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STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN DISTRICT

MENDOCINO COUNTY COASTAL GROUND WATER STUDY

JUNE 1982

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FOREWORD

Throughout history, the availability of an adequate water supply has been the single most important factor in determining the settlement, growth, and productivity of a community. Water is the life blood of any settlement, be it a single-family dwelling or a community of 10,000 residents. In coastal Mendocino County, where ground water is the primary source of water, it has become apparent that what may be considered an adequate water source for a few may not be adequate for many. It is through this realization and the ever-increasing demands on this resource that the county, the California Coastal Commission, and the California Department of Water Resources have jointly undertaken this study.

This report culminates two years of data collection and research. It presents reconnaissance-level information on the geologic and hydrologic conditions that influence the occurrence, storage, and recharge of ground water in the coastal Mendocino County area. It is anticipated that this information will prove useful in managing the coastal ground water resources and will provide a basis for detailed studies of local water supplies and development potential. The report also presents recommendations for conserving ground water resource and for a water level monitoring program, which will be useful in anticipating water shortages and evaluating the impacts of continued development.

Albert J. Dolcini, Chief
Northern District

State of California
The Resources Agency
DEPARTMENT OF WATER RESOURCES
Northern District

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TABLE OF CONTENTS

APPENDICES

TABLES

FIGURES

CONVERSION FACTORS

Quantity	To Convert from Metric Unit	To Customary Unit	Multiply Metric Unit By	To Convert to Metric Unit Multiply Customary Unit By
Length	millimetres (mm)	inches (in)	0.03937	25.4
	centimetres (cm) for snow depth	inches (in)	0.3937	2.54
	metres (m)	feet (ft)	3.2808	0.3048
	kilometres (km)	miles (mi)	0.62139	1.6093
Area	square millimetres (mm^2)	square inches (in^2)	0.00155	645.16
	square metres (m^2)	square feet (ft^2)	10.764	0.092903
	hectares (ha)	acres (ac)	2.4710	0.40469
	square kilometres (km^2)	square miles (mi^2)	0.3861	2.590
Volume	litres (L)	gallons (gal)	0.26417	3.7854
	megalitres	million gallons (10^6 gal)	0.26417	3.7854
	cubic metres (m^3)	cubic feet (ft^3)	35.315	0.028317
	cubic metres (m^3)	cubic yards (yd^3)	1.308	0.76455
	cubic dekametres (dam^3)	acre-feet (ac-ft)	0.8107	1.2335
Flow	cubic metres per second (m^3/s)	cubic feet per second (ft^3/s)	35.315	0.028317
	litres per minute (L/min)	gallons per minute (gal/min)	0.26417	3.7854
	litres per day (L/day)	gallons per day (gal/day)	0.26417	3.7854
	megalitres per day (ML/day)	million gallons per day (mgd)	0.26417	3.7854
	cubic dekametres per day (dam^3/day)	acre-feet per day (ac-ft/day)	0.8107	1.2335
Mass	kilograms (kg)	pounds (lb)	2.2046	0.45359
	megagrams (Mg)	tons (short, 2,000 lb)	1.1023	0.90718
Velocity	metres per second (m/s)	feet per second (ft/s)	3.2808	0.3048
Power	kilowatts (kW)	horsepower (hp)	1.3405	0.746
Pressure	kilopascals (kPa)	pounds per square inch (psi)	0.14505	6.8948
	kilopascals (kPa)	feet head of water	0.33456	2.989
Specific Capacity	litres per minute per metre drawdown	gallons per minute per foot drawdown	0.08052	12.419
Concentration	milligrams per litre (mg/L)	parts per million (ppm)	1.0	1.0
Electrical Conductivity	microsiemens per centimetre (uS/cm)	micromhos per centimetre	1.0	1.0
Temperature	degrees Celsius (°C)	degrees Fahrenheit (°F)	(1.8 × °C)+32	(°F−32)/1.8

INTRODUCTION

A two-year study of the geology, ground water hydrology, and the availability of ground water from marine terrace and alluvial deposits and bedrock formations of the Mendocino County coastal area was begun on July 1, 1980, by the Department of Water Resources (DWR). Funding for this study was supplied by DWR, the County of Mendocino, and the California Coastal Commission (CCC). An interim report, presenting preliminary findings in the coastal area between Cleone and Mendocino, was published in December 1980[1/] and is, in part, included in this report. This final report presents the findings of the two-year study of the coastal area from Rockport to Gualala, forwards specific recommendations for the management of the coastal Mendocino County ground water resource, and includes a proposal for a continued ground water monitoring network.

Purpose and Scope

Historically, the Mendocino coastal area has experienced widespread water shortages during dry years. Some localized areas, however, have water shortages every year, regardless of the climatic conditions. Therefore, the County and the CCC are concerned about the availability and quantity of ground water when making decisions concerning residential, commercial, and industrial developments along the coast. This investigation was undertaken to provide information on the ground water resources of the coastal area to aid in the decision-making process. Ground water quantities are estimated and the occurrence, nature, and quality of the resource is discussed.

1/ Department of Water Resources.
"Mendocino County Coastal Ground Water Study".
Memorandum Report. December 1980.

Area of Investigation

The study area is divided into five subunits, for which the geology and ground water hydrology are described. The subunits are:

WESTPORT:	Rockport to Tenmile River
FORT BRAGG:	Tenmile River to Big River
ALBION:	Big River to Navarro River
ELK:	Navarro River to Mallo Pass Creek
POINT ARENA:	Mallo Pass Creek to Gualala

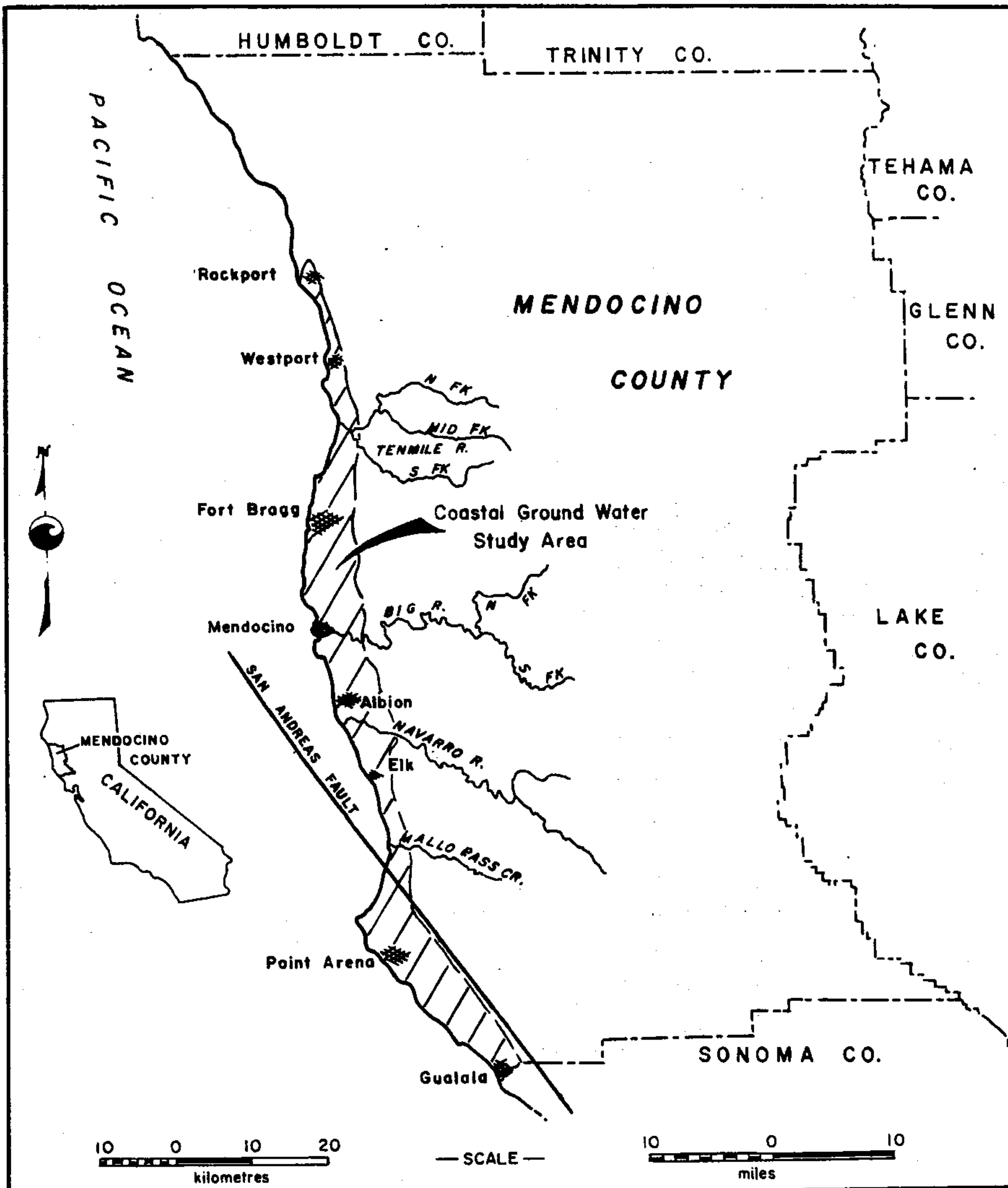
The study area comprises the western coastal portion of Mendocino County and is shown in Figure 1. It extends along the coast from Rockport in the north to Gualala in the south, and inland 1 to 8 km (0.5 to 5 mi) to include all marine terrace lands. The areal extent is about 460 km^2 (180 mi^2). State Highway 1 runs north-south through the study area, and joins Highway 101 northeast of Rockport. Highways 128 and 20, and county roads connect the area with inland cities and highways.

Fort Bragg is the major town in the study area. Other communities of importance include Westport, Mendocino, Albion, Elk, Point Arena, and Gualala. The economy of the area is based principally on lumber, fishing, agriculture, and tourism.

Most coastal residents obtain their water supply from ground water, largely supplied by a relatively thin layer of semi-consolidated terrace material deposited over wave-cut, bedrock benches. Residents of Westport, Fort Bragg, Elk, Point Arena, Anchor Bay, and Gualala obtain their water from municipal or privately owned water systems which divert surface flow, springs, and/or tap shallow alluvial aquifers. Residents of some larger subdivisions have formed their own water districts or mutual water companies that generally have adequate supplies from wells and surface diversions.

Physiography

The topography of the study area is comprised of sea cliffs, beaches, and sand dunes along the coast that give way to elevated terraces, alluvial bottomlands, and the rugged peaks and ridges of the northern Coast Range mountains to the east. Numerous small rivers and creeks drain the area, dissecting the terraces and defining their north and south boundaries.



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LOCATION MAP

JUNE 1982

Major streams in the area are the Tenmile, Noyo, Albion, Navarro, Garcia, and Gualala Rivers. These rivers, with the exception of the Garcia, are characterized by deep, narrow valleys with little bottomlands and are shown on the areal geology and well location maps.

Grasslands, brush, and forest cover the area. Coastal soils are Group 1 soils (Recent alluvial soils) consisting principally of the Noyo, Baywood, and Empire series (USBR, 1979). On upper inland terraces, leaching of nutrients from the upper layers of the soil has produced widespread pygmy forests (Fox, 1976).

Climate

The study area is characterized by cool, foggy summers and cool, rainy winters. Precipitation varies from about 42 to 153 cm (16 to 60 in) annually with a normal or mean of about 97 cm (38 in). More than 96 percent of the total precipitation occurs in an 8-month period beginning in October and ending in May. Table 1 shows mean monthly precipitation for Fort Bragg and Point Arena. The maximum, minimum, and normal seasonal rainfall, based on 51 years of record at the Fort Bragg weather station, are shown in Figure 2. The minimum seasonal precipitations (for the climatological year from October 1 to September 31) was 42.1 cm (16.56 in) in 1976-77, and the maximum was 153.2 cm (60.32 in) in 1940-41.

Methods and Procedures

Lack of historical water level data to assist in studying the ground water resource in the Mendocino coastal hydrographic area necessitated development of a water level monitoring network. In July 1979, through the efforts of Steve Howe (CCC), Freeman Beach (DWR), Christopher Farrar (U. S. Geological Survey--USGS), and William Rummel (Mendocino County), a network of 33 wells was established and monthly measurements begun. By March 1980, 102 wells were being monitored on a monthly basis and in April 1981, 185 wells comprised a monitoring network that extended along the coast from near Westport to Gualala. Also, four continuous water level recorders were used on selected wells to record gradual changes in the water table and seasonal responses of the aquifer to climatic conditions over the study period.

TABLE 1

MEAN MONTHLY PRECIPITATION IN CENTIMETERS [1/]
(Inches in Parenthesis)

Station No. F80 701100 — Pt. Arena Light Station — Elevation: 18 m (60 ft) — 13N/17W/S34

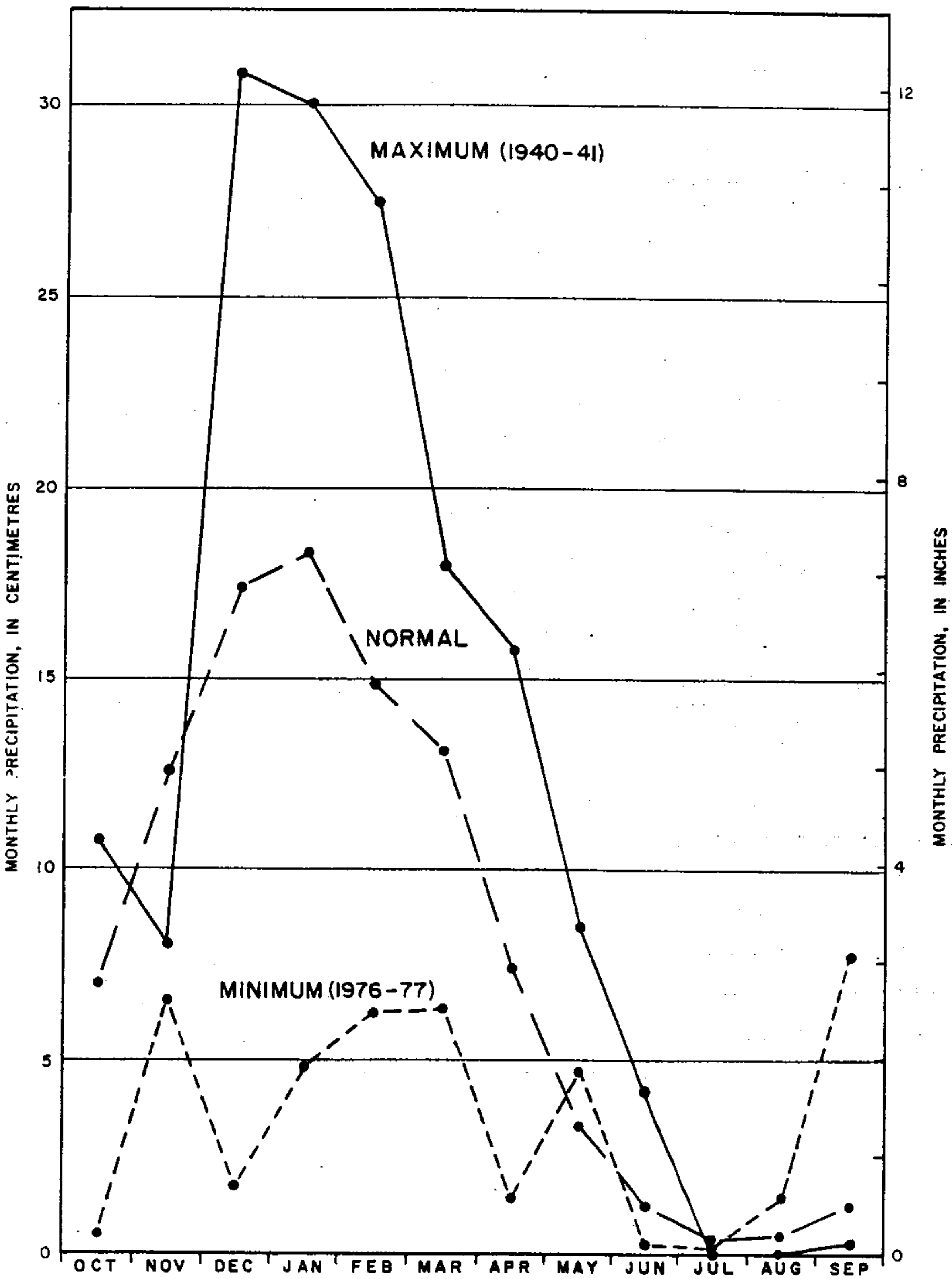
	Total	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.
Mean	88.4	5.0	8.6	17.2	19.0	15.2	10.4	6.8	3.6	1.6	0.1	0.2	0.7
	(34.81)	(1.96)	(3.40)	(6.78)	(7.48)	(5.97)	(4.08)	(2.67)	(1.42)	(0.64)	(0.05)	(0.10)	(0.26)

Station No. F80 316100 — Fort Bragg — Elevation: 24 m (80 ft) — 18N/17W/S6

	Total	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.
Mean	97.5	7.0	12.6	17.4	18.3	14.9	13.1	7.5	3.3	1.2	0.2	0.5	1.3
	(38.40)	(2.77)	(4.96)	(6.87)	(7.22)	(5.88)	(5.15)	(2.96)	(1.29	(0.48)	(0.09)	(0.21)	(0.52)

1/ National Weather Service data

FIGURE 2



Maximum, normal, and minimum seasonal precipitation at Fort Bragg.

Existing geologic data were collected by conducting a literature search. Some detailed geologic mapping exists, but most has been at reconnaissance level. Aerial photo interpretations, existing maps, well log data, and field observation furnished information for the present geologic maps. Determination of subsurface geology, depicted in the generalized hydrogeologic cross sections, is from data obtained from 507 well logs, available geologic maps, bridge foundation bore hole logs, and field observations.

Ground water reservoir capacities were estimated by assigning an average specific yield value to the aquifer, determining the saturated volume of the aquifer (areal extent x saturated thickness), and then multiplying the two; i.e., reservoir capacity = specific yield x saturated volume.

The specific yield, defined as the ratio of the volume of water that will drain by gravity from a saturated sample of material to the total volume of the sample, was estimated from the analyses of all well logs available for the aquifer. Specific yields of the marine terrace deposits were found to range from 3 to 25 percent, with an average value of about 9 percent. The areal extents of the aquifers were estimated using a planimeter and geologic maps, the thickness of the terrace deposits was derived from the interpretation of well logs and from field observations, and the saturated thickness was calculated from the monthly well measurements.

For the purpose of evaluating the water-yielding characteristics of the marine terrace deposits and bedrock, wells were classed, after interpretation of the drillers' reports, as bedrock wells (wells completed wholly within bedrock), composite wells (wells drilled more than 3 m [10] ft into bedrock and having more than 1.5 m [5 ft] of terrace deposits between the bedrock contact and the bottom of the sanitary seal), and terrace deposit wells (wells completed in the marine terrace deposits and not extending more than 3 m [10 ft] into the bedrock). Data concerning yield of wells and specific capacity of wells were obtained from well drillers' reports on wells for which pump tests were conducted.

Determining the permeability of an aquifer in the field requires controlled aquifer tests. Without such tests, it is possible to determine properties that are largely controlled by the permeability. The yield and specific capacity of a well are generally controlled by the permeability and thickness of the material penetrated by the well and are data contained in most drillers' reports. The specific capacity is the ratio of the yield of a well to the drawdown. Drawdown is the difference between pumping water level and static water level. Specific capacity is expressed as litres per minute per metre of drawdown (L/min/m). A well penetrating a permeable material will normally have a higher yield and higher specific capacity than a well penetrating a material of low permeability.

Previous Investigations and Studies

Possibilities for water development and water-related problems of the Mendocino County coastal area have been studied by Federal, State, and local agencies during the past 24 years.

Studies by DWR include Bulletin 62, "Recommended Water Well Construction and Sealing Standards, Mendocino County", in 1958. It included evaluation of a geologic reconnaissance survey, compilation and interpretation of data on hydrology and water quality, and a description of prevalent methods and materials used in well construction and sealing.

A 1971 memorandum report by DWR, "Inventory of Water Problems in the Mendocino Coastal Area", presents an analysis of the existing water supply and sewage systems, a forecast of future demands on these systems, and identifies problems with the systems. Other reports and investigations addressing the water resources and water problems of the Mendocino County coastal area are listed below. A complete bibliography of cited references ~~for this report may be found in A pendix C.~~

State Studies

California Coastal Zone Commission, North Coast Region. "Preliminary Coastal Plan, Mendocino Subregional". 1975.

State of California, Department of Fish and Game. "Fish and Wildlife Problems and Study Requirements in Relation to North Coast Water Development". Water Project Branch Report 5. January 1966.

State of California, Department of Water Resources. "Geologic Conditions and Occurrence and Nature of Ground Water in Mendocino Coast Hydrographic Unit". Office Report. 1963.

----. "Land and Water Use in Mendocino Coast Hydrographic Unit". Volume 1. Bulletin 94-10. March 1964.

----. "North Coastal Area Investigation. Preliminary Edition. Reconnaissance of North Coast". Bulletin 136. September 1965.

----. "Water Resources and Future Water Requirements in the North Coastal Hydrographic Area". Volume I. Bulletin 142-1. April 1965.

----. "Ground Water and Water Quality Conditions in Inglenook Fen Watershed". Memorandum Report. June 1979.

----. "Interim Mendocino County Coastal Ground Water Study". Memorandum Report. December 1980.

Federal Studies

U. S. Department of the Interior, Bureau of Reclamation. "Fort Bragg-Mendocino Portion of the Coastal Plain, Part VII". 1979.

----. "Mendocino County Study, Possibilities for Development of Water Supplies for the Round, Little Lake, and Anderson Valleys, and the Fort Bragg-Mendocino Area". Appraisal Report. October 1979.

Local Studies

Charles McCandless and Company. "An Engineering Report Concerning the Feasibility of Constructing a Water and Sewerage System for the Community of Mendocino". Prepared for Mendocino County Flood Control and Water Conservation District.

Water Resources Engineers, Inc. "Comprehensive Soil and Water Plan—Phase I". Prepared for Mendocino County Soil Conservation District. 1970.

Inventory of county natural resources and uses, and preliminary plan for development.

----. "Comprehensive Area Plans for Water and Sewer Systems". 1970.

Winzler and Kelly of Eureka, California. "Comprehensive Engineering Study, City of Fort Bragg Water System". December 1974.

SUMMARY AND CONCLUSIONS

The Mendocino County coastal ground water study area lies within the Coast Range geomorphic province, extending from Rockport to Gualala along the coast and inland 1 to 8 km (0.6 to 5 mi) to include all Quaternary marine terrace deposits. The terrace deposits are thickest and most widespread in the Fort Bragg-Mendocino area, and are the primary ground water source throughout most of the study area. North of Cleone and south of Albion (except for the Point Arena-Manchester area) the terrace deposits are generally less than 10 m (33 ft) thick, discontinuous, and less dependable as sources of usable ground water.

A monthly ground water-level monitoring program was established which provided data from 185 wells in the study area. Total ground water storage and changes in storage were estimated using these and other data. Data from 507 "Water Well Drillers' Reports" were used to estimate aquifer characteristics and to determine depths to bedrock. The coastal study area was divided into five subunits. The aquifer area, storage capacity, and the estimated change in storage for each subunit are summarized below. The aquifer area is the land area underlain by the water-yielding materials (marine terrace deposits or alluvium); storage capacity is the maximum volume of ground water contained in the aquifer; change in storage is the estimated percent change in the volume of ground water which occurs between spring and fall.

Subunit		Aquifer 1/ Area ha (ac)	Storage Capacity dam^3 (ac-ft)	Percent Change in Storage Spring to Fall 3/
Westport	Qt:	595 (1,470)	3 590 (2,910)	34
	Qal:	405 (1,000)	7 400 (6,000)	1 to 8
Fort Bragg	Qt:	8 100 (20,000)	99 700 (80,800)	17
Albion	Qt:	4 110 (10,100)	33 000 (26,800)	18
Elk	Qt:	1 150 (2,840)	2 800 (2,270)	80
	Qal:	86 (215)	1 590 (1,290)	8
Point Arena	Qt:	2 400 (5,930) 2/	22 700 (18,400)	37
	Qal:	1 550 (3,830)	17 000 (13,800)	8
Total for Study Area	Qt:	16 345 (40,340)	161 790 (131,180)	18 to 80
	Qal:	2 040 (5,050)	25 990 (21,090)	1 to 8

1/ Qt = Marine terrace aquifers
Qal = Alluvial aquifers

2/ Point Arena - Manchester area only
3/ Based on 1980-82 data base

The "availability of ground water", based on aquifer characteristics, spring-to-fall changes in storage, and present land use, is summarized on Figure 3.

For the Mendocino County coastal area, it is concluded that the marine terrace deposits are recharged directly by infiltration of precipitation and under normal rainfall conditions reach maximum storage by mid-January of each year.

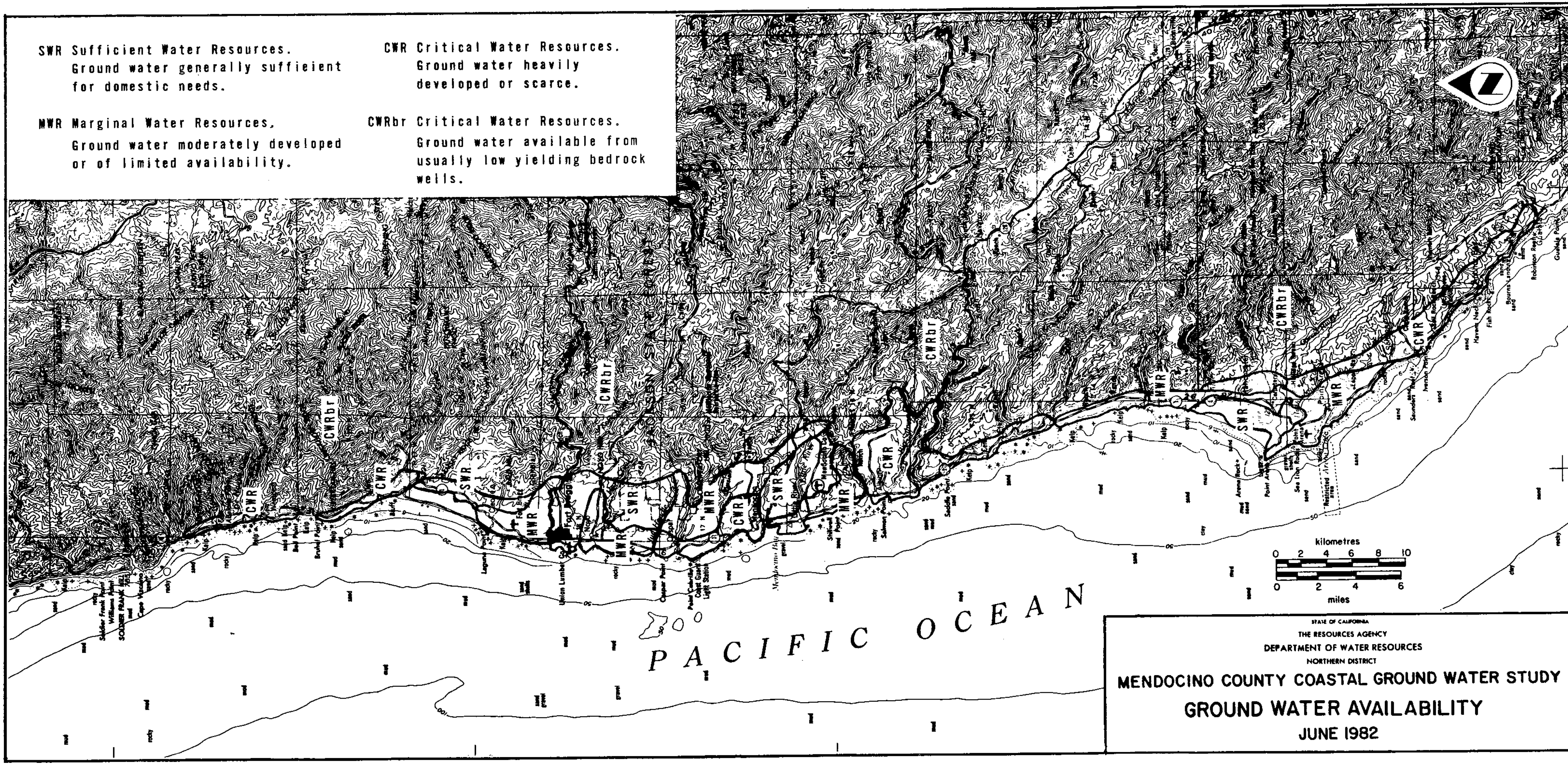
The amount of change in storage of the terrace deposits from spring to fall is related to the aquifer's total thickness, i.e., a 3-m (10-ft) decline of the water table in an aquifer 30 m (100 ft) thick will result in a 10-percent change; the same decline in an aquifer 6 m (20 ft) thick results in a 50-percent change. Terrace deposits less than about 1.5 m (5 ft) thick probably do not store any usable ground water; deposits 1.5 to 5 m (5 to 16 ft) thick are likely to experience a 50-to-100-percent decline in storage by early fall.

Alluvial aquifers, occupying perennial stream and river valleys, are continually recharged by surface flow, and are only marginally exploited because of their unlikely location for development and potential for seawater intrusion.

Bedrock units in the study area, though considered "non-water bearing", often yield enough water for domestic needs. Between Albion and Gualala, the fractured bedrock is the primary source of ground water.

Ground water quality is generally good to excellent though the presence of ferrous iron and sulfide does occur sporadically in the study area. Seawater intrusion is not a common problem in the study area, though it has occurred in localized areas near Point Arena where wells drilled below sea level and near the ocean have reduced or reversed the seaward flow of fresh ground water. Alluvial and bedrock aquifers, and the terrace aquifers between Tenmile River and Laguna Point and Alder Creek and Point Arena are susceptible to intrusion.

FIGURE 3



SWR Sufficient Water Resources. Ground water generally suffieient for domestic needs.
MWR Marginal Water Resources, Ground water moderately developed or of limited availability.
CWR Critical Water Resources. Ground water heavily developed or scarce.
CWRbr Critical Water Resources. Ground water available from usually low yielding bedrock wells.
PACIFIC OCEAN
kilometres
0 2 4 6 8 10
0 2 4 6
miles
STATE OF CALIFORNIA
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NORTHERN DISTRICT
MENDOCINO COUNTY COASTAL GROUND WATER STUDY
GROUND WATER AVAILABILITY
JUNE 1982

RECOMMENDATIONS

It is widely accepted that ground water along the Mendocino County coast is a limited resource that requires conservation and planned development. The following recommendations concern the management of this resource.

Conservation Measures

It is estimated from water-use data for the Fort Bragg and Eureka areas that the average annual per capita water consumption for the Northern California coastal area is 0.25 dam^3/yr (0.2 ac-ft/yr), or 680 L/day (180 gal/day). It is conceivable that implementation of the recommendations in 1 and 2 below could reduce per capita water use by up to 50 percent. Recommendations 3 to 6 are designed to maximize ground water recharge while minimizing runoff.

1. All new development (single family, condominiums, subdivisions, etc.) shall be required to incorporate proven water conservation technology in the planning and construction of the project. These shall include, but not be limited to, low-flush toilets, flow-control inserts on showers, single-control faucets, water-efficient dishwashers and clothers washers, grey-water recycling, and hot-water pipe insulation.

2. Installation of efficient irrigation systems which minimize runoff and evaporation and maximize the water which will reach the plant roots. Drip irrigation, soil moisture sensors and automatic irrigation systems are a few methods of increasing irrigation efficiency.

3. Wherever possible, all new development shall keep rainwater on site in a retention basin to aid in ground water recharge. Where this is not feasible, the development shall be designed to reduce, retard, and disperse runoff. This may be accomplished by mulched and/or terraced slopes to reduce erosion and retain rainfall, porous drain swales and paving materials for infiltration, out-sloped roads to spread runoff evenly down slope, and landscaping

with suitable water-conserving erosion control plants that will protect the soil, facilitate infiltration of rainwater, and reduce runoff.

4. Encouragement of cluster development which can reduce the amount of land being converted to urban use. This will reduce the amount of impervious paving created and thereby aid in ground water recharge.

5. Preserve existing natural drainage areas and encourage the incorporation of natural drainage systems in new developments. This would aid in ground water recharge.

6. Flood plains and aquifer recharge areas which are the best sites for ground water recharge should be preserved as open space.

Development of Water Supplies

1. The "Instructions for Conducting Quantity Testing of Water Wells and Springs for 'Proof of Water'", as presented in "Land Division Requirements", County of Mendocino, Division of Environmental Health, revised January 1, 1982 (Appendix B), shall be amended to reflect the coastal hydrogeology.

    a. The definitions of wells shall be as follows:

    - Shallow wells of the coastal area - wells less than 40 feet deep which obtain their water predominantly from alluvium or terrace deposits, or wells less than 60 feet which obtain their water predominantly from cracks and fissures in bedrock.

    - Deep wells of the coastal area - wells greater than 40 feet deep in alluvium or terrace deposits, or bedrock wells deeper than 60 feet.

    b. The timing of well tests for "proof of water" shall be as follows: For the coastal area, deep wells may be tested any time; shallow well and spring tests shall be conducted during the period of August 20 to November 1.

Ground Water Level Monitoring

1. Ground water levels shall be measured monthly and quarterly on selected wells to evaluate the consequences of climatic variation on the coastal ground water reservoirs, to provide a long-term data base for future investigations, to provide data that may be used to anticipate and/or predict ground water shortages, and to evaluate the impact of future development.

2. Ground water data shall be collected by the Division of Environmental Health or, under contract, by William Rummel, R. S., and forwarded to DWR for compilation and evaluation. The recommended ground water monitoring wells are:

Monthly Measurements	Quarterly Measurements (Jan.,Apr.,July,Oct.)
19N/17W-29A1	19N/17W-16F4*
18N/17W- 4E1	19N/17W-30Q1*
17N/17W-30B1	19N/17W-31Q1
16N/17W-10E1	18N/18W-25B2*
16N/17W- 8E1	18N/17W-29A1
12N/17W-12L1	17N/17W-30F3
11N/15W- 5D1	16N/17W-27F1
	16N/17W-33L1
	15N/17W- 4A1
	15N/17W- 4L1
	13N/16W-31M1*
	12N/17W-12L1*
	12N/16W- 8F1
	11N/15W- 7M1
	11N/15W- 7B1

*Wells currently on the California Statewide Ground Water Index Data Network

Well data (DWR Form 429) and logs for these wells are on file at DWR, Northern District, Red Bluff.

3. After ground water measurements have been compiled for a wide range of rainfall years, to include drought years and very wet years, the well data and rainfall records shall be analyzed and a rainfall-ground water recharge/discharge relationship established. This relationship can then be used to forecast ground water shortages in the coastal area and evaluate the impact on the ground water resource from development.

Land-Use Density

The determination of availability of ground water for a specific development requires professional judgement and interpretation of all available data. This study, though not site specific, has identified coastal areas of differing ground water availability (see Figure 3). From this information, general guidelines can be drawn to aid the planner in reviewing proposed developments.

It is recommended that:

1. Areas designated SWR (Sufficent Water Resources) shall have a minimum lot size of 2 acres (ac); "proof of water" not required. All lots less than 2 ac shall be required to demonstrate "proof of water" (as outlined in Appendix B).

2. Area designed MWR (Marginal Water Resources) shall have a minimum lot size of 5 ac; "proof of water" not required. All lots less than 5 ac shall be required to demonstrate "proof of water".

3. Areas designated CWR (Critical WaterResources) shall have a minimun lot size of 5 ac and demonstration of "proof of water". All lots less than 5 ac shall demonstrate "proof of water" and may require an environmental impact statement.

4. Critical Water Resources-Bedrock areas

   a. Areas designated CWRub (Critical Water Resources, upland bedrock) should have a minimum size of 20 ac. Smaller lots, to a minimum size of 2 ac, may be developed with "proof of water" on each lot.

   b. Bedrock areas that lie west of the eastern limits of the marine terrace deposits shall be designated CWRtb (Critical Water Resources, terrace bedrock). These areas shall have a minimum lot size of 5 ac and demonstration of proof of water. All lots less than 5 ac shall demonstrate proof of water and may require hydrologic study.

REGIONAL GEOLOGY

The study area lies within the northern Coast Range geomorphic province. The topography is dominated by high ridges and narrow valleys which trend northwest, paralleling the regional geologic structure. The San Andreas fault, one of the major structural features of California, crosses the southern boundary of the county about 3 km (2 mi) east of Gualala and intersects the coast 3.5 km (2.2 mi) north of Manchester. This northwest-trending fault has strong topographic expression and controls the lower courses of Alder and Brush Creeks and the Garcia and North Fork Gualala Rivers. The fault separates the Jurassic-to-Cretaceous, Franciscan rocks on the east from the Cretaceous and Tertiary, Gualala Block rocks on the west. Superimposed on these older rock units is a series of discontinuous Quaternary marine terrace deposits, alluvial material in the larger stream valleys, and beach and dune deposits along the coast.

Bedrock Geology

Franciscan Complex

Most of the Coast Range of California is underlain by the Franciscan Complex, which is divided into the melange rocks and the Coastal Belt rocks. It has been suggested that the older melange unit was emplaced by thrust faulting on top of, or sliding by gravity onto, the Coastal Belt rocks before uplift of the whole sequence. The emergency from the sea occurred by the Oligocene, 38 million years before the present (mybp). Throughout the Tertiary (3 to 38 mybp) weak to intensive compressive deformation occurred. This included folding, uplifting, tilting and overturning of the Coastal Belt. Numerous faults resulted, trending primarily in a northwest-to-southeast direction. The San Andreas and other high angle faults have existed for at least 25 million years (DPR, 1977).

The Coastal Belt is the youngest part of the Franciscan Complex and is dated from late Cretaceous (70 mybp) to late Eocene (40 mybp). This thick, 10 000-m (32,800-ft) sequence of graywacke sandstone and shale (Kleist, 1974) forms the bedrock base of the coastal zone east of the San Andreas fault.

Compared to the Franciscan melange, the Coastal Belt rocks are relatively undeformed. The beds have a predominantly northwestern strike and homoclinal northeastern dip (Kleist, 1974). Topography of the basement rocks ranges from mountainous terrain to a series of prominent wave-cut benches. Exposures are largely limited to road cuts, ocean cliffs, and stream channels. Surficially, the rock is deeply weathered (exposures and well logs show this) and covered by marine terrace deposits or soil and vegetation (grass, dense brush, and trees).

The sandstone is poorly sorted, with medium-grained, angular fragments of quartz, feldspar, and mafic minerals. It has an overall blue color, imparted during slight metamorphism, but it weathers to brown. Fresh rocks are well indurated and have a variable fracture pattern. They are considered to be non-water bearing, although minor quantities of water occur where deep weathering, shearing, fracturing, and/or jointing have created secondary permeability and porosity.

Gualala Block

The Gualala Block consists of at least 6 100 m (20,000 ft) of marine sediments deposited in quiet water by turbidity currents and biotic activity and appears to have been deformed twice--in response to shear along the San Andreas fault, and in response to northeast-southwest compressive forces (Boyle, 1967). These rocks consist of intensely folded and faulted shale, sandstone, conglomerate, and basalt. They range in age from upper Cretaceous (70 mybp) to Miocene (26 to 7 mybp) (Williams and Bedrossian, 1977) and have been juxtaposed against the Coastal Belt Franciscan rocks as the result of an estimated 240 km (150 mi) of right lateral movement along the San Andreas fault over the past 25 million years (Boyle, 1967).

Charles Weaver (1943) divided the rocks of the Gualala Block into four units, and for simplicity, his schema will be used here. For a more detailed explanation of the Gualala Block geology, the reader is referred to Boyle (1967) and Wentworth (1967, 1968, 1972).

The formations of the Gualala Block include the Gualala series (upper Cretaceous through Eocene age), the Galloway and Schooner Gulch Formations (Miocene age), the Monterey Formation (Miocene age), and Iverson Basalt (Miocene age).

The Gualala Series consists of alternating lithologic units composed of massive and stratified medium- and coarse-grained sandstone, massive and stratified clayey and sandy shales, units of interstratified layers of shale and sandstone, and units of layers of lenses of fine-to-coarse conglomerate (Weaver, 1943). These sediments are composed of angular-to-rounded grains of quartzite, schist, slate, chert, and jasper. They are grey-to-brown in color, and generally weather to a brownish-yellow. These rocks are well indurated, only mildly fractured and jointed, and considered to be non-water bearing except for secondary permeability and porosity.

The Galloway and Schooner Gulch Formation are composed of dark-grey and brown argillaceous shale, mudstones, and medium-grained sandstone interstratified with thick units of massive and bedded brownish-grey sandy shales and foraminferal shales. These sediments are moderately indurated and fractured and are considered to be non-water bearing except for secondary permeability and porosity.

The Monterey Formation consists of interstratified, thinly bedded siliceous shales and clay shales, massive and stratified sandy shales, and minor amounts of tuffaceous shale, shaley sandstones, and gritty sandstones. These rocks range in color from a light tan to greyish-brown and may exhibit a yellowish- or dark-brown staining on joint surfaces as a consequence of associated petroleum residues. These rocks are considered non-water bearing except for secondary permeability and porosity.

The Iverson Basalt (Weaver's Schooner Gulch Basalt) is exposed in road cuts, sea cliffs, and hill slopes from near Iverson Point north to the vicinity of Ross Creek. It is a dark-grey to black fine-grained basalt with alteration products of opal and calcite irregularly scattered throughout its mass. This unit is non-water bearing and may be a barrier to the lateral movement of ground water from adjacent bedrock.

Surficial Geology

Surficial units in the study area include Quaternary deposits of beach and dune sands, alluvium, and marine terrace clay, sand, and gravel. These units locally overlie bedrock and are the primary water-yielding deposits throughout most of the study area.

Marine Terrace Deposits

Marine terrace deposits of Pleistocene age mantle wave-cut bedrock surfaces along the coast. The terraces range from 12 to 200 m (40 to 650 ft) in elevation and extend 0.3 to 8 km (0.2 to 5 mi) inland. They occur as a series of benches or steps, uplifted above sea level over the last half-million years (Fox, 1976). Five terrace levels have been identified in some areas though fewer are evident along most of the coastal study area. Topographic features can give erroneous indication of terrace deposit occurrence. Some extensive, flat benches show bedrock outcrops and some hilly, inland terrain consists of uplifted and eroded terrace material.

The marine terrace deposits are predominantly massive, semi-consolidated clay, silt, sand, and gravel, and range from 0.3 to 43 m (1 to 140 ft) in thickness. Some small-scale sedimentary structures are present in most exposures; trace fossils are rare. The deposits range from being clean, well-sorted, fine to coarse sand, to poorly sorted, fine to coarse sand with a silty matrix. Fine to medium gravel occurs as lag gravel layers and in lenses of conglomerate. Composition varies and reflects the lithologies of the parent bedrock. North of Alder Creek (location of the San Andreas fault zone), most deposits consist of sand grains of quartz with lesser amounts of feldspar and mafic minerals, and pebbles of chert, quartz, and Franciscan sandstone. South of the creek, the deposits consist of sand grains of quartz with minor amounts of feldspar and shale fragments, and pebbles of quartzite, schist, shale, and chert.

Alluvial Deposits

Alluvium consists of stream channel and associated stream terrace deposits of clay, silt, sand, and gravel derived from erosion of bedrock and adjacent marine terrace deposits. The alluvial material overlies bedrock and some lower elevation marine terraces and occupies drowned river valleys, representing a change in base level as the sea level rose at the close of Wisconsin glacial stage, about 11,000 years ago. These deposits are 150 to 300 m (500 to 1,000 ft) wide at the mouths of the streams, may be more than 36 m (120 ft) deep at the center of the valley, and extend 1.5 to 4 km (1 to 2.5 mi) inland.

Beach and Dune Deposits

Beach deposits next to the ocean are clean, well-sorted sands with minor amounts of well-rounded pebbles, deposited by current and wave action. Associated dune deposits are clean, well-sorted, windblown sand derived from the beach deposits. In the study area there are two notable occurrences of these deposits: between Alder Creek and Point Arena and between Tenmile River and Laguna Point.

Sand dunes cover an area of about 920 hectares (ha) (2,270 acres) to an estimated average depth of 15 m (50 ft). However, due to their land use restrictions, they will be excluded from ground water reservoir capacity and recharge estimates.

GROUND WATER HYDROLOGY

General Hydrologic Principles

Ground water is water occupying openings, cavities, and spaces below the land surface, in the zone of saturation. Its chief source is precipitation, but only a fraction of the precipitation that falls on a given area percolates into the subsurface to become ground water. Some is returned to the atmosphere by plants in a process called evapotranspiration (ET). The remainder becomes surface runoff or is temporarily stored as vadose water.

Ground water recharge is replacement of water in the ground water reservoir. The rate of recharge varies with the pattern of precipitation, ET, and permeability of the subsurface materials and overlying soil.

Ground water discharge is the release of water from the ground water reservoir. It occurs in several ways. Natural discharge occurs when ground water moves downslope into streams that are incised below the water table and by way of seeps and springs which commonly occur at exposed bedrock-terrace deposit contacts. Ground water flow usually occurs year-round. In summer months a few springs are observed flowing at 4 to 11 L/min (1 to 3 gpm). Near the south side of Mendocino Bay, one spring measured 190 L/min (50 gpm) in September 1980.

Artificial discharge of the ground water reservoirs occurs by pumping from wells. As explained by W. Back (1957), it has the following effect on the ground water:

> "When a well is not pumped, equilibrium exists between the head of water in the well and the head of water in the aquifer outside the well. When water is withdrawn from the well, the head inside the well is reduced and a difference in head is created for some distance from the well. In the process of establishing hydraulic equilibrium, the water table develops a cone of depression (see Figure 4). The apex of the cone is at the water level in the well during pumping, the height is equal to the drawdown, and the base is the original water surface. The area affected by a pumped

well (area of influence) is controlled largely by the rate of pumping and rate of recharge. A higher pumping rate in a well produces a greater drawdown, and thereby increases the depth and diameter of the cone and the area of influence."

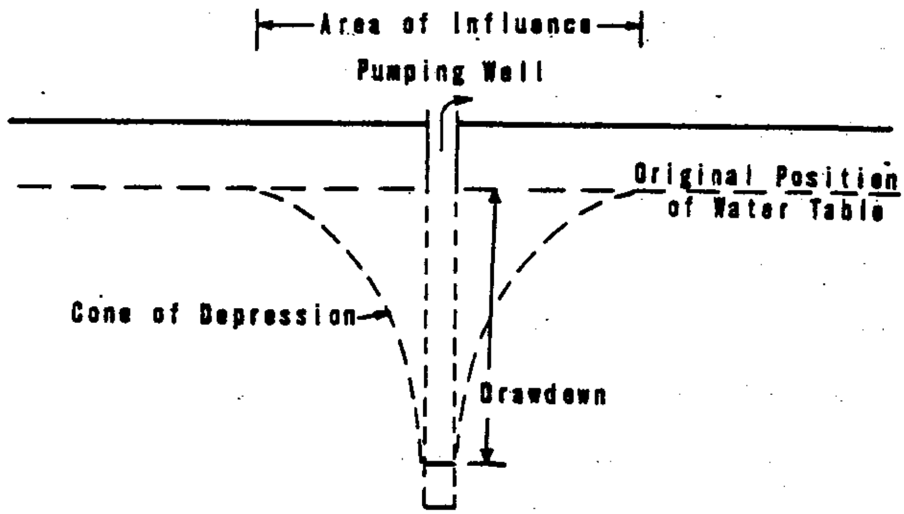


Figure 4. Cone of Depression

Rainfall-Recharge Characteristics

Average annual precipitation along the Mendocino County coast is about 97 cm (38 in), occurring mostly from October to May. Estimated average annual ET for this climatic zone, which is vegetated with grass, brush, and forest, is about 40 cm (16 in). Thus, about 57 cm (22 in) of precipitation is, in normal rainfall years, available for ground water recharge and surface runoff. Runoff is slow-to-medium because of the soil type and vegetation and is estimated to be about 26 cm (10 in). The remaining 31 cm (12 in) is available for ground water recharge. These data are summarized in Table 2, showing separate figures for grass and forest land.

Data from water level recording gages installed on selected wells near Mendocino and Point Arena show that the rates of ground water recharge and runoff vary considerably during the rainy season. Figure 5 shows hydrographs of three wells in the study area and daily rainfall at Point Arena.

TABLE 2

SUMMARY OF
ESTIMATED MENDOCINO COUNTY COASTLINE
TERRACE DEPOSIT HYDROLOGY

	Grasslands	Forest Lands	Average
Deep Percolation	36.9 cm (14.5 in)	25.4 cm (10.0 in)	31.3 cm (12.3 in)
Total ET	35.2 cm (13.9 in)	43.6 cm (17.2 in)	39.4 cm (15.5 in)
Surface Runoff	24.6 cm (9.7 in)	27.7 cm (10.9 in)	26.2 cm (10.3 in)
Annual Precipitation	96.7 cm (38.1 in)	96.7 cm (38.1 in)	96.7 cm (38.1 in)
Runoff Rate	Slow	Slow to Medium	
Effective Rooting Depth	91 cm (36 in)	152 cm (60 in)	

Records for wells 11N/15W-15E and 13N/17W-26G show that the downward trend of water levels was unaffected by rainfall in early October and only slightly influenced by the rainfall of late October. Recovery, beginning in November, is in response to the two week-long storms. Water levels peaked in late November and then fluctuated near these highs in response to continued rainfall for the rest of the rainy season.

Well 17N/17W-30B shows an immediate response to even small amounts of rainfall. The magnitude of the response increases through November and then decreases to near zero in December.

Well 11N/15W-15E, a 9-m (30-ft) deep bedrock well, is on the drainage divide between the Gualala River and the Pacific Ocean. The recorded summer and fall water-level decline in this well is due to natural and artificial discharge, and ET. The 9 cm (3.5 in) of rain in late September and early October did not significantly affect this record, probably because the first 5 to 10 cm (2 to 4 in) of rainfall of the season merely moistens the dry soil; during the first rains, both ground water recharge and runoff are typically low. The recovery beginning on November 3 starts slowly and is probably the result of reduced ET. After November 15, ground water response to precipitation is rapid; each winter storm produces a peak on the hydrograph.

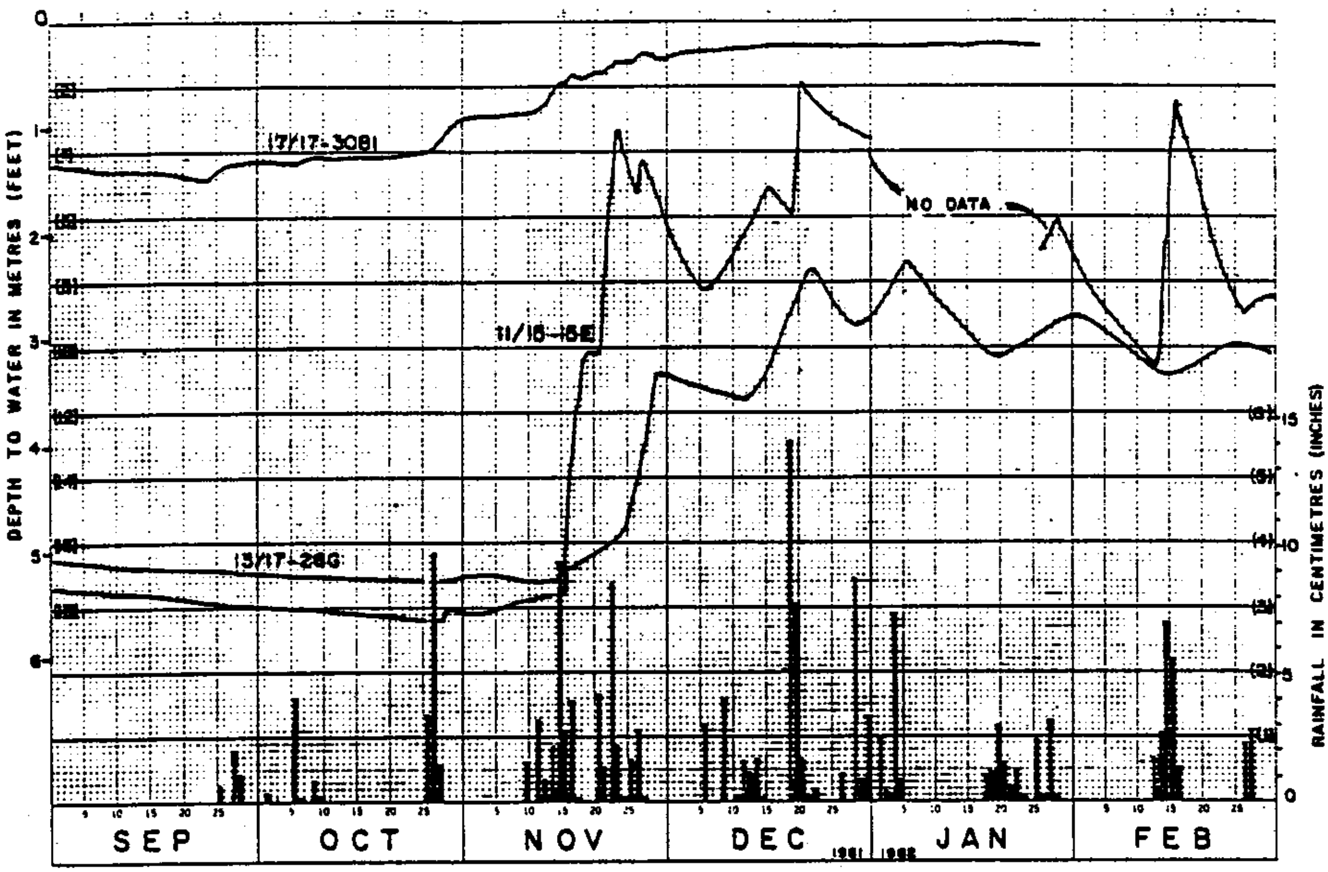


Figure 5. Hydrographs of Three Wells

Well 13N/17W-26G is in a low coastal terrace between Manchester and Point Arena. The rapid rise in water level in response to continued rainfall, beginning about November 24, evidently is due to similar factors observed at well 11N/15W-15E. However, the magnitude and frequency of the water level fluctuations are considerably less and tend to decrease even more as the rainy season proceeds. Also, the lag time between rainfall and corresponding high water level slowly increases, from one to two days in December to nine or ten days in February. These differences are probably due to the greater porosity and permeability of the terrace deposit and the flat topography. Early in the season, after soil moisture and ET are compensated, additional rainfall that does not run off infiltrates to the zone of saturation or is temporarily stored at the surface in the soil or in puddles. As the infiltration rate approaches the rate of natural discharge, as implied by the decrease in magnitude and frequency of ground water fluctuations and the increase in lag time, runoff should be steadily increasing.

Well 17N/17W-30B1, a shallow terrace deposit well near Mendocino, shows immediate and continuing response to rainfall through the end of November. This is due to the shallow nature of the terrace deposit (about 2 m [6 ft] thick) and the impermeability of the underlying bedrock. Rainfall needs to infiltrate only a short distance, hence the quick response, and the shallow bedrock limits the storage capacity of the deposit, which results in full recharge by December 10. Thereafter, recharge and discharge are equal and runoff is moderate to high.

Analyses of all ground water level data collected over the term of this investigation, beginning in July 1979, indicate that the terrace deposit aquifers and fractured and weathered bedrock reservoirs are fully recharged with normal rainfall. The factor that will determine if and when water shortages will occur is the timing of the last significant rainfall of the season. In the absence of sufficient rainfall, ground water discharge will exceed recharge and the water table will decline. If rainfall for the months of April and May are significantly below normal (7.5 cm [2.96 in] and 3.3 cm [1.29 in], respectively), one should expect a greater occurrence of dry wells along the coast. Conversely, if spring rainfall is above normal, with June receiving normal (1.2 cm [0.48 in] rainfall or above, water shortages should be minimal or nonexistent.

HYDROGEOLOGY

Westport Subunit

This subunit is bounded by Cottaneva Creek on the north and Tenmile River on the south and has the towns of Rockport and Westport. The principle streams that drain the inland mountains and valleys are the North Fork Tenmile River and Wages, Dehaven, Howard, Juan, and Cottaneva Creeks. The geology and well locations are shown in Figures 6 and 7.

Local Geology

Coastal Belt Franciscan graywacke and shale underlie the entire subunit. Marine terrace deposits occupy a narrow, 0.14 to 1 km (150 to 1,100 yd) wide bench that ranges from 15 to 70 m (50 to 210 ft) in elevation. The width of the terrace decreases northward and finally pinches out at Union Landing. Further north, marine terrace deposits are absent from the coast until Punta Gorda, 80 km (50 mi) up the coast from Union Landing. Well logs show that the marine terrace deposits are of fairly uniform thickness, ranging from 6.7 to 11.9 m (22 to 39 ft); average thickness is 9.1 m (30 ft).

Significant alluvial deposits occur in the lower reaches of Cottaneva, Juan, Howard, Dehaven, and Wages Creeks and in Tenmile River. They overlie bedrock and extend inland 1.5 to 4 km (1 to 2.5 mi).

Occurrence of Ground Water

For the purpose of evaluating the water-yielding characteristics of the marine terrace deposits, alluvium and bedrock, data were compiled from well drillers' reports for five bedrock wells, nine terrace deposit wells, and three alluvial deposit wells.

Bedrock. The Coastal Belt Franciscan bedrock is considered to be non-water bearing, although springs and wells in these rocks yield minor amounts of water from fissures and fractures. Wells in the subunit drawing solely upon bedrock for water, according to well drillers' reports, yield from 2.8 to 11.4 L/min (0.7 to 4 gpm) and average 7.9 L/min (2.1 gpm), usually accompanied by significant drawdown (9 to 37 m [30 to 120 ft]).

The yield from these wells is a function of the amount of secondary permeability and porosity at the well site. Intensely fractured, sheared, or jointed rock will yield more water than massive, tight rock of the same lithology. It should be noted that secondary permeability and porosity decrease with depth. If a well has not encountered water before a depth of 25 to 30 m (80 to 100 ft), it is not likely that drilling deeper will increase the chances for water.

Marine Terraces. Marine terrace deposits underlie about 495 ha (1,470 ac) to an average depth of 9 m (30 ft). Data obtained from monthly well monitoring show that the water table rises to within 2.4 m (8 ft) of the ground surface in the spring, and recedes to about 4.7 m (15.5 ft) below ground surface by fall. Assuming a specific yield of 9 percent and a saturated thickness of 6.7 m (22 ft), spring storage equals 3 590 dam^3 (2,910 ac-ft). By fall, as a result of natural and artificial discharge and ET, total storage is reduced to 2 370 dam^3 (1,920 ac-ft), a 34-percent change in storage.

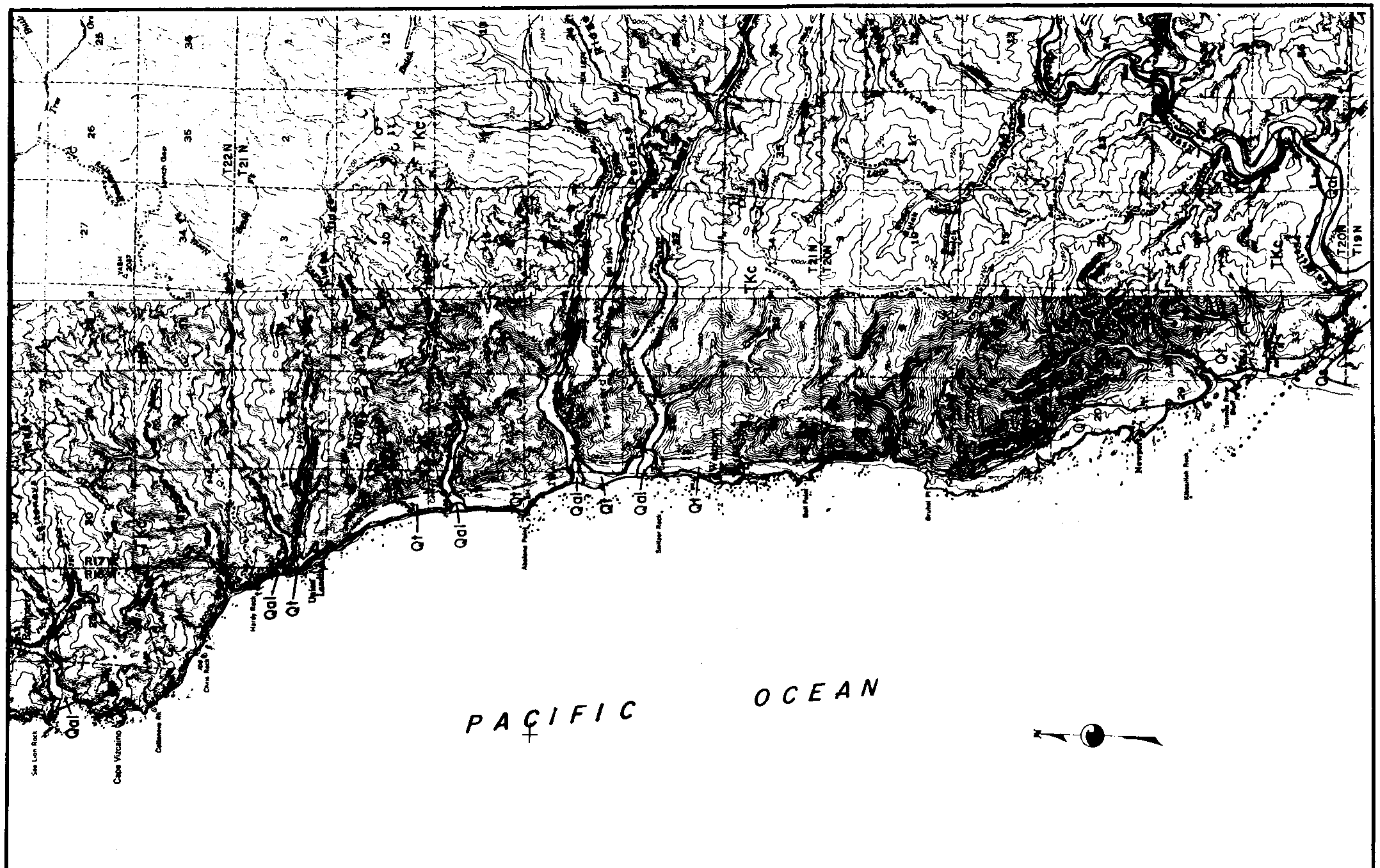
Wells completed in the terrace materials and composite wells yield, according to well drillers' reports, from 5.7 to 135 L/min (1.5 to 36 gpm). Average yield from these wells is 58 L/min (15.5 gpm).

Recharge of the terrace aquifers is from infiltration of precipitation and possibly, to a small degree, by subsurface inflow through joints and fractures in the bedrock. Ground water movement is generally westward, in the direction of the topographic slope.

Alluvium. Alluvial materials underlie about 405 ha (1,000 ac) to an estimated depth of 30 m (100 ft) or more. Data from wells next to Wages and Dehaven Creeks show spring-to-fall water table fluctuations of 0.15 and 1.2 m (0.5 and 4 ft). This reflects year-round recharge provided by these perennial streams; hence, storage remains relatively constant throughout the year, changing by only 1 to 8 percent between spring and fall. Total storage, assuming an average saturated thickness of 15 m (50 ft) and a specific yield of 12 percent, equals 7 400 dam^3 (6,000 ac-ft).

Recharge of the alluvial aquifers is primarily from infiltration of precipitation and surface runoff during the fall-through-spring rainy season, and from surface runoff during the summer.

FIGURE 6



LEGEND

CENOZOIC — Quaternary

- Qs — Beach and dune deposits
- Qal — Alluvium
- Qt — Marine terrace deposits

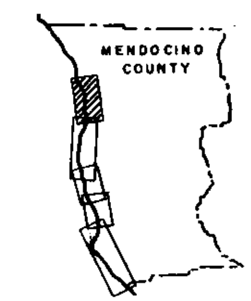
CENOZOIC — Tertiary / MESOZOIC — Cretaceous

- TKc — Coastal Belt Franciscan

Geologic contact; dashed where approximate, queried where questionable, dotted where concealed.

Fault; dashed where inferred, dotted where concealed.

Spring



Location Map

SCALE

1:62500 Contour Interval = 50 feet

0 1 2 3 KILOMETRES

0 1 2 MILES

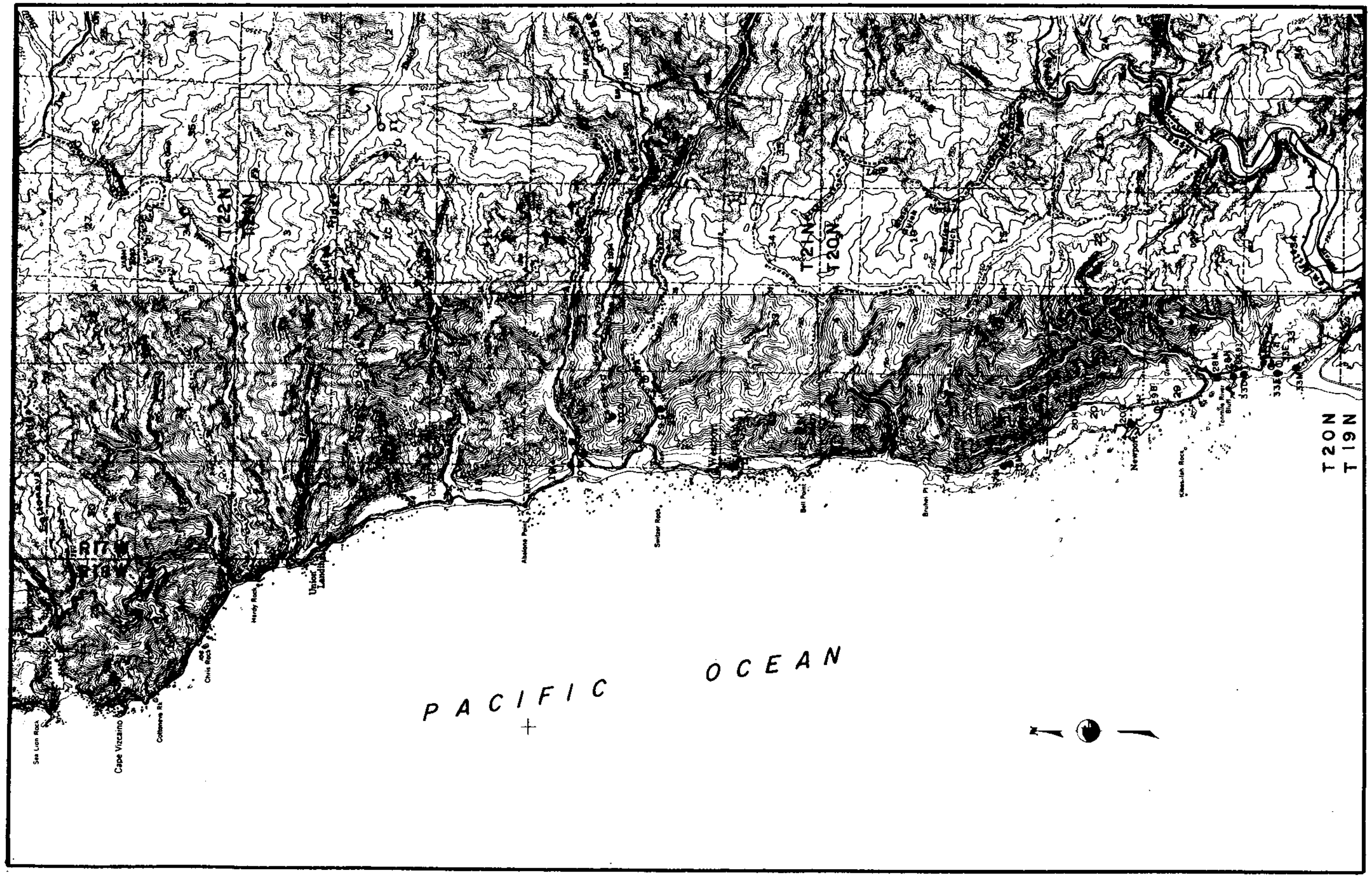
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN DISTRICT

MENDOCINO COUNTY COASTAL GROUND WATER STUDY

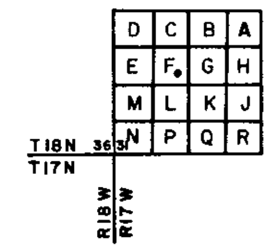
WESTPORT SUBUNIT

AREAL GEOLOGY

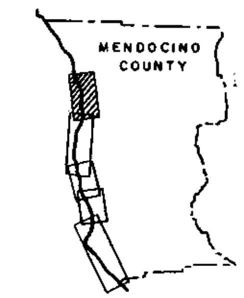
JUNE 1982



KEY TO WELL NUMBERING SYSTEM



WELLS SHOWN ARE NUMBERED BY TOWNSHIP, RANGE AND SUBDIVISION OF SECTION, e.g., T18N / R17W – 31F



LEGEND

33D● WELLS WITH LOGS

17M● MEASURED WELLS WITH LOGS

SCALE

1:62500

Contour Interval = 50 feet

0 1 2 MILES

0 1 2 3 KILOMETRES

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN DISTRICT

MENDOCINO COUNTY COASTAL GROUND WATER STUDY

WESTPORT SUBUNIT

WELL LOCATIONS

JUNE 1982

FIGURE 8

LEGEND

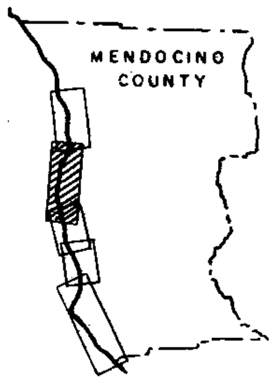
Era	Period	Symbol	Description
CENOZOIC	Quaternary	Qs	Beach and dune deposits
CENOZOIC	Quaternary	Qal	Alluvium
CENOZOIC	Quaternary	Qt	Marine terrace deposits
CENOZOIC	Tertiary		
MESOZOIC	Cretaceous	TKc	Coastal Belt Franciscan

Geologic contact; dashed where approximate, queried where questionable, dotted where concealed.

Fault; dashed where inferred, dotted where concealed.

Spring

Line of geologic cross section. (A–A')



Location Map

SCALE

1:62500 Contour Interval = 80 feet

0 1 2 3 KILOMETRES

0 1 2 MILES

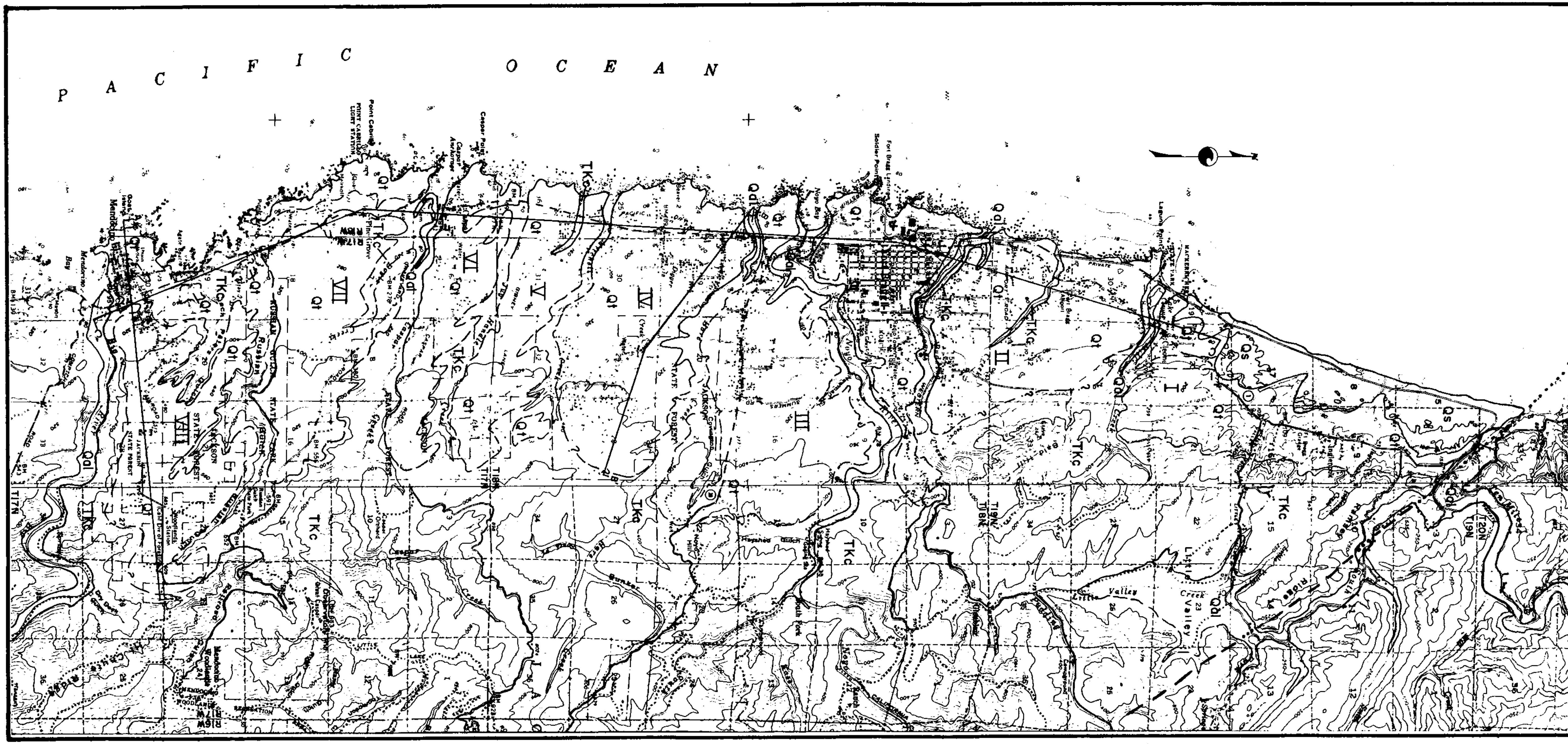
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN DISTRICT

MENDOCINO COUNTY COASTAL GROUND WATER STUDY

FORT BRAGG SUBUNIT

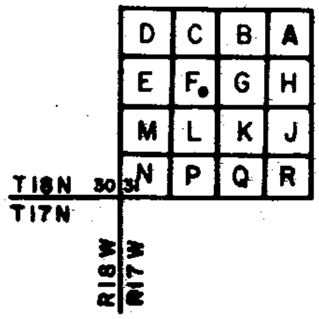
AREAL GEOLOGY

JUNE 1982

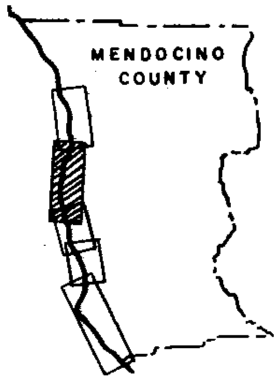


PACIFIC OCEAN
Mendocino
Point Cabrillo
Caspar Point
Fort Bragg Landing
Soldier Point
Noyo Bay
Laguna Point
Little Valley Creek
TKc
Qt
Qal
Qs
I
II
III
IV
V
VI
VII
VIII
T17N
T18N
T19N
T20N
R17W
R16W

KEY TO WELL NUMBERING SYSTEM



WELLS SHOWN ARE NUMBERED BY TOWNSHIP, RANGE AND SUBDIVISION OF SECTION e.g. T18N / R17W — 31F



Location Map

LEGEND

17A● WELLS WITH LOGS

27E● MEASURED WELLS WITH LOGS

SCALE

1:62500

Contour Interval = 80 feet

0 1 2 MILES

0 1 2 3 KILOMETRES

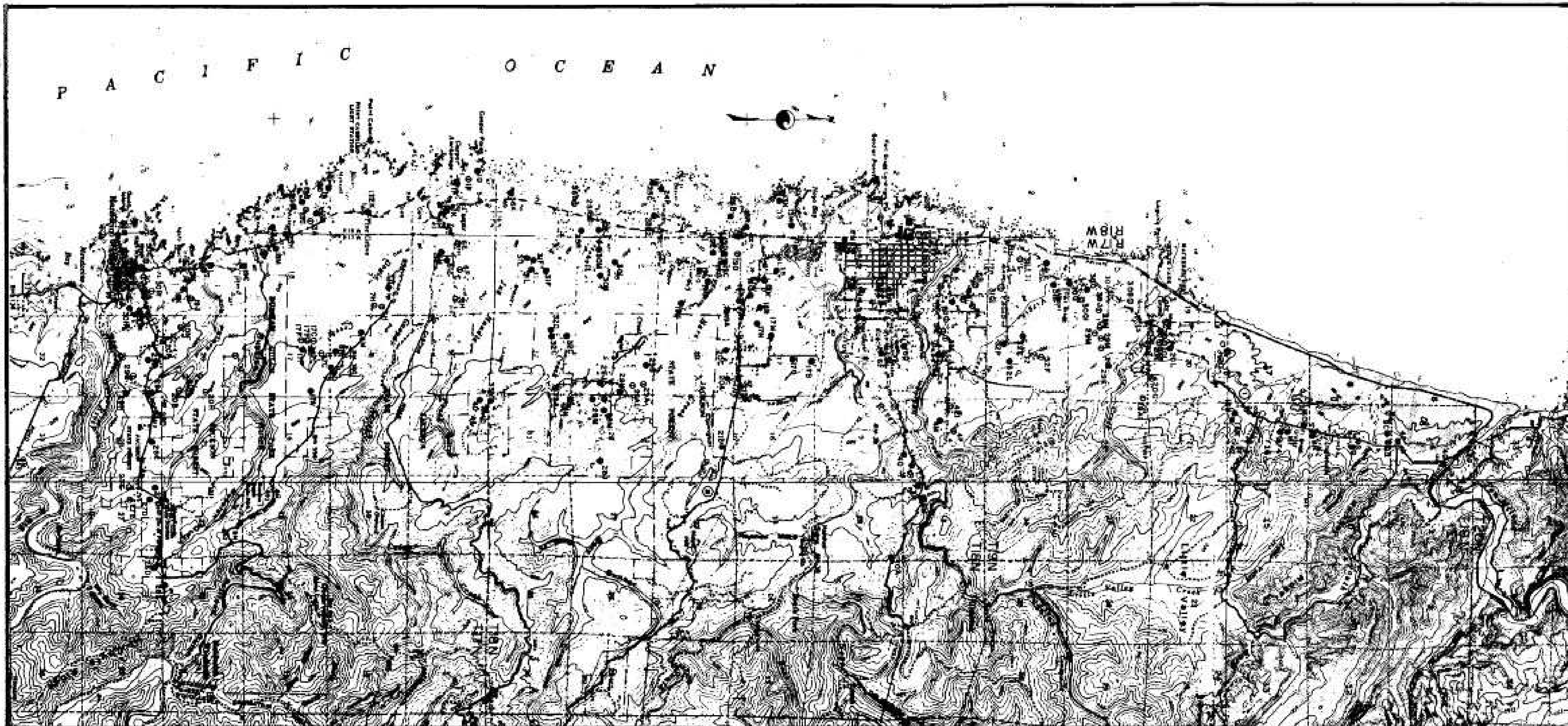
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN DISTRICT

MENDOCINO COUNTY COASTAL GROUND WATER STUDY

FORT BRAGG SUBUNIT

WELL LOCATIONS

JUNE 1982


PACIFIC OCEAN
T1N
T1S
R17W
R18W

Fort Bragg Subunit

This subunit encompasses the coastal area between Tenmile River on the north and Big River on the south. It reaches 2 to 8 km (1.25 to 5 mi) inland. The areal extent is about 124 km^2 (48 mi^2). The principal streams in the subunit are Tenmile River, Mill Creek, Pudding Creek, Noyo River, Hare Creek, Mitchell Creek, Jug Handle Creek, Caspar Creek, Russian Gulch, and Big River. The terrace deposits are subdivided into eight units bounded by the streams that separate them. The occurrence of ground water in each of the eight units is presented. The geology and locations of wells are shown in Figures 8 and 9.

Local Geology

Coastal Belt Franciscan rock underlies the entire subunit. Marine terrace deposits lie unconformably on most wave-cut bedrock benches and extend inland 6 to 8 km (3.7 to 5 mi) from Mendocino to the Fort Bragg area, then narrow to 2 km (1.25 mi) north of Cleone (see Figures 10, 11, and 12). Areal extent of the terrace deposits is about 8 100 ha (20,000 ac).

Terraces range from 12 to 200 m (39 to 650 ft) in elevation. Gardner (1967) has identified at least five terrace levels in some areas. Topographic features can give erroneous indication of terrace deposit occurrence. Some extensive flat benches show bedrock outcrops and some hilly, inland terrain consists of uplifted and eroded terrace material.

The terrace deposits are exposed in cliffs and road cuts and are better exposed than the bedrock. A soil mantle has developed on most terrace material. Vegetation varies from grass on lower terraces to dense brush and heavy forest inland. On the upper inland terraces, podzolization of the soil has led to large areas of pygmy forest (Fox, 1976).

West-east trends in terrace deposit thickness are similar for the north-to-south extent of the subunit, with deposits thickening eastward. Within 1.5 km (1 mi) of the coastline, deposits are 3 to 9 m (10 to 30 ft) thick and increase to a thickness of about 12 m (39 ft) within the third kilometre (second mile) inland. Beyond the third kilometre, thicknesses range from 15 to 43 m (49 to 140 ft). One noticeable exception to this trend occurs south of Noyo, where terrace deposits 1.5 km (1 mi) inland are 30 m (98 ft) thick. Accompanying the narrowing of terrace width from Fort

Bragg to Tenmile River is a thinning of the deposits to Cleone and then a gradual thickening northward to the river. Aside from general trends, depth to bedrock varies appreciably within short distances. This typical, irregular bedrock-terrace deposit contact can be seen along cliff exposures and is apparent in well-log descriptions.

Thick alluvial deposits are found within the stream channels that dissect the terraces. This Quaternary alluvium lies on top of Coastal Belt Franciscan bedrock in thicknesses of as much as 36 m (120 ft) at the mouths of the streams and rivers. Due to the dense vegetation next to the streams, information about depth and areal extent is from bridge foundation test-boring logs and morphological interpretations.

From Cleone north to Tenmile River, beach and dune deposits occupy about 585 ha (1,445 ac) along the coast and up to 1.2 km (4,000 ft) inland. Although these deposits are not important from a ground water standpoint, they are geologically interesting. The presence of the dunes and the thickening of the marine terrace deposits north of Cleone suggest a possible hinge fault concealed in the axis of Tenmile River Valley with a line of flexure extending northeasterly from Laguna Point.

Occurrence of Ground Water

For the purpose of evaluating the water-yielding characteristics of the marine terrace deposits and bedrock, data were compiled from well drillers' reports for 71 bedrock wells, 48 composite wells, and 136 terrace deposit wells. These are summarized in Table 3.

Bedrock. The Coastal Belt Franciscan rocks are considered non-water bearing. They are consolidated and of low permeability and porosity. Ground water contained in these rocks exists only in the soil, weathered rock, or in secondary openings formed by fractures, joints, and shear zones.

In this subunit, bedrock wells yield water up to 170 L/min (45 gpm), with most wells yielding between 4 and 34 L/min (1 and 9 gpm). Yields are taken from well logs, so testing dates vary for all wells. Composite wells have gravel pack and casing perforations occurring in the terrace deposit and at depth in bedrock. Though the source of water cannot be determined, it can be seen by comparing the mean specific capacities of bedrock wells to composite wells that composite wells yield almost twice the water per metre of drawdown as bedrock wells (Table 3).

FIGURE 10

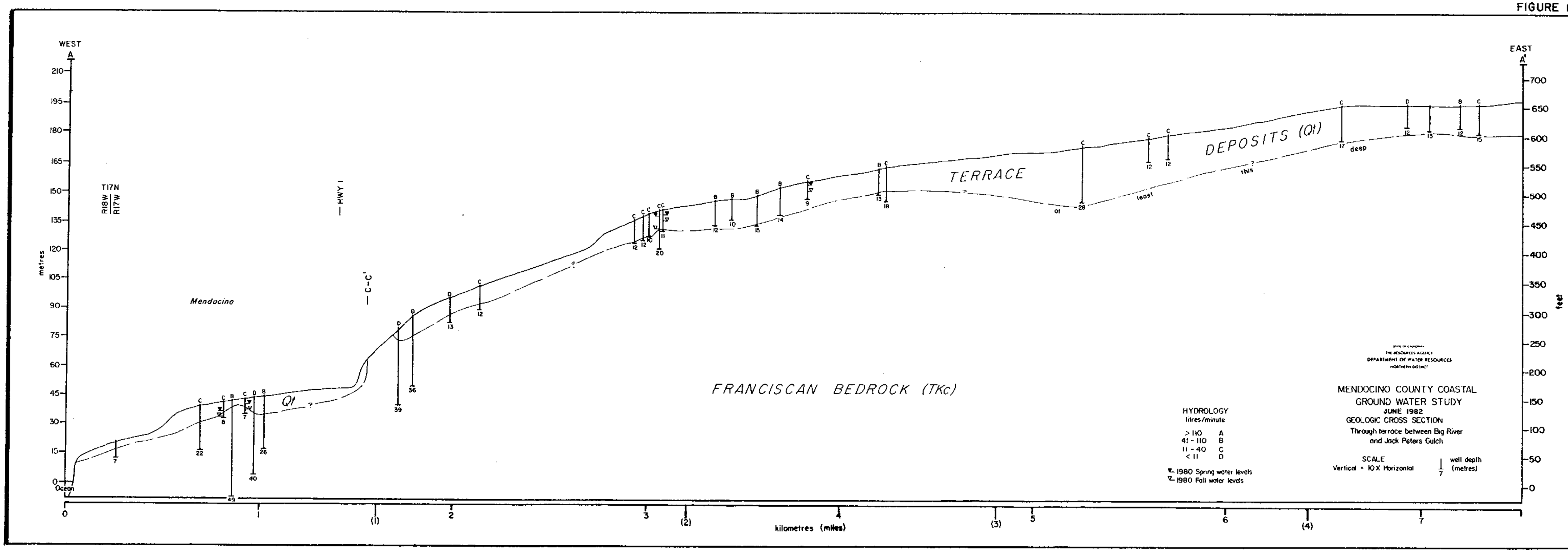
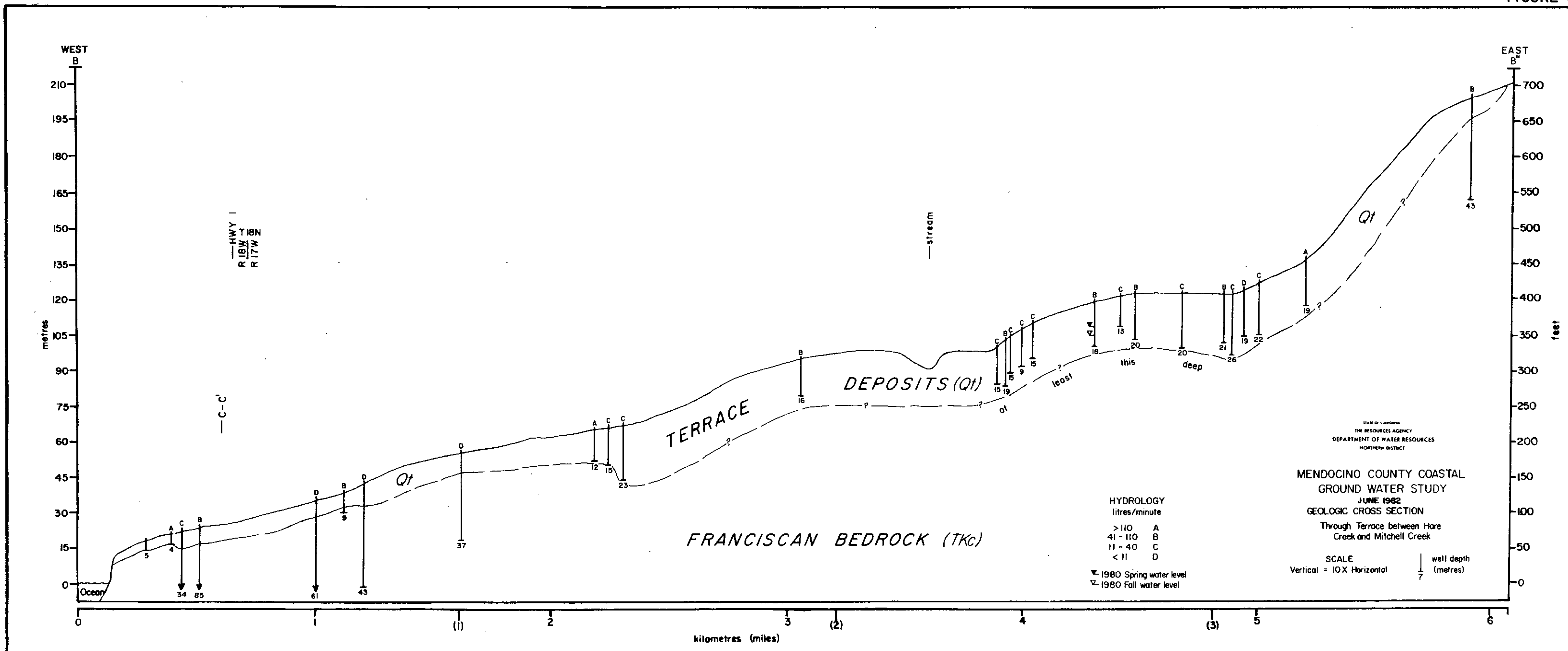
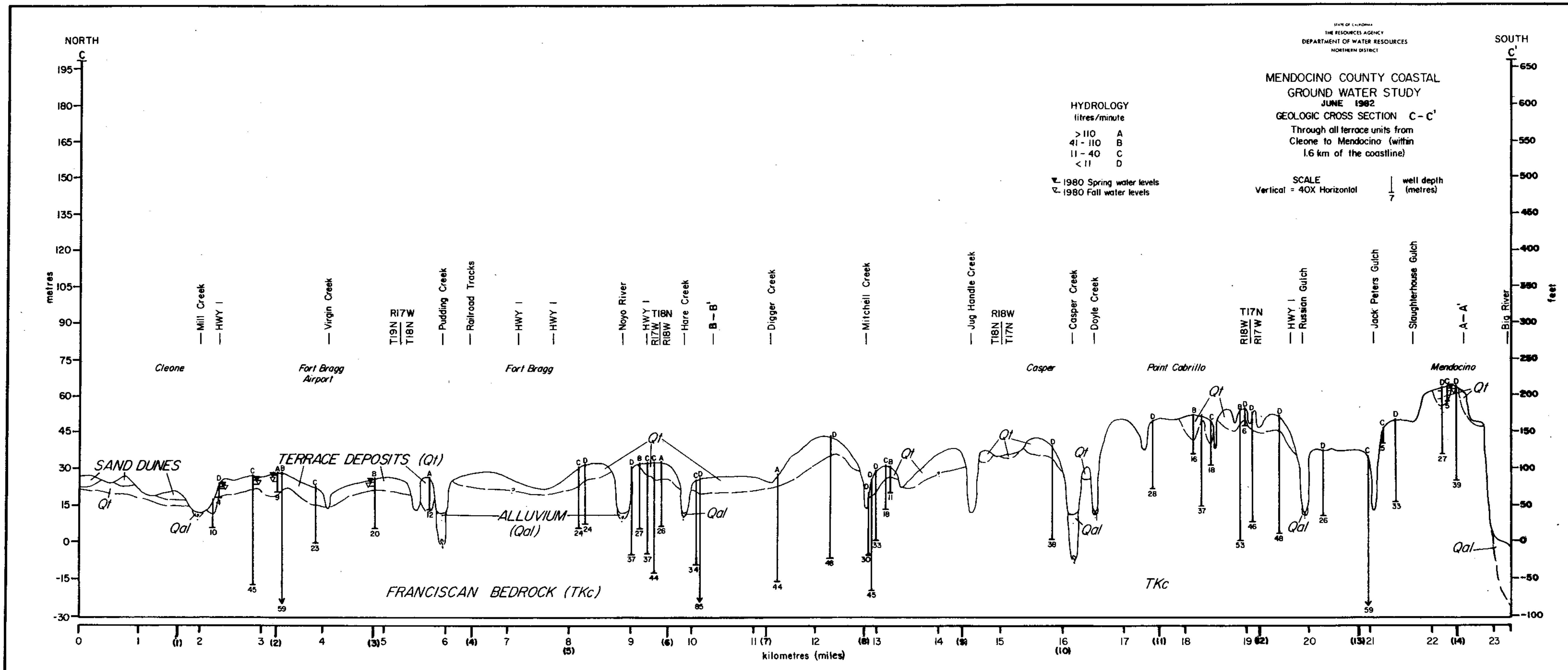

WEST
A
EAST
A'
metres
feet
T17N
R18W | R17W
HWY 1
C–C'
Mendocino
Ocean
Qt
TERRACE DEPOSITS (Qt)
FRANCISCAN BEDROCK (TKc)
kilometres (miles)
HYDROLOGY
litres/minute
> 110 A
41 - 110 B
11 - 40 C
< 11 D
1980 Spring water levels
1980 Fall water levels
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN DISTRICT
MENDOCINO COUNTY COASTAL
GROUND WATER STUDY
JUNE 1982
GEOLOGIC CROSS SECTION
Through terrace between Big River
and Jack Peters Gulch
SCALE
Vertical = 10 X Horizontal
well depth (metres)

FIGURE 11



WEST
B
EAST
B"
metres
feet
HWY 1
T18N
R18W
R17W
C-C'
stream
TERRACE
DEPOSITS (Qt)
Qt
at least this deep
FRANCISCAN BEDROCK (TKc)
Ocean
kilometres (miles)
HYDROLOGY
litres/minute
>110 A
41-110 B
11-40 C
<11 D
1980 Spring water level
1980 Fall water level
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN DISTRICT
MENDOCINO COUNTY COASTAL
GROUND WATER STUDY
JUNE 1982
GEOLOGIC CROSS SECTION
Through Terrace between Hare Creek and Mitchell Creek
SCALE
Vertical = 10 X Horizontal
well depth (metres)

FIGURE 12


STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN DISTRICT
MENDOCINO COUNTY COASTAL
GROUND WATER STUDY
JUNE 1982
GEOLOGIC CROSS SECTION C-C'
Through all terrace units from
Cleone to Mendocino (within
1.6 km of the coastline)
SCALE
Vertical = 40X Horizontal
well depth (metres)
HYDROLOGY
litres/minute
>110 A
41-110 B
11-40 C
<11 D
1980 Spring water levels
1980 Fall water levels
NORTH
C
SOUTH
C'
metres
feet
kilometres (miles)
Cleone
Fort Bragg Airport
Fort Bragg
Casper
Point Cabrillo
Mendocino
Mill Creek
HWY 1
Virgin Creek
R17W
T19N
T18N
Pudding Creek
Railroad Tracks
Noyo River
R17W
R18W
Hare Creek
B-B'
Digger Creek
Mitchell Creek
Jug Handle Creek
R18W
T17N
Casper Creek
Doyle Creek
Russian Gulch
Jack Peters Gulch
Slaughterhouse Gulch
A-A'
Big River
SAND DUNES
TERRACE DEPOSITS (Qt)
ALLUVIUM (Qal)
FRANCISCAN BEDROCK (TKc)
TKc
Qt
Qal

Marine Terraces. The primary water-yielding unit of the Fort Bragg subunit is the marine terrace deposits. Terrace deposit wells yield water from 5.2 to 280 L/min (1.5 to 74 gpm), with most wells yielding between 30 and 110 L/min (8 and 29 gpm). Mean yield is about 52 L/min (13.7 gpm), with a specific capacity of 12.5 L/min/m (1.01 gpm/ft).

Since the terrace deposits cap the bedrock, the aquifer is generally unconfined, meaning that the upper limit of the aquifer is defined by the water table--it is not "capped" by an impermeable layer, though hardpan or clay layers may cause local confinement. Stream channels separate the terrace deposits into eight distinct, limited ground water storage areas with irregular boundaries. These storage units are shown in Figure 8. Aquifer thicknesses range from 1 to 43 m (4 to 112 ft), with an estimated average thickness of 15 m (49 ft). Areal extent of all terrace deposits is 8 100 ha (20,000 ac).

Water level information is based on data from the well monitoring program. In spring, depths to water range from 0.2 to 11 m (0.7 to 36 ft), with an average of 2.5 m (8.2 ft).

The change in the water table from spring to fall ranges from 0.6 to 9 m (2 to 29 ft) with an average decline of 2.7 m (8.9 ft).

Using average water levels and estimated saturated volumes and specific yields of the terrace deposits, the storage capacity of all terraces is about 99 700 dam^3 (80,800 ac-ft). Storage capacity from spring to fall is estimated to decline to 81 800 dam^3 (66,300 ac-ft), which represents an 18-percent change. More specifically, terrace units II, VI, VII, and VIII show high percentages (30 to 44 percent) of change in storage (Tables 4 and 4A). The data used to compute storage capacity and change in storage for the eight terrace units are summarized in Tables 4 and 4A.

Alluvium. Alluvial deposits have not been considered a ground water source in this subunit because of their limited extent and unlikely location for development.

TABLE 3

SUMMARY OF FORT BRAGG SUBUNIT WELL DATA [1/]

Well Type	Yield		Drawdown		Mean Specific Capacity	Percent of Wells Yielding 38 L/min (10 gpm) or More
	Average	Range	Average	Range	L/min/m (gpm/ft)	
Bedrock	33 L/min (8.7 gpm)	1.2 to 170 L/min (0.33 to 45 gpm)	20.7 m (68 ft)	1.5 to 39.3 m (5 to 129 ft)	1.6 (0.13)	24
Composite	27.1 L/min (7.2 gpm)	1.2 to 208 L/min (0.33 to 60 gpm)	9.9 m (30 ft)	1 to 40 m (3 to 131 ft)	3.0 (0.24)	22
Terrace Deposits	52 L/min (13.7 gpm)	5.2 to 280 L/min (1.5 to 74 gpm)	4.2 m (13.6 ft)	0 to 13.7 m (0 to 45 ft)	12.5 (1.01)	58

1/From information in "Water Well Drillers' Reports"

TABLE 4

SUMMARY OF STORAGE CAPACITY DATA FOR FORT BRAGG SUBUNIT TERRACE AQUIFERS 4/
(metric units)

Terrace (see Figure 8)	Maximum Thickness 1/ (metres)	Average Thickness 1/ (metres)	Total Areal Extent 2/ (hectares)	Avg Depth to Water Surface Spring 3/ (metres)	Average Specific Yield 1/ (%)	Storage Capacity (A) (dam^3)	Avg Depth to Water Surface Fall 3/ (metres)	Change in Water Stored (B) (dam^3)	B/A (%)
I. Tenmile River to Mill Creek	18	14.2	910	1.5	8	9 970	3.8	1 800	18
II. Mill Creek to Pudding Creek	12	8	1 120	1.0	10	7 850	4.1	3 480	44
III. Noyo River to Hare Creek	43	38	1 320	2.0	10	47 400	4.0	2 640	5
IV. Hare Creek to Mitchell Creek	43	13	1 310	2.0	10	14 400	4.0	2 620	18
V. Mitchell Creek to Jug Handle Creek	23	11	670	1.0	9	5 990	3.0	1 200	20
VI. Jug Handle Creek to Caspar Creek	9	7	590	1.0	8	2 820	3.5	1 170	42
VII. Caspar Creek to Russian Gulch	15	9	1 060	3.0	5	3 190	5.5	1 330	42
VIII. Russian Gulch to Big River	21	12	1 120	3.0	8	8 040	5.7	2 410	30
Totals	-	-	8 100	-	-	99 660	-	16 650	-
Averages	-	15.3	-	2.5	9	-	4.9	-	17

1/ Data from well logs

2/ Measured with planimeter using geology map

3/ Data from monthly well monitoring

4/ Based on 1980-82 data base

TABLE 4A

SUMMARY OF STORAGE CAPACITY DATA FOR FORT BRAGG SUBUNIT TERRACE AQUIFERS 4/
(customary units)

Terrace (see Figure 8)	Maximum Thickness 1/ (feet)	Average Thickness 1/ (feet)	Total Areal Extent 2/ (acres)	Avg Depth to Water Surface Spring 3/ (feet)	Average Specific Yield 1/ (%)	Storage Capacity (A) (ac-ft)	Avg Depth to Water Surface Fall 3/ (feet)	Change in Water Stored (B) (ac-ft)	B/A (%)
I. Tenmile River to Mill Creek	59	46.5	2,250	5	8	8,080	12.5	1,460	18
II. Mill Creek to Pudding Creek	39	26	2,770	3.2	10	6,360	13.4	2,820	44
III. Noyo River to Hare Creek	141	125	3,260	6.5	10	38,400	13.1	2,140	5
IV. Hare Creek to Mitchell Creek	141	43	3,240	6.5	10	11,700	13.1	2,120	18
V. Mitchell Creek to Jug Handle Creek	75	36	1,660	3.2	9	4,860	9.8	970	20
VI. Jug Handle Creek to Caspar Creek	30	23	1,460	3.2	8	2,280	11.5	950	42
VII. Caspar Creek to Russian Gulch	49	30	2,620	9.8	5	2,590	18.0	1,080	42
VIII. Russian Gulch to Big River	69	39	2,770	9.8	8	6,520	18.7	1,950	30
Totals	-	-	20,030	-	-	80,790	-	13,490	-
Averages	-	50	-	8.2	9	-	16.1	-	17

1/ Data from well logs

2/ Measured with planimeter using geology map

3/ Data from monthly well monitoring

4/ Based on 1980-82 data base

Albion Subunit

The Albion subunit is bounded by the Big River to the north and the Navarro River to the south and reaches 5.6 to 8 km (3.5 to 5 mi) inland from the coast. The areal extent is about 69 km^2 (26.8 mi^2), of which 60 percent is covered with marine terrace deposits. The principal streams draining the subunit are the Albion, the Big, the Little, and the Navarro Rivers, and Big Salmon and Little Salmon Creeks. Albion is the major town in the subunit. The geology and well locations are shown in Figures 13 and 14.

Local Geology

Like the previously described subunits, the Coastal Belt Franciscan rock underlies the entire subunit.

Marine terrace deposits unconformably overlie wave-cut bedrock benches and range from a few decimetres (about a foot) to almost 28 m (90 ft) in thickness. These deposits extend 5.6 to 8 km (3.5 to 5 mi) inland and range from 12 to 200 m (39 to 650 ft) in elevation.

The terrace deposits exhibit a northwesterly thickening trend. Deposits on the lower coastal terrace are generally less than 6 m (20 ft) thick, as are the deposits on Navarro Ridge and the southeastern reaches of Albion Ridge. The thickest sections of terrace deposits are in the vicinity of the county airport (Section 10, T16N, R17W, MDB&M) and on the terrace bounded by Big and Little Rivers (see Figures 15 and 16).

Significant alluvial deposits occur in the courses of the Big, Albion, and Navarro Rivers. These deposits unconformably overlie the Coastal Belt Franciscan with an estimated thickness of 30 m (100 ft) or more.

Occurrence of Ground Water

For the purpose of evaluating the water-yielding characteristics of the marine terrace deposits and bedrock in the Albion subunit, data were compiled from well drillers' reports of 32 bedrock wells, 23 composite wells, and 30 terrace deposit wells, and are presented in Table 5.

Bedrock. The Coastal Belt Franciscan shale and sandstone are considered non-water bearing. Free ground water in these rocks exists in joints and fissures or in near-surface weathered rock.

TABLE 5

SUMMARY OF ALBION SUBUNIT WELL DATA 1/

Well Type	Yield		Drawdown		Mean Specific Capacity	Percent of Wells Yielding 38 L/min (10 gpm) or More
	Average	Range	Average	Range	L/min/m (gpm/ft)	
Bedrock	23 L/min (6 gpm)	0.5 to 170 L/min (0.15 to 45 gpm)	22.9 m (75.2 ft)	7 to 63 m (23 to 207 ft)	1.0 (0.08)	12
Composite	30 L/min (8 gpm)	2.3 to 302 L/min (0.6 to 80 gpm)	18.6 m (61 ft)	3 to 40 m (10 to 131 ft)	1.6 (0.13)	17
Terrace Deposit	37 L/min (9.75 gpm)	4 to 284 L/min (1 to 75 gpm)	6.4 m (21 ft)	3 to 10.3 m (10 to 34 ft)	5.7 (0.46)	33

1/ From information in "Water Well Drillers' Reports"

FIGURE 13

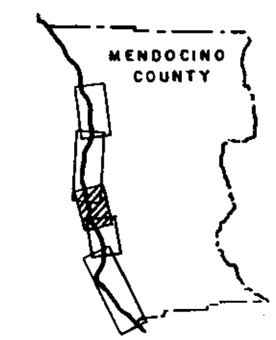
LEGEND

CENOZOIC	Quaternary	Qal	Alluvium
		Qt	Marine terrace deposits
	Tertiary		
MESOZOIC	Cretaceous	TKc	Coastal Belt Franciscan

Geologic contact; dashed where approximate, queried where questionable, dotted where concealed.

Spring

A — A′ Line of geologic cross section.



Location Map

SCALE

1:62500

Contour Interval = 80 feet

0 1 2 3 KILOMETRES

0 1 2 MILES

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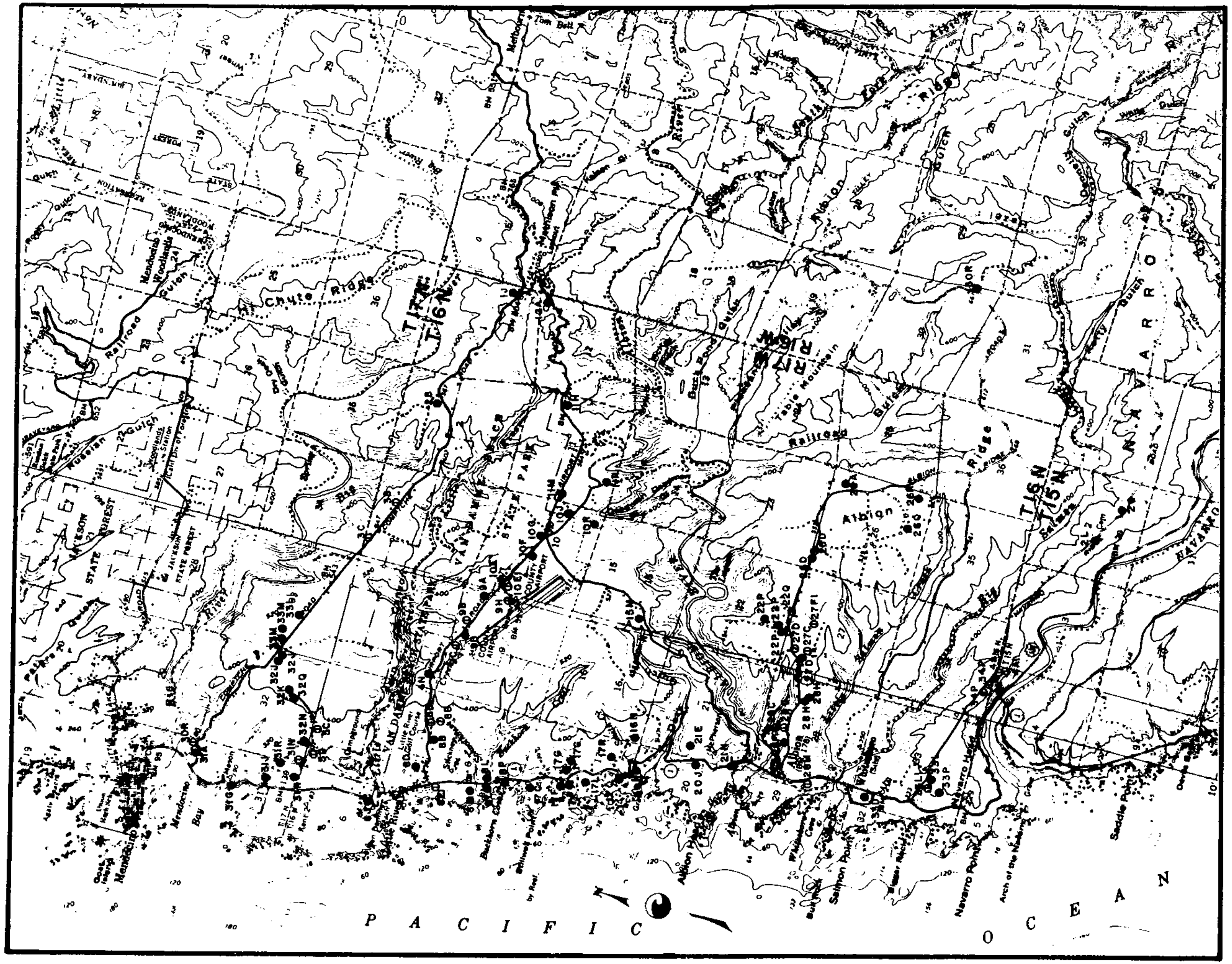
NORTHERN DISTRICT

MENDOCINO COUNTY COASTAL GROUND WATER STUDY

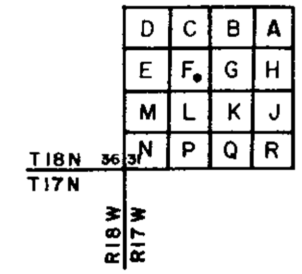
ALBION SUBUNIT

AREAL GEOLOGY

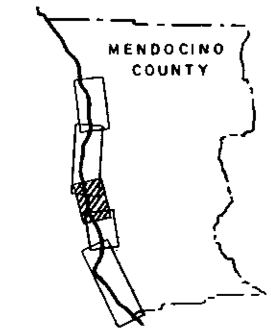
JUNE 1982



KEY TO WELL NUMBERING SYSTEM



WELLS SHOWN ARE NUMBERED BY TOWNSHIP, RANGE AND SUBDIVISION OF SECTION, e.g., T18N / R17W – 31F



Location Map

LEGEND

26A• WELLS WITH LOGS

5D⊙ MEASURED WELLS WITH LOGS

SCALE

1:62500

Contour Interval = 80 feet

0 1 2 MILES

0 1 2 3 KILOMETRES

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NORTHERN DISTRICT

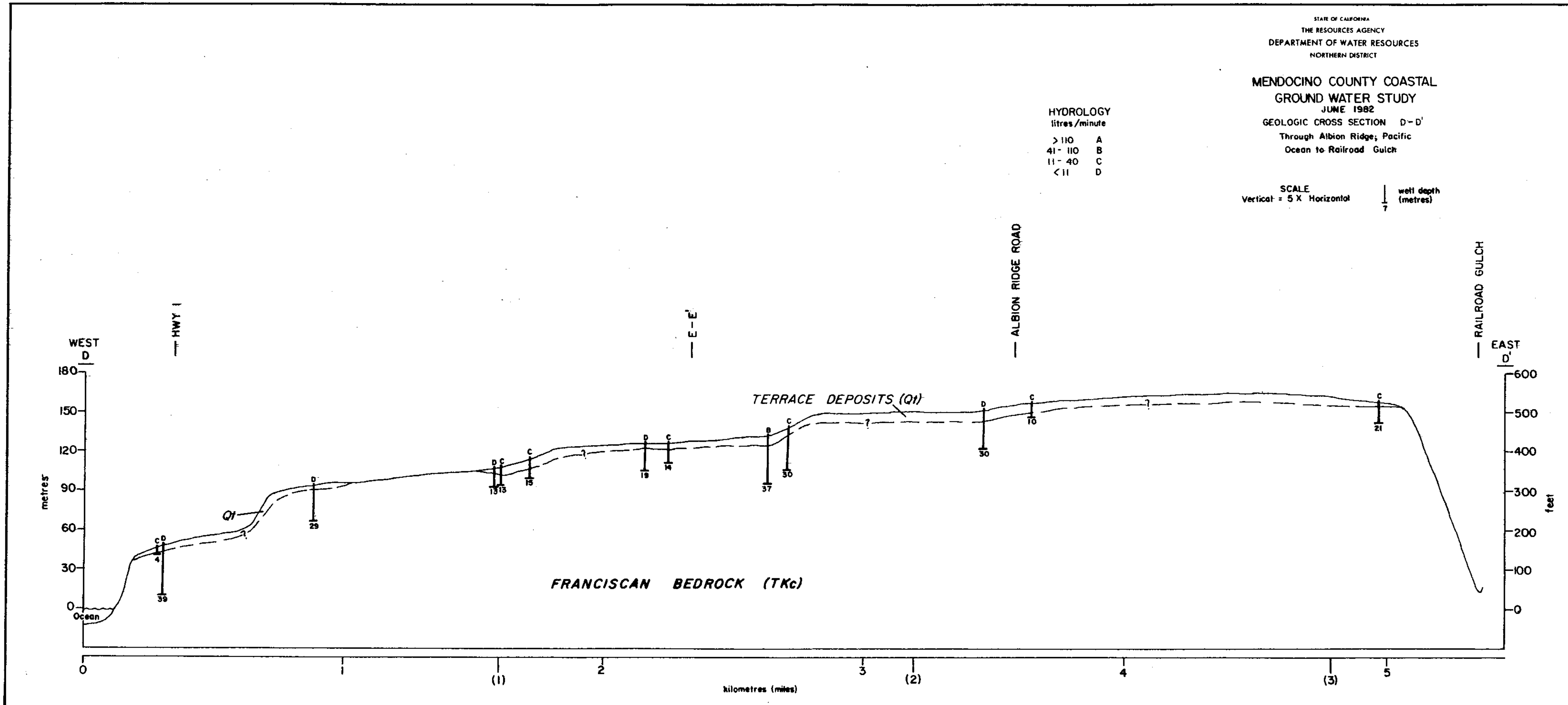
MENDOCINO COUNTY COASTAL GROUND WATER STUDY

ALBION SUBUNIT

WELL LOCATIONS

JUNE 1982

FIGURE 15


STATE OF CALIFORNIA
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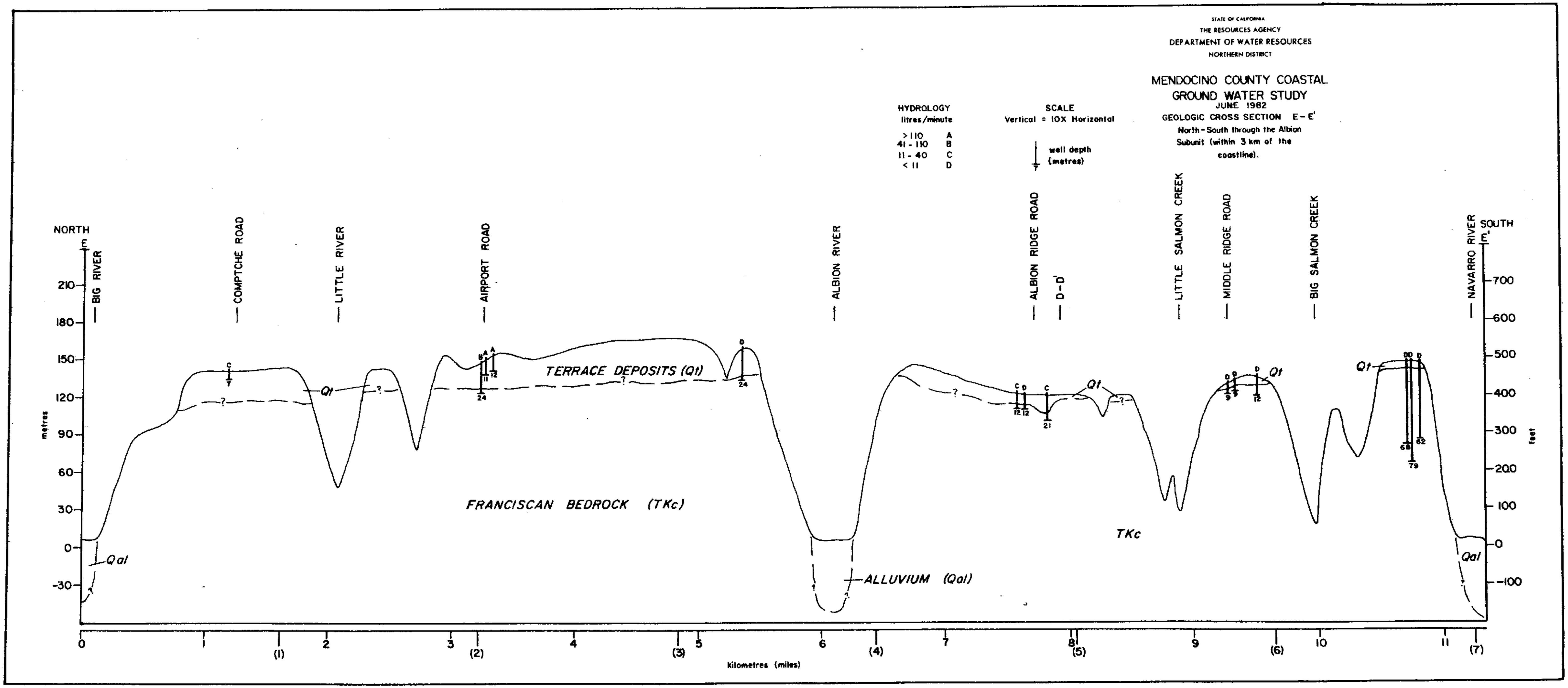
NORTHERN DISTRICT
MENDOCINO COUNTY COASTAL
GROUND WATER STUDY
JUNE 1982
GEOLOGIC CROSS SECTION D-D'
Through Albion Ridge; Pacific
Ocean to Railroad Gulch
HYDROLOGY
litres/minute
>110 A
41-110 B
11-40 C
<11 D
SCALE
Vertical = 5 X Horizontal
well depth (metres)
WEST
D
HWY 1
E-E'
ALBION RIDGE ROAD
RAILROAD GULCH
EAST
D'
TERRACE DEPOSITS (Qt)
Qt
FRANCISCAN BEDROCK (TKc)
Ocean
metres
feet
kilometres (miles)

FIGURE 16


STATE OF CALIFORNIA
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NORTHERN DISTRICT
MENDOCINO COUNTY COASTAL GROUND WATER STUDY
JUNE 1982
GEOLOGIC CROSS SECTION E-E'
North-South through the Albion Subunit (within 3 km of the coastline).
HYDROLOGY
litres/minute
>110 A
41-110 B
11-40 C
< 11 D
SCALE
Vertical = 10X Horizontal
well depth (metres)
NORTH
SOUTH
E
E'
BIG RIVER
COMPTCHE ROAD
LITTLE RIVER
AIRPORT ROAD
ALBION RIVER
ALBION RIDGE ROAD
D-D'
LITTLE SALMON CREEK
MIDDLE RIDGE ROAD
BIG SALMON CREEK
NAVARRO RIVER
TERRACE DEPOSITS (Qt)
FRANCISCAN BEDROCK (TKc)
ALLUVIUM (Qal)
Qt
Qal
TKc
metres
feet
kilometres (miles)

In the Albion subunit, wells drawing solely from bedrock for a water supply yield between 0.5 and 170 L/min (0.15 and 45 gpm). The average yield of bedrock wells is 23 L/min (6 gpm). Composite wells, drawing water from both bedrock and the overlying terrace deposits, are reported to yield between 2.3 and 300 L/min (0.6 and 80 gpm).

Reported drawdowns for both bedrock and composite wells are considerable and usually relate to the total depth of the well (i.e., the deeper the well, the greater the drawdown). Mean specific capacities of bedrock and composite wells (1 and 1.6 L/min/m [0.08 and 0.13 gpm/ft], respectively) show only a slight difference, with the higher composite well value reflecting inflow from the more porous and permeable terrace deposits.

Ground water in bedrock fractures and fissures is assumed to be unconfined. The general direction of its movement is controlled by the continuity and alignment of the fractures and fissures, which are generally oriented in a northwesterly-southeasterly direction, roughly parallel to the structural trend of the Coast Range geomorphic province. Massive, unfractured bedrock will not transmit ground water and is therefore a barrier to the lateral and vertical migration of ground water within the bedrock.

Ground water recharge of the bedrock is by direct infiltration of ground water from overlying materials (i.e., alluvium, terrace deposits, soils) and by the lateral movement of ground water within the fissures and fractures that extend in a general upslope direction.

<u>Marine Terraces</u>. The marine terrace deposits are the primary water-yielding unit of the Albion subunit and underlie about 4 110 ha (10,150 ac) to an average depth of 10.4 m (34 ft). The specific yield estimates range from 3 to 20 percent with a mean value of 9 percent. Terrace deposit wells yield water at 4 to 284 L/min (1 to 75 gpm), with most wells yielding between 14 and 38 L/min (4 to 10 gpm). Mean yield is 37 L/min (9.75 gpm) and the mean specific capacity is 5.7 L/min/m (0.46 gpm/ft).

Data from monthly well monitoring show that the average depth below ground surface to the water table is 1.5 m (5 ft) in the spring and 3 m (10 ft) in the fall. Using these data and assuming an average terrace thickness of 10.5 m (34 ft) with a specific yield of 9 percent, the spring storage capacity of the terrace deposits equals 33 000 dam^3 (26,800 ac-ft);

fall storage reduces to 27 060 dam^3 (21,940 ac-ft), an 18-percent change in storage. However, due to the thinning of terrace deposits southeast of Albion, the spring-to-fall change in the storage capacity of the terrace deposits on Navarro and Albion Ridges can be expected to approach 50 to 100 percent. Conversely, the spring-to-fall change in storage capacity for terrace deposits north of the Albion River is on the order of 10 percent or less.

Alluvium. Alluvial deposits are not considered a ground water source in the Albion subunit because of their location in deep, narrow valleys with extensive tidal reaches.

Elk Subunit

The Elk subunit lies along the coast between the Navarro River and Mallo Pass Creek, and reaches 0.6 to 2 km (0.4 to 1.2 mi) inland. The principal streams in the subunit are the Navarro River and Greenwood, Elk, and Mallo Pass Creeks. Elk is the largest settlement in the subunit. The geology and well locations are shown in Figures 17 and 18.

Local Geology

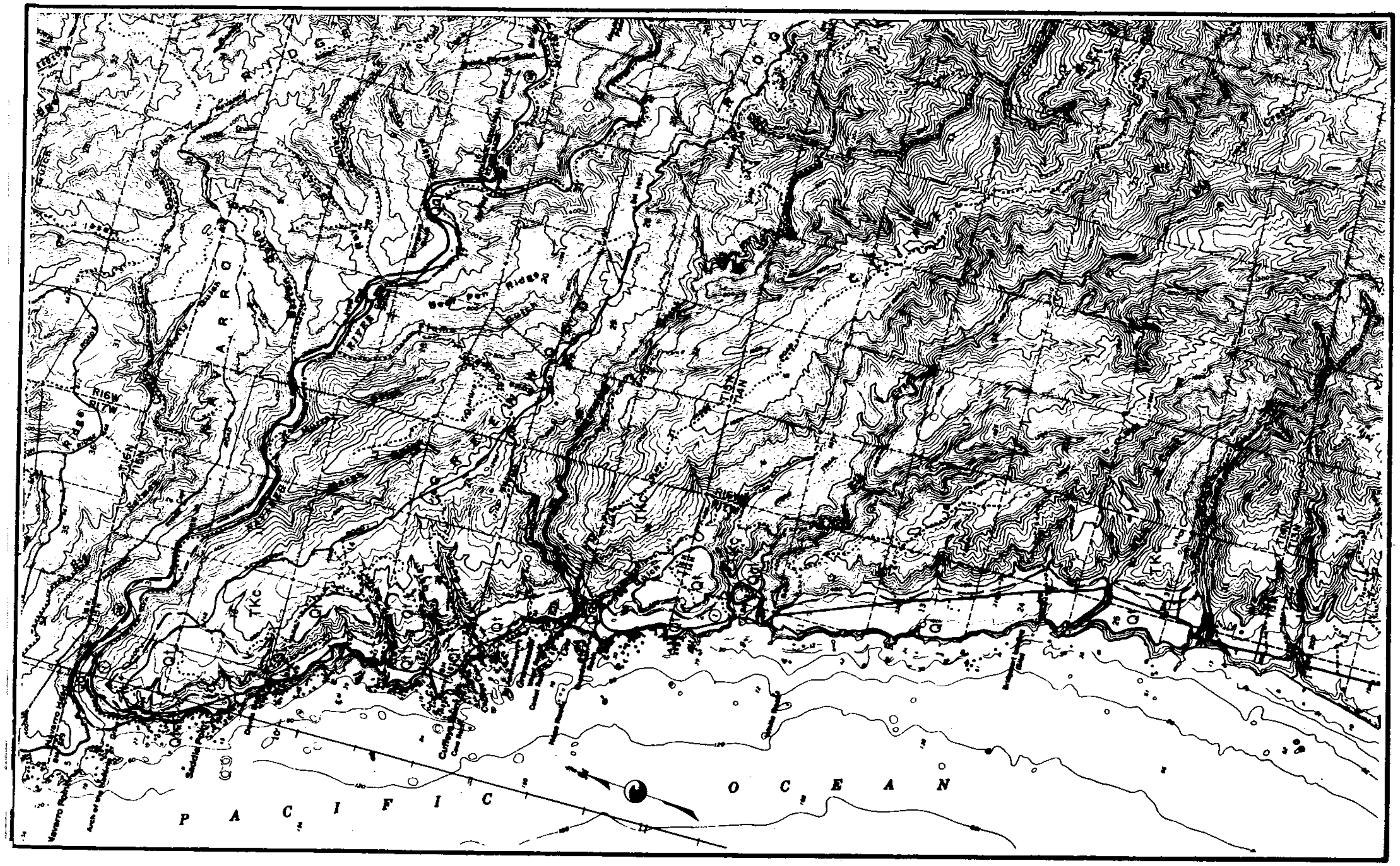
The Coastal Belt Franciscan underlies the entire subunit. Quaternary marine terrace deposits unconformably overlie the bedrock on wave-cut benches that range from 24 to 200 m (80 to 650 ft) in elevation. These marine terrace deposits underlie an area of about 1 150 ha (2,840 ac) and range from 1 to 9 m (3 to 30 ft) in thickness; average thickness is about 6 m (20 ft).

Alluvial deposits to an estimated thickness of 30 m (100 ft) or more occupy the lower courses of Greenwood and Elk Creeks and the Navarro River.

Occurrence and Nature of Ground Water

Because most of the Elk subunit is undeveloped, an evaluation of the ground water resources here is based on meager data and comparisons with similar ground water conditions in the Albion, Fort Bragg, and Westport subunits. Twenty well drillers' reports--15 bedrock wells, 4 composite wells, and 1 terrace deposit well--for wells in the subunit were evaluated.

FIGURE 17

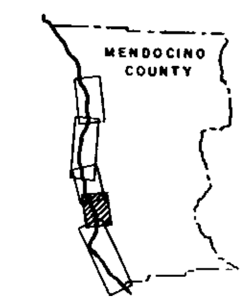


LEGEND

CENOZOIC	Quaternary	Qal	Alluvium
		Qt	Marine terrace deposits
	Tertiary		
MESOZOIC	Cretaceous	TKc	Coastal Belt Franciscan

Geologic contact; dashed where approximate, queried where questionable, dotted where concealed.

Spring



Location Map

SCALE

1:62500 Contour Interval = 80 feet

0 1 2 3 KILOMETRES

0 1 2 MILES

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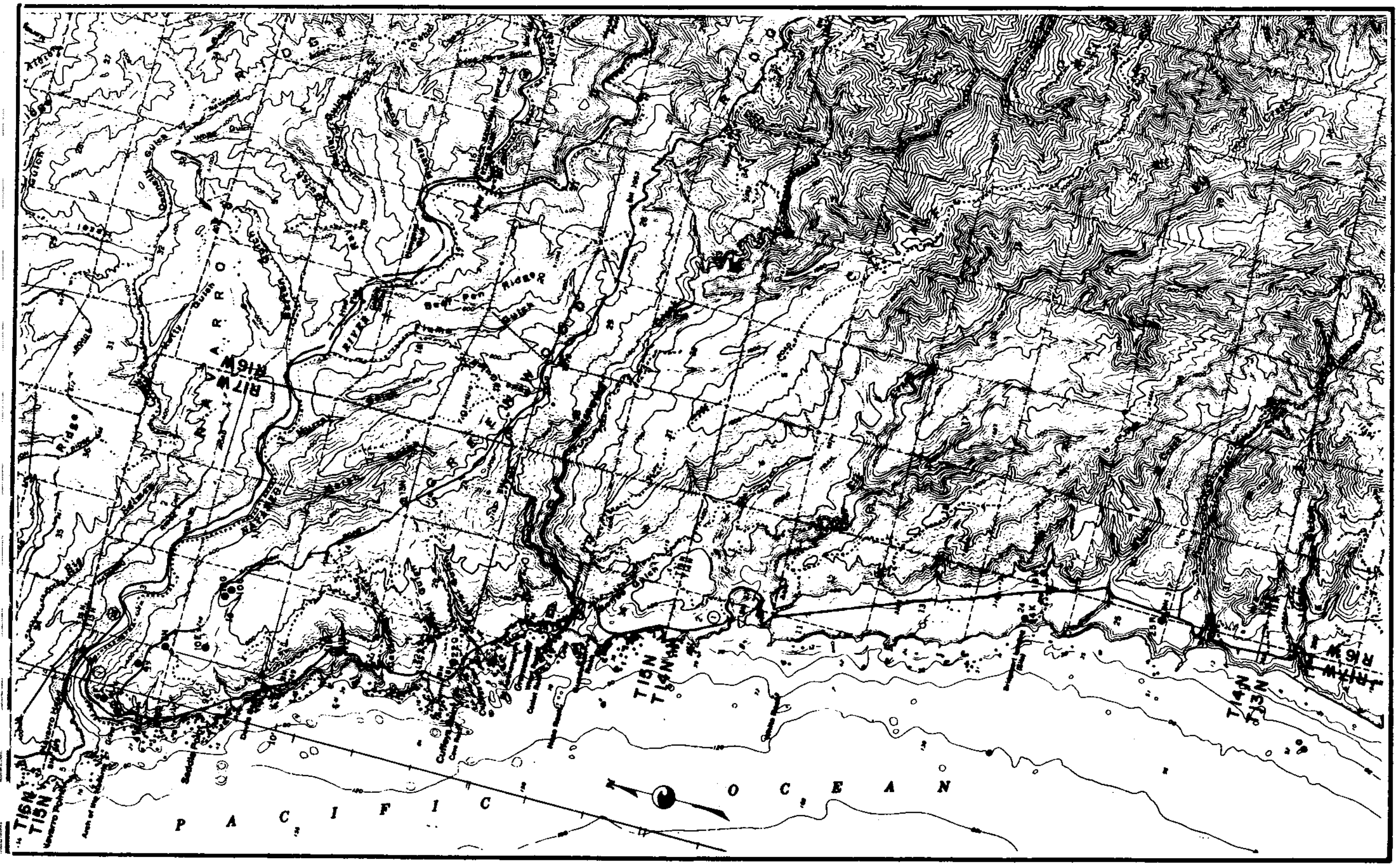
MENDOCINO COUNTY COASTAL GROUND WATER STUDY

ELK SUBUNIT

AREAL GEOLOGY

JUNE 1982

FIGURE 18

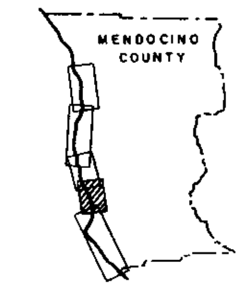


KEY TO WELL NUMBERING SYSTEM

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

T18N 36 31
T17N
R18W R17W

WELLS SHOWN ARE NUMBERED BY TOWNSHIP, RANGE AND SUBDIVISION OF SECTION, e.g., T18N / R17W – 31F



Location Map

LEGEND

4F• WELLS WITH LOGS

15L• MEASURED WELLS WITH LOGS

SCALE

1:62500

Contour Interval = 80 feet

0 1 2 MILES

0 1 2 3 KILOMETRES

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NORTHERN DISTRICT

MENDOCINO COUNTY COASTAL GROUND WATER STUDY

ELK SUBUNIT

WELL LOCATIONS

JUNE 1982

Bedrock. Although the Coastal Belt Franciscan rocks are considered essentially non-water bearing (and a distant second to the marine terrace deposits as a ground water source) in the coastal study area, within the Elk subunit it is the principal water-yielding geologic unit. This is not due to a difference in the physical character of the Franciscan bedrock here, but rather to the relative thinness of the terrace deposits, their limited east-west lateral extent, and consequent lack of storage capacity.

In this subunit, wells drawing upon the bedrock for ground water are reported to yield 2 to 75 L/min (0.5 to 20 gpm) with most wells producing 7.5 to 23 L/min (2 to 6 gpm). The specific capacity of the bedrock wells is on the order of 0.62 to 1.24 L/min/m (0.05 to 0.10 gpm/ft). Composite wells, of which there were four, are reported to produce 11, 15, 30, and 51 L/min (3, 4, 8, and 15 gpm) with specific capacities on the order of 1.86 to 2.48 L/min/m (0.15 to 0.2 gpm/ft).

The depth of the water table below ground surface, according to well measurements, varies from 3 to 24 m (10 to 13 ft) and shows a 2.3 to 4-m (7.5-to 13-ft) decline from spring to fall. The storage capacity and seasonal change for the bedrock cannot be accurately estimated because of the rocks' varying physical character both laterally and with depth. A rough estimate of about 9 250 dam^3 (7,500 ac-ft) of spring storage capacity can be reached by assuming a uniform specific yield of 1 percent for the bedrock and a 37-m (120-ft) thickness of saturated rock underlying the 2 520 ha (6,230 ac) that comprise the subunit; a 4-m (13-ft) decline of the water table from spring to fall would equal an 11-percent reduction in storage.

Marine Terraces. Marine terrace deposits underlie about 1 150 ha (2,840 ac) of the Elk subunit to an average thickness of only 6 m (20 ft). They range from about 1 to 9 m (3 to 30 ft) in thickness.

Monthly well monitoring shows that the water table in the terrace deposits in spring is about 3 m (10 ft) below ground surface; fall water levels drop to about 5.5 m (18 ft) below ground surface. The specific yields estimated from the few well logs available range from 3 to 15 percent; average is 8 percent.

Using the above data, the spring storage capacity of the marine terrace deposits equals about 2 800 dam^3 (2,270 ac-ft); fall storage is calculated to decline by 80 percent to only 570 dam^3 (454 ac-ft). However, it should be noted that terrace deposits less than about 1.5 m (5 ft) thick probably do not store any usable ground water; deposits 1.5 to 5 m (5 to 16 ft) thick are likely to experience a 100-percent decline in storage or "dry up" by early fall. The marine terrace deposits at the northwesterly end of Greenwood Ridge and along Highway 1 north of Saddle Point are as much as 7.5 to 9 m (24 to 30 ft) thick and may experience a spring-to-fall change on the order of 40 percent.

Alluvium. Alluvial deposits of gravel, sand, and clay underlie about 110 and 154 ha (90 and 125 ac) to an estimated depth of about 30 m (100 ft) in the lower reaches of Greenwood and Elk Creeks, respectively. These two perennial streams represent good year-round sources of ground water. The Elk Municipal Water District (ELK MWD) uses the ground water in the Greenwood Creek alluvial aquifer to provide water for its residents. Water is pumped from a well next to the stream into a 150-kilolitre (40,000-gal) storage tank. The water is then distributed through the town by gravity flow.

The ground water storage of these two alluvial aquifers remains relatively constant throughout the year because of the continual recharge provided by the surface flows of the streams. Monthly measurements of the Elk MWD's well show a spring-to-fall water table fluctuation of only about 0.5 m (1.7 ft), a change in storage capacity of probably less than 8 percent.

Point Arena Subunit

The Point Arena subunit includes all terrace lands south of Mallo Pass Creek and north of the Gualala River and extends 1 to 6.5 km (0.6 to 4 mi) inland. Major streams include the Garcia and Gualala Rivers and Alder and Brush Creeks. Manchester, Point Arena, Anchor Bay, and Gualala are the principal towns within the subunit. The geology and well locations are shown in Figures 19 and 20.

Local Geology

Bedrock in the Point Arena subunit is divided into two units by the San Andreas fault. On the east side of the fault are graywacke sandstone and shale of the Coastal Belt Franciscan Complex. To the west are

FIGURE 19

LEGEND

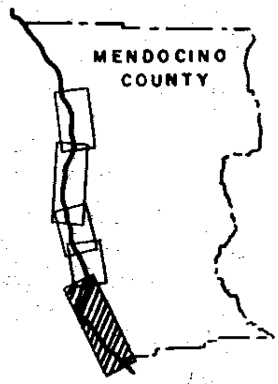
Era	Period	Symbol	Unit
CENOZOIC	Quaternary	Qs	Beach and dune deposits
		Qal	Alluvium
		Qt	Marine terrace deposits
	Tertiary	Ti	Iverson Basalt
		Tmm	Monterey Fm.
		Tmsg	Schooner Gulch and Galloway Fms.
		Tgr	German Rancho Fm.
		TKc	Coastal Belt Franciscan
MESOZOIC	Cretaceous	Kup	Gualala Fm.

Geologic contact; dashed where approximate, queried where questionable, dotted where concealed.

Fault; dashed where inferred, dotted where concealed.

Spring

A — A' Line of geologic cross section.



Location Map

SCALE

1:62500

Contour Interval = 80 feet

0 1 2 3 KILOMETRES

0 1 2 MILES

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN DISTRICT

MENDOCINO COUNTY COASTAL GROUND WATER STUDY

POINT ARENA SUBUNIT

AREAL GEOLOGY

JUNE 1982

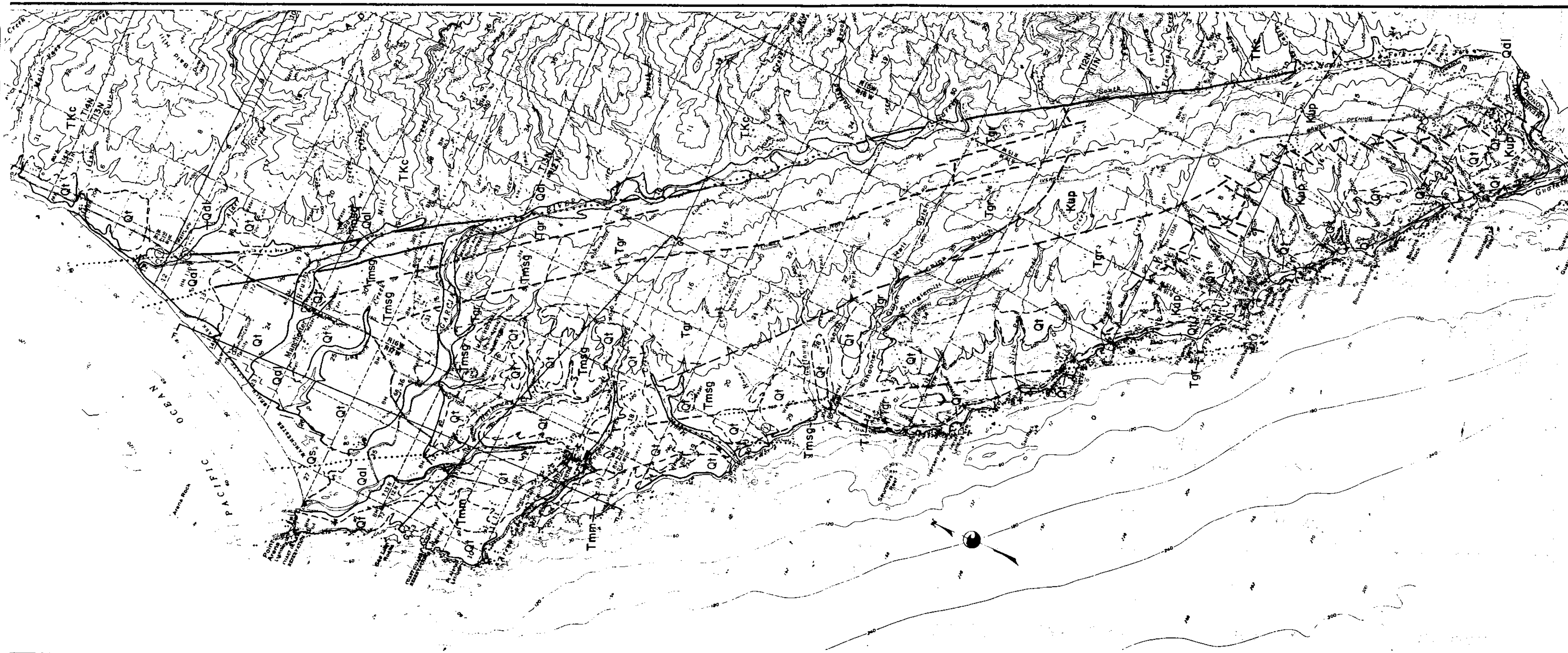
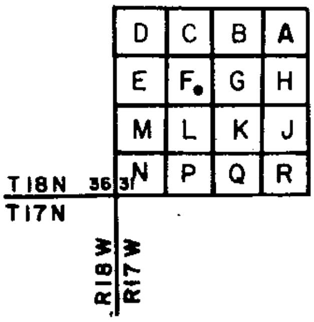
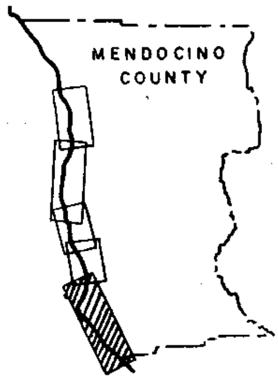

PACIFIC
OCEAN
TKc
Tgr
Tmsg
Tmm
Kup
Qt
Qal
Qs

FIGURE 20

KEY TO WELL NUMBERING SYSTEM



WELLS SHOWN ARE NUMBERED BY TOWNSHIP, RANGE AND SUBDIVISION OF SECTION, e.g., T18N / R17W — 31F



Location Map

LEGEND

7N● WELLS WITH LOGS

5D⊕ MEASURED WELLS WITH LOGS

SCALE

1:62500

Contour Interval = 80 feet

0 1 2 MILES

0 1 2 3 KILOMETRES

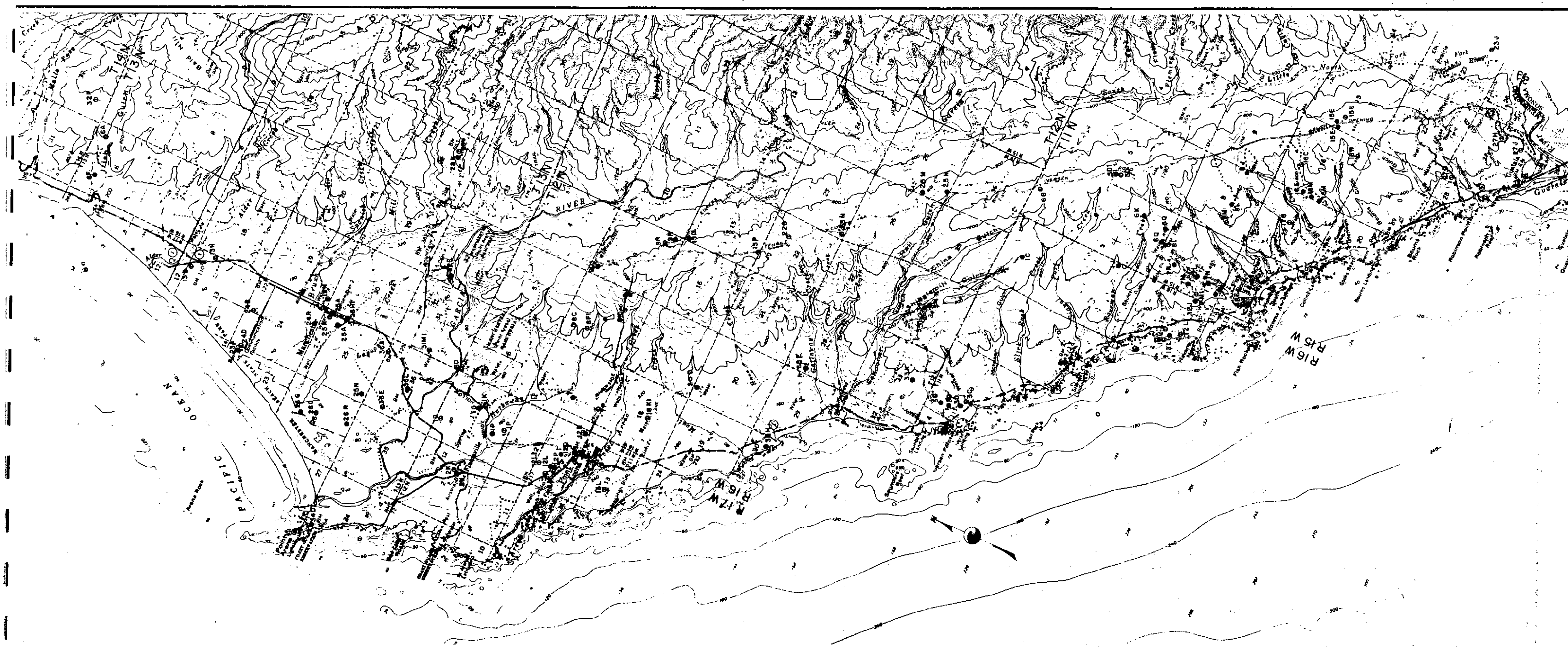
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN DISTRICT

MENDOCINO COUNTY COASTAL GROUND WATER STUDY

POINT ARENA SUBUNIT

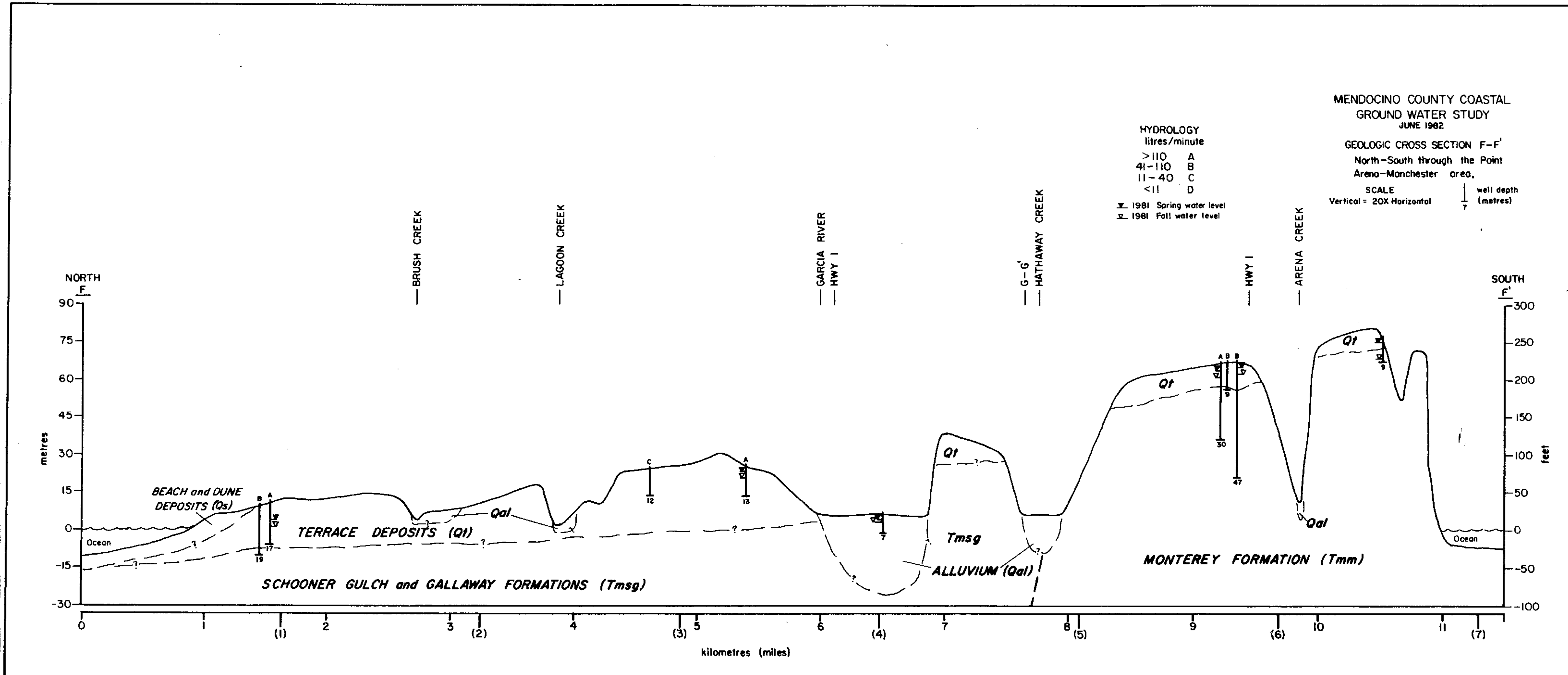
WELL LOCATIONS

JUNE 1982

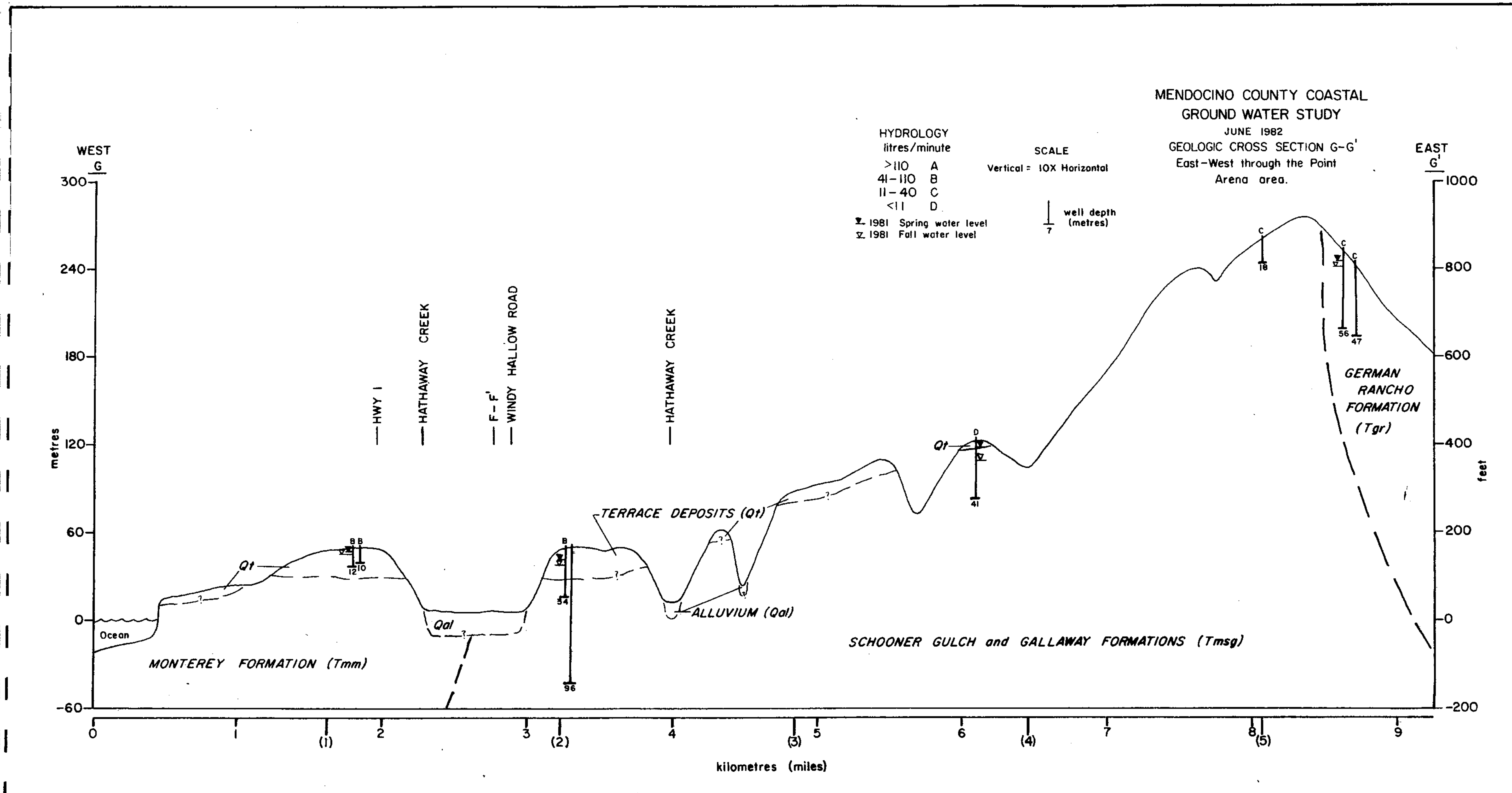


PACIFIC
OCEAN
RIVER
T12N
T11N
R16W
R15W
R17W
R16W

FIGURE 21



MENDOCINO COUNTY COASTAL GROUND WATER STUDY
JUNE 1982
GEOLOGIC CROSS SECTION F-F'
North-South through the Point Arena-Manchester area.
SCALE
Vertical = 20X Horizontal
well depth (metres)
HYDROLOGY
litres/minute
>110 A
41-110 B
11-40 C
<11 D
1981 Spring water level
1981 Fall water level
NORTH
F
SOUTH
F'
BRUSH CREEK
LAGOON CREEK
GARCIA RIVER
HWY 1
G-G'
HATHAWAY CREEK
HWY 1
ARENA CREEK
metres
feet
BEACH and DUNE DEPOSITS (Qs)
TERRACE DEPOSITS (Qt)
Qal
Qt
Tmsg
ALLUVIUM (Qal)
MONTEREY FORMATION (Tmm)
SCHOONER GULCH and GALLAWAY FORMATIONS (Tmsg)
Ocean
kilometres (miles)


MENDOCINO COUNTY COASTAL
GROUND WATER STUDY
JUNE 1982
GEOLOGIC CROSS SECTION G-G'
East-West through the Point
Arena area.
HYDROLOGY
litres/minute
>110 A
41-110 B
11-40 C
<11 D
1981 Spring water level
1981 Fall water level
SCALE
Vertical = 10X Horizontal
well depth
(metres)
WEST
G
EAST
G'
metres
feet
HWY 1
HATHAWAY CREEK
F-F'
WINDY HALLOW ROAD
HATHAWAY CREEK
TERRACE DEPOSITS (Qt)
Qt
Qal
ALLUVIUM (Qal)
Ocean
MONTEREY FORMATION (Tmm)
SCHOONER GULCH and GALLAWAY FORMATIONS (Tmsg)
GERMAN
RANCHO
FORMATION
(Tgr)
kilometres (miles)

marine formations of Cretaceous and Tertiary age and Tertiary volcanic rocks, collectively called the Gualala Block.

Quaternary marine terrace deposits unconformably overlie the bedrock on both sides of the San Andreas fault, extend 1 to 5 km (0.6 to 3 mi) inland, and range from 12 to 168 m (40 to 550 ft) in elevation. The deposits range from a few decimetres (about a foot) to 24 m (79 ft) in thickness with an average thickness of about 7 m (23 ft).

Significant alluvial deposits occur north of the town of Point Arena and west of the San Andreas fault, within the valleys of the Garcia River and Hathaway, Brush, and Alder Creeks. Adjacent to Alder Creek, some alluvial deposits have been uplifted as much as 12 m (40 ft) above the current stream channel level, the result of relatively recent movements within the San Andreas fault zone.

Beach and dune deposits underlie a 1 700-ha (690-ac) area along the coast between Irish Gulch and the Garcia River. These deposits overlie alluvial and marine terrace deposits and are believed to be about 15 m (50 ft) thick.

Occurrence of Ground Water

Data from 90 bedrock, 20 composite, and 17 terrace deposit wells were analyzed to evaluate the ground water properties and characteristics of the bedrock, marine terraces, and alluvial deposits of the Point Arena subunit. As can be seen from the greater number of bedrock wells, bedrock in the subunit is an important source of ground water.

Bedrock. Bedrock in the Point Arena subunit has been differentiated into the Coastal Belt Franciscan, Gualala, German Rancho, Iversen Basalt, Schooner Gulch and Galloway, and Monterey Formations. Bedrock wells are reported to produce between 0.4 and 190 L/min (0.1 to 50 gpm); the average well yield is 29 L/min (7.7 gpm) and the mean specific capacity is about 1.4 L/min/m (0.11 gpm/ft). However, analysis of the well data shows that yields and specific capacities vary significantly from formation to formation and even from place to place within a single formation. A summary of the available well data, by formation, is presented in Table 6.

Wells in the Gualala Formation yield from 1.3 to 190 L/min (0.3 to 50 gpm) with most wells producing between 11 and 45 L/min (3 and 12 gpm).

TABLE 6

SUMMARY OF WELL DATA [1/]

Formation	Yield: Average	Yield: Range	Drawdown: Average	Drawdown: Range	Mean Specific Capacity L/min/m (gpm/ft)	Percent of Wells Yielding 38 L/min (10 gpm) or More
Gualala	49 L/min (13 gpm)	1.3 to 190 L/min (0.33 to 50 gpm)	17.4 m (57.2 ft)	0.3 to 46 m (1 to 150 ft)	2.8 (0.23)	34
German Rancho	16 L/min (4.2 gpm)	0.4 to 150 L/min (0.1 to 40 gpm)	23.4 m (77 ft)	1.5 to 52 m (5 to 170 ft)	0.7 (0.06)	6
Schooner Gulch and Gallaway	36 L/min (9.5 gpm)	5.7 to 95 L/min (1.5 to 25 gpm)	17.4 m (57 ft)	1.5 to 33 m (5 to 108 ft)	2.1 (0.17)	33
Monterey [2/]	63 L/min (16.6 gpm)	2.5 to 114 L/min (0.66 to 30 gpm)	11.7 m (38.5 ft)	6 to 26 m (20 to 85 ft)	4.2 (0.34)	75
Coastal Belt Franciscan	68 L/min (18 gpm)	11 to 136 L/min (3 to 36 gpm)	21 m (68.3 ft)	12 to 27 m (40 go 90 ft)	3.3 (0.265)	50 [3/]
Iversen Basalt			NO DATA			
Marine Terrace	100 L/min (26.5 gpm)	7.6 to 284 L/min (2 to 75 gpm)	5.8 m (19 ft)	0.3 to 10.7 m (1 to 35 ft)	18.1 (1.46)	61

1/ From information in "Water Well Drillers' Reports"

2/ Based on data from 2 bedrock wells and 7 composite wells

3/ Based on limited data from 4 wells

Five wells reported to yield 76 L/min (20 gpm) or more were found to correlate with proximity to the complex fault system that, in part, forms the contact with the German Rancho Formation. The specific capacities of these wells range from 25 to 250 L/min/m (2 to 20 gpm/ft) and when compared to the mean specific capacity of 2.8 L/min/m (0.23 gpm/ft) for all bedrock wells, it indicates greater porosity and permeability in and near the faulted zone.

The German Rancho Formation, which underlies 36 percent of the subunit west of the San Andreas fault, has yields ranging from 0.4 to 150 L/min (0.1 to 40 gpm). Most wells produce between 2 and 23 L/min (0.5 and 6 gpm). Like the Gualala Formation, the high yield-high specific capacity wells of the German Rancho Formation are associated with the faulted contact zone between the two formations.

The Schooner Gulch and Galloway Formations underlie about 26 percent of the subunit west of the San Andreas fault. Bedrock and composite wells drawing from these formations usually yield between 7.5 and 38 L/min (2 and 10 gpm). Extremes range from dry holes to 150 L/min (40 gpm) or more.

The Monterey Formation underlies almost 1 620 ha (4,000 ac). Most of it is mantled by marine terrace and alluvial deposits, which are the primary water-bearing formations for this portion of the Point Arena subunit. Only nine wells were identified from well logs as penetrating the Monterey Formation more than a metre or two. Yields from these wells range from 2.5 to 114 L/min (0.66 to 30 gpm). The mean specific capacity of these wells is 4.2 L/min/m (0.34 gpm/ft).

The Coastal Belt Franciscan rocks, east of the San Andreas fault, have few wells and are therefore lacking a good data base for either bedrock or terrace deposit wells. The meager data indicate that bedrock wells produce adequate volumes of water and exhibit moderate specific capacities. Comparing well data for the Coastal Belt Franciscan rocks in the Point Arena subunit with bedrock well data from the four northerly subunits, average yields are about three times greater and specific capacities almost four times greater for the Point Arena subunit. This apparent disparity is probably due to the absence of an adequate data base for bedrock wells in the Coastal Belt Franciscan rocks within the Point Arena subunit.

The Iversen Basalt is a long, narrow body of volcanic rock, exposed from Iversen Point north to Galloway Creek. Because of its very localized and limited areal extent and a total lack of well drillers' reports of wells into or adjacent to the unit, the Iversen Basalt will be excluded from ground water storage and reservoir estimates.

Marine Terraces. The marine terrace deposits of the Point Arena subunit underlie an area of 3 650 ha (9,020 ac), with nearly two-thirds of this occurring within the northern third of the subunit. The importance of the terrace deposits as a ground water source and reservoir diminishes southward, as the areal continuity of the deposits decreases, and eastward, as the thickness of the terrace deposits generally decrease with increases in elevation. Therefore, the marine terrace deposits north of Galloway Creek, below about 106 m (350 ft) in elevation, can be considered to have good potential as a ground water reservoir. Conversely, deposits south of Galloway Creek and those above 106 m (350 ft) in elevation have a very limited potential due to their generally small areal extent and/or thinness-- generally less than about 3.7 m (12 ft).

Estimated specific yield of the marine terrace deposits in the Point Arena subunit range from 5 to 22 percent with an average of 11.5 percent. Monthly well monitoring data show that the average depth of the water table below ground surface is about 2.7 m (8.8 ft) in the spring, and 5.2 m (17.2 ft) by fall. By assuming that the average thickness of terrace deposits in the subunit is only 7 m (23 ft) for the 3 650 ha (9,020 ac) underlain by the deposits, and using the average values above, the spring storage volume of ground water in the terrace deposits equals 18 550 dam^3 (15,040 ac-ft); by fall, this volume is calculated to decrease by 68 percent to 5 940 dam^3 (4,800 ac-ft). However, as stated above, the deposits south of Galloway Creek and above 106-m (350-ft) elevation have little ground water reservoir potential and thus the above calculations are misleading.

A more realistic estimate of the reservoir capacity and spring-to-fall change in storage can be gotten by discounting those deposits with little ground water potential. What is left is 2 400 ha (5,930 ac). By assuming an average thickness of 12 m (39 ft) for these deposits (well logs verify this), and using the previous figures for ground water elevations and specific yield, spring storage equals about 22 700 dam^3 (18,400 ac-ft), and by fall, storage declines to 14 300 dam^3 (11,600 ac-ft), a 37-percent change.

It should be noted that although the deposits south of Galloway Creek and above 106 m (305 ft) elevation were not included in the calculation of the above estimate, these deposits do represent an ephemeral ground water source. Furthermore, the transitory nature of ground water in these deposits is borne out by the fact that no wells are reported to be completed wholly within these terrace deposits.

Alluvium. Alluvial materials underlie about 1 550 ha (3,830 ac) of bottom land, mostly north of the town of Point Arena, to an estimated average depth of 14 m (46 ft). By assuming an average saturated thickness of 9 m (30 ft), a specific yield of 12 percent, and 0.6 m (2 ft) spring-to-fall decline of water table, these alluvial deposits represent a ground water storage reservoir with a 17 000-dam^3 (13,780-ac-ft) capacity. Because of the continual recharge from the surface flow of the perennial streams, a spring-to-fall change in storage probably would not exceed about 8 percent.

SEAWATER INTRUSION AND WATER QUALITY

While seawater intrusion is not a common problem in the study area, the potential for such intrusion must not be ignored. Coastal aquifers come in contact with the ocean at or seaward of the coastline and normally discharge fresh ground water into the ocean. With increased demands for ground water, however, the seaward flow of ground water may be decreased or even reversed, causing seawater to enter the coastal aquifers. If the salt water travels inland, the aquifers become contaminated with salt and may take years to remove even with adequate fresh ground water available to flush out the saline water.

Most marine terrace deposits lie well above sea level and are not susceptible to seawater intrusion. Alluvial and bedrock aquifers, and the terrace aquifers between Tenmile River and Laguna Point and Alder Creek and Point Arena are in contact with the ocean and are susceptible. Where seawater intrusion occurs, it is generally a localized condition.

Two wells in the Point Arena subunit, 13N/17W-34D1 and 11N/16W-4H2 (see Figure 20), appear to be experiencing seawater intrusion. Water samples from these wells, collected in May and August 1980 and analyzed by the U. S. Geological Survey, show moderate to high electrical conductivity (523 and 7 100 microsiemens per litre) and chloride contents of 120 and 3 000 milligrams per litre, respectively. Both wells are drilled below sea level and are in close proximity to the ocean (90 to 120 m [300 to 400 ft]). A well near Mendocino, 17N/17W-30B2 (see Figure 9), is (from interpretation of continuous water level recorder data) hydraulically connected to the ocean via the fractures and fissures in the bedrock. This indicates that there is the potential to induce seawater intrusion here by heavy and continued pumping from this and other deep bedrock wells in the area.

The occurrence of high reduced iron or sulfur content in well water is common in the study area. The process of iron or sulfur reduction, in general, requires the presence of bacteria and organic matter (Hem, 1970).

The occurrence of 1.0 to 10 mg/L of iron in the ground water is common. This type of water is clear when first drawn from the well, but soon becomes cloudy and then brown from precipitating ferric hydroxide (Hem, 1970). The recommended maximum concentration of iron is 0.30 mg/L (California Water Resources Control Board, 1963). Chemical analyses data of well water, provided by the Mendocino County Division of Environmental Health, show iron concentrations as high as 20 to 40 mg/L in some wells. High iron content occurs in water from deep bedrock wells as well as from shallow terrace deposit wells and appears to be erratically distributed around the study area.

Reduced sulfur, in the form of hydrogen sulfide (H_2S), has the distinctive rotten egg odor and can be detected in water containing only a few tenths of a milligram per litre (Hem, 1970). The presence of H_2S in some wells from the Fort Bragg area to the Point Arena area has been reported by coastal residents (personal communications). The problem is an isolated one and not as widespread as the occurrence of iron. Presence of H_2S is not routinely checked in water quality analyses, and no recommended maximum concentration for domestic water has been established.

Domestic water with high concentrations of ferrous iron or sulfide requires aeration and sedimentation to render it palatable.

APPENDIX A

Definitions

Acre-foot (ac-ft) - equivalent to the volume of water which will cover one acre of land to the depth of one foot. An acre-foot of water equals 325,851 gallons.

Aquifer - a geologic formation that stores, transmits, and yields significant quantities of water to wells and springs.

Basalt - a fine-grained, dark-colored volcanic rock.

Conglomerate - a consolidated sedimentary rock composed of rounded pebbles and cobbles contained in a matrix of finer material.

Cubic Dekametre (dam^3) - 1 000 m^3; a dam^3 of water equals about four-fifths of an ac-ft or 264,167 gallons

Formation - a fairly widespread group of rocks having characteristics or origin, age, and composition sufficiently distinctive to differentiate the group from other units.

Ground Water - subsurface water occurring in the zone of saturation and moving under control of the water table slope.

Hydraulic Gradient - slope of the water table.

Hydrology - the origin, distribution, and circulation of water through precipitation, streamflow, infiltration, ground water storage, and evaporation.

Joint - a fracture or parting in a rock mass along which no appreciable movement has occurred.

Lithology - a term applied to rocks, referring to their general characteristics such as composition and texture.

Mafic Minerals - a general term used to describe rock-forming silicate minerals which contain essential iron and/or magnesium.

Metamorphism - the processes by which changes are brought about in rocks by the agencies of heat, pressure, and chemically active fluids.

Permeability - the capability of soil or other geologic formation to transmit water.

Porosity - voids or open spaces in alluvium and rocks that can be filled with water.

Recharge - flow to ground water storage from precipitation, infiltration from streams, irrigation, spreading basins, and other sources of water.

Salt Water Intrusion - the movement of salt water into fresh water aquifers.

Shale - a stratified rock, finely bedded or laminated, and formed by the consolidation of clay, mud, or silt.

Specific Capacity - the volume of water pumped from a well in gallons per minute per foot of drawdown.

Tracefossil - sedimentary structures resulting from biological activity.

Tuff - a general name for consolidated volcanic ash.

Vadose Water - water which occurs between the ground surface and the water table.

Vesicular - containing many small openings (vesicles).

Water Table - the surface where ground water is encountered in a well in an unconfined aquifer.

Weathering - the process by which rocks are broken down and decomposed by the actions of external agencies such as wind, rain, temperature changes, and plants.

Zone of Saturation - the area below the water table in which the soil is completely saturated with ground water

APPENDIX B

COUNTY OF MENDOCINO

DIVISION OF ENVIRONMENTAL HEALTH

LAND DIVISION REQUIREMENTS

CONTACT THE OFFICE OF ENVIRONMENTAL
HEALTH FOR MOST RECENT REVISION OF
THE LAND DIVISION REQUIREMENTS

APPENDIX C

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