P1	QTc	450	8-27-75	15	95	160	USGS
			12-10-75	12	-	161	DWR
4N/1W-16H1	Qh-QTc	210	9-11-75	30	-	465	DWR
4N/1W-17B1	QTc	491	8-27-75	16	-	176	USGS
			9-11-75	14	-	183	DWR
4N/2W-35E1	Qh	20	8-27-75	74	189	352	USGS
			12- 9-75	72	-	368	DWR
4N/2W-35Q1	Qh	52	8-27-75	17	-	160	USGS
5N/1E-4H4	Qh	125	12-10-75	46	-	487	DWR
5N/1E-8J2	Qh	240	8-26-75	35	197	344	USGS
5N/1E-18Q1	Qal-Qh	375	12-10-75	97	-	831	DWR
5N/1E-20Q1	Qh	157	9-12-75	32	-	295	DWR
5N/1E-30P1	Qh	-	8-26-75	12	94	133	USGS
5N/1W-29Q1	Qs	16	9-12-75	24	-	315	DWR
6N/1E-7B1	Qal	30	8-25-75	13	-	361	USGS
6N/1E-7H1	Qal	17	8-25-75	9	131	234	USGS
6N/1E-7M1	Qal	20	9-11-75	28	-	520	DWR
6N/1E-8H1	Qh	157	9-12-75	15	-	180	DWR
6N/1E-17D1	Qal	64	6-22-70	16	-	435	DWR
6N/1E-18M1	Qal	40	12-10-75	119	-	815	DWR
6N/1E-18N1	Qh	120	8-25-75	9	218	388	USGS
6N/1E-19Q1	Qal	108	9- 5-75	11	-	375	DWR
6N/1E-30N1	Qal	37	9- 5-74	12	-	365	DWR
6N/1E-31C1	Qal	-	8-26-75	16	177	297	USGS
6N/1E-32F1	Qh	640	9- 5-74	82	-	700	DWR

TABLE 2.--*Ground-water quality data*--Continued

Well number	Formation tapped	Depth (ft)	Sampling date	Chloride (mg/L)	Dissolved solids (mg/L)	Specific conductance (micromhos at 25°C)	Analyzed by
6N/1W-1H1	Qh	31	9-11-75	22	-	195	DWR
6N/1W-1P1	Qs-Qal	14	8-25-75	99	465	835	USGS
6N/1W-1R1	Qh	25	8-25-75	33	218	308	USGS
6N/1W-12C1	Qal	25	8-25-75	16	237	417	USGS
6N/1W-12H1	Qal-Qh	148	8-25-75	9	229	402	USGS
6N/1W-13N1	Qs	8	8-25-75	48	-	374	USGS
			12-10-75	27	-	308	DWR
6N/1W-13Q1	Qal	-	8-25-75	160	-	922	USGS
6N/1W-23H1	Qs-Qal	120	8-25-75	34	394	651	USGS
6N/1W-23J1	Qs-Qal	-	8-25-75	25	-	565	USGS
6N/1W-24L1	Qal	-	8-26-75	150	-	905	USGS
6N/1W-25A1	Qal	80	8-26-75	12	240	411	USGS
6N/1W-25P1	Qh	180	8-26-75	10	-	385	USGS
6N/1W-36A1	Qal	20	8-26-75	280	-	1,465	USGS
6N/1W-36C1	Qh	168	12-10-75	10	-	410	DWR
7N/1E-31D1	Qh	50	8-25-75	24	128	227	USGS

It is not known whether the landward limit of the transition zone in 1952 resulted from pumping stress or was a natural freshwater-seawater boundary. No documented information is known to be available prior to the 1951-52 sampling that could indicate whether ground-water development had induced intrusion. However, chloride concentrations in water samples from pumping wells near the landward edge of the transition zone increased from early to late summer 1975 (table 2). This indicates at least some localized temporary shift landward of the edge of the freshwater-seawater transition zone as a result of pumping drawdown near the transition zone and of naturally lower ground-water levels in late summer. This localized summer intrusion of high-chloride water is countered by a seaward retreat in the winter months caused by seasonal recharge which increases the fresh ground-water head.

Mad River valley.--The major aquifer in the Mad River valley underlies the flood plain of the Mad River, where as much as 100 ft of unconsolidated alluvium overlies the Hookton Formation. The freshwater-seawater transition zone is farther inland in the shallow parts of the aquifer near Arcata Bay and the Mad River Slough than in the deeper parts. Deeper wells in that area, beneath the shallow transition zone (fig. 7), for example 6N/1W-12H1 and 6N/1W-25P1, produce water with chloride concentrations of less than 10 mg/L. The shallow ground water is cased out, and the wells tap only the partly confined deeper alluvium and the underlying more compact and finer grained Hookton Formation. Seawater is not present in the Hookton Formation to any appreciable extent landward of the coastline in this area. Similarly, the Dows Prairie-McKinleyville area, which is underlain by the Hookton Formation except along the coast where sand dunes are present, shows no sign of seawater.

Ground-water samples from the dune sands along the North Spit indicate some diffusion of ocean or bay water into freshwater lenses. Water in well 6N/1W-1P1 (fig. 7) had the highest concentration of chloride, 99 mg/L; water in other wells had concentrations of 25 to 50 mg/L.

Table Bluff-Eureka Plain.--The major part of the Eureka Plain is an elevated terrace dissected by alluvial drainage channels. The terrace is composed of the finer-grained sand and silt of the Hookton Formation, 400 and more ft thick, which are underlain by clay and sand of the Wildcat Group. Generally low chloride concentrations in the Hookton Formation indicate that heads in 1975 were sufficient to prevent any appreciable seawater intrusion, either directly from seawater or by diluted seawater leaking from overlying material. Ground-water development on the terrace is limited because the city of Eureka and most of the surrounding area rely on water imported from the Mad River rather than on ground water.

The shallow alluvial aquifers surrounding Arcata and Humboldt Bays are in hydraulic connection with the tidal marshlands and contain a freshwater-seawater transition zone inland from the marshlands. Few wells penetrate these aquifers near the shorelines of the bays, and data are insufficient to define a transition zone. The alluvial aquifers do not have continuity with the deeper confined aquifers; diluted seawater in the alluvial aquifers is not expected to infiltrate the deeper aquifers, owing to higher heads in the underlying aquifers. Water from shallow wells in the alluvial valleys of the Elk River and Freshwater and Salmon Creeks (fig. 1) has low chloride concentrations; this is attributed to the combined effects of an adequately high water table and direct infiltration of streamflow to the alluvium.

Eel River valley.--North of the Eel River, the flood plain is at low altitude (generally less than 10 ft above sea level) and under tidal influence. Water from most wells has high chloride concentrations, 260 to 2,600 mg/L. Some shallow wells that tap freshwater lenses in the upper alluvium that is recharged by local rainfall (for example, 3N/2W-14M1) and some wells in or near the river channel deposits (for example, 3N/2W-24C1) have lower chloride concentrations. Almost all the alluvial aquifer north of the Eel River, between the Eel River and the surface contact with the Hookton Formation, is naturally degraded by seawater. At this geologic contact along Copenhagen Road, the chloride concentrations diminish abruptly from more than 250 mg/L in the alluvium to about 30 mg/L in the Hookton Formation.

South of the Eel River the flood plain rises from sea level at the coast to more than 50 ft above sea level to the southeast. As in the northern part of the flood plain, diluted seawater within the alluvium was detected in wells along the coast where the land-surface altitude of the alluvium is less than 10 ft. In this area, water from wells drilled to 5 ft below sea level had chloride concentrations of 50 to 150 mg/L. Water from similar wells half a mile to the east and at land-surface altitudes of 10 to 15 ft had lower chloride concentrations. Water from these wells drilled 15 to 30 ft below sea level had chloride concentrations of 20 to 70 mg/L. This indicates that chloride concentrations in the ground water at a given depth below sea level decrease with distance from the coast (fig. 9). Also, within the transition zone chloride concentrations increased with well depth.

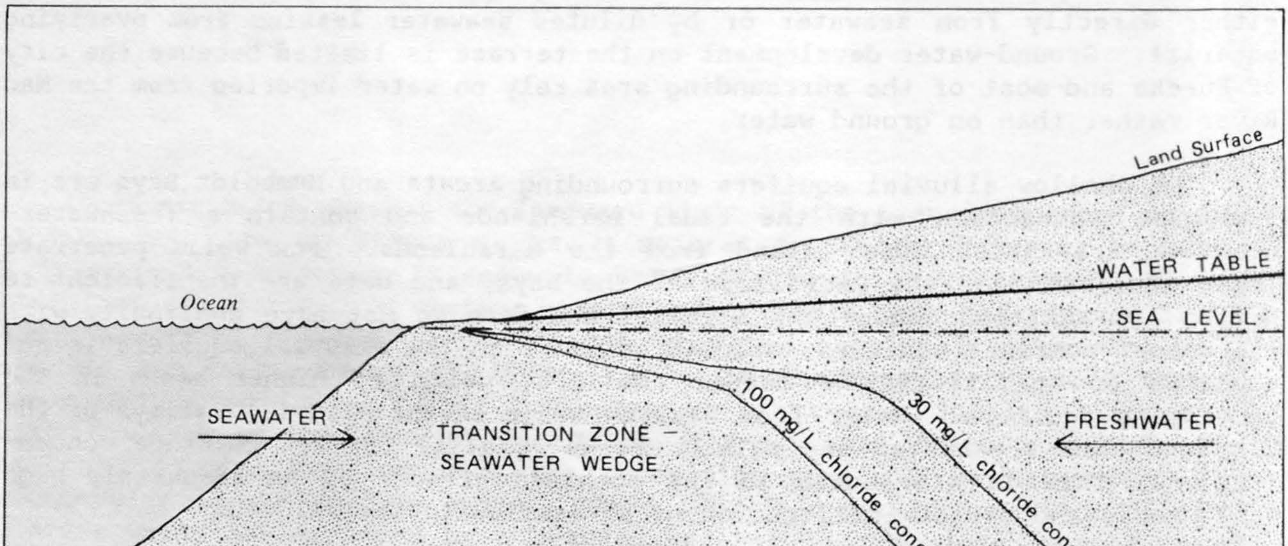


FIGURE 9.--Schematic section showing transition wedge in shallow aquifer.

Seawater apparently penetrates the alluvial aquifer along the coast and sloughs and extends inland under the less dense fresh ground water in the form of a transition wedge (fig 9). Along the east or landward edge of the transition zone (fig. 8), generally coinciding with the 10-ft land-surface altitude, chloride concentrations of shallow well water average 100 mg/L. The seawater wedge deeper in the alluvium may, however, extend farther inland. The eastward extent of the 30-mg/L chloride line shown in figure 8 is defined by wells that are generally less than 50 ft deep.

A 7-mi reach of the Eel River above the tidal zone moderates the natural movement of seawater into the alluvium south of the river by maintaining a seaward hydraulic gradient where freshwater heads in the summer are sustained above sea level. This reach, however, does not affect the alluvium north of the river, most of which adjoins the tidal reach. Between the Eel River and the Salt River, water of poorer quality is held below sea level in sections 26 and 35 (T. 3 N., R. 2 W.) owing to the river head and the permeable nature of the alluvium. In this area and extending to the confluence of the Eel and Van Duzen Rivers, about 6 mi to the southeast, the alluvium is composed of coarse sand and gravel deposits (Ogle, 1953) capable of accepting substantial amounts of recharge from river seepage (U.S. Bureau of Reclamation, 1969). South of the Salt River and generally west of Coffee Creek (fig. 8), most of the alluvial deposits are of low permeability, consisting of fine silt and clay which not only deflect westward-moving ground water to the northwest but also have the effect of impeding seawater movement through sections 2, 3, and 4 (T. 2 N., R. 2 W.).

The Carlotta and Hookton Formations underlie the alluvial flood plain of the Eel River and extend beneath the ocean. The lower Carlotta Formation may form a continuous aquifer beneath the flood plain, as indicated by tidal fluctuations on the hydrograph of well 3N/1W-34J1, which taps the Carlotta Formation at Fortuna (California Department of Water Resources, 1973). How far fresh water extends seaward of the coastline in these formations in the northern part of the flood plain is unknown. Three deep wells on the southern part of the flood plain within a mile of the coast, 3N/2W-32N1, 3N/2W-32Q1, and 2N/2W-7D1, penetrate the Carlotta Formation. In this area the Carlotta contains water with chloride concentrations ranging from 200 to 275 mg/L, which is considerably less than that in the overlying alluvium. Diluted seawater probably does not extend as far inland in the deeper confined aquifers as in the overlying alluvium, although there are no deep wells in the central part of the Eel River flood plain to confirm this.

The freshwater-seawater transition zone in the Carlotta Formation reacts to small changes in head within the aquifer. The water in well 3N/2W-32Q1 had a chloride concentration in 1975 about the same as in 1952--230 mg/L compared to 220 mg/L. However, samples from this well have shown fluctuations from a low of 106 mg/L in 1958 to 411 mg/L in 1961, indicating that chloride concentrations vary with small changes in head near the coast.

PUMPAGE

The principal use of ground water in the Eureka area in 1975 was for irrigation, and most of the irrigation pumping was concentrated on the Eel and Mad River flood plains. Ground water was used for domestic supplies by people in the southern part of the Eureka area. Some ground water was used for industry and livestock.

About 425 wells supplied irrigation water to the Eureka area in 1975; half of those wells are on the Eel River flood plain. The wells are used from May through October, with the heaviest pumping demand from June through September.

Irrigation pumpage.--Irrigation pumpage is commonly determined by either the land-use or the energy-lift method. In the land-use method a unit applied-water requirement for each crop type is multiplied by the number of acres for each crop type, and the products are summed. The unit applied-water requirement is the quantity of water that must be made available within a given geographic location in California to provide for transpiration, evaporation, and other losses associated with irrigation of a particular crop type. In the energy-lift method the electric energy used for pumping water is determined at individual meters from utility company power accounts. The volume of water pumped is then calculated directly from the electrical energy consumed, the pump efficiency, and the amount of water lift (McClelland, 1963). The pump efficiency and water lift can be obtained from pump-efficiency tests that are conducted by utility companies as a service to customers.

Inherent in both methods is a degree of error. In the land-use method the number of irrigated acres is determined approximately from aerial photographs and may require field checks for accurate delineation of crop type. Also, the actual application of the unit applied-water requirement to the acreage is not guaranteed. In the energy-lift method, the energy consumed is known for a particular well, but the pump efficiency and amount of water lift may change with time and season. The energy-lift method also presumes that irrigation accounts can be identified and separated from other utility uses. In both methods, irrigation by pumping of surface water must be identified and separated from ground-water pumpage.

Table 3 shows ground-water irrigation pumpage for 1952, 1958, 1968, and 1975. The 1952 pumpage was conservatively estimated by Evenson (1959) on the basis of acreage and pumpage information furnished by landowners. The 1958 and 1968 values were determined from the California Department of Water Resources 1958 and 1968 land-use surveys and the unit applied-water requirements (table 4). The 1975 pumpage is based on electrical-energy use and pump-efficiency test information provided by the Pacific Gas and Electric Co.

TABLE 3.--*Irrigation pumpage*

[Pumpage given in acre-feet]

Area	Land-use method						Energy-lift method
	1952[1]		1958[2]		1968[3]		1975
	Acres	Pumpage	Acres	Pumpage	Acres	Pumpage	Pumpage
Eel and Van Duzen River valleys upstream from confluence	1,200	1,200	1,900	3,200	1,900	3,000	2,900
Eel River flood plain	8,400	8,400	9,000	14,800	9,800	15,800	14,400
Mad River flood plain	1,600	1,600	1,900	3,200	2,400	4,100	4,100
Other areas[4]	800	800	1,000	1,700	1,400	2,300	2,500
Total	12,000	12,000	13,800	22,900	15,500	25,200	23,900

[1]Evenson, 1959. Based on 1 acre-foot/acre (12 inches per unit area).
[2]Based on California Department of Water Resources, 1965a and 1965b.
[3]Based on file data, California Department of Water Resources, Red Bluff, Calif.
[4]Principally the Table Bluff-Eureka Plain area, Dows Praire-McKinleyville area, and Blue Lake area.

Large differences in irrigation pumpage between 1952 and 1958 are probably due to differences in assessing water application by the land-use method rather than a substantial increase in consumption of ground water. The 1952 pumpage was based on an average annual application of 12 inches of ground water per acre, whereas the 1958 pumpage was based on an annual irrigation requirement of 12.0 to 20.4 inches of water per acre, depending on crop type. Pasture lands constitute a major part of the irrigated land in the Eureka area. They were assessed on the basis of a 20.4-inch application rate for determining the 1958 pumpage but only on a 12.0-inch rate for the 1952 pumpage.

TABLE 4.--*Unit applied-water requirement by crop type for Humboldt County coastal areas*

[From California Department of Water Resources, 1971]

Crop type	Unit applied-water requirements — Inches per unit area
Miscellaneous truck	12.0
Miscellaneous field	12.0
Alfalfa	18.0
Pasture	20.4

Between 1952 and 1958, ground-water consumption increased with an increase in irrigated acreage. A Bureau of Reclamation land-use survey made during 1953-54 (U.S. Bureau of Reclamation, 1956) showed 11,963 irrigated acres in the Eureka area, which agreed with Evenson's 1952 estimate. The Bureau estimated the irrigated acres for 1958 at 15,000 (U.S. Bureau of Reclamation, 1960b). Additional increases in the acres irrigated by ground water from 1958 to 1968 are partly due to the conversion from surface-water pumping to ground-water pumping since the December 1964 flood which destroyed many pump installations on the river.

Irrigation pumpage between 1958 and 1975 did not change significantly (less than 5 percent). The 1968 pumpage (land-use method) and the 1975 pumpage (energy-lift method) correlate well, considering the computational errors inherent in each method. A 1975 field update of the 1968 land-use maps for irrigated acreage (not shown in table 3) resulted in little overall change in the estimated land-use pumpage between 1968 and 1975. The energy-lift pumpage was computed for 1974 and found to agree with the 1975 energy-lift pumpage. Energy-lift information prior to 1974 was not available for inclusion in this report.

Pumpage figures in table 3 indicate that total ground-water pumpage for irrigation has remained fairly stable from the late 1950's to the mid-1970's and was estimated in 1975 to be 23,900 acre-ft/yr. The major growth in ground-water pumpage occurred from the early 1940's, when little irrigation was practiced, to the mid-1950's. Conservation measures now practiced for economic reasons are stabilizing pumpage; higher energy costs are weighed against the advantage of additional irrigation.

Other pumpage.--Ground water is also used for public and domestic supplies, industry, and livestock. Municipal and industrial users in the Eureka area are now less dependent on ground water than they were in the early 1950's. With the creation and expansion of the Humboldt Bay Municipal Water District, surface water from the Mad River (about 61,300 acre-ft in 1975) is now supplied to municipal and industrial users from the northern part of the study area to the southern end of Humboldt Bay (Humboldt Bay Municipal Water District, 1975). Smaller communities in the southern part of the study area still rely on local ground-water systems. Likewise, some industries such as creameries in the southern area continue to use ground water, but they use it more efficiently and in smaller quantities than in previous years. One creamery at Loleta mentioned by Evenson (1959) decreased ground-water use from about 1,100 acre-ft in 1952 to about 34 acre-ft in 1975 by relying on brackish river water for cooling. Creameries and other industries combined probably pumped a minimum of 1,100 acre-ft in 1975. This figure is based in part on data supplied by industry and in part on records from the Pacific Gas and Electric Co.

Of the 84,000 people living in the study area in 1975 (written commun., California Department of Finance, 1975), about 18,000 use ground water from community well systems or private domestic wells as their principal source of supply. Most of these users live south of Humboldt Bay, outside the area served by the Humboldt Bay Municipal Water District. Three-fourths of these people are on community systems (Winzler and Kelly, 1973). Ground-water pumpage in the Eureka area for all public and domestic supply was estimated to be 2,000 acre-ft in 1975.

A significant quantity of ground water, about 500 acre-ft/yr, is used to water livestock. Dairy cattle are the dominant livestock. The 1972 dairy cow inventory showed some 16,800 milking cows in the study area (Humboldt County Planning Department, 1975); each producing cow consumes 25 to 30 gal/d.

Ground-water pumpage for all uses in the Eureka area in 1975 is summarized in table 5. The total pumpage of 27,500 acre-ft is probably a conservative estimate of the current annual pumpage, most of which is from the alluvium and terrace deposits. Irrigation continues to be the largest user of ground water.

TABLE 5.--*Ground-water pumpage for all uses, 1975*

Use	Pumpage (acre-ft)
Irrigation	23,900
Public and domestic supply	2,000
Industry	1,100
Livestock	500
Total	27,500

POTENTIAL FOR ADDITIONAL DEVELOPMENT OF GROUND WATER

Water-bearing deposits in the Eureka area attain a maximum thickness of about 4,000 ft. However, most of the ground water being pumped comes from the alluvial aquifers, which are generally less than 150 ft thick. The aquifers have the capacity to meet 1975 pumping stress without a long-term reduction in freshwater storage. This is indicated by the stable freshwater-seawater transition zone and the lack of a downward trend in water levels between 1952 and 1975.

The ability of the alluvial aquifers and other shallow aquifers of the Hookton Formation and terrace deposits to withstand additional pumping can be determined by comparing pumpage from these aquifers to their storage capacity and recharge potential. The storage capacity of an aquifer, as defined in this report, is the maximum quantity of usable ground water that can be held in storage at any given time. The recharge potential, as defined in this report, is the amount of recharge an aquifer will receive under stress. Estimates of storage capacity and recharge potential are shown in table 6. Estimates of storage capacity are based on storage-unit boundaries, usable saturated thicknesses, and specific yields. Estimates of recharge potential are based on rates of infiltration of precipitation; percolation of applied irrigation, municipal, and industrial water; assumed infiltration losses from rivers and streams; and the rates of movement of this water once it is in the aquifer.

TABLE 6.--*Estimates of storage capacity and recharge potential in the shallow aquifers of the Eureka area*

Storage unit	Storage capacity (acre-ft)			Recharge potential (acre-ft)		
	U.S. Geological Survey[1] (spring water level)	California Department of Water Resources[2] (spring water level)	U.S. Bureau of Reclamation[3] (summer water level)	U.S. Geological Survey[1]	California Department of Water Resources[4] ("safe yield")	U.S. Bureau of Reclamation[3] (available June-November)
Eel and Van Duzen River valleys:	125,000	136,100	79,000	--	60,000	65,700
Lower	12,000	13,800	--	--	--	--
Middle	67,000	63,000	--	--	--	--
Upper	46,000	59,300	--	--	--	--
or Eel River flood plain	79,000	76,800	43,000	--	50,000	43,000
Eel and Van Duzen River valleys above confluence	46,000	59,300	36,000	--	10,000	22,700
Table Bluff-Eureka Plain area:[8]	--	--	--	--	--	--
Mad River valley:	25,000	48,000	22,500	--	--	--
Mad River flood plain	11,000	[5]11,000	[6]4,500	--	8,600	[6]8,000
Blue Lake area	14,000	37,000	[6]18,000	--	--	[6]23,000
Dow Prairie-McKinleyville area:	--	9,300	--	--	[7]2,500	[6]2,500

[1] Evenson, 1959.
[2] California Department of Water Resources, 1965c.
[3] U.S. Bureau of Reclamation, 1969.
[4] California Department of Water Resources, 1971.
[5] California Department of Water Resources, 1975a.
[6] U.S. Bureau of Reclamation, 1960a
[7] California Department of Water Resources, 1969
[8] Estimates lacking for this area

Eel and Van Duzen River Valleys

In the Eel and Van Duzen River valleys irrigation pumpage in 1975 was 17,300 acre-ft, much less than the estimated storage capacity or recharge potential of the alluvium (table 6). However, it may not be advisable to increase pumpage near the edge of the freshwater-seawater transition zone (fig. 8) because summer pumping at 1975 rates caused some localized seasonal movement inland of high-chloride water to pumping areas.

The potential for additional development, particularly in the drier summer months, depends largely on the availability of recharge from the river channels of the Eel and Van Duzen Rivers. These river channels serve as infiltration zones in the area from the tidal zone near Fernbridge to the areas just upstream from the contact between the alluvium and the Scotia Bluffs Sandstone and Carlotta Formation.

Alluvium.--The greatest potential for additional development is from shallow wells in the alluvial plains of Yager Creek, Van Duzen River, and Eel River inland from the freshwater-seawater transition zone. The flood plains typically are underlain by many braided-channel gravel deposits that are as much as 40 ft thick and surrounded by finer-grained flood-plain deposits. These channel deposits are highly permeable and in good hydraulic connection with the rivers. Many irrigation wells on the Eel River flood plain have maximum pumping drawdowns of only a few feet, indicating high transmissivity.

With rapid replacement by infiltration from the rivers, large amounts of water can be extracted from these deposits without lowering the water table below natural low levels and disrupting the virtually stable freshwater-seawater boundary in the aquifer. During the wet season, storage is replenished and the maximum altitude of the water table is regained. In the relatively dry summer months this water table is lowered by natural drainage, evapotranspiration, and pumping. When the storage is reduced such that the water table in the flood plain is sufficiently lower than the river stage, water infiltrates from the river channels to the aquifer and maintains a fresh ground-water head sufficient to sustain flow toward the coast, thereby preventing any appreciable movement inland of the freshwater-seawater transition zone (fig. 4). Ground-water withdrawals have not exceeded the ability of the river channels to recharge the aquifer rapidly enough to maintain water levels above sea level, and the transition zone is in the same position it was in 1952. Without this infiltration from the rivers, seawater would tend to move inland during the summer months as pumping, natural drainage, and evapotranspiration reduced water in storage and thereby lower the fresh ground-water level. In effect, river water infiltration tends to maintain a nearly constant quantity of ground water in storage during the summer pumping season.

The maximum infiltration rate from the river channels is not known, but it is probably quite high. The Geological Survey made several gain-and-loss tests between selected stations on the Eel River for the Bureau of Reclamation from October 1967 through September 1968. The highest recorded loss over the Eel River infiltration zone was 80 ft^3/s, measured on October 3, 1967 (U.S. Geological Survey, 1968, p. 492). This loss is equivalent to 179 wells pumping 200 gal/min; however, not all the loss resulted from pumping. Although a considerable fluctuation in infiltration rates occurred between late June and late September 1968, the Bureau of Reclamation (1969) estimated the average infiltration for this period to be between 30 and 35 ft^3/s. The Bureau used this information in deriving the recharge potential values in table 5. Limited summer sampling by the Geological Survey since the 1967-68 tests indicated smaller average infiltration losses in the Eel and Van Duzen River channels, but rates continued to fluctuate. The Eel and Van Duzen Rivers evidently react quickly to pumping stress in the alluvial aquifers underlying the flood plains.

River flows during the irrigation season probably could supply recharge to the alluvium of the Eel River flood plain nearly equal to the flow in the Eel and Van Duzen Rivers, particularly if pumping were concentrated near the river. During the higher flow period, December through May, potentially higher pumping rates than those during the irrigation season could be met by infiltration from the rivers and from precipitation, without any risk of lowering the water table to a level that would permit seawater intrusion. However, the potential effects, on the rivers, of inducing abnormally high rates of infiltration to the alluvium should be considered. Important changes in the regimen and ecology of the streams and on fisheries could result.

Changes in the river channel geometry upstream from Fernbridge could adversely affect the river's infiltration rate and the quantity and quality of the ground-water resource. For example, increasing the conveyance of the river by straightening and deepening the channel above the tidal zone would tend to reduce the river stage, thus reducing head differentials between the river and the aquifer and lessening the recharge potential of the river. In this case, infiltration rates similar to those presently induced by pumping would not occur until ground-water levels were lower than presently required, and the tendency for a landward shift of the freshwater-seawater transition zone could increase. If the river channel upstream from the tidal zone were lowered below sea level, seawater would move up the channel into reaches of the river that are now fresh, the effective freshwater infiltration zone would be reduced, and seawater would tend to invade the eastern part of the flood plain. To help assure that the Eel River remains an effective source of additional recharge to the alluvium, that the fresh ground-water storage is maintained, and that the position of the freshwater-seawater transition zone is maintained, the river bed infiltration zone should remain above sea level and a maximum river stage should be maintained.

Hookton Formation.--The Hookton Formation probably extends under the coastal part of alluvial flood-plain deposits but pinches out before reaching the southeastern part of the Eel River flood plain. It is recharged where it crops out to the north and south of the flood plain, and the freshwater-seawater transition zone probably is not as far inland in this unit as it is in the overlying alluvium. The Hookton Formation along the coast is not favorable for extensive development, owing to limited recharge and potential seawater intrusion. It could be tapped as a limited source of usable water where it underlies the alluvial aquifer north of the Eel River.

Wildcat Group.--The upper two formations of the Wildcat Group, the Scotia Bluffs Sandstone and Carlotta Formation, show potential for ground-water development under the Eel River flood plain. The water in the upper part of the Carlotta is known to have lower chloride concentrations than water in the overlying alluvium along the coast, which indicates that the freshwater-seawater transition is not as far inland in the Carlotta as in the alluvium. Water in the Carlotta could be used for stock or irrigation in areas where the overlying alluvial aquifer contains water with excessively high chloride concentration. Wells for larger water-supply systems tapping the Carlotta might best be situated below the confluence of the Eel and Van Duzen Rivers in the southeastern part of the Eel River flood plain as far as practicable from the coast. The effect of large-scale pumping on artesian pressures in the aquifer underlying the flood plain near the coast and the potential for resultant seawater intrusion are unknown. To help answer these questions, exploratory wells and aquifer tests would be needed.

The Scotia Bluffs Sandstone and Carlotta Formation underlie all the alluvial flood-plain deposits, and logs of exploratory gas wells indicate a combined maximum thickness of more than 4,000 ft along the Eel River syncline near the coast (fig. 3). These two units are known to be 1,500 ft thick near the northern edge of the Eel River syncline and under the southeastern part of the Eel River flood plain, indicating a large storage potential. These units also have sufficiently large outcrops for potentially high recharge rates from precipitation and stream channel infiltration.

The large storage potential of the sandstone in the Scotia Bluffs and the gravel in the Carlotta does not mean that these units contain equally large freshwater reservoirs. Water quality could deteriorate with depth. The upper few hundred feet of the Carlotta probably contain relatively fresh water stored under confined conditions. However, data are not adequate to define the usable saturated thickness of the Carlotta under the alluvial flood plain. At Loleta, the Carlotta section that yields fresh to slightly saline water is estimated to be 300 ft thick, on the basis of a series of chemical analyses made of water samples collected while drilling well 3N/1W-18K1 (Evenson, 1959). Below this section the chloride concentration and total hardness each increased to more than 2,000 mg/L. Under the eastern part of the Eel River flood plain, slightly saline water (1,000-3,000 mg/L of dissolved solids) may be found at depths of 500 to 1,100 ft, judging from electric logs of oil exploration wells in secs. 14, 16, 23, and 24 (T. 2 N., R. 1 W.).

The recharge potential of the two units is not known. The Bureau of Reclamation (1960a) estimated the recharge from precipitation over the outcrop areas to be 30,000 acre-ft/yr. However, river recharge may also be important in increasing the ground-water potential of these two units. The Eel River and the Van Duzen River and its tributaries cross the outcropping Scotia Bluffs Sandstone and Carlotta Formation. Because the Carlotta consists of poorly consolidated river gravel that was deposited in the same manner as the alluvium of the present flood plain, significant quantities of river water could infiltrate the poorly consolidated gravel of the Carlotta. The potential rate of recharge depends on the hydraulic conductivity of the Carlotta. Estimated from specific capacity tests on a few wells, the hydraulic conductivity of the Carlotta averages 53.5 ft/d (U.S. Bureau of Reclamation, 1960a) compared with 267 ft/d for the overlying alluvium.

Other development.--Freshwater could be pumped from the river channels by shallow wells or Ranney collectors immediately adjacent to the Eel and Van Duzen Rivers. This water would then be delivered to other parts of the Eureka area via an aqueduct system similar to the Mad River system. The amount of water that could be removed from June through November would depend on the water available in excess of that needed to maintain recharge to the alluvium, the Carlotta Formation, and the Scotia Bluffs Sandstone. As mentioned in the discussion of the alluvium, the effects of removing large quantities of water from the river should be considered.

Table Bluff-Eureka Plain

In the Table Bluff-Eureka Plain, there is probably no potential for substantial development of ground water in the alluvium. Storage capacities of the alluvial deposits at the mouths of the Elk River and Salmon and Freshwater Creeks are considered to be small and have not been estimated.

Any additional development in the area will be limited to low- or moderate-capacity wells tapping moderately permeable sand and gravel in the Hookton Formation or the upper part of the Wildcat Group. Drillers' logs from the Eureka Plain indicate that the total water-bearing section above the bedrock ranges in thickness from 290 to 460 ft. Oil exploration logs from wells in the Table Bluff and Tompkins Hill area indicate that sedimentary rocks possibly containing fresh to slightly saline water are 700 to 1,600 ft thick. No estimates of storage capacity have been made in this area, however, owing to the high variability in porosity of coarse-grained sand and gravel beds within the dominantly finer-grained sediment. Where these coarse-grained beds are sufficiently thick, well yields are adequate for irrigation.

The potential to develop additional ground water in this area is also limited by the ground-water recharge potential. Recharge is primarily from direct infiltration of precipitation on the uplands where the Hookton, Carlotta, and other formations of the Wildcat Group crop out. The Bureau of Reclamation (1960a) estimated the combined annual recharge potential of the Wildcat Group to be 12,000 acre-ft in the Salmon Creek and Elk River valleys area and 2,400 acre-ft north of the Elk River in the area around Eureka.

Mad River Flood Plain

In the Mad River flood plain, the 1975 irrigation pumpage of 4,100 acre-ft (table 3) is near the estimated summer storage capacity of 4,500 acre-ft (table 6). However, because of the additional recharge potential from the river to the alluvium (table 6), the summer storage capacity is maintained, and additional development is possible. As in the Eel River area, the alluvium occurs as intersecting and interlaced channels of sand and gravel interbedded with clay and silt flood-plain deposits that are in hydraulic connection with the Mad River. Pumpage from the 4,500 acre-ft of estimated summer storage has been augmented by as much as 10 ft^3/s of percolation from the Mad River, as indicated by limited summer sampling. With this available recharge during the 6-month low-flow period from June through November, pumpage could be about 8,000 acre-ft without causing an excessive decline in water level.

Historically, flows have fallen below 10 ft^3/s in the infiltration zone between the gaging station at Mad River near Arcata (11481000, fig. 2) and the tidal estuary. However, from 1968 through 1975, releases of water from Ruth Reservoir (not shown in map) that reached the upper end of the infiltration zone have averaged at least 30 ft^3/s at the gaging station for each of the low-flow months. Only during periods in September 1972 and July 1975 was flow below 10 ft^3/s, and larger releases from Ruth Reservoir could have prevented this. Nevertheless, effects of inducing further recharge on fisheries and esthetics need to be considered.

The Hookton Formation has some potential for development of water supplies for light industrial or domestic uses where it underlies the tidally affected alluvium in the flood plain or where it occurs in the upland areas east of Arcata. The Hookton is only moderately permeable and, therefore, is not considered to be a potential source for irrigation supply. The Bureau of Reclamation (1959) estimated that the recharge potential of the Hookton is about 1,000 acre-ft/yr.

Little information is available to confirm the existence of the Wildcat Group beneath the Mad River flood plain. Data from oil exploration wells and water wells indicate that the Scotia Bluffs Sandstone and Carlotta Formation extend as far north as Humboldt Hill. If the upper Carlotta extends beneath the Mad River flood plain, as suggested by Evenson (1959), it should consist predominantly of shallow marine clay, judging from its changing lithology north of the Eel River syncline. The possibility of the Wildcat Group being developed in this area is poor.

Blue Lake Area

In the Blue Lake area only the alluvium has known potential for ground-water development. Underlying and surrounding the valley is the Franciscan Formation of pre-Tertiary age. Above the Franciscan basement rock and underlying the 80 or more feet of alluvium is the Falor Formation, which does not crop out in the study area (not shown in table 1). Manning and Ogle (1950) pointed out that their Falor Formation is mostly marine in origin and may be equivalent to a part of the Wildcat Group. The upper 200 ft of the Falor Formation may be of continental origin, similar to the Carlotta Formation, and have ground-water storage potential. Some wells penetrate clay and sandstone lenses in the Falor Formation and produce water reportedly high in iron. More water-quality and well data are needed to evaluate this formation.

The storage capacity of the alluvium in the Blue Lake area is estimated to be 14,000 to 37,000 acre-ft (table 6), on the basis of saturated thicknesses of 25 to 75 ft. Approximately 5,000 acre-ft of this storage capacity is estimated by the California Department of Water Resources (1965c) to be at altitudes higher than the Mad River channel. Although the alluvium is recharged rapidly by seepage from small perennial tributary streams and infiltration of precipitation on the valley floor, increased pumping for summer irrigation would reverse water-table gradients and induce additional seepage from the Mad River. Irrigation wells within a half mile of the river presently derive at least part of their summer water by inducing infiltration from the river.

The recharge potential from the Mad River is high in the Blue Lake area (table 6). The Bureau of Reclamation (1959) has estimated that the potential river percolation is about 50 ft^3/s per mile of river, which is greater than natural river flows from June through October. During those months the recharge potential to the alluvium when ground-water levels are below river stage is probably limited only by the amount of water discharged from Ruth Reservoir.

Increased development of the ground-water resource within the alluvial aquifer of the Blue Lake area could be supported by its largely unused storage capacity. During drought periods, when river flow ceases, ground water could be removed from storage. Subsequent river flow would undergo appreciable loss in crossing this alluvium until ground-water storage was replenished.

Dows Prairie-McKinleyville Area

The Dows Prairie-McKinleyville area has little potential for additional ground-water development. The elevated terrace is composed principally of 150 to 200 ft of fine-grained sedimentary rocks of the Hookton Formation. These rocks are of moderately low permeability and contain unconfined ground water. Underlying the Hookton Formation are fine-grained marine sedimentary rocks composed of compact mudstone, claystone, and siltstone, all of which are virtually non-water-bearing.

SUGGESTIONS FOR FUTURE STUDIES AND MONITORING

Infiltration measurements.--To better assess the response of the Mad and Eel Rivers to pumping stress and natural ground-water depletion in the alluvial aquifers underlying the flood plain, additional measurements to determine gain and loss in the rivers need to be made. Large fluctuations in infiltration rates, noted from previous measurements, indicate the need for continuous monitoring of streamflow through the infiltration zones to document weekly and daily infiltration. Tests are needed principally from May through October.

It is feasible to use existing gaging stations and establish one or two additional stations to monitor infiltration losses on the Eel and Mad River alluvial flood plains. Three stations are needed for the Eel River flood plain. The two existing gaging stations at Scotia and Fernbridge (fig. 2) could be used, and a staff gage could be constructed on the Van Duzen River at Highway 101 and read daily during the test period. The station at Fernbridge and the staff gage at Highway 101 would need to be rated for discharge. Two stations are needed for the Mad River alluvial plain. The existing gaging station at Arcata (fig. 2) could be used, together with a staff gage to be constructed below U.S. Highway 101. This staff gage would also need to be rated and read daily.

Infiltration losses from the Eel and Van Duzen Rivers that recharge all aquifers in the Scotia Bluffs Sandstone, Carolotta Formation, and alluvium could be determined from a different complement of gaging stations and staff gages. Existing stations on the Eel River at Scotia (fig. 2) and on the Van Duzen River at Bridgeville (several miles upstream from the outcrop of the Scotia Bluffs Sandstone) would provide data on inflow. The station on the Eel River at Fernbridge (fig. 2) would measure outflow. An additional staff gage would be needed on the Van Duzen River at the outcrop of the Scotia Bluffs Sandstone to account for tributary inflow between the outcrop and Bridgeville. Information from this additional gage would be used to adjust the Bridgeville station to obtain estimated inflow at the outcrop of the Scotia Bluffs Sandstone. A second gage would also be needed to measure the inflow of Yager Creek at the outcrop of the Scotia Bluffs Sandstone. Both staff gages would need to be rated and should be read daily.

Drilling program.--In the flood plain of the Eel River, little information is available to determine the quality of the water confined in the upper part of the Carlotta Formation. Electric logs indicate the possibility of fresh to slightly saline water in the depth range of 500 to 1,100 ft under the eastern part of the flood plain. To confirm this, exploratory wells in the flood plain are necessary to obtain the needed water-quality information from the deeper parts of the alluvium and the underlying aquifer in the Carlotta. The total depth of such exploratory wells is required to be about 1,000 ft.

Three wells are proposed. One well might be in sec. 10 or 15 (T. 2 N., R. 1 W.) in the eastern part of the Eel River flood plain. This could be a good area for siting future municipal wells because it is close to major recharge areas of the Eel and Van Duzen Rivers and far from coastal areas subject to seawater intrusion. A second well might be in sec. 32 (T. 3 N., R. 1 W.) midway between the eastern edge of the flood plain and the coast, centered over the Eel River synclinal axis, and east of the freshwater-seawater transition zone in the alluvial aquifer. The third well might be needed within the tidal zone of the flood plain in sec. 26 (T. 3 N., R. 2 W.) to evaluate coastal influences on the fresh ground-water reservoir in the deeper aquifers.

An exploratory well program should include geological and geophysical logging, water-quality sampling and analysis, and aquifer performance tests. The water-level and water-quality information obtained from the test wells would supplement information from the 268-ft well, 3N/2W-32Q1, which penetrates the Carlotta Formation near the coast (fig. 8). These wells could be included as observation wells in the Department of Water Resources ground-water monitoring program for the Eel River flood plain. Information from the new wells correlated with existing logs of gas wells could be used by the California Division of Oil and Gas to better define the base of the freshwater zone for use in specifying oil-well abandonment procedures in the Eel River area. Abandoned wells are plugged in their upper casing to protect the fresh ground-water resources from intrusion by brines that could flow up the well from deeper formations.

Monitoring program.--The California Department of Water Resources' ground-water monitoring program is adequate for regional sampling of water quality and water levels in the shallow aquifers of the Eureka area. However, additional water-quality data are needed in the vicinity of the freshwater-seawater transition zone in the alluvial aquifers underlying the Eel and Mad River flood plains. Water-quality data are needed on a continuing basis to assure that the stability of the freshwater-seawater transition zone is maintained. Prospective areas for selecting these additional water-quality monitoring wells are indicated in figures 7 and 8.

On the Eel River flood plain, only three wells (3N/1W-30N1, 3N/2W-13J1, and 3N/2W-35M1) monitored by the Department of Water Resources for water quality in 1975 were located in or near the freshwater-seawater transition zone in the alluvial aquifer. Only one well (3N/2W-32Q1) monitored water quality in the Carlotta Formation. Areas suggested for additional water-quality monitoring are indicated in figure 8. For these recommended areas, the minimum additional well selection might be one well at each of the following locations: 3N/2W-26R or 25M, 3N/2W-35C, and 3N/2W-36F or G. Additional water-quality sampling in the Carlotta Formation is needed, but a scarcity of wells in the Carlotta restricts possibilities for additional water-quality monitoring without constructing new wells especially for purposes of monitoring.

On the Mad River flood plain three wells (6N/1E-7M1, 6N/1E-19Q1, and 6N/1E-30N1) used to monitor water quality are located near, but to the east of, the freshwater-seawater transition zone (fig. 7). Water-quality samples from these wells indicated no seawater intrusion in 1975. Additional observation wells should be sampled closer to or in the transition zone. As indicated in figure 7, wells for additional monitoring should be located in secs. 18, 19, and 31, T. 6 N., R. 1 E., and in secs. 12, 24, and 25, T. 6 N., R. 1 W. Of these recommended well locations, the minimum well selection might be one well site at 6N/1E-18N.

SUMMARY AND CONCLUSIONS

Pumping from the alluvial aquifers of the Eel and Mad Rivers has increased since 1952. This increase, however, has not significantly altered water levels or water quality. Increased river infiltration, induced as ground-water pumping is increased, has played an important role in maintaining ground-water storage and the position of the freshwater-seawater transition zone. This is especially so for the summer pumping season. Because of the rivers' indicated recharge potential, the alluvial aquifers underlying the Eel and Mad River flood plains and the Blue Lake area probably have the capacity for additional development without adverse effects. To better assess this capacity for additional development, more information is needed about the rivers' recharge potential. It is therefore recommended that additional infiltration tests be made for the Eel and Mad Rivers. Also, the California Department of Water Resources water-quality and water-level monitoring program should be continued with some additional water-quality monitoring near the transition zone. Other alluvial and terrace deposits that receive perennial surface-water recharge also show some potential for limited development.

The potential for substantial ground-water development may exist in the Scotia Bluffs Sandstone and the Carlotta Formation of the Wildcat Group of Ogle (1953) in the Eel River valley. Large confined aquifers exist under the Eel River flood plain with recharge potential principally from Van Duzen River and its tributaries. A drilling program is recommended to determine aquifer characteristics and to measure the thickness and determine the water quality of the upper saturated zone. Other formations of the Wildcat Group and older formations in the Eureka area do not show potential as sources of large ground-water supplies.

The Hookton Formation overlying the Wildcat Group is not considered to be a potential source for irrigation supply in the Eureka area; however, the part of the formation beneath the freshwater-seawater transition zone within the alluvium of the flood plains near the coast shows some potential for development as an alternative source for domestic use. The Hookton Formation has little potential for additional ground-water development in the Dows Prairie-McKinleyville area.

The effect of further ground-water development on depletion of streamflow and resulting degradation of fisheries, wildlife habitat, and esthetics must be considered for each river and its flood plain.

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