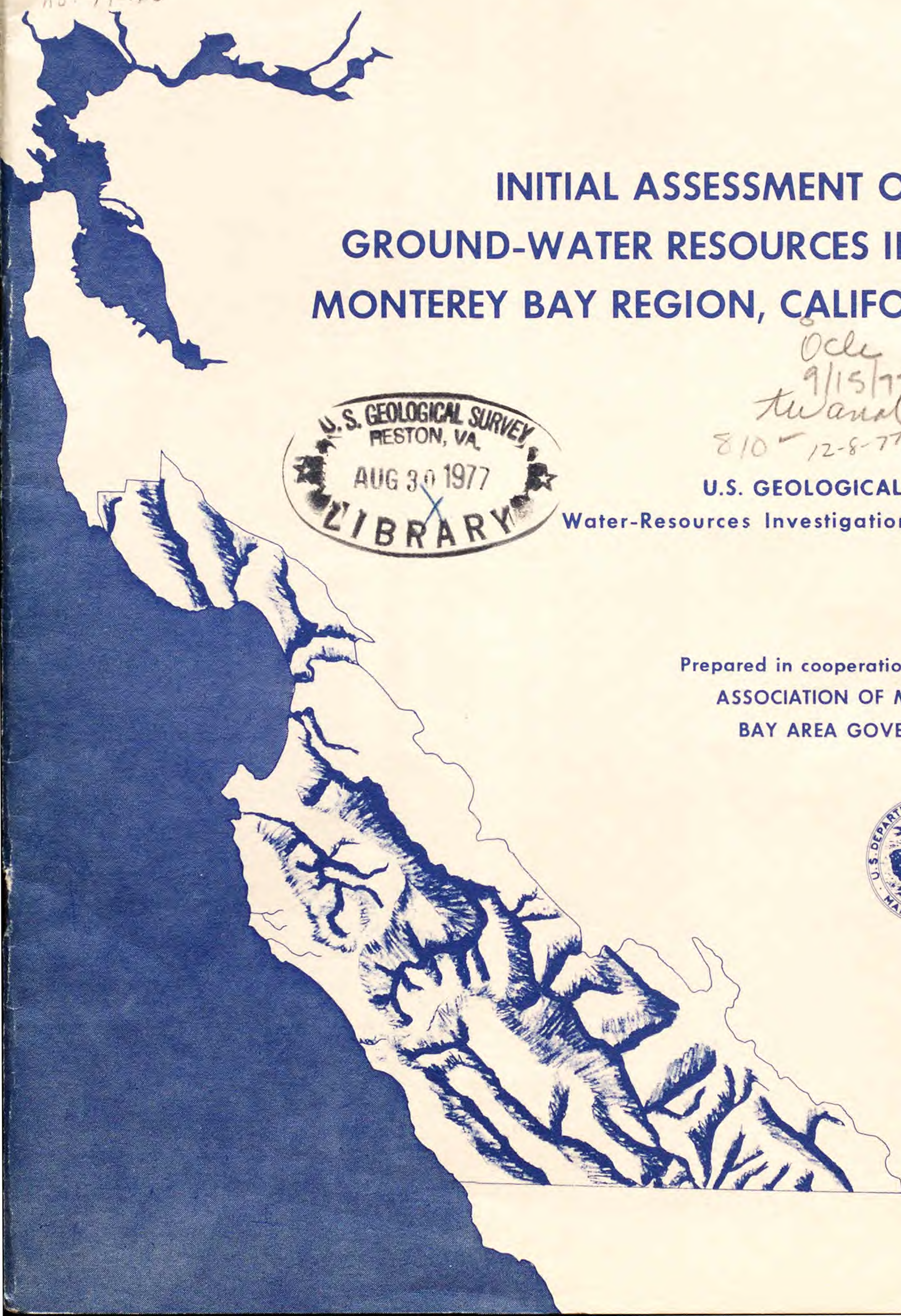

INITIAL ASSESSMENT OF THE GROUND-WATER RESOURCES IN THE MONTEREY BAY REGION, CALIFORNIA

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 77-46

Prepared in cooperation with the
ASSOCIATION OF MONTEREY
BAY AREA GOVERNMENTS

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16. Abstracts

Because urban growth has placed an increasing demand on the ground-water resources of the Monterey Bay region, an assessment of the ground-water conditions was made to aid the development of local and regional plans. Ground water provides 80 percent of the water used in the region, which includes six ground-water subbasins. In several of the subbasins, pumpage exceeds safe yield. Existing water-quality degradation results from seawater intrusion, septic-tank effluent, and irrigation-return water. Potential sources of degradation include municipal sewage disposal, leachates from solid-waste disposal sites, and poor-quality connate water. High-priority items for future study include location of recharge areas, detection of seawater intrusion, and well-monitoring of landfill sites.

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4024-04

August 1977

UNITED STATES DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS

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

English	*Multiply by*	*Metric*
ft (feet)	3.048×10^{-1}	m (meters)
ft^3/s (cubic feet per second)	2.832×10^{-2}	m^3/s (cubic meters per second)
mi (miles)	1.609	km (kilometers)
mi^2 (square miles)	2.590	km^2 (square kilometers)

INITIAL ASSESSMENT OF THE GROUND-WATER RESOURCES IN THE MONTEREY BAY REGION, CALIFORNIA

By K. S. Muir

SUMMARY AND RECOMMENDATIONS

Ground water is the principal source of water supply in the Monterey Bay region, providing more than 80 percent of the water used, with local surface water providing the remainder. No water is imported.

Six ground-water subbasins have been delineated in the region. All of them have felt the pressures of urban growth. These pressures have placed an increasing burden on the water resources--especially on the ground-water resources. The development of ground water has been on a localized basis, with little or no overall planning involved. It is now obvious to those responsible for water-resource planning that the time has come to take a careful look at the resource with respect to subbasin and regional planning--to explore its availability, limits, characteristics, and existing and potential sources of degradation.

This report presents the results of an initial assessment of ground-water conditions in the Monterey Bay region and is the first step toward the development of subbasin and regional plans. It fulfills the requirements of the initial (phase I) ground-water assessment of the Association of Monterey Bay Area Government's 208 program. The available hydrologic data were evaluated to determine current knowledge of the quantity and quality of the ground-water resources. The results of this evaluation are summarized in table 1.

Water-quality problems, both existing and potential, were assessed. These findings are summarized in table 2. Finally, recommendations were made for studies and programs that, when implemented and completed, would help the planner provide for management of the ground-water resource of each of the six ground-water subbasins in the Monterey Bay region. These recommendations, together with priority evaluations, are summarized in table 3.

TABLE 1.--*Status of hydrologic knowledge*

[A, considerable knowledge; B, some knowledge; C, little knowledge; D, no knowledge]

Elements of the ground-water system	Degree of knowledge of subbasin					
	Santa Cruz Coastal	San Lorenzo	Aptos-Soquel	Pajaro	Salinas	Carmel
Geologic units and their water-bearing properties	C	C	C	B	B	C
Source of ground water	B	B	B	B	B	B
Occurrence of ground water[1]	C	C	B	B	B	C
Movement of ground water	C	B	B	B	B	B
Recharge areas	C	B	B	B	B	C
Amount of recharge	D	D	D	D	B	C
Discharge areas	C	C	B	B	B	B
Amount of discharge	D	D	D	B	B	B
Water-level fluctuations	C	C	C	B	A	B
Storage quantity	D	D	D	C	B	B
Storage fluctuations	D	D	D	C	B	B
Yield of subbasin	D	D	D	B	B	B
Quality of water	C	C	B	A	A	B

[1]The geologic units that contain ground water

TABLE 2.--*Status of ground-water quality degradation*

[E, existing degradation; P, potential degradation; N, no foreseeable degradation; I, insufficient data to evaluate]

Elements of ground-water degradation	Degree of degradation in subbasin					
	Santa Cruz Coastal	San Lorenzo	Aptos-Soquel	Pajaro	Salinas	Carmel
Seawater intrusion	P,I	P,I	P,I	E	E	E
Septic-tank effluent	P,I	P,I	E,I	E	E	P,I
Solid-waste leachates	E	P,I	N	P,I	P,I	N
Industrial and agricultural waste discharges	N	N	N	P,I	P,I	N
Municipal sewage disposal	N	P,I	N	P,I	P,I	N
Abandoned wells						
Oil	N	E,I	N	N	N	N
Water	P,I	N	P,I	E	E	N
Irrigation-return water	P,I	N	N	E	E	P,I
Poor-quality connate water	P,I	E	P,I	P,I	P,I	P,I

TABLE 3.--*Study recommendations and priorities*

[A, reconnaissance investigation; B, areal investigation; C, quantitative investigation; 1, first priority; 2, second priority. No designation is given if the item is not applicable or a study is already in progress]

Items for study or implementation	Type and priority of study in subbasin					
	Santa Cruz Coastal	San Lorenzo	Aptos-Soquel	Pajaro	Salinas	Carmel
Assessment of ground-water resource						
Location of recharge areas	A1	A1	A1	A1	A1	A1
Seawater-intrusion detection	A1	--	A1	--	--	A1
Ground-water potential of geologic formations	A2	A1	A1	--	--	A1
Landfill site ground-water quality	A1	A1	--	A1	A1	--
Ground-water quantity and quality appraisal	--	B1,C2	B1,C2	C2	B1	C2
Septic-tank effluent ground-water evaluation	--	A2	A2	--	A1	A2
Nitrate-contamination evaluation	--	--	--	--	B1	--
Connate-water contamination near Bear Creek	--	B1	--	--	--	--
Scotts Valley-Kaiser Pit sewage-disposal evaluation	--	B1	--	--	--	--
Monitoring of ground-water resource						
Seawater-intrusion monitoring	1	--	1	--	--	1
Landfill site well-monitoring network	1	1	--	1	1	--
Subbasin-wide water-level and quality monitoring	2	--	2	--	--	--

INTRODUCTION

The Association of Monterey Bay Area Governments (AMBAG) has been designated as the areawide waste-treatment-management planning agency for the Monterey Bay region under Sec. 208 of the Federal Water Pollution Control Act Amendments of 1972 (Public Law 92-500). Sec. 208 establishes the authority and responsibility of the designated local agency to investigate water-quality problems and plan solutions to them.

In developing a waste-management program all aspects of water resources must be evaluated. AMBAG's 208 work plan established an initial problem assessment phase designed to serve as the basis for subsequent 208 program tasks. AMBAG requested that the U.S. Geological Survey make that portion of the initial assessment that was concerned with ground water. This report presents the findings of the assessment.

Purpose and Scope

The purpose of this investigation and report is to assess the ground-water resource in the AMBAG planning area, in order to identify existing and potential problems that should be considered in developing a waste-treatment-management program.

The ground-water hydrology and quality in the area are described to the extent possible from existing data and literature; deficiencies in existing knowledge are pointed out; and studies and monitoring programs are recommended where ground-water information is insufficient for planning purposes.

Ground-Water Planning

Ground water is the principal source of water in the Monterey Bay region, accounting for more than 80 percent of the total water use because it is a dependable supply. The development of this resource has been on a more or less localized basis, with no real concern for overall regional management. A few years ago, when there was sufficient water for all, this lack of concern for management was of little apparent consequence. In recent years, the situation has changed. Increases in population and changes in land and farming practices have resulted in increases in ground-water pumping. Pumping has increased in several areas to exceed "safe yield."[1] This has caused undesirable effects, such as seawater intrusion in the Pajaro and Salinas River areas, and has created other problems that are discussed later in this report. The increasing use and consequent problems have made it obvious that planning and management of ground-water use in the region are necessary.

In past years, water-resources planning was devoted largely to development of supplies to meet quantitative demands. The main concerns were determining: (1) Where there was ground water and (2) how much there was. Ground-water quality was a secondary consideration. Increasing attention is now being devoted to the quality of water and its management. It is now generally recognized that both aspects of water resources, quantity and quality, are important and interdependent.

Added stresses placed on ground-water basins, or reservoirs as they are sometimes called, can make protection of ground-water quality difficult. A contaminated surface-water reservoir may be restored to acceptable standards of quality in a few years or less; parts of a ground-water reservoir may be rendered useless for many years, or forever, if contaminants or pollutants get into the system.

Chemical, physical, and biological characteristics of ground water are all important considerations in ground-water quality planning and management. These characteristics determine the usefulness of the water. Maintenance of ground-water quality at acceptable levels is one of the major requirements of successful management of ground-water reservoirs.

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[1]The "safe yield" of an area in the Monterey Bay region is defined as the rate at which water can be pumped from wells year after year without decreasing ground water in storage to the point where the pumping lift would become economically infeasible or where water of poor quality would begin to intrude the area. In this region, intrusion of water of poor quality will occur first.

Many agencies are concerned with ground-water quality in the Monterey Bay region. The Association of Monterey Bay Area Governments, the Monterey County Flood Control and Water Conservation District, the Santa Cruz County Flood Control and Water Conservation District, the California Department of Water Resources, the county health departments, the California Coastal Commission, the California Water Resources Control Board, the California Regional Water Quality Control Board, and the U.S. Environmental Protection Agency are some of the more active agencies. They have established water-quality objectives that they feel are necessary to protect the beneficial uses of surface and ground water (see Selected References). They are attempting to reach and maintain these objectives by placing restrictions and regulations on real estate developments, wastewater discharges, and other potential sources of water-quality degradation.

Ground-Water Investigations and Monitoring

Interpretation of ground-water quality data on a ground-water reservoir involves delineating areal variations in water quality and relating the quality distribution to ground-water flow patterns of the system. To do this the physical character of the ground-water reservoir must be known. One of the most important parts of any ground-water reservoir system that should be considered for protection is its recharge area. Land-use changes in the recharge area of a ground-water basin, such as result from urban growth, can have serious adverse effects on the rate of recharge and on the quality of the water being recharged. Contaminants or pollutants introduced in the recharge area of a ground-water reservoir may travel through the whole system.

Actions needed to acquire the knowledge for effective ground-water planning and management fall into two general categories: (1) Assessing the resource and (2) monitoring the resource. The needs of planners and managers determine the type of assessment or monitoring and how comprehensive it must be.

Basically, there are three levels of assessment investigations: (1) reconnaissance investigations, (2) areal investigations, and (3) quantitative investigations. Following is a brief description of each type.

1. A reconnaissance study evaluates the adequacy of existing geologic and hydrologic data and defines the general physical and chemical character of the ground-water system. The evaluation is used to develop a conceptual model of the ground-water system to describe water-supply or other water-management problems in terms of existing hydrologic knowledge, and to guide future studies and data collection. This initial assessment of the Monterey Bay region ground-water resources is considered a reconnaissance study.

2. Areal investigations can be made when sufficient well data are available in an area to describe the geologic framework and hydrology of the ground-water system adequately. Such investigations provide qualitative results that generally include delineating the ground-water reservoir and its subdivisions; determining the source, occurrence, and direction of movement of ground water within the reservoir; identifying areas of recharge and discharge; evaluating the relative importance of the various means of recharge and discharge; and describing the chemical quality of the ground water. During an areal investigation, some quantitative data may be collected, such as the amount of ground water pumped by wells and static water levels in wells.

3. In quantitative investigations, values are determined for the physical characteristics of the aquifer system, and for the many different elements of inflow and outflow to that system. Determining these values may be quite difficult and time consuming and may require extensive field procedures, such as making aquifer tests by pumping wells to determine aquifer transmissivities and storage coefficients. These data may be used as input to mathematical models designed to simulate ground-water conditions at any desired time. The models are stressed by applying variations in climate and changes in development and use of the ground-water resource. In modeling the ground-water system, complex mathematical equations are solved through use of high-speed digital computers. The development of ground-water quality models has lagged behind that of quantity models; however, some water quality predictive models are in use and have given reasonable results.

In addition to short-term studies as described above, long-term monitoring of ground-water resources through use of observation wells is needed. The aim of an observation-well network is to function as an early warning system to alert those responsible for managing and protecting the ground-water resources of an area to adverse changes in that resource. Two types of data should be collected--water levels and water quality. Static water levels in wells indicate the effects of stresses on the ground-water system. They also monitor the status of ground-water storage and whether it is increasing or decreasing. Ground-water quality data are needed to detect changes in the chemical and biological character of the ground water.

GROUND-WATER SUBBASINS

The subbasin designations used in this report are the same, for the most part, as those used by the California Water Resources Control Board (1974) for its Central Coastal basin hydrologic unit. Six of the State Board's Central Coastal subbasins fall within AMBAG's jurisdiction: Santa Cruz Coastal, San Lorenzo, Aptos-Soquel, Pajaro, Salinas, and Carmel (fig. 1). Of the Pajaro subbasin, the AMBAG planning area includes only the part in Santa Cruz and Monterey Counties, herein called the Pajaro Valley ground-water subarea. The source, movement, mode of occurrence, quantity available, and quality of ground water are quite varied among the different subbasins. This is also true of the ground-water problems in the several subbasins. Consequently, for planning purposes the ground-water resources in each subbasin should be considered separately.

How much is known about the ground-water resources of each of the six subbasins? How much should be known, and what types of investigations are required to find the answers needed? The following sections of this report will attempt to answer these questions.

Santa Cruz Coastal Subbasin

Location and general features.--The Santa Cruz Coastal subbasin includes a number of small coastal drainages approximately between the city of Santa Cruz and Pescadero Point (fig. 2). The subbasin is bounded on the north by the Butano Creek drainage basin and on the east by the drainage basin of the San Lorenzo River. The subbasin covers approximately 149 mi^2.

The headwaters of the creeks making up this subbasin are in steep, heavily forested mountains. Along the coast, the mountains are separated from sandy beaches by a sloping marine terrace with an average width of half a mile.

The area depends almost completely on ground water for its water supply. Most of the water is used for irrigation. Some surface water and springs are developed, but most water from these sources is exported to the city of Santa Cruz.

Ground-water hydrology.--Ground-water recharge in this subbasin is from precipitation that enters the aquifers through direct infiltration on the land surface and stream seepage. There is probably little or no subsurface inflow from adjacent subbasins. The recharge areas have not been delineated, and the amount of recharge is not known.

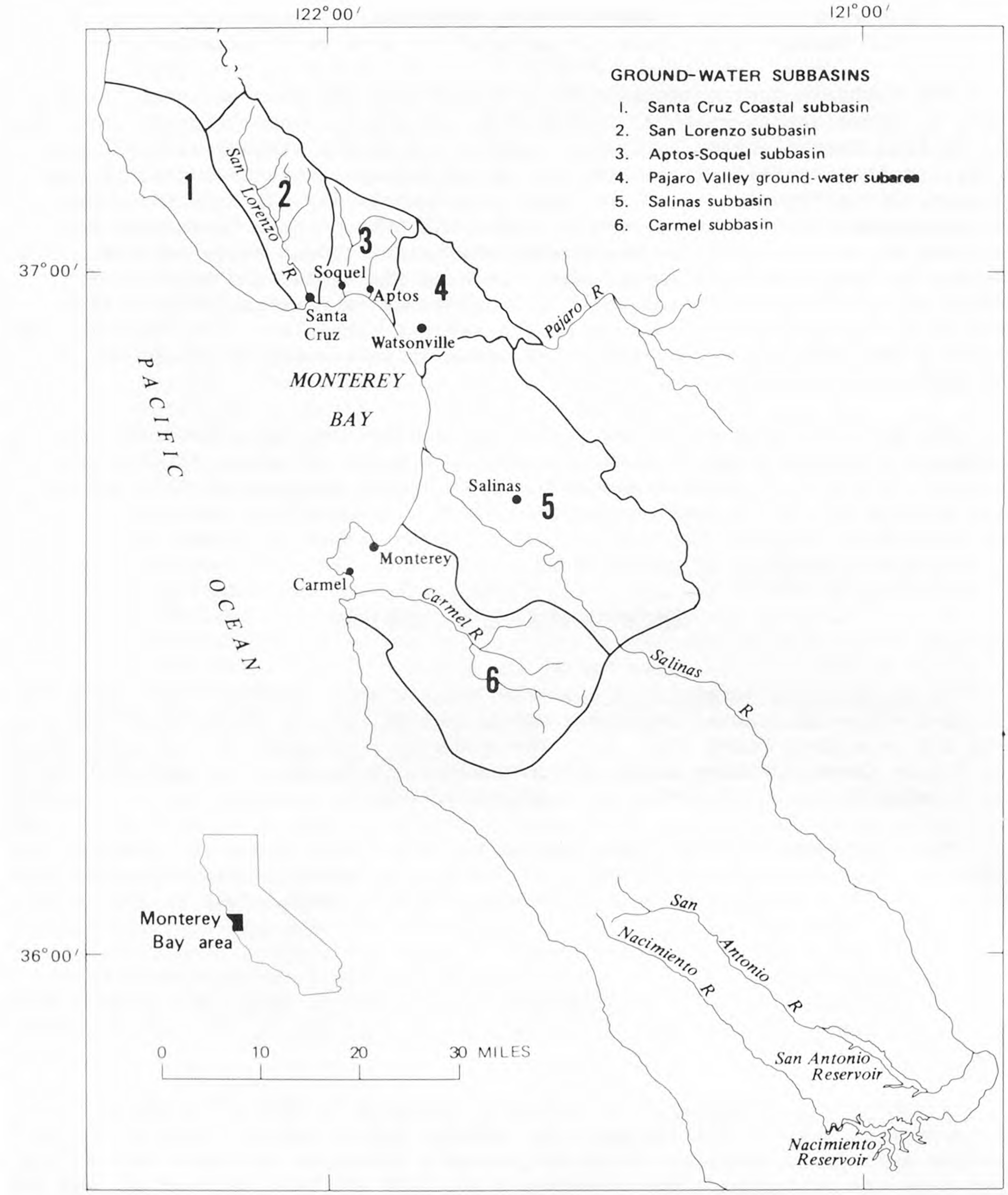

FIGURE 1.--Ground-water subbasins, Monterey Bay region.

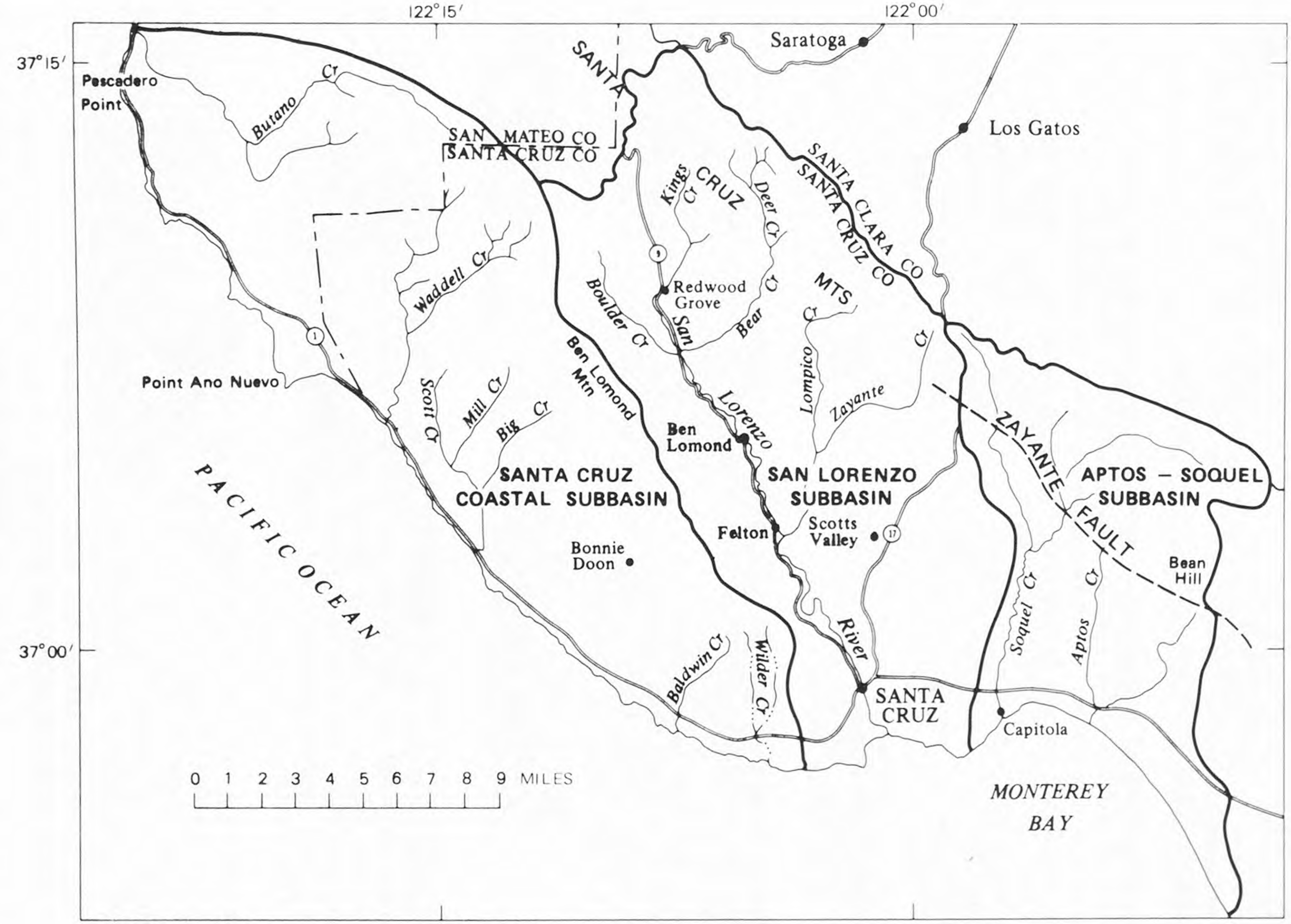

FIGURE 2.--Santa Cruz Coastal subbasin, San Lorenzo subbasin, and Aptos-Soquel subbasin.

Most of the ground water occurs in the alluvium along the major creeks that drain the area (most notably Scott and Waddell Creeks, fig. 2), in the marine terraces, and in the Miocene Santa Margarita Sandstone. Some ground water is found in the overlying Miocene Santa Cruz Mudstone of Clark (1966), in the metamorphic rocks (mostly marble) in the vicinity of Bonnie Doon, and in the quartz diorite on Ben Lomond Mountain (fig. 2).

The direction of ground-water movement is from the east toward the west. The amount of ground water pumped, the quantity in storage, and the subbasin safe yield are not known. A reconnaissance-level investigation of this area has been completed by the Geological Survey in cooperation with the Santa Cruz County Flood Control and Water Conservation District (Akers and Jackson, 1977). The study indicates potential for developing some additional ground-water supplies in this subbasin. As part of this study, a test-well drilling program has been proposed that is designed to improve knowledge of the ground-water potential. As of July 1977, one test well had been drilled.

Ground-water quality.--Little data exist on the quality of ground water in this subbasin. Available data indicate that the general ground-water quality is suitable for most uses.

Reports from residents in this subbasin indicate that there may be some local quality problems. Water pumped from some irrigation wells, located within about 1,000 ft of the ocean, is said to become "salty" toward the end of summer, and complaints have come from well owners in the vicinity of the Santa Cruz city dump that leachates have migrated from the dump area and polluted their ground water. There are no data available to prove or disprove either of these reported problems.

There are five known potential causes for adverse effects on ground-water quality in this subbasin: seawater intrusion, irrigation-return water, septic-tank system effluents, saline connate water, and leachates from disposal sites.

Seawater intrusion is a danger to all wells that are in the subbasin immediately adjacent to the coast and withdraw ground water from aquifers that lie below sea level. If pumping causes water levels to decline below sea level and reverses the present seaward ground-water hydraulic gradient, seawater could migrate landward and occupy parts of the aquifers that now contain freshwater.

Irrigation-return water is that part of the water applied to the land surface for irrigating crops that manages to percolate downward and return to ground water. Mineral concentrations are increased in the return water by evaporation and by applications of fertilizers. The return water also tends to increase the mineral content of the ground water by leaching minerals from the soil. In addition, pesticide residuals carried with the irrigation-return water could adversely affect the quality of ground water, especially if the water is being used for domestic purposes.

Septic-tank systems, which are used extensively in this subbasin, could be a source of pollutants, both chemical and biological, to wells in the vicinity of the septic tank drain fields.

Many of the geologic formations in this area are marine in origin. Consequently they contained seawater during, and for sometime after, their deposition. If this saline connate water is still present in the formations, it could migrate into parts of aquifers now being pumped.

Study recommendations.--Five items are recommended for investigation.

1. The ground-water recharge areas of this subbasin should be determined and delineated on a map.

2. Water levels should be measured and water samples collected for chemical and biological analyses from wells in the vicinity of the city of Santa Cruz landfill site, where solid and liquid wastes are disposed. This site is in the unnamed drainage that lies between Baldwin Creek and Wilder Creek (fig. 2). Additional observation wells may need to be drilled if existing wells are not adequate. Determination of frequency of data collection and detailed lists of chemical and biological parameters will require additional study. The data collected should indicate whether leachates are moving away from the immediate vicinity of the landfill and if they are entering the ground-water system.

3. A network of wells should be established along the coast to detect and monitor seawater intrusion. Water levels should be measured and the ground water analyzed for chloride concentration and specific conductance. Initially, all available wells along the coast with construction information should be measured and sampled for chloride and specific conductance. Based on the results of this first set of data, a well network can be established. Only a few wells in strategic locations may be needed to monitor this potential problem. Measurements should be made and chloride and specific conductance determined twice a year--in April and September. This sampling frequency would reflect the annual periods of highest (April) and lowest (September) water levels.

4. A network of wells should be established to monitor subbasin-wide water-level fluctuations and water quality. Only a few wells should be needed. This network would act as an early-warning system to indicate how the subbasin reacts to variations in quantity and quality of recharge and discharge. The water should be analyzed for major ions. At this time (1977) it would be necessary to measure and sample the wells only once a year (in the spring).

5. Exploration of the ground-water supply potential of the different aquifers, especially the Santa Margarita Sandstone, should continue. This will necessitate drilling test wells. Available hydrologic data are insufficient to make either a comprehensive areal or a quantitative study of the subbasin; but the necessary data may be obtained from additional test wells and from aquifer tests.

References.--Following are the principal references for the Santa Cruz Coastal subbasin (see "Selected References"): 3, 4, 5, 6, 8, 10, 14, 15, 16, 18, 32, 33, 35, 38, 40, 42, 46, 47, 48, 55, 69, 80.

San Lorenzo Subbasin

Location and general features.--The San Lorenzo subbasin covers approximately 140 mi^2, all within Santa Cruz County. The area extends from near the San Mateo-Santa Cruz County line south to Monterey Bay and is bounded on the west by Ben Lomond Mountain and on the east by the Santa Cruz Mountains (fig. 2).

The San Lorenzo River flows generally south-southeast in a narrow valley through the subbasin. Tributaries include Boulder Creek from the west and Kings, Bear, Lompico, and Zayante Creeks from the east. Most of the subbasin area is rugged mountainous terrain which is densely forested. Maximum altitude in the subbasin is approximately 3,200 ft.

Ground water is one of the important sources of water in this subbasin. Surface water and springs have also been developed for water supplies. Water uses are domestic, light industrial, and irrigation.

Ground-water hydrology.--Ground-water recharge in this subbasin is from precipitation that enters the aquifers through direct infiltration on the land surface and stream seepage. Subsurface inflow from adjacent subbasins is probably little or none. The recharge areas have not been delineated, and the amount of recharge is not known.

Ground water occurs in most of the sedimentary formations of Tertiary age (the best aquifers being the Miocene Lompico Sandstone of Clark (1966) and overlying Santa Margarita Sandstone) and in the granitic rocks of Cretaceous age and metamorphic rocks of pre-Cretaceous age. Some ground water is obtained from alluvium along the major streams. Well yields vary from small, enough for individual domestic supplies, to several hundred gallons per minute. Some wells drilled have been dry. This variability in well success is a reflection of the complex nature of the geology of the area.

The direction of ground-water movement in this area is controlled largely by topography and geologic structure. In general the water moves, under the influence of gravity, through fractures in rock or intergranular permeability in sandstone. Flow is from recharge areas at higher altitudes to the lower areas where ground water emerges as springs or seeps to become base flow to perennial streams. The amount of ground water pumped, the quantity in storage, and the subbasin safe yield are not known.

A reconnaissance-level investigation of this area has recently been completed by the Geological Survey in cooperation with the Santa Cruz County Flood Control and Water Conservation District (Akers and Jackson, 1977). The study indicates potential for developing some additional ground-water supplies in this subbasin.

Until recent years this area had a transient-type population. A large percentage of the houses and cabins in the area were occupied only during the summer months. Urban growth has changed this pattern. More people are moving into the area, and many are becoming permanent residents. Prior to urban growth, impact on the available ground and surface water was minimal, and few water-supply problems existed. Along with urban growth has come more demand on the limited water resources of the area, and local water shortages and water-quality problems have developed.

Ground-water quality.--Little data exist on the quality of ground water in this subbasin. The data that are available indicate local water-quality problems are related mainly to poor-quality formational water. This, along with low well yields from many of the geologic formations, will limit the use of ground water in this subbasin. Attempting to develop additional good-quality ground water will necessitate costly test-well drilling programs. The San Lorenzo Valley County Water District is attempting to find sources of good-quality ground water to supply expanding water needs. They have drilled several test wells in the vicinity of Ben Lomond (fig. 2) and have encountered poor-quality, nonpotable water.

Progressive quality degradation seems apparent in the ground water east-southeast of Redwood Grove (fig. 2) near Bear Creek and in the water of Bear Creek. The source of degradation is not definitely known, but it may be brines that are leaking upward from depth through improperly sealed, abandoned oil test wells in the area.

Septic tanks are the most commonly used means in this subbasin for the disposal of liquid domestic waste. The combination of shallow domestic wells and septic-tank systems on small home sites, such as found on the slopes of Ben Lomond Mountain, poses potential water-quality problems. Much of the area is not suitable for this type of disposal system because of thin soil cover and a shallow water table. Disposal system failures have been common, with unrenovated wastes leaking to the land surface.

A serious water-quality problem may be developing in Scotts Valley (fig. 2) where several hundred thousand gallons per day of primary sewage-plant effluent from the city of Scotts Valley has been discharged for several years into an abandoned Kaiser Co. sand pit. The pit is excavated in Santa Margarita Sandstone--the principal aquifer in the Scotts Valley area. The direction and rate of movement of the wastewater in the aquifer is not known. This sewage effluent could pollute the water resources, both ground water and surface water. The city of Scotts Valley had John Carollo Engineers (Carollo, 1975) briefly investigate the situation. They found that inadequate hydraulic and water-quality data were available to make a meaningful evaluation. Since that time the city of Scotts Valley has begun a well-monitoring program to collect some of the data recommended by Carollo Engineers. The city now measures water levels and collects water samples at about a dozen wells and springs monthly.

The waste-disposal landfill site near Ben Lomond poses another threat to ground-water quality in the San Lorenzo subbasin. The site has received sewage sludge and solid wastes in the past. Now, only solid wastes are deposited. The site is on the outcrop of the Santa Margarita Sandstone. If leachates are produced they could migrate down the hydraulic gradient and pollute domestic and municipal wells in their path. Water quality in creeks and the San Lorenzo River downgradient from the disposal site could be affected.

Seawater intrusion is a potential threat to ground-water quality in the south end of the subbasin, where the subbasin borders Monterey Bay. There are few wells in this area, and the amount of ground-water pumped is small. If ground-water development increases, and this in turn causes ground-water levels to decline below sea level, seawater intrusion would occur.

Study recommendations.--Seven items are recommended for investigation.

1. The ground-water recharge areas of this subbasin should be determined and delineated on a map.

2. Many of the geologic formations in this subbasin have potential for development as sources of additional ground-water supplies. These Miocene to Eocene formations include, from youngest to oldest, the Santa Margarita Sandstone, Lompico Sandstone, Lambert Shale, Vaqueros Sandstone, Zayante Sandstone, San Lorenzo Formation, and Butano Sandstone. A detailed evaluation of the quantity and quality of ground water in these formations should be made. Any investigation of this type would involve test-well drilling--probably six wells.

3. The relation between septic-tank systems and the amount and quality of their effluent that percolates to the aquifer should be studied.

4. The source and extent of the saline water in wells in the Bear Creek area should be determined. This contamination is in the recharge area of the subbasin and could become a more extensive problem. If the problem is related to improperly sealed oil test wells, recommendations should be made to locate and properly seal them.

5. Water levels should be measured and water samples collected for chemical and biological analyses from wells in the vicinity of the Ben Lomond landfill site. This site is in the ground-water recharge area of the subbasin, on the Santa Margarita Sandstone. Additional observation wells may be needed if existing wells are not adequate. Determination of frequency of data collection and detailed lists of chemical and biological constituents and properties will require additional study.

6. Studies should be made in Scotts Valley to define what is happening to the wastewater discharged into the Kaiser Co. sand pit. The purpose of the study would be to define wastewater movement in the aquifer and how it is affecting the quality of the ground water. Test holes may be needed to supplement the data now being collected by the city of Scotts Valley.

7. Consideration should be given to making an areal ground-water investigation of the Scotts Valley area. Scotts Valley is experiencing rapid urban growth. This, in turn, is placing an ever-increasing burden on the water resources of the area. The study should elaborate on the reconnaissance study that Akers made of the area (Akers, 1969). It should include such items as determining the extent and depth of the water-bearing formations, the amount of recharge to and discharge from the ground-water reservoir, and how the system is reacting to stresses of urban growth. The amount of ground water in storage, the safe ground-water yield of the valley, and ground-water quality should also be determined.

Possibly a numerical ground-water model of Scotts Valley should be developed. A model would require determination of the hydraulic parameters (transmissivity and storage coefficient) of the aquifer system. Aquifer tests would be necessary. The model would enable predictions to be made of the effects of hydraulic stresses on the aquifer system. A quality model could also be used to predict the movement of pollutants in the system.

References.--Following are the principal references for the San Lorenzo subbasin (see "Selected References"): 1, 3, 4, 5, 6, 8, 10, 14, 15, 16, 18, 19, 32, 33, 35, 36, 38, 40, 41, 42, 46, 47, 53, 55, 56, 69, 70, 80.

Aptos-Soquel Subbasin

Location and general features.--The Aptos-Soquel subbasin covers about 77 mi^2 and lies entirely within Santa Cruz County. It extends south from the Santa Cruz-Santa Clara County boundary to Monterey Bay. The subbasin lies between the San Lorenzo River subbasin on the west and the Pajaro Valley ground-water subarea on the east (fig. 1). Its western boundary coincides with the western boundary of the Soquel Creek drainage basin. The eastern boundary is formed by the drainage basin boundary between Corralitos Creek (not shown in fig. 2), which drains to the Pajaro Valley, and Aptos Creek.

The Aptos-Soquel subbasin contains rugged mountain terrain in the north that grades to rolling hills and well-developed marine terraces along the coast. The terraces are abruptly terminated along the coastline by high cliffs.

The area is almost completely dependent on ground water for its water supply. Water uses are domestic, irrigation, and light industrial.

Ground-water hydrology.--Ground-water recharge in this subbasin is from precipitation that enters the aquifers through direct infiltration on the land surface and stream seepage. Some ground water probably enters the subbasin by subsurface inflow from the San Lorenzo subbasin. The recharge areas have not been delineated, and the amount of recharge is not known.

The Zayante fault (fig. 2), which traverses the subbasin in a northwest direction about through Bean Hill, divides the subbasin into two parts. That part which lies north of the fault, about one-third of the subbasin, is underlain mainly by formations of early Tertiary age. Their water-bearing properties are not known. The Geological Survey, in cooperation with the Santa Cruz County Flood Control and Water Conservation District, has begun a study to assess the ground-water potential of this area. The remaining two-thirds of the subbasin, which lies south of the fault, is mostly underlain by the Purisima Formation of late Tertiary age. This formation is the principal aquifer in the subbasin, yielding most of the water pumped by wells.

Little data are available on the direction of movement of ground water in the subbasin. In the area north of the Zayante fault, ground-water movement is probably mostly southeast into the Pajaro Valley ground-water subarea, with some component of flow south through the fault zone. In the south two-thirds of the subbasin, the principal direction of ground-water flow is probably toward Monterey Bay, with some movement southeast into the Pajaro Valley ground-water subarea. The amount of ground water pumped, the quantity in storage, and the subbasin safe yield are not known.

Ground-water quality.--Most of the wells in this subbasin are in the area south of the Zayante fault. The available data indicate that the quality of water from these wells varies depending on well depth and location. In general, the water is classified as hard, but it seems to be acceptable for most uses. Locally, iron and manganese in the ground water are in high enough concentrations to be objectionable. No data are available on ground-water quality north of the Zayante fault.

Local residents have reported that water pumped from shallow wells in the alluvium of the various creeks in this subbasin is sometimes polluted by effluent from septic-tank systems. No data are available to support these reports.

Seawater intrusion into the aquifers in this subbasin is a potential problem. The aquifers extend out to, and under, Monterey Bay, and their seaward extensions undoubtedly contain saltwater. As long as there is a seaward flow of fresh water from the aquifer, the seawater-freshwater interface will lie offshore. Pumping of ground water onshore, however, could cause cessation and reversal of this freshwater flow, and seawater would then advance landward. No evaluation has been made of the present (1977) location of the interface.

Study recommendations.--Five items are recommended for investigation.

1. The ground-water recharge areas of this subbasin should be determined and delineated on a map.

2. The relation between shallow domestic wells and septic-tank systems should be investigated to determine the impact of septic-tank sytems on ground-water quality.

3. A quantitative ground-water investigation of the subbasin should be made. Initially, the study should update the work done by Hickey (1968) almost 10 years ago. Other phases of the study should include the determination of the amount of ground water in storage, safe yield of the basin, pumpage, and how the aquifer system responds to variations of inflow and outflow. The status of seawater intrusion and ground-water quality should also be studied. Possibly a numerical ground-water model of this subbasin may be developed which could be used as a predictive tool. This would require detailed investigations to more precisely define the hydrologic system and its boundaries.

4. A network of wells should be established to monitor subbasin-wide water-level fluctuations and water quality. Only a few wells would be needed. This network would act as an early-warning system to indicate how the subbasin reacts to variations in quantity and quality of recharge and discharge. The water should be analyzed for major ions. At this time (1977) it would be necessary to measure and sample the wells only once a year (in the spring).

5. A network of wells should be established along the coast to detect and monitor seawater intrusion. Water levels should be measured and the ground water analyzed for chloride concentration and specific conductance. Initially, all available wells along the coast should be measured and sampled for chloride and specific conductance. Based on the results of this first set of data, a well network should be established. Only a few wells in strategic locations may be needed. Measurements should be made, and chloride and specific conductance determined, twice a year--in April and September. This sampling frequency would reflect the annual periods of highest (April) and lowest (September) water levels.

References.--Following are the principal references for the Aptos-Soquel subbasin (see "Selected References"): 2, 4, 5, 6, 8, 10, 14, 15, 16, 18, 32, 33, 35, 38, 40, 46, 47, 54, 64, 69, 80.

Pajaro Subbasin

Location and general features.--There are two major ground-water subareas within the Pajaro subbasin: the Gilroy-Hollister ground-water subarea upstream from Pajaro Gap, and the Pajaro Valley ground-water subarea downstream (fig. 3). At the present time (1977) only the Pajaro Valley ground-water subarea is within the boundary of the AMBAG Sec. 208 planning area. Therefore, only that subarea will be discussed in this report.

The Pajaro Valley ground-water subarea covers about 120 mi^2 and extends from the southern part of Santa Cruz County to several miles south of the county line into Monterey County. It is bounded by the Pacific Ocean on the west and the Santa Cruz Mountains on the east.

The subarea is almost completely dependent on ground water for its water supply. More ground water is pumped in this subarea than in any other part of Santa Cruz County. Irrigation is the largest water use, followed by municipal and then industrial use.

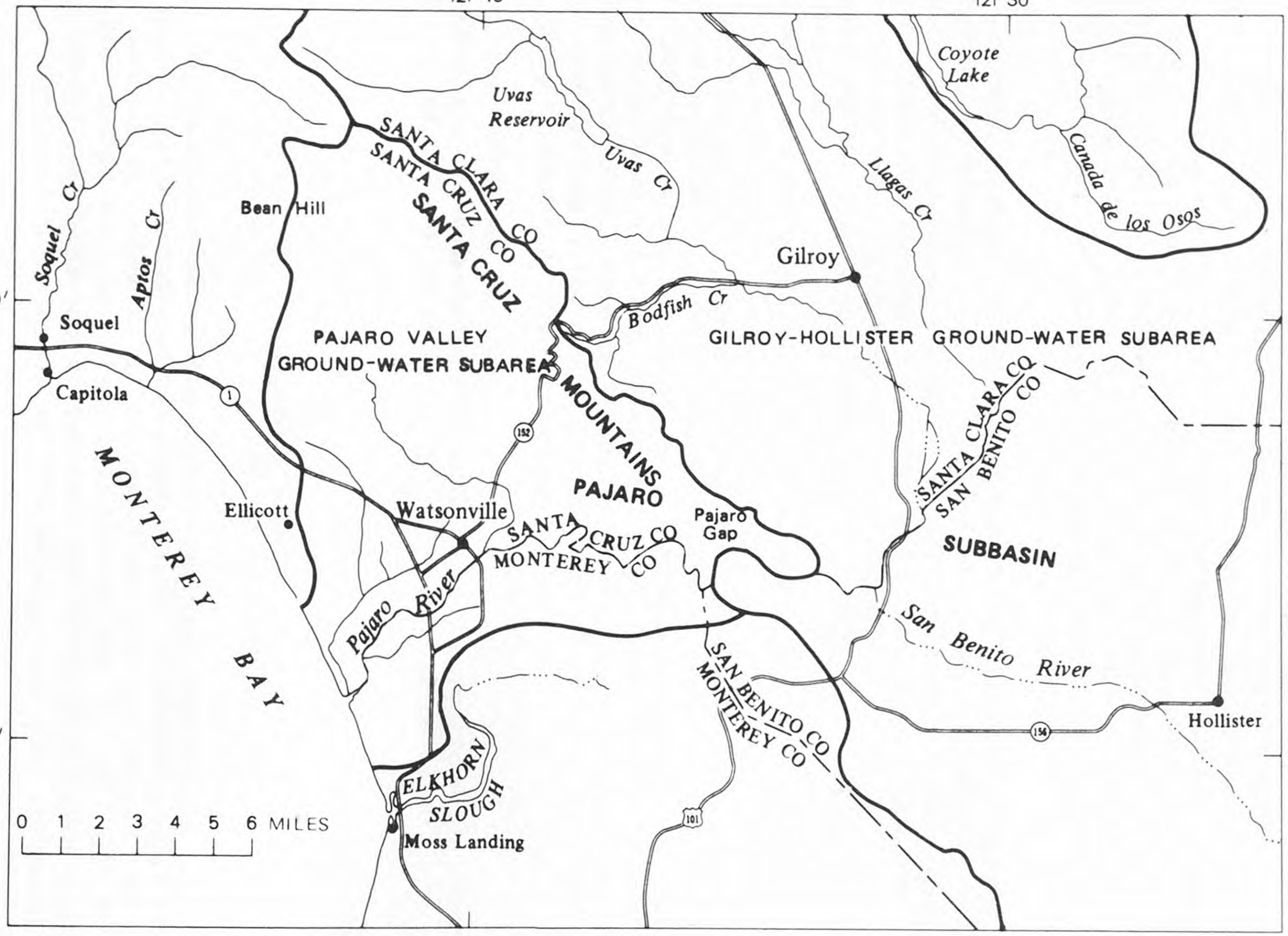

FIGURE 3.--Pajaro subbasin.

Ground-water hydrology.--Ground-water recharge in the subarea is from three sources: (1) precipitation within the subarea, (2) seepage from the Pajaro River carrying runoff that originates upstream from the subarea, and (3) underflow southeast from the Aptos-Soquel subbasin.

The Purisima Formation, the Pleistocene Aromas Sand, terrace deposits, and alluvium constitute the aquifers in the ground-water subarea. These deposits underlie an area of about 80 mi^2 and have a maximum thickness of about 4,000 ft. The alluvium yields most of the water pumped from wells.

In the northern part of the subarea, ground water moves south and southwest toward Monterey Bay. In the south part of the subarea, ground water moves almost due west.

Ground-water pumpage has exceeded the safe yield for many years (Muir, 1974). The quantity of ground water in storage is not known.

The Monterey and Santa Cruz County Flood Control and Water Conservation Districts make water-level measurements and sample many wells in this subarea on a regular basis. The data are collected to help identify changes that may occur in the hydrologic system.

Ground-water quality.--In the Pajaro Valley ground-water subarea there are two distinct ground-water-quality zones: (1) The shallow, semiperched ground water in the upper part of the alluvium, and (2) the deeper, confined ground water in the lower part of the alluvium, terrace deposits, Aromas Sand, and Purisima Formation.

Ground-water quality in the shallow zone, which extends to a depth of 30 to 40 ft beneath most of the main valley, is affected by irrigation-return water and discharge from domestic septic tanks and industrial plants. In general, the shallow, semiperched ground water has large concentrations of dissolved solids, with individual concentrations of sulfate, nitrate, chloride, and manganese commonly exceeding 100 mg/L (milligrams per liter). This poor-quality ground water is a source of contamination to the deeper aquifers. It reaches the deeper aquifers by downward percolation through breaks in the confining beds and through abandoned wells or defective well casings.

The chemical quality of ground water in the deeper, confined aquifers is comparatively good. Concentrations of major constituents and dissolved solids, however, vary appreciably over the subarea. Ground water in the east part of the subarea is of poorer quality than that in the north and central parts. The main source of recharge in the east part is water from the Pajaro River, the flow of which averages less than 45 ft^3/s 70 percent of the time. During these periods of low flow, most of the water in the river is irrigation wastewater averaging about 1,000 mg/L of dissolved solids. This is undoubtedly the cause for poor-quality ground water compared with that in the north and central parts of the subarea. Hardness is objectionably high for domestic or industrial use throughout the subarea.

The quality of ground water in the lower part of the Purisima Formation, which is the deepest lying of the subarea's aquifer, is unknown; no water wells are known to penetrate to that depth.

Seawater intrusion occurs in the Pajaro Valley subarea directly to the north and south of the mouth of the Pajaro River and in a separate small area about 4 mi north of the mouth of the river. In 1972 the intrusion extended inland about 1 mi. Two water-bearing zones are being intruded--the depth intervals are 100-200 ft and 300-600 ft. Seawater intrusion occurs because ground-water pumpage apparently has exceeded the long-term replenishment of freshwater.

Leachate from two adjacent landfill waste-disposal sites southeast of Ellicott (fig. 3) could be a source of contamination to ground water in that area. One of these sites is operated by Santa Cruz County and the other by the city of Watsonville. They receive solid wastes and sewage sludge. The sites are on the Aromas Sand--a very permeable sand and an aquifer.

Study recommendations.--Three items are recommended for investigation.

1. The ground-water recharge areas should be determined and delineated on a map.

2. Water levels should be measured and water samples collected for chemical and biological analyses from wells in the vicinity of the two landfill sites. If existing wells are not adequate, additional observation wells may need to be drilled. Determination of frequency of data collection and detailed selection of chemical and biological constituents and properties will require additional study.

3. Ground-water overdraft in this basin will probably continue. A means to predict how this will affect the ground-water resource, such as increases in seawater intrusion or excessive declines in water levels, would be invaluable to the planner. Possibly a numerical ground-water model should be built that could be used to make these predictions. Prior to any model development, detailed evaluation of the hydrologic parameters and boundaries would have to be made.

References.--Following are the principal references for the Pajaro subbasin (see "Selected References"): 4, 5, 6, 7, 8, 9, 11, 12, 14, 15, 16, 18, 21, 28, 32, 33, 35, 37, 38, 40, 45, 46, 47, 49, 55, 60, 61, 63, 66, 68, 76, 77, 78, 79, 80.

Salinas Subbasin

Location and general features.--This subbasin lies in the northern half of the Salinas Valley. It occupies the part of the valley from just south of Gonzales to Monterey Bay. For planning purposes the Monterey County Flood Control and Water Conservation District divides the subbasin into three parts: Salinas Valley, Salinas Highlands, and El Toro (fig. 4). The subbasin is bounded on the east by the Gabilan Range and on the southwest by the Santa Lucia Range.

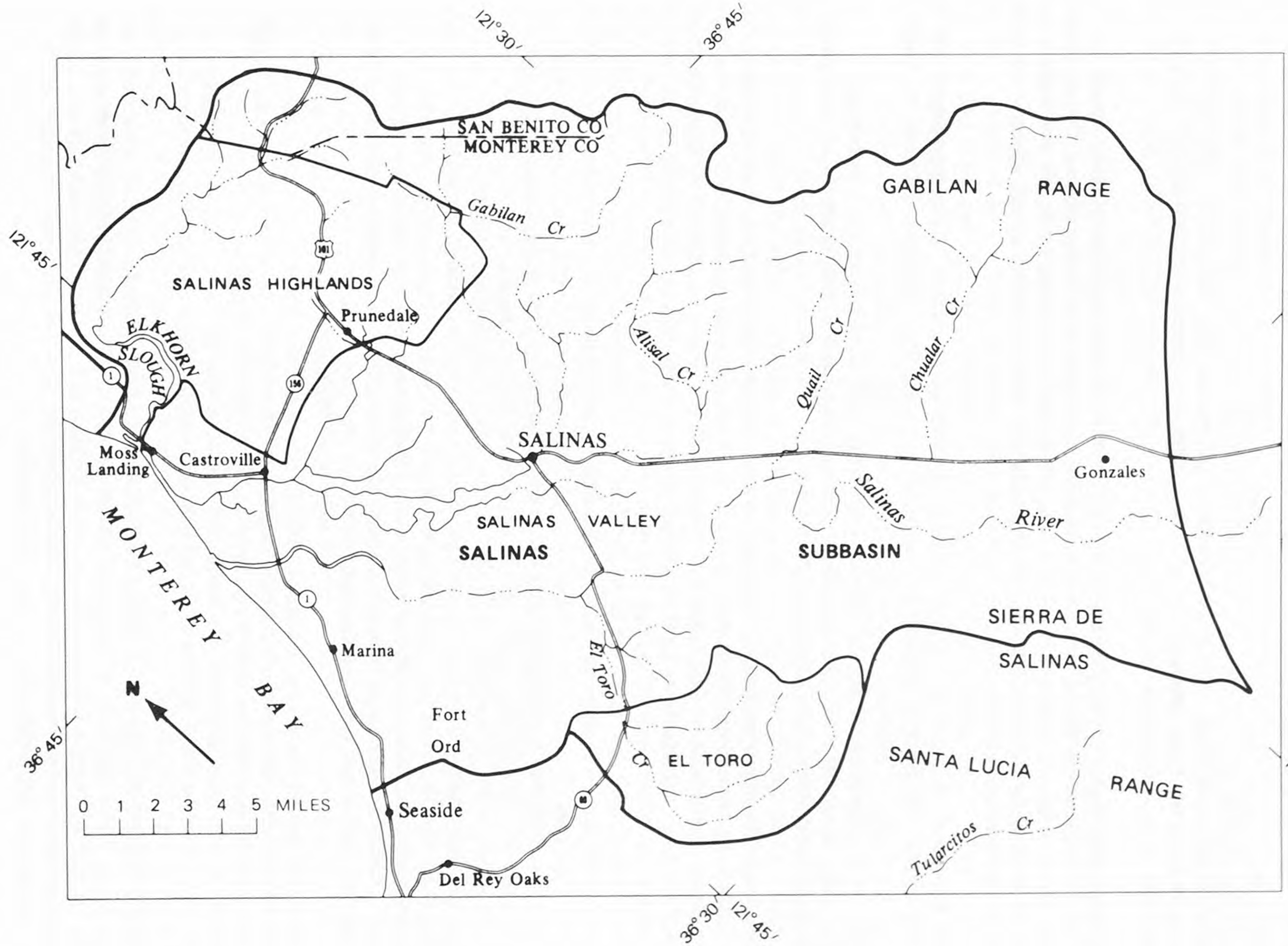

FIGURE 4.--Salinas subbasin.

The Salinas Valley, with a drainage area of about 4,400 mi^2, is a highly developed agricultural area flanking the Salinas River and extending southeast, upstream, nearly 100 mi from the mouth of the river at Monterey Bay.

Ground water is the principal source of water for the area. Large amounts are pumped from wells to irrigate crops. Lesser amounts are pumped for domestic and industrial uses.

Ground-water hydrology.--Many water-resource studies have been made in the Salinas Valley by governmental agencies and private consulting firms (see Selected References). These studies have included evaluations of various aspects of the ground-water system--especially those relating to quantity and quality of ground water.

The Geological Survey, with funding provided by the U.S. Army Corps of Engineers Urban Study Program, is developing numerical models of the Salinas Valley ground-water system. Two models are being developed; one will emphasize the quantity aspects of the system, and the other the chemical aspects. These models are to predict how the ground-water system will react to different recharge and pumping stresses.

Monterey County Flood Control and Water Conservation District is very active in water-resource data collection in the Salinas subbasin. They measure water levels in, and sample, many wells in the subbasin. They prepare an annual report tabulating and evaluating the data collected (see Selected References).

Ground-water recharge in the subbasin is from four sources: (1) precipitation within the subbasin, (2) seepage from the Salinas River which carries runoff from upstream of the subbasin, (3) underflow from the area upvalley of Gonzales, and (4) irrigation-return flow.

Within the past 20 years, the hydrology of the subbasin has been substantially influenced by the construction of large reservoirs on the Nacimiento and San Antonio Rivers in the headwaters of the Salinas River (fig. 1). Runoff stored in these reservoirs is released when conditions for ground-water recharge are favorable.

The main water-bearing formations in the Salinas subbasin are the unconsolidated and semiconsolidated deposits that make up the alluvium, Aromas Sand, and the Pleistocene and Pliocene Paso Robles Formation. They are probably several thousand feet thick in the center of the valley. Their outcrops are covered by terrace deposits and dune sand along the coast.

Ground-water movement is generally in a downvalley direction toward Monterey Bay. The amount of ground water pumped, the quantity in storage, and the safe yield of the subbasin have been estimated by various agencies. The numerical ground-water model being developed by the Geological Survey will make it possible to evaluate these estimates.

Ground-water quality.--In general, ground water in the subbasin is of good quality; however, it is being degraded in certain areas by wastewater discharges and seawater intrusion. Potential degradation to ground water exists from six solid-waste disposal sites in the area. If water percolates through these sites, leachates will be formed. These leachates could migrate down the hydraulic gradient and enter the ground-water system--causing both chemical and biological pollution.

Seawater intrusion occurs along the coast from Marina to north of Moss Landing (fig. 4). Different zones within the aquifer system are being intruded to varying degrees. Maximum intrusion is found in the "180-ft" aquifer, near the mouth of the Salinas River, where intrusion has extended inland about 4 mi. Intrusion occurs because ground-water pumpage in this area of the Salinas Valley is exceeding freshwater replenishment. This results in ground-water levels falling below sea level, allowing inland movement of seawater in the aquifer. This condition has existed for many years.

There are four other localized water-quality problem areas in the Salinas subbasin: (1) an area 1-2 mi northwest of Gonzales, (2) an area just west of Salinas, (3) the Seaside-Marina area, and (4) the Salinas Highlands area of north Monterey County, from about Prunedale north. In these areas the concentrations of certain dissolved constituents (chloride, sulfate, and nitrate) in the ground water are many times higher than normally found in the subbasin. The concentration of nitrate in ground water pumped from some wells in these areas is over the limit considered safe for domestic use. The high dissolved-solids concentration in the ground water in the four areas probably results from the accumulation of dissolved solids from agricultural-return water and industrial and domestic waste discharges.

Study recommendations.--Four items are recommended for investigation.

1. The ground-water recharge areas of this subbasin should be determined and delineated on a map.

2. The areas of excessive nitrate concentrations should be delineated and the cause determined. This would require detailed ground-water sampling, evaluation of the geology, survey of land-use practices, and the location and evaluation of possible pollution sources.

3. A well-monitoring network should be established in the vicinity of the six solid-waste disposal sites in this subbasin. Water levels should be measured and water samples collected for chemical and biological analyses. Additional observation wells may need to be drilled if existing wells are not adequate. Determination of frequency of data collection and detailing of the chemical and biological constituents and properties to be measured will require additional study.

4. A detailed areal ground-water investigation of the Salinas Highlands area of north Monterey County (fig. 4) should be made. This area is experiencing rapid urban growth. Concern has been voiced that there may not be sufficient ground water of suitable quality to supply the present and future needs of the area. The California Department of Water Resources investigated certain aspects of the Salinas Highlands ground-water system in the late 1960's. The resulting report from this study (1970a) did not go beyond the preliminary stage, and it does not include sufficient detail for planning and management purposes.

References.--Following are the principal references for the Salinas subbasin (see "Selected References"): 4, 6, 8, 13, 14, 15, 16, 17, 18, 20, 22, 24, 25, 26, 27, 28, 29, 30, 32, 33, 34, 35, 39, 40, 43, 44, 49, 50, 51, 52, 57, 58, 59, 60, 61, 62, 63, 65, 67, 71, 72, 74, 75, 76, 77, 78, 80.

Carmel Subbasin

Location and general features.--The Carmel subbasin covers about 254 mi^2. The subbasin extends about 35 mi inland from Carmel Bay, and the major axis of the subbasin lies in a northwest-southeast direction (fig. 5). It includes the Monterey Peninsula, the Canyon Del Rey area, and the Carmel Valley.

The water supply for this subbasin is from surface-water and ground-water sources. In 1972, these two sources supplied about equal amounts of water to the area. The surface water is from reservoirs behind the San Clemente and Los Padres Dams (fig. 5). The ground water comes from wells in Carmel Valley, on the Monterey Peninsula, and in the Canyon Del Rey area. Most of the water is used for domestic or irrigation purposes.

Ground-water hydrology.--Two ground-water systems are in this subbasin; one is in the Carmel Valley, and the other is in the Canyon Del Rey area. They are separated geologically from each other by faults and essentially non-water-bearing consolidated deposits.

In the Carmel Valley area, ground-water recharge is from precipitation that falls on the drainage area. Recharge reaches the aquifers by direct infiltration of rainfall and seepage from streams. The aquifer is apparently composed mostly of alluvium and terrace deposits. Ground water moves northwest down the valley and discharges into Carmel Bay.

In the Canyon Del Rey area most of the ground-water recharge is from rainfall infiltration on the grass- and brush-covered terrain. Two geologic units make up the aquifer system--recent sand dunes and underlying unconsolidated sediments that are equivalent to the Paso Robles Formation and Aromas Sand. Ground-water movement is northwest toward Monterey Bay.

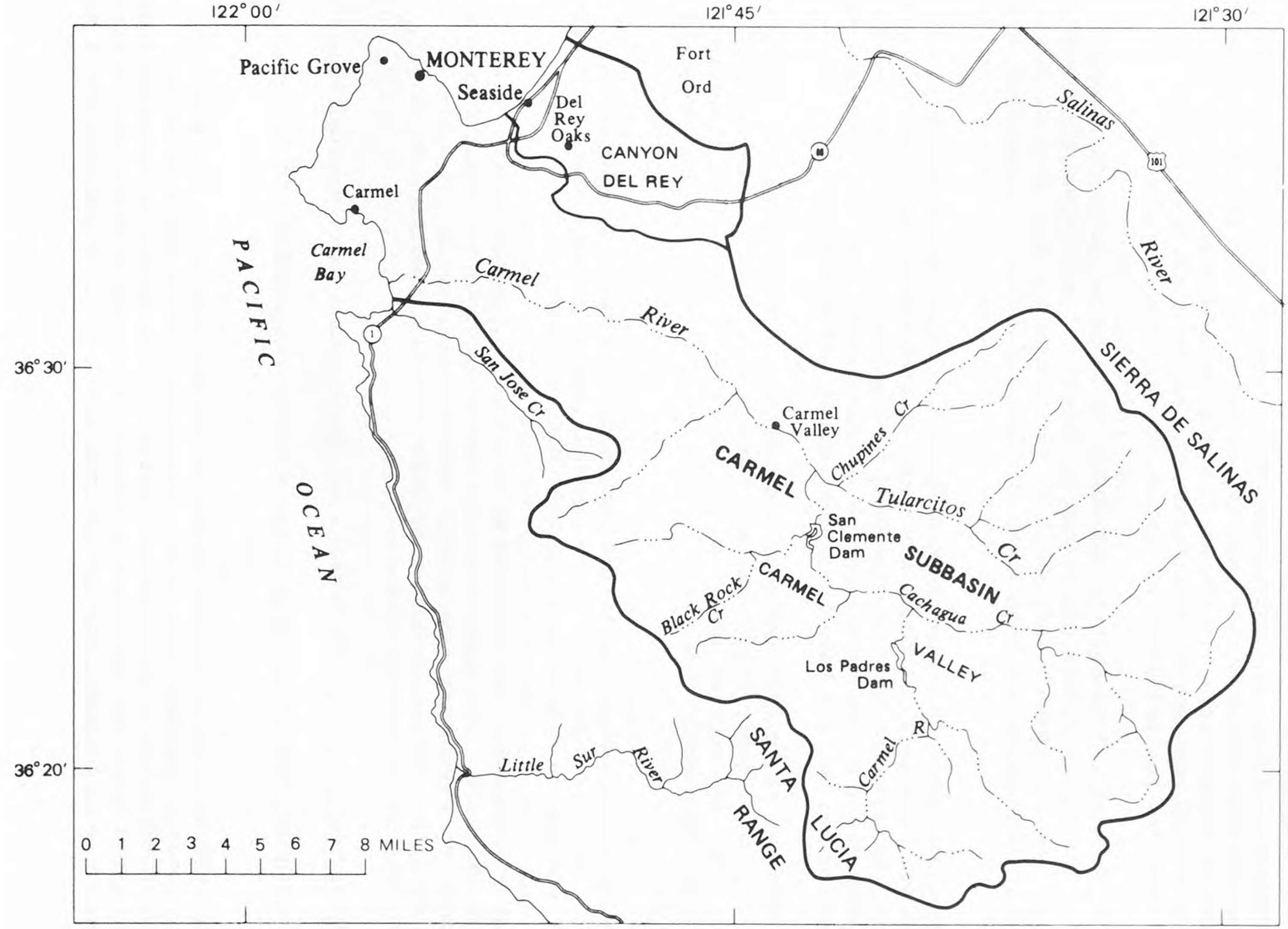

FIGURE 5.--Carmel subbasin.

The amount of ground water pumped, the quantity in storage, and the safe yield of the subbasin have been estimated by the California Department of Water Resources (1974). Some hydrologic consultants judge that some of the geologic formations that underlie, and are adjacent to, the alluvium in Carmel Valley contain considerable quantities of usable ground water. The Department of Water Resources considered these formations as essentially not water bearing. Data are not available to confirm or deny either judgment.

Monterey County Flood Control and Water Conservation District is very active in water-resource data collection in the Carmel subbasin. They measure water levels in, and sample, many wells in the subbasin. They prepare an annual report tabulating and evaluating the data collected (see Selected References).

Ground-water quality.--Ground-water quality in the Carmel subbasin is acceptable for most uses, although the water is considered "hard" for domestic use. Also, the concentration of dissolved iron and manganese in the ground water in some areas of the Carmel Valley is undesirably high for domestic use. These problems can be, and have been, overcome by water treatment.

Residents in the middle and upper part of the Carmel Valley use septic tanks to dispose of their liquid wastes; there are no sewers. The liquids eventually enter the aquifer system as ground-water recharge. If they are insufficiently renovated, they could pollute the system--both chemically and biologically.

Seawater intrusion occurs in the Canyon Del Rey area. At the present time (1977) the intrusion seems to be limited, and it affects only those wells that pump from the sand dune deposits near Monterey Bay.

Seawater intrusion does not seem to be occurring in the Carmel Valley part of the subbasin. The uncertainty in the above statement results from a lack of wells to sample near the coast. Ground-water levels and hydraulic gradients upvalley indicate ground-water flow toward Carmel Bay, which, if maintained, should prevent intrusion.

Study recommendations.--Five items are recommended for investigation.

1. The ground-water recharge areas should be determined and delineated on a map.

2. A well-monitoring network should be established along the coast to detect and monitor seawater intrusion. Observation wells may need to be drilled if suitable wells do not exist. Water levels should be measured and the ground water analyzed for chloride concentration and specific conductance. Measurements should be made, and samples collected, twice a year--in April and September.

3. The impact of septic tanks on the quality of water withdrawn from shallow domestic wells should be determined. Investigation should include evaluation of the amount of recharge to the ground-water reservoir by septic tanks.

4. Indications are that the Carmel Valley area will experience continued urban growth for years to come. This will add to the burden of planning and managing the water resources of the area. A numerical ground-water model would help the planner by predicting how the ground-water system would react to changes in recharge and discharge. Prior to any model development, however, detailed investigations would have to be made to determine the transmissivity and storage coefficient and to define boundaries.

5. In the Carmel Valley area little is known of the water-bearing properties of, or the quality of water in, the geologic formations that are older than the alluvium. A study should be made to evaluate their potential for ground-water development. Test wells will need to be drilled to carry out this evaluation. These wells would be used for identifying, testing, and evaluating the potential of the penetrated formations for supplying water.

References.--Following are the principal references for the Carmel subbasin (see "Selected References"): 4, 6, 8, 14, 15, 16, 18, 20, 23, 28, 31, 32, 33, 35, 40, 51, 52, 60, 62, 73, 75, 80.

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