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THE ECOLOGY OF THE SOUTHERN CALIFORNIA BIGHT: IMPLICATIONS FOR WATER QUALITY MANAGEMENT

Three-Year Report of the Southern California Coastal Water Research Project

SCCWRP

SOUTHERN CALIFORNIA COASTAL WATER RESEARCH PROJECT
A local government agency for marine ecological research

1500 East Imperial Highway, El Segundo, California 90245

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SOUTHERN CALIFORNIA COASTAL WATER RESEARCH PROJECT
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21 March 1973

Mr. Bert Bond
President, Commission
Southern California Coastal Water
Research Project Authority

Dear Mr. Bond:

Your Consulting Board takes great pleasure in transmitting to the Commission of the Southern California Coastal Water Research Project Authority the report of the first three years work undertaken by the Project.

As you well know, the Consulting Board has guided the Project and its staff since its inception. The program has now culminated in a creditable report on the characteristics and quality of the waters, creatures, and sediments of a major portion of the Southern California Bight. We believe that the extensive list of specific findings of the Project and the very relevant and timely conclusions and recommendations go far to document existing conditions and to point both the directions for needed improvements and the studies necessary for further understanding and improvement of our local marine environment.

The Consulting Board is most pleased to inform you that the Board unanimously agrees with and endorses the findings, summary and conclusions as enunciated by the Project staff.

We wish to emphasize the practical and relevant nature of several of the report's conclusions concerning present wastewater management practice:

1. The Board concurs that there is no evidence to document that present wastewater disposal practices have had any substantial adverse or irreversible effects on the general ecological characteristics or environmental quality of the Bight.

2. On balance, marine wastewater management practices in the study region have been generally competent and responsive to new findings and developments.

3. Implementation of the recommended changes for marine wastewater discharge (particularly improved control of persistent pesticides, other persistent organics, toxic metals, and floatables) and continuation of research into man's general marine effects are essential for the continued preservation and enhancement of the quality of Southern California's marine environment.

4. The perspective attained by the study on the broad area of man's effects on the Southern California Bight is of major importance, along with the specific findings, for the guidance of future marine related activities.

5. Present disposal regulations designed largely for freshwater and estuarine environments have limited specific applicability to Southern California discharge practice.

The Consulting Board wishes to express their great pleasure in serving the Commission in the unique capacity as scientific and technical consultants to this most interesting and important project. We hope that the findings, conclusions and recommendations will prove to be of substantial benefit to the Commission, its members' agencies and to the general public.

Should you have any questions related to the statement presented in this Report, please do not hesitate to call on the members and chairman of the Consulting Board.

Sincerely,

John D. Isaacs

John D. Isaacs
Chairman, Consulting Board
Southern California Coastal Water
Research Project

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County of Ventura

Herbert P. Nilmeier

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Paul R. Bonderson	California Water Resources Control Board
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Paul de Falco, Jr.	Environmental Protection Agency
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Raymond M. Hertel	Regional Water Quality Control Board, Los Angeles Region
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Vern Tenney	Environmental Protection Agency

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Crew of RV Thomas G. Thompson	University of Washington
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Thomas B. Widdowson	California State University, Long Beach
Thor Willsrud	Ventura College

All of the SCCWRP staff members have participated to some extent in the preparation of this report. Oceanographic data was compiled by James H. Jones and Alfred J. Carsola; responsibility for the geographical and oceanographic information in Chapter 3 was assumed by Dr. Carsola, assisted by John Harding. Chen-Shyong Young compiled the data on industrial and municipal wastewater inputs described in Chapters 3 and 4; his assistant was Yuan-Yuan Tsai. Mr. Young also wrote Chapter 10 and conducted the surface phenomena study described in that chapter. David R. Young supervised the trace material investigations described in Chapters 4, 5, 6, 7, and 8; he was assisted by Kimm Crawford, Theadore Heesen, Joseph Johnson, Eugene Leong, Deirdre McDermott, and Gerald Shiller. The fisheries program described in Chapter 7 was conducted by Alan J. Mearns, with the assistance of James Allen, Ricard Gammon, and Marjorie Sherwood. Irwin Haydock supervised the benthic invertebrate studies discussed in Chapter 8, with the assistance of Thomas Sarason. Dr. Haydock also supervised the plankton investigations (Chapter 9). Terry Hendricks formulated the phytoplankton response model, as well as the ocean dispersion model described in Chapter 3; his assistant, James R. Taft, programmed the models for the computer. The preparation of the initial draft was coordinated by Chen-Shyong Young. Robin Simpson performed the grammatical edit.

Philip N. Storrs, Engineering-Science, Inc., performed the technical edit of the report and supervised the staff and Consulting Board review of the final draft. In this and several other activities of the project, Mr. Storrs has participated with skill and dedication; we are most grateful for his assistance.

Chapter 1

INTRODUCTION

The southern California coastal region contains one of the most rapidly expanding urban complexes in the United States. Most of this expansion has occurred in Los Angeles and Orange Counties, which in recent years have had high rates of population increase. Two other coastal counties--San Diego and Ventura--are entering periods of similar growth.

Proximity to the Pacific Ocean has been a key factor in southern California's growth. The ocean's influence on the weather of the region results in a temperate, subtropical climate that has drawn people from all parts of the country. Natural resources have made possible the development of such industries as oil, power production, transportation, commercial and sport fishing, mineral extraction, and tourism. The coastland has become a center for science and advanced technology and is valued for its excellent recreational facilities and scenic beauty. At present, it sustains a population of 11 million, and its continued growth seems certain. Inevitably, the demands on ocean resources will also increase.

The waters within a few kilometers of shore are perhaps most directly influenced by the intense development in the coastal region. There are both negative and positive aspects of man's influence on these nearshore waters. On one hand, marine ecosystems may be severely stressed or permanently altered as a result of human exploitation. Conversely, technology and knowledgeable planning and management may enhance the marine environment for its inhabitants and permit replenishment of important marine resources. If the ocean is to continue to satisfy the often conflicting demands of the human population, both of these aspects of the environment quality issue must be considered--the coastal water environment must be both protected and enhanced.

Traditionally, one of the important uses of the coastal waters for man has been as a repository for his wastes. Although the ocean is vast, its ability to assimilate these wastes without significant environmental degradation is limited. Considering the absence of generally accepted criteria for environmental quality control and the complexities of the physical, chemical, and biological systems involved, it is not surprising that there is concern over the adequacy of present-day marine wastewater management practices. Today, particular attention is focused on certain waste constituents--oils and greases, particulates, persistent pesticides, and some trace metals and metallic compounds. These substances may have far-reaching effects on marine ecosystems or the public health, yet their true behavior and effects have not been established to the degree necessary to permit implementation of effective controls. Progress is hampered by several factors. Some substances have been detected in various components of the marine ecosystem; however, in all but a few cases, neither their exact source nor the modes by which they are distribibed in the environment are known, nor are their effects understood. Many suspect substances are not detectable in the environment with existing technology; the natural levels of other waste constituents are imperfectly appreciated.

In southern California, evaluation of the impact of waste discharge is further complicated by the complex physical, chemical, and biological character of the receiving waters. Geologically, the southern California offshore region has existed essentially in its present form for thousands of years. But, because of the often extreme cyclic and noncyclic changes in weather and currents that characterize the Pacific Ocean in this area, local marine organisms have been subjected to a variety of environmental stresses; ecological changes are thus a part of the natural history of the area. Changes occurring in recent times as a result of man's activities may resemble, blend with, or perturb such natural fluctuations. Alternatively, long-standing effects of man's historical actions may become established as the "natural" state of things. For these reasons, both natural phenomena and man's acts in the recent past and present must be considered in evaluating the impact of present wastewater discharges upon the ecology of the area.

In the last decades, water quality management techniques and wastewater treatment methods have been steadily improving. There is the technical capability (disregarding cost) to remove virtually any constituent from the wastewater stream. However, without adequate understanding of the relative significance of various waste constituents, valuable resources can easily be expended in implementing controls that do not significantly benefit either man or the environment.

There is particular danger of misspent effort in marine water quality control. Because the problems of freshwater pollution have been recognized for some time, treatment systems and controlling regulations are most highly developed in this area. However, these techniques and controls are not always applicable to marine systems as the chemistries of the two realms differ in fundamental and profound ways.

Unquestionably, the protection and enhancement of the marine environment is an important goal in the Nation's environmental quality program. However, it is doubtful that marine waste management systems such as those in southern California can be optimized without improvement in our knowledge of the characteristics of the wastes discharged and the ecosystems of the marine waters that receive them. Only with improved understanding of these two elements and the interactions between them can the limited financial resources available for wastewater control be allocated with assurance of benefit. And, although each particular area and situation must be considered separately, much of the understanding of marine waste disposal problems in southern California will be broadly applicable to planning and improving similar marine systems elsewhere in the world.

1.1 STUDY PURPOSE AND SCOPE

The basic goal of the Southern California Coastal Water Research Project (SCCWRP) is to increase understanding of the ecology of the coastal waters off southern California and of the effects of man's activities (especially municipal wastewater discharge) on the marine environment. The project aims at encouraging the conservation and enhancement of local marine resources by providing broad scientific insight and guidance to agencies affecting these resources and to the general public. The ultimate goal of the project is to acquire a reservoir of information on the ecology and the nature of wastewaters so that the effects of past and present wastewater discharges can be evaluated and future discharges can be appropriately planned and meaningfully monitored.

SCCWRP was founded in 1969 by the five government agencies[1] responsible for most of the municipal wastewater discharges into the ocean off southern California. Believing that their established research programs could benefit from the addition of a project with regionwide focus, the agencies entered into a joint powers agreement to sponsor SCCWRP. The sponsors delegated control of the project to a commission of local civic leaders and elected officials who could reflect the current public interest in environmental quality, but be free from partisan pressures. This arrangement has given the project freedom from control by other agencies and has fostered a broad and balanced viewpoint.

The project differs from its sponsors' continuing research efforts in the scope of its investigations. The goals of most current and recent studies have been to develop and confirm engineering design criteria for waste treatment and ocean disposal, to demonstrate compliance with regulatory requirements, or to resolve special problems. In the SCCWRP program, studies of specifics--isolated substances, areas, and effects--are balanced by broader investigations of the coastal water region as a whole, its natural history, its large-scale physico-chemical characteristics and functions, its biological communities, and its responses to various human activities. In initiating this project, the sponsors realized that these fundamental investigations are necessary to the development of a sound basis upon which to evaluate the ecological significance of present and proposed wastewater disposal systems.

1.1.1 Objectives

The specific objectives of the study described in this report were:

A. To obtain background information on the general physical, chemical, and biological characteristics of the coastal water ecosystem.

B. To identify and investigate ecologically significant but insufficiently understood physical, chemical, and biological processes and phenomena occurring in the southern California coastal waters.

C. To identify the significant sources of inputs to these waters and to characterize the inputs with respect to the nature and quality of their constituents; to describe the transport and fate of certain constituents that are known or suspected to be potentially hazardous to the environment or the public health.

D. To identify quantifiable species, population, and community responses to environmental stresses.

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[1] Ventura County, the Cities of San Diego and Los Angeles, and the County Sanitation Districts of Orange and Los Angeles Counties.

E. To determine the significance of findings to water quality management systems--specifically, to make economically and technologically feasible recommendations on effluent and receiving water standards and monitoring procedures.

F. To identify and define further research that is most urgently needed to ensure that the environment and its resources are adequately protected.

1.1.2 Study Area

The Southern California Bight (Figure 1-1) is defined as the open embayment of the Pacific Ocean bounded on the east by the reach of the North American coastline extending from Point Conception, California, to Cabo Colnett, Baja California, Mexico, and on the west by the California Current. The joint powers agreement creating SCCWRP specified the project's primary study area as the portion of the Bight defined on the east by the strip of California coastline extending from the Santa Barbara/Ventura county line to the United States/Mexico border and on the west by the edge of the mainland shelf. (Waters in the harbors of the Bight and in the tidal prisms of its estuaries were excluded from the primary study area.) However, to provide perspective for the study, the Bight as a whole and those transports across its boundaries pertinent to the fate of wastes introduced into the primary study area were considered in the SCCWRP investigations. Therefore, in this report, no distinction is made between the "Southern California Bight," "southern California coastal waters," and "the study area."

SCCWRP studies of the coastal basin bordering the Bight have focused on the land draining through streams on the United States portion of the coast (shaded area in Figure 1-1); this land is referred to in this report as the southern California coastal basin. The coastal basin of northern Baja California is sparsely populated and generally undeveloped and is drier than the land to the north; hence, inputs to the Bight from this area are generally of less magnitude and significance. However, because Baja California waters are used as a control area for many ecological studies of the waters off southern California, features of the land draining into the Mexican portion of the Bight will be investigated in future SCCWRP programs.

1.2 PLAN AND ORGANIZATION

Some rather extensive background data on the ecology of southern California coastal waters exist as a result of a number of research and survey programs carried out by universities and Federal, State, and local agencies. Much of the data from the local government agencies had been unanalyzed prior to SCCWRP's formation. Thus, one of the first steps in the SCCWRP investigations was to examine and integrate the material collected in these programs.

In connection with this review, SCCWRP designed a research program to supplement and expand the existing data. Laboratory and field studies were conducted both by the SCCWRP staff and by other groups under contract (major contractors are listed in Appendix A). In addition, several programs were carried out in cooperation with local and State agencies.

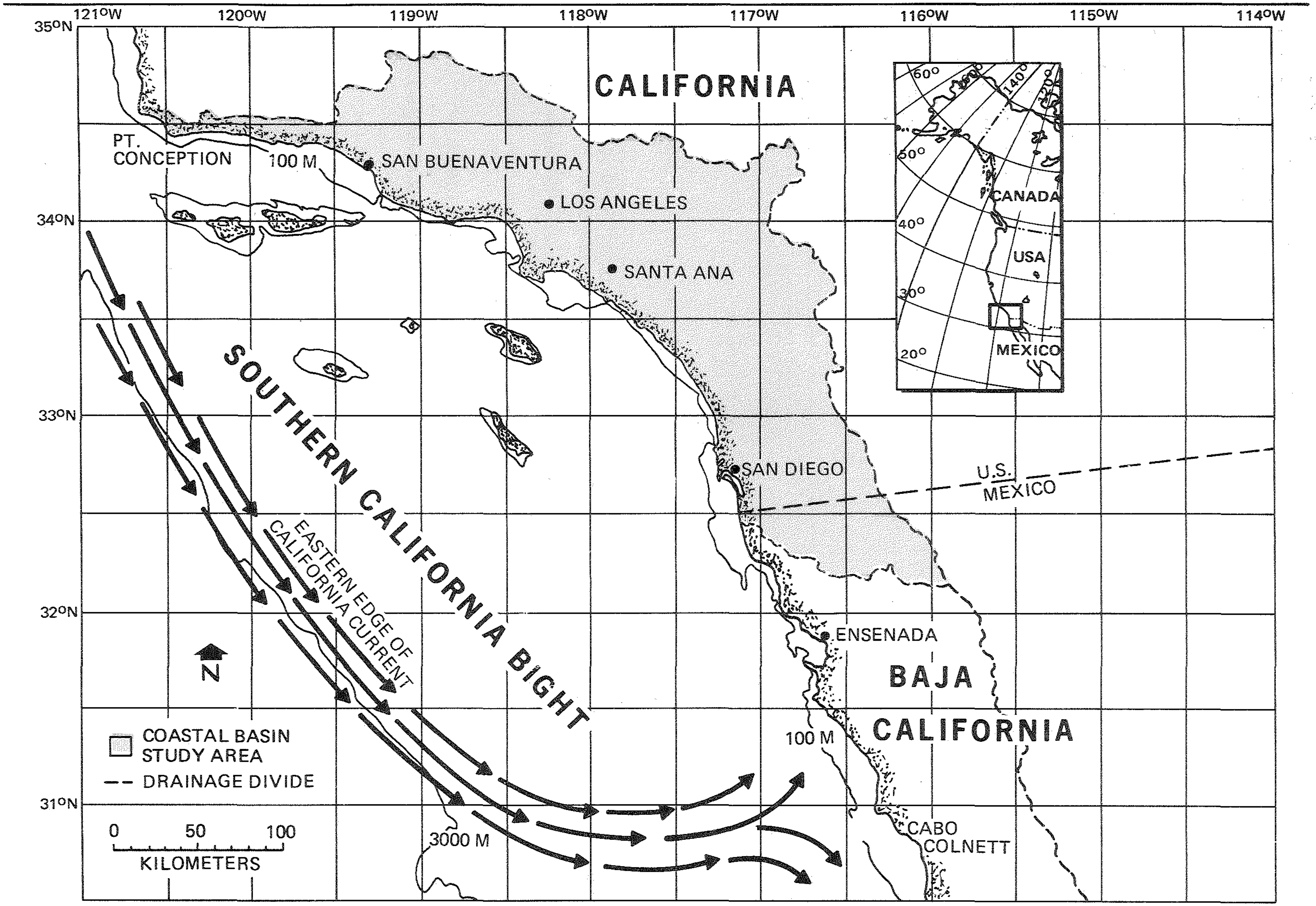

Figure 1-1. The SCCWRP Study Area.

Both the review and research phases of the effort involved the professional disciplines of physical and chemical oceanography, marine biology and ecology, public health, sanitary engineering, and systems engineering. The SCCWRP organization and primary areas of responsibility are shown in Figure 1-2.

1.3 ORGANIZATION OF THE REPORT

The next two chapters (Chapters 2 and 3) provide an overview of the many facets and complexities of ecological study in the Bight and a general description of the characteristics of the coastal basin and the nearshore waters. Chapter 4 deals with quantities and characteristics of municipal wastewater discharges, natural runoff from storm drains and streams, industrial discharges, and other, more diffuse sources of potential pollutants. A brief general discussion of water quality characteristics and current patterns in the nearshore waters is included in Chapter 5; general sediment characteristics are also described in this chapter. SCCWRP investigations of the concentrations of trace metals and chlorinated hydrocarbons in the sediments of the Bight, particularly those around major municipal wastewater outfalls, are discussed in Chapter 6.

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Figure 1-2. SCCWRP Organization and Principal Areas of Responsibility.

SCCWRP investigative and analytical work on fish, benthos, and plankton is described in Chapters 7, 8, and 9, respectively. Chapter 10 is a discussion of the public health aspects of marine wastewater discharges. The final two chapters of the report are devoted to the summary and discussion of the Project's work and to conclusions and recommendations stemming from the work done to date.

Chapter 2

A PERSPECTIVE FOR CONSIDERATION OF THE SOUTHERN CALIFORNIA BIGHT

A long, largely unrelieved portion of the west coast of North America extends from the Strait of Juan de Fuca at the United States/Canada border to Cabo San Lucas at the southern tip of the Baja California peninsula. This 3,200-km reach is almost precisely bisected by Point Conception, which is often called "the Cape Horn of the Pacific" because of the conspicuous change in climates and fauna that it marks. However, it is not the salient Point Conception, per se, that creates this climatic and faunal discontinuity, but rather the sharp eastern break of the coast to the south of the point and the resulting indentation that extends for 575 km to Cabo Colnett on the Baja California coast. This great Southern California Bight describes the immediate milieu of the marine problems attending southern California's human population. The broad geological, physical, and organic processes that set the general conditions of the Bight and cause profound aperiodic fluctuations of all its characteristics are described in this chapter.

Geologically, the Southern California Bight has existed much in its present form since early Pleistocene times, 3 to 4 million years ago. It is a feature of the great crustal movements of the earth circling the Pacific. More locally, it is a result of a complex fault system dominated by the San Andreas Fault. The Bight's comparatively rapid geological evolution has resulted in the development of an unusual sea floor configuration--a series of coastal basins, troughs, and submarine canyons, which, in a more stable environment, would have inevitably been smothered long ago by a heavy blanket of sediments. The rugged underwater topography of the region allows deep, cold bathypelagic waters and attendant nutrients and organisms to encroach shoreward of the island-bearing continental borderland.

This highly irregular continental shelf imposes other conditions on the southern California region. For example, it largely protects the coastland from the heavy winter swells from the North Pacific and effectively reflects the great tsunamis that periodically sweep the Pacific from Alaska to Chile. Conversely, it allows the summer entry of the long southern swell generated by the violent winter storms of the South Pacific, and it can be expected to "trap" and accentuate any tsunamis ever generated within the Bight.

The most important effect of the Bight is to interrupt the ponderous flow of the California Current. This current, the eastern branch of the great North Pacific Gyre, converges off the Washington Coast and sweeps 1,500 km without major perturbations, commonly departing from its coastal flow only at Point Conception. This sudden departure can be viewed as a "stall" in the flow of the current--a hydrodynamic discontinuity that is ordinarily associated with a return eddy, the Southern California Countercurrent.

The effects and importance of the Southern California Countercurrent, the most permanent feature of the variable circulation of the Bight, are innumerable. Appropriate to mention here are (1) its action as a delay or reservoir in the otherwise straight sweep of the California Current, with a consequent warming of the oceanic water in the Bight, an over-all advection of food material into the Bight from farther up the coast, and a net consumption of food material elaborated upstream and (2) its importance as an enclave in which many organisms can maintain a breeding stock. The most notable effect of the countercurrent on the Bight is the creation of a region in which southern, western, northern, and upwelling waters and organisms converge. These four relatively independent regimes, each subject to its own individual fluctuations, meet in southern California in a variable concert.

The oceanographic conditions of the Bight are also influenced by several weather regimes and storm systems. However, the vulnerability of the southern California region to changes in weather does not result solely from its location near the terminus of several atmospheric and oceanic influences. In general, weather moves from west to east. Thus, weather features reaching the Bight have been generated in or transported and modified across the greatest and most featureless expanse of water in the northern hemisphere, a sea spanning one-third the girth of this globe. These weather events are "steered" across the Pacific by their interaction with the varying air and water masses, which are in turn created by the weather events themselves. The course of weather events in their motion across the Pacific is only weakly and peripherally influenced by any permanent features (e.g., the Aleutian Islands) but is strongly affected by impermanent and fluctuating interactions. The results of this changeable steering are indirectly exhibited in the great year-to-year and decade-to-decade variability of storms, rainfall, fog, air and water temperature, and abundance and composition of marine populations in the Southern California Bight.

The direct terminal effect of this weather on oceanic conditions is equally variable. For example, extra-tropical storms may be steered directly to the southern California coast, leading to high runoff and the encroachment of southern or central water and southern organisms. Stronger than normal storms, steered into the northwest coast, greatly impede the flow of the California Current and lead to the development of a strong, narrow countercurrent flowing north from subtropical waters through southern California and, in extraordinary cases, continuing up the coast as far as Vancouver Island. Under other circumstances, strong northwesterly winds intensify the California Current, leading to strong upwelling, cool summers, and the presence of northern fauna in the Bight. A variety of other conditions may also exist. Weak summer northwesterly winds and a sluggish California Current encourage the development of high water temperatures and the invasion of southern California by tropical storms, such as the fierce Mexican chubasco. In some periods in the early 1800's, the southern California coast apparently was affected by these hurricanes several times a year. These conditions were probably accompanied by abnormally high temperatures in autumn and an influx of tropical creatures, an association that has occurred several times in this century. Certain periods, sometimes lasting for years, stand out as quite warm and others as quite cold. For example, warm periods occurred in 1850-70, 1926, 1931, 1939-41, 1957-58, 1968-69, and 1971-72, and cold periods in 1880-90, 1924, 1933, and 1946-56. Some of these extremes extended far across the continent.

It has been estimated that the average upwelling on the California coast involves the continuous input of about 1 million kw of mechanical power and 1 billion kw of thermal power. Since year-to-year upwelling varies by similar amounts, the year-to-year variation in thermal power related to upwelling is of the order of the thermal discharge from all of the electrical generating plants on the continent.

The pelagic regime and its conditions, currents, transport, chemistry, and organisms are of course most directly affected by these large-scale variations. A pelagic creature born into the Bight has only a little assurance of the nature of its food, predators, transport, and associates. Therefore, at least in the pelagic regime, the classical concepts of a complexly balanced ecological system or of steady mixing and stable transport are largely fictional. Instead, the creatures are opportunistic, variable, and resilient and absorb great insults inflicted by an often inconstant nature.

In the other environments of the Bight--those of the littoral, bathypelagic, and benthic creatures--the strength of these fluctuations is variously modified or weakened. Not only are these regimes insulated from the pelagic events by a step of remoteness, but the habitats offer an added degree of insulation. For example, food material in sediment cannot be destroyed by any ordinary short-term event, and benthic organisms can retain a viable breeding population for a substantial time period although their progeny may be largely swept away in extended periods of adverse currents. Thus, in these environments, some real degree of stable, balanced ecological complexity may often exist. However, the substantial, decade-to-decade natural fluctuations observed in littoral and shallow benthic species and populations indicate that the ecological balance of these regimes is also profoundly affected by large-scale fluctuations, although on a longer time scale.

The present-day conditions in the Bight are not solely the result of natural phenomena modified by the effects of contemporary man's actions, for man has been involved in the ecology of the Bight for millenia. In some areas, he has exerted more profound influence in the past than at present. For example, over a century ago, Russian and American hunters and whalers nearly exterminated the sea otter and the gray whale in the region. Although both of these species are now returning, the imbalances engendered by their 100-year or more absence have not been evaluated fully. The decline of some southern California kelp beds are perhaps more readily attributable to the absence of the sea otter (a predator of the sea urchin, which feeds on the kelp) than to other causes.

In the more remote past, burning of the backcountry by the Spanish and Indians, local overgrazing, and, most particularly, cessation of the centuries of harvesting of littoral and rocky shore animals by the Indians have been shocks to the nearshore environment--shocks that we are apt to consider as being within the natural order of things. The cliff-high layers of shells in the kitchen-middens of southern California Indians indicate the extent of their daily cropping, to which the littoral creatures had adjusted over 40 centuries. In the accessible coastal areas where the cropping occurred, an ecological imbalance may have followed its sudden discontinuance.

More recent historical effects of man must also be considered in ecological studies. Major rivers and streams, with their associated loads of sediment and debris, have been regulated. Commercial fisheries have blossomed and then been legislated out of existence. For example, the bottom trawl fishery within 5 km of the southern California shoreline became illegal in 1925; ecological adjustments to this fishery and its sudden demise must still reverberate through the communities of benthic creatures.

The most profound effects of sport and commercial fisheries may stem from their selectivity. For example, the fisherman's pursuit of the large predators has probably imposed an important background condition on the Southern California Bight. In a marine biological community, sick, injured, or abnormal fish (or even those that are merely behaving erratically) are usually quickly removed by large predators; abnormal prey can only be present in a community in which the populations of major predators have been selectively reduced. Thus, an equivocation of evidence arises with a report of abnormal fish: Abnormality or disease in a population indicates a preexisting imbalance or scarcity of the species' predators. This is a particularly apt example of the importance of conducting research on the influence of one of man's contemporary acts in the context of other preexisting and often unassociated man-related activities.

This brief description of the Southern California Bight abstracts from the great and increasing store of knowledge and understanding that has been gathered by many marine scientists. The intent of this summary is to emphasize a number of vital features of the Bight that are now understood with considerable certainty. Particularly important are the facts that the fluctuating conditions in the Bight result from processes involving at least the entire North Pacific; that, as a consequence, study of the oceanographic conditions of the Bight alone cannot provide an adequate picture of events occurring within its boundaries; that the Bight constitutes a unique biological and climatic discontinuity and enclave in the California Current; that waterborne pollutants in the Bight comprise not only those from local sources, but also a substantial fraction of those introduced along the entire west coast of North America; that the natural fluctuations of physical conditions and organisms occurring in the Bight are driven by energy fluxes involving millions of megawatts of power; that only a partial stability exists in the circulation and pelagic populations of the Bight; and that the present-day conditions of the Bight are influenced by over 40 centuries of man's activities in the region.

Chapter 3

THE GEOGRAPHY OF THE SOUTHERN CALIFORNIA BIGHT AND THE ADJACENT COASTAL REGION

3.1 INTRODUCTION

The structure, topography, climatology, hydrology, and water movements of the southern California and northern Baja California region contribute to the uniqueness and coherence of the Southern California Bight. These elements and their interrelationships are briefly discussed in this chapter. As human activities in the region are related to some extent to all of the physical features and conditions described here, the chapter also contains general data on the southern California population and its use of land and water resources. Three other physical parameters--sediments, water characteristics, and nearshore circulation, which are particularly relevant to the SCCWRP studies, are treated separately in Chapter 5.

3.2 LAND AND SUBMARINE PHYSIOGRAPHY

The Southern California Bight (Figure 3-1) is the open embayment of the Pacific Ocean extending from Point Conception on the north to Cabo Colnett, Baja California, on the south. The California Current roughly defines the Bight on the west. As the Bight's current system usually extends westward to the area with water depth in the order of 3,000 m, a more precise western boundary is the continental slope off southern California and northern Baja California. Within these boundaries, the Bight is approximately 500 km long and 200 km wide, covering a surface area of 100,000 sq km.

The Bight is located in a region that is carved and sliced extensively by faults (Figure 3-2). This fault system, which has been intermittently active during long periods of Cenozoic time, has been fundamental to the geomorphic development of the area.

The fault system has a number of immediate influences on the inputs into the Bight. For example, the larger active faults are effective in continuously reducing their flanking rocks into particles much finer than those produced by ordinary weathering. Thus faults often become water courses, bearing the fine sediment to the sea. Faults also contribute significant amounts of oils and tars through natural seeps, particularly at times of high seismic activity.

Faults are also commonly associated with highly mineralized ponds, geothermal springs, and mineral deposits and thus undoubtedly contribute disproportionately to the mineral input from stream flow. Possible geothermal power-plant developments will be related to faults.

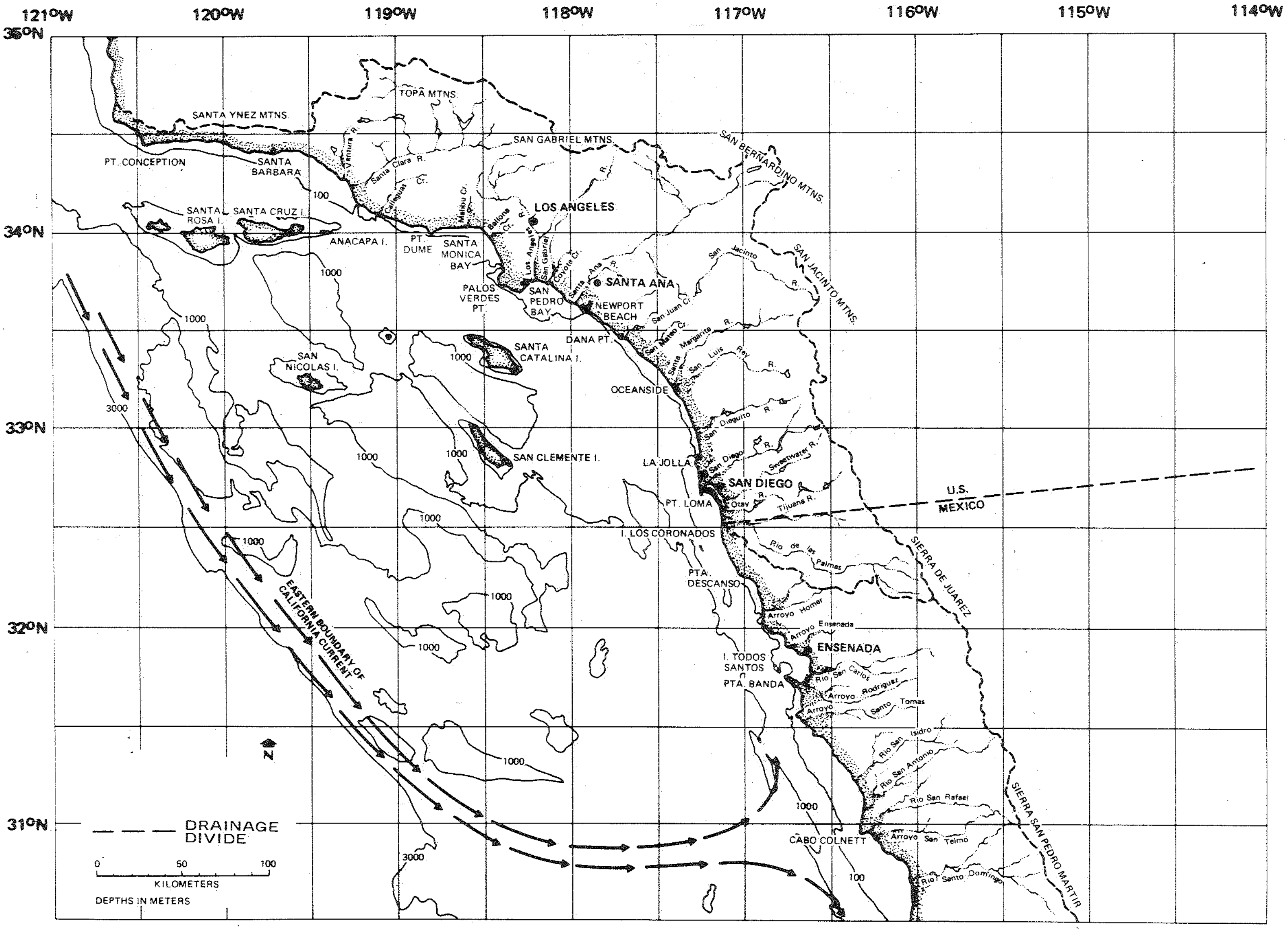

Figure 3-1. The Southern California Bight and the Adjacent Coastal Basin.

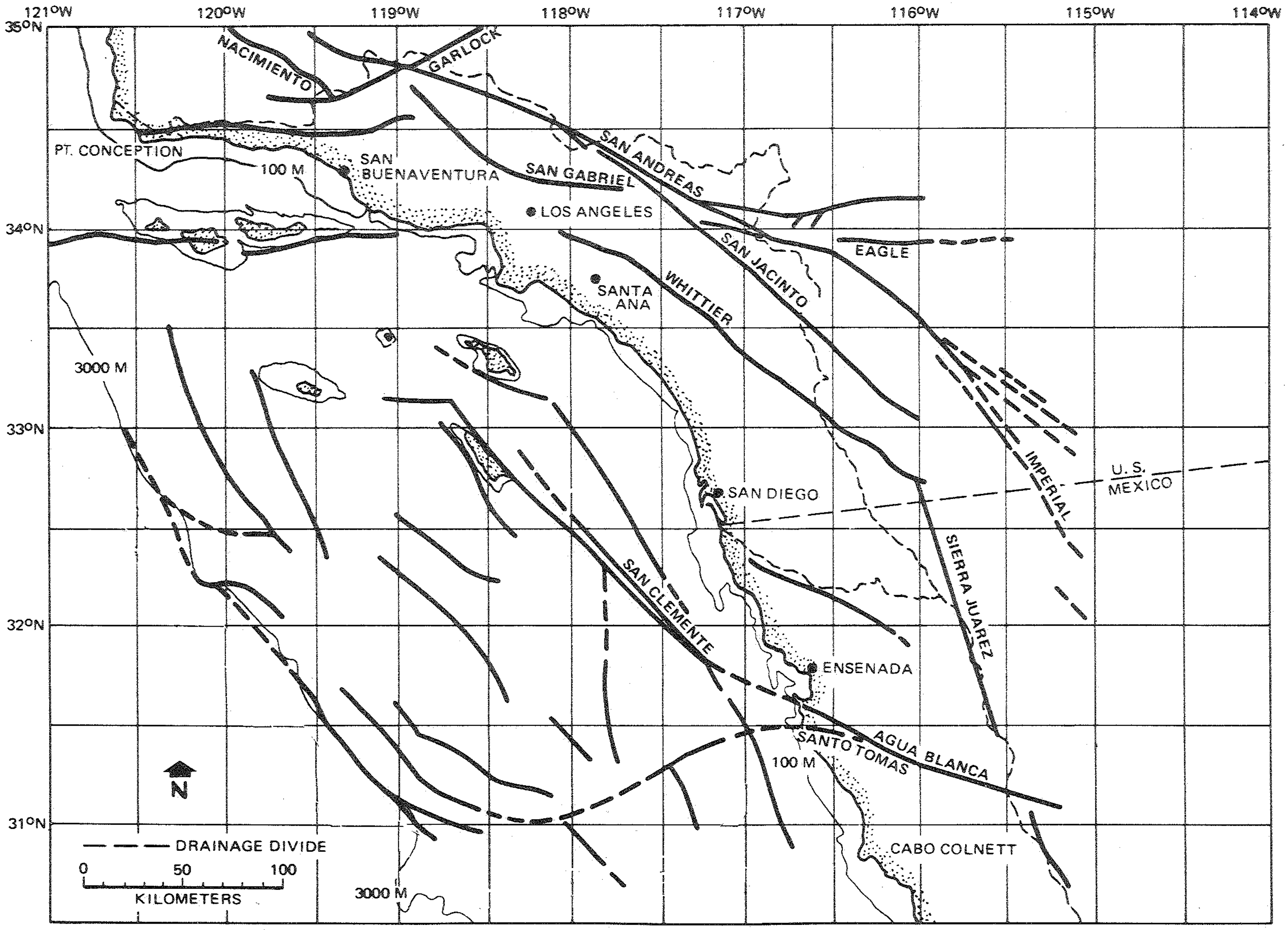

Figure 3-2. Major Faults in Southern California and Northern Baja California. From Moore 1969, Plate 13.

Undersea faults in other geologically active regions of the world recently have been shown to be immense producers of metallic inputs. The Red Sea brines and associated Red Sea sediments and the sediments of the East Pacific Rise are so heavily mineralized as to be potentially minable. Brines of this type have been tapped in the Imperial Valley. Although no similar flows have been demonstrated in the floor of the Bight, they have not been sought, and it would be surprising if, in so complex and active a fault system, submarine inputs of metals were not important. It is probable that any such inputs are rapidly mixed into the waters of the Bight rather than pooled as they are in the weakly circulating Red Sea. Materials in such geothermal brines include silver, copper, arsenic, radium, zinc, selenium, lead, and mercury as well as many other ecologically significant substances.

There are two natural geologic provinces in the southern California and northern Baja California coastal area (Figure 3-3). The Transverse Ranges, which have a west-to-east trend, stretch from Santa Rosa Island inland to within 100 km of the Colorado River. The province formed by these ranges is about 475 km long and from 25 to 100 km wide. It is marked by topographic contrasts ranging from broad river valleys to high mountain chains (highest elevation: 3,073 m at San Antonio Mountain) dissected by deep, narrow canyons. Several large, low-angle thrust faults are major elements in the structure of the Topatopa Mountains, and the Transverse Province is intersected in that area by the San Andreas and associated northwest-to-southeast faults.

The Peninsular Ranges parallel the northwest-to-southeast trend of most of the major ranges of California. The province extends southward from the foot of the southern slopes of the Transverse Ranges to the tip of Baja California and westward to the continental slope. The exposed portion is 1,450 km long, from 90 to 220 km wide, and 3,294 m at its highest point, San Jacinto Peak. (The continental borderland, the submerged part of the province, is described later in this section.) The profile of the province is asymmetric, with the eastern slopes rising steeply from the desert and the western slopes long and gentle, broken locally by a wide variety of features. The coastal zone is irregular, ranging in width from a few meters to about 50 km.

3.2.1 The Coastline

The coastline, which comprises the beaches, cliffs, coastal terraces, and other land features immediately affected by the ocean, is a region sensitive to the phenomena occurring on land as well as to the sea's erosional and depositional processes. In southern California, the human activity on the land is intense: A significant portion of the shoreline has been dredged, filled, or reshaped for the development of ports, harbors, marinas, and jetties and for other purposes. These and other human activities, some occurring far inland, combine and interact with natural processes to change the existing coastline and to affect the character of the adjacent coastal waters and sea floor.

A rough but useful classification of the shoreline can be made in terms of rocky and sandy. In general, rocky shorelines have been shaped by erosional processes, whereas sandy beaches backed by deltas, alluvial fans, or mudflats are depositional. Sandy shorelines backed by cliffs are influenced by both processes; i.e., they are erosional on a long-term basis, although the beach indicates temporary depositional characteristics. The lengths of southern California

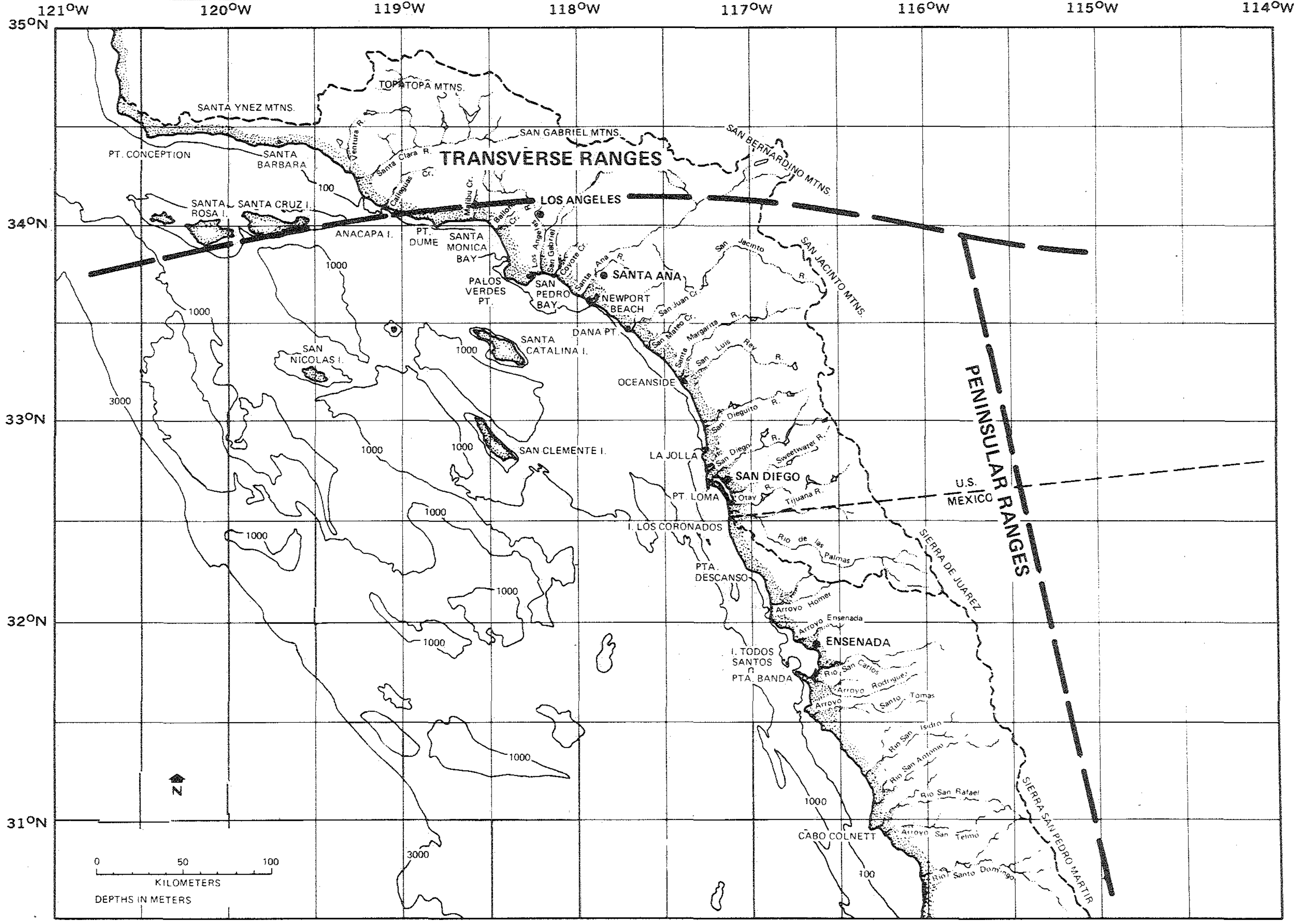

Figure 3-3. The Natural Geologic Provinces of Southern California and Northern Baja California.

shoreline that fall into each of these categories are given in the following table:[1]

	Rocky (Erosional)	Sandy: Backed by Cliffs (Erosional)	Sandy: Backed by Lowlands (Depositional)	Total
Mainland	81 km	278 km	129 km	488 km
Islands	410	92	0.5	502
Total	491 km	370 km	129 km	990 km

As the table shows, almost 87 percent of the coastline of southern California (including the islands, where most shorelines are rocky) is erosional. It is also interesting to note that the total length of island coastline exceeds that of the mainland.

Erosional Coasts

Most erosion at the coastline occurs through mechanical processes, such as abrasion by suspended sands and gravel or by runoff. Substantial quantities of debris also enter the sea through the activities of boring and shell-bearing organisms. Overall, the erosion of rocks other than by surface runoff is occurring at an extremely slow rate in southern California.

The cliffs of the erosional coasts of southern California range in height from 2 to more than 150 m. Direct erosion at the shore occurs only at the level between high and low tides. Thus the bulk of erosion of high cliffs is caused indirectly by the undercutting that finally results in landslides. About 12 percent of the total length of shoreline in southern California has been affected by such landslides.

Land-form erosion is a perennial and variable process. For example, the presence of a talus or gravel rampart at the foot of many southern California coastline cliffs usually affords protection against marine erosion. However, during severe storms, waves may reach the cliffs, and considerable erosion may result. More significantly, storms greatly increase the amount of erosion through surface runoff. As the rate of input of natural particulates by erosional processes is far from constant, the offshore deposition of the particulate material (which sometimes greatly alters the character of offshore habitats) also varies. In addition, the input of various minerals to the Bight fluctuates, depending upon the amount of erosion and the geological nature of the source material.

Depositional Coasts

Most of southern California depositional coasts are sandy beaches along the mainland. About 30 percent of the sandy beaches of the area are backed by lowlands (marshes or mudflats) and are thus truly depositional. The remainder are found at the base of sea cliffs in coastal areas that must be considered only temporarily depositional.

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[1] From Emery 1960, tab. 2.

Beach Sand Transport. The role of waves and tides in the transport of beach materials is an important indication of the natural transport processes available for pollutants. Waves at the shoreline and related nearshore water movements initiated by waves move sediment in three directions--onshore, offshore, and alongshore. Most of the waves in the Bight come from the southwest in the summer and from the west and northwest in winter, with a resultant concentration of sand in the central part of the Bight, i.e., between Ventura and San Diego. The estimated rate of transport of sand along the coastline toward the middle of the Bight is about 250,000 cu m/yr.

Net offshore transport of sand may occur where submarine canyons intercept the sand transport zone. Four submarine canyon systems fall into this category: The Hueneme-Mugu-Dume group, Redondo, Newport, and the Scripps-La Jolla group. These divide the region into five nearly independent beach units.

There is a natural annual onshore-offshore movement of sand on most beaches, resulting in a lowering of the intertidal portion of beaches during the winter and a buildup during the summer. The lunar tidal cycle of low neap and high spring tides (each event occurring about once a month) also causes a periodic variation in beach level. Another cycle of beach sand movement occurs because of changing water levels during the tides, and other changes are observed with changing wave height, length, and angle of approach.

Finally, the longshore transport of sand by littoral currents causes changes in erosion and deposition along the shoreline. The average size of the grains on a beach, as well as the thickness and extent of the sand, varies with changes in the currents and the characteristics of the waves that supply the transport energy to the system. The interposition of breakwaters, groins, piers, and other structures across this transport system has serious consequences. Erosion occurs downcurrent from a structure such as a groin, while deposition occurs on the upcurrent side (Figure 3-4). This sequence of events has occurred with the building of almost every structure across southern California beaches, sometimes with far-reaching effects on the character of the coastline. For example, the section of shoreline from Santa Monica to Redondo Beach formerly received sediment from river drainage, but this beach area has been so extensively altered by development of piers, groins, breakwaters, flood controls, and buildings that the present configuration only vaguely resembles that which existed around 1850. Beach erosion now occurs where formerly this coastline was depositional, and sand must be brought from inshore sand dunes to replenish losses to the sea.

Marine Terraces

One of the more impressive features of the southern California coastal area is the mesaland topography of some sections of the coastline. The marine terraces, which may appear as steps on the coastal hills, were cut from the sedimentary rocks of the coastal zone by waves at other stands of sea level. Terraces are exposed on all the southern California islands, in the San Diego area, and at many other places along the coast. Most are under 150 m in elevation, but some on the islands reach over 600 m. Widths range from a few meters to over 8 km.

The terraces display a unique fossil record of prehistoric marine life, but are primarily of significance to man because of their suitability for construction. In many hilly areas adjacent to the coast, virtually all works of man are located on the terraces, and the characteristics of surface runoff in these areas is thereby affected.

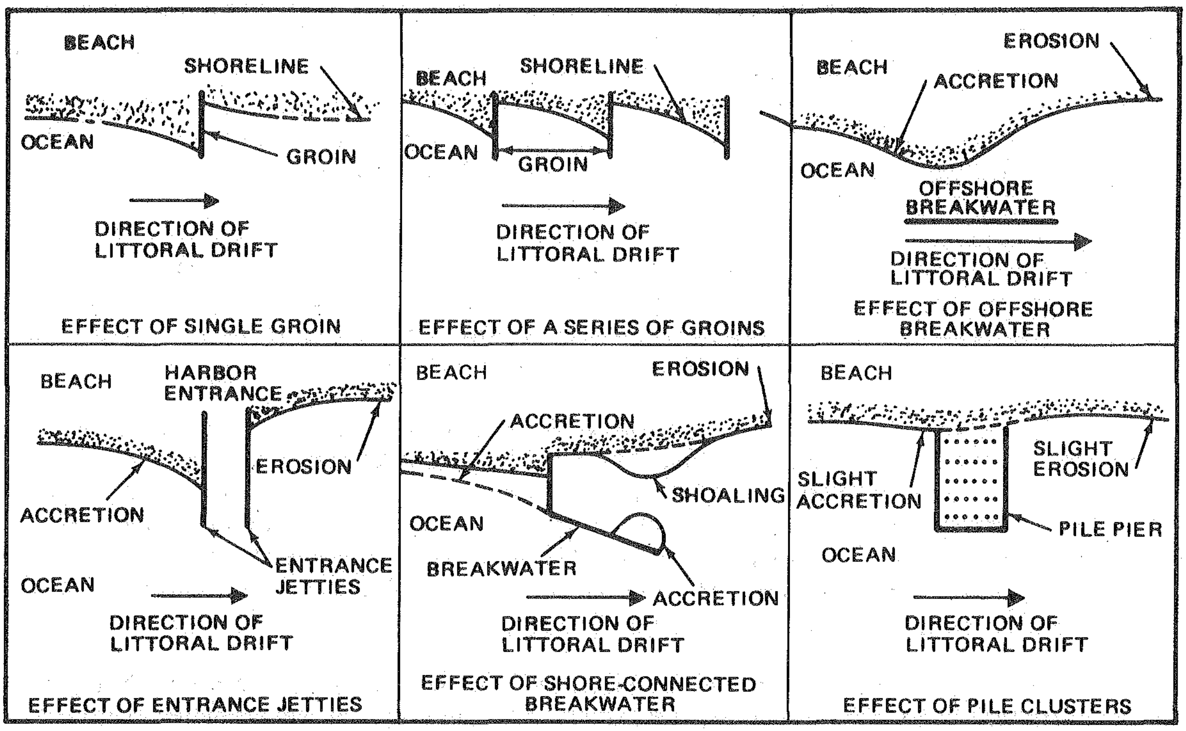

Figure 3-4. The Effect of Man-Made Structures on Littoral Drift. (From Peel and Kaplan 1953, figs. 40-45

Beach Sand Supply. Sand and gravel are supplied through local erosion of sea cliffs and through surface runoff in streams. The latter is by far the more important source of sediment (but probably not of erosional trace minerals). An average of nearly 2 million cu m of sediments (including silt and clay) are contributed to the Bight annually (Table 3-1). On a long-term basis, most of the input occurs during large, infrequent floods (a pattern typical of semiarid regions). For example, 6.2 million cu m of sand alone were deposited at the mouth of the Los Angeles River during the flood of 2 March 1938.

As surface runoff is the major source of beach sand, man's obstruction and modification of stream courses has had a significant impact on the coastline. Channeling of stream beds and dam construction for soil erosion prevention or flood control have reduced beach sand supply and changed prograding river deltas into tidal inlets, consequently inducing beach erosion.

3.2.2 The Offshore Islands

There are eight islands off the coast of southern California, commonly called the Channel Islands. The northernmost group consists of San Miguel, Santa Rosa, Santa Cruz, and Anacapa; these islands are the exposed extensions of structural features found on the mainland. The others--San Nicolas, Santa Barbara, Santa Catalina, and San Clemente--which are dispersed widely through the center of the Bight, are the emergent peaks of undersea ridges. The dimensions and elevations of the islands are given in Table 3-2.

Table 3-1
ESTIMATE OF LONG-TERM BEACH SAND SUPPLY
FROM MAJOR SOUTHERN CALIFORNIA STREAMS*

Streams	Mean Sediment Load (1,000 cu m/yr)
Santa Ynez Mtn. Group	28
Ventura River	77
Santa Clara River	344
Santa Monica Mtn. Group	12
Ballona Creek	35
Redondo-Palos Verdes Group	46
Santa Ana River	22
Aliso Creek	8
San Juan Creek	44
San Mateo Creek	25
Santa Margarita River	12
San Luis Rey River	269
San Dieguito River	3
San Diego River	84
Tijuana River	694
TOTAL	1,703

*Based on California Depart. of Water Resources 1969.

Beach sand transport and other shoreline processes discussed in the preceding subsection are strongly influenced by the islands, which have a "shadowing" effect on the mainland. The islands are spawning grounds for some species and thus affect the operations of local sport and commercial fisheries. In addition, the islands are a determinant of water circulation and shipping lane patterns in the Bight.

Over half the coastline of southern California belongs to the islands, and they are an important source of erosional inputs. As on the mainland, the character of these and other inputs to the Bight from the islands is influenced by the human activities found there as well as by the rock and soil types. Santa Rosa and Santa Cruz are devoted to ranching; Santa Catalina has several natural harbors and coves used extensively by pleasure craft and a public resort at

Table 3-2
DIMENSIONS AND ELEVATIONS OF THE CHANNEL ISLANDS

Island	Length (km)	Maximum Width (km)	Highest Elevation (m)
San Miguel	13	6.5	254
Santa Rosa	21	13	466
Santa Cruz	34	8	740
Anacapa			
West	2.5	0.3	294
Middle	2.5	0.3	99
East	1.5	0.3	76
Santa Barbara	2.5	1.5	194
Santa Catalina	30	11	648
San Nicolas	14.5	5	277
San Clemente	29	6.5	598

Avalon; and San Miguel, San Nicolas, and San Clemente are U.S. Naval reservations. All, including the uninhabited Anacapa and Santa Barbara, are used heavily by sports fishermen and scuba divers.

3.2.3 The Sea Floor

The classic continental slope-abyssal sea floor sequence outward from the coastline does not appear in southern California. Instead, the mainland shore is bordered by a narrow continental shelf, followed by a narrow slope region. Next comes a wide, complex region of basins and troughs interspersed with ridges locally piercing the surface as offshore islands. This is the continental borderland (Figure 3-5). Finally, the continental slope, the transition feature between the borderland and the deep-sea floor, is found as much as 250 km from the coast (Figure 3-6).

While the borderland is a distinct physiographic province, it is readily subdivided into its component features--mainland and island shelves, basin and trough slopes, submarine canyons, basins and troughs, and continental slope.

Mainland and Island Shelves

Shelf profiles are generally smooth and regular, except where extensive rock outcrops are exposed on the sea floor. The submerged terraces are generally wider and flatter than most of the emergent shelves exposed on land. The outer terrace is generally regarded as the true outer edge of the shelf. The depth of this edge in the Southern California Bight ranges from about 76 m on the shelf off the Palos Verdes Hills to about 140 m to the south and west.

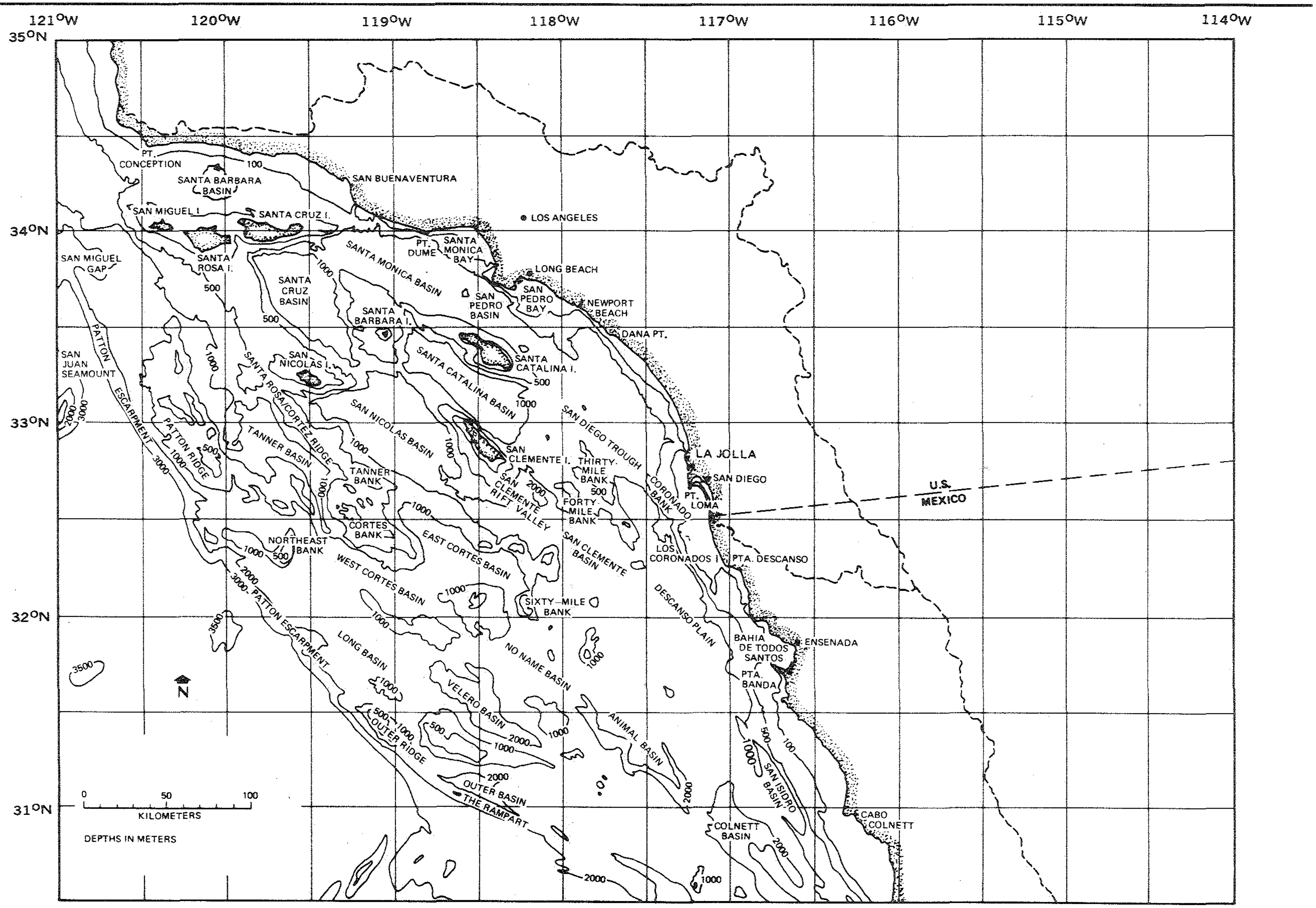

Figure 3-5. The Sea Floor of the Southern California Bight. From Moore 1969, Plate 1

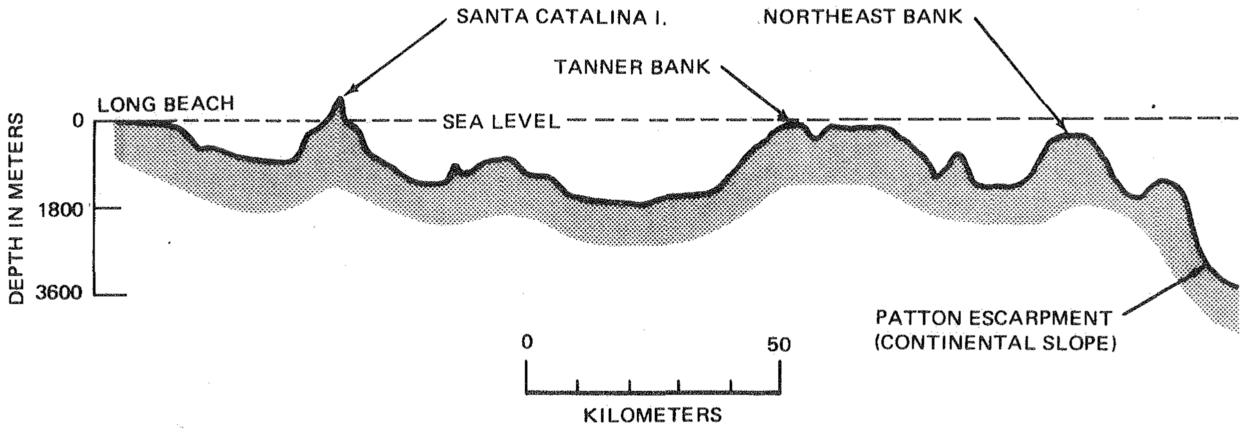

Figure 3-6. A Typical Profile of the Sea Floor Off Southern California. From Shepard 1963, fig. 130.

Basin and Trough Slopes

The slopes that border shelves and bank tops of the Bight and lead down into the adjoining offshore basins and troughs are commonly long and straight; several extend for more than 80 km in nearly straight lines. The slopes, which are generally steeper near the top than near the bottom average 8° in steepness (Figure 3-7). The most prominent departures from the average are slopes that exceed 15 to 20° for long distances on the Coronado, San Pedro, San Clemente, and Santa Catalina escarpments and on the scarps east of Thirty-Mile Bank and west of Forty-Mile Bank; these are believed to be closely related to recent active faulting. Irregularly sloped bottoms usually coincide with (1) partial sediment cover of a rocky bottom (e.g., off Santa Catalina Island) or (2) landsliding (e.g., off the Palos Verdes Hills). Step-like irregularities on some slopes are possibly due to local faulting of a minor nature. An apron of sediment is commonly found at the base of slopes bordering the mainland shelf; this feature is rare for slopes below insular shelves and banks. The greater geomorphic maturity of these nearshore slopes and their proximity to the mainland source of sediment is the most probable explanation.

Submarine Canyons

The submarine canyons off southern California are among the most famous in the world. Although the canyons may not appear impressive as shown on hydrographic charts, several are comparable in size to the Grand Canyon of the Colorado River.

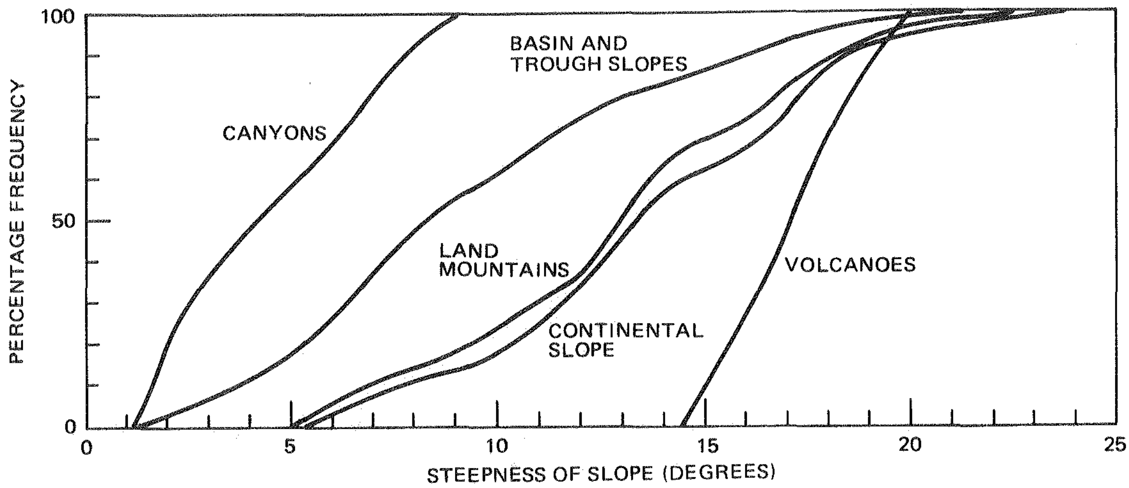

Figure 3-7. Cumulative Curves of Measurements of Steepness of Basin and Trough Slopes and Other Land and Submarine Features of the Southern California Area. From Emery 1960, Fig. 39.

Emery (1960) identifies 32 submarine canyons in the United States portion of the Bight; 20 of these indent the mainland shelf, 10 are located near the Channel Islands, and 2 are adjacent to offshore banks. Several hundred other canyons no doubt exist--many so small as to be best classified as sea gullies, others buried and thus concealed from ready identification. None cross the true continental slope, the transition from the continental borderland to the abyssal sea floor.

Of the 14 major canyons in the Bight that have been identified and named (Figure 3-8), all but Tanner Canyon cross at least the outer third of the mainland or island shelves. La Jolla, Newport, Redondo, Dume, Mugu, and Hueneme Canyons penetrate the mainland shelf to within hundreds of meters of the shoreline and thus trap and funnel littoral-borne material into the offshore sediments.

Although the submarine canyons of the northern and central California coast have been most often associated with upwelling, southern California canyons also provide avenues for the occasional movement of upwelling water or organisms of mid-depth or deep-water origin into the shallow nearshore environment. Partial, temporary filling by sediments takes place; however, these canyons are generally sites of long-term, often very active erosion.

Multiple heads are common features of the canyons that penetrate the shelf to the vicinity of the coastline. Detailed examination of the area around the head of Santa Monica Canyon by the City of Los Angeles prior to construction of the 7-mile Hyperion Treatment Plant sludge outfall revealed the presence of at least three small tributary canyons at the head, where only one had been

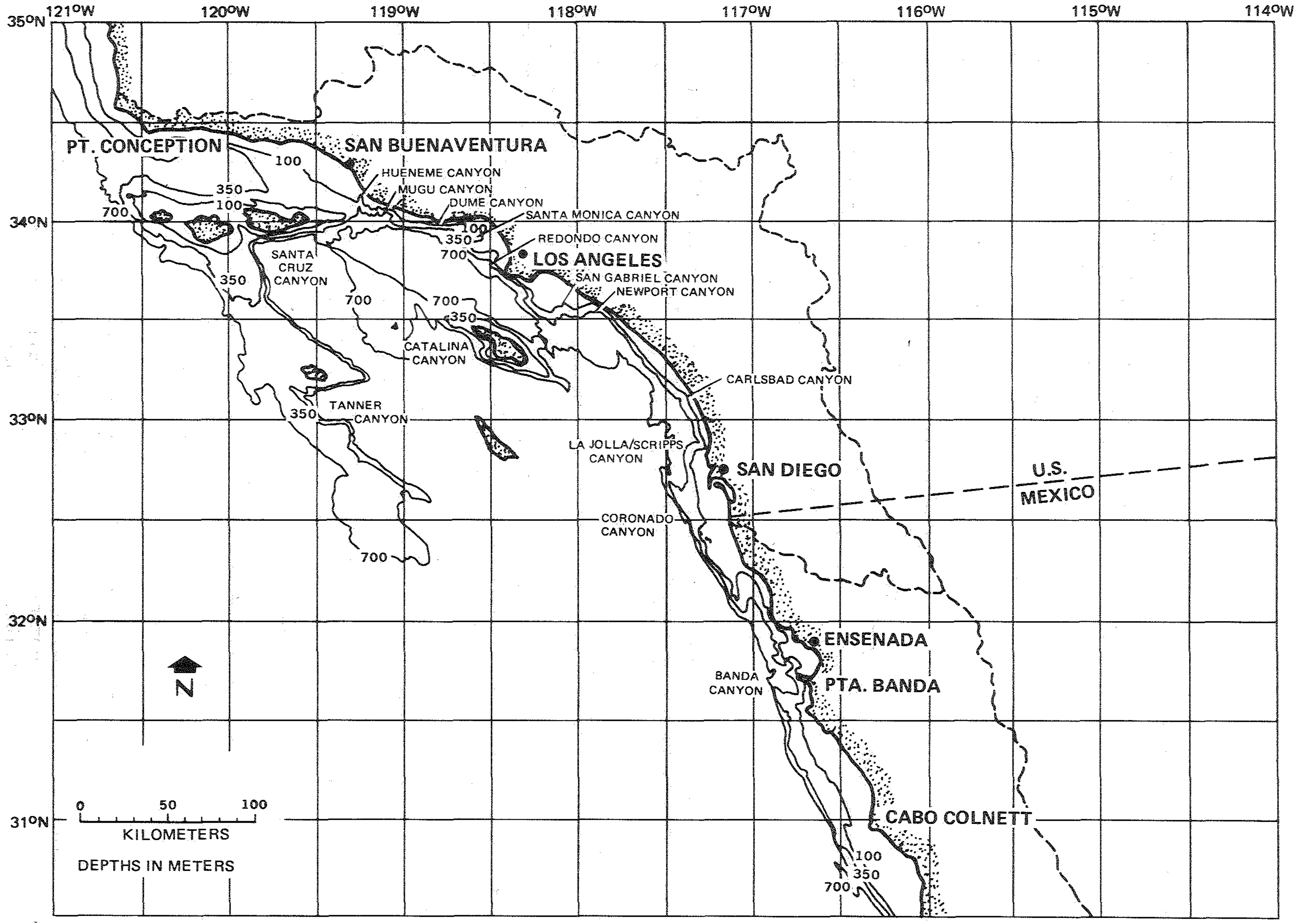

Figure 3-8. Submarine Canyons of the Southern California Bight.

believed to exist. Slopes near the heads are greater than those farther offshore. Like canyons on land, these features also become wider with increasing distance from the head.

Basins and Troughs

Marine geologists generally define a basin as a closed depression, deeper than its surroundings, approximately equidimensional in plan view. A trough is an elongated basin with two sides roughly parallel to each other. A low point on the basin rim is a sill; multiple sills may occur. There is an inverse relationship of shoaling, broadening, and flattening of basins with distance from the mainland shore (Figure 3-9): The nearshore basins are generally shallower, broader, and have more regular floors than those farther offshore. These observations, augmented by measurements of rates of deposition and some seismic data, support the conclusions that the nearshore basins are receiving the most sediment and that this has been occurring for a long time. However, these regions have been virtually ignored in marine pollution monitoring efforts.

The longer dimensions of basins are generally parallel to associated land features. Thus, the Santa Barbara Basin and the filled Ventura Basin have an east-west trend parallel to the Transverse Ranges. The other submarine basins have a northwest-southeast trend parallel to the Peninsular Ranges of southern

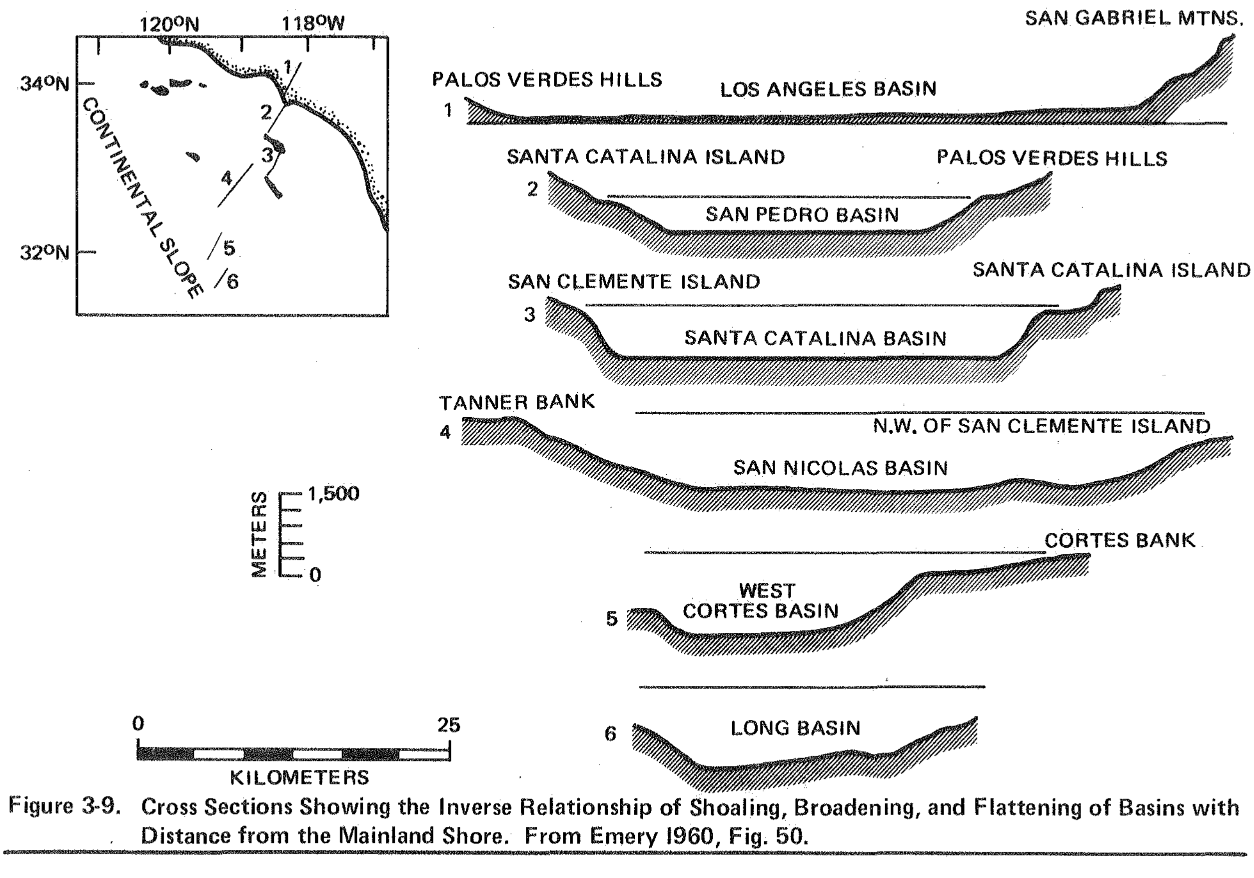

Figure 3-9. Cross Sections Showing the Inverse Relationship of Shoaling, Broadening, and Flattening of Basins with Distance from the Mainland Shore. From Emery 1960, Fig. 50.

California. The remaining filled basins on land have an east-west trend like the mountains that enclose them.

The Continental Slope

The continental slope off southern California lies 90 to 300 km from the coastline. The average width of the slope is about 19 km, and its base on the abyssal sea floor is at a depth on the order of 3,000 m. The average slope is about 8 to 9°. The profile is nearly straight, interrupted only by small irregularities. Five gaps in the slope are believed to be of structural origin; no submarine canyons have been recognized.

3.3 CLIMATOLOGY AND HYDROLOGY

The mild "Mediterranean" climate of the southern California coastal basin has always been considered one of its strongest attractions. Summers are warm and almost rainless; winters are pleasant with occasional mild storms, although heavy rains and rapid runoff from the mountains and coastal slopes have sometimes caused serious flooding and large aperiodic inputs to the ocean.

In the southern California coastal basin, there are 18 major watersheds, with a combined land area of some 33,000 sq km, through which water and silt (as well as the dissolved substances and particle-borne materials associated with them are introduced into the Pacific Ocean. These watersheds, designated Hydrologic Units H1 to H18,[2] are shown in Figure 3-10. Some of the hydrologic units are integrated river systems; others are smaller watersheds in coastal areas that drain by one or more streams directly into the sea. The major river systems are those of the Santa Clara, Los Angeles-San Gabriel, Santa Ana, and Tijuana Rivers.

3.3.1 Precipitation

Annual precipitation in the southern California coastal basin strongly depends on distance from the coast, elevation, and topography. Twenty-two U.S. Weather Bureau stations have been selected to present a general description of precipitation distribution in the coastal region; station names and locations are shown in Table 3-3 and Figure 3-11, respectively.

Precipitation in the coastal basin occurs as rainfall on the coastal lowlands and as snow and rainfall in the mountains. Table 3-3 presents normal annual precipitation data as well as precipitation data for two relatively abnormal years. The large variations in rainfall are evident even on this annual basis. Approximately 90 percent of the precipitation occurs during the period November through April. Figure 3-12 illustrates the large seasonal variation of annual precipitation in the region.

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2. This drainage basin division is essentially that adopted by the California Department of Water Resources (1971).

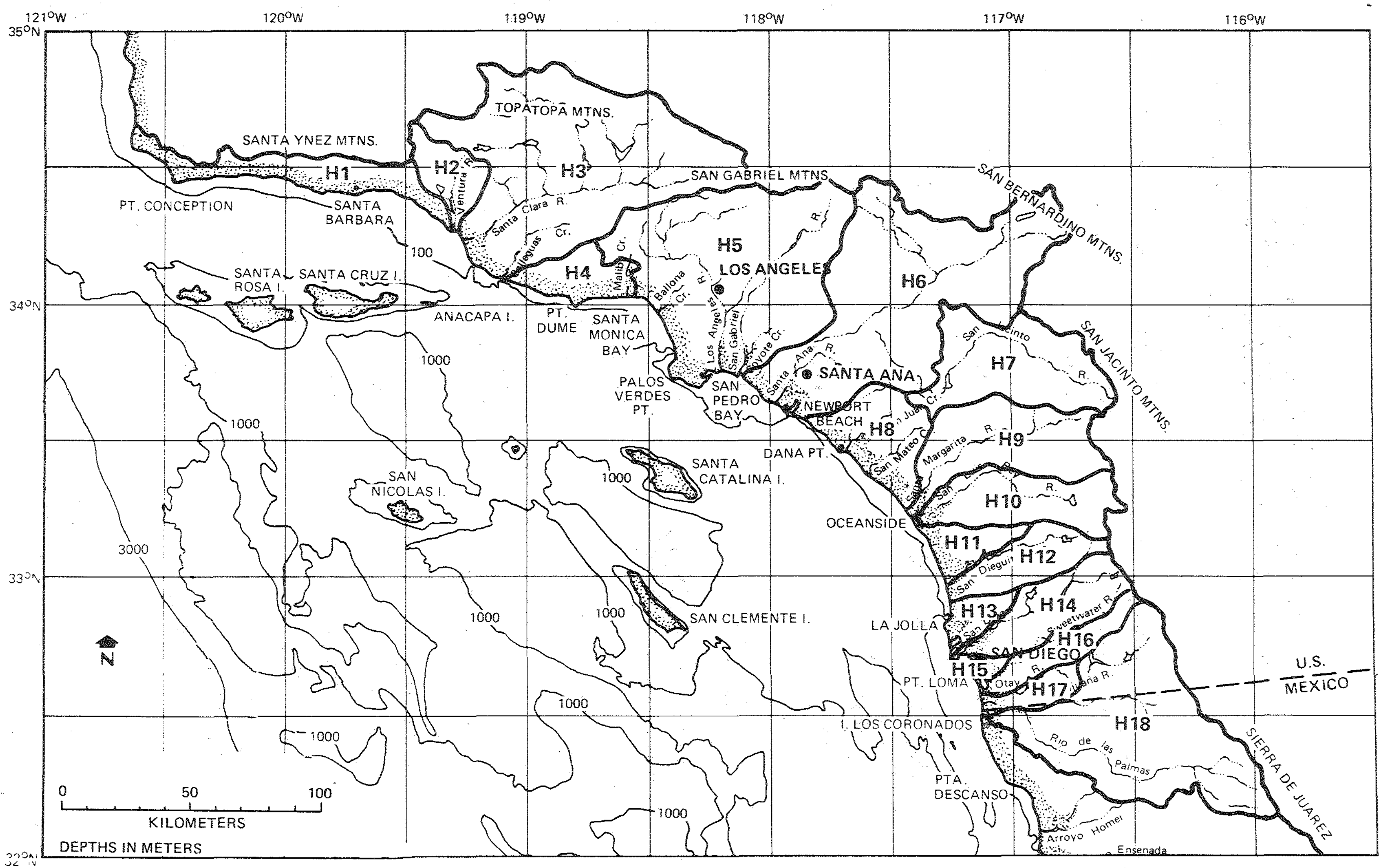

Figure 3-10. Hydrologic Units in the Southern California Coastal Basin.

Table 3-3
ANNUAL PRECIPITATION AT SELECTED STATIONS
IN THE SOUTHERN CALIFORNIA COASTAL BASIN

Ref. No.*	Station	Annual Precipitation (cm) Normal	1968	1969
1	Santa Barbara	43.4	29.7	74.9
2	Ojai	51.6	30.7	116.1
3	Oxnard	37.3	25.4	53.3
4	Sandberg Weather Serv. Off.	30.7	11.9	42.9
5	Los Angeles Weather Serv. Off.	32.8	18.8	40.1
6	San Fernando	43.7	18.3	70.6
7	Pasadena	51.3	19.8	82.3
8	Mt. Wilson	78.0	30.7	166.9
9	Long Beach Weather Serv. Off.	25.1	14.5	51.1
10	Pomona (Calif. State Polytechnic College)	47.5	23.9	73.9
11	Corona	31.2	17.5	62.2
12	San Bernardino Co. Hosp.	45.0	19.6	81.3
13	Big Bear Lake	81.5	31.5	141.7
14	Beaumont Pumping Station	52.1	28.7	83.3
15	San Jacinto	32.8	16.5	43.4
16	Elsinore	25.4	14.5	55.9
17	Laguna Beach	32.0	14.7	56.6
18	Warner Springs	40.1	24.1	60.5
19	Escondido	41.1	15.5	47.2
20	Cuyamaca	96.3	41.7	118.1
21	San Diego Weather Serv. Off.	27.2	9.4	29.7
22	Barrett Dam	43.9	21.1	57.4
	Average of 22 Stations	45.0	21.8	73.2

*Key to location on Figure 3-11.

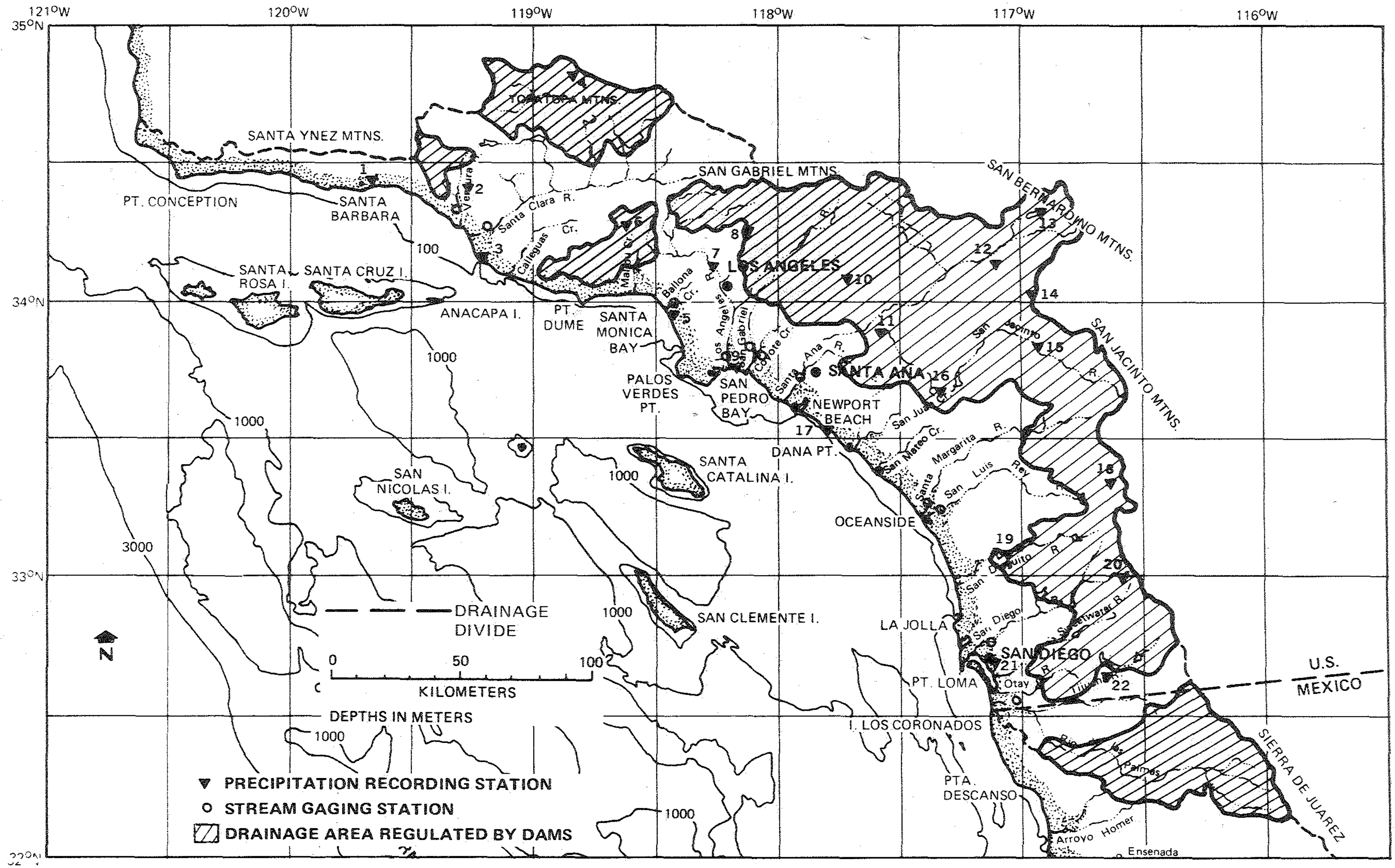

Figure 3-11. Regulated Watersheds and River Gauging and Rainfall Recording Stations in the Southern California Coastal Basin.

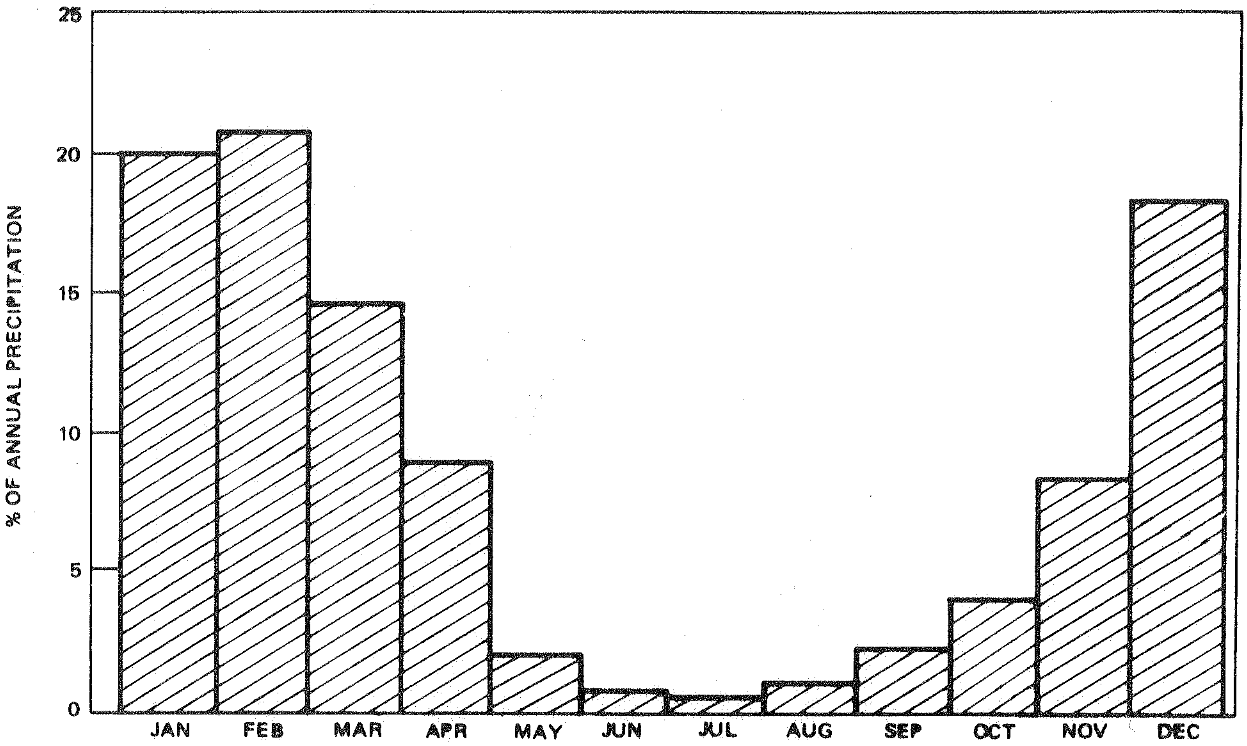

Figure 3-12. Monthly Variation of Precipitation in the Southern California Coastal Basin (Average of 22 Stations).

In the lowlands along the Pacific coast, precipitation varies from north to south. For example, Santa Barbara has a normal annual precipitation of approximately 43 cm, Los Angeles has 33 cm, but San Diego (the southernmost point) receives only about 27 cm. The wetter locations in the interior lowlands are usually on the seaward side of the mountains and at elevations above 300 m. Typical rainfall amounts in these areas are 25 to 50 cm (Ojai, Pasadena, San Fernando, San Bernardino, and Elsinore). As the valley floor rises to the mountains, annual precipitation increases to as much as 78 to 96 cm (Mount Wilson, Big Bear Lake, and Cuyamaca).

1968 was a relatively dry year for the entire coastal basin--as little as 40 percent of the normal annual precipitation was recorded. Conversely, 1969 was a relatively wet year, with up to 220 percent of normal annual average Precipitation.

3.3.2 Stream Runoff

Stream runoff, one of the major inputs to the ocean, is controlled by regional hydrology. Within the southern California coastal basin, there are more than 150 streams discharging at points along the coastline, excluding the storm drains in the urbanized areas. Table 3-4 lists 19 major streams for which there are relatively long flow records. The total area tributary to the gauging stations on these streams is about 22,500 sq km, or 70% of the total land area of southern California coastal basin. As already mentioned, 1968 and 1969 are two of the most recent atypical years in southern California hydrologic history. The annual discharges in 1968 and 1969 from these streams are presented in Table 3-4, along with the mean annual flow rate during the record years up to 1970; these data and those in Table 3-3 are summarized as follows:

	Long-Term Average	1968	1969
Precipitation			
Average of 22 selected stations (cm)	45	22	73
Percent of long-term average		49	162
Stream Runoff			
Total flow of 19 gauged streams (10^6 cu m/yr)	566	173	3,846
Percent of long-term average		31	680
Ratio of total runoff to total annual precipitation (10^6 cu m/cm)	12.6	7.9	52.7

This comparison illustrates that the natural fluctuations in storm pattern and rainfall intensity/duration relationships preclude close estimates of stream flow from annual precipitation data.

Most of the stream flows in the southern California coastal area have been considerably altered by regulation and impoundment, either for flood control or

Table 3-4
ANNUAL FLOW RECORDS OF MAJOR RIVERS IN THE SOUTHERN CALIFORNIA COASTAL BASIN*

						Records of Flow		
Ref No.**	Hydrologic Unit	Stream	Gauge Location	Area of Basin Above Gauge (sq km)	Years Kept	Mean Annual Average (10^6 cu m/yr)	1968 Flow (10^6 cu m/yr)	1969 Flow (10^6 cu m/yr)
H1	Santa Barbara/ Rincon	Jalama Cr.	Lompoc	53	5	3.1	0.2	7.4
		San Jose Cr.	Goleta	14	29	1.7	0.4	5.7
		Atascadero Cr.	Goleta	49	29	3.5	1.0	26.0
		Carpinteria Cr.	Carpinteria	34	29	2.6	0.2	30.1
			Total H1	150		10.9	1.8	69.2
H2	Ventura	Ventura R.	San Buena-ventura	487	43	52.3	5.0	310.6
H3	Santa Clara/ Calleguas	Santa Clara R.	Montalvo	4,175	26	102.8	5.0	1,099.6
H4	Malibu	Malibu Cr.	Crater Camp	272	39	19.6	9.4	148.6
		Topanga Cr.	Topanga Beach	47	39	5.1	1.2	36.4
			Total H4	319		24.7	10.6	185.0
H5	Los Angeles/ San Gabriel	Ballona Cr.	Culver City	232	20	38.9	28.4	89.9
		Los Angeles R.	Long Beach	2,155	41	148.5	87.6 50.6%	961.4 25%
		Coyote Cr.	Los Alamitos	352	7	30.2	17.5	79.7
		San Gabriel R.	Los Alamitos	1,222	42	25.2	3.8	257.4
			Total H5	3,961		242.8	137.3	1,388.4
H6	Santa Ana	Santa Ana R.	Santa Ana	4,375	30	28.1	6.5	479.9
H8	San Juan	San Diego Cr.	Irvine	104	21	2.7	1.5	19.7
		San Juan Cr.	San Juan Capistrano	275	42	12.3	1.6	95.8
			Total H8	379		15.0	3.1	115.5
H9	Santa Margarita	Santa Margarita Cr.	Ysidora	1,914	47	25.9	0	144.1
H10	San Luis Rey	San Luis Rey R.	Oceanside	1,445	38	13.8	2.4	31.4
H14	San Diego	San Diego R.	Santee	976	57	20.7	1.3	17.9
H18	Tijuana	Tijuana R.	Nestor	4,377	35	28.7	0.1	4.6
			TOTAL	22,549		565.7	173.1 1/3X	3,846.2 6.5X

*Based on U.S. Geological Survey 1968, 1969, 1970

**Key to location on Figure 3-11.

See P. 24

Table 3-5
MAJOR DRAINAGE AREAS CONTROLLED BY DAMS
IN THE SOUTHERN CALIFORNIA COASTAL BASIN*

Stream	Total Drainage Area (sq km)	No. of Dams	Drainage Area Controlled by Dams	
			Sq km	% of Total
Ventura R.	590	7	240	41
Santa Clara R.	4,250	4	1,450	34
Malibu Cr.	310	4	280	90
Los Angeles R.	2,180	23	1,470	67
San Gabriel R.	1,610	21	1,160	72
Santa Ana R.	7,200**	42	5,860	81
Santa Margarita R.	1,920	3	830	43
San Luis Rey R.	1,450	2	530	37
San Dieguito R.	850	4	780	92
San Diego R.	1,130	3	700	62
Sweetwater R.	470	2	380	81
Otay R.	390	2	260	67
Tijuana R.	4,490	4	3,200	71
TOTAL	26,840	121	17,140	64

*Based on Calif. Dept. of Water Resources (1969) and Norris (1964).
**Including 1,990 sq km upstream of Lake Elsinore.

water conservation purposes. At present, there are 121 dams on 13 of the major streams (Table 3-5). As of 1970, stream runoff from approximately 17,100 sq km of drainage area was controlled or regulated by dams; this controlled area is about 64 percent of the combined drainage area tributary to the 13 major streams listed on Table 3-5 and is more than 50 percent of the land area of the southern California coastal basin. The extent of the controlled area, illustrated in Figure 3-11, is expected to increase.

3.3.3 Wastewater

Another important source of freshwater to the Bight, especially during the dry season of the year, is the continuous discharge of various municipal and industrial wastewaters. Besides drawing water from local surface and ground sources, the southern California coastal area has been dependent on imported waters (from Hoover Dam via the Colorado Aqueduct, from the Sierra Nevada via the Los Angeles Aqueduct, and from northern California via the California Aqueduct) for its domestic, industrial and agricultural uses. Most of the waters used for domestic and industrial purposes and some of the agricultural waters find their way into the municipal wastewater treatment plants and eventually enter the coastal waters. At present, the total amount of municipal and industrial wastewaters discharged directly into the coastal waters is estimated to be more than 1,100 mgd (1.5 x 10^9 cu m/yr)--more than twice that of the long-term average input via stream runoff from the gauged drainage area described in Table 3-4. At present, five major ocean outfalls discharge about 940 mgd (1.3 x 10^9 cu m/yr) of treated municipal wastewaters into the coastal waters. The distribution of this freshwater inflow and the mass emission rates of associated constituents are examined in Chapter 4.

3.3.4 Input of Solar and Atmospheric Radiation

The heat budget of a natural water body simply states that the time rate of change of heat content (and hence, temperature) of the water body is equal to the sum of the fluxes of heat added to the body minus the sum of the fluxes of heat lost from the body. In utilizing such heat budgets, it has been usual to consider the shortwave solar radiation as the only input term acting through the surface, and to combine the incoming longwave radiation from the atmosphere with the outgoing longwave radiation from the water surface into a single loss term, often called the net back radiation.

The incoming longwave radiative flux from the atmosphere depends upon the water vapor content and temperature of the atmosphere, while the outgoing longwave radiative flux from the water surface depends only upon the surface water temperature. The two terms are quite independent, and the incoming longwave radiative flux of heat from the atmosphere is just as much a source term in the heat budget as is the incoming shortwave radiative solar flux. Any comparison of the relative size of a man-made heat source to the waters of the Southern California Bight should be made against the sum of the natural heat sources.

The amount of shortwave radiation reaching the earth surface varies with latitude, time of day, season, cloud cover, and other atmospheric conditions. To illustrate the regional characteristics of this fundamental ecological force, monthly mean values of solar radiation at Fresno, Riverside, and La Jolla are shown in Figure 3-13 and the arithmetic mean for these three locations is plotted as Curve 5.

Along the coast, the clear sky solar radiation ranges from 380 cal/sq cm-day during the winter to as high as 785 cal/sq cm-day during the summer, with an annual average of 575 cal/sq cm-day (Curve 1, Figure 3-13). The annual net solar radiation energy absorbed by the earth surface is estimated as 388 cal/sq cm-day, a value typical of sunny climates.

The incoming longwave radiative flux from the atmosphere to the water surface varies with latitude and with season, but this variation is relatively much less than in the case of the solar radiation. The variation in the longwave radiation from the atmosphere with season results from variations in the weighted vertical mean air temperature; the dependence being to the fourth power of the absolute temperature. The mean temperature of the lower layers of the atmosphere over the Bight varies from about 7°C (280°K) in winter to about 22°C (295°K) in summer, and consequently the incoming longwave radiation from the atmosphere to the water surface varies seasonally by only about 10 percent above and below its annual average.

The annual average flux of incoming longwave atmospheric radiation to the surface waters of the Bight is about 710 cal/sq cm-day, or slightly less than twice the annual average solar radiative flux. The annual average sum of solar and atmospheric radiative flux input to the waters of the Bight is then about 1,100 cal/sq cm-day.

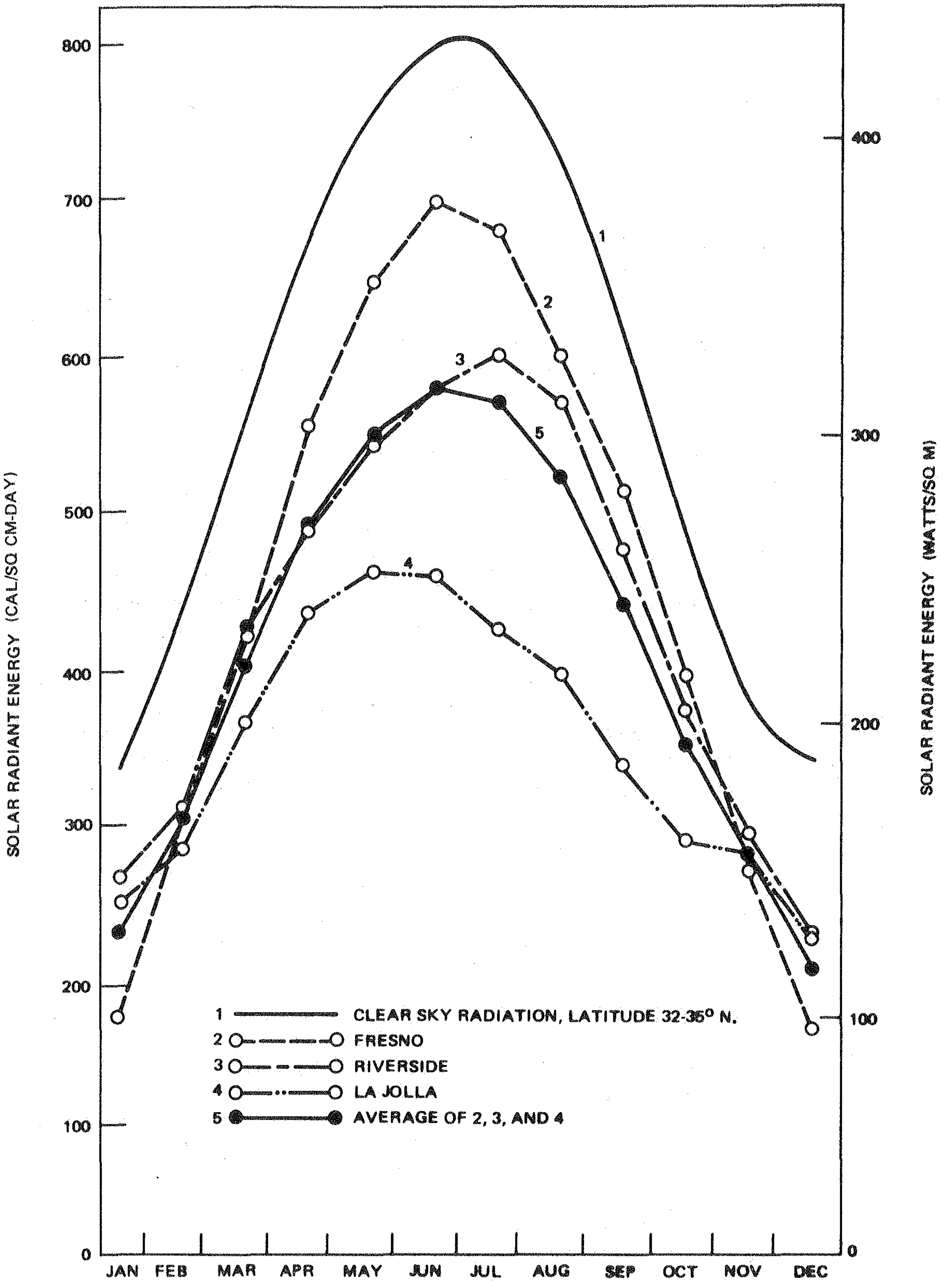

Figure 3-13. Average Monthly Solar Radiation Received on the Horizontal Surface in Southern and Central California. From Young 1971, Fig. 4.

3.4 PHYSICAL AND DYNAMIC OCEANOGRAPHY

There are three principal types of currents present in the Bight: (1) those related to the distribution of mass, (2) those caused directly by the stress of the wind on the sea surface, and (3) those produced by tidal forces.

The first type--called geostrophic currents--results from the fact that, in the presence of a horizontal density gradient, surfaces of equal pressure (called isobaric surfaces) slope relative to geopotential surfaces (surfaces along which no component of gravity acts). There is a force directed down the slope of the isobaric surfaces due to gravity. In the sea, this pressure force is very nearly balanced by the Coriolis force resulting from the rotation of the earth. The Coriolis force is directed at right angles to the current direction (to the right--as viewed "downstream"--in the northern hemisphere, to the left in the southern hemisphere). The resulting geostrophic current in the Southern California Bight is therefore directed in such a manner that the downslope of the isobaric surfaces is to the left of the current and the upslope to the right. Isobaric surfaces slope in a direction opposite to surfaces of equal density. Consequently, the direction of the geostrophic current is such that lower density water is to the right of the flow and higher density water to the left. Since the horizontal variation in density in the Southern California Bight is related more to variations in temperature than to salinity, the flow of the geostrophic current is generally such that the warmer water is to the right of the current and colder water to the left. Geostrophic currents can be computed from the observed density distributions.

The second type of current is due to wind stress on the sea surface. The wind moves the surface water, which is then subject to both friction and the Coriolis force. In offshore areas, the surface water moves at an angle of about 45° to the right of the wind direction. This motion is transferred to the underlying layer of water, causing it to move at a lower speed and slightly to the right of the flow of the overlying layer. At the greatest depth in the layer affected by the wind, the water is moving very slowly in a direction opposite to the surface current. This current profile is called the Ekman Spiral. The angle between the surface current and wind direction depends on latitude and interference from water piled up by the wind against a boundary. The integrated effect over the entire layer under the influence of the wind is an average transport at right angles to the wind. A second effect is the redistribution of mass, which produces a geostrophic flow, the first type of current described.

Off southern California, as a result of these processes, the onset of strong, steady, northerly winds blowing in the late winter moves the warmer surface water to the west and permits colder (denser) water to well up near the coast. This water brings up nutrients, which support heavy plankton blooms and cause the area to be one of high organic production. The resulting redistribution of mass maintains a geostrophic current directed southward.

Tidal currents are produced when the tide rises and falls in the ocean as a result of the gravitational attraction between earth, moon, and sun and the centrifugal force that balances the attractions. Although lunar and solar tides produce a rhythmic wave motion, irregular sea-bottom and shoreline topography cause many secondary effects.

The California Current, typical of eastern boundary currents, is best described as a meandering, diffuse southeastward flow, with short-term variations in speed that are of the same order as the mean speed itself. The current, which is a continuation of the westerly drift in the North Pacific, starts its southward flow near the Canadian border and initially contains water characteristic of the subarctic. As this water moves southward, the surface characteristics are modified by solar heating, by upwelling, and by the effects of river inflow and exchange with estuaries and embayments. The flow generally follows the coastline until it reaches the northern limit of the Southern California Bight--Point Conception. Here, the coastline turns abruptly eastward, and the flow of water departs from the coast, generally continuing in a southeastward direction (Figure 3-14). Further south, off the coast of northern Baja California, the main portion of the current turns toward the land, and the flow divides into two branches. One branch, known as the Southern California Countercurrent, turns northward and flows through the Channel Islands, forming the inshore side of the Southern California Eddy. The second branch turns southward and continues down the coast of Baja California, where it eventually turns westward and contributes to the North Equatorial Current.

The Southern California Eddy, a nearly permanent feature of the flow pattern, is seasonal in character. The Eddy is usually well developed in summer and autumn and weak (and occasionally absent) in winter and spring (Figure 3-15).

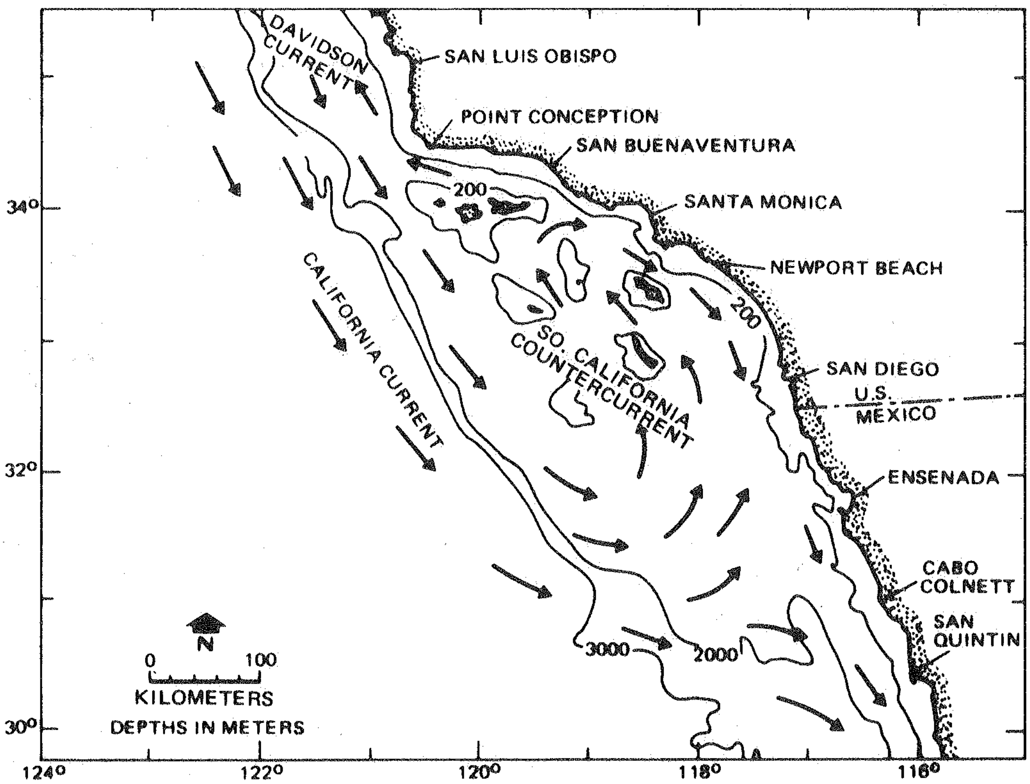

Figure 3-14. Surface Circulation (0—100 m) in the Southern California Bight. (Arrows Indicate Approximate Direction of Flow). From Jones 1971, Fig. 1.

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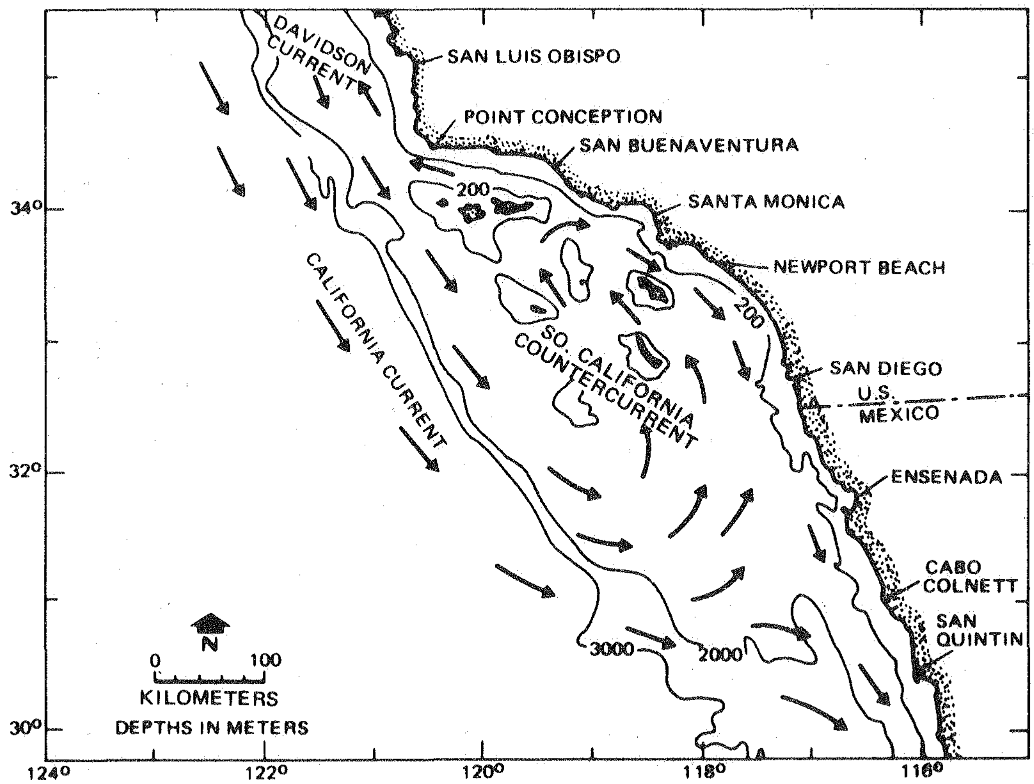

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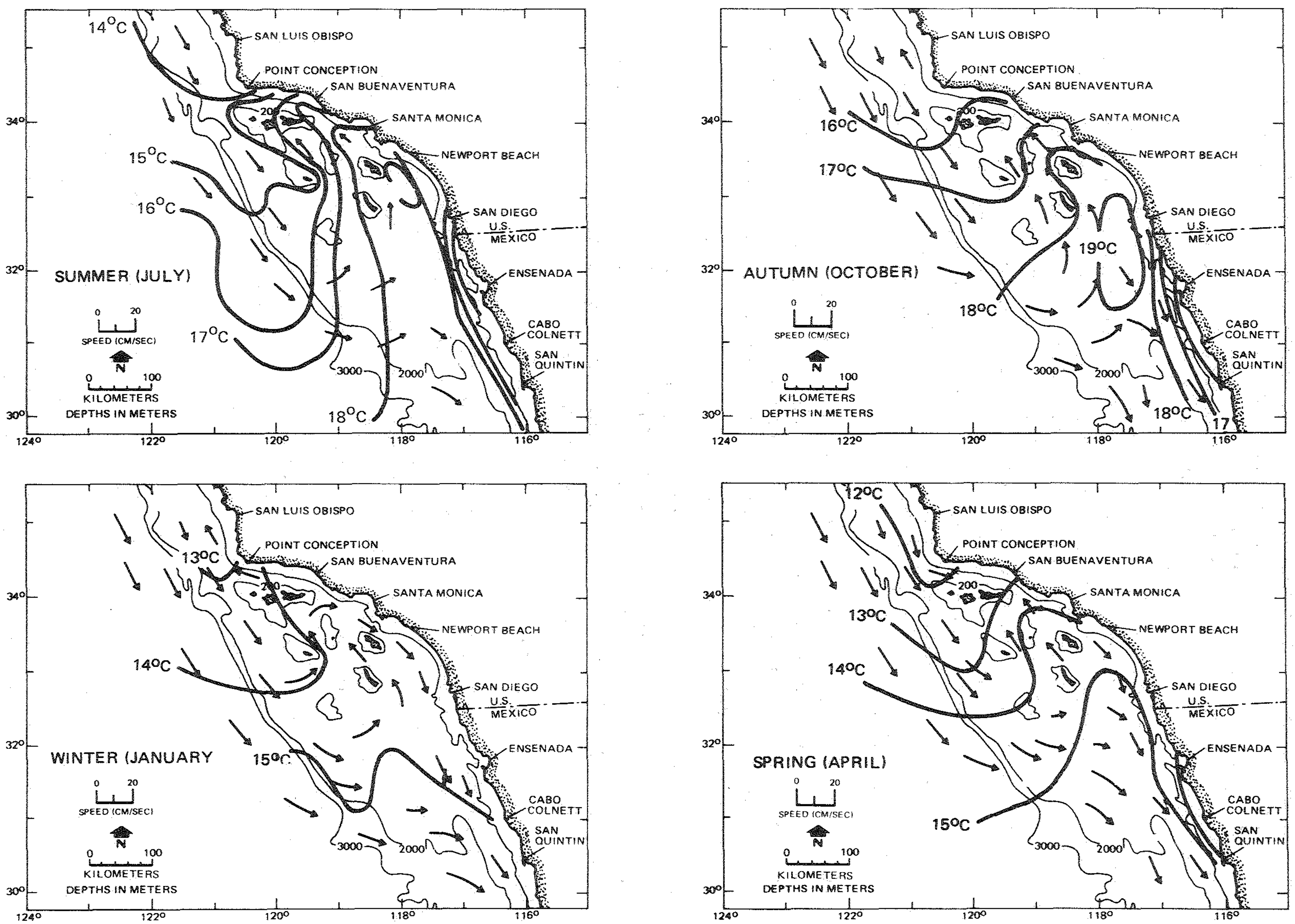

Figure 3-15. Average Geostrophic Surface Flow (Arrows) and Surface Isotherms (Degrees C) in the Southern California Bight. From Jones 1971, Figs. 5-8.

The presence of the coastal countercurrent, known as the Davidson Current (Figure 3-14), north of Point Conception may be considered the antithesis of upwelling. When the dynamics of the circulation are such that a strong Davidson Current is in evidence, no upwelling is likely to occur in the Point Conception area. The Davidson Current is strongest in autumn and winter--the seasons of the weakest northwest winds (Figure 3-16).

Most of the present knowledge about the circulation in the Southern California Bight is based upon information from programs not specifically intended to deal with the dispersion of pollutants as they enter the ocean environment. We have knowledge of the average seasonal variations of some oceanographic parameters, and some data on the monthly variations are available. However, pertinent information is missing regarding the small-scale, horizontal eddy structures, which are important in describing lateral mixing as well as in determining the residence time of a parcel of water or the half-life of a substance in the Bight. Valid estimates of these parameters must await specialized oceanographic field programs and dynamic models of the circulation in the Southern California Bight.

Evidence has indicated that the flow in the California Current is highly responsive to the influence of the winds. Much of the information necessary to document the response of the current to changes in the wind is available. However, no adequate study aimed at predicting changes in the flow pattern has been attempted to date.

The nature of the California Undercurrent (Figure 3-17), especially off southern California, is not at all well understood. It has been suggested that the Davidson Current is a surface manifestation of this flow occurring north of Point Conception. Further understanding of the vertical properties and the northward transport of biota into the region of the Bight is necessary.

3.5 HUMAN POPULATION AND INDUSTRY

Population data for the southern California coastal basin have been compiled from many sources, including reports from the U.S. Bureau of Census, the California State Department of Finance, and the Southern California Association of Governments. Table 3-6 shows the estimated population of seven southern California counties for 1960 and 1970. As the county lines do not match the coastal basin drainage divide, estimates have been made for the portion of each county within the coastal basin proper as well as for the total county. Land areas are also given in Table 3-6 for reference. In 1970, the total resident population in the southern California coastal basin was approximately 11 million, a 29 percent increase from the 1960 population.

3.5.1 Land Use

Data on the uses of land in the southern California coastal basin are essential to the estimation and prediction of runoff-associated waste loads. Land use data have been compiled from a wide variety of sources, each with its own hydrologic or operational units and time bases. Therefore, the data have been updated to 1970 and integrated into six selected land use categories by hydrologic unit. These six categories are defined below.

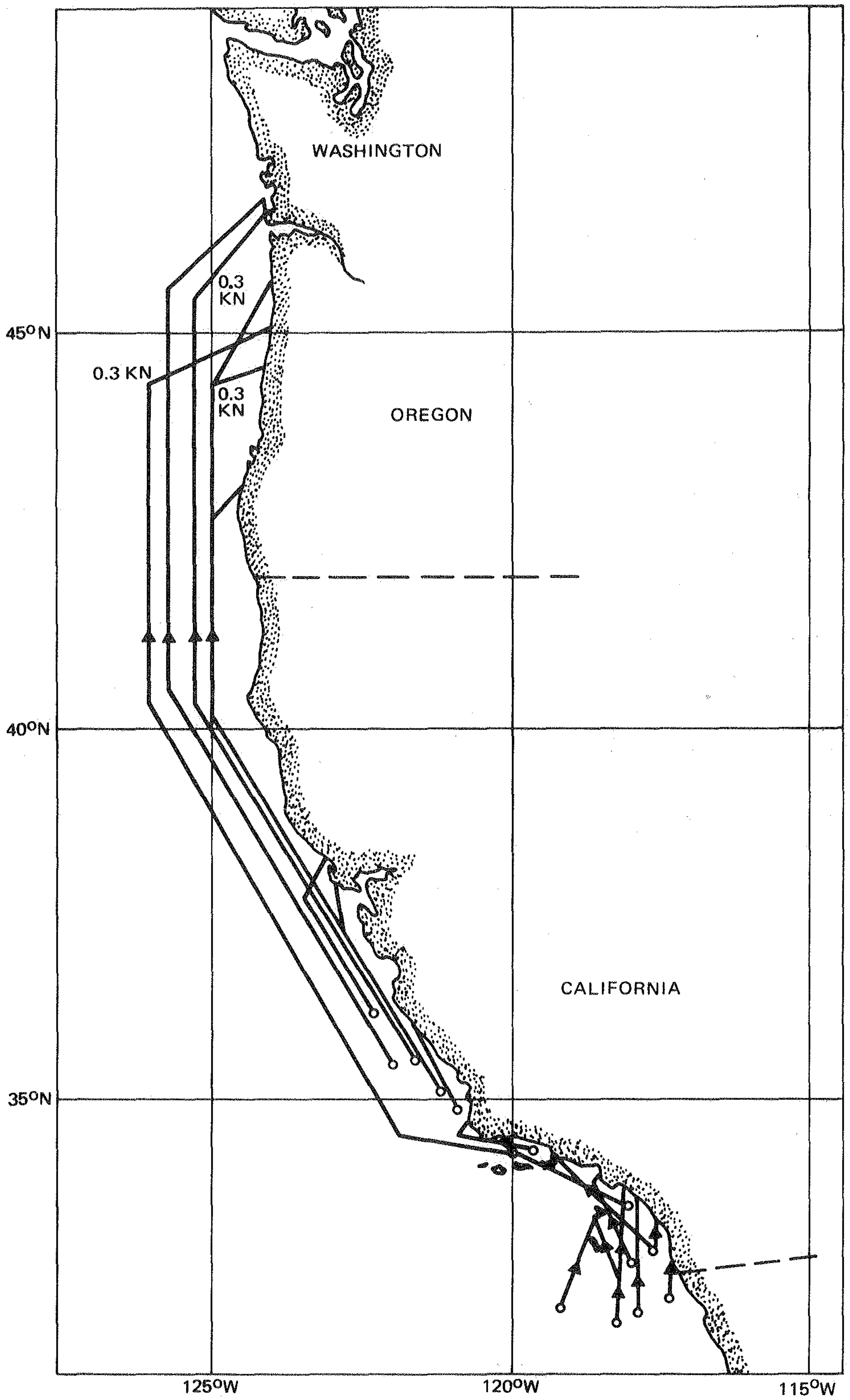

Figure 3-16. An Unusually Strong Coastal Countercurrent During November 1957 (Direction and Speed of Flow Indicated by Drift Bottles). From Schwartzlose 1963, Fig. 1.

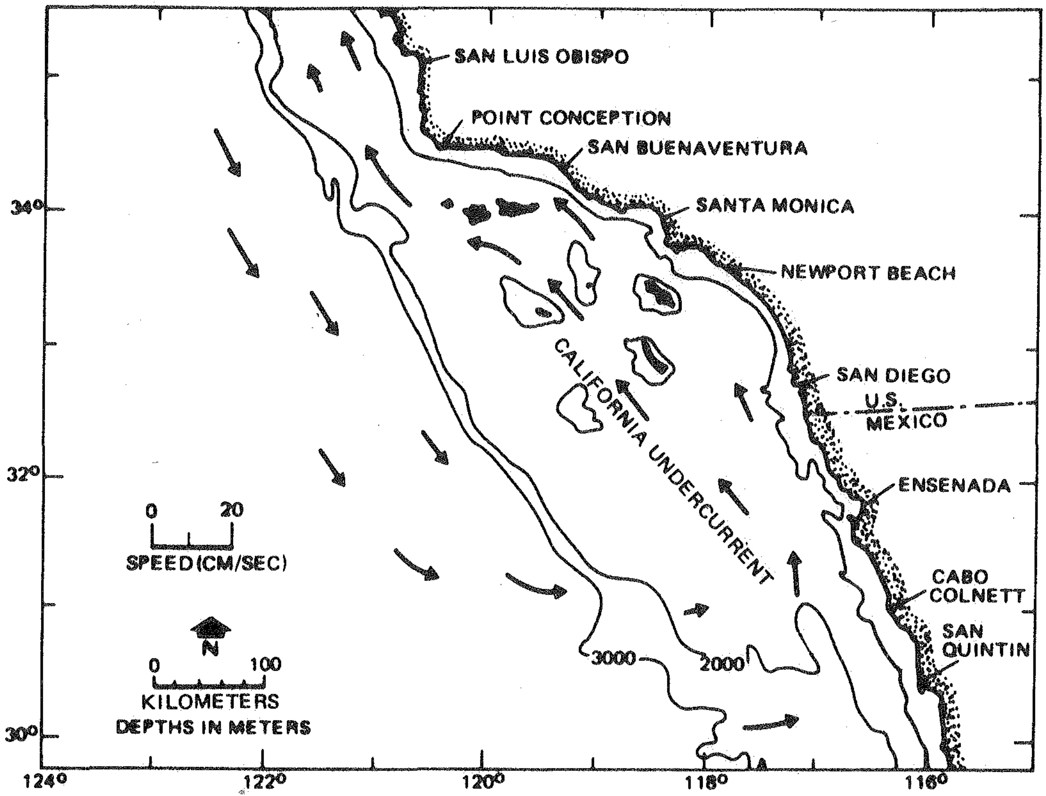

Figure 3-17. Mean Geostrophic Flow at 200 m Depth in the Southern California Bight (Arrows Show Direction and Magnitude of Flow). From Jones 1971, Fig. 11.

Table 3-6
LAND AREA AND POPULATION OF
SOUTHERN CALIFORNIA COUNTIES, 1960-1970

	Land Area (sq km)		Population (thousands)			
			Total		In Coastal Basin	
County	Total	In Coastal Basin	1960	1970	1960	1970
Los Angeles	10,540	7,410	6,039	7,032	5,979	6,949
Orange	2,020	2,020	704	1,420	704	1,420
Riverside	18,590	4,980	306	459	216	319
San Bernardino	52,100	2,640	504	684	408	548
San Diego	11,040	7,840	1,033	1,358	1,020	1,320
Santa Barbara	7,090	750	169	264	91	150
Ventura	4,830	4,150	199	376	198	374
TOTAL	106,210	29,790	8,954	11,593	8,616	11,080

A. Residential. Land used for residences, including single and multiple-unit buildings.

B. Commercial. Area used for retail trade and general office buildings, such as shopping centers; includes strip commercial buildings and central business districts.

C. Industrial. Manufacturing, industrial nonmanufacturing, and wholesale trade areas.

D. Public. Sites of public buildings, schools and educational and recreational facilities, parks, military bases, transportation and public utilities facilities.

E. Agricultural. Cultivated areas, including crop lands, orchards, grazing and dairy lands.

F. Wilderness. Land that is undeveloped or unsuitable for development.

Table 3-7 summarizes the 1970 land use characteristics of the southern California coastal basin by hydrologic unit. The table illustrates the large proportion (62 percent overall) of wilderness area throughout the basin (with the exception of the Ventura, Los Angeles/San Gabriel, Santa Ana, and Coronado hydrologic units).

Figure 3-18 shows the 1970 distribution of developed area among the five uses for the entire coastal basin. About 27 percent of the developed land area in 1970 was in agricultural use. More than 30 percent was urbanized, and the remainder was in public ownership for various uses.

3.5.2 Recreational Activities in the Coastal Zone

The sandy beaches, scenic shorelines, and marinas are major recreational resources in the southern California coastal area. There are approximately 180 km of improved public beaches fronting the Pacific Ocean in southern California. It has been estimated that more than 85 million recreation-days are spent at southern California beaches each year. Uses of the public beaches and adjacent coastal waters involve swimming, wading, surfing, skin and scuba diving, sunbathing, picnicking, camping, fishing, and aesthetic enjoyment of the view of land and ocean and of bird life. Most of these recreational activities are limited to relatively shallow waters. For example, skin divers normally remain within the 10-m contour, scuba divers may venture to depths up to 30 m, but over 90 percent of all diving activities is reportedly done within the 20-m contour. These extensive recreational uses are the basis for the long-standing constant surveillance of the beaches and near shore waters for bacteriological safety and account for the high public interest in the aesthetic qualities of the coastal zone.

There are presently 14 marinas and small boat harbors in southern California, each with capacities for more than 600 boats. The populations of boats in these facilities are given in Table 3-8; the locations of major marinas are shown in Figure 3-19. The estimated total number of boats is 34,860, which represents an average of 3.5 boats per 1,000 dwellers in the entire coastal basin. However, Orange County has an ownership ratio of as high as 25 to 30 boats per 1,000 dwellers.

Table 3-7
LAND USE CHARACTERISTICS BY HYDROLOGIC UNIT, 1971 (IN SQ KM)

Ref. No.*	Hydrologic Unit	Residential	Commercial	Industrial	Public	Agricultural	Total Developed	Wilderness	Total Land Area
H1	Santa Barbara/ Rincon	27	7	13	140	27	214	620	834
H2	Ventura	28	6	37	63	188	322	269	591
H3	Santa Clara/ Calleguas	114	55	24	1,498	426	2,117	2,882	4,999
H4	Malibu	12	2	2	100	1	117	510	627
H5	Los Angeles/ San Gabriel	1,498	194	320	1,501	291	3,804	1,262	5,066
H6	Santa Ana	720	83	167	591	1,114	2,675	2,536	5,211
H7	San Jacinto	22	8	8	320	389	747	1,242	1,989
H8	San Juan	27	4	1	506	23	561	786	1,347
H9	Santa Margarita	4	2	0	37	91	134	1,809	1,943
H10	San Luis Rey	15	6	0	90	157	268	1,195	1,463
H11	Carlsbad	44	21	1	13	88	167	398	565
H12	San Dieguito	13	10	1	33	146	203	696	899
H13	Penasquito	46	9	1	27	8	91	323	414
H14	San Diego	68	10	2	81	66	227	900	1,127
H15	Coronado	138	34	28	142	2	344	3	347
H16	Sweetwater	50	7	8	78	74	217	490	707
H17	Otay	6	1	3	4	107	121	273	394
H18	Tijuana	55	47	5	39	155	301	4,193	4,494
	TOTAL	2,887	506	621	5,263	3,353	12,630	20,387	33,017

*Key to location on Figure 3-10.

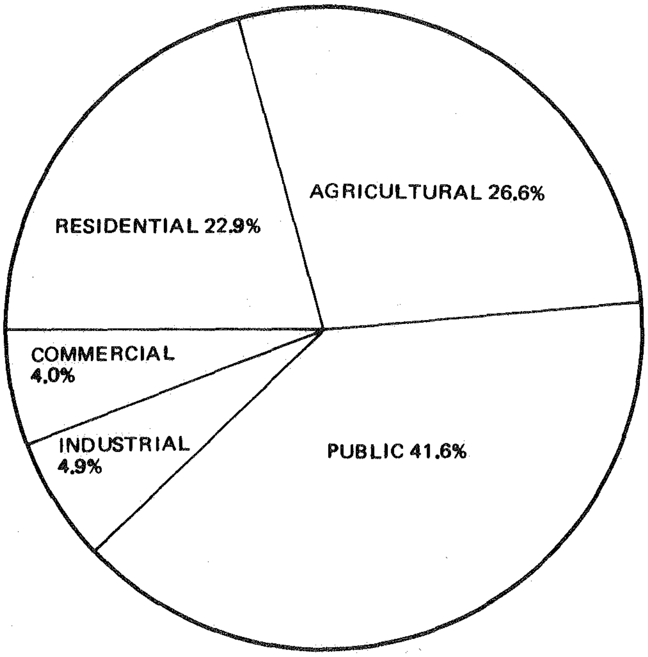

Figure 3-18. Distribution of the Use of Developed Land in the Southern California Coastal Basin, 1970.