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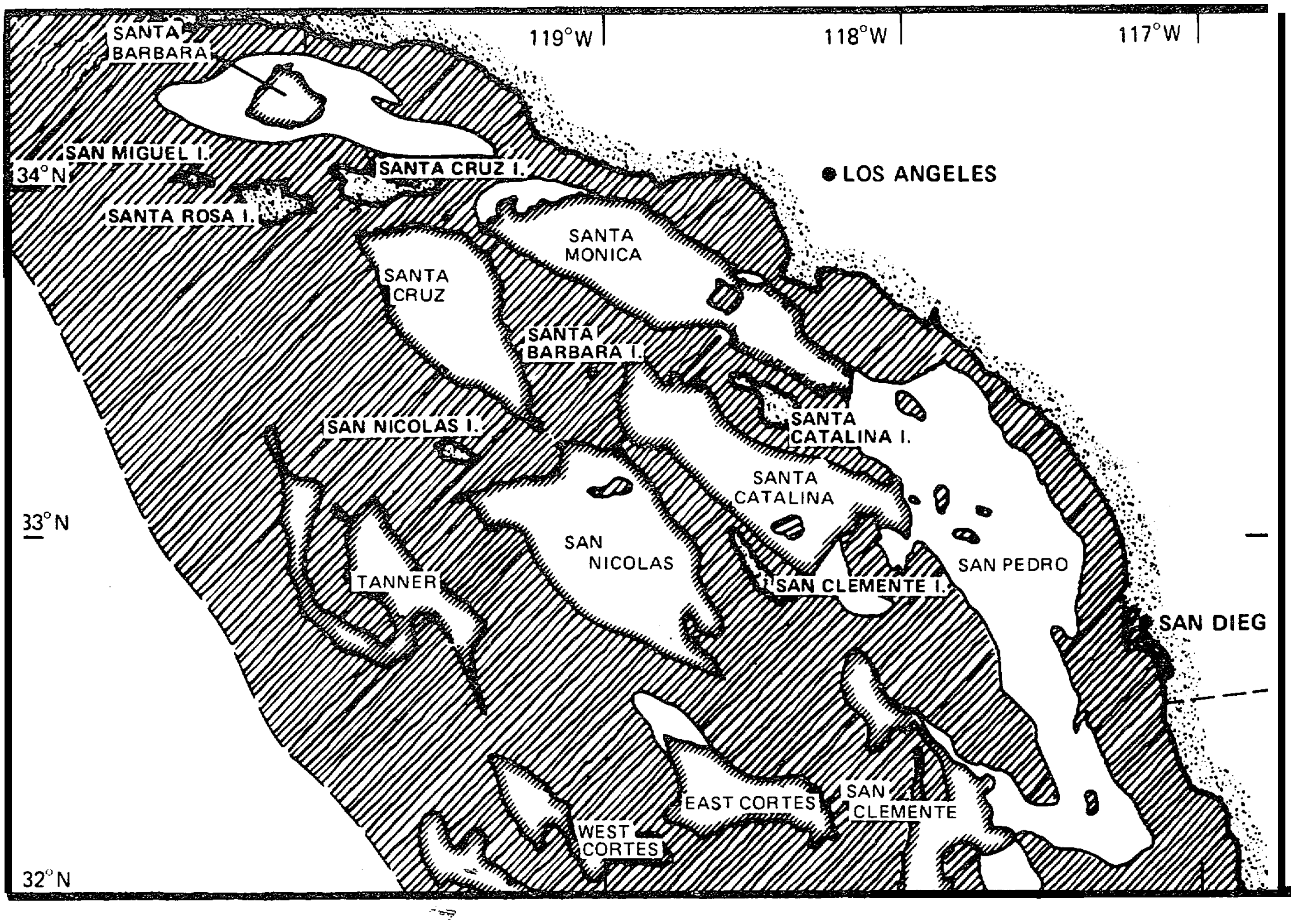
Southern California Ocean Studies Consortium

A SUMMARY OF KNOWLEDGE
OF THE
SOUTHERN CALIFORNIA COASTAL ZONE
AND
OFFSHORE AREAS

Volume I - Physical Environment



The California State University and Colleges
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A SUMMARY OF KNOWLEDGE OF THE SOUTHERN CALIFORNIA COASTAL ZONE AND OFFSHORE AREAS

Volume I

PHYSICAL ENVIRONMENT

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PREFACE

This volume is part of a report which offers a description of the economic and physical forces, and biological and social resources existinq in the Southern California Continental Borderland Area. The purpose is to provide the basis for (1) analyzing the feasibility of offering some of the Area for future mineral development, and (2) assessing the environmental impacts that might result from a proposed leasing action.

The subject matter has been grouped into three volumes which reflect the major disciplines as examined: I. Physical Environment; II. Biological Environment; III. Social and Economic Elements. Each volume includes a master bibliography for its contents. All figures are at the end of each chapter following the bibliography.

Each of the twenty-two separate chapters is essentially self-contained and intended to stand alone as a summary of the available knowledge in that subject. Cross-references to complementary information in other chapters are intended to aid the underlying aims of the report. An overview of the subject matter is provided in the Introduction. Neither value judgments or other assessments have been included in accordance with the basic guidelines for the report. Gaps in available knowledge relative to the purposes of the report, and suggested research to provide the needed additional information, have been prepared as supplementary material.

The work was supported under Contract No. 08550-CT4-1 from the Bureau of Land Management, U.S. Department of the Interior. The Southern California Ocean Studies Consortium has had overall responsibility for preparation of the report. Murray D. Dailey, Director of the Consortium, served as project director. Most chapter authors are faculty members at one of the State Universities which comprise the Consortium, with others coming from University of California, Irvine and the City of Long Beach. Management support was provided by Neal Lansing of Environmental Feasibility Studies and Barbara Hill of the Consortium staff served as project administrator. Cynthia Klepadlo, also of the Consortium staff, prepared the master bibliographies and typed much of the final manuscript.

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Volume I
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GENERAL INTRODUCTION

The geographic limits of this summary include the Southern California Continental Borderland Area and the adjacent coastal zone. The Borderland Area is defined as being south of 34° N parallel, north of the United States and Mexico international boundary and east of 120° W longitude (including the Channel Islands) (Figure I-l). The coastal zone is considered to be the thousand-yard wide strip adjacent to mean low water, although the limits have been extended where appropriate for the purpose of the summary.

Geologically, the Borderland is a basin-ridge complex consisting of closed basins separated by submarine ridges, banks and islands. The southward trend of the California Current is broken by the northern most islands, creating an immense eddy in the Southern California Bight, the open embayment which includes the Borderland waters and adjacent reaches of the ocean to the west and south. Eighteen lagoons and harbors are located along the mainland coast within the study area.

Conditions in the Borderland and coastal zone are strongly influenced by human activities in the adjoining major metropolitan areas and other communities. Nearly ten million people live within settlements that stretch inland from the coast. In both the Los Angeles-Long Beach-Orange County and San Diego areas, the demand for coastal zone space is increasing for residential, recreational, commercial, and industrial uses. Much of the energy needed for this complex originates within or near the coastal zone. Production from oil and gas fields, and waterborne petroleum imports provide a large proportion of the regional energy sources. Petroleum refineries and electrical generating plants are other major elements of the energy industry located at or near the coast. Commercial and naval shipping combined with recreational uses rank the offshore areas among the most intensively used of all maritime locations. Solid, liquid and airborne wastes, either deposited directly or transported naturally to the ocean significantly influence its chemical and biological characteristics. Concern for the public interest in these developments has led to establishment of the California Coastal Zone Commission with broad regulatory and planning powers.

Although used much less intensively, the offshore islands and the Borderland have unique characteristics. Some islands and ocean areas are reserved for military use where others are included in the Channel Islands National Monument. The low level of human activity has left some island locations in essentially pristine condition. The locales include the principal remaining breeding areas for the California sea lion, as well as important nesting grounds for many marine and shore birds.

The study area summary has been grouped into three volumes, describing the physical, biological, and social economic aspects as follows:

VOLUME AND CHAPTER TITLES

I. PHYSICAL ENVIRONMENT

1. Geological Features - John G. Dennis (California State University, Long Beach)
2. Climate - John C. Kimura (California State University, Long Beach)
3* Physical Oceanography - Neil Maloney (California State University, Fullerton) and Kwan-Ming Chan (California State University, Long Beach)
4. Chemical Oceanography - Kwan-Ming Chan (California State University, Long Beach)
5* Hydrography of Harbors, Lagoons and Sloughs - Neil Maloney (California State University, Fullerton) and Kwan-Ming Chan (California State University, Long Beach)
6. Pollution Sources - Willard Reed and Theodore Bakker (California State University, Long Beach)

II. BIOLOGICAL ENVIRONMENT

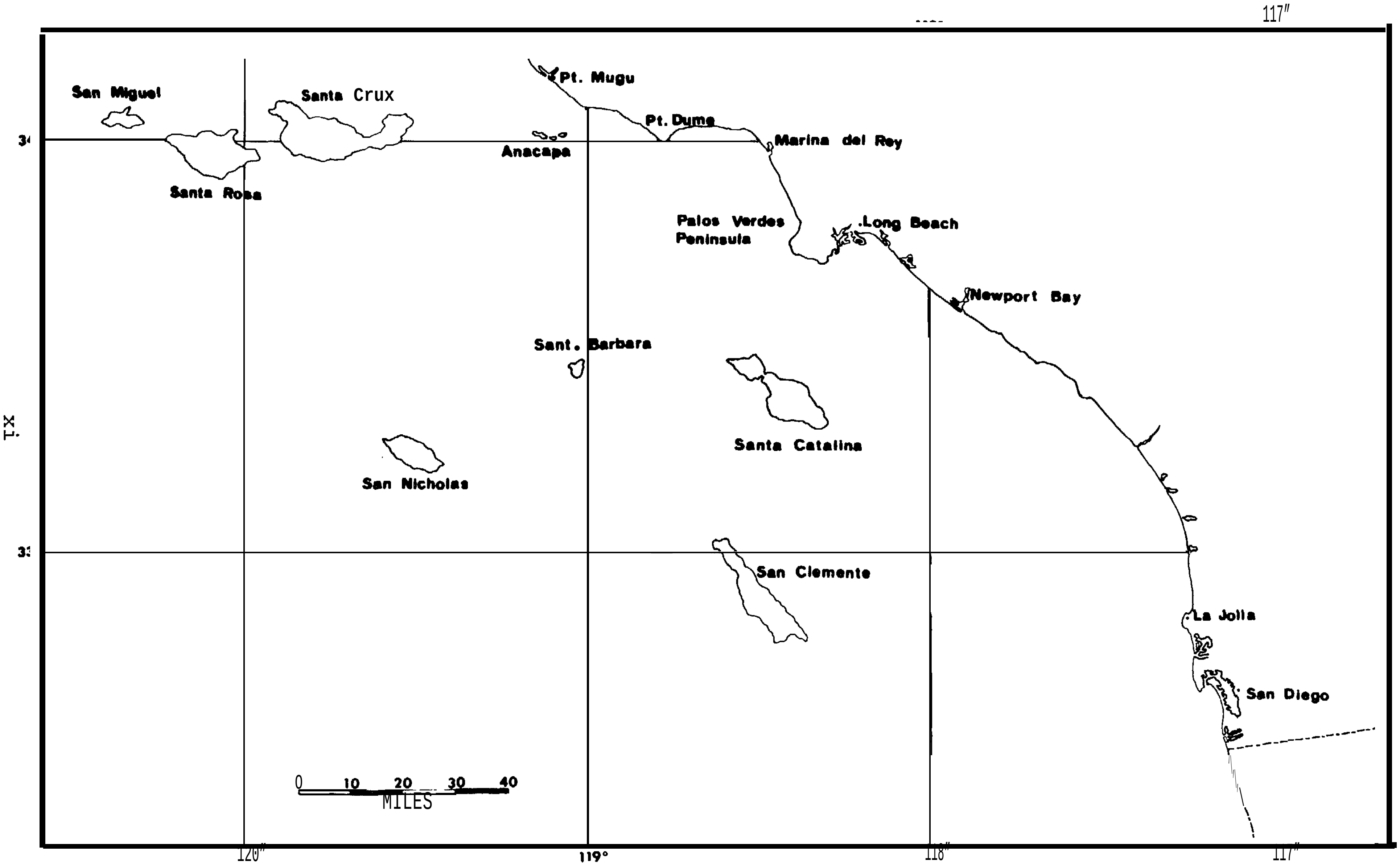
7. Phytoplankton - Raymond Z. Riznyk (California State Polytechnic University, Pomona)
8. Zooplankton - Roger R. Seapy (University of California, Irvine)
9. Benthic Algae and Grasses - Steven N. Murray (California State University, Fullerton)
10. Benthic Invertebrates - Donald B. Bright (California State University, Fullerton)
11. Fishes - Michael H. Horn, (California State University, Fullerton)
12. Marine Mammals - Murray D. Dailey (Southern California Ocean Studies Consortium)
13. Marine and Shore Birds - Kristin E. Bender, Charles T. Collins and Stuart L. Warter (California State University, Long Beach)
14. Marshes and Bays - Ju-Shey Ho (California State University, Long Beach) "

III. SOCIAL AND ECONOMIC ELEMENTS

15. Demography - Gary Peters (California State University, Long Beach)
16. Land and Water Use - Richard Outwater and Joel Splansky (California State University, Long Beach)
17. Transportation - Elbert Segelhorst (California State University, Long Beach)

18. Energy Industries - Robert Rooney (California State University, Long Beach)
19. Port Activities - Louis F. Jobst (City of Long Beach)
20. Fisheries - Michael H. Horn (Califonria State University, Fullerton)
21. Wetland Resources - Raymond Z. Riznyk (California State Polytechnic University, Pomona)
22. Shipbuilding and Ocean-Oriented Manufacturing - Andrew Stern (California State University, Long Beach)

The necessity to divide the elements of this complex system results in unavoidable relationships between chapters and some redundancies. 'Thus, Chapter 6 deals with pollution sources, while pollution effects are considered by individual subject. Again, Chapter 5, 14 and 21, respectively, describe the physical, ecological and biological production aspects of bays, harbors, lagoons and associated wetlands. In general, an effort has been made to note in each chapter other chapters which include either more detailed descriptions or complementary information.



117"
San Miguel
Santa Crux
Pt. Mugu
Pt. Dume
Marina del Rey
Anacapa
Santa Rosa
Palos Verdes
Peninsula
Long Beach
Newport Bay
Sant. Barbara
Santa Catalina
San Nicholas
San Clemente
La Jolla
San Diego
0 10 20 30 40
MILES
120"
119°
118"
117"

Figure I-1

1. GEOLOGICAL FEATURES

John Dennis

1. Introduction

This chapter summarizes basic current knowledge of the geology in the Southern California coastal zone and the offshore continental borderland, and provides a guide to the relevant literature. The bibliographic references include all those which contain information of potential value to this study, but not, as a rule, works which are primarily of academic interest.

2. Geological Framework

2.1 Introduction

This chapter brings together known information about the geology of the reference area, in the form of a summary and guide to available literature and other data. The area is currently under intense investigation, so that new data will continue to accumulate at a rapid rate.

Southern California geology is complicated because large displacements along faults have subdivided the crust here into a number of morphotectonic segments or blocks (Figure 1-1) whose mutual geologic relationships are still, in large measure, controversial. The area covered by the present report is subdivided into two main segments by the Newport-Inglewood zone of deformation. The block lying to the northeast of that zone is underlain by normal continental basement of Mesozoic age; the southwesterly block appears to be underlain by basement rocks belonging to the Mesozoic Catalina (Franciscan) succession which, on current evidence, appear to rest directly on oceanic crust. We shall here refer to the northeastern block as the Santa Ana block, and to the southwestern block as the Catalina block. To understand present geological relationships in the area, it is necessary to know the broad outlines of its geological history.

2.2 Summary of Geological History (see Table 1-1)

2.2.1 Pre-Middle Miocene. The basement rocks are pre-Turonian in age, and are separated from the non-metamorphic overlying rocks by a major unconformity. This suggests emergence and erosion in Turonian or later time. The present coastal and offshore area received shelf-type sedimentation beginning with the late Cretaceus and ending in mid-Miocene time. The sequence records shallow marine and also, in early Tertiary time, flood plain deposition with sources to the northeast. Thicknesses vary, to a maximum of 5,900 feet of Cretaceus and 11,000 feet-of early Tertiary (through Lower Miocene) sediments.

Table 1-1

GEOLOGICAL TIME SCALE
Cenozoic and Mesozoic

Era	Period	Epoch	Approx. Absolute Age of Base
Cenozoic	Quaternary	Holocene	11,000 yrs.
		Pleistocene	2 million yrs.
	Tertiary	Pliocene	5 million yrs.
		Miocene	24 million yrs.
		Oligocene	37 million yrs.
		Eocene	53 million yrs.
		Paleocene	70 million yrs.
Mesozoic	Cretaceus		135 million yrs.
	Jurassic		190 million yrs.
	Triassic		230 million yrs.

Upper Cretaceus sedimentary rocks of limited extent in the offshore are evidence of late Cretaceus submergence of the Catalina block, but no upper Cretaceus rocks are known from islands, other than the northern Channel Islands, which are part of the Transverse Range Province. Paleocene and Eocene rocks from large areas of the offshore Catalina block also suggest submergence of that area in early Tertiary time; Oligocene rocks are not well confirmed, and may be absent, but lower Miocene rocks in many parts of the segment indicate at least partial submergence for that time. The different pre-middle Miocene sequences of rocks on either side of the Newport-Inglewood zone suggest different geologic evolution of the two segments prior to middle Miocene time.

2.2.2 Middle Miocene and Later History. A distinct new phase of tectonic and stratigraphic evolution throughout the region, including both the Peninsular and the Transverse Range blocks, was initiated at the beginning of middle Miocene time. A number of restricted basins began to subside deeply, accompanied by volcanic activity in late middle Miocene time. Basin subsidence and sedimentation were at a peak in late Miocene and Pliocene time.

Thus, the record today shows a broad apron of late Cretaceous and early Tertiary sediments, on which are superimposed a number of restricted basins filled with thick sequences of mid- and late Tertiary, as well as Pleistocene sediments. General uplift in late Pleistocene time has left raised marine terraces along much of the coastline under consideration.

2.3 Present Geological Framework

The stratigraphic frame of reference is provided by the columnar sections of Figure 1-2. The most important boundaries are the pre-Turonian, mid-Miocene and mid-Pleistocene unconformities. The sequences separated by these unconformities may for convenience be called the basement, the early shelf sequence, the late Cenozoic basin sequence, and the late Quaternary veneer. Structurally the area of interest may be subdivided broadly into the Transverse Range block (Figure l-l), essentially the northern Channel Islands; the Catalina block, that is, the area to the southwest of the Newport-Inglewood fault zone; and the Santa Ana block, that is, the area north of the Newport-Inglewood fault zone.

The northern Peninsular Ranges consist of a backbone of pre-Turonian granitic and metamorphic basement, underlying a late Cretaceus through Pleistocene sedimentary cover with an overall seaward dip in the coastal zone. The mainly offshore Catalina block consists of a series of northwest trending ridges and basins (Figure 1-3) , some of which are probably fault bounded (see section 3). The northern Channel Islands are part of the Transverse Range block which consists of metamorphic-plutonic basement and sedimentary cover, thrust southward over the Catalina and Santa Ana blocks (Figures 1-1 and 1-4).

The Newport-Inglewood zone has been traced from Beverly Hills southeast as far as an area off Laguna Beach (Figure l-l). It is a narrow zone of deformation marked by a northwest trending chain of low hills and fault scarps and, structurally, by a series of discontinuous faults subparallel to the alignment. The low hills typically reflect faulted anticlines which have trapped a number of producing oil accumulations along the trend (Yerkes et al., 1965). No unique, clear-cut fault trace has been identified at the surface. At depth, this zone overlies a major break in the basement which appears to mark the boundary between the Catalina and the Santa Ana blocks. This deep discontinuity probably marks the Cretaceus and early Tertiary subduction zone which at that time separated the Farallon plate to the west from the Americas plate to the east (Southern California Edison Company, 1971). This old plate boundary can be recognized in central and northern California (Page, 1970) and was probably over 3,000 km long when it was active. It is now essentially inactive, except for posthumous adjustments reflecting movement along the San Andreas system. The San Andreas fault, in turn, has displaced the subduction zone by several hundred kilometers.

In the southwestern part of the Los Angeles basin the former plate boundary appears to be subject to exceptional local stresses, resulting in local displacement at depth. This has caused deformation in the late Cenozoic sedimentary cover, now expressed as the Newport-Inglewood fault zone; it appears to end abruptly at the Santa Monica fault zone to the north, but seems to die out gradually at its southern end southeast of Newport Beach. G. W. Moore (1972) presents evidence for continuation of the zone to the Rose Canyon fault near La Jolla, but there is no sign for current activity southeast of Laguna Beach. Maximum cumulative displacement of 3,000 m right slip has been obtained from. proprietary oil company data. There is no record of historic ground displacement.

Detailed accounts of the Newport-Inglewood problem are in Southern California Edison Company (1971) , Yeats (1973) and Barrows (1974).

3. Offshore Geology

3.1 Introduction

The Southern California borderland is a basin-ridge complex raised above the main Pacific floor along the Patton escarpment to the west (Figures 1-3 and 1-5). It consists of about 14 closed morphological basins separated by submarine ridges, banks and offshore islands. Some of these basins contain thick sequences of late Tertiary marine sedimentary rocks which are time equivalents of known petroleum reservoirs on land.

Depositional evolution of the sedimentary basins is controlled by the structural evolution of the basin margins, and the record of this development is critical for locating petroleum accumulations. Oil fields in the Los Angeles basin (Figure 1-4) are clearly controlled by distinctive structures which evolved contemporaneously with petroleum accumulation.

The early Tertiary shelf sequence was deposited by simple prograding, but much of the later Cenozoic basin sequence accumulated by turbidite deposition (Moore, 1969) . Near-shore basins would fill first, up to sill depth, and adjoining basins would fill in sequence, by "overflow". Because of on-going deformation, some by-passing of basins may have occurred, but the outer basins are most likely to be "starved" (Parker, 1971). On ridges and high areas currents remove most of the fine sediment that is deposited, allowing slow accumulation of phosphorite and associated precipitates,

The area of prime interest in this section lies almost entirely southwest of the Newport-Inglewood zone and south of the northern group of Channel Islands. This is the Catalina block; its sedimentary and structural history differs from that of the adjoining structural blocks. The contrast is especially great with the Ventura Basin - Santa Barbara Channel - Northern Channel Island region (Transverse Range block) , so that comparisons with that region are hazardous.

The geomorphology of the region is well brought out in Figures 1-3 and 1.5. Comparison with the tectonic map (Figure 1-4) shows that not all steep escarpments necessarily express faults. The inner continental terrace is incised by gullies, most of which were carved by subaerial erosion (Buffington and Moore, 1963) and are thus inactive at present. The heads of submarine canyons, however (Figure 1-5) , are loci of appreciable bottom instability.

3.2 Summary of Stratigraphy

Sections 3.2 and 3.3 are excerpted from U.S. Geological Survey (1973) , with few changes. Compare Figures 1-2, 1-6 and 1-7.

3.2.1 Upper Cretaceus. On the coast, Upper Cretaceus rocks are known from the Santa Ynez, Santa Monica and Santa Ana Mountains, and from a few localities south of Oceanside. Offshore, Upper Cretaceus is exposed on San Miguel Island. Parker (1971) shows 610 m of Upper Cretaceus beneath the Santa Rosa-Cortes ridge and the Santa Cruz basin. The Upper Cretaceus is a poor producer of petroleum in Southern California.

3.2.2 Paleocene and Eocene. In the Catalina block, 1,070 m of middle and late Eocene have been measured on San Nicolas Island. The base and top are not exposed (Vedder and Norris, 1963) . Much of the submerged shelf between San Nicolas and Begg Rock is underlain by similar rocks. On the Santa Rosa-Cortes ridge northwest of San Nicolas Island there may be as much as 610 m of Eocene (Parker, 1971) . None of the oil fields in the Los Angeles basin has produced from Eocene or Paleocene rocks.

3.2.3 Oligocene. Reports of Oligocene rocks from the Catalina block are very sparse and may be inaccurate. It is not known whether marine Oligocene rocks occur beneath the outer ridges and banks.

3.2.4 Lower Miocene. Lower Miocene siltstone and sandstone occur on the northern flank of the Santa Monica basin (Jennings and Strand, 1969) , on the northern part of the Santa Rosa-Cortes ridge between Santa Rosa Island and San Nicolas Island, and on the shelf west of San Miguel Island.

3.2.5 Middle Miocene. Strata of middle Miocene age in coastal Southern California are characterized by three distinct units, a siliceous shale, a dominantly feldspathic sandstone, and a blueschist breccia. The siliceous shale and related rocks form one of the most widely distributed sedimentary facies along the coast; they are absent only from the Oceanside to San Diego area, Santa Catalina Island and San Nicolas Island. They are known to underlie large parts of the mainland and shelf around the islands and presumably are exposed on many of the banks and ridges on the borderland (Jennings, 1962; Strand, 1962; Rogers, 1965; Jennings and Strand, 1969). Presumably these highly organic shaly strata constitute a primary source rock for petroleum in the Ventura and Los Angeles basins. The sandstone unit, which generally is slightly older than the shale unit, is not present along the mainland coast between Point Conception and Point Mugu but is a major stratigraphic unit in the Santa Monica Mountains, where it is as much as 1,220 m thick, and along the southeast side of the Los Angeles basin where it is about 1,020 m thick in outcrop. It is not known to be present on the mainland southeast of the San Joaquin Hills and has not been reported from the borderland north of the Mexican boundary. The breccia and associated conglomerate and sandstone compose a distinctive lenticular unit that is discontinuously distributed along the nearcoast area from the Santa Monica Mountains to Oceanside (Woodford, 1925; Woodford and Bailey, 1928); it also occurs on Santa Rosa, Santa Cruz, and Anacapa Islands and the adjacent seafloor (Scholl, 1960; Weaver et al., 1969; Yeats, 1970). Much of the section on Los Coronados Islands, just south of the Mexican horder, consists of the breccia unit. Elsewhere on the borderland, it is reported from Lasuen Seaknoll, possibly from Santa Monica Bay (Emery, 1960), and in outer San Pedro Bay.

In the Los Angeles basin, only one field has yielded oil from sandstone of middle Miocene age (Yerkes et al. , 1965) . The breccia unit has produced none, presumably because of its low porosity, and is considered a poor target for exploration.

3.2.6 Upper Miocene. Upper Miocene strata presumably are widespread, but common occurrences are documented only on the insular shelf around the northern Channel Islands, on the segment of the Santa Rosa-Cortes ridge north of San Nicolas Island, and at sites along the mainland shelf. Other scattered localities are in Redondo Canyon, La Jolla Canyon, on a seaknoll about 16 km east of Santa Catalina Island and on the ridge a few miles northwest of Santa Barbara Island. On his map showing the distribution of upper Miocene and/or Pliocene rocks, Parker (1971) implies that large areas of the borderland are underlain by strata of late Miocene age.

More than 40 percent of the oil from fields in the Los Angeles basin came from reservoirs in upper Miocene rocks (see Chapter 18). No oil has been produced from strata of late Miocene age in the Santa Barbara Channel region, but oil is present in sandstone reservoirs of this age in the central and eastern Ventura basin.

3.2.7 Miocene Volcanic Rocks. Because volcanic rocks of Miocene age constitute a significant part of the borderland and because similar rocks have produced small quantities of petroleum on shore, their distribution and nature are important not only for regional correlations but also as possible sites of oil reservoirs.

Extrusive and intrusive igneous rocks that range in composition from basaltic to rhyolitic form parts of the northern Channel Islands and the western Santa Monica Mountains. Similar rocks, chiefly andesitic, encircle the Los Angeles basin, both at the surface and at depth (Eaton, 1958) , but are not present in the coastal zone southeast of Dana Point (Figure 1-3). Although some are late Miocene in age (Yerkes et al., 1965) , the bulk are middle Miocene (Yeats, 1968; Turner, 1970). On the southern group of islands, volcanic rocks of middle Miocene age form most of Santa Barbara (Emery, 1960) and San Clemente Islands (Olmsted, 1958), but constitute less than half of the exposures on Santa Catalina Island (Bailey, 1941) and occur only as minor intrusions on San Nicolas Island (Vedder and Norris, 1963) and at Begg Rock . On San Clemente Island the flow sequence probably is more than 450 m thick (Olmsted, 1958; Merifield et al., 1971) .

One of the commonest rock types in seafloor samples from the borderland is andesitic and/or basaltic volcanic rock that occurs along the ridges and banks. Volcanic rocks are present on the submarine ridge system between the east end of Santa Cruz Island and San Clemente Island and much of the shelf area around the northern group of islands (Moore, 1969) . Tanner Bank, Cortes Bank, and Patton Ridge have volcanic rocks along their crests (Holzman, 1952; Moore, 1969) but these may represent only local shallow intrusions or flows.

3.2.8 Pliocene. Marine strata of Pliocene age are the most prolific producers of petroleum in the Ventura and Los Angeles basins, but they are restricted to existing deep depositional basins and their closely adjacent margins. In the vicinity of Ventura, the Pliocene section is as much as 3,800 m thick and is nearly as thick in the central Los Angeles basin. The sole exception to productivity is the San Diego district, where oil has not been recovered from the exhumed shallow basin edge. There the section is about 300 m thick and is restricted to shelf deposits. The same basin-fill basin-margin relationship exists in the deeper parts of the Continental Borderland; thus the chances of obtaining oil from the topographically high parts of the banks and submarine ridges are not great.

Reported offshore exposures of Pliocene sedimentary rocks, chiefly mudstone, are sparse and are restricted primarily to the mainland shelf at San Pedro Bay, Santa Monica Bay, eastern Santa Barbara Channel and Coronado Bank. Other scattered occurrences are on the slope northeast of San Clemente Island, on both slopes of the Santa Rosa-Cortes Ridge, on the western slope of the ridge northwest of Santa Barbara Island and on Lasuen Seaknoll (Emery, 1960; Moore, 1969) . Deeper water sites of Pliocene samples are near the southeast end of San Nicolas basin and on the flanks of Santa Catalina basin (Parker, 1971).

3.2.9 Quaternary. Rocks of this age form a westward thinning veneer on underlying rocks. Great thicknesses may, however, exist in basin centers. The nature of seafloor sediments is indicated in Figure 1-9.

3.3 Summary of Structure

Faults on the southern group of islands have north to northwest orientations in general; most have dip-slip offsets. Some of the large faults inferred from seafloor topography south of the northern Channel Islands trend northwest and may have major components of both dip-slip and strike-slip movement according to Emery (1960). Recent geophysical work, however, indicates that several of these inferred faults do not exist. (See Figures 1-4 and 1-8)

3.3.1 Folds. Trends of major folds in the Catalina block are southeast-northwest and tend to parallel the major fault system. In contrast to the large fault zones, the folds are arranged en echelon and are rarely more than 16 to 24 km long. Folds along many of the through-going fault systems such as the Newport-Inglewood zone are deviate from the fault trend by about 20° (U.S. Geological Survey, 1973).

Broad, faulted anticlines are present on San Clemente (Olmsted, 1958) and San Nicolas Islands (Vedder and Norris, 1963), but the age of the folding can be dated only as pre-late Pleistocene and post-middle Miocene. Elsewhere on the continental borderland many of the persistent ridge systems may reflect en echelon anticlines and some of the larger basins such as Santa Cruz and San Nicolas are synclinal (Figure 1-4) . Because most of the ridge crests are composed of truncated Miocene rocks and because late Pleistocene surfaces are relatively unwarped, the latest major episode of folding must have occurred sometime during late Miocene to late Pliocene time. Elevated Pleistocene terraces on the islands, however, indicate late stages of uplift that may still be in progress (Vedder and Norris, 1963). Sediments in the basins that commonly are assigned a Pliocene age also show little deformation, except in the lower part of the section and on the margins of the basins, suggesting that the most intense period of folding occurred near the end of Miocene time. There is a suggestion from seismic profiles, however, that regional tilting caused westward migration of the trough of San Nicolas basin between Eocene and Miocene time.

3.4 Resources (Only hydrocarbon resources are included.)

3.4.1 Potential for Hydrocarbon Source and Reservoir Rocks. So little is known about the stratigraphy, lithology and reformational history of the rocks underlying the Santa Rosa-Cortes ridge region that definitive statements cannot be made about the presence or absence of strata that might have served as source beds for oil or gas. The published work on San Nicolas Island and the Santa Barbara Channel Islands provides little useful information for evaluating the amount, nature, or thermal and diagenetic history of organic matter remaining in rocks that could be considered source beds. Whatever can be said is therefore largely conjectural and is consequently heavily influenced by knowledge of presumably analogous regions onshore in California (U.S. Geological Survey, 1973).

Little can be said until borehole information becomes available, so that rock types can be identified and mapped. A denser profiling network will be needed in order to locate structural traps.

4. Coastal Zone Geology

4.1 Introduction

The California Division of Mines and Geology has prepared a comprehensive report on the physiography, geology, and mineral resources of the coastal zone on land (Davis et al., 1971) . Sections 4.2 through 4.4 are adapted and modified from portions of that report. The State geological map sheets 1:250,000 covering the area are referenced under California Division of Mines and Geology (1959-1969).

4.2 Geomorphology

The Peninsular Ranges province extends from the Los Angeles basin southeastward to the Mexican border, and beyond into Baja California. The province consists essentially of eastern mountain masses, modified intervening upland surfaces, and a western coastal plain. The eastern ranges trend northwestward, as do the ridges of the continental borderland. The offshore islands of Santa Barbara, Santa Catalina, San Nicolas, and San Clemente are included in the province.

The lowland of the Los Angeles basin extends from Santa Monica southeastward along the coast for about 85 km to Newport Bay, and for 20 to 30 km inland. It slopes gently southwestward to the sea. Midway along the coast the low shoreline is interrupted by the nearly 500-meter high Pales Verdes Hills, a former island now connected with the mainland, upon whose slopes thirteen levels of marine terraces have been carved. Tide and submerged lands on the margin of the coastal plain near San Pedro, Long Beach, Seal Beach, and Newport Beach have permitted development of harbors at these localities.

A broad asymmetric coastal plain characterized by elevated marine terraces fringes the shoreline from Newport Beach to Oceanside. The terraces commonly end seaward at steep bluffs and narrow sandy beaches, or rocky points which conceal small secluded coves. Frequently the coastal bluffs and bluffs bordering tributary streams are modified by talus and highly dissected upper slopes leading to landslides. Considerable evidence of subsidence is apparent from Oceanside to the Mexican border. Tidal marshes accompanied by sloughs, marshes, and meandering streams occupy the lower end of broad stream valleys. Wave and wind action have closed the mouths of seven major streams, forming lagoons. The southerly curve of the coastline is broken at La Jolla where the cape-like mass of Soledad Mountain and La Jolla Mesa juts into the sea. A long narrow sand bar extends southward from the outer edge of the cape to the seawall protecting the entrance to Mission Bay.

Near San Diego the elevated coastal plain has been highly dissected. Eroded remnants of the original surface remain as mesas sloping westward and as isolated hills. South of Mission Bay the peninsula of Point Loma, a former island, extends westward and southward from the mainland forming the north boundary of San Diego Bay. The western boundary of the bay is a long sand bar extending northward from the alluviated flood plain to the Tia Juana River, to Coronado and North Island. The estuary of the Tia Juana River connects with the ocean about 1½ km north of the Mexican border.

4.3 Bedrock Geology - Los Angeles Basin Coast

The Los Angeles basin is generally underlain by rocks of Mesozoic and Tertiary age; much of the surface cover consists of unconsolidated or semi-consolidated sediments of Quaternary age.

Holocene beach and dune sand line the coast from Santa Monica to the Pales Verdes Hills, except for alluvium encountered near Venice at the outlet of Ballona Creek. Marine sedimentary rocks of middle Miocene age intruded by basalt crop out along the coastal border of the Pales Verdes Hills and patches of non-marine sedimentary rocks mantle thin marine terrace deposits of Quaternary age. East and southeastward from the Pales Verdes Hills alluvial deposits, chiefly from the Los Angeles, San Gabriel and Santa Ana Rivers, and San Diego Creek, alternate with stream terrace deposits, as far as Newport Beach.

Deposition during the Quaternary Period was accompanied by uplift so that the basin can be described as a series of northwest-trending fault blocks, stepped upward to the south-' west. The western coastal part of the basin lies in an uplifted block between the Newport-Inglewood fault zone and Pales Verdes fault zone, along the northeast border of the Pales Verdes Hills. The Pales Verdes Hills block was elevated sufficiently to permit the exposure of the basement rocks by erosion during the late Quaternary. Along the periphery of the Pales Verdes Hills, penecontemporaneous folds can be seen in the mid-Miocene Monterey Formation.

Two destructive landslides have taken place along the Pales Verdes Peninsula coast, at Portuguese Bend and at Point Fermin (see Section 5) .

The Wilmington anticline is not exposed, and this extensive oil field (Figure 1-4, largest oil field shown) was one of the last to be discovered in the entire basin. It extends northwestward for 7 km, joining the older Torrance oil field in a structural saddle, and also extends 3½ km offshore to the southeast, opposite Long Beach. During the course of its development the ground surface at Long Beach subsided almost 10 m in some locations, causing considerable damage to surface structures. A technique has been developed to reduce subsidence by the injection of sea water into the subsurface strata (see Section 5) .

Proceeding southeastward along the coast, oil fields at Seal Beach, Huntington Beach, and Newport Beach are associated with the Newport-Inglewood fault zone. This trend is the locus of other important oil fields in the western part of the Los Angeles basin, as shown in Figure 1-4 (see also Chapter 18).

4.4 Bedrock Geology - Coastline South of Newport Beach

The narrow irregular coastal plain extending southeastward from Newport Beach slopes gently seaward and exposes marine and non-marine strata of Late Cretaceus, Tertiary, and Quaternary age. The rocks are chiefly siliceous and diatomaceous shales of the Monterey Formation as far south as South Laguna, with some Tertiary andesite exposed just northeast of Laguna Beach. Sandstone, siltstone, and shale of the upper Miocene Capistrano Formation are found as far south as San Onofre, along with some thick-bedded sandstone and the San Onofre breccia (Woodford, 1925). Middle Miocene rocks reappear south of San Onofre and can be traced as far as Oceanside. The underlying rocks of Eocene age crop out from Oceanside to La Jolla. These are massive white sandstone, siltstone, and conglomerate of the Santiago Formation, massive sandstone and local siltstone of the Torrey Formation, and varicolored fine sandstone of the Delmar Formation interbedded with siltstone and mudstone.

Interbedded sandstone and shale of Late Cretaceus age occur along the coast from La Jolla to Pacific Beach, where they are overlain by upper Pliocene rocks. Upper Cretaceus rocks are overlain by Quaternary terrace deposits. Quaternary marine, and some non-marine, terrace deposits overlie Miocene and Eocene rocks locally between Newport Bay and La Jolla. A thin strip of Holocene dune sands covers the seaward side of San Diego Peninsula, overlying Quaternary alluvium that extends from Coronado to Imperial Beach.

Structurally, the coastal plain is etched into an uplifted block which trends northwest. The block is tilted southwestward from the Elsinore fault, its eastern margin. The coastal plain is covered locally by flatlying marine and nonmarine terrace deposits which extend inland as much as 3½ km. The effects of subsidiary faulting in the uplifted block are evidenced along the coast in the San Joaquin Hills, near San Onofre, near La Jolla, and in the upper Otay Valley. Soledad Mountain near La Jolla has been uplifted on a fault trending northwestward, along its northeast flank. Cretaceous rocks are exposed in the core of the anticline formed by the uplift; Mission Bay on the south is a structurally depressed area. Near San Diego a series of mesas has been carved on the gently westward-dipping rocks of Cenozoic age.

Estuarine conditions at the mouths of numerous coastal streams testify to local subsidence during Holocene time.

5. Geological Hazards

5.1 Earthquake Risk

In the area under consideration, earthquake risk is greatest along the coast, diminishing seaward.

5.1.1 Coastal Zone. The whole area of interest is in an active seismic zone. The risk in the coastal zone has been summarized by Greensfelder (1971) ; this paragraph is an adaptation of parts of Greensfelder's account.

From Santa Monica to Laguna Beach the coast is in an area of moderate to high earthquake risk. This is of special concern in view of high population density and because industrial operations, such as shipping and oil pumping, storage, and refining, are greatly concentrated along this coast.

The Long Beach earthquake of 1933, which is the largest known in this area, had a magnitude of 6.3 and a maximum intensity of VIII to IX. Although this shock was not of major magnitude, it ranks as the third most destructive earthquake in United States history, with a property loss of about $40 million. Structural damage was widespread and severe because so many buildings were poorly constructed: unreinforced masonry construction was common. School buildings were among those most generally and severely damaged, as they were not designed to resist lateral forces. Had the shock taken place during school hours great loss of life would have occurred. It is estimated that a recurrence of this earthquake would cause damage valued in the neighborhood of $600 million (Algermissen et al., 1969). The number of deaths in the 1933 earthquake is placed at 120; probably two-thirds of these deaths were caused by persons being struck by falling cornices, parapets, and ornaments as they fled from inside buildings.

The known active Newport-Inglewood fault zone extends from the Santa Monica Mountains to the shelf off Newport Beach. It lies about 8 km inland at its north end and 800 m inland south of Long Beach. The 1933 earthquake and numerous small shocks have occurred in this fault zone; however, no surface ground breakage has ever been observed on any of the fault traces as a result of historic earthquakes.

The San Andreas fault passes within 70 km of Los Angeles, and a major earthquake along it could cause damage in the Santa Monica to Laguna Beach area. The 1857 Fort Tejon earthquake involved the San Andreas fault north of this area; however, the sketchy reports concerning this great shock (probable magnitude 8+) indicate very little or no structural damage in Los Angeles (Lawson et al., 1908). Since most buildings in the Los Angeles area in that day were adobes, the maximum intensity there was probably VI.

Seven earthquakes with modified Mercalli intensity VII to VIII and fourteen with intensity V to VI have occurred within 40 km of San Pedro Bay (Eppley, 1966); these are notably clustered near the Newport-Inglewood fault zone. As these shocks occurred between 1889 and 1963, about one intensity VII to VIII and two intensity V to VI shocks approximately every 10 years can be expected in this area. An earthquake as great as that of 1933 can be expected perhaps once in a century.

Earthquakes in this region have unusually high local intensities due to the presence of thick deposits of soft, saturated surficial materials. Quarternary alluvium, consisting of unconsolidated stream and beach deposits, from several hundred to more than one thousand feet thick, underlies most of this region. These materials are water saturated throughout most of their vertical extent, the water table generally lying less than 10 m below sea level in the spring season. Some ground cracking occurred in the wet bottom land of the Los Angeles plain during the 1933 earthquake. Along the shore between Long Beach and Newport Beach road fills and similar earth construction resting on marshy land or other wet ground settled, shook apart, or lurched, causing considerable damage to concrete highways and bridge approaches.

The coast from Newport Beach to San Diego lies in a region of moderately low seismicity and has experienced only one damaging earthquake. This occurred in 1894 and had intensity VII to VIII in the immediate San Diego area. The San Diego area can be expected to have a shock of intensity V to VI about once in every five years; the region north towards Newport Beach is somewhat less active (Algermissen et al., 1969). The known active fault nearest the coast is the Elsinore fault, which lies from 40 to 70 km inland. This fault might generate an earthquake large enough to be damaging at the coast; however, it has not to date been the locus of a great shock.

5.1.2 Offshore Seismic Risk. Seismic risk from sources other than the Newport-Inglewood and San Andreas zones appear to be minor in the Borderland area (Figure 1-10). Nevertheless, installation sites should be evaluated individually.

The soft, uncompacted sediments that cover much of the outer borderland undoubtedly are subject to amplified shaking during earthquakes, and seafloor failures in the form of liquefaction, cracking, lurching, slumping, or generation of turbidity currents could develop. Ground responses of this nature would be most likely to occur on the steeper slopes such as those on the Patton Escarpment where gradients as great as 28^{o} occur locally. Short segments of the seawardofaces of Cortes Bank are as steep as 25° and as much as 15 at places along the west edge of the northern Santa Rosa-Cortes Ridge. Seaward of the islands, typical basin slopes such as the one that drops from Tanner Bank into San Nicolas basin average about 8^{o} (U.S. Geological Survey, 1973).

5.1.3 Tsunami Risk. Tsunamis may be generated locally, by vertical movement of the seafloor or by submarine slides; or they may be generated at great distances from shores which may sustain damage. Tsunamis propagate perpendicular to the axis of deformation; since many faults in the area of interest are parallel to the shore, large wave amplitudes may be directed toward the shore, if tsunamis are generated by such faults. In the past, destructive tsunamis have occurred in the Santa Barbara Channel (Hamilton et al., 1969) . The area south of Santa Monica has no history of exceptional tsunami risk. However, certain areas along this coast are subject to some risk (Figure 1-4) , and caution is advisable during alerts. A detailed discussion of tsunami risk along the California coast is given by Welday (1971). Figure 1-4 shows tsunami risk for the coastline under consideration. See also Chapter 3.

5.2 Oil and Gas Seeps

Oil and tar, as well as gas seeps, are associated with the Los Angeles basin and its extension offshore. They do not extend south of Huntington Beach. Historical and current seeps are shown in Figure 1-4.

Seeps are usually transient phenomena. Their exact source on the sea floor is very difficult to determine. Commonly, they occur as groups of small individual seeps concentrated in a restricted area where a structural trap has been tapped by erosion. They may be activated or reactivated by tectonic or seismic movement.

The Present state of knowledge in the area under consideration-is summarized by Wilkinson (1972); Zebal (1968) deals with the gas seeps off Newport Beach. Table 1-2 shows historical and current seeps as listed by these authors.

Table 1-2

HISTORICAL AND CURRENT SEEPS
IN THE SOUTHERN CALIFORNIA AREA

Location	Characteristics
1 and 2	Mostly tar.
3	Discovered by continuous presence of oil, gas bubbles and tar on the water.
4	At 50 fathom contour on line between Point Dume and Point Vicente.
5 and 6	Oil seeps.
7 and 8	Oil and gas, about 4% sulfur; 7 and 8 together estimated to be discharging about 10 barrels of oil per day in 1928.
9	Oil seep.
10	Oil and gas.
11	Oil and gas, about 3.5% sulfur; intermittent flow in 1927; no estimate made.
11a	No remarks.
12	Analyzed by Atlantic Richfield Co.
13	Oil droplets and slabs of tar as large as 8"x5"x1".
14 and 15	Half-acre oil slick sighted from steamer, 1923; frequently sighted by fishermen; now inactive.
16	Gas bubbles from outcrop, probably from marsh gas sands.

Numbers refer to locations noted on Figure 1-4.

Source: Wilkinson (1972) and Zebal (1968).

5.3 Shoreline Processes

Shoreline processes off the coast of Southern California are governed by northwest to southeast longshore currents which transport stream-derived sediment along the coast, until the sediment is lost down submarine canyons. In the area of interest, such canyons exist off Redondo Beach, Newport Beach, and La Jolla. (See also Chapter 5.)

Chief of Engineers (1971) gives the following account of the shoreline (Figure 1-11):

<u>5.3.1 Santa Monica to Pales Verdes.</u> Thirty-five km of shoreline is composed of soft bluffs of the marine terrace deposits which change to river alluvium and then become dune sand. In spite of the soft material, this shoreline has been very stable, with beach widths of 30 to 270 m. The Santa Monica breakwater traps material, partially interrupting downcoast littoral movement. The entrance jetties to Marina del Rey and Ballona Creek are holding sand very well at Dockweiler State Beach.

<u>5.3.2 Pales Verdes Peninsula.</u> Twenty-five km of shoreline is composed of high seacliffs of resistant basalt and marine sedimentary rock, overlain by soft marine terrace deposits which are fronted by narrow pocket beaches. The half-mile long Cabrillo Beach at the foot of the Los Angeles breakwater has been stabilized by a 240 m groin constructed by the Corps of Engineers in 1962. The remaining 15 km of the Los Angeles County shoreline is protected by the Los Angeles-Long Beach breakwater.

<u>5.3.3 Orange County.</u> The shoreline length is about 72 km, extending in a southeasterly direction from the San Gabriel River to San Mateo Point. From the San Gabriel River for 30 km to the Newport Harbor entrance the shoreline is a wide sandy beach backed by low alluvial bays and marshes. From the Newport Harbor entrance downcoast 39 km to the southern county line at San Mateo Point, the foreshore is generally rocky, interspersed with pocket beaches backed by cliffs.

Seal Beach, just downcoast from the San Gabriel River, has been partially stabilized by construction of a pre-stressed concrete groin in 1959. The Surfside-Sunset feeder beach has continued to provide sand to nourish downcoast beaches at Bolsa Chica and Huntington Beach. Erosion at Newport Beach has been partially controlled by construction of six groins and placement of 1.5 million cubic meters of sand by the Corps of Engineers during 1967 to 1969. The Santa Ana River deposited an additional 3 million cubic meters in a delta during January and February, 1969, rains. As a result of studies conducted by the Corps of Engineers and others, it is concluded that coarse beach sand is being carried upcoast away from Newport Beach by southerly swells, and that little or no beach sand is being carried into the Newport Submarine Canyon. From Newport Harbor entrance downcoast for 24 km to Doheny Beach, most of the shoreline is backed by 20 to 70 m high cliffs of resistant andesite, marine sedimentary siltstone, sandstone and shale, covered by soft marine terrace deposits. Small pocket beaches are nourished by intermittent coastal streams found in this reach. Most of these beaches are stable, with no serious erosion problems noted. In January and February, 1969, heavy rains brought 1.5 million cubic meters of sand to Doheny Beach. Following debris removal and dredging of a flood control channel, this beach should remain in excellent condition for many years.

For 12 km from San Juan Creek to San Mateo Point, the south county boundary, the shoreline is backed by 20 to 30 m high cliffs of marine siltstone, sandstone and shale, covered with soft marine terrace deposits. The Capistrano Beach colony, immediately downcoast of Doheny Beach, has had frequent erosion problems. Storms have often torn out seawalls and damaged oceanfront homes along this private beach. San Clemente City Park and State Beach have remained stable with beach widths of 8 to 30 m.

5.3.4 San Diego County. The shoreline extends approximately 125 km downcoast from San Mateo Point near the city of San Clemente to the Mexican border. The first 25 km of shoreline fronts Camp Pendleton Marine Corps Reservation and is composed of 20 to 45 m high bluffs of marine sedimentary rock. Downcoast of the Del Mar Boat Basin and Oceanside Harbor, the beach has had continuous erosion problems. The breakwater and jetties of the Oceanside Harbor complex have been extended several times in an attempt to keep sand on the beach and out of the harbor, but these efforts have not succeeded. From 1965 through 1969, Oceanside Harbor has been dredged annually, placing 1,760,000 cubic meters of material on Oceanside Beach. At Wisconsin Avenue historical photographs show that a 30 m wide beach in 1967 and 1968 has eroded back to a 25 m beach in 1969. In 1965, 5 to 22 cm cobbles interspersed with the dredge material became exposed, eventually covering three-fourths of the city beach. These cobbles have been temporarily covered by succeeding beach fills, with erosion uncovering them again. Although a cobblestone beach is not acceptable for bathing recreation it does provide some protection against further shoreline erosion.

There have been few erosion problems with the coastline between the cities of Carlsbad and La Jolla. The Pacific Coast Highway closely parallels the beach along most of this coastline, and is revetted in places. Undercutting of 7 km of sea cliffs fronting La Jonas has forced closure of the famous sea caves and required 400 m of revetment to be constructed at Bird Rocks by the Corps of Engineers in 1966.

Ocean Beach, just downcoast of the San Diego River, was partially stabilized by a 170 m groin constructed in 1955 by the City of San Diego. From Ocean Beach to Point Loma 9 km of shoreline consists of soft sedimentary cliffs rising to

100 m high above the area. A Corps of Engineers shore protection project has been authorized to protect the road bordering Sunset Cliffs from severe cliff erosion in this region. Also, the Point Loma lighthouse is in jeopardy from cliff erosion.

Silver Strand spit, which extends 17 km downcoast from San Diego to the city of Imperial Beach, has a wide sand beach supplied with sand flowing upcoast from the Tijuana River. Imperial Beach has had an erosion problem, and two groins have been built by the Corps of Engineers in an effort to improve the sand beach. Very fine sand indigenous to the area does not hold a protective beach berm, so soil underlying homes and apartments is exposed to erosion. Private interests have built bulkheads and revetments to protect their developments.

5.4 Landslides, Slope Stability

Unstable slopes and cliffs are very characteristic of the coastal zone under consideration. To explain some of the underlying causes, a brief summary of slope evolution in late Pleistocene and Recent time will be given.

Throughout late Quaternary time, the coastal zone has been undergoing slow uplift. When and where uplift and sea level rise were proceeding at almost the same rate, marine terraces were carved. On land, in late Pleistocene time, erosion of the rising mountain land took place under possibly periglacial conditions of abundant precipitation. Well-rounded landforms, undergoing intense erosion by creep and solifluction were the result. The products of these processes accumulated along the valleys, resulting in locally very thick colluvial and alluvial deposits. More differentiated climatic conditions superimposed steep slopes in many places, usually carved in bedrock, on the previous, gently rounded morphology. The corresponding slope break is prominent on many Southern California slopes. Slope failures in this area occur in two principal ways: failure in colluvial and other unconsolidated material; and failure in bedrock under specific circumstances.

The two prominent landslides of the Pales Verdes Peninsula illustrate the two conditions. The Point Fermin landslide occurred because unstable, slideprone Alta Mira shale (mid-Miocene), with dips toward the free cliff face, was further weakened by year-round watering of lawns, by traffic along a main thoroughfare, and by weight of buildings. The Portuguese Bend landslide is a reactivated fossil slide in colluvial material. It was reactivated as a result of highway excavations undertaken without adequate previous study. Slide risk is particularly high in the area under consideration because slopes are comparatively recent geologically and have had little time to adjust to recurring seismic and climatic events. Human Interference further upsets the delicate equilibrium of many slopes. Fossil slides, possibly at rest under present natural conditions, may be reactivated by human interference, be it change in vegetation, fires, or engineering works.

"Landslides are concentrated in the seaward-dipping shales between Abalone Cove and Cabrillo Beach, along the shores of the Pales Verdes Peninsula. Here 52% of the coastline has been affected by landslides and much of the remainder is potentially unstable.

More than 86% of the area is undergoing active marine erosion. Over the past several thousand years, sea cliff retreat has averaged ±5 cm/year for cliffs composed of Tertiary sedimentary bedrock. Average rates of sea cliff retreat may be as great as ±22 cm/year in hard igneous rocks. Within a given area, erosion is most active along faults, shears, and joints. Kelp, reefs, wide beaches, rip-rap and other obstructions seaward of the sea cliffs slow or prevent marine erosion of the sea cliff.

The configuration of the coastline is controlled by rock type and structure. Sea cliffs composed of uniform rocks form straight coastlines while irregular coastlines result where variable rock types are exposed. Faults are largely responsible for the gross configuration of the coastline as well as many local irregularities.

The seismic environment of the area is similar to most of Southern California (see Section 5.1). No active faults are exposed in the sea cliffs." (Ploessel, 1972)

Undersea slides are likely to occur around submarine canyon heads (Figure 1-3) and following earthquakes on steep slopes (as low as 10° or less in unconsolidated material).

5.5 Subsidence

Subsidence has occurred in the area under consideration where fluids have been withdrawn from underlying rocks. This includes both groundwater and oil. The most famous example is that of the Wilmington oil field. Here withdrawal of oil resulted in subsidence in and near the city of Long Beach, locally reaching almost 9 m in depth. The situation has now been stabilized by water injection. Such subsidence can be prevented by controlled water injection during oil withdrawal.

Groundwater withdrawal from incompletely compacted rocks has resulted in subsidence in several areas of the Los Angeles basin, for example in the Huntington Beach area. Controlled withdrawal can almost eliminate damage to structures from this cause.

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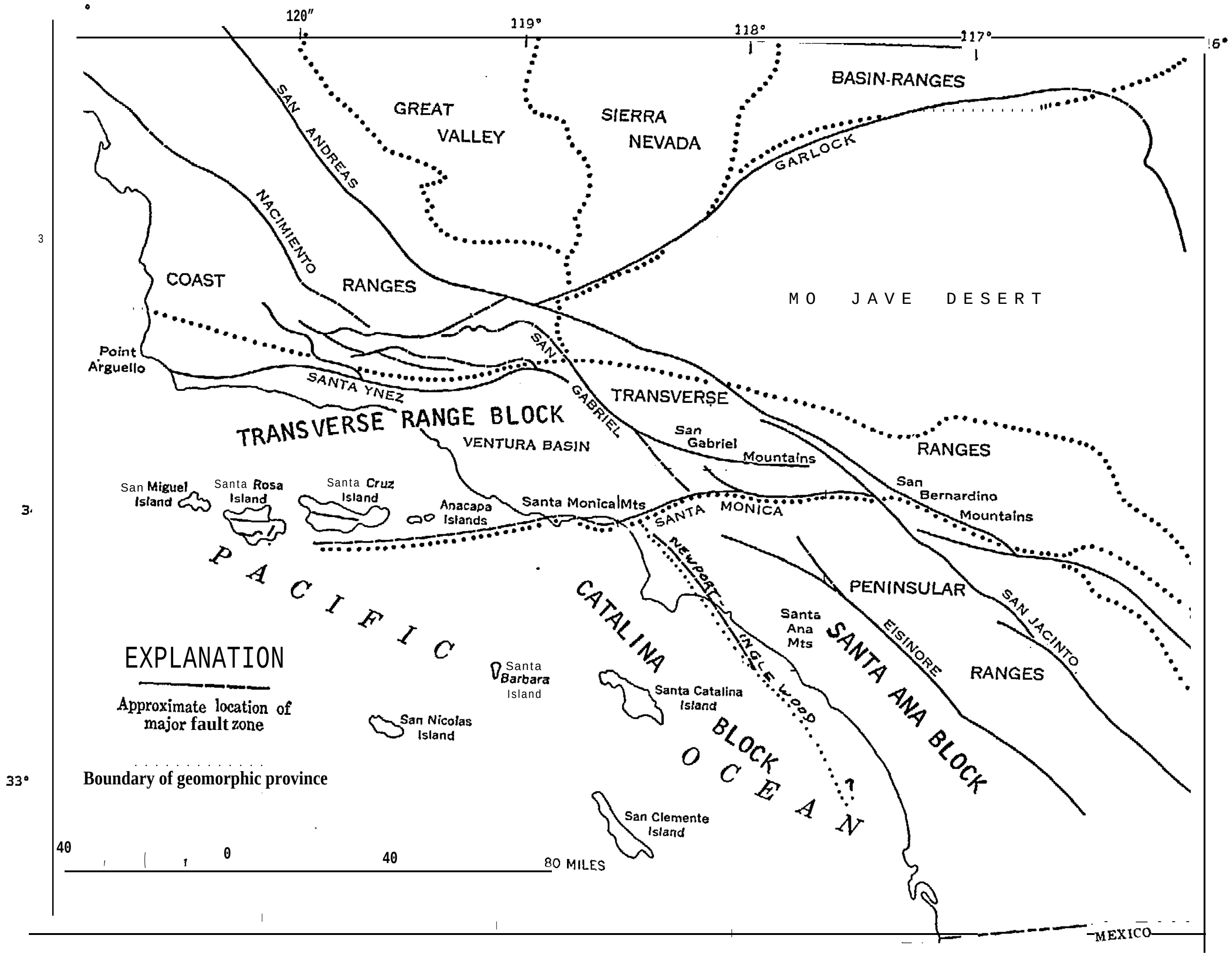


Figure 1-1. Regional Geological Subdivisions of Southwestern California (Vedder, et al., 1965, modified)

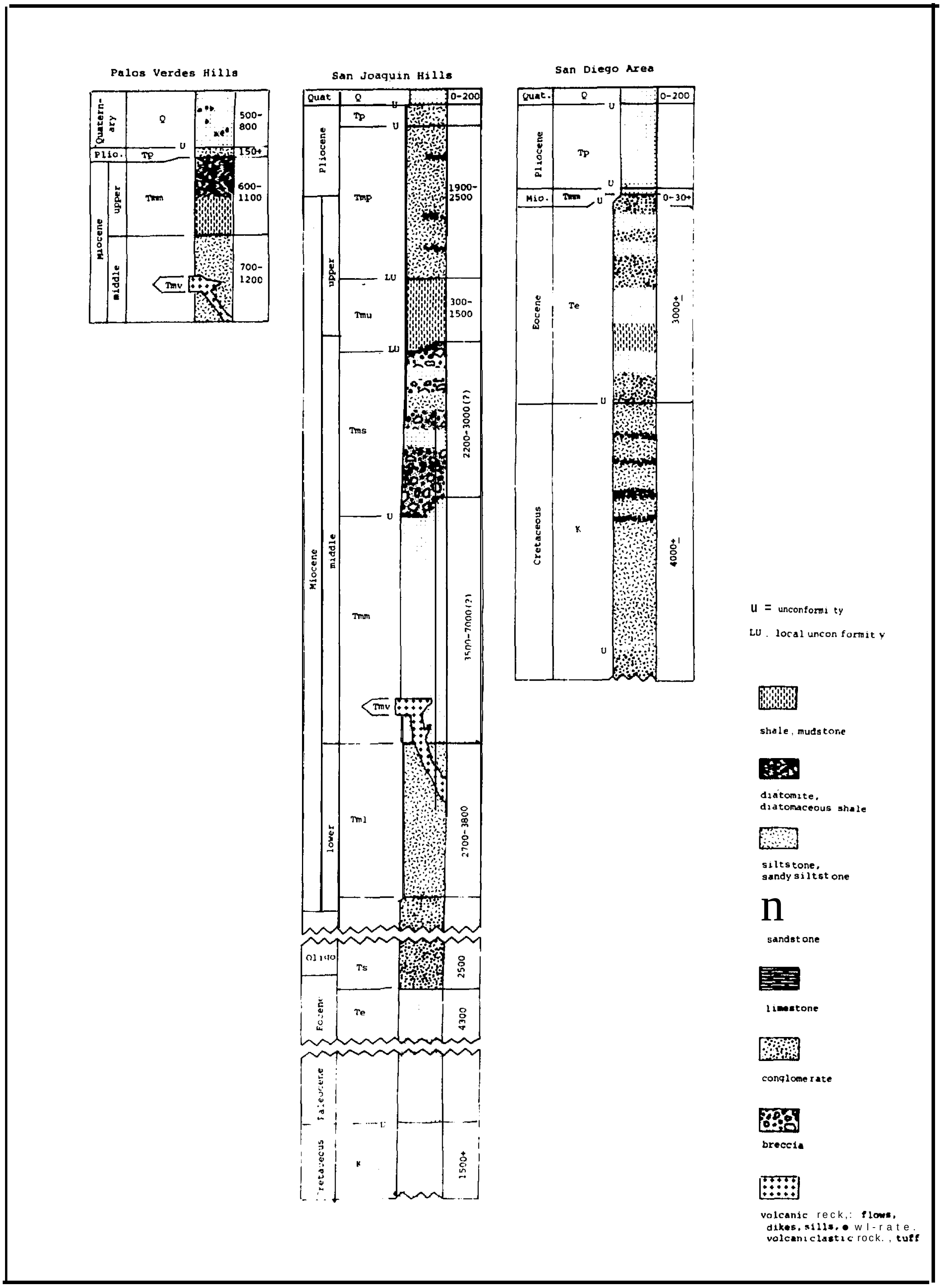
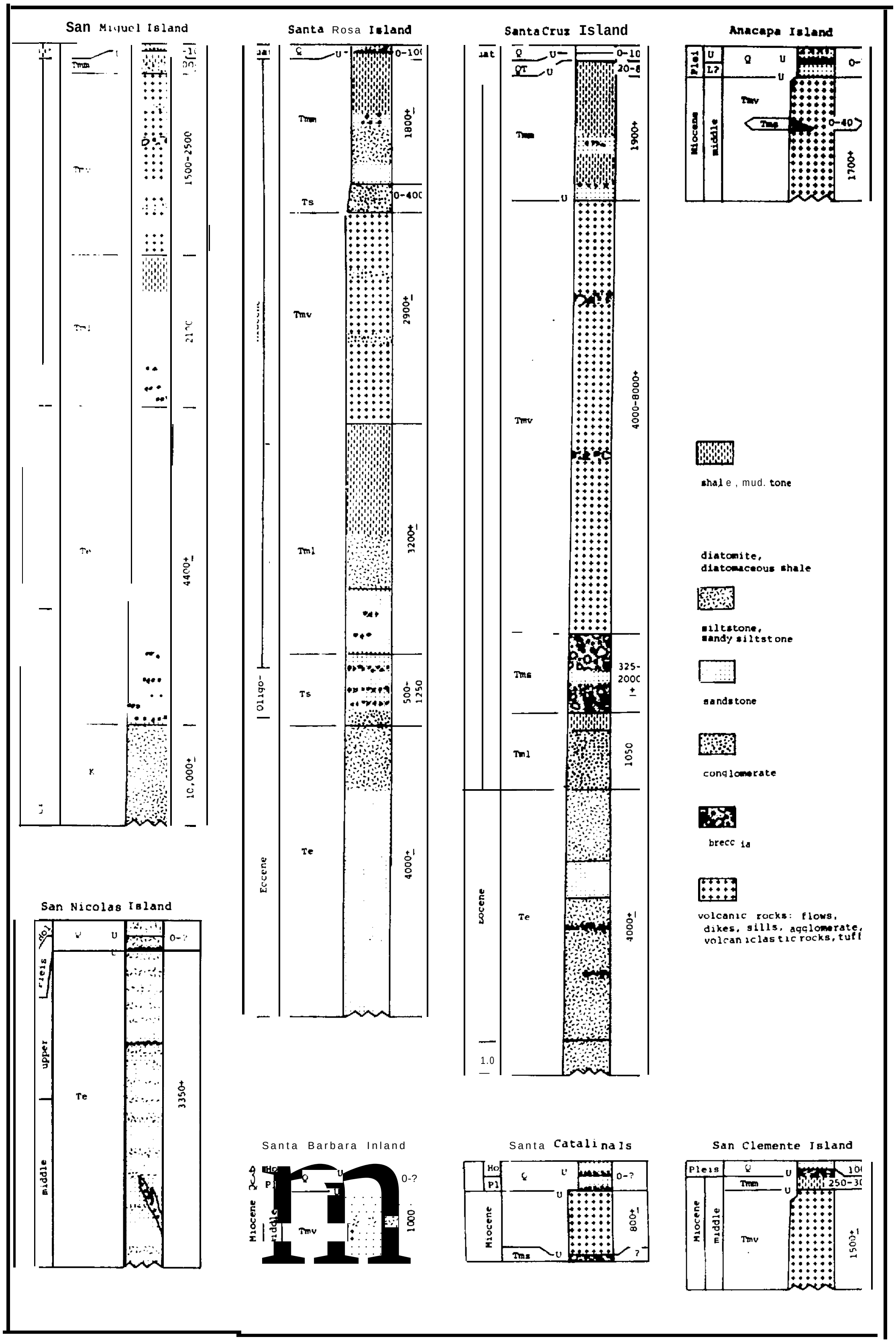


Figure 1-2. (A) Stratigraphic columns from shore points in Southern California (U. S. Geological Survey, 1973).



(B) Stratigraphic columns from islands off Southern California (U. S. Geological Survey, 1973) .

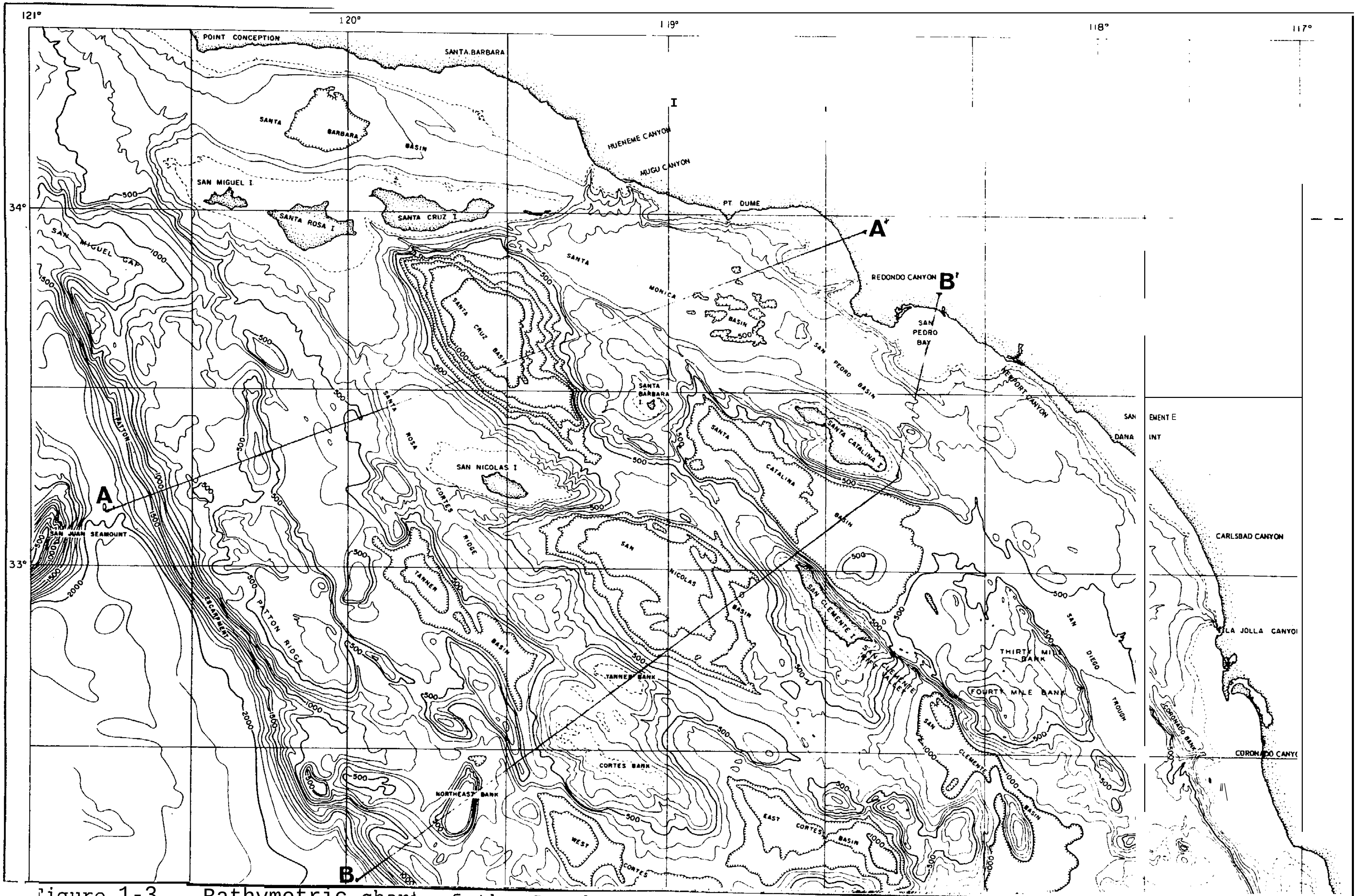


Figure 1-3. Bathymetric chart of the Southern California borderland. Contour interval: 100 fathoms, plus 50 fathoms where feasible. (Moore, 1969). See Figure 1-6 for cross section diagrams of A - A′ and B - B′.

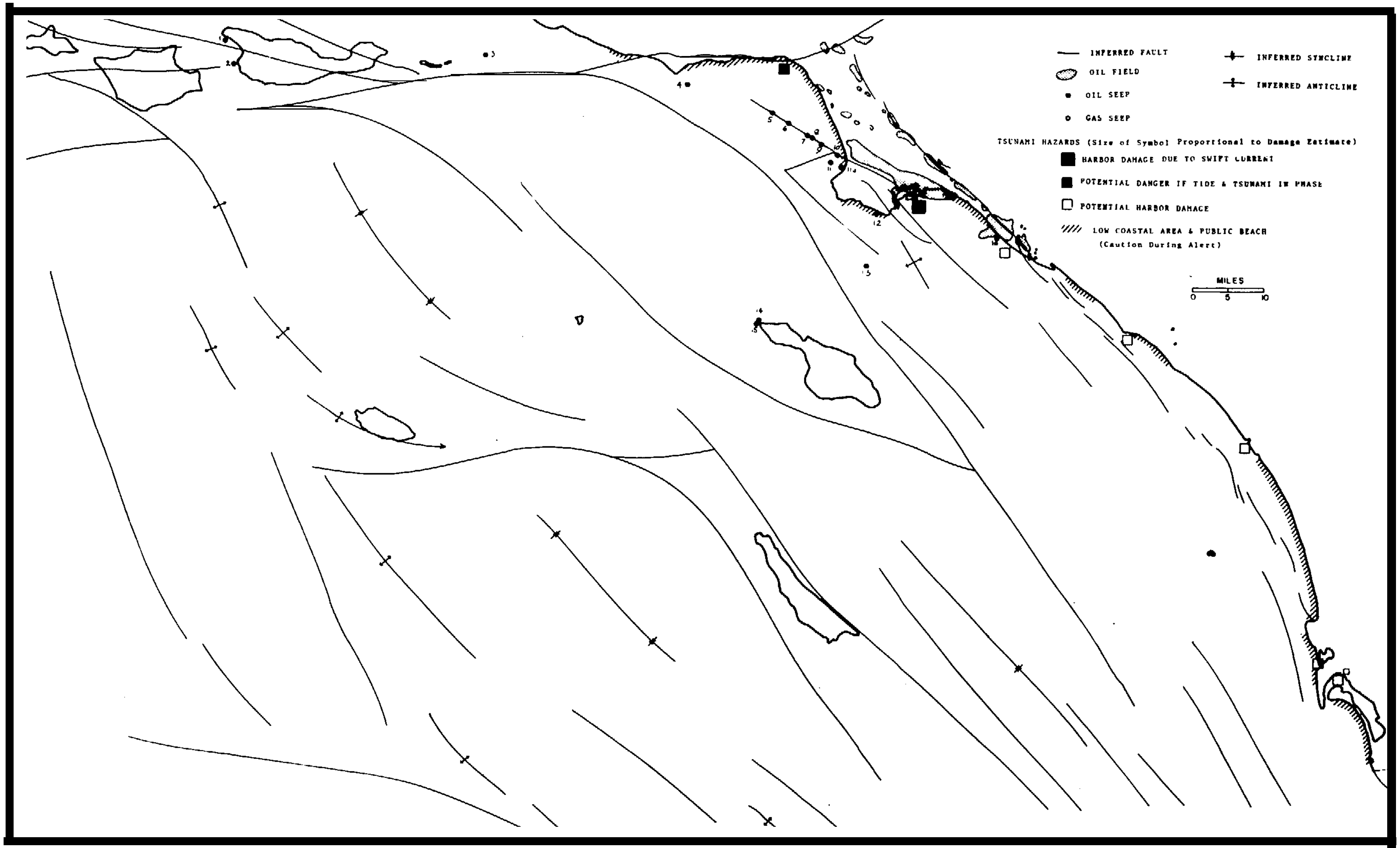


Figure 1-4. Inferred faults and folds (U.S. Geological Survey, 1973), Tsunami hazard (Unpublished data, Calif. Dept. Conservation, Seismic Safety Information 72-5) and oil and gas seeps (Wilkinson, 1972). (For explanation of numbers, see Table 1-2).

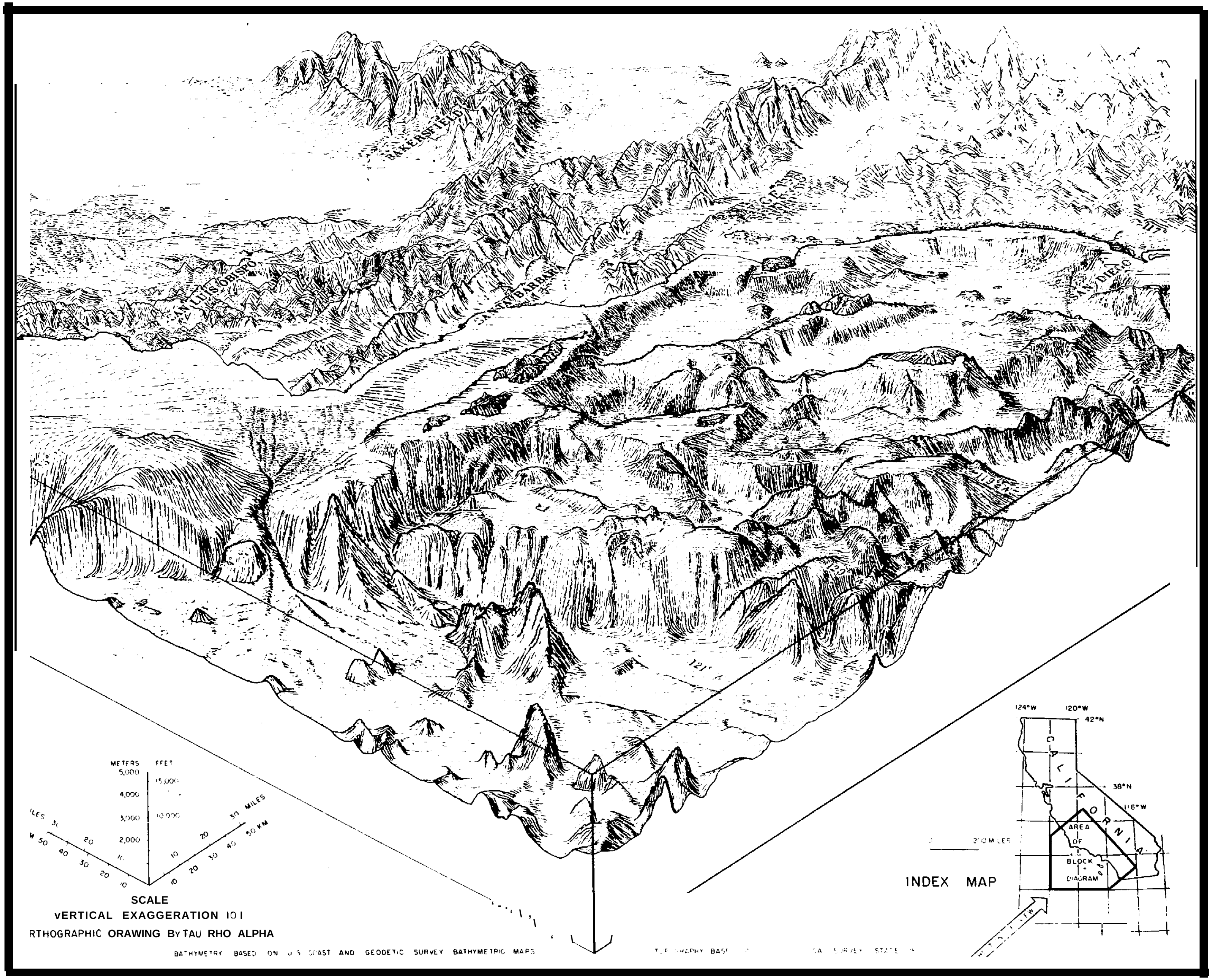


Figure 1-5. Block diagram showing relief of the Southern California Borderland. (U.S. Geological Survey).

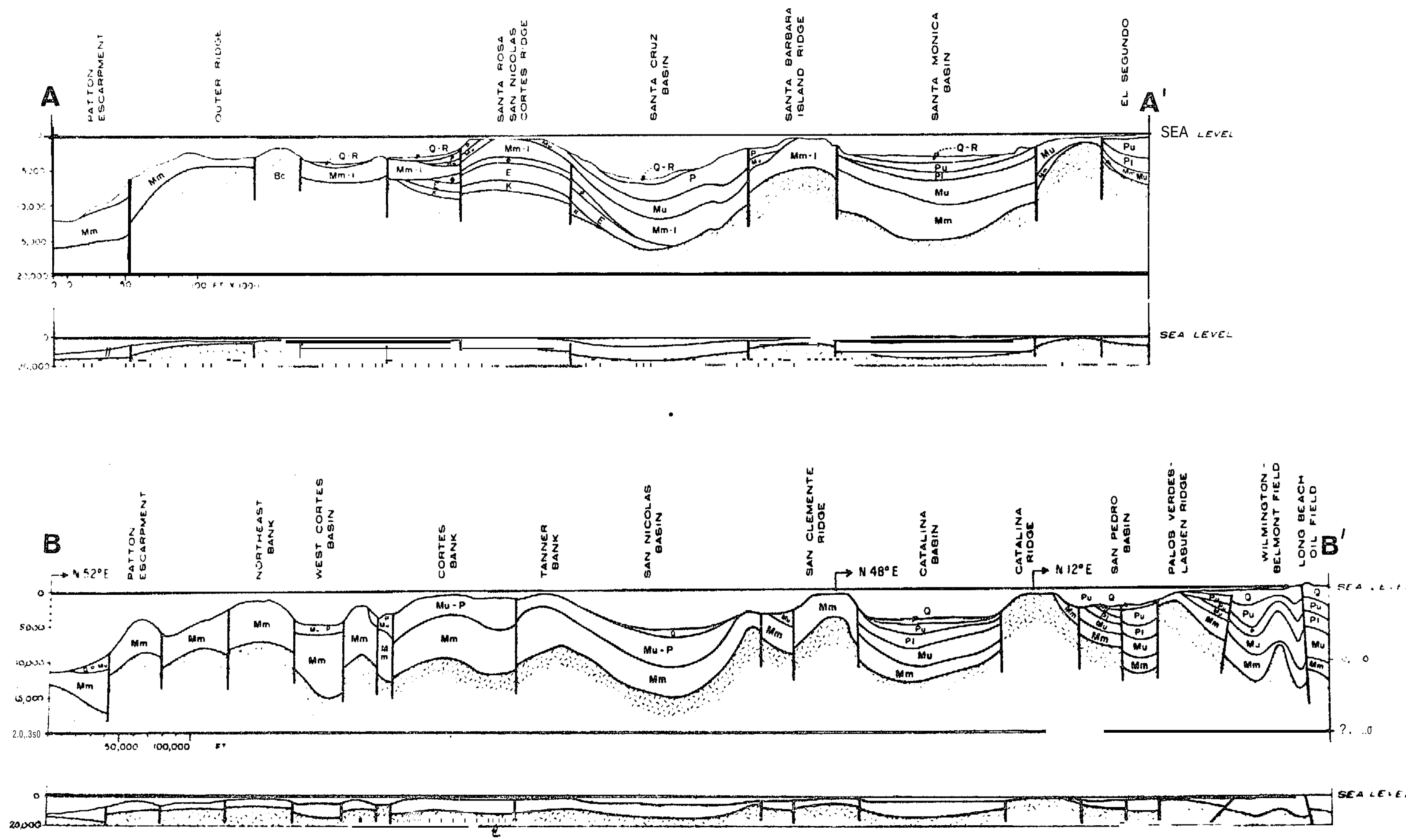


Figure 1-6. Cross-sections AA′ and BB' (see Figure 1-3). Horizontal scale slightly smaller than Figure 1-3. Vertical scale = horizontal scale in lower cross-sections; in upper cross-sections vertical exaggeration is five times. K = Cretaceus, E = Eocene, O = Oligocene, Mm-l = Middle and Lower Miocene, Mm = Middle Miocene, Mu = Upper Miocene, MU-P = Upper Miocene and Pliocene, P = Pliocene, Q = Pleistocene, Q-R = Quarternary undivided. (Parker, 1971). Note: Time boundaries inferred; no borehole information available.

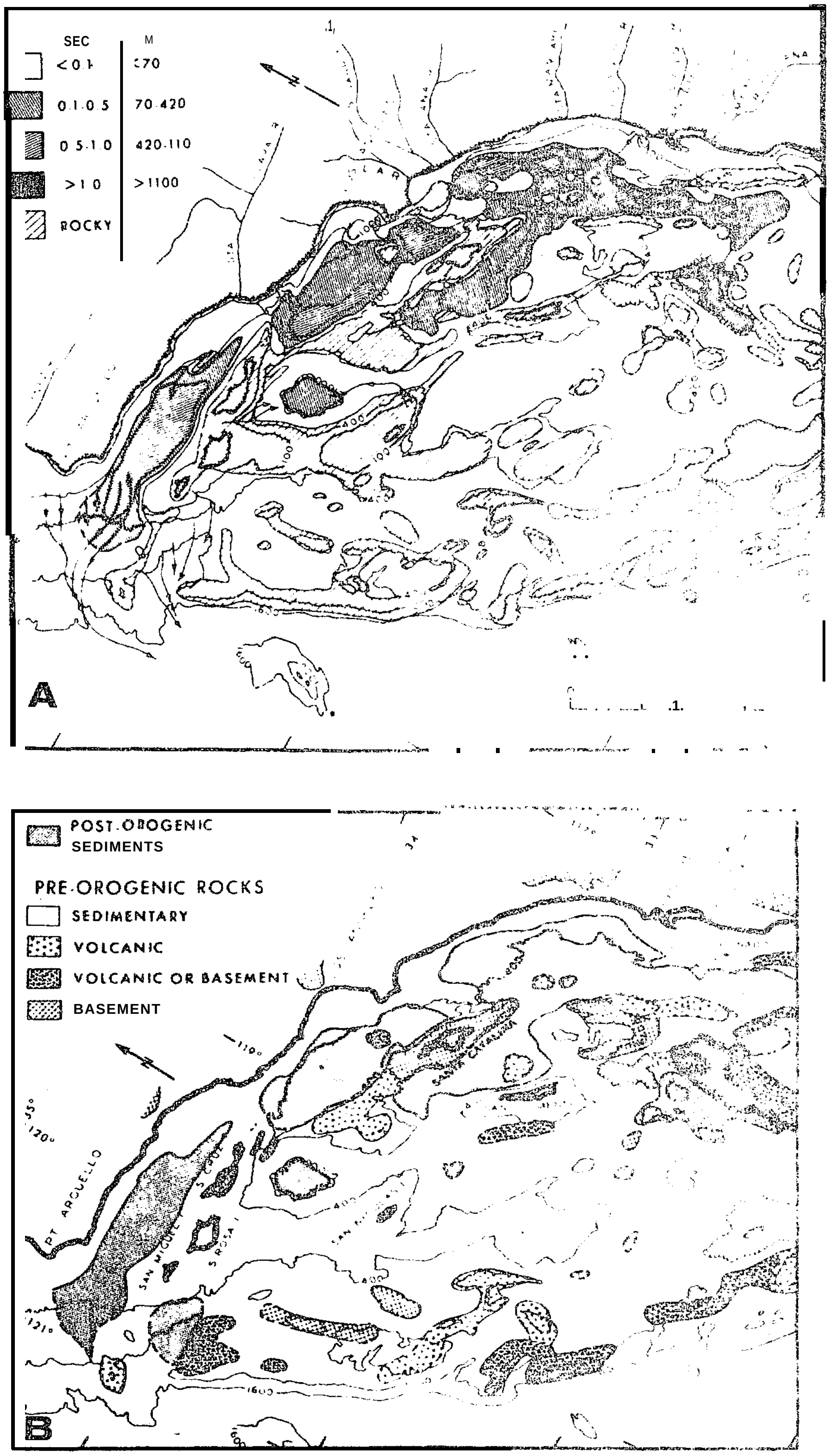
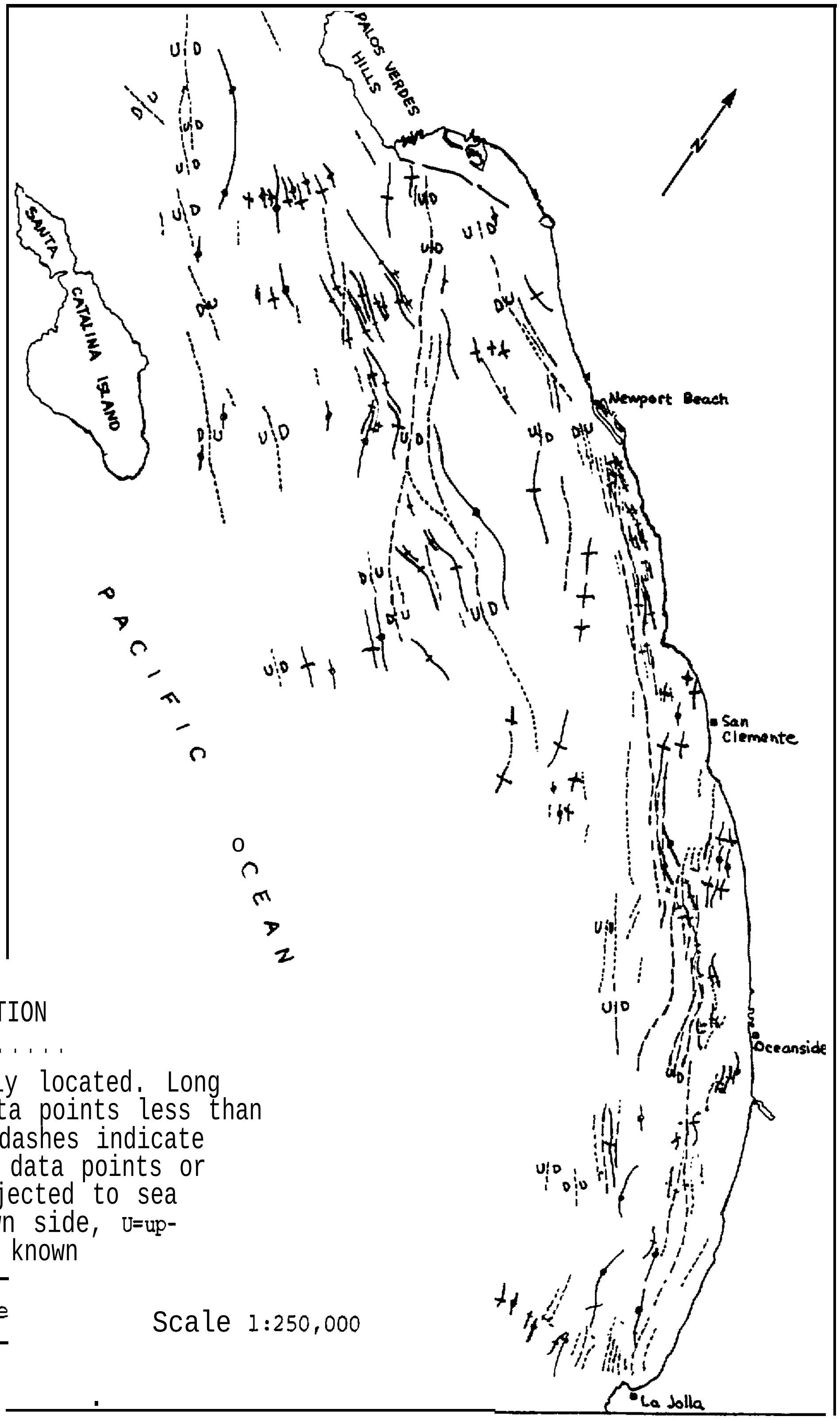


Figure 1-7. (A) Volumetric distribution of "post-orogenic" sediments. (B) Distribution of litho-orogenic units according to Moore (1969).



EXPLANATION

Fault, approximately located. Long dashes indicate data points less than 4 km apart; short dashes indicate greater spacing of data points or deep structure projected to sea floor; D=downthrown side, U=up-thrown side, where known

Anticline

Syncline

Figure 1-8. Detailed tectonic map of nearshore area from Pales Verdes to La Jolla. (Compiled by H. C. Wagner and Arne Junger, U.S. Geological Survey, 1973).

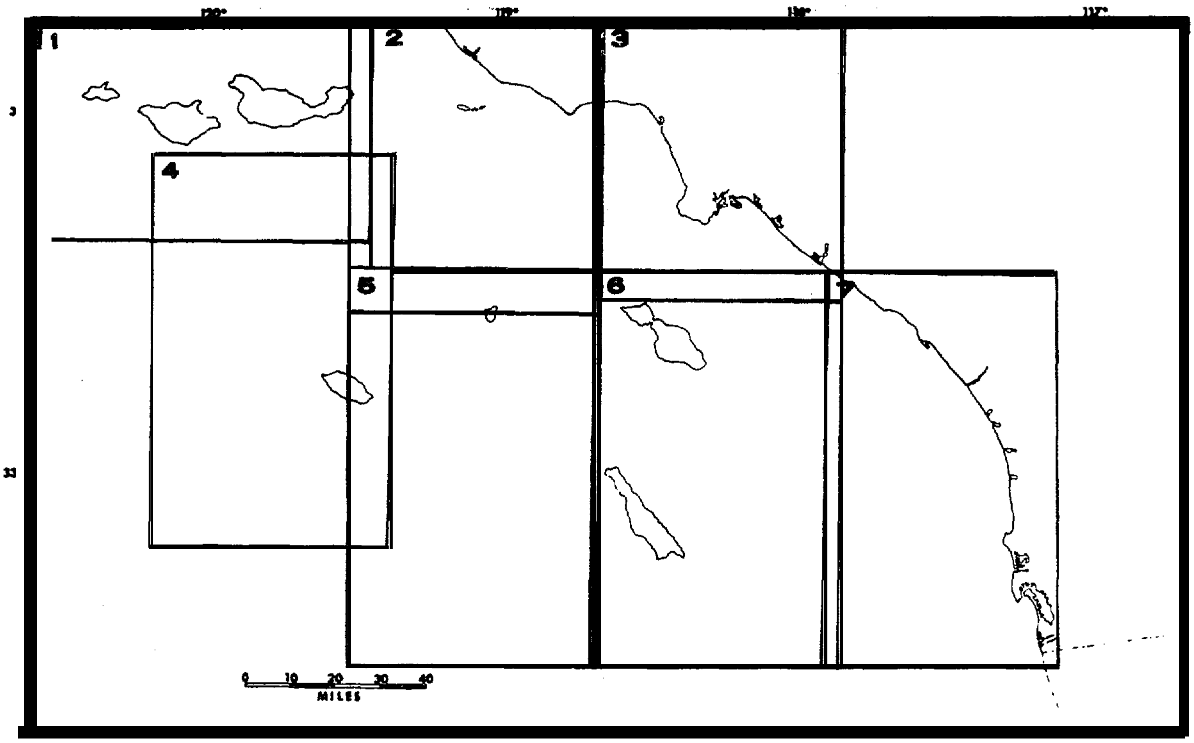
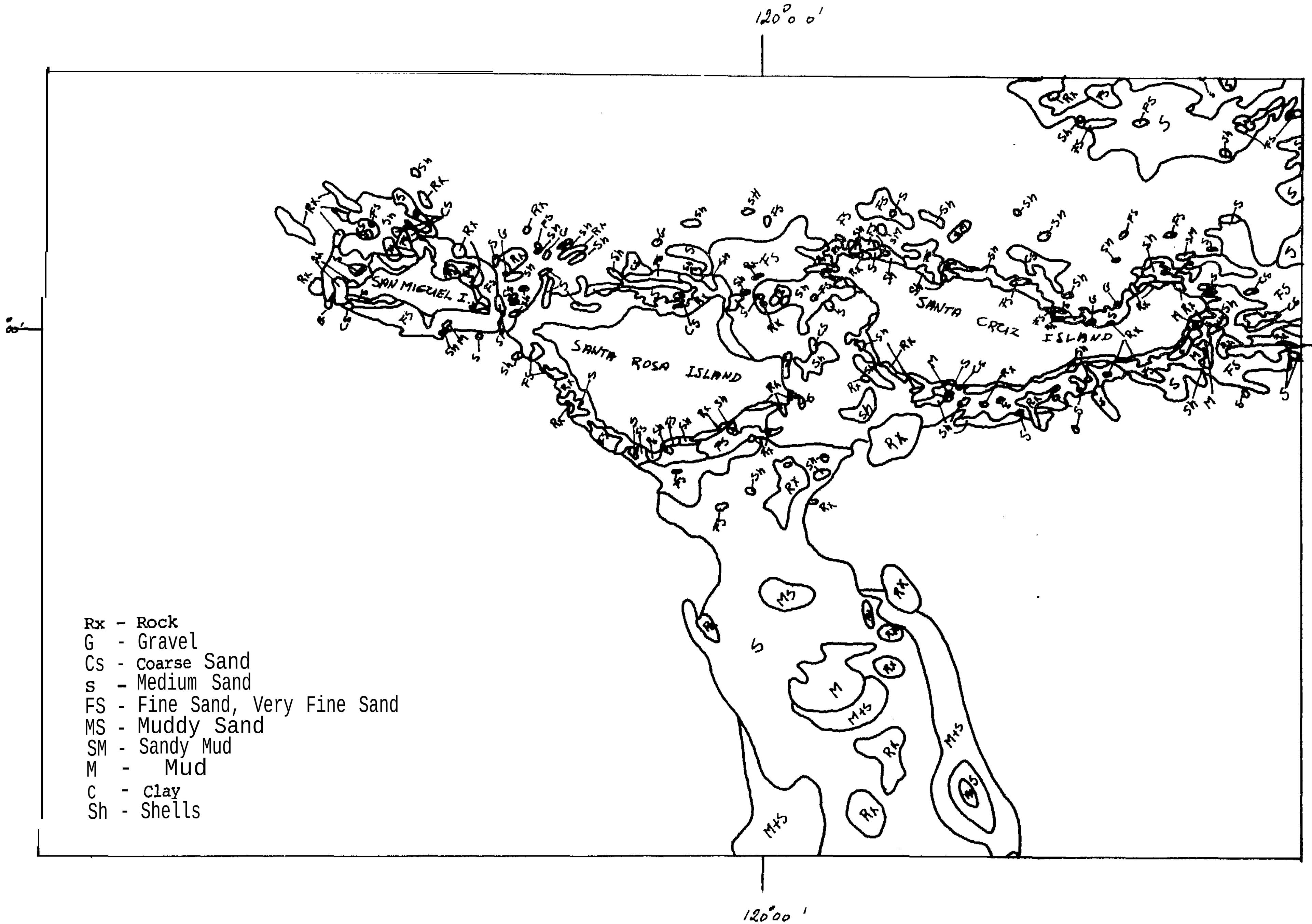
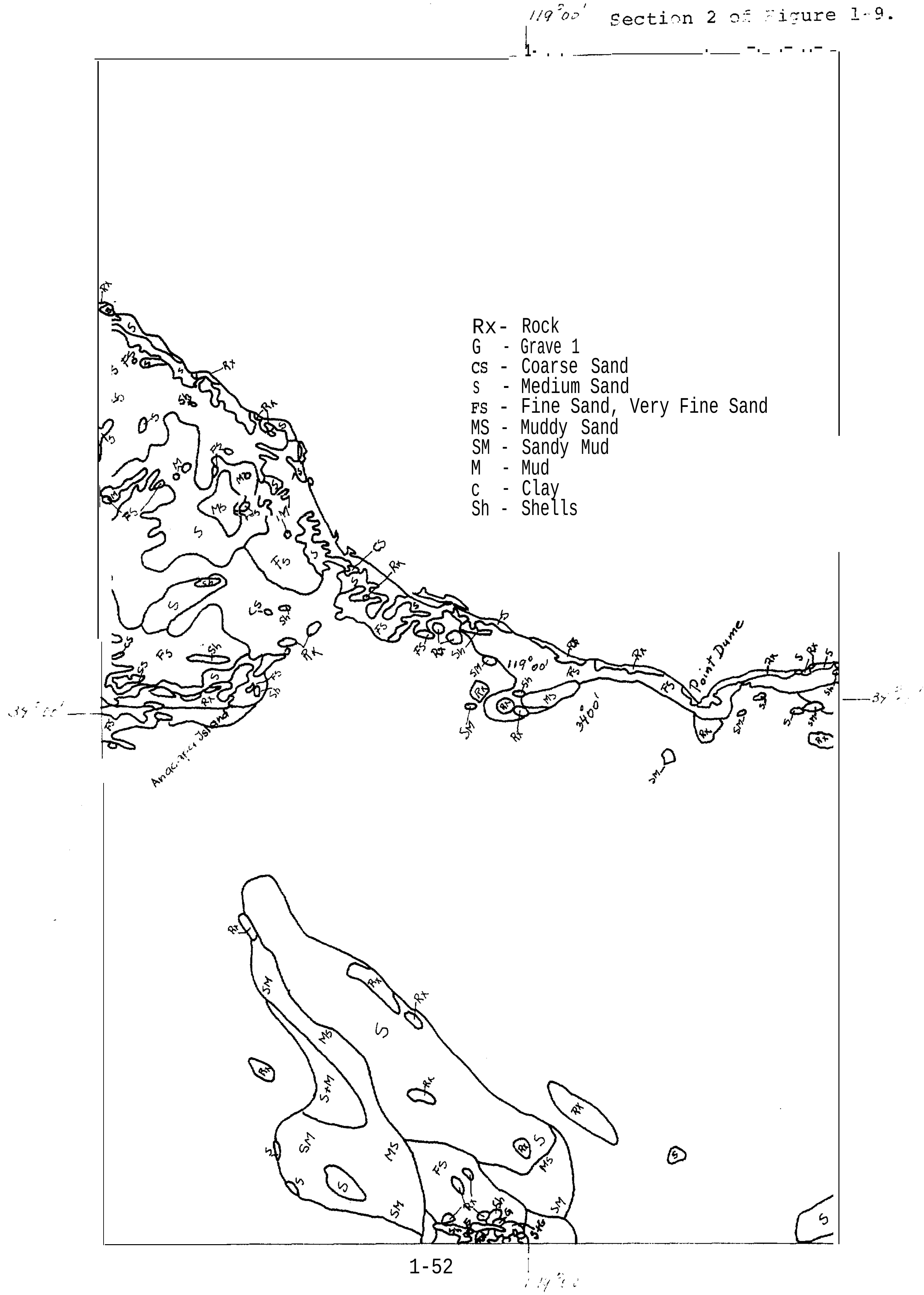


Figure 1-9. Nature of the sea floor. The study area has been divided into 7 sections as shown above. The following 7 section maps were redrawn from a manuscript map by E. Welday (in press, California Division of Mines and Geology).

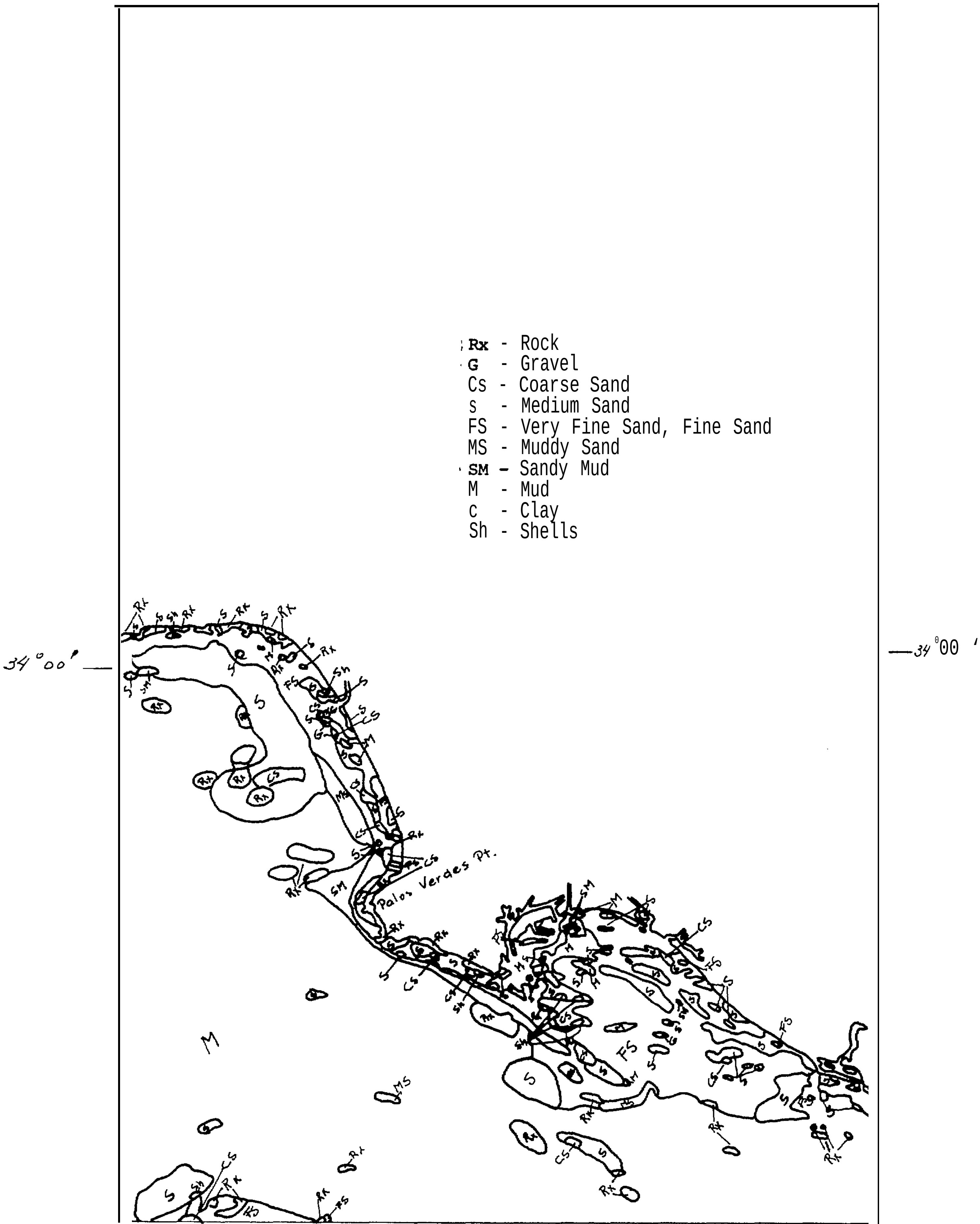
The Rock (RX) designation referred to on the following maps indicates that rocks have been dredged up - presumably, but not necessarily, from bedrock exposures.



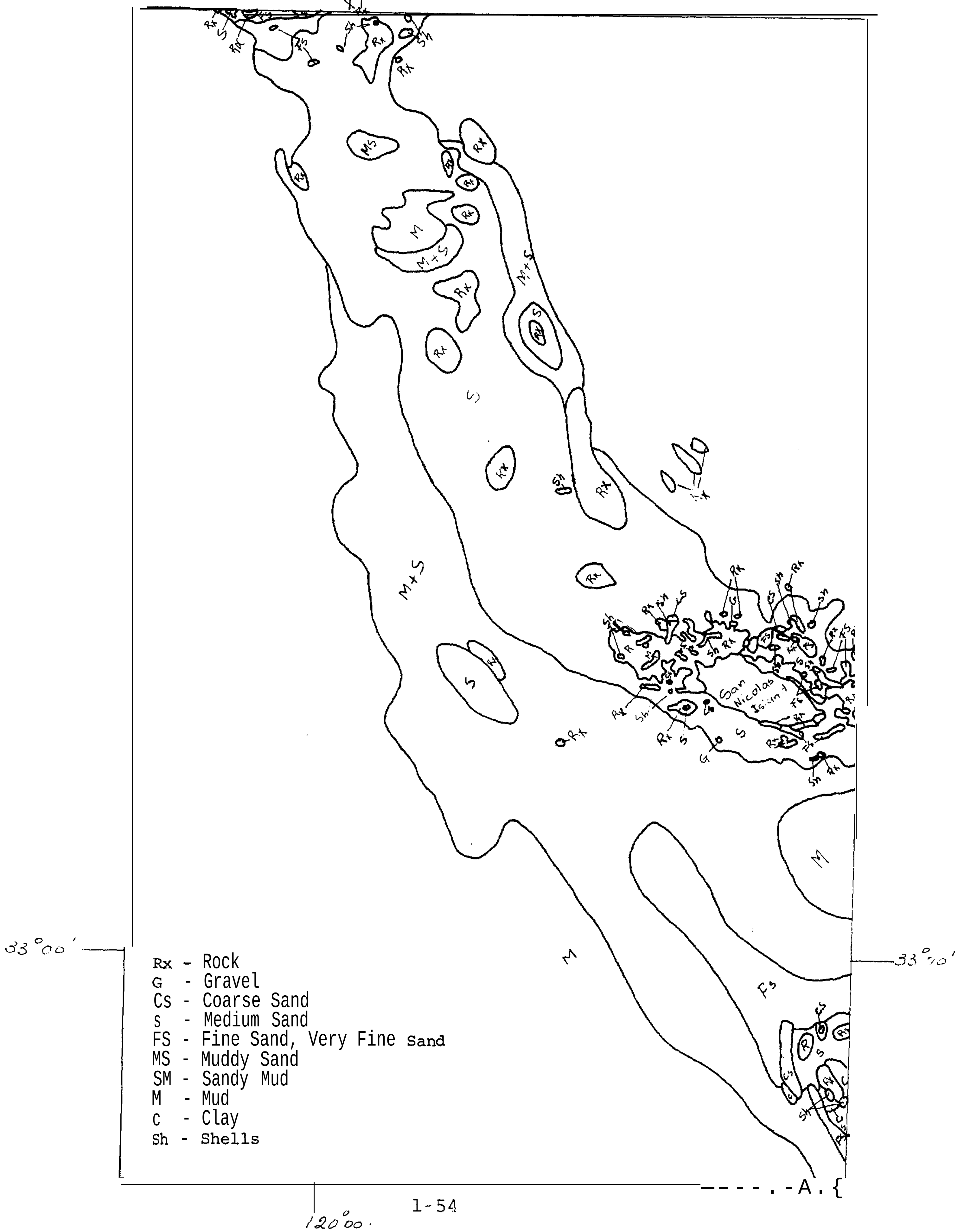
Section 1 of Figure 1-9.


Rx - Rock
G - Grave 1
cs - Coarse Sand
s - Medium Sand
FS - Fine Sand, Very Fine Sand
MS - Muddy Sand
SM - Sandy Mud
M - Mud
c - Clay
Sh - Shells
Point Dume
Anacapa Island
119°00'
34°00'

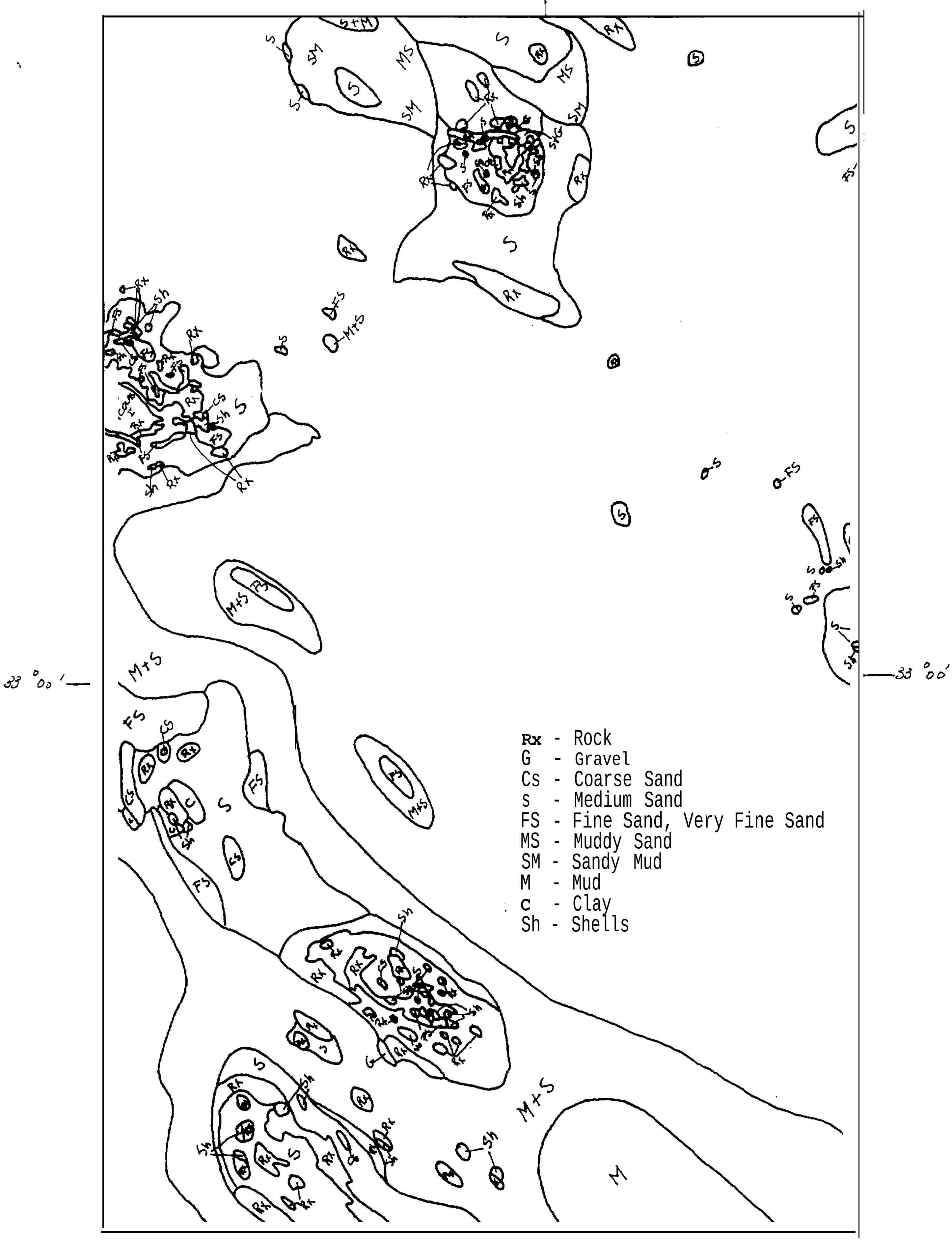
Section 3 of Figure 1-9.

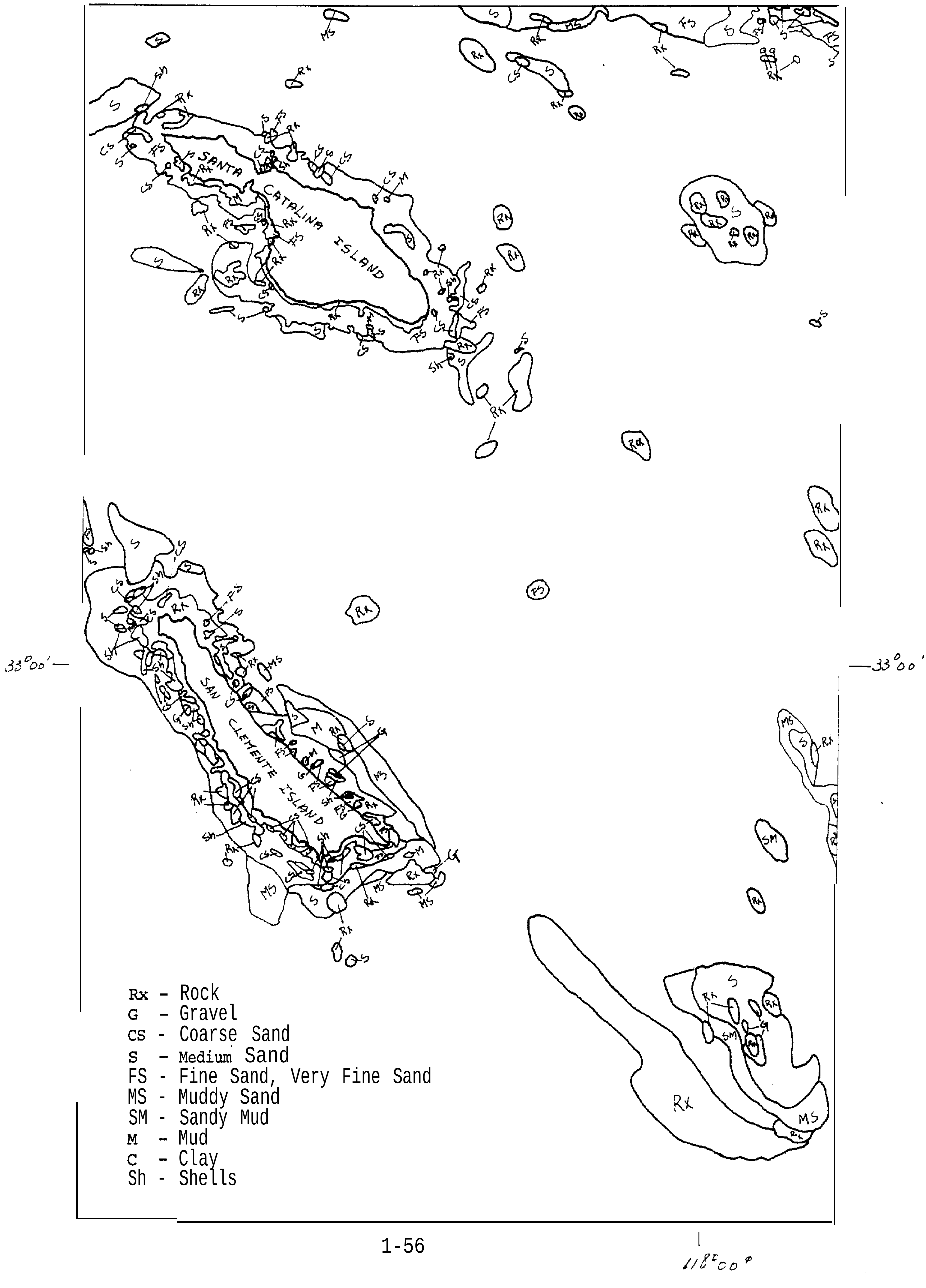


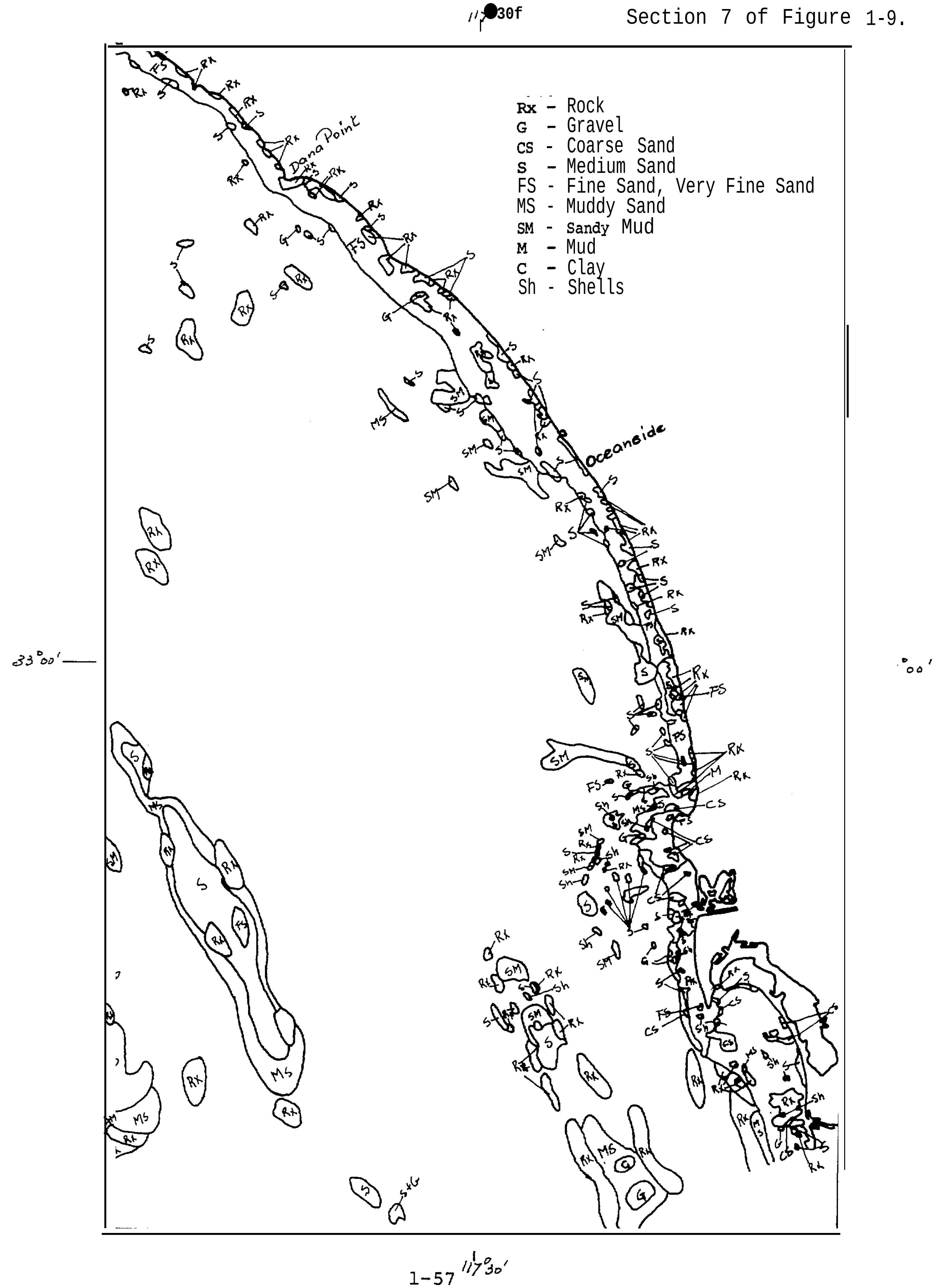
Section 4 of Figure 1-9.



Section 5 of Figure 1-9.




SANTA CATALINA ISLAND
SAN CLEMENTE ISLAND
33°00'
33°00'
118°00'
Rx - Rock
G - Gravel
CS - Coarse Sand
S - Medium Sand
FS - Fine Sand, Very Fine Sand
MS - Muddy Sand
SM - Sandy Mud
M - Mud
C - Clay
Sh - Shells


Rx - Rock
G - Gravel
CS - Coarse Sand
S - Medium Sand
FS - Fine Sand, Very Fine Sand
MS - Muddy Sand
SM - Sandy Mud
M - Mud
C - Clay
Sh - Shells
Dana Point
Oceanside
33°00'
117°30'

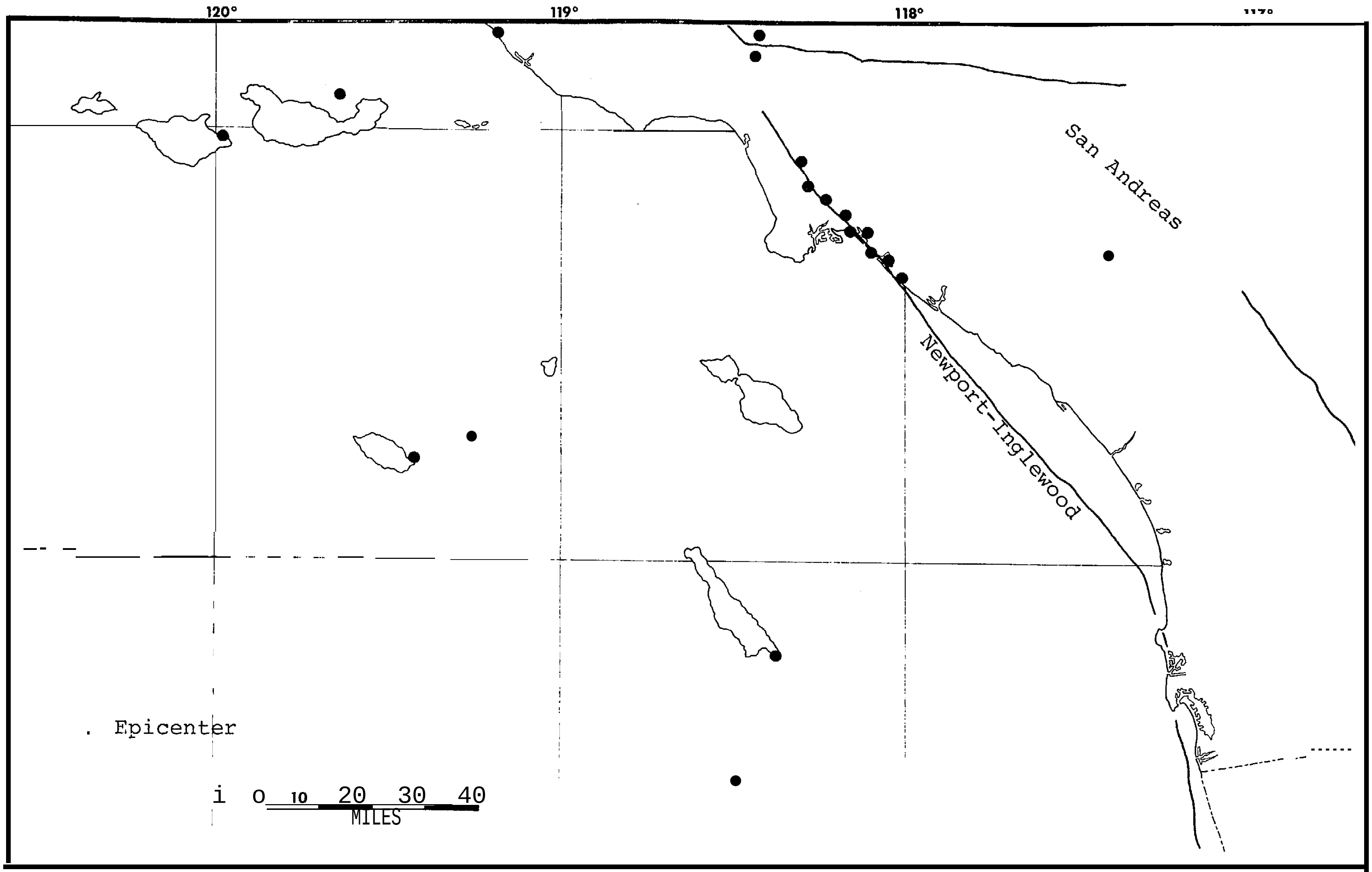


Figure 1-10. Events equal to or greater than magnitude-5 (1932 through (1972) (Hileman, et al., 1972).

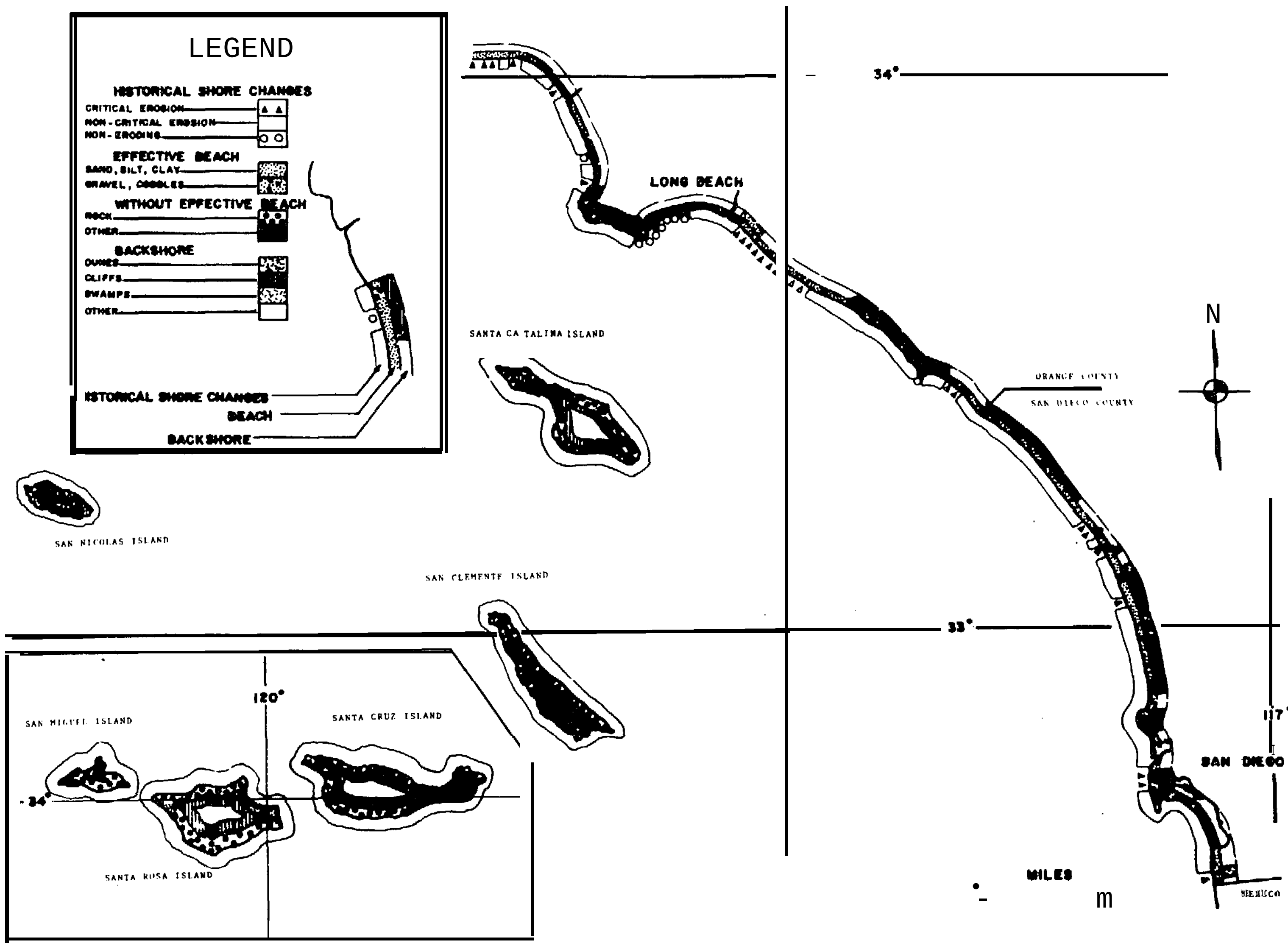


Figure 1-11. Shore line conditions (Redrawn from Chief of Engineers, 1971).

2. CLIMATE

John C. Kimura

1. Introduction

The climate of the Southern California Coastal and Offshore Zone is adequately covered in quantitative terms. This is especially true of the immediate coast, where numerous weather stations are operated by the National Weather Service, the United States Navy, airports and universities. In addition, a weather station is maintained at Avalon Pleasure Pier by the Weather Service. The Navy monitors atmospheric conditions on San Nicolas and San Clemente Islands. There are, however, numerous gaps, especially over the ocean, and for San Miguel, Santa Rosa, Santa Cruz, Anacapa and Santa Barbara Islands, and extrapolation and interpolation are necessary for many of the climatic elements.

1.1 Primary Sources of Information

Detailed long-term summaries of the various aspects of precipitation and temperature are contained in Weather Bureau publications: Climatography of the United States No. 11-4, Climatic Summary of the United States, California, Supplement for 1931 through 1952, (1953); Climatography of the United States No. 86-4, Climatic Summary of the United States, Supplement for 1951 through 1960, (1964); and the Environmental Science Service Administration publication, Climatography of the United States No. 60-4, Climate of California, (1970). Weather Bureau Technical Paper No. 54, Meteorological Summaries Pertinent to Atmospheric Transport and Dispersion Over Southern California, (1965), contains a variety of meteorological summaries, among which, excellent streamline charts are presented. Naval Electronics Laboratory (A. L. Crozier and F. A. Sabransky) Research Report No. 542, Upper Air Data for Southern California, (1954), has analyses and tabulations of upper-air soundings (not within the scope of this report) of temperature and humidity for the adjacent ocean as well as for the San Diego vicinity.

Fairly large scale maps of an assortment of climatological and oceanographic elements by months are portrayed in the Navy Fleet Weather Facility, San Diego publication, Climatological Study Southern California Operating Area, (1971). This volume is an excellent reference for the offshore area. Climatology of California Coastal Waters, (1969), prepared by Fleet Weather Central, Alameda Naval Air Station, contains smaller scale maps of similar climatological and oceanographic data by seasons. An excellent coverage of the climatology is contained in Climatic Handbook for Point Mugu and San Nicolas Island, Volume 1, Surface Data, (1967), prepared by the Pacific Missile Range (R. de Violini). Though in a lighter vein, nevertheless, an extremely helpful short article was authored by R. R. Strange (unpublished preliminary draft of basic data of the Channel Islands National Monument) entitled A Climatological Survey of San Miguel, Anacapa and Santa Barbara Islands, (1973).

US Naval Service Command publications, Summaries of Synoptic Meteorological Observations, North American Coastal Marine Areas, Volumes 7 and 8, (1970), portray twenty-one meteorological and wave conditions by percentage frequencies. The observations were made by ships at sea; therefore? there is in all probability a bias toward fair weather samples, because vessels tend to avoid storms. However, these publications provide excellent average coverage of relatively large sectors. The volumes are divided into areas. Area 22 (San Diego) covers from latitude 31 tc 34° North, and. from the coast to 120° West Longitude; Area 23 (Santa Rosa Island.) from 31 to 34° North, by 120 to 125° West Longitude; and the geographic coverage of Area 24 (Point Mugu) is from 34 to 36° North and westward from the coast to the 125th Meridian.

Synoptic Series, Daily Weather Maps, Northern Hemisphere Sea Level and 500-Millibar Maps arid Data Tabulations, Part I, (monthly), and Daily Weather Maps, Weekly Series, published by the Weather Bureau, present synoptic conditions of the atmosphere. Both include the 500-millibar charts, and the latter has charts on the high.est and lowest temperatures and daily precipitation.

Other works that are specialized will be cited in the appropriate sections.

1.2 General Sources of Information

Numerous other sources exist; however, their usefulness is limited primarily by the smallness of the scales that were utilized. These include two Weather Bureau publications.

Atlas of Climatic Charts of the Oceans, (1938) , and Climatological and Oceanographic Atlas for Mariners, Volume 2, North Pacific Ocean, (1961), contain monthly summaries of a variety of observations. The Environmental Science Service Administration Climatic Atlas of the United States, (1968), portrays useful information, but covers the entire country, excluding the offshore area. Accordingly, the value of this volume is limited from the standpoint of both coverage and scale. Naval publications in this category include Marine Climatic Atlas of the World, Volume 2, North Pacific Ocean, NAVAER 50-1C-529, (1958), Oceanographic Atlas of the North Pacific Ocean, (1963), and Monthly Charts of Mean, Minimum and Maximum Sea Surface Temperatures of the North Pacific Ocean, (1969). Generally, these are similar to the Weather Bureau Atlases that have been cited above.

1.3 Agencies From Which Information is Available

Climatological and meteorological data and information are available from several organizations, mostly in the local area. These include:

(1) National Weather Service, West Los Angeles. Published and unpublished temperature, pressure, precipitation, sunshine amounts, as well as other observations are available. Summaries of wind data for stations operated by the Weather Service and the Federal Aviation Agency are on file.

(2) National Weather Service, State Climatologist, San Francisco. In addition to similar data that are available from the West Los Angeles National Weather Service, tabulations of severe weather, wind observations from private industries, and special summaries of climatological data for local areas may be obtained.

(3) Air Pollution Control District, Los Angeles, has an intricate network of wind stations throughout the county. Other data, such as upper-air soundings and summaries of inversions for Los Angeles International Airport, Santa Monica and Long Beach are also available.

(4) National Weather Records Center, Asheville, North Carolina, is a store-house of climatological and meteorological records from the National Weather Service, military, Civil Aeronautics Administration, and Federal Aviation Agency stations. Data are published in series or as climatographical summaries as cited in 1.1 above (Weather Bureau and Environmental Science Service Administration publications) . Special summaries of any data could also be prepared by the Center on request.

(5) United States Navy, Fleet Weather Facility, North Island, San Diego, maintains records for naval facilities on the coast and the offshore islands of San Nicolas and San Clemente. 'I'he Geophysics Division at the headquarters of the Pacific Missile Range at Point Mugu observes and has available meteorological data for Point Mugu and San Nicolas Island.

(6) The Engineering Library at the University of California at Los Angeles has the most extensive collection in Southern California of source materials on meteorology and climatology.

2. General Climatology

2.1 Climatic Features of the Southern California Coastal and Offshore Area

The immediate coastal zone of Southern California seaward to the western boundary of this study area (121st Meridian) is classified as belonging to the Mediterranean Dry Smer Subtropical climatic type, with a cool summer regime. Along the maritime fringe, temperatures are controlled by the sea. The warm month average is comfortably below 72°F, while the cold month average is above 50°F. Because of the moist air, the relative humidity at night is high, generally above 90%. As the temperature rises during the day, relative humidity decreases to about 60%. Precipitation is strongly concentrated in winter, with average annual values in the vicinity of 15 inches, decreasing over the sea and the immediate rainshadows of the islands, and increasing over the coastal mountain slopes. Fewer than half of the days of the year are classed as cloudy (7/10 or more of the sky covered by clouds) , and heavy fog averages 53 days per year at Los Angeles International Airport, decreasing to some 30 days at San Diego.

2.2 Summer Pattern

During both summer and winter, the dominant climatic control is the Pacific Subtropical Anticyclone. In summer, this anticyclonic cell strengthens and migrates northward with. its eastern edge off the coast of Oregon and California, where active subsidence occurs. This results in air heating by compression; therefore, a temperature inversion is created at about the 2,000 ft. level. The relatively cold water that is flowing southward along this coast not only maintains equitable summer temperatures but creates a surface inversion by chilling the overlying air. These two inversions result in an extremely stable atmospheric condition, and precipitation is generally precluded during the summer.

April, May and June are the cloudiest months, with low-lying stratus which is often associated with unmeasurable light drizzles. This thick, gray overcast, usually less than 3,000 ft. thick, may last for several days or even a week or more. As summer approaches, clouds recede during the day as solar heating becomes dominant, and only night and morning coastal cloudiness remains. During summer, a thermally-induced low pressure center is created in southwestern Arizona. This, coupled with the strengthening of the Pacific High results in a pronounced sea breeze condition during the day along the coast, superimposed on the general northwesterly circulation.

Although from June through August, and often into September, the weather map changes only slightly from day to day, occasional nonperiodic weather does occur. The most frequent is the warm Santa Ana condition, with its hot, dry, northeast winds. Usually this pattern does not produce strong winds below the canyons and on the coastal fringe; however, on occasion, extremely strong gusts have been noted. The Chubasco rain is somewhat less frequent in coastal Southern California than the Santa Ana. The origin of this condition is in the tropical waters west of southern Mexico and Central America. Moist, maritime tropical air masses could invade this coastal zone from either the Pacific or the Gulf of California, and bring hot, humid weather associated with thunderstorms. On extremely rare occasions tropical storms, too, have been observed over Southern California waters. The least frequent pattern results when the Atlantic Subtropical Anticyclone strengthens and migrates to the west. A moist tongue then may enter Southern California and bring warm and humid weather with thunderstorms.

2.3 Winter Pattern

In winter although the Pacific Subtropical Anticyclone weakens and migrates to the south, the dominant weather in coastal Southern California is still related to this high pressure cell. Winter is the rainy season with 95% of the precipitation being received between November through April. However, there are many more non-rainy days. The weakening and the southward migration of the Pacific Anticyclone permit the large storms that form over the sea (Aleutian Low) to invade Southern California as early as in October. Usually, the storms are short in duration, lasting only for a day or less. On occasion, however, storms of longer duration occur, lasting as long as a week. The predominant circulation is still northwesterly. During winter and spring, the winds can reach velocities of about 40 kph with resulting 10-foot waves. Superimposed on these winds are those associated with the passage of storms and fronts. The circulation is usually southeasterly in advance of a cold front. Although this wind can attain a force exceeding 50 kph, the southeasterly is the least frequent of the severe winds. After the passage of the cold front, continental air may build up over the Basin and Range Plateau, and thus produce a cold Santa Ana condition. During such periods extreme wind conditions may be experienced below the canyons and over the channel (gale to hurricane force winds) which could result in high seas. Despite heating by compression, temperatures remain low, because of the low initial temperature, but freeze conditions are rare. The relative humidity can decrease to 5%.

3. Air and Water Temperature

Air temperatures over the Southern California Coastal and Offshore Region are controlled by marine influences. Mild conditions are, therefore, the rule, and uniformity exists from day to day and from season to season. Diurnal differences also tend to be small, contributing to the cool days and relatively warm nights.

3.1 Sources of Information Regarding Temperature

Detailed temperature summaries concerning means, maxima, minima and extremes are available for numerous stations along the coast from Weather Bureau publications. Especially noteworthy are: Climatography of the United States No. 11-4, Climatic Summary of the United States, California, Supplement for 1931 through 1952, (1953); Climatography of the United States No. 86-4, Climatic Summary of the United States, California, Supplement for 1951 through 1960, (1964), and the Environmental Science Service Administration publication, Climatography of the United States No. 60-4, Climate of California, (1970). Detailed description of temperature for San Nicolas Island is contained in a Pacific Missile Range (R. de Violini) publication, Climatic Handbook for Point Mugu and San Nicolas Island, Volume I, Surface Data, (1967); Climatological Study Southern California Operating Area, (1971), prepared by NWSED, Asheville, North Carolina, for the Naval Fleet Weather Facility, San Diego, contains very adequate large scale monthly mean air ancl sea surface temperatures.

Specialized temperature summaries are published by the Weather Bureau. Such summaries include: combined increments of temperature-relative humidity, 24-hour average dry-wet bulb-readings, departures from normal, maximum and minimum temperatures with dates of occurrence; temperatures by time, number of days that temperatures exceeded 90°F and was below 32°F, mean values at standard pressures, mean daily maximum and minimum, standard deviations of monthly average temperatures, percent distribution of dry-wet bulb temperatures vs. wind speed, and other categories. Publications in which they may be found include: Climatological Data, (monthly and annual), Local Climatological Data, (monthly), Climatological Data, National Summary, (monthly and annual), Monthly Climatic Data for the World, Daily Normals of Temperature and Heating Degree Days, (1963, single volume issue), Summary of Hourly Observations, 1951-1960, Weather Bureau Technical Paper No. 9, Temperatures at Selected Stations in the United States, (1949), and Climatic Sub-station Summaries. The last entry consists of climatic summaries of smaller communities. These are published in cooperation with chambers of commerce, trade organizations, schools and colleges, public utilities and industrial organizations.

3.2 Mean Air Temperatures

The mean cold month temperatures are experienced in January, while the mean warm month temperatures occur in August along the coastal belt seaward for several tens of miles. In most of the study area that is over the ocean and beyond the immediate coastal and sea strip, February is the month with the lowest mean, and September has the highest mean temperatures. Thus, Avalon on Santa Catalina Island has a mean annual temperature curve similar to that of coastal stations, while San Nicolas Island, some eighty miles from the Pales Verdes Peninsula, and sixty miles west of Santa Catalina Island, experiences the lowest mean monthly temperature in February, and the mean warm month temperature in September. Ordinarily, January and July represent the months with seasonal temperature extremes; however, these lags represent the greater heat holding capacity of water as compared to land. Therefore, water bodies heat and cool more slowly than land areas. The mean air temperatures for January and August are portrayed in figures 2-1 and 2-2.

3.3 Mean January Air Temperature

A comparison between the temperatures (figure 2-1) on the immediate coastal strip and those over water reveals that the coastal land areas have temperatures that are 2 to 5°F lower than those over the adjacent water. On the coast, temperatures increase southward by 3°F from Point Mugu to San Diego. The mean January temperature at Point Mugu is 52 degrees and at San Diego 55°F. There appears to be a pocket of slightly warmer temperature at the northern head of Santa Monica Bay. The mean January temperature at Santa Monica Pier is 55.6°F.

Over the sea surface there is a 2 to 3°F increase in temperature southeastward. The northwestern portion of the area has a mean January temperature of 56 degrees, and the southeast section has a January mean temperature of 58 to 59°F. A slightly higher temperature (59°F) is noted seaward for about 20 miles from Seal Beach to Newport Beach. In addition, temperature increases in a 20-mile seaward strip from San Clemente to San Diego, then remains constant to the western edge of the study area.

3.4 Mean August Air Temperature

Figure 2-2 shows that, unlike the mean January temperatures, the August means are similar to those over the adjacent sea. One notable exception is Long Beach, where the coastal temperature is slightly higher than that of the air over the water. This condition is related to the directional trend of San Pedro Bay. Because the coastline is essentially east-west and because of the blocking effect of the Pales Verdes Hills, the full effect of the cooling sea-breeze is not realized, and solar heating plays an important role in the temperatures at Long Beach. Temperatures along the coast range from 64°F at Point Mugu, increasing to 68° and 69°F along the coast of Santa Monica Bay and to 71.3°F at Long Beach. A uniform temperature of about 69°F is experienced along the coast south of Seal Beach to the international border.

The air temperature over water likewise shows a divergent pattern from that of January. The January gradient is slight and the trend is northwesterly. However, the August gradient is 7°1? in 225 miles, and the directional trend. is westward, or from the coast seaward. The temperatures are 69°F near the coast, decreasing to 62 degrees on the western margin of the study area.

3.5 Means and Extremes of Temperatures

Figures 2-3 and 2-4 illustrate means and extremes of temperatures at Point Mugu and at San Nicolas Island. Mild, marine temperature conditions generally prevail throughout the year, which is the rule rather than the exception. The mean warm-cold month temperature ranges are slight for the entire study area. The differences are generally less than 10°F over the ocean, and about 15°F at coastal stations.

Mean maximum temperatures for the cold month are in the low-

60's in the channel islands and over the water, and in the mid-60's at adjacent coastal stations. The mean maximum temperatures for the "warm month are about 10 degrees higher for the offshore region, and approximately 15°F greater for the coast than the mean maximum temperatures for the cold month. These temperatures are decidedly comfortable; however, high temperatures are experienced on occasion. The average annual number of days with maximum temperatures above 90°F range from less than 1 day along the west facing coast north of San Clemente and over the oceanic region, to 15 days at Long Beach (south facing). South of San Clemente to San Diego, the average annual number of days with maximum temperature above 90°F is 3 days. Extremely high maximum temperatures usually occur in late summer to early fall -- most frequently in September. Though rare, temperatures exceeding 100°F have occurred. Ninety-one degrees was the highest recorded at San Nicolas; 105°F at point Mugu; and maximum temperatures of 111°F were recorded at both Long Beach and San Diego. Strange (unpublished, 1973) states that at Santa Barbara on June 17, 1859, the temperature rose from 80 degrees in the morning to 133°F in the afternoon. This was the hottest day ever recorded on the North American continent and remained as such in the annuals of the Weather Bureau until Death Valley recorded a temperature of 134.6°F in 1934.

Extreme maximum temperatures are associated with Santa Ana conditions (figure 2-5). As the Pacific Subtropical Anticyclone migrates onshore north of Southern California and over the Basin and Range Plateau, the normal circulation around the anticyclone is clockwise, therefore from the northeast. The air is on a trajectory to coastal Southern California, and is heated adiabatically 5.4°F/1000 ft. of descent. Because the elevations in the Basin and Range Plateau are on the order of about 4,000 ft., temperatures will be warmer by more than 20°F than the source region, and the cool water of the Pacific offers no relief. Since coastal regions are lower in elevation than inland areas, coasts are often hotter than inland stations.

The average annual maximum relative humidity for this entire study region is above 90%. At night and in the early morning hours, 100% relative humidity can be attained when the temperatures are the lowest. The average annual minimum values drop to about 60% in the afternoons. However, during Santa Ana conditions, a large decrease in a short period can occur, and relative humidity can dip to 15%, or on rare occasions to less than 5%. Moreover, lower than normal values can occur at night as a result of offshore breezes generated by the normal land-sea breeze regime.

Mean minimum temperatures for the coldest month are in the low 50's over water and in the mid 40's at the adjacent coast, while the mean minimum temperatures for the warm month are 7 to 10°F higher in the Channel and 14 to 20°F greater on the adjacent coast than the mean minima for the cold month. Though not especially cold, these temperatures represent decidedly chilly conditions. The average annual number of days with minimum temperatures falling below 32°F (freeze days) is non--existent in the offshore region and minimal at the adjacent coastal zone. Along the entire coast of this study region, the highest average annual number of days that the minimum temperature falls below 32 degrees is 3 days at Torrance. Most of the other coastal stations average less than a day. Extreme minimum temperatures of lower than 35*F are rare over most of the offshore coastal zone. Lowest temperatures ever recorded at San Nicolas was 41°F, and the lowest at Santa Monica Pier was 34°F. However, lower temperatures are recorded on the coast. The extreme minimum at Long Beach was 21°F, and at San Diego 29°F. Freeze conditions in Southern California are related to invasions of Polar Continental air. These conditions usually occur in the wake of a well-developed cyclonic storm (figure 2-6). Polar Continental air associated with a cold anticyclone from the north could follow the cold front and settle over the Basin and Range Plateau. The circulation is similar to that of the warm Santa Ana and the winds are northeasterly. Clear skies and the dry air of the anticyclone permit strong nocturnal cooling by radiation of the already cold air. Despite adiabatic heating, air temperatures .remain low.

3.6 Mean Sea Surface Temperature

Mean sea surface temperatures for January and August are portrayed in figures 2-7 and 2-8. In January a difference of about 2°F (57 to 59°F) is noted between the northern and southern boundaries of the study area. A comparison between figures 2-1 and 2-7 reveals that the mean January sea-surface temperature is slightly (about a degree) warmer than the mean air temperature. A similar condition is also noted for August between the mean sea-surface and mean air temperatures (figures 2-8 and 2-2). The difference appears to be slightly greater in August. The August sea-surface temperature gradient is far greater than that of January. The temperature near the northern border is 62°F and that near the southeastern boundary of the study area is 69°F. The sea-surface temperature difference between January and August ranges from 5 to 10°F.

A striking pattern is noted for the mean August sea-surface temperature, the mean August air temperature and to a lesser extent the mean January sea-surface temperature. The trend of the isotherms between 118 and 120° West Longitude is SSE by NNW, thus, the gradient decreases westward. This condition may be explained by the prevailing current direction and upwelling. From Pt. Conception, the coast abruptly trends eastward, and west of bearing 140° from the point the current is essentially flowing in a southern component. East of this bearing, however, the prevailing and secondary currents may be northward.

4. Precipitation

The Southern California Coastal and Offshore Zone is a part of the Mediterranean Dry-Summer Subtropical climatic type. As the name of the climate indicates, summers are dry, and the wetter part of the year is winter. The semi-permanent Pacific Subtropical Anticyclone is strong and is in a northerly position, with its eastern periphery along the Northern California-Oregon coast. The center of this high pressure cell, however, is farther west than the normal winter 'position. The stronger and more northerly position of the cell in summer effectively steers traveling storms farther north and weakens them. Accordingly, frontal precipitation is rare in summer. However, because the Pacific High is weaker and farther south, storms are able to reach Southern California in winter. Accordingly, 95% of the precipitation is received from November through April, and over 50% is recorded in the three winter months of December, January and February.

4.1 Information Sources Regarding Precipitation

Detailed precipitation summaries concerning mean annuals, totals, and maxima and minima for numerous coastal stations are contained in the widely circulated Weather Bureau and and Environmental Science Service Administration publications: Climatography of the United States No. 11-4, Climatic Summary of the United States, California, Supplement 1931 through 1952, (1953), Climatography of the United States No. 86-4, Climatic Summary of the United States, California, Supplement for 1951 through 1960, (1964), and Climatography of the United States No. 60-4, Climate of California, (1970). Precipitation summaries for two of the Channel Islands are available from Climatic Handbook for Point Mugu and San Nicolas Island, Volume I, Surface Data, (1967), published by the Pacific Missile Range (R. de Violini), and from the Naval Weather Service Environmental Detachment, San Clemente Island, (unpublished).

Specialized summaries concerning frequency occurrences of specified increments for each hour, departures from normal, greatest precipitation in 24 hours and date, excessive short duration fall, number of days with certain increments, maximum falls for increments of hours and multiple hours, wettest and driest year, percentage distribution of precipitation, and other summary categories are available in: Local Climatological Data, (monthly), Climatological Data, (monthly and annual), Climatological Data, National Summary, (monthly and annual), Hourly Precipitation Data, (monthly), Monthly Climatic Data for the World, Storm Data, (monthly), Climatic Sub-station Summaries, Average Precipitation in the United States, (1944), Weather Bureau Technical Paper No. 15, Maximum Station Precipitation for 1, 2, 3, 6, 12 and 24 Hours, Part XXIII, California, (1959), Rainfall Frequency Atlas of the United States for Durations from 30 minutes to 24 hours and Return Periods from 1 to 100 years, (1961), Weather Bureau Hydrometeorological Report No. 36, Interim Report, Probable Maximum Precipitation in California, (1961), and the Weather Bureau Hydrometeorological Report No. 37, Meteorology of Hydrologically Critical Storms in California, (1962).

4.2 Average Annual Precipitation

The distribution of average annual precipitation in the Southern California Coastal and Offshore Zone varies considerably along the coast and over the water (figure 2-9). Values along the coast are about 20 inches at the coastal fringe of the Santa Monica Mountains, decreasing northward to less than 14 inches on the Oxnard Plain. Average annual precipitation also decreases southward. The figure is about 13 inches at Los Angeles International Airport, and decreases to 12 inches around the coastal Pales Verdes Hills extending to Oceanside; however, near the summit of the Pales Verdes Hills, precipitation reaches 16 inches. South of Oceanside, the average annual values decrease to 10 inches at San Diego and to about 8 inches in the vicinity of La Jolla.

Because of the scarcity of reporting stations on the offshore islands, extreme difficulty is encountered in determining the average annual values. However, Avalon Pleasure Pier reports 13 inches and Santa Catalina Weather Bureau Airport shows an average annual figure slightly exceeding 14 inches. San Nicolas Island has 7.50 inches and the northern portion of San Clemente has an average annual precipitation of 5.40 inches. It is estimated that the summit (1,965 ft.) of San Clemente Island has an average annual value of about 7 inches. Strange (unpublished, 1973) estimates the annual rainfall of San Miguel to be about 11.5 inches, Anacapa Island slightly less than 10 inches, and Santa Barbara Island about 6 inches.

Average annual precipitation and totals for individual years indicate that precipitation figures are lower on the offshore islands. Based on this information, isohyets for the offshore waters were estimated and portrayed as dashed lines on figure 2-9. Because the average annual values decrease from the coast to the offshore islands, it can be assumed that this trend also prevails over the sea. Accordingly, the isohyets were drawn to show a southward decrease over the ocean, and a seaward decrease of precipitation from the coast.

Precipitation is, in the overwhelming majority of cases, in the form of rain. Drizzles prevail; however, this is dissimilar from the light, early morning drizzles from low-lying stratus that is characteristic of coastal Southern California in summer. The latter is generally unmeasurable and is recorded as trace. Snow is extremely rare. The last snowstorm occurred in 1949. Needless to mention, melting occurs rapidly. Hail is almost as rare as snow, generally occurring in association with summer thunderstorms; however, hail is not unknown during winter. Usually hailstones are small, measuring l/8th of an inch or less, and the storm duration is short, ordinarily lasting about 10 minutes or less.

4.3 Variability of Precipitation

While the average annual rainfall figures range from 8 to 20 inches along the coast, and 6 to 14 inches over the water and the offshore islands, these areas by no means receive these amounts constantly year after year. Rather, the annual totals show great extremes from year to year. The average annual precipitation for Long Beach is 13.00 inches. The highest total received during the period 1931 to 1960 was in excess of 25 inches (1941), and the lowest total-during the same period was less than 4 inches (1947). Moreover, in January 1969, 11.24 inches were recorded at Long Beach, while in January of 1948 no rain occurred. Table 2-1 illustrates total precipitation for selected stations for the ten-year period 1951 through 1960 (also see table 2-3).

A fair assumption can be made that the total precipitation for any given year will be lower than that indicated by the average annual figures, because the relatively few years that have excessive amounts unduly raise the average

Table 2-1

TOTAL PRECIPITATION, 1951-1960

Station	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	Normal
Avalon Pleasure Pier	13.40	18.59	4.10	14.42	9.11	9.83	13.40	18.84	7.92	12.13	12.89
Los Angeles International Airport	11.06	18.59	4.76	12.91	10.14	11.71	12.29	15.43	6.44	10.67	12.63
Long Beach	11.31	21.47	5.11	14.17	9.89	11.59	12.51	16.87	6.98	9.02	13.00
San Nicolas Island	6.48	13.49	3.93	6.85	3.88	4.27	5.45	11.17	4.44	5.86	7.57
San Diego	11.22	15.52	3.41	9.52	6.91	4.39	12.73	10.93	5.88	7.05	10.40

Table 2-2

AVERAGE MONTHLY PRECIPITATION

Station	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
Avalon Pleasure Pier	2.42	3.13	1.89	1.08	0.19	0.06	0.00	0.04	0.13	0.60	0.99	2.36	12.89
Los Angeles International Airport	2.66	2.88	1.79	1.05	0.13	0.05	0.01	0.02	0.17	0.39	1.09	2.39	12.63
Long Beach	2.63	3.13	1.82	1.02	0.13	0.05	T	0.04	0.17	0.39	1.08	2.54	13.00
San Nicolas Island	2.06	1.67	1.12	1.03	0.10	0.02	0.00	0.00	0.02	0.01	0.48	1.06	7.57
San Diego	2.01	2.15	1.57	0.79	0.15	0.05	0.01	0.08	0.15	0.49	0.90	2.05	10.40

Source: Department of Commerce, Weather Bureau, 1964, Climatography of the United States No. 86.4, Climatic summary of the United States, Supplement for 1951 through 1960, Washington, D.C.

annual values. Table 2-1 may not illustrate this condition adequately.

4.4 Seasonality of Precipitation

Precipitation seldom occurs during the months of June, July and August, because of the dominance of the Pacific Subtropical Anticyclone with its active subsidence. This subsidence, coupled with the cold water offshore, creates an upper-level as well as a surface temperature inversion. The result is extreme atmospheric stability.

First rain for the year (July through June) usually occurs in late fall. Conroy (1933) studied the relative distribution of early and late seasonal precipitation for Los Angeles and San Diego for a 50-year period, from 1877 to 1927 by decades. Early rain (July through November) amounted to 13.5% in Los Angeles, and the percentage for San Diego was 14.0. The decade variations ranged from 10.9 to 16.1%, and 10.7 to 15.6% for Los Angeles and San Diego respectively. Mid-season "rain (December through March) in Los Angeles was 75.9% with a variation of 69.5 to 84.3% for the decade periods. The values for San Diego were similar, with an average of 74.6% falling during the mid-season, with variations of 70.4 to 80.6% for the decades. On the other hand, late rain (April through June) was 10.6% in Los Angeles and 11.4% in San Diego; however, the variations for the decade periods were a low of 4.2% to a high of 15.8% for Los Angeles. San Diego also had wide variations with values ranging from 5.3 to 17.4%. The study indicates that the early and mid-seasonal rains are relatively constant from the standpoint of percentages; however, late season rain is highly variable. When early and late season rains are compared, late seasonal rainfall shows a far greater percentage departure than does early rain.

Table 2-2 shows average monthly precipitation for selected stations. Table 2-3 illustrates monthly precipitation amounts and days as well as averages and extremes for San Nicolas Island from July, 1949, through June, 1966.

4.5 Frontal Storms

The principal type of storm that affects Southern California is frontal. (Figure 2-10) These storms affect Southern California most frequently during winter, and less often during the intermediate seasons. During smer, the storms in general are well to the north. Most frontal storms advance on Southern California from the northwest as cold fronts or in the occluded stage. Because of cold front occlusion, the characteristics of occuluded fronts that affect

Table 2-3

PRECIPITATION AMOUNTS AND DAYS AT SAN NICOLAS ISLAND
(July 1949 through June 1966)

Note: Amounts are in inches; number of days with measurable precipitation are enclosed in parentheses.

Season	July	Aug.	Sept.	Ott .	Nov.	Dec.	Jan.	Feb.	Mar.	April	May	June'	Total
1949 - 1950	T	0.00	0.00	T	0.58(2)	2.05(7)	1.29(6)	1.33(4.)	0.40(2)	0.61(1)	0.05(1)	T	6.31(23)
1950 - 1951	0.13(2)	T		T	1.42(3)	0.10(3)	1.73(9)	0.97(4)	0.30(2)	1.65(5)	0.02(1)	0.16(6)	6.48(35)
1951 - 1952	T	T	0.%1(1)	0.17(2)	0.23(3)	4.20(13)	4.61(10)	1.46(8)	2.55(13)	0.16(1)	T	0.00	13.49(27)
1952 - 1953	T	T	0.00	T	1.02(4)	1.69(7)	0.63(5)	0.01(1),	'0.17(2)	0.40(7)	T	0.01(1)	3.93(27)
1953 - 1954	T	0.02(2)	0.08(3)	0.00	1.57(4)	0.00	3.04(8)	.0.58(3)	1.31(10)	0.15(5)	0.08(2)	0.02(1)	6.85(38)
1954 - 1955	T	T	0.00	0.00	0.44(3)	0.32(2)	1.40(6)	0.97(2)	0.33(1)	0.39(3)	0.03(1)	T	3.88(18)
1355 - 1956	T	T	T	0.01(1)	0.42(2)	1.30(5)	1.20(3)	0.08(1)	T	1.01(4)	0.25(1)	T	4.27(17)
1956 - 1957	T	T	0.00	0.34(2)	T	0.24(1)	1.71(5)	0.77(5)	1.58(5)	0.81(3)	T	T	5.45(21)
1957 - 1958	T	T	0.01(1)	1.61(7)	0.20(4)	0.65(4)	0.91(3)	2.69(7)	3.12(10)	1.98(7)	T	0.00	11.17(43)
1958 - 1959	0.00	T	0.09(1)	0.02(1)	0.01(1)	0.04(1)	1.41(3)	2.28(7)	0.00	0.59(2)	T	T	4.44(16)
1959 - 1960	0.01(1)	T	0.05(2)	0.03(1)	T	0.16(3)	3.22(11)	1.75(8)	0.09(3)	0.55(1)	T	T	5.86(30)
1360 - 1961	0.04(1)	0.00	0.00	0.00	1.57(8)	0.04(2)	0.80(3)	T	0.11(3)	0.02(1)	T	0.01(1)	2.63(19)
1961 - 1962	T	T	0.01(1)	0.00	1.38(4)	1.31(3)	0.79(3)	5.45(8)	1.49(5)	T	0.00	0.00	10.43(24)
1962 - 1963	T	0.00	0.00	0.00	0.02(1)	0.03(1)	0.37(3)	2.20(5)	1.05(6)	0.98(5)	0.04(2)	0.15(2)	4.84 (25)
1963 - 1964	0.00	0.00	0.44(2)	0.43(2)	1.29(6)	0.03(2)	0.92(5)	0.05(1)	0.37(5)	0.10(2)	0.15(2)	0.07(1)	3.85(29)
1964 - 1965	0.00	0.00	0.00	0.44 (2)	'0.62(8)	0.72(8)	0.83(5)	0.45(2)	1.28(7)	2.68(8)	T	0.01(1)	7.03(41)
1965 - 1966	T	T	0.04(1)	0.00	5.62(11)	2.15(12)	0.88(2)	0.83(4)	0.03(1)	T	0.06(2)	T	9.62(33)
Average Amount	0.01	T	0.04	0.18	0.97	0.88	1.51	1.29	0.83	0.71	0.04	0.03	6.49
Average Days	----	----	0.7	1.1	3.8	4.4	5.3	4.1	4.4	3.2	0.7	0.8	28.8
Extremes:													
Maximum Amount	0.13	0.02	0.44	1.61	5.62	4.20	4.61	5.45	3.12	2.68	0.25	0.16	13.49
Days	2	2	3	7	11	13	11	8	13	8	2	6	4 3
Minimum Amount	0.00	0.00	0.00	0.00	T	0.00	0.37	T	0.00	T	0.00	0.00	2.63
Days	0	0	0	0	0	0	2	0	0	0	0	0	16

Source: de Violini, P.., 1967, Climatic Handbook for Point Mugu and San Nicolas Island, Volume I, Surface Data, Pacific Missile Range, Point Mugu, California, p. 56.

Southern California are similar to cold fronts. Upon encountering the coast, the fronts pivot and slow, allowing the trailing portion to advance from the south. Other storms may be associated with wave development and approach from the southwest. On rare occasions, warm frontal development may take place east of the Hawaiian Islands and approach from the west. These fronts are able to advance actively on Southern California because the Pacific Subtropical Anticyclone migrates to the south and weakens during winter. However, the latitudinal as well as the longitudianl position of this high is significant in determining whether or not storms can be expected. Although the high has weakened and in general migrated, it is not in a southerly position throughout the winter; therefore, the blocking function is still performed. Weather Bureau Hydrometeorological Reports No. 36, Interim Report, Probable Maximum Precipitation in California, (1961), and No. 37, Meteorology of Hydrologically Critical Storms in California, (1962), estimate probable maximum precipitation for storm durations to 72 hours by months for the primary precipitation period of October through April; describe the significant meteorological aspects of significant storms; and classify storms by synoptic aspects and relation to precipitation of the storm components of wind, moisture transport and convergence, as well as the effect of topographic lifting on these components.

4.5.1 Classification of Storms. Storms are classified under three main groups, depending on the longitude, from west to east, respectively of upstream or downstream blocking patterns which are effective before and/or during the course of the storm. This, in turn, determines the latitude of approach of the storms toward the coast.

High-Latitude Type. Blocking takes place east of 160°W Longitude, and storms reach California from a higher latitude. The center of the low forms off the British Columbia and Washington coasts, moves southward along the coastline and causes heavy precipitation in Southern California. Thereafter, the storm center moves east or northeast.

Mid-Latitude Type. In this type, low pressures form in the central and eastern Pacific and are affected by varying degrees of blocking from continental highs over Western North America as the storms move eastward across the Pacific at low latitudes. Depending on the offshore circulation, and the effectiveness of the continental blocking highs, the storms can approach from the south, southwest and the west, and affect Southern and Northern California in about the same number.

Low-Latitude Type. Blocking occurs in the mid-Pacific between 160°W and 180°W Longitude. The storms, therefore, reach the coast from a low latitudinal position from under the blocking high. These storms are characterized by wave development from Hawaii eastward to the coast. The trajectory for the most part is to the northeast; accordingly, Northern California is mostly affected by this type.

4.5.2 Moisture Transport in Frontal Storms. The amount of moisture in the air reaching the coast in a major storm depends on where in the Pacific Ocean area the air originates and where it passes over, and the absence or presence of convergence to destabilize the lapse rate. Moreover, sea-surface cooling enroute tends to reduce the moisture in the lower levels, but does not greatly diminish the total in the column. The most effective geostrophic inflow wind direction for moisture transport at the coast and over the offshore water is southwesterly. In some persistent and intense storms of the Low-Latitude type, southwest currents extend as far as 2000 miles, providing direct transport of moisture from a warm ocean source. Storms of the High-Latitude type in which the blocking effect is penetrated by lows from the west, modified polar air reaches the coast from a considerable distance to the southwest with ample moisture. In the same type of storms, but with storm centers moving south-southeastward, air reaches the coast after having had little opportunity for heating to have taken place at a lower latitude, which limits atmospheric moisture. Although a polar source region in the central or western Pacific is the origin of air for the southwesterly Mid-Latitude storm type, heating to high levels enroute to the coast at low latitudes may provide a moisture supply similar to that of tropical air.

Precipitation wind rose data for Los Angeles International Airport and San Diego for the years 1957 through 1961 are presented in table 2-4. The tabulations are a summary of all hourly observations at which precipitation was occurring.

4.6 Thunderstorms

Local summer convective storms are rare because of the dominance of the precipitation-inhibiting Pacific High. When the Pacific Anticyclone weakens or becomes displaced from its normal position, an inflow of moist tropical air from the Gulf of Mexico, Gulf of California or from the tropical eastern Pacific can result. On occasion the Atlantic Subtropical Anticyclone strengthens and extends far to the west in the upper-air. As a result, moist air inflow aloft may be observed over Southern California, and

Table 2-4

PRECIPITATION WIND ROSE DATA, 1957-61

Upper Number is Percent of Rainfall Occurrence
Lower is Average Wind Speed (m.p.h.)

Month	Number of Hours	Percent Occurrence	N NNE NE ENS EESESESSE S SSW SW WSW W WNW NW NNW Calms
LOS ANGELES INTERNATIONAL AIRPORT			
Oct	3,720	1.5	2 1 11 911 14 9 2 5 3 4 139 2 2 3 8 4 8 7 7 7 5 3 7 7 7 90 3 5
Nov	3,600	2.6	2 3 6 122017 3 5 8 8 4 2 3 2 3 2 1 0 6 7 8 1 3 1 1 8 S1011121012 98
Dec	3,720	2.1	8 5103215 96 41 4 1 3 1 1. 8 811 13 8 12 7 9 6 9 7 12 7
Jan	3,720	5.7	2 1 7 18 25 11 9 6 1 5 3 3 2 2 2 3 6 6 8 1 3 1 0 9 14 15. 9 13 12 10 16 10 7
Feb	3,384	7.0	* 1 5 8201512 65 5 3 5 5 3 1 1 5 3 11 11 91111111417 12111112 85 4
Mar	3,720 .	3.7	1 1 3 7 14 11 7 3.6 64 811 41 5 8 4 6 8 9 1 1 9 8 6 1 0 1 4 9 1 0 1 1 1 1 6 8 "
Apr	3,600	2.9	1 1 7 7 1 4 1 2 7 6 10 7 2 135 4 2 2 5 4 7 12 10 98 6 9 8 2 1 1 1 4 9 7
May	3,720	0.6	4 4 4 17 25 17 13 12 4 "o .3 3 3 14 12 7 6 5 4
LINDBERGH FIELD, SAN DIEGO			
Ott	3,720	1.8	3 9 3 6 6 2 3 14 912 2 12 3 4 2 4 6 7 7 8 5 6 7 8 1113 10 8 6 5' 5 6 5
Nov	3,600	2.8	1 2 9 5 " 7 7 6 1413 5 6 6 11 4-2 .2 2 3 5 6 5 661212151410 9 15 10
Dec	3,720	3.2	1 4 8 8 12 11 7 1114 4 4 4 2 2 2 2 4 7 6 7 7 7 8 7 9 9 1 0 9 a 913 5 6
Jan	3.720	5.8	3 6 6 3 4 8 15 11 14 6 5 2 4 34 1 5 5 5 7 6 7 7 9 1111 13 9 13 8 88 9
Feb	3,384	5.7	1 3 2 1 2 3 .7 1623 165 6 5 3 3 1 3 5 5 5 6 6 69121414111010 810 6
Mar	3,720	4.4	1 2 3 7 3 2 2 1118 11 10 12 5 7 2 2 2 12 69 7 7 85101412 911111011 5
Apr	3,600	3.2	3 1 1 1 3 1 3 2020 14'3 7 9 7 3 3 1 5 510 35 6 8 1115 15 14 9 9 7 9 4"
May	3,720	2.0	31 1 1 1 3 515" 1511169103 3 3 5 4 3 2 5 3 810 1110 9 5 6 6 6

*Less than 0.5 percent.

Source: Department of Commerce, Weather Bureau. 1965. Technical. Paper No. 54, Meteorological Summaries Pertinent to Atmospheric Transport and Dispersion Over Southern California. Washington, D.C., p. 60

spells of thunderstorms may occur in the desert and the mountains more often than in the coastal and offshore regions of Southern California. However, on October 12, 1889, nearly 8 inches of rain fell in 8 hours at Encinitas, 12 miles south of Oceanside. Moist, tropical air from the eastern Pacific (Chubascos) may enter Southern California from either the Gulf of California or along the Pacific coast. This air is related to tropical disturbances, and warm, humid, showery weather is the rule.

4.7 Tropical Storms

Numerous tropical storms develop off of the coast of Central America and Southern Mexico between latitudes 10 and 20° North. Period of greatest activity is from June through October, particularly in September. These tropical storms and hurricanes move northwestward to Baja California and veer onshore to the northeast, or go out to sea in a northwesterly direction. As such, coastal and offshore Southern California are hardly ever affected, excepting occasional high seas, as well as thundershowers in the southern desert and mountains. On September 25, 1939, however, a tropical storm with winds of 60 knots and a center pressure of 971 mb caused widespread damage ($1,500,000) largely from wave action at the coast of Los Angeles. Rainfall ranged from 2 to 4 inches along coastal Los Angeles. Precipitation potential, however, of tropical storms in Southern California is limited, because storm energy is depleted by the cooler water of the California Current. On September 12-14, 1918, upper circulation from a former tropical storm caused heavy rain as far north as Northern California. Tropical Storms invade California only when there is a strong north-south trough on the coast.

4.8 Funnel Clouds

Small funnel clouds are not unusual in the Southern California Coastal and Offshore Area; however, there are no reports of a fully developed funnel ever having reached the ground. On occasion, incipient waterspouts have been observed. Atmospheric conditions are not conducive to such activity, and those funnel clouds that occur are short-lived.

4.9 Frequency of Precipitation and. Storm Occurrence

Pacific Missile Range (R. de Violini) publication, Climatic Handbook for Point Mugu and San Nicolas Island, Volume I, Surface Data, (1967), portrays in table form frequency of precipitation occurrences at San Nicolas Island from July, 1949, through June 1966 (table 2-5). Percent occurrence

Table 2-5

FREQUENCY "OF PRECIPITATION OCCURRENCE AT SAN NICOLAS ISLAND

(July 1949 through June 1966)

Period	Frequency of Rain Days (Percent)	Frequency of Trace Days (Percent)	Number of Days with Amounts of Rain (Inches) 0.01-0.09	0.10-0.24	0.25-0.49	0.50-0.74	0.75-0.99	1.00-1.99	2.00-2.99	3.00 Plus	Average Amount Per Rain Day (Inches)	Maximum Amount "One Calendar Day (Inches)
Jul												
1-10	1.2	4.1	1	1	0	0	0	0	0	0	0.07	0.11
11-20	0.0	5.3	0	0	0	0	0	0	0	0	0.00	T
21-31	1.2	6.4	2	0	0	0	0	0	0	0	0.03	0.04
Aug												
1-10	1.2	2.9	2	0	0	0	0	0	0	0	0.01	0.01
31-20 "	0.0	7.6	0	0	0	0	0	0	0	0	0.00	T
21-31	0.0	3.2	0	0	0	0	0	0	0	0	0.00.	T
Sep												
1-10	1.2	4.1	1	"0	1	0	0	0	0	0	0.22	0.41
11-20	4.1	2.9	7	0	0	0	0	0	0	0	0.03'	0.05
21-30	1.2	2.4	2	0	0	0	0	0	0	0	0.04	0.09
Ott												
1-10	2.4	0.6	3	0	1	0	0	0	0	0	0.10	0.28
11-20	3.5	4.7	2	2	1	0	1	0	0	0	0.24	0.76
21-31	..5.3	3.2	7	1	1	1	0	0	0	0	0.12	0.50
Nov												
1-10	10.0	2.4	9	4	3	1	0	0	0	0	0.26	0.74
11-20	18.2	2.4	17	3	7	0	0	3	1	0	0.31	2.57
21-30	9.4	1.8	8	4	1	1	1	1	0	0	0.24	1.07
Dec												
1-10	15.3	4.7	10	- 8	4	3	1	0	0	0	0.22	0.91
11-20	17.6	3.5	16	6	7	1	0	0	0	0	0.15	0.48
21-31	11.2	4.3	11	6	1	0	1	2	0	0	0.22	1.07
Jan												
1-10	13.5	4.7	10	4	4	3	2	0	0	0	0.25	0.84
11-20	18.2	.5.3	8	14	2	4	1	2	0	0	0.31	1.67
21-31	19.3	5.9	14	10	5	1	3	3	0	0	0.29	1.23
Feb												
1-3.0	17.1	5.9	13	4	5	4	0	3	0	0	0.34	1.46
11-20	12.3	5.9	9	4	2	3	0	3	0	0	0.37	1.71
21-29	14.3	2.1	10	4	2	4	0	0	0	0	0.21	0.67
Mar												
1-10	14.1	5.3	14	5	3	2	0	0	0	0	0.15	0.68
11-20	18.2	1.2	17	7	5	0	0	2	0	0	0.22	1.19
21-31	11.8	7.5	11	6	3	1	1	0	0	0	0.18	0.89
Apr												
1-10	11.2	5.9	5	5	5	4	0	0	0	0	0.28	"0.71
11-20	8.2	4.1	5	5	2	2	0	0	0	0	0.20	0.56
21-30	12.9	11.2	9	7	4	2	0	0	0	0	0.19	0.70
May												
1-10	5.3	7.1	7	1	1	0	0	0	0	0	0.07	0.25
11-20	0.6	7.1	1	0	0	0	0	0	0	0	0.02	0.02
21-31	1.1	11.2	2	0	0	0	0	0	0	0	0.04	0.04
Jun												
1-10	,3.5	7.1	6	0	0	0	0	0	0	0	0.03	0.07
11-20	2.9	7.1	4	1	0	0	0	0	0	0	0.07	0.14
21-30	1.2	3.5	2	0	0	0	0	0	0	0	0.02	0.02

Source: de Violini, R. 1967. Climatic Handbook for Point Mugu and San Nicolas Island, Volume I, Surface Data, Pacific Missile Range, Point Mugu, California, p. 60.

of days with measurable precipitation (rain days) was determined for 10-day periods within each month. Similarly, the percent occurrence of days with a trace was also cletermined for each period. A frequency distribution of the number of rain days occurring within the entire period of record which had precipitation totals within the specified ranges is included for each 10-day period. The tables conclude with a listing of the average amount of rain per rain day and the maximum amount of precipitation recorded in any one calendar day. Percent occurrences of precipitation during fall, winter and spring as represented by the Fleet Weather Central, Alameda Naval Air Station in Climatology of California Coastal Waters, (1969), are included in figures 2-11, 2-12, and 2-13. Fall consists of the months of October and November; winter is regarded as the months of December through March; and spring from April through May. Though no explanation was given, it is assumed that these percentages are ratios between precipitation days and non-precipitation days.

Detailed studies regarding the frequency of storm passage in Southern California are nearly nonexistent. Weather Bureau Research Paper No. 40, Principal Tracks and Mean Frequencies of Cyclones and Anticyclones in the Northern Hemisphere, (1957), illustrates the number of highs and lows for each 5° grid squares by months; however, the scale is extremely small. Miller (1932) conducted a census of centers of cyclones and anticyclones passing through each 5° grid in the United States for the period 1892 to 1912 on a monthly basis. Hosler and Gamage (1956) made a similar study for a 50-year period from 1905 to 1954, but on an average monthly basis. It is noted that the variability of cyclonic frequency has increased throughout the 50-year period, and this is paralleled by a similar increase in the variability of sunspot numbers in the same period, and year-to-year changes in frequency are common to all areas in the United States. The discussions show that, as compared to the rest of the nation, the frequency of cyclonic passage in Southern California is low. The winter months of December through March show the highest average monthly frequencies, with 0.4 to 0.6 cyclones per month; the average April frequency decreases to 0.3; and the values for May and June are 0.1. July and August show no center of lows passing through Southern California, but a gradual increase is noted from September. The September and October mean frequencies of cyclones are 0.1 and the value for November is 0.2. These frequencies as compared with storm passage are extremely low, because only the centers of cyclones and not the associated fronts were noted. In mid-winter, frontal storm passage occurs every 7 to 10 days, and precipitation can be expected on 5 days per month. The frequency of rain days decreases. to 2 or 3 in spring and fall. Figure 2-14 illustrates the mean number of days with precipitation equal to or greater than 0.10 inches, and equal to or greater than 0.50 inches.

4.10 Precipitation Intensity, Duration and Probability

In the Southern California Coastal and Offshore Area, rain is generally light and lasts less than a day. However, extremely intense precipitation as well as rain for long durations has been reported. While the durations are generally short, many have lasted as much as 6 continuous days. In November, 1861, Los Angeles experienced 28 consecutive days of rain.

Weather Bureau publications, Technical Paper No. 25, Rainfall Intensity-Duration-Frequenty Curves, (1955), and Technical Paper No. 40, Rainfall Frequency Atlas of the United States for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years, (1961), contain curves for Los Angeles' and San Diego, and intensity, duration and frequency maps for the United States. These maps, however, are presented at a small scale; therefore, their utility is limited. Pacific Missile Range (R. de Violini) Climatic Handbook for Point Mugu and San Nicolas Island, Volume I, Surface Data, (1967)-, portrays durations and return periods for Point Mugu (table 2-6), and for San Nicolas Island (table 2-7). The tables show the amounts of precipitation that may be expected within a specified period and with a given return period (recurrence interval). The values in the body of the tables are the amounts of rain likely to occur within the stated duration at least once within the specified return period. The number of years of each return period may be divided into 100 to provide the probability of occurrence of the amount of rain for a given duration.

5. Cloud Cover, Ceiling and Visibility

The principal cloud type that contributes to low ceiling and restricted visibility in the Southern California Coastal and Offshore Region is stratus. The sea-surface temperature plays an essential role in the formation of stratus and fog over and near the ocean. In addition to its seasonality, there is a marked diurnal variation in the occurrence of stratus. As this cloud is advected inland a few miles by the sea breeze during the day, heat which the land absorbs evaporates the stratus, while the surrounding sea may be fogged in.

Table 2--6

PRECIPTTATION DURATIONS AND RETURN PER1ODS
FOR POINT MUGU

Duration (Hours)	Return Period (Years) 2	5	10	25	50	100
	Precipitation (Inches)					
1	0.6	0.9	1.0	1.2	1.4	1.6
3	1.0	1.3	1.6	1.9	2.2	2.4
6	1.3	1.8	2.1	2.6	2.9	3.2
12	1.6	2.3	2.8	3.3	3.8	4.2
24	2.2	3.1.	3.7	4.4	5.0	5.6
36	2.5	3.6	4.3	5.2	5.9	6.6
48	2.8	4.0	4.8	5.8	6.6	7.3
72	3.4	4.8	5.7	6.9	7.8	8.7

Note : Maximum probable 24-hour rainfall: 12.8 Inches.

Table 2-7

PRECIPITATION DURATIONS AND RETURN PERIODS
FOR SAN NICOLAS ISLAND

Duration (Hours)	Return Period (Years) 2	5	10	25	50	100
	Precipitation (Inches)					
1	0.4	0.6	0.7	0.8	0.9	1.0
3	0.6	0.7	1.0	1.3	1.4	1.6
6	0.8	1.2	1.4	1.7	1.9	2.1
12	1.1	1.5	1.8	2.2	2.5	2.7
24	1.4	2.0	2.4	2.9	3.3	3.6
36	1.7	2.3	2.8	3.4	3.8	4.3
48	1.8	2.6	3.1	3.8	4.3	4.8
72	2.2	3.1	3.7	4.5	5.1	5.6

Note : Maximum probable 24-hour rainfall : 8.3 Inches.

Sources: de Violini, R. 1967. Climatic Handbook for Point Mugu and San Nicolas Island, Volume I, Surface Data, Pacific Missile Range, Point Mugu, California, pp. 62-63.

Department of Commerce, Weather Bureau. 1961. Technical Paper No. 40, Rainfall Frequency Atlas of the United States for Durations from 30 minutes to 24 hours and Return Periods from 1 to 100 Years, Washington, D.C.

5.1 Sources of Information Regarding Cloud Cover, "Ceiling and Visibility

While data concerning cloud cover and visibility are not as plentiful as for temperature and precipitation, quantitative values especially for cloud cover are available in Weather Bureau publications. However, the most detailed descriptions are contained in the Fleet Weather Facility (San Diego) publication, Climatological "Study" Southern California Operating Area, (1971), and Climatic' Handbook for Point Mugu and San Nicolas Island, Volume 1,' Surface Data, (1967), published by the Pacific Missile Range (R. de Violini). Seasonal maps contained in Climatology of California Coastal Waters, (1969), by Alameda Naval Air Station, Fleet Weather Central, is detailed; however, because all of the offshore area of California is included, the scale is smaller. Weather Bureau publication, California Stratus Investigation of 1944, (1945), by Neiburger, Beer and Leopold, discusses forecasting the ceilings in the summer stratus over Southern California. Office of Naval Research (D. Leipper) report, Fog Forecasting on Coasts, (19481, investigates the theory of fog formation and dissipation; examines the principles of fog forecasting; analyses the importance of inversion air, sea-surface, and dew point temperatures, and moisture content of the air; and presents visibility and fog indices for San Diego.

Summaries with respect to means, hourly, daily and monthly sky cover, average sky cover by hour of day, combined increments of ceiling-visibility-wind direction, percent frequencies of selected visibility, selected weather types that restrict visibility to ¼ mile or less, number of days with heavy fog, and other summary categories are found in numerous Weather Bureau publications. They include: Climatological Data, (monthly and annual), Climatological Data, National Summary, (monthly and annual), Local Climatological Data, (monthly), Climates of the States No. 60-4, Climate of California, (1970), Climatic Atlas of the United States, (1968), Summary of Hourly Observations? 1951-1960, and Technical Paper No. 12, Sunshine and Cloudiness at Selected Stations in the United States, Alaska, Hawaii, and Puerto Rico, (1951).

5.2 Formation of Stratus and Fog

Leipper (1948) notes that although the diurnal variation is small (about 0.5 °F) and the seasonal change gradual, sea-surface temperature is important in the formation of stratus and fog. It is an important variable in determining the amount of modification to the overlying air mass, because the change in content of heat and moisture depends largely upon the temperature differences and the vapor-pressure difference between the' air and sea surface, and the temperature and the" vapor pressure at the sea surface depend almost entirely upon the sea-surface temperature. The formation of stratus and fog is favored by a temperature inversion. Because air temperature is higher than the sea-surface temperature and the dew point is likewise higher than the sea-surface temperature, cooling of the air below by conduction will occur, which may result in condensation and fog. Fog will usually not result on the first day of an inversion, because time is required for the air to obtain moisture. After fog is formed, radiation from the cloud cools the nearly stagnant fog layer to a temperature several degrees lower than the sea surface. Under this condition, there is a continual upward flux of heat at the sea surface, but the air remains colder than the sea. Because the air is colder than the sea, evaporation continues. Thus, radiational cooling causes first a decrease in temperature and then an increase in evaporation. Both of these effects markedly intensify fog and serve to maintain it.

As the sea-breeze strengthens during the daytime, fog is carried shoreward and arrives at the coast in late morning or in the early afternoon. When fog first arrives at the coast it is usually thin and is soon dissipated by the daytime heat of the land. At night, the sea-breeze weakens and fog is generally found offshore.

5.3 Cloud and Fog in the Coastal and Offshore Area

Stratus (fog) is the most important cloud type along the coastal and offshore area; accordingly, there is a high frequency of low clouds and fog, especially in summer. The stratus season lasts from April to October, with a minimum in winter, During some summers, stratus may persist for a week, dissipate for a day or two and reform for another week, while during other summers the condition may be irregular and brief. Generally, during the season, overcast conditions may prevail on 20 to 25 mornings per month, and on 3 to 4 of these days the condition may prevail throughout the day. Early afternoon breakup may be expected on 6 to 9 days per month, and complete clearing of low clouds may occur on an additional 12 to 15 days. The sky may be completely clear throughout the day on 10 to 15 days of the month. In addition to the seasonality, diurnal variation is also strongly evident. During the stratus season , thick fog may exist from 0400 to 0800, and decrease on the coast and over the islands in the late mornings or the early afternoons, with "a minimum between 1400 and 1600. Low stratus conditions, however, are likely to persist over the water throughout the "day and the islands may be completely surrounded by a fog bank. Tables 2-8 and 2-9 illustrate the percent of observations for given sky conditions at Point Mugu and San Nicolas Island, and tables 2-10 and 2-11 portray mean sky cover' by hour and month at both Point Mugu and San Nicolas Island.

5.4 Ceiling

Figures 2-15 and 2-16 show percentage frequencies of ceiling heights for various ranges for the months of January and July . There is a greater frequency of low ceiling during the stratus season (July) than during the nonstratus month (January). Moreover, the frequency of no ceiling is far lower during the former than the latter season. At about sunrise, ceiling is lowest, on occasion less than 100 ft., or even resting on the surface, but generally lower than 1,000 ft. As the morning passes into afternoon, clouds lift as the inversion rises, but are lower than 2,500 ft. Over the water, on the other hand, fog may not be far off the water throughout the day. The top of the stratus is almost invariably at the base of the inversion. Figures 2-17 and 2-18 portray the percentage of ceiling occurrences below 3,000 ft. at Point Mugu and at San Nicolas Island.

5.5 Visibility

The primary restriction to visibility is fog. Figure 2-19 illustrates the percentage of hourly observations reporting fog at Point Mugu. Although the visibility may be reduced to 1 statute mile or less by fog near sunrise, or to under 3 miles by haze and smoke in the afternoon, visibility at both Point Mugu and San Nicolas Island is greater than 7 miles in the majority of hourly observations. Table 2-12 gives the frequencies of observations by months at Point Mugu and San Nicolas, reporting risibilities less than or equal to ½ mile and 3 miles, and equal to or greater than 7 miles and 10 miles respectively. Figures 2-20 and 2-21 portray in table form percentage frequencies of visibility of various ranges within ½ degree quadrangles. Figures 2-22 and 2-23 show low range ceiling-visibility for January and July. The only region of greater frequency of ceiling less than 300 ft. and/or visbility less than 1 mile, and ceiling less than 600 ft. and visibility less than 2 miles in January as compared to July is in the coastal waters from Santa Monica to San Pedro Bay. The July picture portrays a fairly high frequency of those two categories between the Oxnard Plain and Santa Cruz Island.

Table 2-8

PERCENT OF OBSERVATIONS FOR GIVEN SKY CONDITIONS
AT POINT MUGU

(October 1946 through September 1963)

Month	Sky Conditions			
	Clear	Scattered	Broken	Overcast
January	39.6	20.7	16.4	23.3
February	36.2	21.3	15.9	26.6
March	36.2	24.9	17.6	21.3
April	33.0	21.4	15.8	29.8
May	37.0	18.8	12.9	31.3
June	37.5	15.9	11.6	35.0
July	35.9	17.4	12.7	34.0
August	34.7	18.6	12.5	24.2
September	42.4	16.5	10.4	30.[illegible]
October	40.2	18.5	13.3	28.0
November	46.6	21.5	13.8	18.1
December	41.9	21.3	15.2	21.6
Year	38.4	19.7	14.0	27.9

Table 2-9

PERCENT OF OBSERVATIONS FOR GIVEN SKY CONDITIONS
AT SAN NICOLAS ISLAND

(November 1947 through October 1963)

Month	Sky Conditions			
	Clear	Scattered	Broken	Overcast
January	26.9	25.2	22.7	25.2
February	31.2	21.6	23.4	26.8
March	26.7	27.3	24.0	22.0
April	26.8	24.4	21.3	27.5
May	27.8	23.9	19.7	29.6
June	28.3	21.1	15.0	35.6
July	25.6	24.9	15.7	33.8
August	23.1	28.6	17.1	31.2
September	37.8	23.3	13.4	25.5
October	35.6	22.9	17.2	24.3
November	40.1	25.7	17.2	17.0
December	32.8	24.6	20.2	22.4
Year	30.1	24.5	18.6	26.8

Clear = no clouds (0/10 cover)
Scattered = scattered clouds (1/10 through 5/10 cover)
Broken = broken clouds (6/10 through 9/10)
Overcast = overcast clouds (10/10 cover)

Source: de Violini, R. 1967. Climatic Handbook for Point Mugu and San Nicolas Island, Volume I, Surface Data, Pacific Missile Range, Point Mugu, California, p. 33.

Table 2-10

MEAN SKY COVER BY HOUR AND MONTH AT POINT MUGU
(October 1946 through September 1963)

Note: Units are tenths of sky covered by clouds at all heights.

Hour (PST)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct.	Nov	Dec
0000	3.4	3.8	3.4	4.1	3.8	4.4	4.7	5.1	4.2	4.3	3.0	3.3
0100	3.4	3.8	3.4	4.3	4.1	4.8	5.3	5.5	4.7	4.5	3.0	3.3
0200	3.5	4.0	3.4	4.5	4.3	5.1	5.8	6.0	4.8	4.6	3.0	3.3
0300	3.5	3.9	3.5	4.4	4.5	5.2	6.2	6.3	5.1	4.6	3.0	3.2
0400	3.5	4.0	3.5	4.7	5.2	5.9	6.5	6.5	5.4	4.6	3.0	3.2
0500	3.5	4.1	3.8	5.3	5.8	6.3	7.2	7.0	5.9	4.8	3.1	3.2
0600	3.8	4.6	4.8	5.6	5.9	6.7	7.3	7.2	6.2	5.3	3.8	3.7
0700	4.5	5.0	5.2	5.8	5.8	6.7	7.2	7.2	6.1	5.4	4.1	4.5
0800	4.7	5.1	5.0	5.7	5.7	6.4	6.6	6.9	5.8	5.3	4.1	4.7
0900	4.7	5.1	5.0	5.7	5.4	6.1	5.9	6.2	5.2	4.7	4.0	4.6
1000	4.6	5.0	4.8	5.5	5.2	5.7	5.5	5.4	4.5	4.5	3.9	4.6
1100	4.7	4.9	4.7	5.3	5.1	5.4	5.1	4.9	4.1	4.2	3.9	4.4
1200	4.7	4.9	4.6	5.1	4.8	5.0	4.6	4.5	3.7	4.1	3.9	4.4
1300	4.8	4.8	4.5	4.8	4.6	4.6	4.1	3.8	3.3	4.0	3.9	4.5
1400	4.7	4.8	4.6	4.5	4.4	4.1	3.5	3.1	3.0	3.9	3.8	4.3
1500	4.8	4.7	4.6	4.5	4.2	3.8	3.1	2.6	2.8	3.7	3.7	4.4
1600	4.9	4.7	4.4	4.4	4.2	3.5	2.9	2.6	2.8	3.8	3.6	4.5
1700	4.7	4.7	4.5	4.6	4.1	3.5	2.9	2.9	2.9	3.9	3.4	4.6
1800	4.3	4.6	4.3	4.7	4.3	3.5	3.1	3.2	3.3	3.9	3.1	4.0
1900	4.0	4.1	3.8	4.5	4.3	3.6	3.4	3.7	3.5	3.8	2.9	3.5
2000	3.7	4.0	3.5	3.9	3.9	3.6	3.6	3.7	3.6	3.8	2.8	3.3
2100	3.7	3.9	3.4	3.9	3.8	3.6	3.6	3.9	3.9	3.6	2.9	3.2
2200	3.6	3.8	3.4	4.0	3.7	3.8	3.9	4.1	4.0	4.0	2.9	3.2
2300	3.6	3.8	3.4	4.0	3.7	3.9	4.4	4.5	4.0	4.1	2.9	3.1
All hours	4.1	4.4	4.2	4.7	4.6	4.8	4,8	4.9	4.3	4.3	3.4	3.9

Table 2-11

MEAN SKY COVER BY HOUR AND MONTH AT SAN NICOLAS ISLAND
(November 1947 through October 1963)

Note: Units are tenths of sky covered by clouds at all heights.

Hour (PST)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0500	*	*	*	*	6.0	7.4	7.6	7.2	5.0	*	*	*
0600	4.2	4.1	4.8	5.6	6.1	7.1	7.6	7.9	5.9	5.8	4.0	3.9
0700	5.0	5.0	5.3	6.0	6.2	6.9	7.7	7.8	5.9	5.8	4.1	4.7
0800	5.3	5.1	5.3	5.8	6.0	6.7	7.1	7.5	5.9	5.6	4.2	4.9
0900	5.1	5.2	5.0	5.6	5.7	6.2	6.5	8.6	5.2	4.9	4.1	4.7
1000	5.0	5.2	4.9	5.4	5.4	5.7	5.8	5.7	4.5	4.5	3.8	4.7
1100	4.9	5.1	4.8	5.1	5.0	5.2	4.9	4.8	3.8	4.2	3.6	4.4
1200	4.8	4.9	4.7	4.8	4.6	4.7	4.2	4.0	3.2	3.8	3.4	4.6
1300	5.1	4.7	4.6	4.6	4.4	4.1	3.6	3.4	2.9	3.7	3.3	4.4
1400	5.0	4.6	4.5	4.6	4.1	3.7	3.3	3.0	2.7	3.4	3.4	4.4
1500	5.0	4.6	4.5	4.5	4.0	3.4	3.0	2.8	2.4	3.4	3.4	4.4
1600	4.9	4.5	4.3	4.5	3.7	3.4	2.8	2.9	2.6	3.4	3.4	4.2
1700	5.1	4.5	4.8	4.5	*	*	*	*	*	3.4	3.4	4.5
All hours	5.0	4.8	4.8	5.1	5.0	5.3	5.2	5.1	4.1	4.4	3.7	4.5

*Indicates insufficient observations for a representative value.

Source: de Violini, R. 1967. Climatic Handbook for Point Mugu and San Nicolas Island," Volume I, Surface Data, Pacific Missile Range, Point Mugu, California, p. 32.

Table 2-12

FREQUENCY OF CERTAIN VISIBILITY VALUES AT POINT MUGU AND SAN NICOLAS ISLAND

(October 1946 through September 1963)

Month	Point Mugu				San Nicolas Island			
	≤ ½ mile	≤ 3 miles	≥ 7 miles	≥ 10 miles	≤ ½ mile	≤ 3 miles	≥ 7 miles	≥ 10 miles
	Percent				Percent			
Jan	2.6	13.7	76.0	67.4	5.7	12.1	80.3	65.3
Feb	3.2	15.4	73.9	64.4	5.4	13.1	77.3	64.9
Mar	1.9	8.6	79.6	68.7	1.8	6.7	82.2	70.0
Apr	2.9	14.2	71.6	59.1	2.7	12.6	74.5	56.4
May	1.3	13.7	72.7	59.3	2.8	13.5	71.6	50.3
Jun	2.4	19.2	62.1	46.2	4.7	20.9	59.4	39.6
Jul	2.9	22.9	53.2	34.3	5.5	24.4	45.0	22.0
Aug	5.4	27.9	49.3	32.9	5.5	25.4	46.5	21.7
Sep	6.6	28.2	51.9	36.6	3.1	19.8	54.9	30.1
Oct	5.4	28.3	56.0	44.6	3.8	18.3	58.7	38.4
Nov	5.0	19.5	69.4	59.7	2.4	12.7	71.4	53.5
Dec	3.6	16.2	74.6	66.5	4.4	13.0	75.8	60.7
Year	3.6	19.0	65.8	53.2	4.0	16.1	66.2	47.4

Source: de Violini, R. 1967. Climatic Handbook for Point Mugu and San Nicolas Island, Volume I, Surface Data, Pacific Missile Range, Point Mugu, California, p. 35.

December to March is the most clear period, while the greatest restriction to visibility corresponds with "the stratus season. The diurnal pattern likewise is similar to the daily frequency of stratus occurrence; low visibilities occur during the early mornings, and as the mornings and early afternoons pass, visibility increases.

6. Atmospheric Pressure

The primary year-round determinant of the weather of Southern California is the location of the Eastern Pacific semi-permanent high pressure cell. The primary functions of this high pressure are to: (1) provide a blocking effect to the storms that form in the Aleutian Low, especially in winter; (2) provide a prevailing northwesterly (onshore) circulation; (3) provide active subsidence on the eastern edge of the high pressure cell to create extreme atmospheric stability, especially in summer. Moreover, the central pressure of this cell, the pressure along the coast, and the pressure in the desert to the south-east also play an important rôle in the broad-scale weather pattern throughout most of the year.

6.1 Sources Regarding Atmospheric Pressure

The primary source of barometric pressure information is outlined in Climatic Handbook for Point Mugu and San Nicolas Island, Volume 1, Surface Data, (1967), published by the Pacific Missile Range (R. de Violini). The Environmental Science Service Administration publishes a number of series related to hourly, daily and monthly pressure; however, the coverage tends to be far greater than that of the Southern California Coastal and Offshore Zone. The series are: Local Climatological Data, (monthly), Climatological Data, National Summary, (monthly and annual), and Monthly Climatic Data of the World. Normal pressure tendency charts are presented in Weather Bureau Technical Paper No. 1, Ten-Year Normals of Pressure Tendencies for the United States, (1943). A supplement to this publication portrays Normal 3-Hour Pressure Tendencies for the United States at the Intermediate Synoptic Hours, (1945).

6.2 Atmospheric Pressure of the Southern California Coastal and Offshore Zone

The geographical distribution of barometric pressure in the study area is steady. The lowest mean monthly pressure is on the order of 1012 mb (September), and the highest mean monthly pressure is approximately 1018 mb (January), with the mean annual reading being 1015 mb for the Southern

California Coastal and Offshore Area. Because of the existence of a thermal trough "over Southern California, the lowest monthly mean occurs in late summer to early fall, despite the strengthening and northward migration of the Pacific High in summer. The highest monthly mean, on the other hand, is experienced during winter (December to January). This is related to lower temperatures during this time of year and the resultant denser air. Moreover, pressure extremes also occur during winter. Cold, dense air causes the barometer to rise; however, extreme minima are recorded during periods of storm passage. Summers, on the other hand, are periods of relatively constant pressure. Figure 2-24 illustrates means, standard deviations and extremes of pressure for Point Mugu. The determinations were based on 1950 through 1963 hourly sea-level observations.

7. Wind

The basic air flow along the Southern California Coastal and Offshore Area is northwesterly? resulting from the semi-permanent Pacific Anticyclone. This anticyclone is most dominant in the warm months, when northwest winds are strongest and most constant. During the colder part of the year, the high pressure cell weakens and the center moves from about 35° to near 30° North Latitude. The winds, however, are still primarily from the northwest, but they are somewhat reduced in frequency. Moreover, in winter, wind direction and speed are modified by migrating centers of low pressure. When a storm is approaching from the west, winds are from the east and southeast, and at times these winds are strong and damaging. As the storm progresses inland, winds veer to the south and southwest; and as the cold front passes, northwest and finally northeasterly winds may result.

Another modifier of the general circulation is the superimposition of the diurnal sea-land breezes. The onshore sea-breeze is persistent and strong during the summer but becomes weaker in winter. On the other hand, the land-breeze is strong in winter, but diminishes during summer.

7.1 Sources of Information Regarding Winds

The most detailed wind summaries for Southern California are contained in Weather Bureau Technical Paper No. 54, Meteorological Summaries Pertinent to Atmospheric Transport and Dispersion over Southern California, (1965), and Climatic Handbook for Point Mugu and San Nicolas Island, Volume I, Surface Data, (1967), by the Pacific Missile Range (R. de Violini). Other excellent sources are: Strange (unpublished), A Climatological Survey of San Miguel, Anacapa and Santa Barbara Islands, (1973), and Winds over Coastal Southern California, (1960), by Stevenson. Detailed monthly wind summaries over the offshore area are provided in map form in San Diego Fleet Weather Facility publication Climatological Study Southern California Operating Area, (1971). Seasonal summaries also portrayed by maps are contained in Climatology of California Coastal Waters, (1969), by the Alameda Naval Air Station Fleet Weather Central.

Other summaries such as: hourly, average hourly, daily, monthly, prevailing direction, fastest mile, occurrence increments of wind speed by hour of day, occurrence of combined increments of wind speed-relative humidity-temperature, occurrence of weather by 16-point wind direction, 24-hour resultant direction, speed and direction at standard pressure surfaces, monthly percentage of time from prevailing direction, annual mean hourly, number of days fastest mile exceeded specified limits, annual wind rose, mean vector winds, vertical wind profiles -- and other summary categories are found in the following Weather Bureau publications: Climatological Data, (monthly and annual), Climatological Data, National Summary, (monthly and annual), Local Climatological Data, (monthly), Monthly Climatic Data for the World, Climatic Atlas of the United States, (1968), Summary of Hourly Observations, 1951-1960, Technical Paper No. 32, Upper-Air Climatology of the United States, part III, Vector Winds and Shear, (1959), Technical Paper No. 41, Meridional Cross-Section of Upper Winds Over the Northern Hemisphere, (1961), and Climatography of the United States, No. 60-4, Climate of California, (1970).

7.2 January and July Average Winds

The most persistent wind direction, which also on the average is the strongest, is the northwesterly wind. Figures 2-25 and 2-26 portray January and July wind roses for each one-half degree grid square illustrating average directional frequencies and mean speeds (knots). It should be noted that some of the wind roses are based on relatively few observations. In January, winds along the coast to the islands tend to be variable, favoring the west to northeasterly components, with a slightly prevailing direction from the northwest, with a mean speed of 10 knots; however, these winds occur only about 25% of the time. At Point Mugu, the most frequently observed direction is northeast. Seaward of the Channel Islands, northwesterly winds become progressively prevailing and stronger, with frequencies of 25 to 60%, and mean speeds of 10 to 20 knots. The July map shows that over the immediate coastal waters, winds favor the westerly direction, with northwest and southwest components playing secondary roles. Westerly wind frequencies are between 25 and 50%, with mean velocities between 5 to 15 knots. Seaward from the Islands, the westerlies gradually give way to northwesterly winds, with frequencies ranging from 50 to 75%, and mean speeds between 12 to 16 knots. Figures 2-27 and 2-28 show frequency of wind direction versus time of day and mean wind speed by direction and time of day at Point Mugu for January. Figures 2-29 and 2-30 represent similar portrayals for the month of July. The January graphs indicate that north to northeast winds are most frequent between 2000 to 1100. Thereafter, westerly winds (sea breezes) become dominant, with southeasterly winds being secondary. Moreover, the northeasterlies attain the highest speeds (to 20 knots) during daylight hours, but the westerly sea-breeze is only half as strong at this time of the year. Before sun-up to before noon, east-southeast winds attain mean velocities to 20 knots. After sunset, highest mean speed (15 knots) is associated with south-southeast winds; however, 10-knot winds are common from a variety of directions.

On the other hand, in July, an overwhelming sea-breeze pattern is evident in the diurnal winds. From about 0900, the wind becomes westerly and. the frequency increases to 60% at about 1700. After sunset, the wind becomes northwesterly with a high relative frequency (30%), but diminishes at about 2300. North to northeasterly winds increase in frequency between 0100 to about 0800, with frequencies only as high as 15%. Though the directional. frequency of the sea-breeze (westerlies) is high, the mean wind speed is only 10 knots. South and southeasterly winds show slightly greater speeds. These winds correspond to the time of the beginning of the sea-breeze (0900 to 1400).

Percentage frequencies of winds equal to or less than 6 knots, between 11 and 12 knots, equal to or greater than 34 knots for January and July as presented by Fleet Weather Facility, San Diego, (1971), are included in figures 2-31, 2-32, 2-33 and 2-34. The frequencies of low velocity winds are high near the coast and diminish almost regularly seaward to the islands. From San Pedro to Seal Beach, the frequency of wind speed equal to or less than 6 knots is 60%; the value decreases to 50% along a strip 10 miles from the coast from Point Mugu to the Mexican border; in the next 10-mile strip, identified by a line from Santa Cruz Island to Santa Catalina Island to the waters of the international border, the frequency decreases to 40%; and seaward. from about 50 miles (San Miguel and Santa Rosa to San Clemente Island) , the values fall below 30%. Frequencies for the intermediate wind speeds (11 to 21 knots) are lower than those of low velocity winds. From Point Mugu to the coastal international border and within a strip 10 miles of the entire coast of the study area, the frequency of 11 to 21 knot winds is 20%. The 30 and 40% frequencies run southward and loop north near San Nicolas Island before trending southeast. The former is within 60 miles of the coast and the latter is about 100 miles out to sea. Only a small percentage of winds equals or exceeds 34 knots. Within the study area the frequency values of these winds are lower than 1%.

The over-all July pattern is similar to that of January. The percentage frequencies of the lower velocity winds decrease seaward; however, those of intermediate speeds (11 to 21 knots) increase seaward. Percentage frequency of winds equal to or less than 6 knots is highest (60%) in the immediate vicinity of Point Mugu, and from Newport Beach to Oceanside; the 50% frequency is in a strip within 10 to 20 miles from the coast; the 40% frequency is 20 to 30 miles from shore; the southeast trend also continues for the 30 and 20% frequencies. The former extends from Santa Cruz to San Clemente Island"and southeastward, within 60 miles from the shore, and the latter is about 80 miles from the coast, extending from San Miguel Island southeastward. The southeast trend of the percentage frequencies is also evident for the map portraying intermediate wind speeds. The percentage frequency of wind speed-of 11 to 21 knots is lowest from Point Mugu to Point Dume (10%); along most of the coast and for a strip about 20 miles wide the frequency is 20%; from Santa Cruz Island trending southeastward within 40 miles of the coast the frequency is 30%; the 40% frequency is within 60 miles of the coast, from Santa Rosa Island southeastward; and to the southwest, 50% of the winds have speeds between 11 and 21 knots. Only the extreme northern portion of the study area has winds exceeding 34 knots; however, the frequencies are small.

Monthly averages and extremes of winds for Point Mugu and San Nicolas Island are portrayed in tables 2-13 and 2-14.

7.3 The Effect of the Coast on Winds in the Vicinity of the Channel Islands

The outstanding wind feature of the offshore area, especially in the northern portion of the study area is the sustained northwesterly winds that frequently exceed 25 knots. They are persistent and often severe, because of the creation of a jet effect in the vicinity of prominent headlands. A strong jet of air is projected south of Point Arguello, southward past San Miguel and San Nicolas Islands. As winds en-

Table 2-13

MONTHLY AVERAGES AND EXTREMES OF SURFACE WINDS AT POINT MUGU
(October 1946 through September 1963)

Month	Most Frequently Observed Direction: Direction	Mean Speed (Knots)	Observations (Percent)	Mean Speed All Directions (Knots)	Maximum Observed Speed (Knots)	Direction of Maximum Speed
January	NE	14	19.0	8.4	45	ENE
February	W	11	13.8	7.5	39	NE
March	W	12	18.5	7.7	45	SE
April	W	11	24.2	7.4	38	W
May	W	11	25.9	7.1	36	W
June	W	9	23.4	6.4	30	SE
July	W	9	24.1	6.2	26	SE
August	W	9	22.5	5.7	36	SE
September	W	9	20.7	5,5	30	NE
October	W	9	15.3	5.9	36	W
November	NE	13	15.7	7.8	50	NE
December	NE	14	20.2	8.5	50	W
Year	W	10	18.2	7.0	50	NE/W

Note: Maximum speed is the highest. observed 1-minute wind speed.

Month	Peak Gusts: Speed (Knots)	Peak Gusts: Direction	Observations with Speed Greater than 20 Knots (Percent)	Percent of Observations: Calm	Wind from N, NNE, NE	Wind from W, WSW , SW
January	61	ENE	5.5	6.4	48.3	15.9
February	51	SE	3.8	7.2	38.1	23.4
March	52	WSW	3.7	7.1	29.1	31.9
April	57	W	2.8	6.9	22.0	38.8
May	49	W	1.9	3.8	14.9	44.6
June	42	NE	0.2	10.5	12.7	42.6
July	33	SE	0.1	9.2	15.0	41.0
August	52	SE	0.1	11.3	18.5	37.2
September	42	NE	0.2	12.7	20.7	33.4
October	53	W	1.0	9.9	32.0	26.8
November	78	NE	5.1	6.6	43.3	18.1
December	70	ESE	6.5	5.8	48.7	14.3
Year	78	NE	2.6	8.5	28.5	30.8

Note: The peak gust is the highest observed, wind gust.

Source: R. de Violini, 1967. Climatic Handbook for Point Mugu and San Nicolas Island, Volume I, Surface Data, Pacific Missile Range, Point Mugu, California, p. 19.

Table 2-14

MONTHLY AVERAGES AND EXTREMES OF SURFACE WINDS AT SAN NICOLAS ISLAND
(November 1948 through October 1963)

Month	Most Frequently Observed Direction: Direction	Most Frequently Observed Direction: Mean Speed (Knots)	Most Frequently Observed Direction: Observations (Percent)	Mean Speed All Directions (Knots)	Maximum Observed Speed (Knots)	Direction of Maximum Speed
January	NW	13	35.1	9.5	40	W
February	NW	14	36.9	10.2	50	Nw
March	NW	16	44.1	12.2	40	WNw
April	NW	16	45.4	12.0	36	Nw
May	Nw	17	52.5	12.8	39	NW
June	NW	15	46.4	11.4	33	WNw
July	Nw	12	44.8	9.5	31	Nw
August	Nw	13	48.6	10.0	30	Nw
September	NW	13	48.6	10.1	32	Nw
October	NW	13	41.8	9.1	32	Nw
November	NW	13	36.1	9.3	42	N
December	Nw	13	31.0	9.1	38	Nw
Year	NW	14	43.0	10.4	50	NW

Note: Maximum speed is the highest observed l-minute wind speed.

Month	Peak Gusts: Speed (Knots)	Peak Gusts: Direction	Observations with Speed Greater than 20 Knots (Percent)	Percent of Observations: Calm	Percent of Observations: Wind from WNW, NW, NNW
January	48	Nw	4.8	5.2	53.7
February	64	W	7.7	4.9	55.4
March	54	Nw	12.7	3.2	65.3
April	56	NW	12.1	4.1	65.9
May	56	NW	16.1	3.9	70.5
June	52	Nw	9.1	4.2	66.2
July	40	W	3.6	4.3	65.2
August	38	NW	3.1	4.0	68.8
September	47	NW	5.3	4.4	59.5
October	50	NW	5.1	5.6	59.9
November	52	Nw	6.6	7.1	55.8
December	55	Nw	5.0	5.7	50.6
Year	64	W	7.5	4.7	62.3

Note: The peak gust is the highest observed wind gust.

Source: de Violini, R. 1967. Climatic Handbook for Point Mugu and San Nicolas Island, Volume I, Surface Data, Pacific Missile Range, California, p. 25.

counter islands, the flow is around such obstructions, and local eddies and deflection of flow readily occur.

Table 2-15 illustrates seasonal wind conditions at Point Arguello, San Nicolas Island, Point Mugu, San Miguel, Anacapa and Santa Barbara Islands.

Strange (unpublished, 1973) states that San Miguel Island is noted for its northwest winds. At times these winds are strong, even when there is little wind activity in surrounding areas. Northwest winds persist throughout the day and night with only a slight variation. Maximum winds occur during the late morning and early afternoon. Prolonged periods of relative calm can be expected during the fall and winter. However, strong northeast winds may occur briefly after a frontal passage following the northwesterly winds. Northeasterly winds (Santa Ana) may reach 40 to 50 knots, but normally these winds do not exceed 25 knots.

Anacapa Island is the closest to the coast of all the Channel Islands. As such, it is vulnerable to Santa Ana (northeasterly) winds from the Santa Clara River Valley. Wind speeds of 30 to 40 knots are common, and occasional gusts to 80 knots have been recorded. It is reported that Anacapa experiences 18 Santa Ana conditions per year. Northwesterly winds are less frequent at Anacapa than at San Miguel Island, but on occasion they can be just as severe, especially in spring and summer. Unlike the winds at San Miguel Island, those at Anacapa frequently die in the mornings.

Santa Barbara Island is more favorably situated than either San Miguel or Anacapa. Strong west to northwesterly winds, as well as the Santa Ana wind, have minimal effect; however, cold and strong winds (west to northwest) caused by the southward shift of the jet stream can produce 30 to 35 knot winds with gusts to 50 knots at Santa Barbara Island as well as the other islands. All three islands are vulnerable to southeast winds with speeds of about 25 knots or more. These winds occur on about 6 to 8 days in winter and 3 to 4 days in the spring and fall.

7.4 Severe Winds

Table 2-15 also includes maximum wind speeds and peak gusts for the four seasons at Point Arguello, San Nicolas Island, Point Mugu, San Miguel, Anacapa and Santa Barbara Islands. Strange (unpublished, 1973) notes that the northwest winds are the most important of all severe winds. They occur at any time of the year, but predominantly in spring, and are associated with a strong buildup of high pressure offshore

Table 2-15

STATISTICAL WIND DATA

		Point Arguello	San Nicolas Island	Point Mugu	San Miguel Island	Anacapa Island	Santa Barbara Island
WINTER	Prevailing Direction	NW	NW	NE-W	Nw	NE-W	WNW
	Mean Speed	11	11	8	14-16	10-12	8-10
	Maximum Speed	56 NW	50 Nw	45 NE-SE	55-60 NW-SE	60-65 NE	40-45 SE-W
	Peak Gust	N. A.	64 W	61 NE	80-85 NW-SE	90-95 NE	55-60 SE-W
SPRING	Prevailing Direction	Nw	Nw	W	NW	WNW	WNW
	Mean Speed	14	12	7	18-20	12-14	10-12
	Maximum Speed	49 SE	39 NW	36 W	55-60 NW	50-55 NW	40-45 WNw
	Peak Gust	N. A.	56 NW	49 W	80-85 NW	70-75 NW	55-60 WNW
SUMMER	Prevailing Direction	NNW	Nw	W	Nw	W	WNW
	Mean Speed	15	10	6	16-18	10-12	8-10
	Maximum Speed	52 NW	33 WNw	36 SE	40-45 NW	30-35 WNw	25-30 WNW
	Peak Gust	N. A.	52 NW	52 SE	55-60 NW	45-50 WNw	35-40 WNw
FALL	Prevailing Direction	Nw	Nw	W-NE	NW	W-NE	WNW
	Mean Speed	12	10	7	12-14	8-10	6-8
	Maximum Speed	52 SE	32 NW	50 NE-W	50-55 NW	60-65 NE	35-40 SE-W
	Peak Gust	N. A.	47 Nw	78 NE	70-75 Nw	90-95 NE	50-55 SE-W

Note: Wind speed and gusts are in knots

Source: Strange, R. 1973. A Climatological Survey of San Miguel, Anacapa and Santa Barbara Islands, (unpublished).

on the heels of a low pressure center moving inland. Figure 2-35 illustrates streamlines and isotachs of such a condition.

A buildup of a cold high pressure ridge over the Basin and Range Plateau produces northeasterly winds which may be severe below coastal canyons. These winds usually follow a cold front and the northwesterlies, and are commonly referred to as Santa Ana winds. Severe cold Santa Ana conditions generally occur between November through February or March. Stevenson (1960) states that these winds can extend 100 miles seaward. Streamlines and isotachs of northeasterly winds are presented in figure 2-36, and a synoptic pattern of a warm Santa Ana is found. in figure 2-5.

The least frequent of severe wind conditions are the southeasterly winds. They are, however, potentially damaging. They occur in advance of an approaching cold front, with winds generally less than 50 knots; however, winds of 75 to 80 knots with gusts exceeding 100 knots have occurred near Point Conception.

7.5 Sea and Land 13reezes

Weather Bureau Technical Paper No. 54, Meteorological Summaries Pertinent to Atmospheric 'Transport and Dispersion over Southern California, (1965), and Winds Over Coastal Southern California by Stevenson, (1960), have detailed seasonal accounts of the sea-land breezes in the Southern California Coastal and Offshore Area. These diurnal winds are created by pressure gradients alternating landward and seaward between day and night. Accordingly, they are primarily produced by heating and cooling on land during day and night. During the day, especially in summer, the land surface is greatly heated as compared to the sea surface. Accordingly, the air over the land surface becomes less dense than that over the sea, and a landward pressure gradient is created, which accounts for the sea-breeze. On the other hand, at night, and especially in winter, the land surface radiates heat, thus becoming colder, and the air becomes more dense than the adjacent sea surface. This initiates a seaward pressure gradient and the resultant land-breeze. Moreover, in summer, the center of the Pacific Anticyclone is situated at its northern most position, dominating the synoptic picture and causing the circulation to be northwesterly, reaching Southern California with an onshore component. With the Pacific High over water, and a thermally-induced low in southwestern Arizona and adjacent California, the pressure gradient tends to be steep. The summer sea-breeze, therefore, is steady and strong. In winter, the Pacific Anticyclone is least developed and has migrated to its southern most position, and in the face of a nonexistent thermal low in the desert, the sea-breeze tends not to be as steady and as strong as that in summer; therefore, it is insufficient to sustain a daytime flow for many hours and air transport landward is the lowest for the entire year.

7.5.1 July Sea-Land Breezes. During the day there is a marked landward flow of air in Southern California. Over the water the direction is primarily west-northwesterly; however, the coastal approach direction is west-southwesterly to westerly. The inertia associated with the sea-breeze is strong; accordingly? this flow may last until after midnight and gradually diminish as the land-breeze becomes more organized with time. Over the ocean there is little diurnal variation, but the flow over the coast is extremely complex. At night, from Ventura to Point Mugu, the flow is still onshore; in coastal Santa Monica Bay the land breeze is easterly to slightly east-southeasterly; marine air parallels the Pales Verdes Hills; southeast of Long Beach, the flow for the first 15 miles is offshore and in the next 15 miles south, it parallels the coast and is from the southeast; the breeze is offshore from Dana Point to Carlsbad; and, the flow is parallel and from the north from Carlsbad to the Mexican border.

7.5.2 October Sea-Land Breezes. The flow pattern during the day in October is similar to that of July, but not as persistent. Because land heating is not as great as in July, but greater than water heating, air transport is still onshore. However, the winds do not persist as long per day as in July. At night, there is no onshore flow as in July, and the land-breeze is well organized. The entire coast has land-breezes and the zone of convergence is farther out to sea than in July, but does not reach the islands.

7.5.3 January Sea-Land Breezes. The daytime onshore flow is the least well-marked and lowest in frequency and speed during this time of year, while at night, the land breeze shows the greatest development during this month. The seaward islands still experience little diurnal variation in flow; however, Anacapa, Santa Catalina and San Clemente Islands may experience land-breezes. The zone of convergence is well offshore and may reach as far as 60 miles.

7.5.4 April Sea-Land Breezes. The sea-breeze condition during April resembles that of July. The flow tends to be fairly strong, although surface land heating is not as great as that of July. The night land-breeze, on the other hand, tends to resemble that of October and is predominant, though it is not as well organized as it is in January. From the coastal islands seaward, there is little diurnal variation, and no marked nocturnal" change "in flow. There "is a dual flow at Point Mugu and north of the Pales Verdes Hills; the breeze parallels the coast 10 miles northwest of Dana Point; but for most of the coast the flow is offshore.

7.6 The Catalina Eddy

Studies concerning the Catalina Eddy have been conducted primarily by personnel of the Weather Bureau (Fletcher, [1943], Fink, [1943], Graham, [1950], and Meyer, [19551). The Catalina Eddy represents cyclonic vorticity formed by north and northwesterly winds flowing around the coastal projection and mountains near Point Conception. The coast and the mountain range have a north-south orientation north of Point Conception, but abruptly become oriented in an east-west axis. The flow from the northwest causes the winds to recurve immediately in the lee of the mountains, while a more northerly flow causes the area of curvature to be displaced to the south. The cyclonic flow deepens on the downwind side and moves down the coast. The recurvature causes southwesterly to southerly winds locally rather than north to northwesterly flow as expected by the coastal gradient. The greatest effect on the air flow is over the water, and the actual location of the Eddy varies with the size, direction and speed of the wind; however, the small low pressure center is generally centered near Santa Catalina Island. Figure 2-37 illustrates the flow pattern during a strong Eddy development.

When the Eddy becomes intense, marine air deepens rapidly, forcing the inversion upward and permitting greater vertical mixing. Deepening occurs to as much as 6,000 ft., and cloud formation is favored, resulting in overcast days of especially late spring and early summer. During the stratus season, this condition occurs on 20 to 30 days, and on the average lasts for a period of 3 days, but on occasion for 6 or more days. The Eddy explains the considerable changes that sometimes occur in the coastal weather without corresponding changes in the surface synoptic chart.

The effects of the Eddy are to: radically alter at times the daytime streamlines over the sea and near the coast; permit light onshore winds to persist all night; influence the development of stratus and fog, and permit incomplete dispersal and banks of fog and low clouds to remain throughout the entire Eddy period; delay daytime temperature increases along the immediate coast and coastal valleys, and raise daily minimum temperatures.

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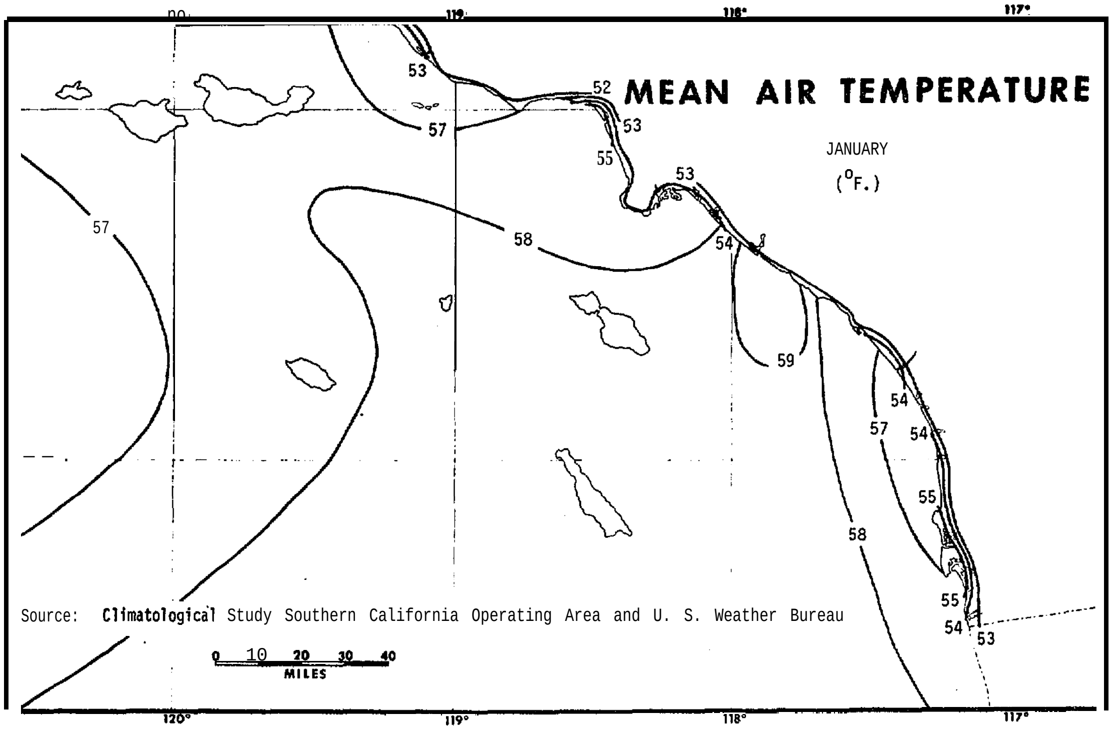


Figure 2-1

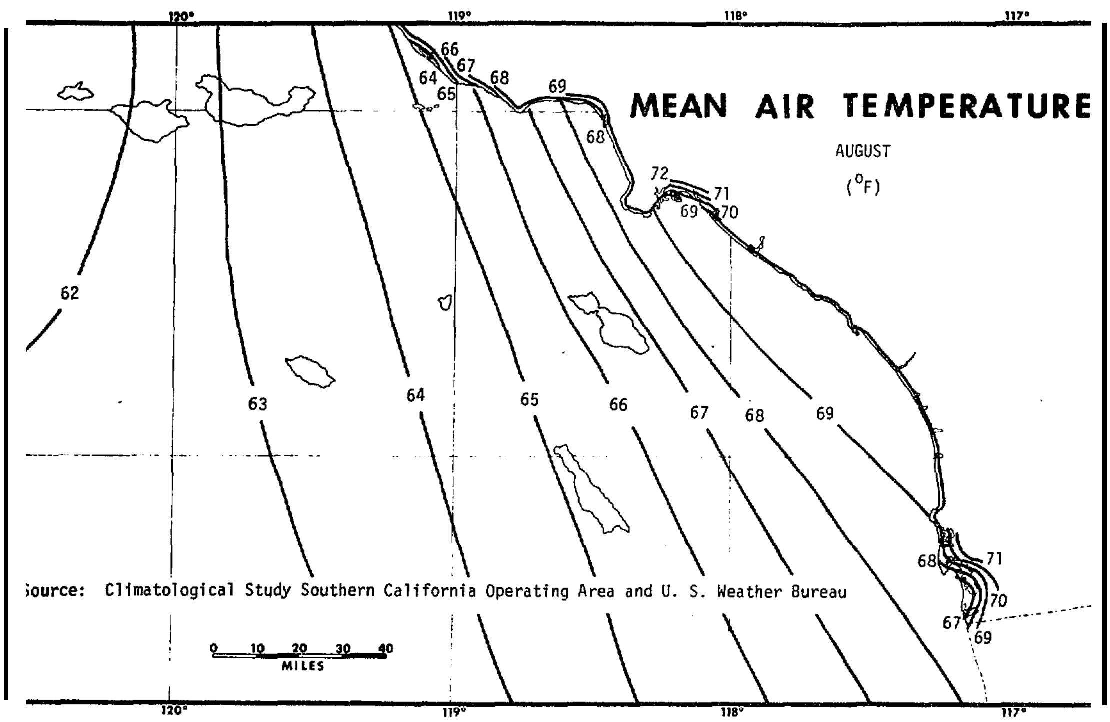
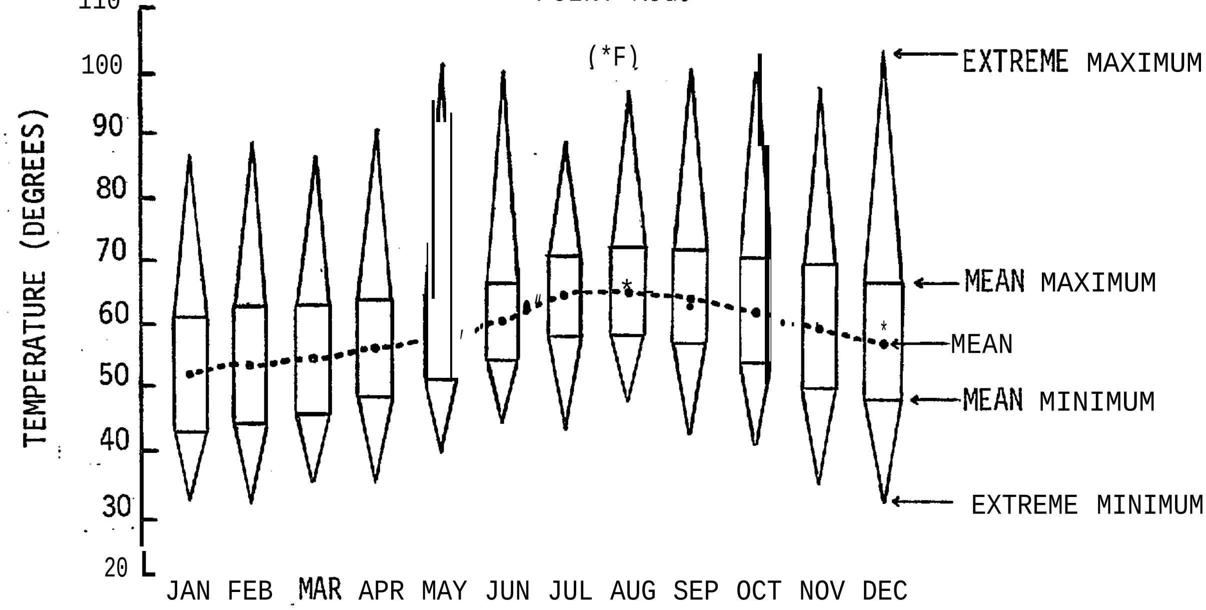


Figure 2-2

MEAN AND EXTREME TEMPERATURES

POINT MUGU



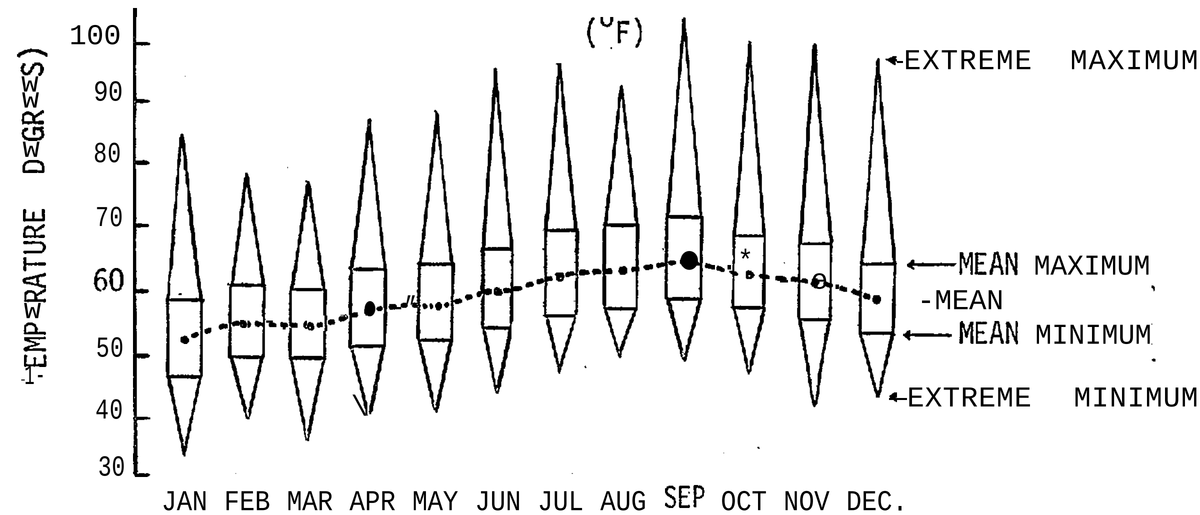
Means from January 1949 through December 1964; Extremes from March 1946 through June 1967.

Figure 2-3

MEAN AND EXTREME TEMPERATURES

nor

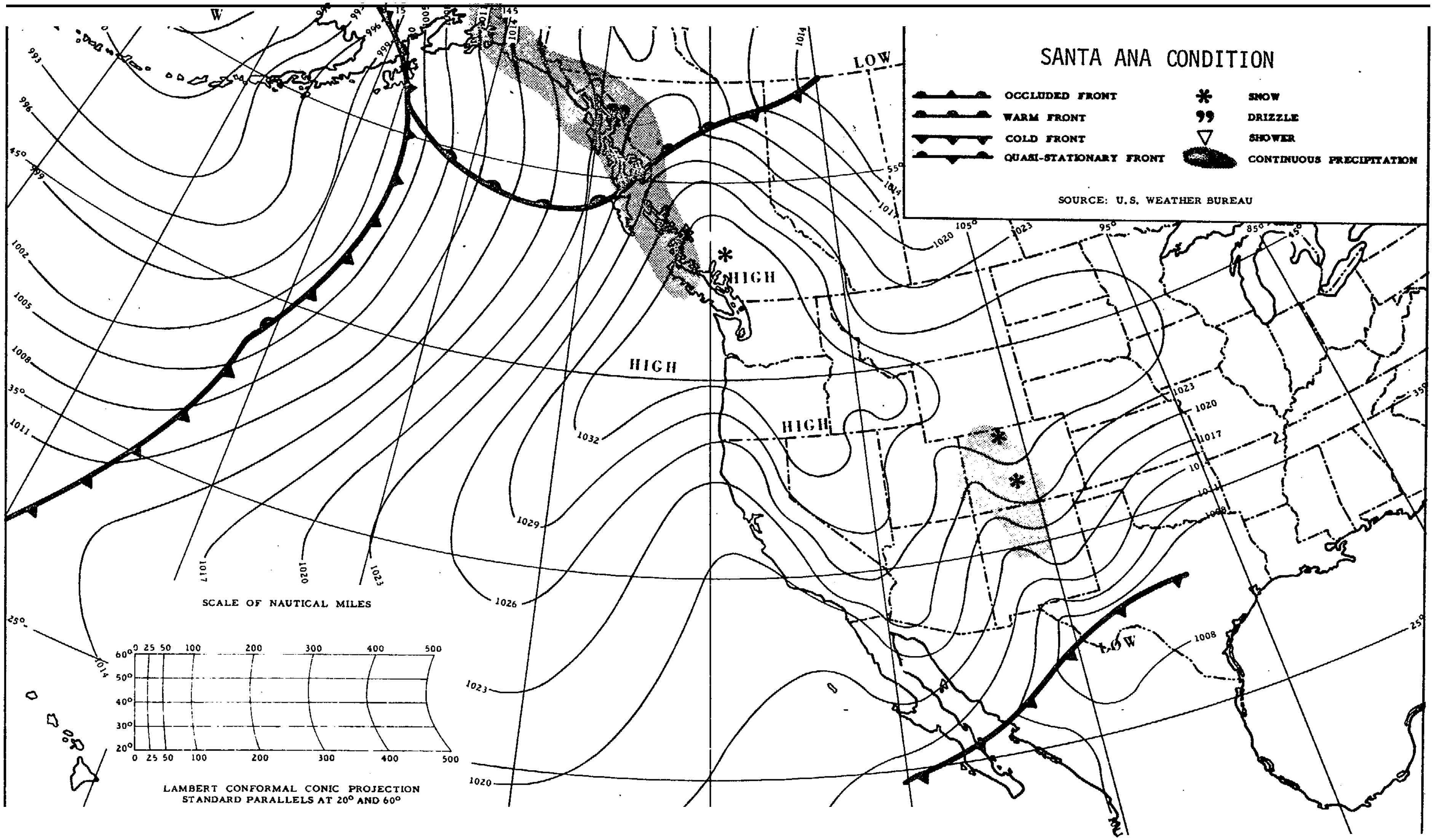
SAN NICOLAS ISLAND



Means from January 1947 through September 1965; Extremes from January 1947 through June 1967.

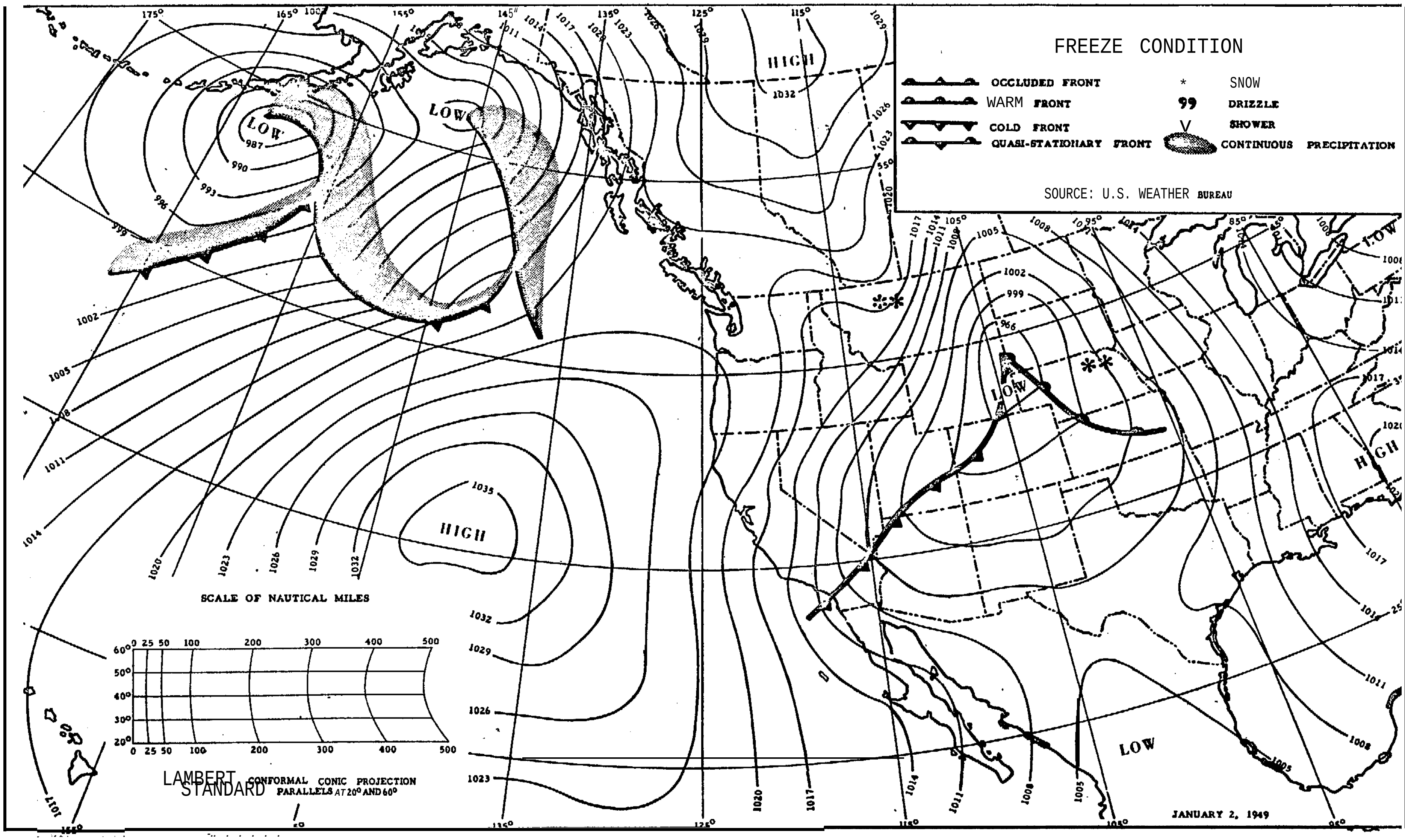
Source: Climatic Handbook for Point Mugu and San Nicolas Island

Figure 2-4



After: Patterns on the Land

Figure 2-5



- After: Patterns on the Land

Figure 2-6

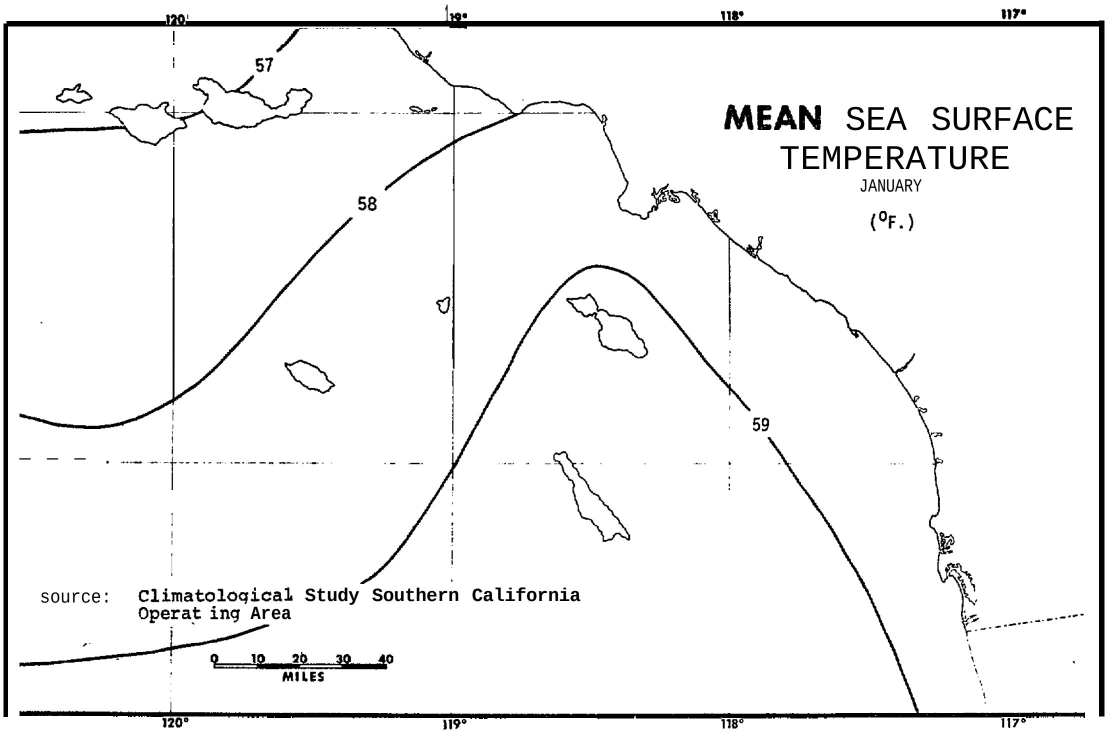


Figure 2-7

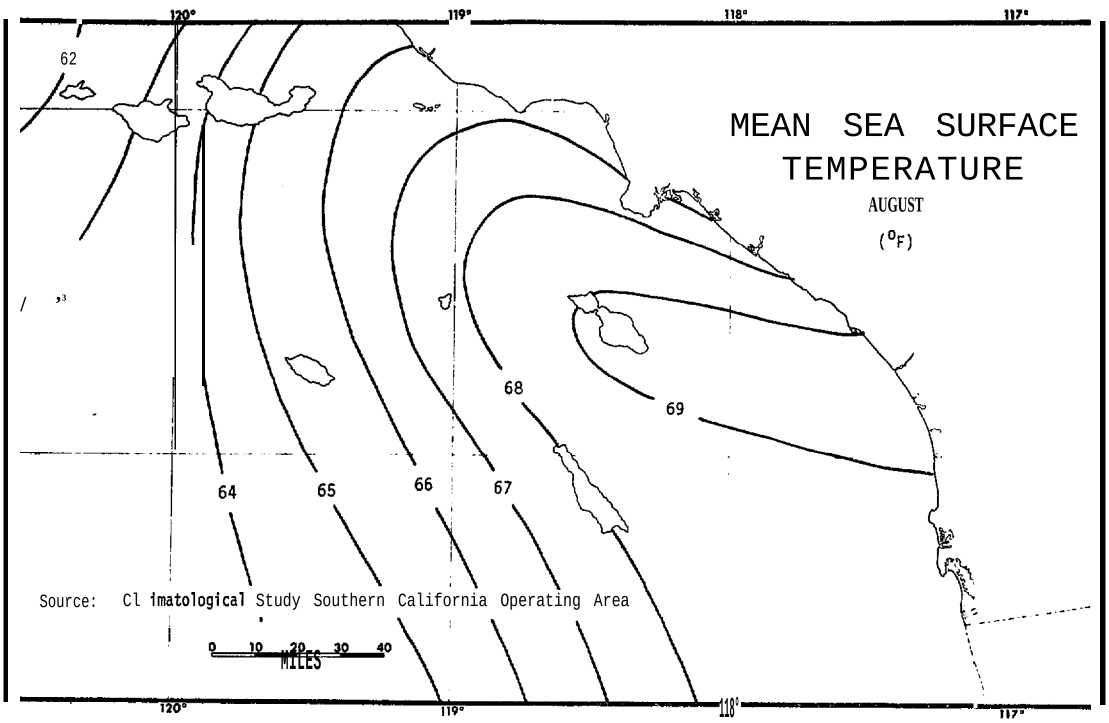
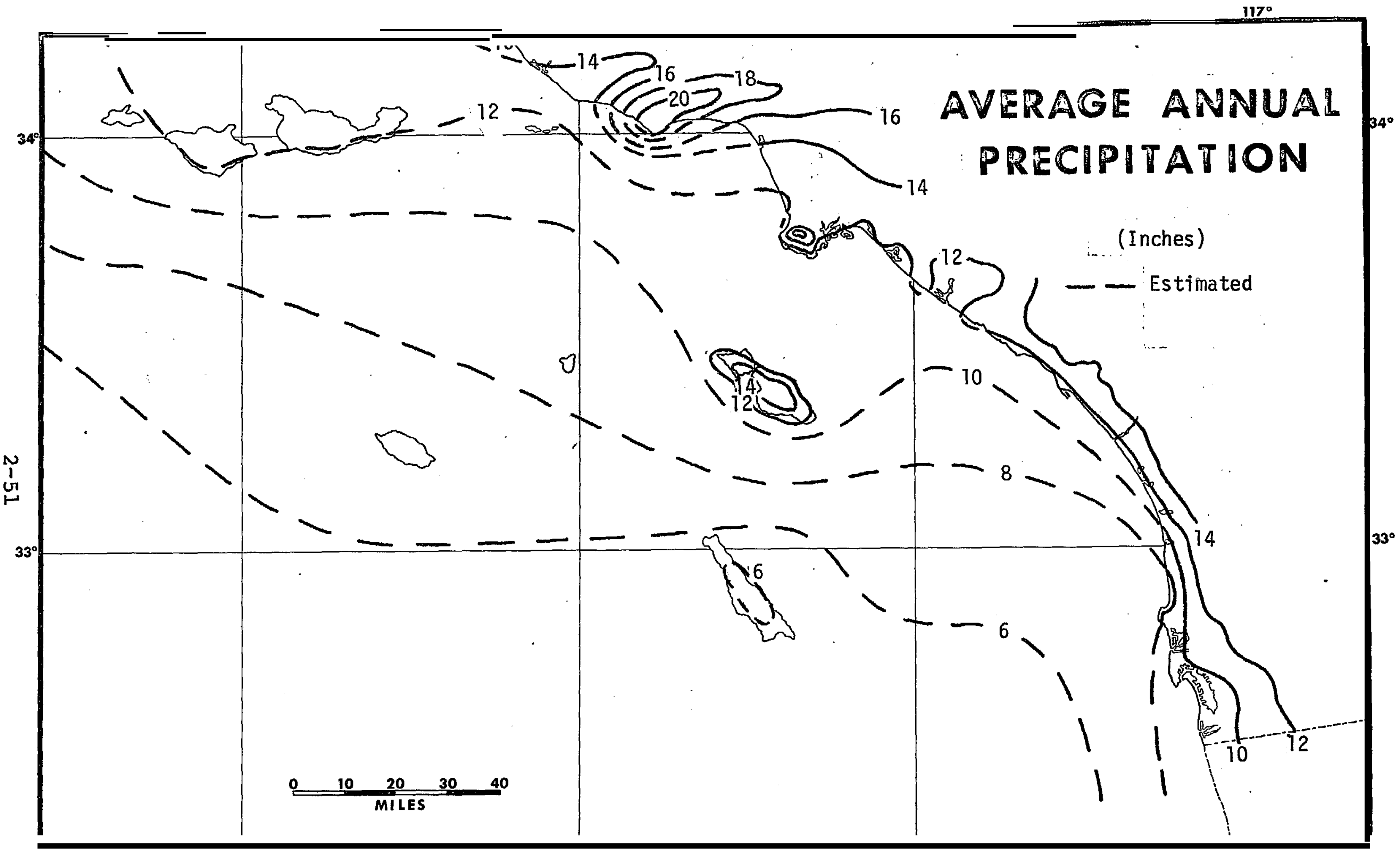
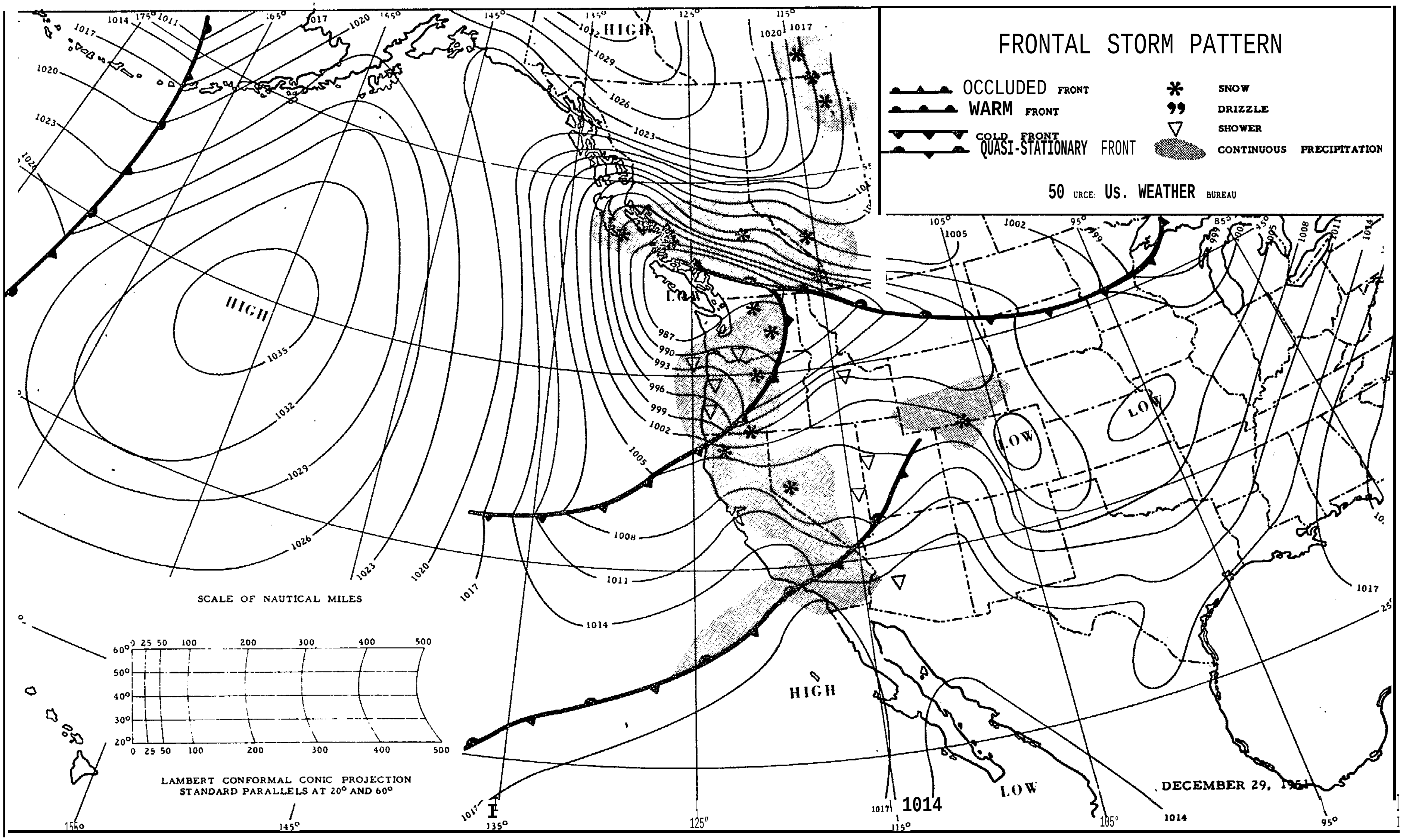


Figure 2-8

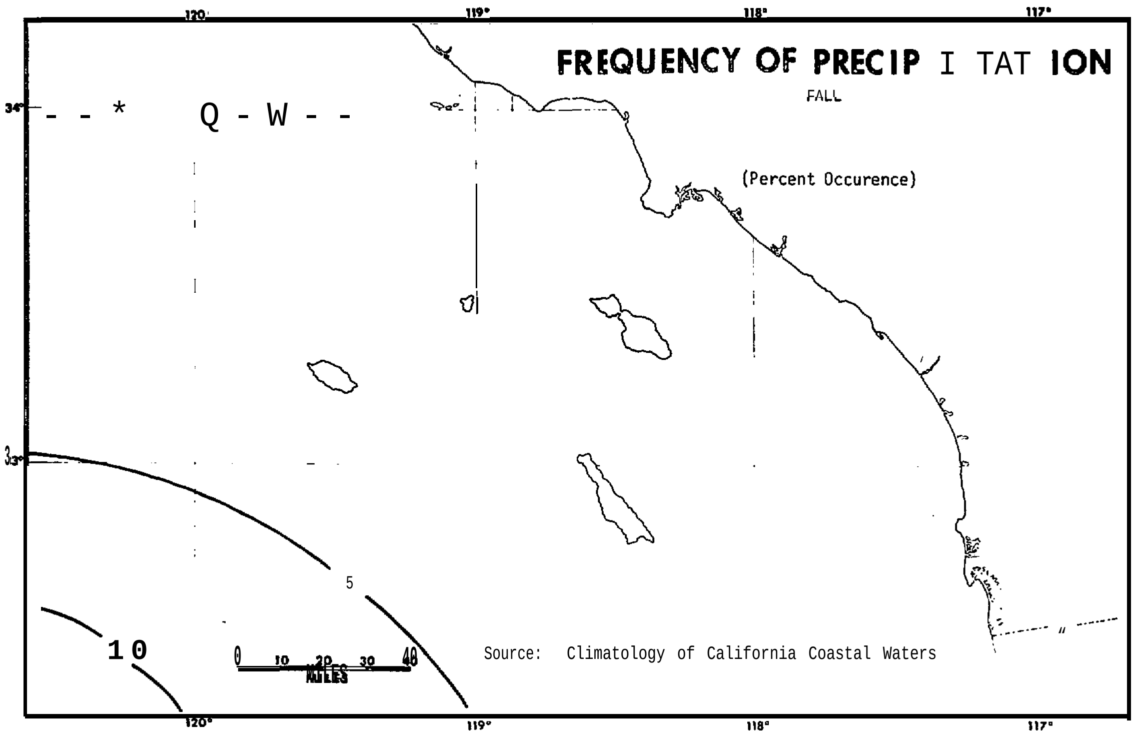


Source: Department of Commerce, Weather Bureau and United States Navy

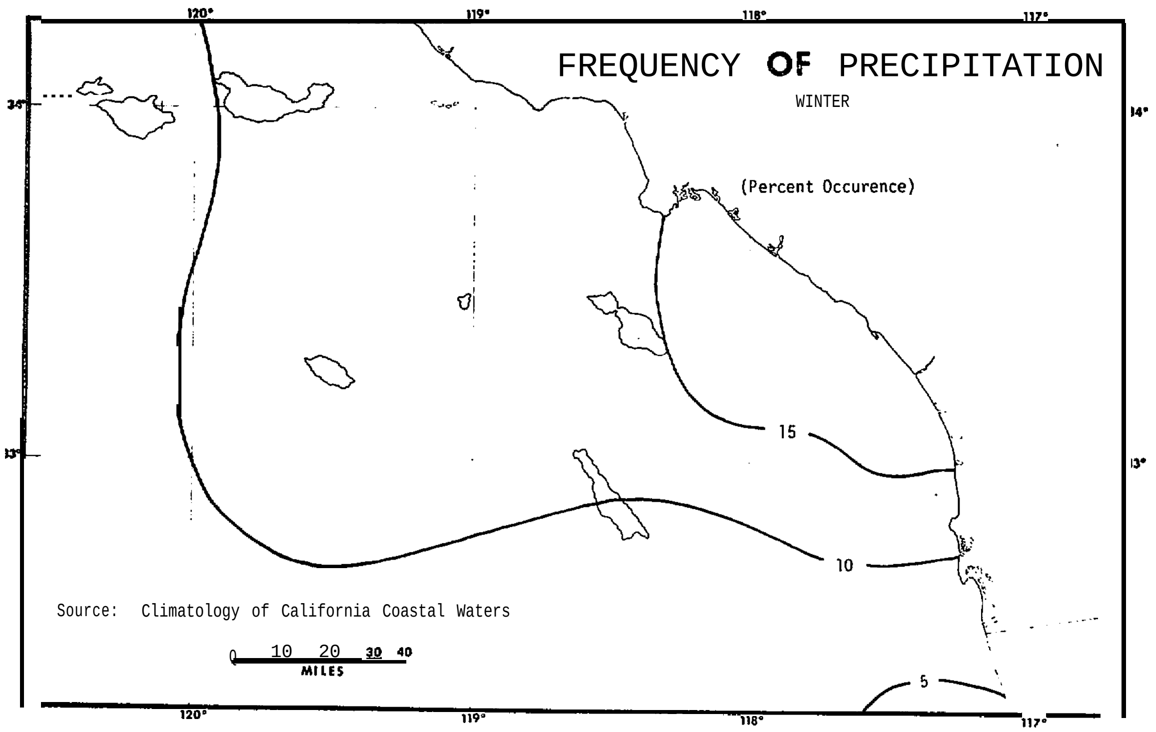


After: Patterns on the Land

Figure 2-10



" Figure 2-II



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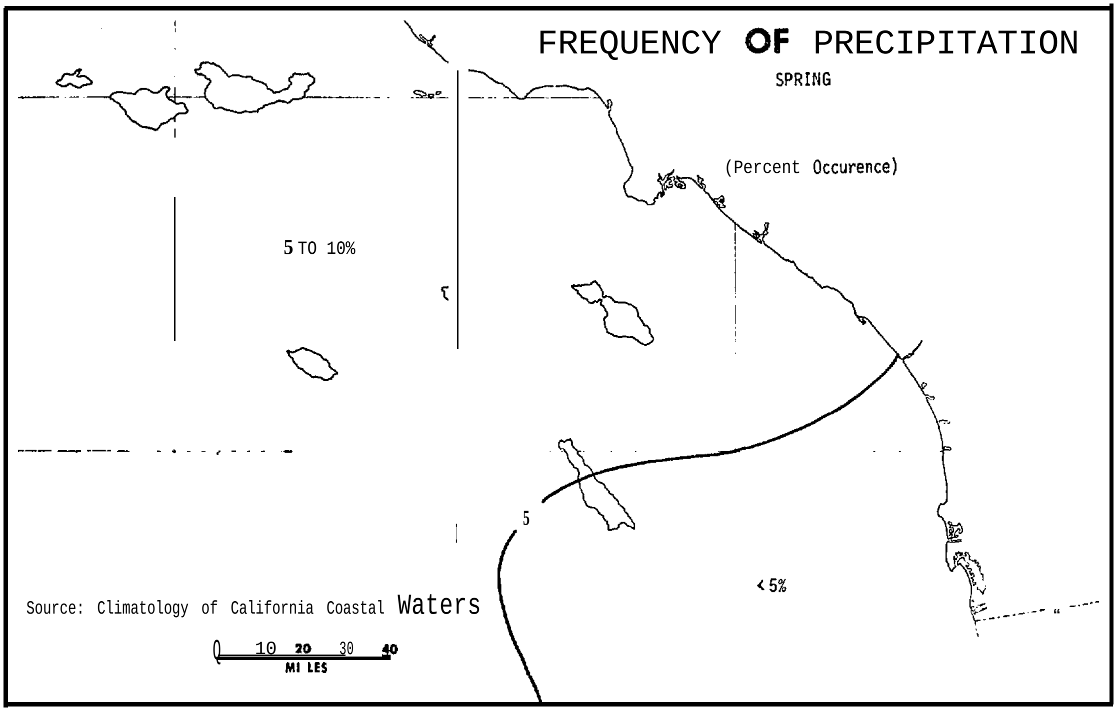


Figure 2-13

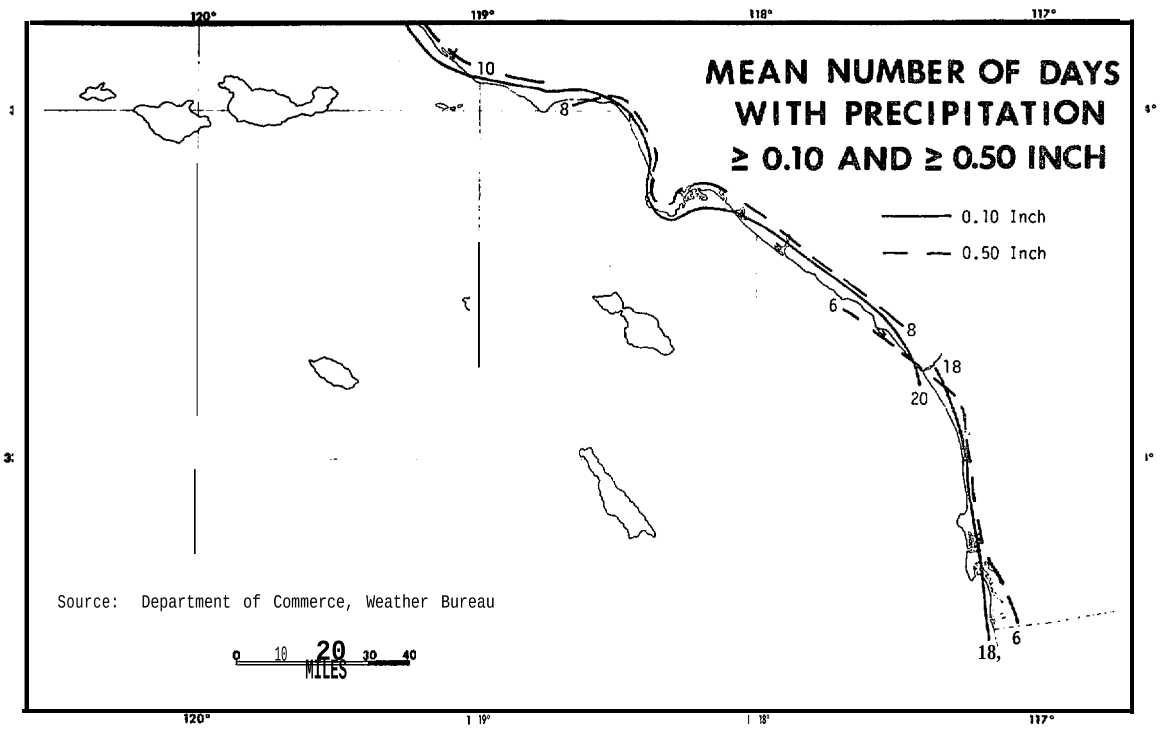
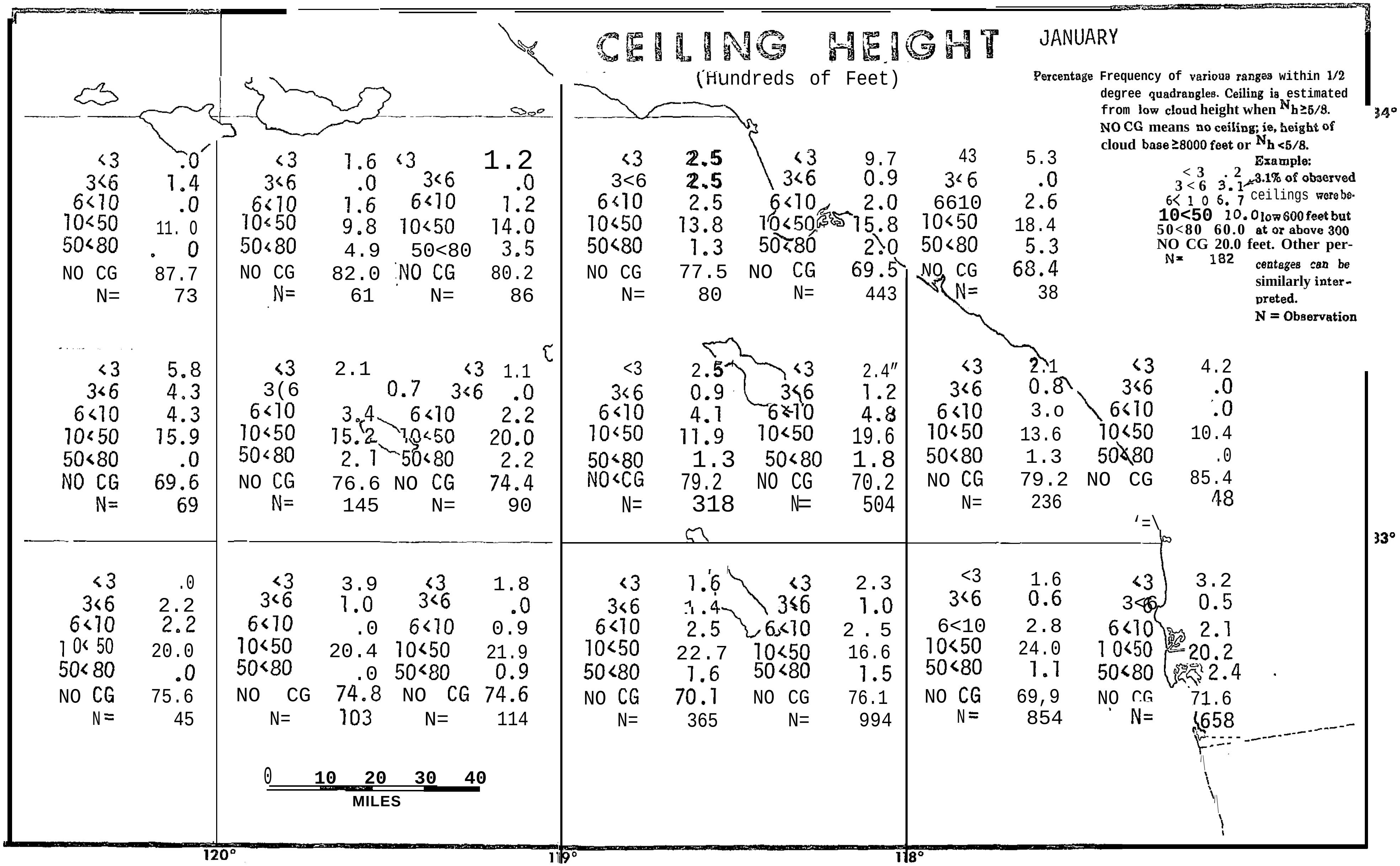
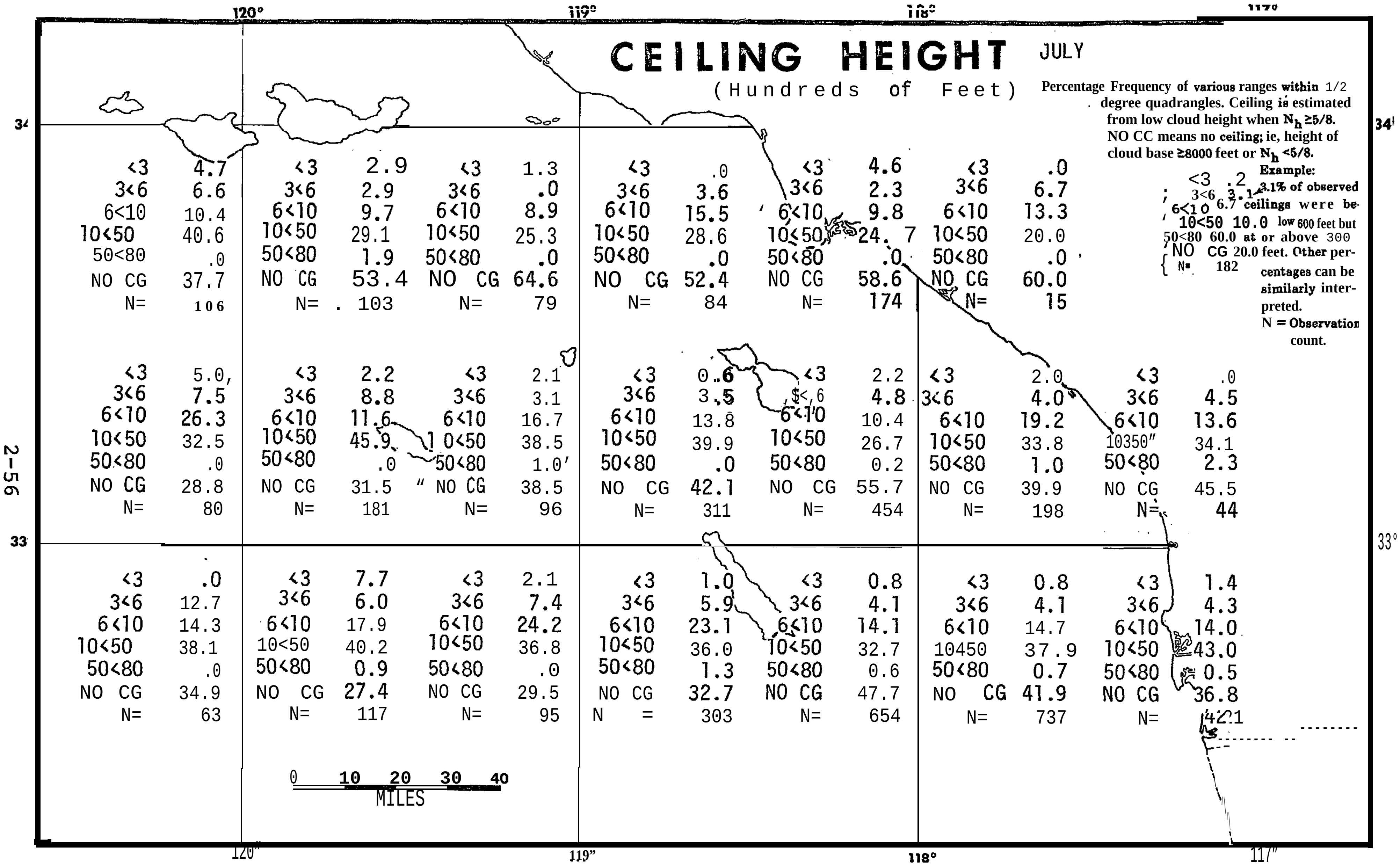


Figure 2-14



Source: Climatological Study Southern California Operating Area



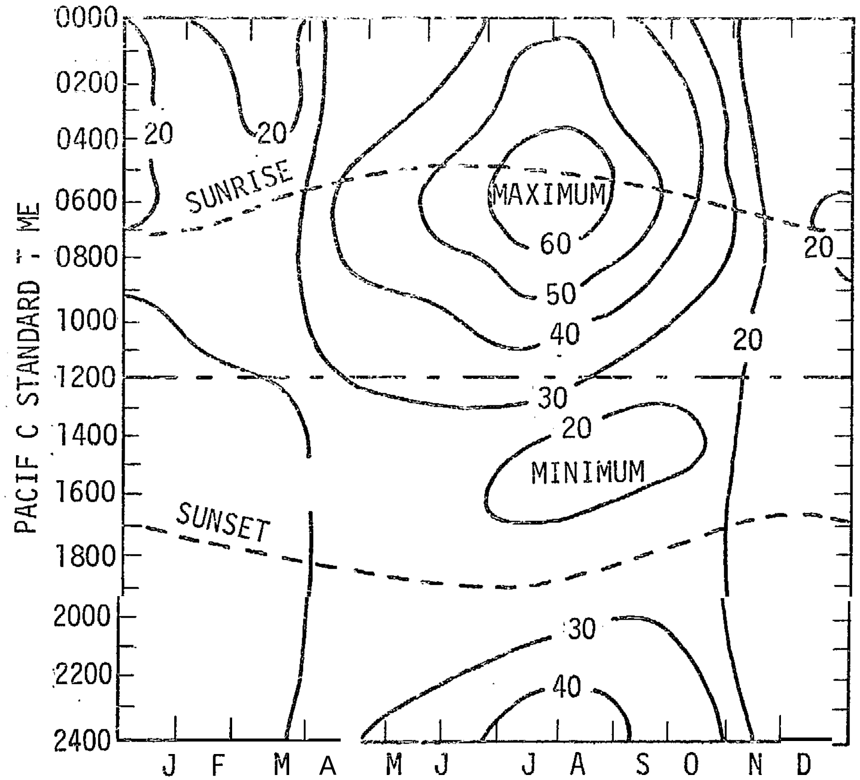
Source: Climatological Study Southern California Operating Area

Figure 2-16

PERCENT OF CEILING BELOW 3000 FEET

POINT MUGU

(By Time of Day Versus Months)



Source: Climatic Handbook for Point Mugu and San Nicolas Island

Figure 2-17

SAN NICOLAS ISLAND

(By Time of Day Versus Months)

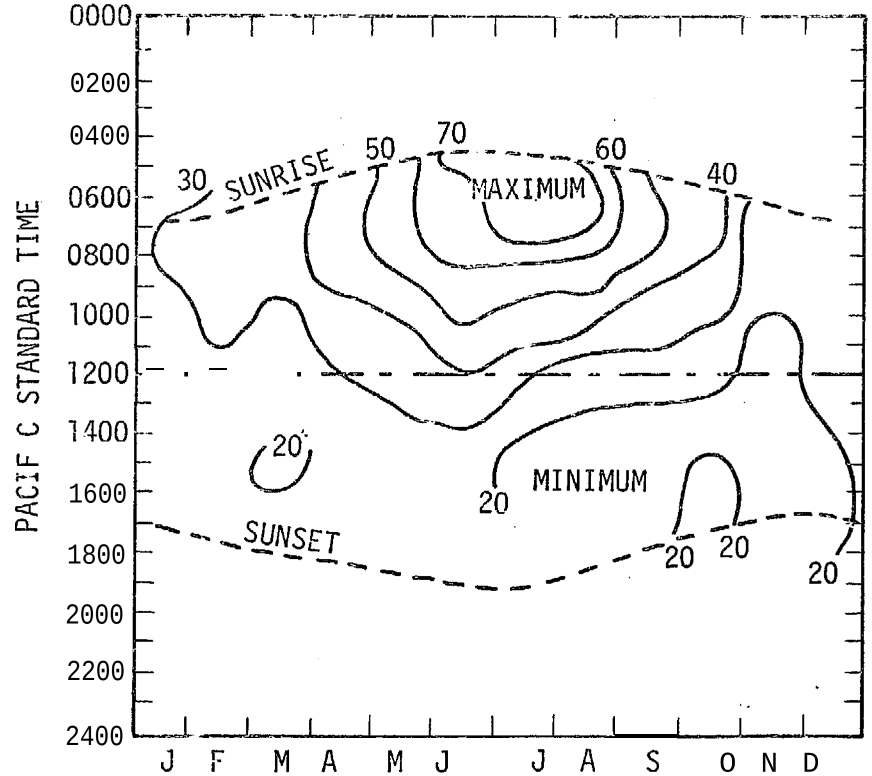
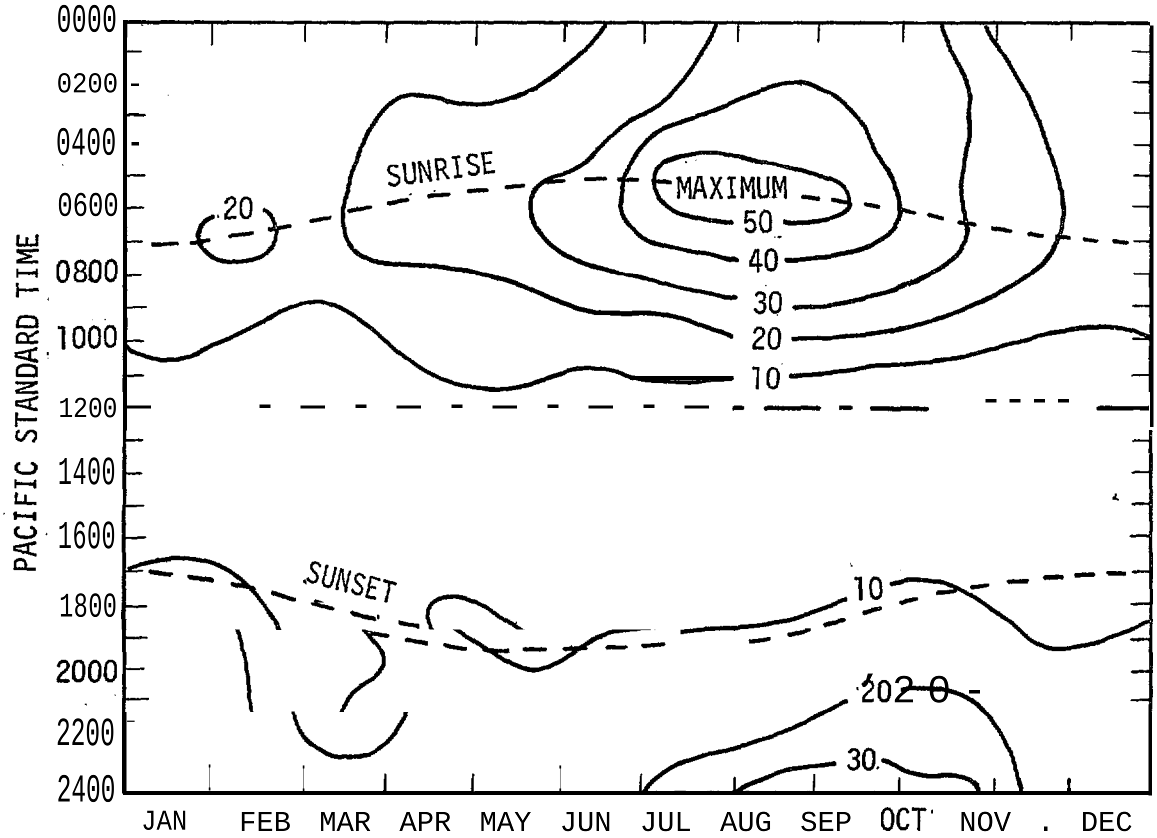


Figure 2-18

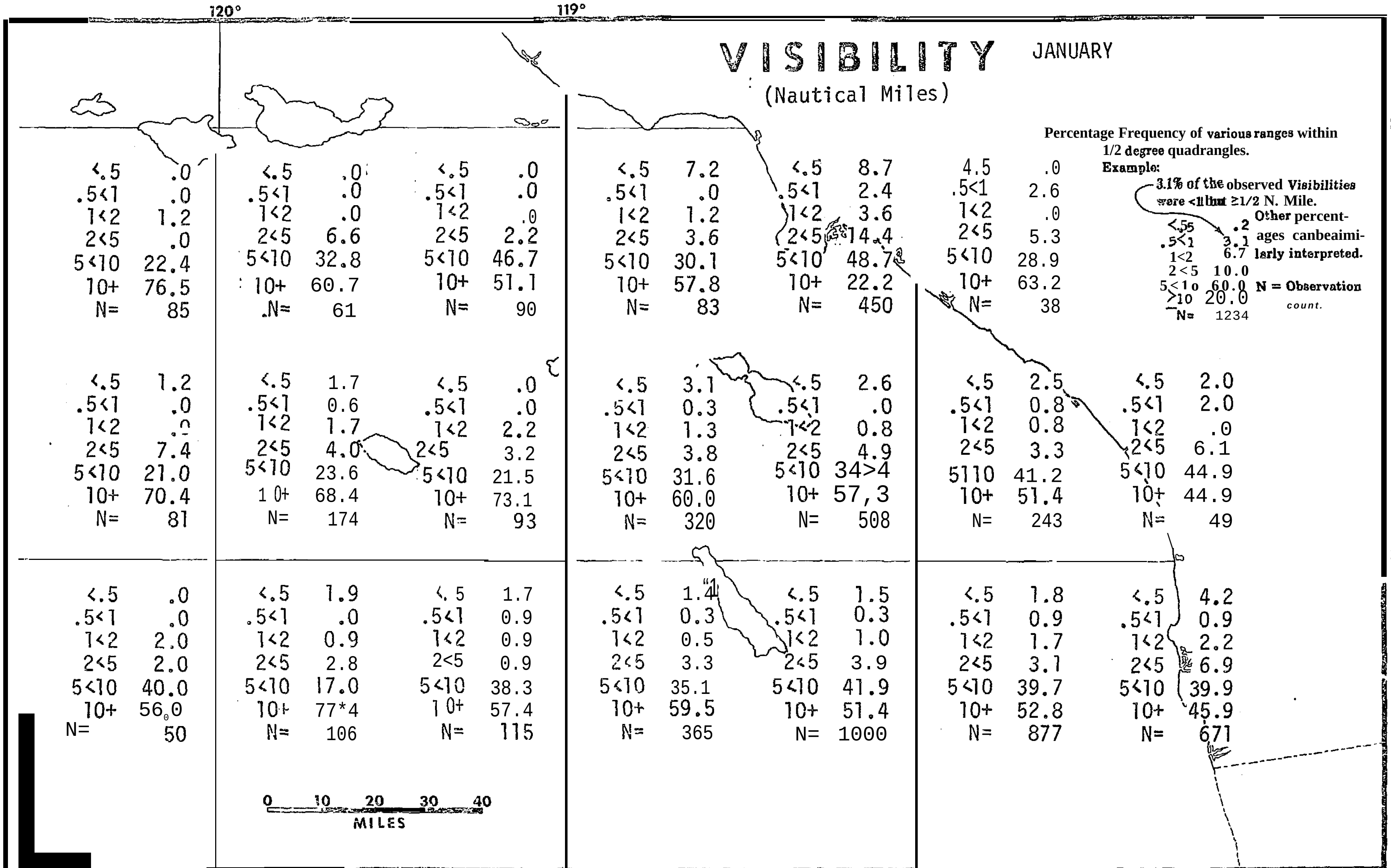
PERCENT FOG

POINT MUGU



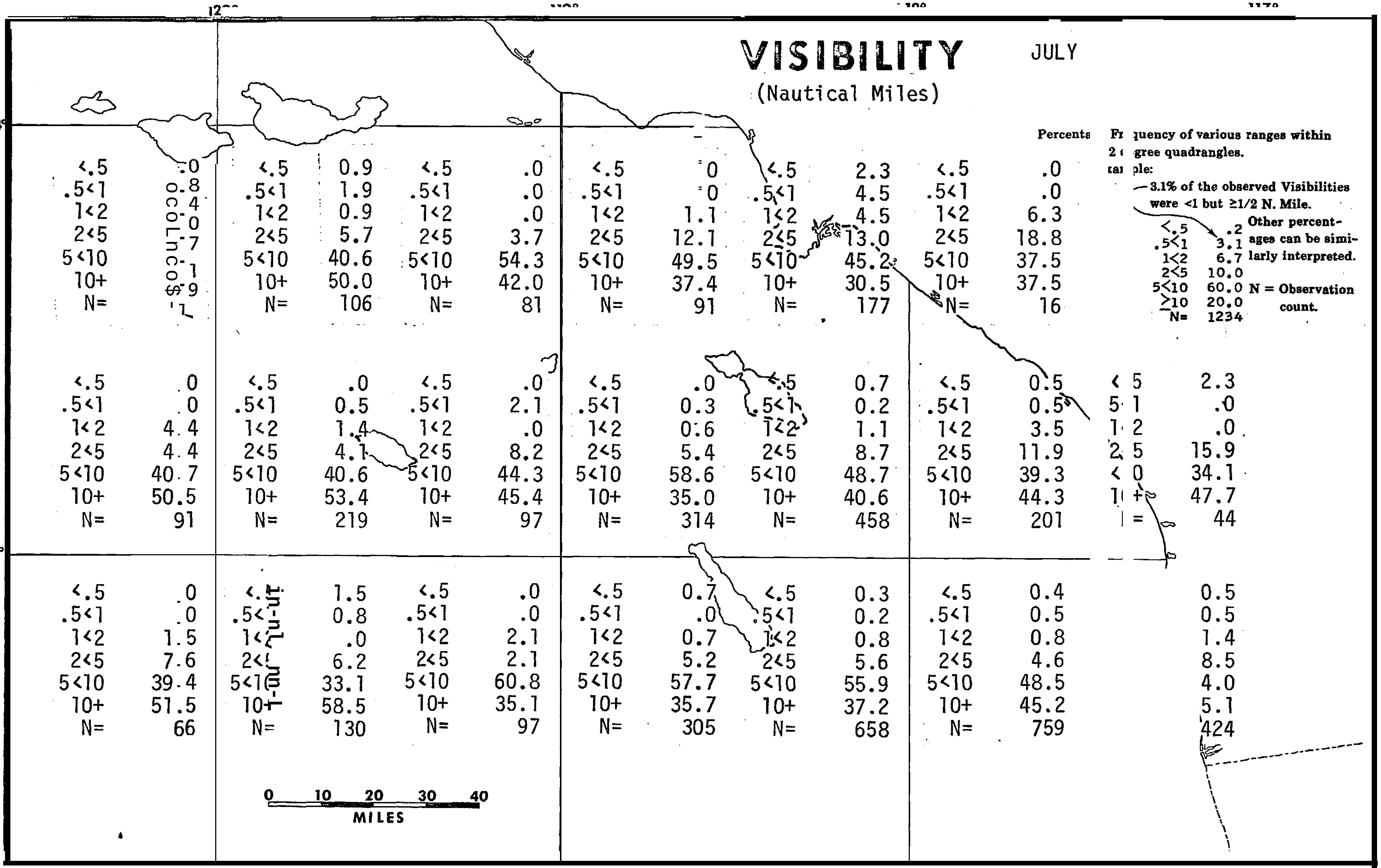
Source: Climatic Handbook for Point Mugu and San Nicolas Island

Figure 2-19



source: Climatological Study Southern California Operating Area

Figure 2.20



Source: Climatological Study Southern California Operating Area

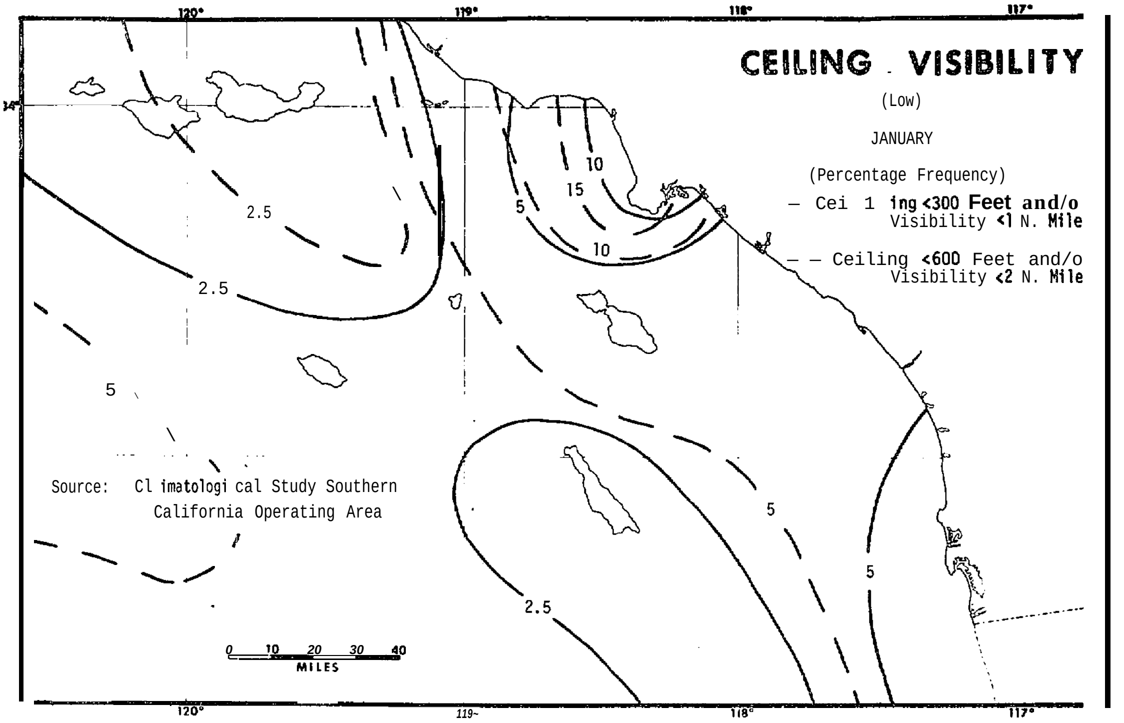


Figure 2-22

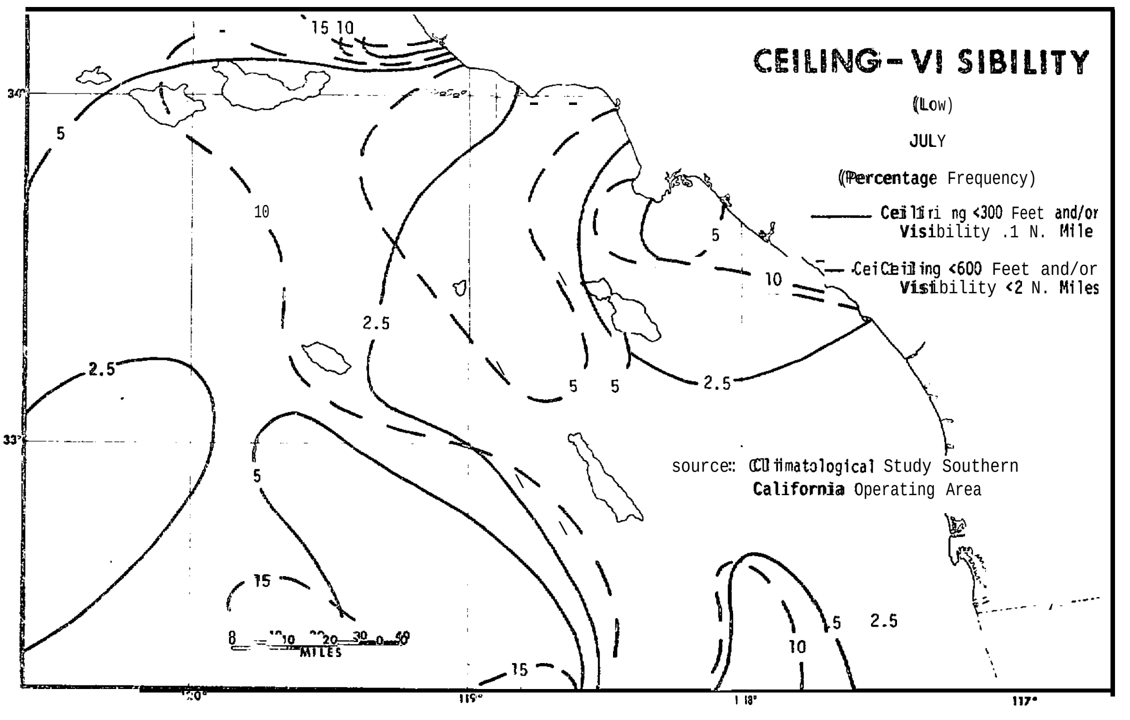
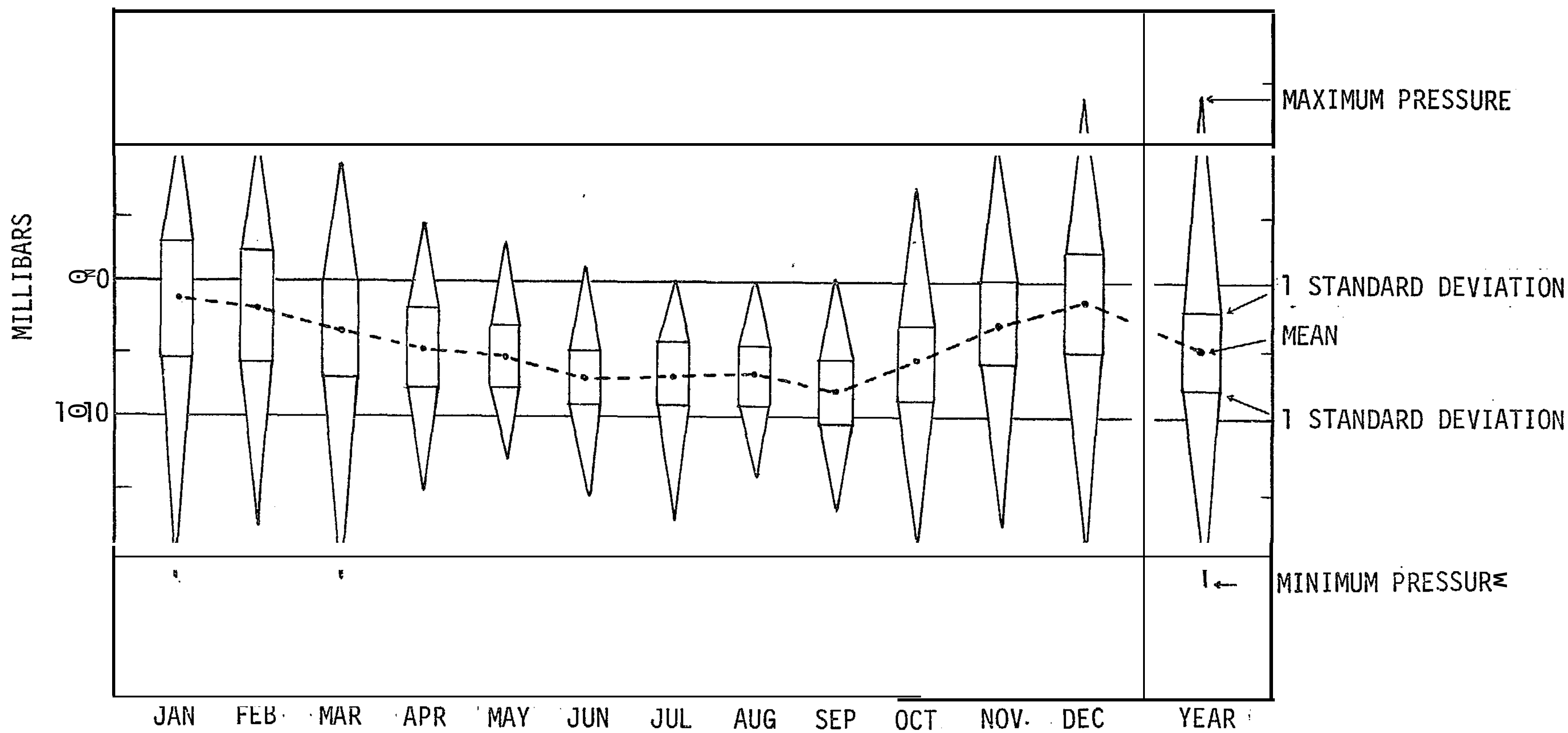


Figure 2-23

MONTHLY SEA LEVEL PRESSURE

POINT MUGU

(January 1950 Through February 1963)



Source: Climatic Handbook for Point Mugu and San Nico as Is and

Figure 2-24

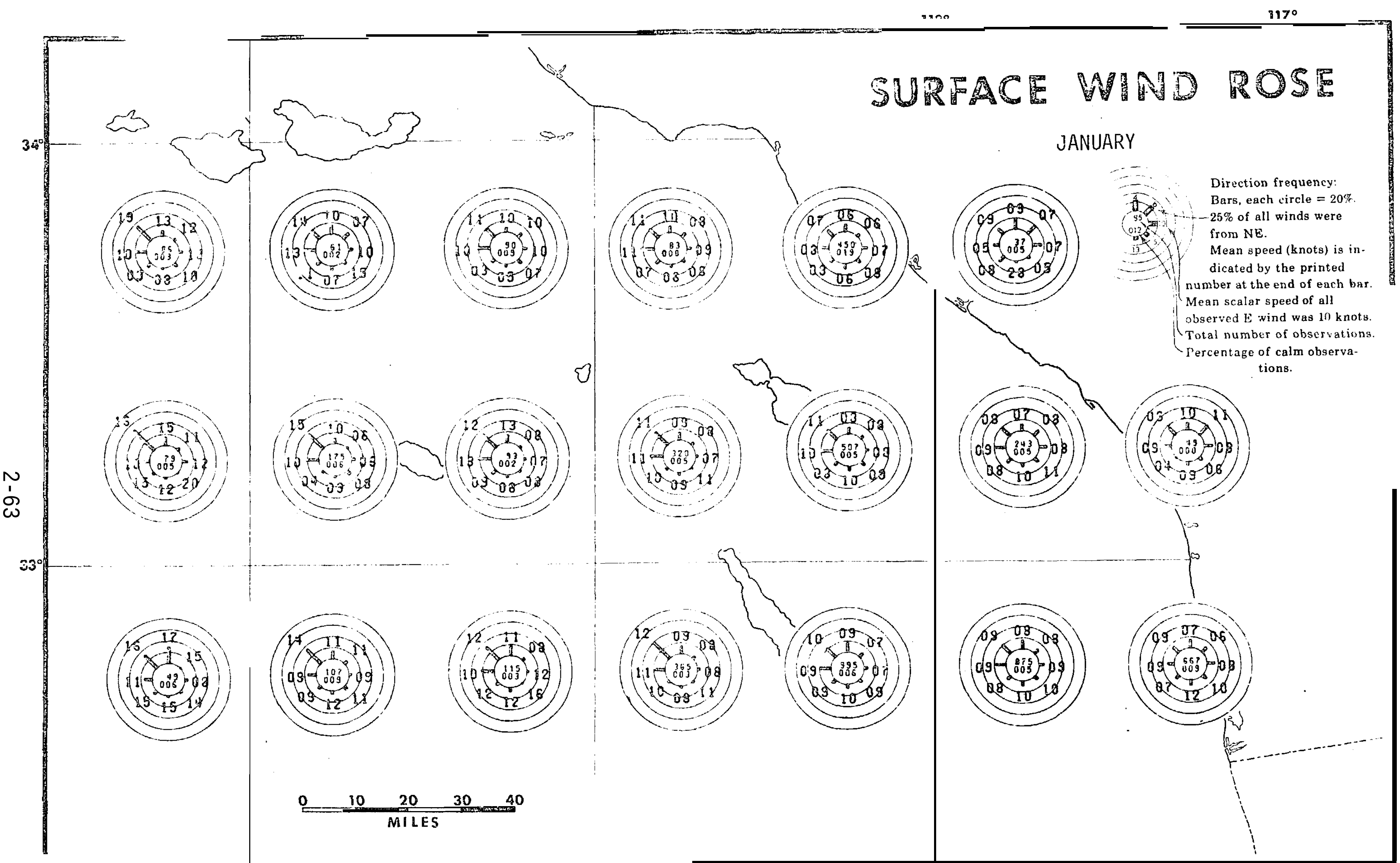
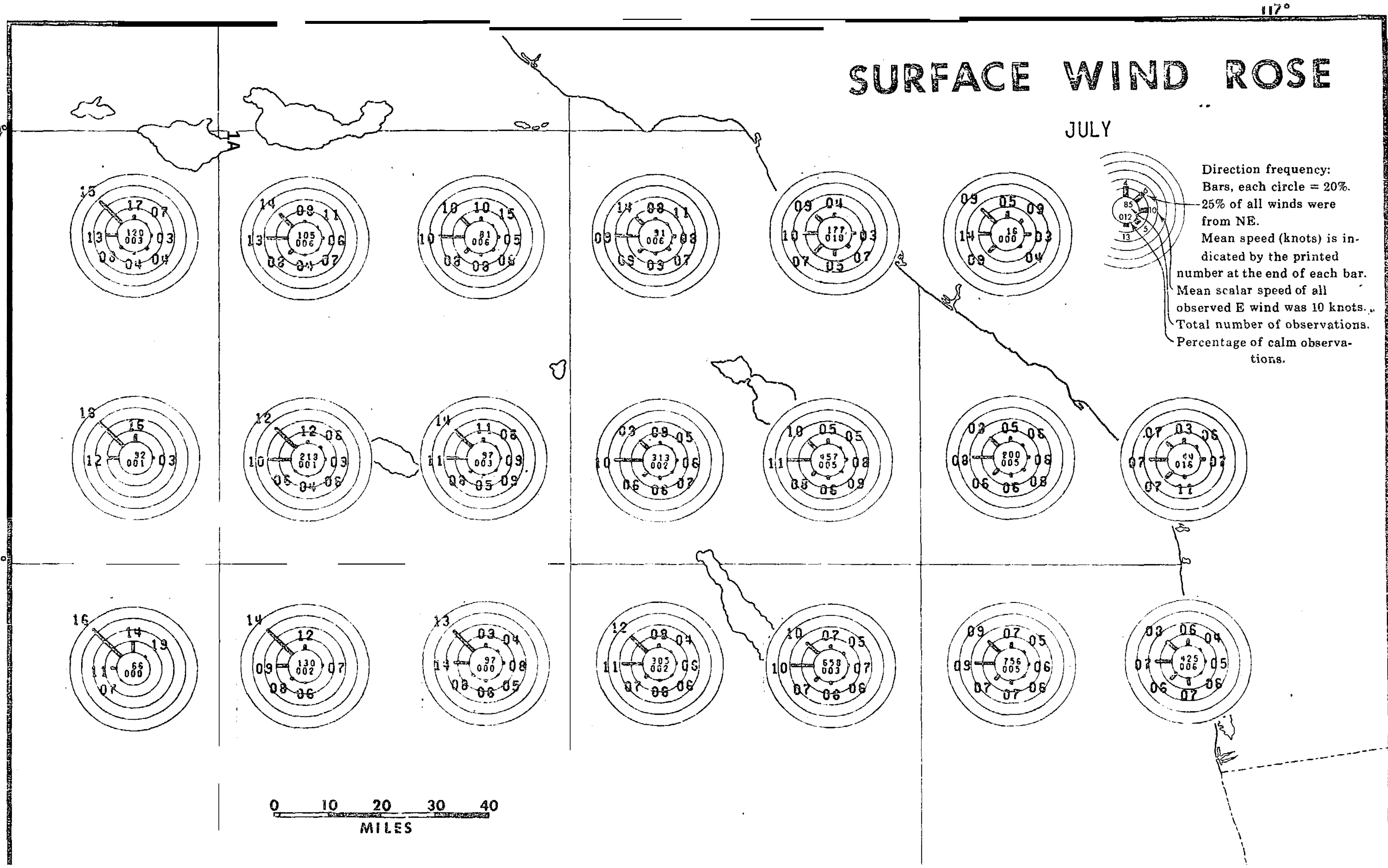


Figure 2-25 : Climatological Study Southern California Operating Area



Source: Climatologica Study Southern California Operating Area

FREQUENCY OF WINDS

DIRECTION VERSUS TIME OF DAY AT POINT MUGU

(JANUARY)

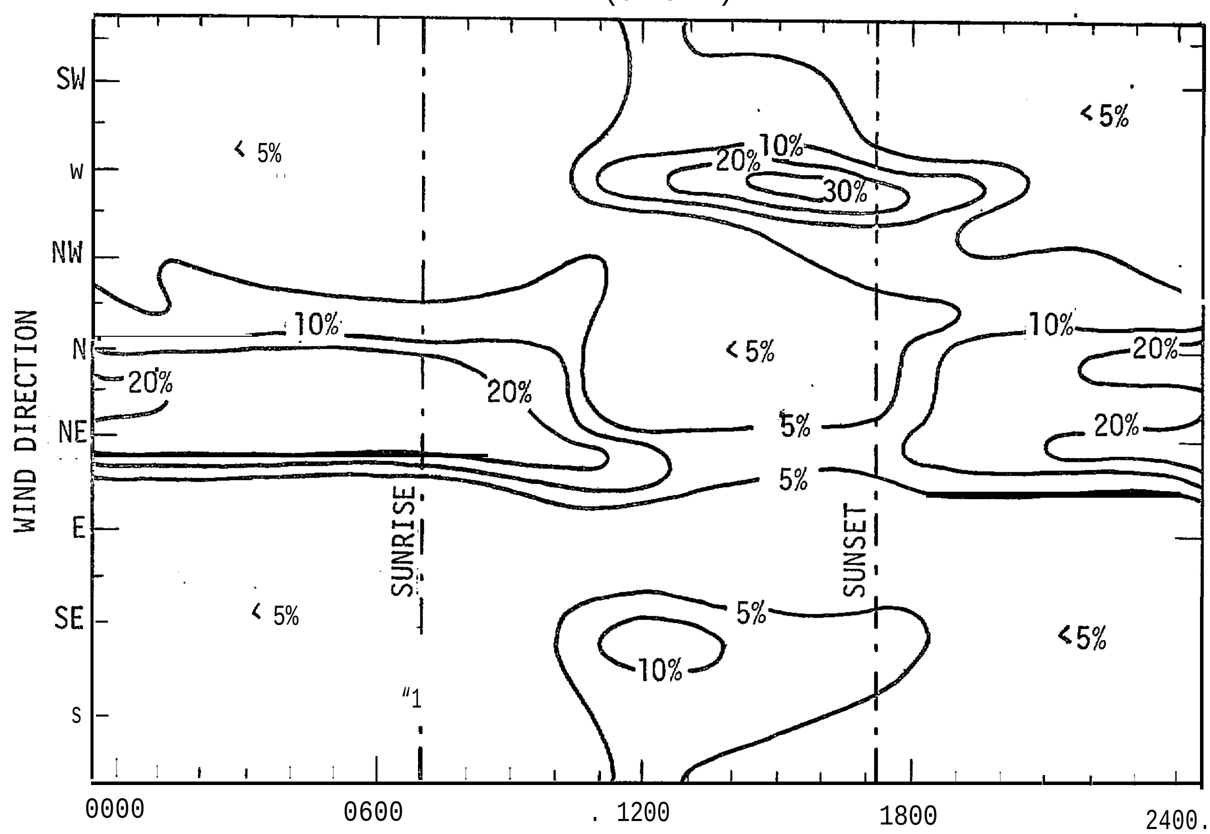


Figure 2-27

MEAN WIND SPEED VERSUS TIME OF DAY

POINT MUGU

(JANUARY)

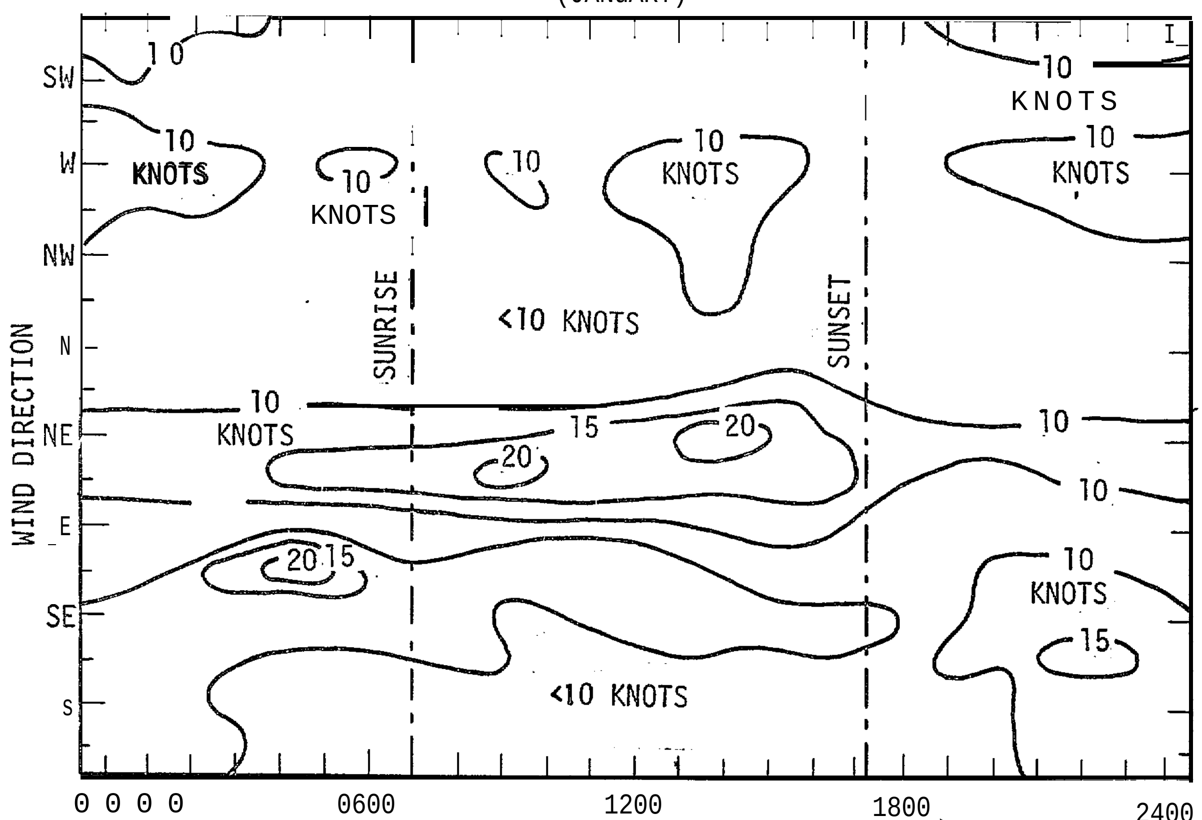


Figure 2-28

Source: Climatic Handbook for Point Mugu and San Nicolas Island

FREQUENCY OF WINDS

DIRECTION VERSUS TIME OF DAY AT POINT MUGU

(JULY)

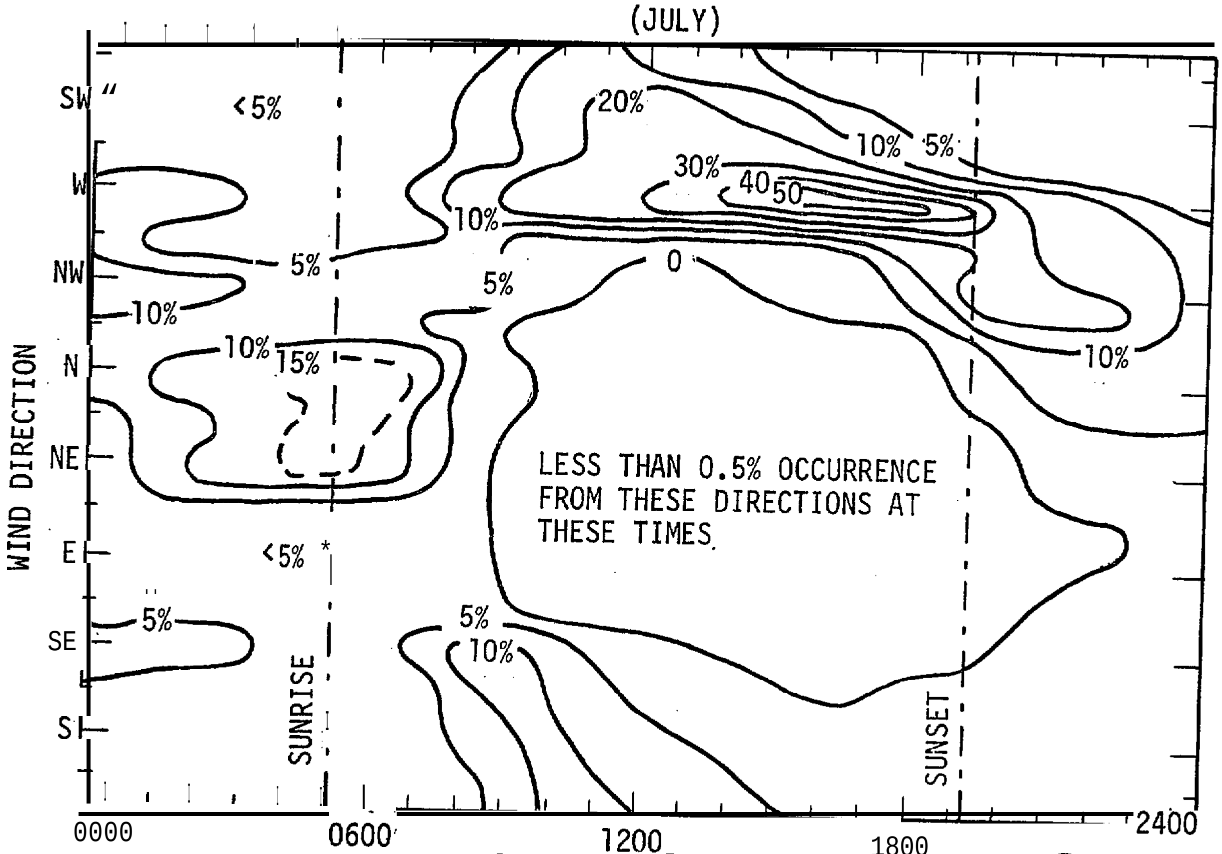


Figure 2-29

MEAN WIND SPEED VERSUS TIME OF DAY

POINT MUGU

(JULY)

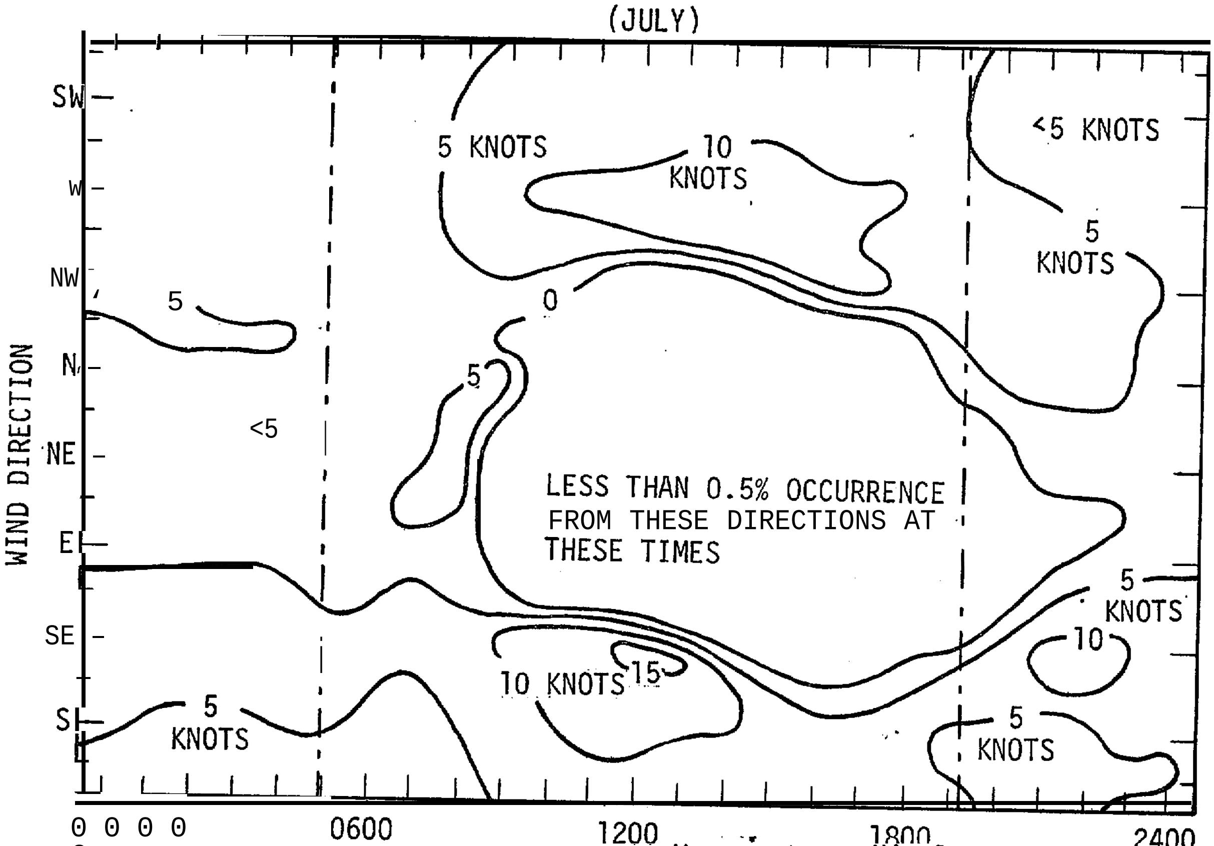


Figure 2-30

Source: Climatic Handbook for Point Mugu and San Nicolas Island

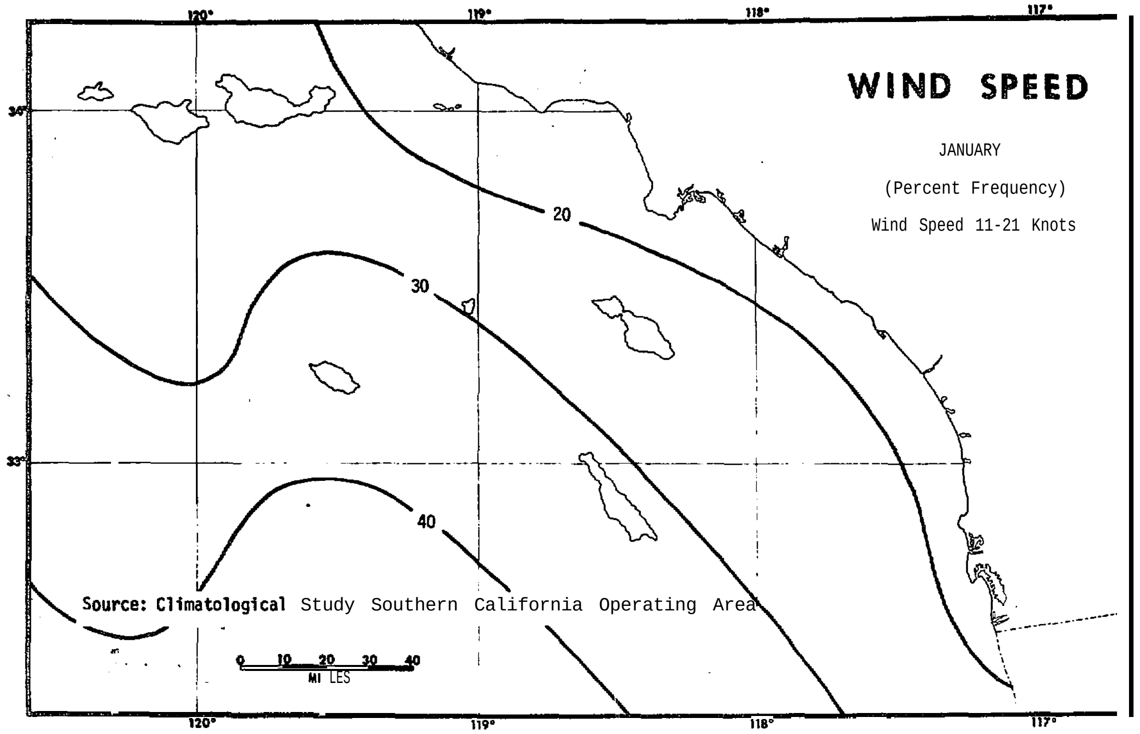


Figure 2-31

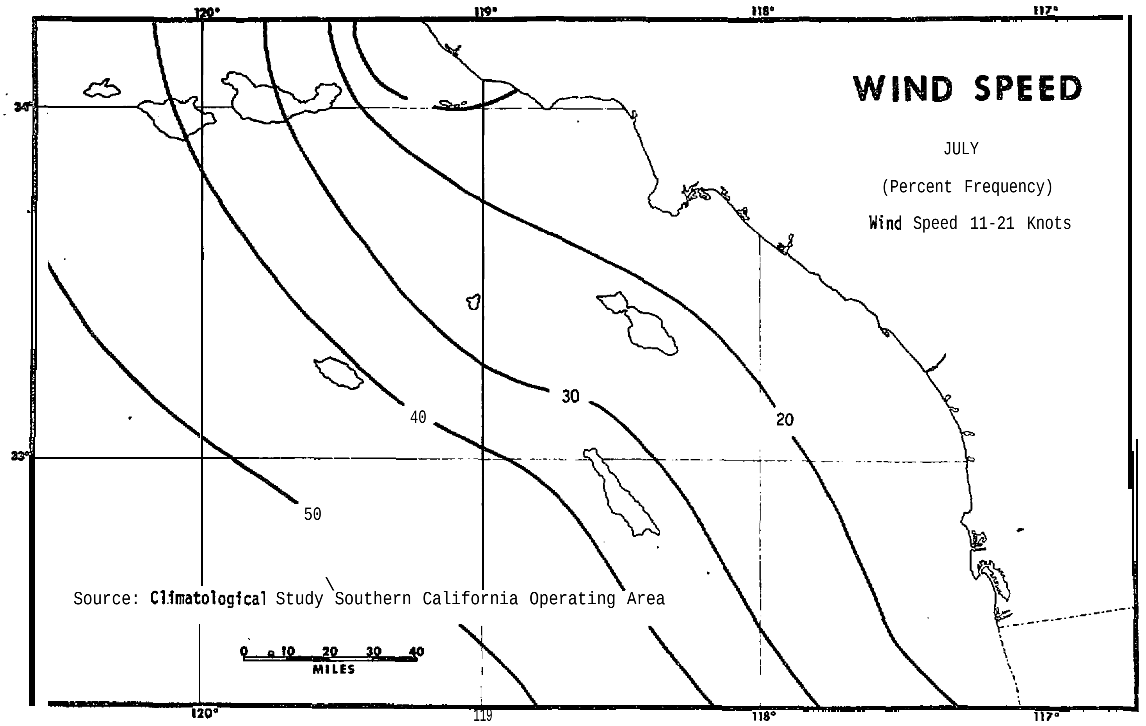


Figure 2-32

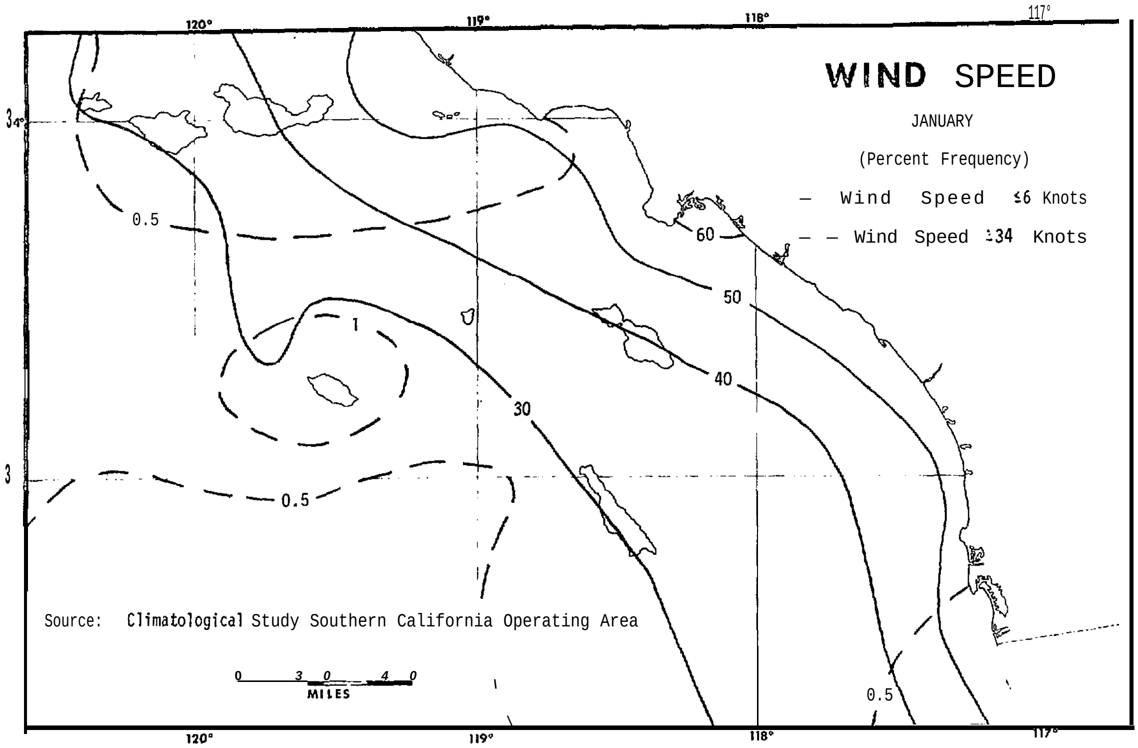


Figure 2-33

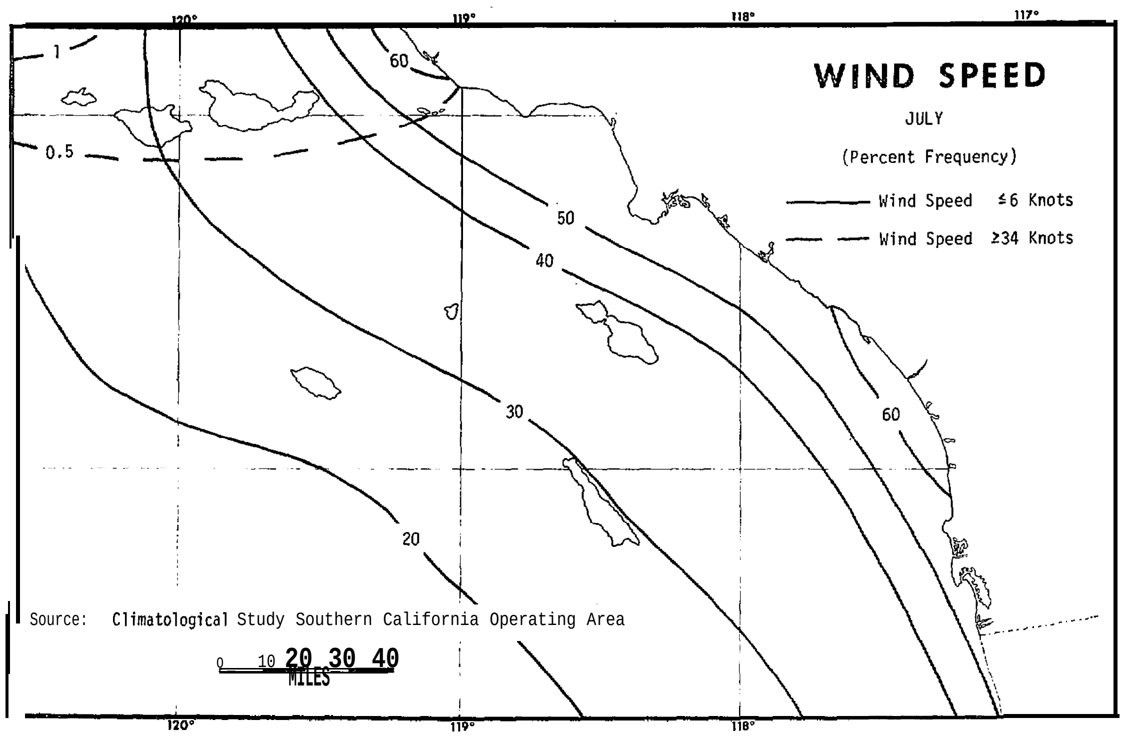


Figure 2-34

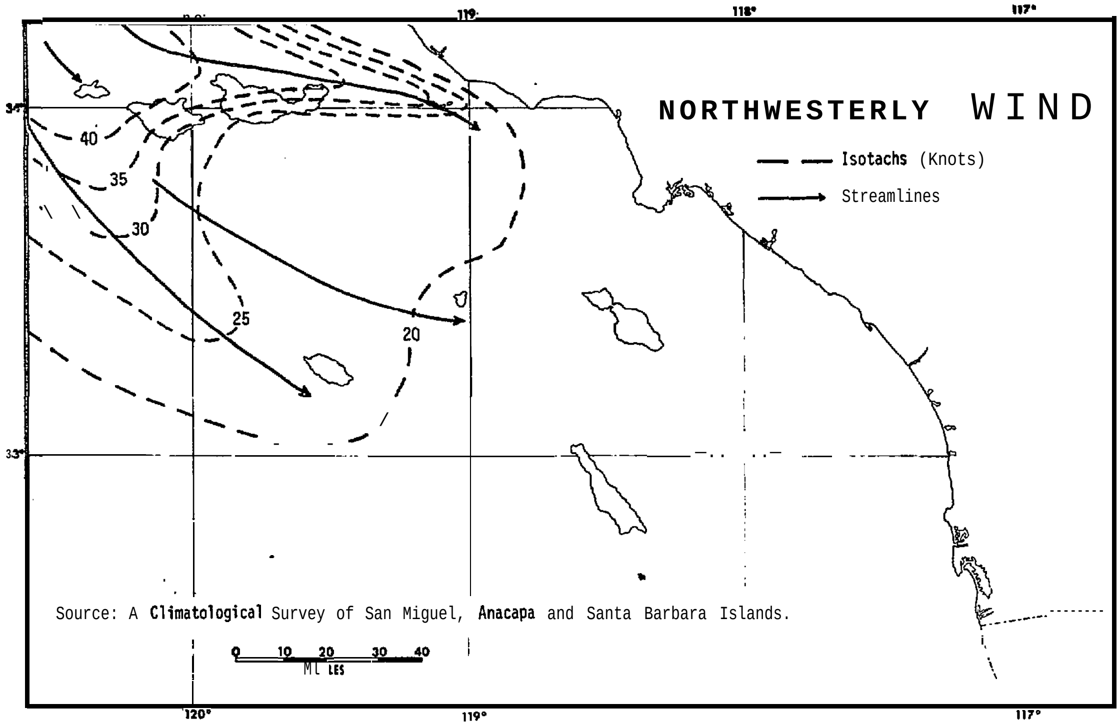


Figure 2-35

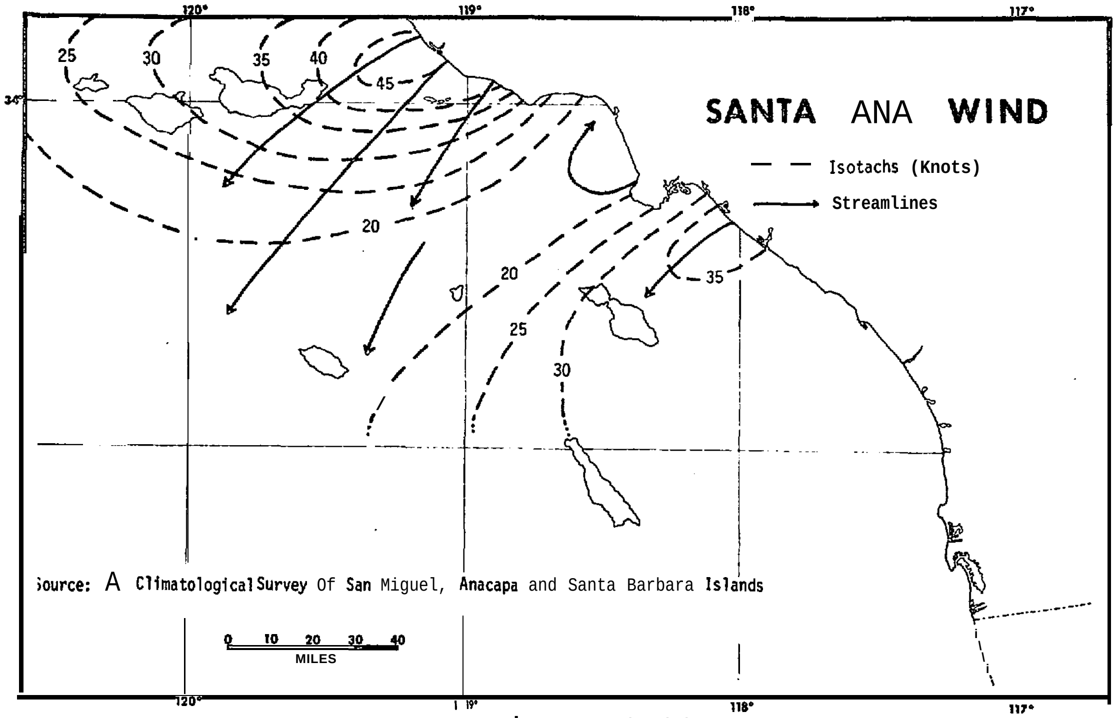
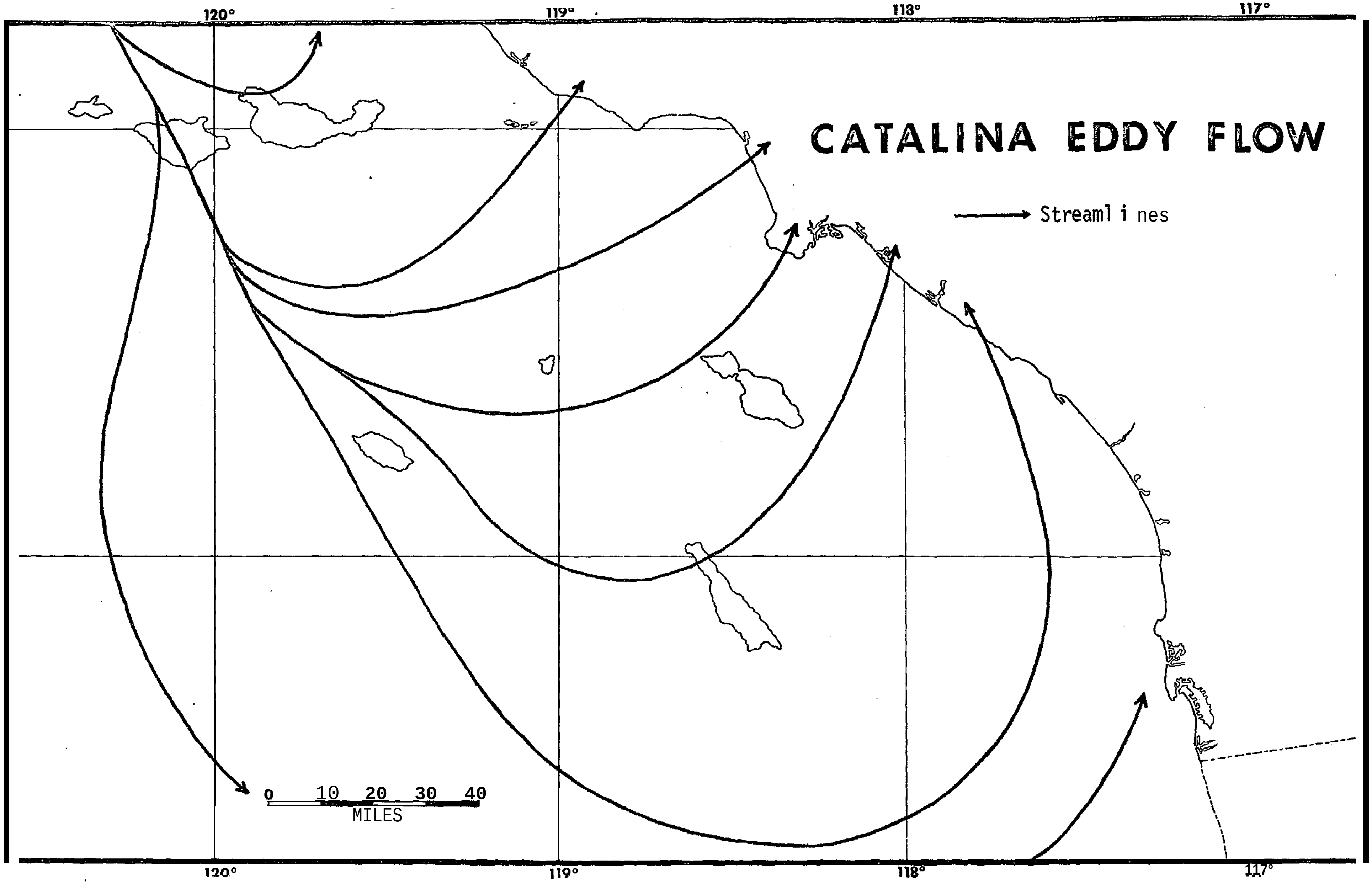


Figure 2-36



Source: Divergence and Vorticity of the Southern California Coastal Winds

Figure 2-37

3. PHYSICAL OCEANOGRAPHY

Neil J. Maloney
and
Kwan-Ming Chan

1. General Features

The oceanography off Southern California has been studied by the Allan Hancock Foundation of the University of Southern California, the Scripps Institution of Oceanography, the California Department of Fish and Game, the U.S. Bureau of Commercial Fisheries, the Southern California Coastal Water Research Project, and the local water and sanitation districts. Emery (1960) summarized much of the oceanographic information and SCCWRP (1973) updated this synthesis with respect to the mainland shelf.

This chapter summarizes information concerning the oceanic circulation, waves, tides, and physical properties of the water in the Southern California Bight. Much of the material in this chapter is interrelated with chemical oceanography which is covered in Chapter 4. Parts of the chapter also relate with Chapters 2, 5, 6, and 7. The place names used in the chapter are located on Figure 3-1.

2. Ocean Currents

Southern California is located on the eastern boundary of the North Pacific Ocean. As a result, the surface water seaward of the offshore islands moves south with the eastern boundary current, the California Current. A southerly current flows north below the California Current, and a southerly surface countercurrent occurs landward of the California Current (Figs. 3-2 and 3-3). Seasonal coastal upwelling, mixed semidiurnal tides, and wave motion cause distinct circulation patterns in the littoral zone.

2.1 Oceanic Circulation

2.1.1 California Current. The California Current is the broad, sluggish, eddying eastern boundary current of the North Pacific Ocean. It has its origin where the North Pacific Current (West Wind Drift) intersects the North American continent at 45° to 50° north latitude and turns south along the California Coast. The current is 600 to 1,000 km wide and 100 to 500 m deep. Sverdrup and Fleming (1941) estimated that more than 90% of the California Current transport occurred within 800 km of the coast in depths of 0 to 300 m. It comes within 40 to 150 km of the coast in the region north of Point Conception. South of the Point, in the Southern California Bight, the California Current flows some 200 km offshore. The separation of the current from the coastal zone results from the curvature of the coastline in the bight.

Emery (1960) calculated geostrophic current velocities of about 30 cm/sec with regard to the 300 decibar surface and an average total volume transport of 10 x 10^6 m^3/sec. He found seasonal variations in flow during 1950-1952 (Fig. 3-4). The current is strongest during the summer and weakest and most meandering in the winter.

Pavlova (1966) calculated a geostrophic current averaging 15 cm/sec and a volume transport of 12 x 10^6 m^3/sec. Direct current measurements with parachute drogues showing maximum short-term velocities of 50 cm/sec and average short-term velocities of 20 to 30 cm/sec were observed by Schwartzlose and Reid (1972). They also observed loops and eddies with a southeast drift of about 12.5 cm/sec and concluded that the average current speed is about 12.5 to 25 cm/sec.

Figures 3-2 and 3-3 show the mean geostrophic currents at the surface and at 200 m relative to the 500 decibar surface during January and July (Schwartzlose and Reid, 1972). The surface current is stronger and closer to shore during the summer. The geostrophic currents at 200 m relative to the 500 decibar surface are very weak, 2 to 3 cm/see, during both seasons. The January 1964 currents show the same pattern as the mean currents but more details of the meandering current direction can be seen (Fig. 3-5).

The water masses present in the Southern California Bight result from the mixture of northern and southern water. Kindyushev (1967) summarized the water masses in the region.

The California water mass is a mixture of subarctic and subtropical water that moves south with the California Current. It is found at depths of 40 to 600 m and is distinguished by low temperatures and salinities. It is much modified in Southern California by mixing with warmer and more saline southern water. Surface temperatures of 8° to 12°C and salinities of 33.5 ‰ to 33.8 ‰ are typical of this water mass in Southern California. The temperature decreases to 5.5°C and the salinity increases to 34.2 ‰ at depth.

2.1.2 Southern California Eddy and Countercurrent. The California Current swings east towards the coast in the area around Ensenada, Mexico, and part of this water turns and flows to the northwest between the California Current and the coast as a countercurrent (Figs. 3-2, 3-3, 3-4, 3-5).

Geostrophic current measurements show that the countercurrent exists during all seasons, though it is probably best developed during the winter. Upon intersecting the Channel Islands and Point Conception, the countercurrent either continues north as the Davidson Current or turns back and flows southeast along the continental shelf. This looping feature of the surface current system is called the Southern California Eddy (Jones, 1971) or Gyre (Schwartzlose and Reid, 1972).

Drogue and drift bottle studies in the countercurrent show that variable flow directions and eddies are present. Bottles released during November, 1957, went north with a strong current (Fig. 3-6). Those released during April, 1960, January, 1964, and December, 1969, traveled south with the current over the shelf or with the California Current. Drogues released between San Nicolas and Santa Catalina Islands in October, 1958, recorded numerous small scale eddies (Fig. 3-7) (Schwartzlose and Reid, 1972). Gorsline and Grant (1972) measured a boundary current shear between the countercurrent and a south-flowing inshore current in the San Pedro Channel. The countercurrent was strongest, 5 to 30 cm/sec at the surface, and closest to shore during the spring. All these data indicate that the countercurrent and eddy form a complicated system that has both large and small scale variations in flow direction.

Drift bottles released as far as 150 km off shore have been recovered along the coast (Fig. 3-12) . The closer the release sites were to the coast the higher the percentage of recovery (Schwartzlose and Reid, 1972) . Up to 35% of the bottles were recovered from stations located within 16 km of shore. It is likely that pollutants released offshore also would be washed onto the coast by the Southern California Eddy.

The geostrophic speed of the countercurrent was calculated to be about 12 to 18 cm/sec by Sverdrup and Fleming (1941), and Pavlova (1966) demonstrated that the volume transport of the countercurrent is only slightly less than that of the California Current. Parachute drogue and drift bottle studies show that the currents in the eddy have a complex nature of flow and that the geostrophic method may not be valid. Schwartzlose (1963) found that the counterclockwise gyre was present throughout most of the year, being absent during March through May. The maximum countercurrent development occurs during the winter months when velocities of 35 to 40 cm/sec are attained. Emery (1960) states that the water in the counterclockwise gyre takes 10 to 20 days to travel one half revolution.

The water in the countercurrent is a mixture of northern, California Current, water and southern water. The mean monthly temperatures range from 14° to 19°C, one to three degrees higher than the California Current, at a depth of 10 m (Lynn, 1967). At 10 m, the salinities range from 33.4 ‰ to 33.6 ‰ and are 0.1 ‰ to 0.2 ‰ greater than the California Current.

<u>2.1.3 California Undercurrent</u>. A persistant north to northwesterly flowing undercurrent is present at depths of more than 150 to 200 m and less than 500 to 800 m in the Southern California Bight. Figures 3-2, 3-3, 3-4 and 3-5 show geostrophic current measurements near the upper boundary of the undercurrent. Wooster and Jones (1970) found a subthermocline poleward flow of warm, salty, low oxygen water. The center of the current contains a salinity maximum of 34.4 ‰ to 34.6 ‰, and a σ_t surface of 26.54. Measurements show that the current is confined by the continental slope where it is 20 km wide and 300 m thick in the bight (Wooster and Jones, 1970) . Wooster and Jones use the salinity and density to define distribution of the undercurrent (Fig. 3-8). It is broad off Baja California but narrows to a thin current over the Southern California continental slope, seaward of the 200 m isobath.

Reid (1963) measured maximum current velocities of 8 cm/sec off Southern California. Wooster and Jones (1970) recorded velocities of up to 40 cm/see, averaging 30 cm/see, off Baja California. If these data are correct, then the current diminishes in strength as it moves north into the bight. The volume transport off Baja California is 2 x 10^6 cm^3/see, about one-fifth of the California Current (Wooster and Jones, 1970). Seasonal variations in the undercurrent are poorly known.

The trough and ridge topography of the Southern California borderland divides the undercurrent into sinuous streams that flow into the offshore basins (Fig. 3-9). Emery (1960) showed that the basin water characteristics are determined by the sill depths and the undercurrent.

The water mass transported with the undercurrent is formed near South America through gradual transformation of subantarctic water. Kindyushev (1967) calls it the Equatorial Transformed water mass. It is present at depths of 100 to 800 m, and is much modified by the time it reaches Southern California. This southern water is saltier and denser than the water in the California Current. The undercurrent water has a maximum salinity of 34.35 ‰ and temperatures that range from 6° to hoc.

The undercurrent water mass mixes with the California Current water mass at its upper boundary. Sverdrup and Fleming

(1941) applied the core method of water mass identification to determine the amount of mixing between the currents. The temperature-salinity diagram shown in Figure 3-10 gives the curves for northern water in the California Current and the southern water in the undercurrent, as well as curves showing the percentage of mixing of the water masses. Using these curves, Emery (1960) calculated that 50% southern water occurs at depths of 200 to 300 m. Higher percentages are present at greater depths (Fig. 3-11) . Southern water does not extend west much beyond the continental slope, but it does present a broader current than the 26.54 σ_t surface does (Fig. 3-8). This may result from mixing across the density surfaces of the water masses.

2.2 Nearshore Circulation

2.2.1 Coastal Currents. The currents measured over the continental shelf seaward of the surf zone appear to be dominated by the local wind, the tides, and the offshore geostrophic current direction. Table 3-1 summarizes the coastal current studies in the Southern California Bight.

Table 3-1

CURRENT SURVEYS IN THE SOUTHERN CALIFORNIA BIGHT, 1935-72

Area	Time Span	Measurement Instrumentation or Technique	Source
Santa Monica Bay	1955, 1956	Surface drift cards, drogues, current meters	Stevenson, Tibby & Gorsline, 1956
Pales Verdes (White Point)	1960-1964, 1972	Current meters	Parkhurst, Whitt & Gorsline; SCCWRP, 1973
San Pedro Channel	1935	Current meters, current pole	Haight, 1939; Gorsline & Grant, 1972
Orange County	1964, 1966, 1967	Drogues	SCCWRP, 1973
San Onofre	1964, 1965	Surface drogues, subsurface current meters	Marine Advisers, 1965a, 1965b
Oceanside	1971	Bottom drifters, current meters(?)	R. Stone (unpublished)
Point Loma	1956, 1957, 1972	Drogues, current meters	Gaul & Stewart, 1960; SCCRWP, 1972; Hendricks & Harding, 1974

From Carsola (1973).

Daytime current measurements at or near the surface record velocities in the range of 5 to 20 cm/see, occasionally reaching 36 cm/sec (Allan Hancock Foundation, 1965) . Currents commonly differ in direction up to 90" and sometimes as much as 180°. Maximum velocities over the mainland shelf occur anywhere from the surface to near the bottom. Usually the velocities are greatest at the surface, being about twice those 16 m below. Most sewage and oil discharges float and will be influenced by the surface current directions and velocities.

Drift bottle studies show that there is a high percentage of onshore surface current (Fig. 3-12) . Schwartzlose and Reid (1972) found that bottles dropped 5 to 8 km offshore travel quickly to the coast and are recovered close to their release points.

Santa Monica Bay is frequented by a south-flowing current that induces a slow counterclockwise eddy (Stevenson, Tibby and Gorsline, 1956). Velocities of 10 to 20 cm/sec are most common. Drift card surveys in February and July, 1956, resulted in the recovery of 14% to 50% of the cards showing an onshore motion of water occurring both seasons (Fig. 3-13) .

Northwest and east-southeast flowing currents occur over the shelf off Pales Verdes Peninsula except during the winter when northwest to west-southwest moving currents have been recorded (SCCWRP, 1973). Current velocities range from 5 to 25 cm\sec with the strongest currents occurring in the summer and the weakest in the spring.

Mean wind and current speeds are shown in Table 3-2. The weak horizontal currents of spring time are related to the increased vertical upwelling. The strongest currents occur during summer and correspond with the time of strongest winds. There is a decrease in velocity with depth; it is most pronounced during the summer when the pycnocline is best developed. The surface currents frequently reversed directions during the periods of weak wind. South to southeasterly flowing surface currents are frequent during the summer (SCCWRP, 1973). Changes in current direction with depth are common. The vertical current shear is best developed during the summer and autumn with the current reversals at 8 to 15 m during the summer and 15 to 30 m during the fall. Parkhurst, et al. (SCCWRP, 1973) found that the currents above the thermocline traveled from the west 64% of the time and the currents below the thermocline were from the east 56% of the time, indicating the presence of an undercurrent. They found that the winter currents were less clearly defined than the summer currents.

Table 3-2

MEAN WIND AND CURRENT SPEEDS (m/see)

	Winter	Spring	Summer	Fall
Wind	2.0	2.0	3.5	3.0
Current				
1 m	0.20	0.10	0.25	0.20
3 m	0.20	0.10	0.25	0.20
8 m	0.20	0.10	0.20	0.20
15 m	0.18	0.10	0.20	0.20
30.5 m	0.15	0.10	0.15	0.15
46 m	0.15	0.05	0.15	0.15
61 m	0.18	0.05	0.10	0.13

From SCCWRP (1973).

The surface currents over San Pedro Channel are complicated. There is a boundary shear between the northwest flowing countercurrent and a southerly inshore current. Gorsline and Grant (1972) found the inshore current best developed during the fall and winter when they measured velocities of 20 to 100 cm/sec. The inshore current was much more restricted and compressed toward the shelf during the spring.

Current measurements off the Orange County sewage outfall showed that the predominant movement was to the east-southeast with a secondary direction of motion to the north-northwest (John Carollo Engineers, 1967) . The surface current is dominantly wind drift and the subsurface current is tidal. Similar results were found at San Onofre (Marine Advisers, 1965a, 1965b), Oceanside (Neste, Brudin and Stone Engineers) , and Point Loma (San Diego Marine Consultants, 1959; Gaul and Stewart, 1960; SCCWRP, 1973). The current velocities off San Onofre rarely exceeded 15 cm/see, and the surface currents off Point Loma have speeds of about 2% of the wind speed.

Current measurements over the San Clemente Island shelf show that the primary current directions are southeast and northwest parallel with the bottom contours (Naval Oceanographic Office, 1968). Velocities ranged from 0.0 to 25.0 cm/sec.

Hendricks and Harding (1974) used 10 m parachute drogues to measure currents off Point Loma (San Diego) at the surface and at a-depth of 39 m in May, 1972. South flowing surface currents of 15 to 71 cm/see, averaging 45 cm/see, were recorded (Fig. 3-14) . The deep drogue moved at speeds of 3.1 to 12 cm/see, averaging 7.3 cm/see, to the south. The wind blew O to 18 km/hr during the survey.

In general, the ocean currents over the mainland shelf are complex and variable. The surface currents respond to the wind, Ekman transport, and topography. The deeper currents respond to the tides and the undercurrents.

2.2.2 Upwelling. Physical models: Ascending motions of some duration and sizable extent in which the subsurface water is brought to the surface is called upwelling. This is usually caused by horizontal divergence of the surface water. The Southern California borderland lies in the eastern boundary current region of the northern hemisphere where the prevailing north to northwestern winds carry the surface water away from the coast and upwelling is particularly conspicuous. Upwelling also occurs at the heads of submarine canyons as a result of the tides.

The first physical explanation for the wind-generated upwelling is based on Ekman's Theory (1905), which was used by Sverdrup (1938) and Sverdrup and Fleming (1941) to quantitatively interpret the upwelling off Southern California. Hydrographic surveys off the Southern Californian coast in 1937 showed qualitative agreement with the proposed model. A well-defined boundary was located offshore with a current flowing parallel to the coast and hence with the prevailing wind.

Yoshida proposed a two-layer ocean model in which upwelling was considered as a transient boundary phenomenon (1955b) or a quasi-steady state phenomenon (1967) . The amount of upwelling was assumed to decay exponentially away from the shore. Such a model for the California waters would give the maximum speed of upwelling at the coast of about 5×10^{-3} cm/sec and the effective width of the coastal upwelling of about 20 to 100 km (1955b). Yoshida and Mao (1957) also used a two-layer ocean model and vorticity equation to show that if the meridional transport in the surface layer is negligible, then

$$\text{the rate of upwelling} = \frac{1}{\rho f}\left[\frac{\partial \tau_y}{\partial x} - \frac{\partial \tau_x}{\partial y}\right]$$

where τ_x and τ_y are the x and y components of the wind stress on the sea surface ρ is the density, and f is the Coriolis parameter. Observations off Southern California seemed to agree with this model. When the wind stress increases, the density at 150 m also increases, indicating the effect of upwelling.

Cairns and LaFond (1966) found that the seasonal depth of the shallow thermocline off San Diego is related to the wind stress with the following imperical relationship:

$$h' = 11 - 0.8\ W_{wnw}$$

where h′ is the depth in meters to the thermocline center, and W_{wnw} is the west-northwest component of the wind.

Upwelling is also associated with tidal currents in submarine canyons (see section 2.2.3) (Stevenson and Gorsline, 1956; Stevenson, 1958). Spring tides pump deep water up to the heads of submarine canyons. This upwelling is non-seasonal and recurs every two weeks. It is best observed during the summer when the thermocline is developed to its fullest.

Characteristics of upwelling: Since upwelling is the result of wind stress, it will be most marked when the winds become northerly or northwesterly. During spring and summer the North Pacific High dominates the atmospheric circulation (see Chapter 2), and causes north to northwesterly winds. In late fall and winter the North Pacific High becomes weakened and moves southward. The region of most intense upwelling also shifts with the seasons. Upwellings are strongest off Southern California in May and June. They are best developed during the spring to the south, off Baja California, and during the summer in the north, off Oregon. The effect of upwelling seems to be more pronounced at locations south of capes and points, e.g. , Point Mugu, Point Conception, Point Dume, Point Loma.

Upwellings generated by the tides are centered near the heads of shallow submarine canyons. Specific locations of upwelling, including those due to tidal currents which cause the formation of "cold spots", have been described in Santa Monica Bay, Pales Verdes, and Newport Beach (Fig. 3-l). They are developed at the surface and/or at shallow depths as cold water flows out the heads of submarine canyons. This upwelling is attributed to spring tidal currents in submarine canyons, and is most easily observed when the summer thermocline is present over the canyon heads (Arthur, 1954; Leipper, 1955; Allan Hancock Foundation, 1965). Stevenson (1958) found that the density currents, caused by the elevated position of the cold water, were initiated after a period of several hours if the wind did not exceed 16 km/hr. The sequence of "cold spot" development off Newport Beach is illustrated in Figure 3-15. Shifts in the "cold spot" position and depth is dependent upon the wind and current conditions.

Stevenson and Gorsline (1956) observed upwelling over the San Pedro shelf during a period of little wind and concluded that the upwelling was caused by internal tides. Some of the temperature inversions recorded over the Santa Monica shelf are probably also related to internal waves generated by the tides. Emery and Gunnerson (1970) conclude that internal tide-generated surf causes these inversions.

Airborne infrared radiometry studies in the Southern California Bight (Squire, 1971) show the presence of cold coastal water at Point Dume, Pales Verdes Peninsula, and Point Loma during the late spring and early summer, suggesting that these areas may be centers of upwelling.

Properties of the upwelling water: Upwelled water alters the normal pattern of physical and chemical properties. The water reaches the surface from depths of several hundred meters and is colder than the normal surface water. During the upwelling season the shallow isotherms ascend steeply and may even intersect the surface, and the surface isotherms run nearly parallel to the coastline (Lynn, 1967) . This results in a large horizontal temperature gradient.

Upwelling regions also have high salinities. The distribution of this high salinity water is further influenced by the circuitous flow of the Southern California Eddy (Lynn, 1967) . The combined effect of the ascending thermocline and halocline produces a very strong pycnocline (Smith, 1968) .

The dissolved oxygen content of the surface waters is near saturation due to direct exchange with the atmosphere and photosynthesis. In the periods of intense upwelling, the water of low oxygen content reaches the surface and it may remain below saturation for several days before it is- reaerated to the saturation level (Reid, Roden and Wyllie, 1958) . The concentration of plankton then decreases rapidly because after the newly upwelled water is at the surface for some time, most of its nutrients are consumed.

2.2.3 Currents in Submarine Canyons. Currents in submarine canyons on the continental borderland are important because the up-canyon currents cause upwelling and the down-canyon currents transport sediment away from the littoral zone into deep water. "Shepard and Dill (1966) observed that the currents in La Jolla Canyon changed from up-to-down canyon in direction during one saucer dive. They observed currents strong enough to move silt.

Many of the observed currents are tidal in nature, reversing in direction with periods of 20 minutes to more than 12 hours. Shepard and Marshall (1973) found the longer period tidal generated waves were more evident at depths of more than 250 m, and shorter period oscillations related to internal waves predominated in shallower water (Fig. 3-16) . The net motion is down-canyon in most of the canyons they studied, and they found no decrease in velocities with depth in the canyons (Table 2-3). Figure 3-17 shows the currents in Newport and La Jolla Canyons and their relationships to the tides.

Shepard and Marshall (1973) conclude that the peak down-canyon velocities are strong enough to transport sand. Inman (1970) recorded currents of over 180 cm/sec on two occasions in the head of Scripps Canyon. These currents were associated with strong onshore winds and large surf conditions. Reimnitz (1971) encountered currents of more than 100 cm/sec while diving in Rio Balsas Canyon off western Mexico during high wave conditions. These infrequent high velocity currents most certainly transport sediment down the canyons, and may be associated with surf beats.

Sediment layers on the canyon floors and deep-sea fans give evidence of infrequent strong bottom currents (see Chapter 1). Heezen and Ewing (1952) described a bottom current flowing down off the Grand Banks as a "turbidity current", or a cloud of turbid water. Such density currents could occur in the submarine canyons in the Southern California borderland, but none have been observed in the bight. (See Chapter 1 for the geological evidence of turbidity currents.)

Shepard and Dill (1966) describe scoured surfaces, sand falls, ripple marks and other features that give evidence of strong ocean currents on canyon bottoms other than turbidity currents. All currents that stir up bottom sediment can rework pollutants from the sediment into the water column.

2.3 Littoral Circulation

Littoral circulation is formed mainly from surface waves building up and breaking, and from variations in water level resulting from the tides. Shepard and Inman (1950, 1951) showed that the littoral circulation occurs in cells containing: (a) shoreward mass transport from waves carrying water through the breaker zone; (b) currents flowing parallel to the shore (longshore currents) inside the breakers; (c) seaward flow as concentrated rip currents; and (d) longshore movement of the expanding rip current head (Fig. 3-18). The size and location of these circulation cells is controlled by the wave size, the direction of the wave attack, and the nearshore bathymetry.

2.3.1 Longshore Currents. The momentum of a wave breaking at an angle on the beach has a component along the coast in the direction of the wave propagation. This generates longshore currents running parallel to the beach inside the breaker zone.

Table 3-3

CANYON CURRENT STATISTICS

Canyon Station	Canyon Location	Depth (Meter,)	Number Successful Lowerings	Mean Velocity	Highest Velocity cm/sec	% time > 18 cm/sec		Net Transport Meters/hr		Total Directional Plow in Minutes		% Time Direct Flow		Average Length ol flows" (Min.)	
						Up	Down	Up	Down	Up	Down	Up	Down	Up	Down
1	La Jolla	, 46	2	1.07	26	.003	0	33.7	0	4,290	3,530	54.9	45.1	65.6	53.5
6	La Jolla	78	2	0.60	17	0	0	26.5	0	5,860	4,260	57.9	42.1	76.0	60.0
5	La Jolla	167	8	1.12	29	. 017%	1.24%	0	37,1	20,810	24,090	46.4	S3.6	75.0	94.0
3	La Jolla	206	14	2.51	29	, 065%	3.23%	0	63.6	31,360	40,450	43,6	, 56.4	74.0	97.0
10	La Jolla	375	.2	2.08	22	1.29%	0.64%	0	15.8	5,840	6,709	46.5	53.5	216.0	247.0
9	Scripps	125	2	0.85	34	0.65%	1.58%	0	13.9	4,190	5,870	41.6	58.4	47.0	63.0
14	San Lucas	137	3	0.s5	17	0	0	0	29.4	2,850	5,540	33.9	66.1	12.0 I	23.0
13	San Lucas	216	1	0.44	9.5	0	0	0	13.6	1,770	2,890	28.6	71.4	18.18.0	28.0
15	San Lucas	328	2	3.70	33	0	6.20	0	123.1	2,870	7,190	, 39.0[	62.0	30.0	71.0
20	Newport	101	,	0.92	17	0	0	0	34.1	2,345	2,980	44.1	55.9	87.0	105.0
21	Newport	252	1	0 // 16	11// 5	0	0	0	0	1,010	1,530	39// 7	, 60// 2	168.0	255// 0
18	Redondo	92	2	1.97	27,0	.006	.011	0	34.2	8,275	12,112	41.5	58.5	87.4	114.9
19	Redondo	283	1	3.19	19.0	002	0	119.4	0	2,315	820	73.8	]26,2	231.0	91.0
11	Carmel	156	1	3.36	20.0	0	0.28%	0	113.9	2,500	4,580	35.3	64.6	71.0	117.0
					TOTALS	2,01	13.18	179.6	468.7	97,065	123,412			1,313.0	1,467.0
					AVERAGES	0.14	0.94	59.8	66.9	6,471	8,827	44.8	55.2	87.5	97.8

From Shepard and Marshall (1973).

The magnitude of the longshore current depends on the gradient of the breaker height along the beach and the angle between the breaker and the beach (Inman and Bagnold, 1963). Inman and Quinn (1952) measured longshore currents in the field and found that their velocities pulsate, increasing from zero on the side immediately downstream from a rip current to a maximum value just ahead of its seaward deflection into the next rip current. This distance ranges from 30 to 1,000 m and the maximum velocities are in the range of 150 to 250 cm/sec (Carsola, 1973).

The magnitude of the current is a function of the energy of the incoming waves. Longuet-Higgins (1970) demonstrated that the momentum of the incoming waves can be evaluated using the radiation stress. He showed that the mean longshore component of velocity is equal to:

$$\frac{5s \quad U_{max} \sin \theta}{8c}$$

where s is the local beach slope, θ is the angle of incidence, and u_{max} is the maximum particle velocity in the waves. He assumed that the friction coefficient, c, is constant and that lateral mixing is not important. Galvin and Eagleson (1965) found that the velocity also depends on the distance from the shoreline. The maximum velocities occur about halfway between the mean shoreline and breaker line.

Seasonal changes in the wind and wave directions result in reversals in the longshore currents during the year in Southern California (see section 3.1). Sea and swell from the west and northwest cause easterly to southeasterly flowing littoral currents during the summer. The southerly swell results in north to northwest flowing longshore currents usually in the late summer and fall. The southerly swell is normally longer in period, and it therefore disturbs the bottom to greater depths.

Inman and Frauschy (1966) showed that the Southern California Bight contains three littoral drift compartments .(Fig. 3-19) . The compartments end at rocky headlands and sediment is lost to the littoral zone in submarine canyons located near the southern ends of the compartments. The Santa Monica compartment extends from the Santa Monica Mountains to Pales Verdes Peninsula. Beer and Gorsline (1971) measured the transport of sediment in the bottom water of Redondo Canyon near the southern border of the compartment. The San Pedro compartment is located between Pales Verdes Peninsula and Newport. Newport Canyon, located at the southern end of the compartment, is not receiving sand from the surf zone (Felix and Gorsline, 1971). The sediment apparently is being deposited on the outer shelf north of the canyon. The Oceanside compartment extends from Dana Point to La Jolla, and sand is being lost from the longshore current into the head of La Jolla Canyon.

Man-made structures such as groins, piers, oil towers, and jetties interfere with the longshore currents and, the complex current patterns that result cause coastal erosion or sedimentation.

A summary of the amount of sediment transported by longshore currents in the Southern California Bight is presented in Table 3-4.

Table 3-4

SUMMARY OF MEASURED RATES OF LITTORAL DRIFT ALONG THE CALIFORNIA COAST

Location	Predominant Direction of Drift	Rate of Drift (CU. yds. per year)	Method of Measuring Rate of Drift	Years of Record
Santa Barbara	East	280,000	Accretion	1932-1951
Oxnard Plainshore	South	1,000,000	Accretion	1938-1948
Port Hueneme	South	500,000	Accretion	1938-1948
Santa Monica	South	270,000	Accretion	1936-1940
El Segundo	South	162,000	Accretion	1936-1940
Redondo Beach	South	30,000	Accretion	---
Anaheim Bay	East	150,000	Erosion	1937-1948
Camp Pendleton	South	100,000	Accretion	1950-1952

From Johnson and Eagleson (1966).

Wave action has resulted in erosion at Pacific Palisades, Pa-10S Verdes, Anaheim Bay, Newport Beach and Doheny State Beach.

2.3.2 Rip Currents. Rip currents are strong, narrow currents that flow seaward through the breaker zone (Fig. 3-18). They result from the onshore transport of water by waves in the surf zone, its accumulation and longshore transport, and finally its flow back through the breaker zone. Individual rip currents are 10 to 30 m wide and attain velocities of 90 cm/sec (Cook, 1970) to 150 cm/sec (Carsola, 1973) . The current ends in an eddy that drifts with the coastal current.

Shepard and Inman (1950, 1951) demonstrated that rip currents form an integral part of the nearshore circulation cells (Fig. 3-18) . They form at points of convergence of longshore currents. Bowan and Inman (1969) found that waves incident on the beach generate standing edge waves and that the interaction of the incident and the edge waves gives rise to the cell dimensions. The rip currents occur at alternate antinodes of the edge wave, and their spacing is a function of the edge wave length.

The largest rip currents are formed during periods of intense wave activity. Cook (1970) concluded that the optimum conditions for currents are: (1) large, long period waves; (2) exposed, relatively flat foreshore; (3) established rip channels 1 to 3 m deep; and (4) negligible breeze. Shepard and Inman (1950) found that the rip currents off La Jolla had pulsating velocities passing through the small wave groups that followed the large waves.

Rip currents occur along most portions of the coast in the Southern California Bight. They are important in the offshore transport of sediment in the surf zone (see Chapter 1) .

3. Waves and Tides

3.1 Wind Waves

Waves are formed by wind that occurs far out to sea (swell) and by local wind (sea) . Swell comes to the Southern California Bight from storms in the Aleutians, the Hawaiian area, the western North Pacific typhoon region, the tropical storms west of Mexico, and the pressure gradient around the Pacific High pressure cell in the North Pacific, as well as from the New Zealand area and the high latitude region of the South Pacific (Marine Advisers, 1961). The swell derived from the northern hemisphere storms approaches the coast from the west in contrast with the southern hemisphere swell which comes in from the south and the southwest.

Swell from the northern hemisphere predominates during the winter and spring when the storm systems are more intense. Southerly swells occur during the summer and fall when hurricanes off southern Mexico and extratropical storms are present in the southern hemisphere. The characteristic nature of the swell in terms of size, frequency and origin are summarized in Table 3-5.

The wind waves formed locally come from the northwest, west, southwest and south (Marine Advisers, 1961) . They respond to northwest winds from the Pacific High pressure regions, winds of the Santa Catalina Eddy, and the offshore Santa Ana winds. The largest sea waves occur when cyclonic and tropical storms approach the Southern California coast. The average maximum wave heights are 3 to 5 m. Emery (1960) notes the occasional occurrence of 6 to 8 m high waves.

Table 3-5

SWELL IN SOUTHERN CALIFORNIA BIGHT

Area of Generation	Frequency	Height	Period	Direction
Southern Gulf of Alaska	2-3 times a month in winter; 1-2 times in summer	1-1.5 m	13 sec.	280°-3300
Northern Boundary Pacific High	Once a month in winter; less in summer	1-1.5 m	10-12 sec.	225°-2800
Hawaiian Lows	Once a month; irregular distribution	1-2 m	12-15 sec.	225°-2800
Southern Hemisphere	2-3 times a month in summer	1-1.5 m	13-20 sec.	180°-2250
Tropical Hurricanes	Once a year	1-1.5 m	9-11 sec.	180°-2250
Cold Front Passages	2-4 times a month in winter	1-2 m	5-9 sec.	270°-2800
Coastal Lows	Infrequent	1 m	8-10 sec.	225°-2700
Thermal Lows	Frequent and constant in summer	1-1.5 m	6-9 sec.	280°-3000

From Stevenson (1959).

The Southern California coast is partially protected from wave attack by the offshore islands and the coastal headlands (Fig. 3-20). Swell can strike the coast between Point Dume and Pales Verdes unhindered from azimuths of 240° to 270° and 180° to 200°. The Long Beach to Newport Beach coast receives swell from 260° to 280° and 180° to 200°. Only southerly swell arrives unaffected along the coast between Newport Beach and Oceanside. The San Diego coast is most exposed receiving waves from 190° to 280°.

Jen (1969) studied the wave refraction patterns near San Diego Bay. The only windows of wave access to the bay are from the south between Santa Catalina Island and the mainland coast and from the west between San Nicolas and Santa Rosa Islands. The west window is filtered such that it receives only waves with periods of less than 30 sec. The south window is accessible to all waves, except for waves from the southeast with periods of more than 30 sec. (Fig. 3-20).

Despite the modifying influences on the waves approaching San Pedro, Gorsline and Grant (1972) found that wave convergence zones occur over the shelf and that waves disturb the bottom out to depths of 100 m. A 2 m high, 620 m long wave has particle velocities of 40 cm/sec in 50 m of water and 25 cm/sec in 100 m.

Marine Advisers (1961) and Timme (1973) have compiled statistical data on wave frequencies, directions, and size off Southern California. These data can be applied to any segment of the coast to determine the engineering criteria necessary there.

3.2 Tsunamis

Tsunamis, also called seismic sea waves and tidal waves, are produced by volume displacements of the ocean floor, usually associated with earthquakes or sea floor slides. They are long, low, shallow water waves that sometimes build up to heights of more than 15 m at the shore. The Pacific Ocean is frequented by tsunamis, and many island groups and mainland coastal zones have been badly damaged by these waves. The 1964 Alaskan earthquake produced a large tsunami that did extensive damage as far south as Crescent City, California.

No large tsunamis have been recorded in the Southern California area. This portion of the coast is less susceptible to large tsunamis than other coastal zones because of the wave refraction over the basin and ridge bathymetry of the borderland (VanDorn, 1965). Figure 3-21 is a computer simulation of the 1964 Alaskan tsunami (Chen, 1973). The wave moved parallel with the coastline minimizing the impact.

Tide gauge records following the tsunami generated by the Alaska earthquake are presented in Figures 3-22 and 3-23 (Cox, 1972). The initial wave had a height of less than one meter. Oscillations continued to arrive for several days; some of the waves measured 1 to 10 hours after the first pulse were actually of greater height than the initial wave. These low-frequency, tsunami-induced oscillations caused strong and unusual currents within the bays and harbors.

Los Angeles-Long Beach Harbor can receive only direct, unfiltered tsunamis from the south (Jen, 1969). Wilson (1971) studied the power spectra of tsunamis registered in the harbor and compared them with theoretical resonant nodes of oscillation of the continental shelf. The data is shown in Table 3-6.

Table 3-6

THEORETICAL AND OBSERVED OSCILLATION PERIODS IN LOS ANGELES-LONG BEACH HARBOR

					Time in Minutes				
Theoretical			75		38	25			
Chilean, 1922			65.4	49.2	40.8	31.2		22	17
Aleutian, 1946			60						
Chilean, 1960	138-150		56	50	40	34.2-33.2	26.2	21.4	19
Alaskan, 1964		102	60		40-37.8	32.4-31.2			

From Wilson (1971).

From this data he concludes that harbor oscillations are related to the resonant oscillations on the shelf. The differences between the oscillations produced by the Alaskan and Chilean tsunamis indicate that there is a directional difference. This probably relates to the bathymetry and the wave windows. The 1946 Aleutian tsunami had less energy and for this reason lacked the long period oscillations.

A model study of wave intrusion into San Diego Harbor was conducted for waves with periods of 40 to 186 seconds and deep water heights of 4 to 13 m (Whalin et al., 1970) .

These waves are similar to those that might be generated by a nearshore earthquake or ocean bottom slide. They found that Silver Strand, Coronado and portions of North Island would be completely inundated. Waves of up to 9 m would enter the harbor entrance, and strong currents (up to 3.1 m/see) would result from water passing over the spit and entering the harbor. Oscillations, reflections, rip currents and bores were observed in the model.

Small waves from a Japanese tsunami in March, 1952, were recorded at La Jolla and oceanside (Munk, 1953) . The largest waves had periods of about 30 minutes and amplitudes of 2 to 5 cm. The amplitudes were much smaller than would be predicted from Hawaiian records. This may be explained by reflection from the mainland shelf.

Low frequency waves related to the 1960 Chilean earthquake were recorded for a week at La Jolla (Miller, Munk and Snodgrass, 1962). The wave energy diminished at a rate of l/e per half day, and the higher frequencies decayed at the highest rate.

The tsunamis that have arrived in Southern California in 1855, 1872, 1885, 1927, 1946, 1957, 1960 and 1964 have all been small. Damage of about $175,000 to $275,000 was done in Los Angeles Harbor as a result of the 1964 tsunami. This was the result of the strong currents and not the wave heights.

Tsunamis could be created along faults in the Southern California borderland (see Chapter 1). However, no tsunamis have been formed by local earthquakes during historical times.

3.3 Internal Waves

Internal waves form along density discontinuities within the water column. They are most easily recorded in the thermocline by measuring vertical oscillations of the temperature with time at a point. Internal waves have elliptical, orbital motion similar to surface waves, but they differ in having slower phase velocities, larger wave heights and dominant components that correspond to the tidal periods and the wind stress (SCCWRP, 1973). Fmery (1960) describes internal waves with periods of 9 to 236 minutes, wave lengths of 97 to 343 m, speeds of 3 to 16 cm/see, and average heights of 1.5 to 5 m. Periods of as little as 1.35 minutes (Carsola and Callaway, 1962) and as much as one year (Cairns and LaFond, 1966) have been recorded. Short period waves, 10 minutes, have observed heights of up to 9 m (Armstrong and LaFond, 1966) and tidally generated waves of more than 15 m.

Many of the internal waves that have been measured are generated by internal tides. Observations at the U.S. Navy tower located off San Diego show periodic oscillations in the vertical thermal gradient with periods of approximately 6, 8, 12 and 24 hours. Cairns (1968) concludes that these waves are related to internal tides. Figure 3-24 shows the relationship between the surface and the internal tides during May, 1965. The internal tides lag behind the surface tide by 3 to 5 hours and average 4 to 5 times as great in amplitude (Cairns and LaFond, 1966).

Flood and ebb currents associated with internal tides occur in submarine canyons at depths of more than 250 m (Shepard and Marshall, 1973). Figure 3-16 shows the strong semidiurnal current oscillations in La Jolla and Newport Canyons.

Emery and Gunnerson (1970) measured internal waves of tidal periods over the Santa Monica shelf. These waves have velocities of 13 km\hr in deep water, decreasing in speed to less than 2 km/hr across the shelf. The decrease in speed is accompanied by an increase in height and finally an internal surf develops causing temperature inversions and a complicated pattern of short wave length internal oscillations.

Internal waves with periods much shorter than the tides also are present. Cairns and LaFond (1966) measured waves with average velocities of 0.5 km/hr, heights of 1.7 m and periods of 1.7 minutes. Oscillations with periods as short as 20 minutes have been recorded in the heads of submarine canyons (Shepard and Marshall, 1973) .

Cairns and LaFond (1966) recorded wind generated internal waves with a diurnal oscillation, a 4-1/2 day oscillation, and a seasonal oscillation related with the summer upwelling. The diurnal waves crest at about 0600 hours and trough at 1800 hours off San Diego, and are caused by diurnal wind variations; The 4-1/2 day period is associated with a north-south wind-velocity components oscillation of 3.8 days and a mean range of about 24 to 17 km/hr. The seasonal oscillation crests during the summer and has a broad trough during the winter (Fig. 3-25). It results from seasonal reversals in Ekman transport direction resulting from seasonal changes in wind directions (see section 2.2.2) . Cairns and LaFond (1966) found that there is a 14- to 16-hour difference between the initiation of the wind and motion in the thermocline.

The distribution and characteristics of internal waves in

Southern California are important with respect to vertical mixing in the surface water and the seasonal thermocline. Much more work needs to be done to define the wave systems in this area accurately.

3.4 Tides

Southern California is marked by mixed semidiurnal tides that move from southeast to the northwest. High tide takes 30 minutes to travel from San Diego to Point Conception (Jones, 1971). The diurnal tidal range varies from 1 to 3 m. The spring tides are more semidiurnal than the neap tides, and the equinox has more highly semidiurnal tides than the solstice. The relative times of arrival and the mean tidal ranges at the tidal stations located in Southern California are given in Table 3-7.

Official sea level is taken at mean lower low tide.

The wind driven currents mask the tidal currents down to depths of 10 to 15 m over the mainland shelf (Gaul and Stewart, 1960). Below this depth the tidal currents at any point rotate in different directions with time, completing 360° in 12.5 to 25 hours depending on the relative strength of the main tidal components (Jones, 1971). Particle velocities associated with the tides are about 20 cm/sec.

Tides observed in submarine canyons are discussed in the section on currents in submarine canyons. Alternating flood and ebb currents flow up and down the canyons in the Southern California Bight (Fig. 3-16). The ebb tide is larger than the flood in most canyons (Shepard and Marshall, 1973).

Internal tides measured in the shallow thermocline have 4 to 5 times the amplitude of the coastal tides and lag 3 to 5 hours behind the surface tides. Internal tides are described in section 3.3.

3.5 Other Waves

Edge waves, surf beats, seiches and other shelf waves are grouped in this section.

Edge waves are standing waves formed nearshore and parallel with the beach (Munk, Snodgrass and Carrier, 1956). These waves are highest at the beach and diminish offshore to one wavelength where they are negligible. Atmospheric pressure and wind variations cause edge waves of 1 to 5 cm in height. Bowan and Inman (1969) measured edge waves that were formed by wind waves in the surf zone. These waves control the

Table 3-7

TIDES IN SOUTHERN CALIFORNIA

Place	Position		Differences				Ranges		Mean Tide Level
			Time		Height				
	Lat. (N)	Long. (W)	High Water h. m.	Low Water h. m.	High Water feet	Low Water Feet	Mean feet	Spring feet	feet
Point Loma	32°40′	117″14′	-0 12	-0 06	*0.92	*0.92	3.7	5.3	2.8
San Diego, Quarantine Station	32°42′	117″14′	-0 07	-0 02	*0.96	*0. 96	3.9	5.6	2.9
San Diego (Broadway)	32°43′	117°10′	Daily predictions				4.1	5.7	3.0
National City, San Diego Bay	32°40′	117″07′	+0 01	+0 06	+0.2	0.0	4.3	5.9	3.0
Mission Bay entrance (inside)	32°45′	117″15′	+0 38	+0 35	*0.74	*0.74	3.0	4.4	2.2
Mission Bay Causeway	32°46′	117°14′	+1 09	+0 50	*0.74	*0.74	3.0	4.4	2.2
La Jolla (Scripps Institution Wharf)	32°52′	117″15′	-0 03	-0 04	*0.90	*0.90	3.6	5.2	2.7
San Clemente	33°25′	117″37′	-0 18	-0 15	*0.92	*0.92	3.7	5.3	2.7
Corona del Mar, Newport Bay	33°36′	117″53′	-0 05	-0 01	*0.97	*0.97	3.7	5.3	2.8
Balboa (Ocean Pier)	33°36′	117°54′	-0 05	-0 10	*0.98	*0.98	3.7	5.3	2.7
Santa Ana River entrance (inside)	33°38′	117″57′	+0 22	+1 45	*0.55	*0. 22	2.4	3.3	1.4
Los Pates (highway bridge)	33″43′	118°03′	+0 59	+1 10	*0.85	*0.67	3.4	4.7	2.3
Long Beach, Outer Harbor, Pier A	33″46′	118°12′	+0 02	+0 06	*0.98	*0.98	3.7	5.3	2.7
Long Beach, Inner Harbor	33°46′	118°13′	+0 03	+0 03	*0.98	*0.98	3.7	5.3	2.7
Los Angeles, Outer Harbor	33″43′	118″16′	Daily predictions				3.8	5.4	2.8
Los Angeles Harbor, Mormon Island	33″45′	118°16′	+0 03	0 00	0.0	0.0	3.8	5.4	2.8
El Segundo, Santa Monica Bay	33°55′	118°26′	+0 12	+0 11	*0.98	*0.98	3.7	5.3	2.7
Santa Monica	34″00′	118°30′	+0 01	+0 05	-0.1	0.0	3.7	5.4	2.8

* Ratio.

From U.S. Department of Commerce (1969).

size of the nearshore circulation cells.

Ocean waves, with frequencies between 0.2 and 10 cycles per hour, were measured at La Jolla and San Clemente Island, 100 km offshore (Snodgrass, Munk and Miller, 1962). Waves with frequencies of less than 0.7 c/hr, periods of more than 14 hours, occur at both stations and are coherent and in phase. Those having shorter periods are not coherent or in phase between La Jolla and the island. There is a distinct phase reversal which suggests the presence of standing waves. The failure of the reversed wave to be coherent suggests that there are multiple modes. That is, some of the energy is still associated with the in-phase modes after most of the energy has been reversed and is out of phase. Some of these waves appear to be trapped shelf waves.

Surf beats are formed by the energy distribution in the surface wave sets. They have periods of 2 to 5 minutes (Munk, Snodgrass and Carrier, 1956); they are not edge waves. Waves of longer periods, 10 to 30 minutes, do agree with the edge wave theory. These waves may be caused by abrupt weather changes.

Seiches are standing waves produced in enclosed bodies of water by the wind or by resonance of progressive waves. A steady wind blowing in one direction will pile up water on one side of the enclosure. The seiche is formed when the wind stops. The dimensional characteristics of the seiche depend on the depth and length of the water body. They are significant in large harbors such as Los Angeles-Long Beach and San Diego. The U.S. Army Corps of Engineers have conducted studies of seiches, and surging currents associated with them in the deep water harbors. Emery (1960) states that the maximum seiche amplitudes in Los Angeles Harbor are about 11 cm.

Oscillations are also produced by long waves such as tsunamis entering semi-enclosed bodies of water. These standing waves are discussed in section 3.2.

4. Water Characteristics

The water in the Southern California Bight region of the California offshore is a mixture of relatively low temperature-low salinity water transported south in the California Current with higher temperature-higher salinity water brought north in the California Undercurrent (Figs. 3-2 and 3-3). The California Current water dominates in the upper few hundred meters of the ocean seaward (west) of the borderland. The undercurrent is predominant below 500 m and the 200 to 500 m depth range is a zone of mixed water (Emery, 1960; Sverdrup and Fleming, 1941). The Southern California Eddy mixes northern with southern surface water, and modified surface water occurs over much of the borderland. Local climatic conditions further modify the surface water characteristics.

4.1 Water Temperature

The ocean surface water temperature ranges from 12.5°C in the north to 19.5°C in the south (Emery, 1960), and the surface is coldest in the winter, December to February, and warmest in the months of August and September (Emery, 1960; Reid, 1965). Above normal sea surface temperatures occur in the Southern California Eddy as a result of the local climate (SCCWRP, 1973). Temperature data obtained over a large number of years from Balboa Pier, Newport and Scripps Pier, La Jolla show that the sea surface temperature varies no more than 2°C above or below monthly average temperatures (Jones, 1971).

Diurnal and seasonal temperature changes are noticeable to depths of 10 to 50 m. A thermocline of 3°C to 7°C is present in this depth zone (Fig. 3-26). The Allan Hancock Foundation (1965) recorded temperatures of 10° to 15°C at 60 m below the surface. SCCWRP (1973) observed that this shallow thermocline is better developed during the summer, probably because of the warm climatic conditions.

Heat exchange at the ocean surface in the Southern California Bight is mainly the result of radiation and advection with the atmosphere (Roden, 1959). Short wave radiation arrives from the sun at a rate of about 400 cal/cm²/day. Back radiation takes place at an average rate of about 120 cal/cm²/day, and the sensible heat exchange is approximately 150 cal/cm²/day of loss to the' ocean. Convection amounts to less than 10% of the sensible heat. The ocean gains heat during the months between July and September and losses heat between November and January (Roden, 1959).

Cairns and Nelson (1970) measured the shallow seasonal thermocline gradients off San Diego. The gradients averaged 0.33°C/m during the period between late April and early September. A maximum of 1.27°C/m in late June was observed. The smallest vertical temperature gradients occur between late November and early March when the average is about 0.15°C/m. Figure 3-25 shows the seasonal shift in the thermocline. The larger summer thermocline results from surface heating and upwelling.

The shallow seasonal thermocline oscillates greatly as a result of internal waves and tides. These oscillations are discussed in section 3.3.

A small, permanent thermocline is developed at depths between 200 and 500 m where the northern and southern waters mix. The temperature drops from between 8° to 9°C at 200 m to between 5.5° and 6.2°C at 500 m. This thermocline is better developed where warm southern water predominates in the surface layer.

Below the thermocline the water temperature decreases slightly with depth. Emery (1960) found that the borderland basins are isothermal below the sill depth (see Chapter 4, Fig. 4-11). The basin temperatures are the same as the undercurrent temperatures at depths that are slightly less than the sill. The temperatures, depths, salinities and basin data are presented in Table 3-8.

Table 3-8

TEMPERATURE AND SALINITY OF BASIN WATERS

Basin	Temperature (°C)	Salinity (°/00)	Bottom	Sill	Effect. Sill
Santa Barbara	6.26	34.25	627	475	510
San Pedro	5.06	34.29	912	737	750
Santa Monica	5.05	34.31	938	737	750
Santa Catalina	4.02	34.42	1357	982	1010
Santa Cruz	4.15	34.52	1966	1085	980
San Nicolas	3.71	34.52	1833	1106	1100
Tanner	3.85	34.56	1551	1165	1060
West Cortes	3.37		1796	1362	
East Cortes	3.13	34.52	1979	1415	1370
No Name	2.9?		1915	1553	
Long	2.7?		1938	1697	
San Clemente	2.60	34.56	2107	1816	1750
Velero	2.52	34.58	2571	1902	1700

From Emery (1960).

4.2 Salinity

Variations in the salinity of the water in the Southern California Bight are small, ranging from 33.5 °/00 to 34.5 °/00. Figure 3-27 shows the vertical distribution of salinities, and Figure 4-26 (see Chapter 4) shows a profile of salinity across the borderland. The mainland shelf is frequently isohaline below 15 m (SCCWRP, 1973). The surface water is more saline during the summer and autumn than in the winter and spring (Allan Hancock Foundation, 1965) . This results from the greater amount of rain during the winter and increased evaporation during the summer (SCCWRP, 1973) .

The salinities in the mixed zone, 200 to 500 m deep, are intermediate betweenothe northern water which increases in salinity from 33.85 /oo at 200 m to 34.22 O/oo at 500 m, and the southern water which is almost isohaline at 34.3 °/00 to 34.4 °/00. The maximum halocline is developed under the California Current. The deep water below 1,000 m has salinity values of 34.5 °/oo to 34.6 °/oo; the water column is almost isohaline (Allan Hancock Foundation, 1965).

4.3 Density and Salinity

The stability of a column of water is the amount of work energy necessary to move water vertically. The greater the rate of increasing density with depth the more the stability and the less likely the sinking and rising of water.

The densities of sea surface water at tide stations in harbors are given in Table 3-9.

Table 3-9

MEAN MONTHLY σ_t VALUES AT COASTAL TIDE STATIONS

Station	J	F	M	A	M	J	J	A	S	O	N	D	All Year
San Diego	24.6	24.6	24.7	24.8	25.0	25.1	25.3	25.2	25.1	24.8	24.9	24.7	24.9
La Jolla	24.9	24.8	24.8	24.9	24.9	25.0	25.0	25.0	24.9	24.9	24.9	24.9	24.9
Balboa	24.8	24.8	24.8	24.9	24.9	25.0	25.0	25.0	24.9	24.9	24.9	24.9	24.9
Los Angeles	24.6	24.6	24.7	24.9	25.0	25.0	25.0	25.0	25.0	24.9	24.9	24.9	24.9
Santa Monica	24.8	24.7	24.8	25.0	25.0	25.1	25.1	25.0	25.0	24.9	24.9	24.8	24.9

From U.S. Coast and Geodetic Survey (1957).

The minimum densities occur during winter as a result of rain and run off, and the highest densities in the summer in response to evaporation. The mean density is 1.0249 g/cm^3 for all stations, and the variations are $\pm$0.0004 g/cm^3.

The water column is stable at all levels in the open ocean off Southern California (Fig. 3-28) as the density increases from a minimum of 1.0242 g/cm^3 at the surface to more than 1.0276 g/cm^3 below 1,700 m. The maximum stability occurs in the depth range of 0 to 200 m during the warm summer months (SCCWRP, 1973). The water is also stable below 200 m but the rate of change of density decreases in the deeper water.

Muromtsev (1958) analyzed the seasonal density distribution in the California Current region. σ_t fluctuations of up to 1.08 are recorded. Table 3-9 shows the density extremes in the upper 100 m of water.

Table 3-10

DENSITY VARIATIONS IN THE CALIFORNIA CURRENT

Depth (m)	Maximum (σ_t)	Minimum (σ_t)	Difference (σ_t)
0	24.97	23.89	1.08
25	25.23	24.67	0.54
50	25.62	25.22	0.41
100	26.27	25.90	0.37
150	26.60	26.24	0.36
200	26.70	26.41	0.29
300	26.74	26.66	0.08
400	26.90	26.81	0.09
500	27.03	26.96	0.07

From Muromtsev (1958).

The density fluctuations are maximum in the upper 25 m (Fig. 3-28). The maximum densities occur in the winter and the minimum densities were encountered during the late spring (Muromtsev, 1958). Density maximums occur in the summer and minimums in the winter in the 25 to 200 m depth range. The density lows are caused by the influx of southern water in the undercurrent, and the summer high density is related to upwelling and advection. The September density maximum is caused by relatively high salinities. Only small density fluctuations occur below 200 m.

Seasonal shifts occur in the pycnocline. It is smallest in the winter when the air cools the ocean surface, and highest, 0.05 σ_t/m, in July. the pycnocline in the 25 to 100 m depth range is smallest in late spring and early, summer due to upwelling. Below 100 m the pycnocline is less than 0.01 σ_t/m. The depth of maximum pycnocline development is 30 to 70 m below the surface. It is deepest during the winter.

The Allan Hancock Foundation (1965) used the rate of change of σ_t with respect to depth to calculate the vertical stability of the water over the mainland shelf. Maximum stability values ranged from 10 to 105 g/cm^3/m x 10^3. The greatest stability occurs during the late summer and the least stability in the winter.

The water enclosed below the sill depths in the borderland basins is isothermal and isohaline (Table 3-8). Density increases only slightly with depth as a result of pressure. The water columns in these basins are almost neutrally stable and therefore large scale vertical mixing may occur below the sill depth.

4.4 Turbidity

The clarity of ocean water is important in planktonic productivity and distribution. SCCWRP (1973) found Secchi disc risibilities of 2 to 5 m. The poorest transparencies occurred close to shore and during the spring especially off Santa Monica Bay and the coast south of San Pedro. Extinction coefficients range from 0.08 to 0.40 per meter (SCCWRP, 1973).

Light transmission measurements made by the California Water Quality Control Board (1965) showed that on most occasions the light transmission curve below a depth of one meter was linear. The greatest deviations from this linearity occur where the water is turbid, generally in the upper 1 to 3 m. Eighty-three percent of the light entering the ocean was lost in the upper 1.4 m of water. Extinction coefficients range from 0.05 to 0.60 per meter corresponding to the range between clear open ocean water and turbid water off the Mississippi River Delta. Representative light transmission rates are shown in Figure 3-29. All four locations have the same transmission rate down to about a depth of 2 m. Below this depth there are large variations in light transmission between the locations. Station A was located near the Ventura River in turbid water and has the highest extinction rate as a result.

North (1962) found the poorest light penetration over the San Pedro shelf, near San Clemente and Del Mar, and south of Point Loma. The most turbidity occurs nearshore off aluvial plains and near sewage outfalls. The greatest clarity occurs far offshore. Some normally clear water areas are periodically turbid due to plankton blooms.

The effect of a sewage outfall on the transparency is illustrated by the data in Table 3-11. The light penetration of all colors is poorer off the Santa Barbara outfall than at Gaviota where there is no outfall. Green and blue have greater penetration than red and orange at both stations.

The presence of kelp beds also reduce the light transmission as is shown in Table 3-12. The light under the kelp is only 20% to 50% of that in open water at the same depth. The penetration is better over sandy bottoms than over muddy bottoms.

Chan presents a comprehensive section on the composition and distribution of suspended particulate matter in Chapter 4. The turbidity consists of inorganic mineral material and organic material consisting of plankton and organic detritus. This turbidity comes from river floods, waves on coasts, plankton blooms, benthic plants and sewage outfalls. The distribution of suspended matter is illustrated in Figures 4-23, 4-24 and 4-25. Most of the particulate material is suspended at the top of the pycnocline and just above the bottom (Drake and Gorsline, 1973).

The accumulation of particulate matter in and above the thermocline is illustrated in Figure 3-30 (Armstrong and LaFond, 1966). this accumulation may be the result of the density increase in the water trapping the low density organic material. Patches of lower transparency are probably caused by convergent circulation of internal waves. Beer and Gorsline (1971) found that a high percentage of the suspended sediment floats at the surface as a result of the high surface tension of water. The surface sediment is transported by wind drift; the sediment on the pycnocline is moved by coastal currents and internal waves; and the near bottom sediment is carried by near bottom currents. Tidal currents transport the near bottom sediments in submarine canyons.

5. Historical Oceanographic Changes

Robinson (1965) compared 19th century sea surface temperatures in the Pacific Ocean with present day temperatures and concluded that today's temperatures are higher. No long-term temperature changes have been observed in the last 40 years at shore stations in Southern California (Jones, 1971) .

Analysis of the temperature and salinity in the California Current over a 13-year period shows a warm tongue-like projection of water in the Southern California Bight that has a standard deviation of $+1.5^{\circ}C$ to $+2.0^{\circ}C$ from the mean and

Table 3-11

LIGHT ATTENUATION MEASUREMENTS AT SANTA BARBARA AND AT A CONTROL STATION AT GAVIOTA

Location	Red	Orange	Green	Blue	Date (1960-61)
Santa Barbara	0.00062	0.0018	0.011	0.0031	9/14
Santa Barbara	<0.0015	0.0041	0.0064	0.0022	9/29
Santa Barbara	< 0.0013	0.0074	0.062	0.020	10/12
Santa Barbara	<0.0042	<0.00029	<0.0071	<0.0051	10/27
Santa Barbara	<0.0055	0.0081	<0.013	<0.013	11/17
Santa Barbara	<0.0013	0.00049	0.0015	<0.0030	1/11
Average*	0.00062	0.0044	0.020	0.008	
Gaviota	0.0091	0.055	0.16	0.087	9/15
Gaviota	0.0064	0.14	0.20	0.11	9/30
Gaviota	0.0052	0.031	0.073	0.076	10/13
Gaviota	0.0032	0.0109	0.069	0.036	10/28
Gaviota	0.0088	0.0050	0.33	0.270	11/18
Gaviota	0.0013	0.0040	0.048	0.018	1/12
Average	0.0057	0.04	0.15	0.10	

*Excluding all values where water opacity was so great that no bottom reading was obtained.

Values represent the fraction of the surface light reaching a horizontally oriented photocell at the bottom. Depths were 10 m at both stations.

From North (1962).

Table 3-12

VALUES OF GREEN RADIANT ENERGY MEASURED AT VARIOUS LOCATIONS
DURING THE FINAL WEEK OF MARCH, 1958

Date	Location	Time	Sky Condition	Depth (ft.)	Green Radiant Energy Ergs/cm^2/see	Remarks
3/24/58	Central Point Loma	Midmorning	Clear	66	1600	Under kelp canopy
3/24/58	Central Point Loma	Noon	Clear	36	2000	Under kelp canopy
3/24/58	Central Point Loma	Noon	Clear	36	8700	Same location as previous reading but not under canopy
3/24/58	Entrance to San Diego Bay	Midafternoon	Clear	27	2400	
3/25/58	1 mile N. of S10	Midafternoon	Cloudy	70	6300	Sandy bottom
3/25/58	La Jolla Kelp Bed	Midafternoon	Cloudy	60	0	Very turbid water
3/26/58	Santa Barbara Kelp Bed near Outfall	Midafternoon	Scattered clouds	40	700	Very turbid water
3/27/58	Whites Point	Midafternoon	Scattered clouds	25	7800	
3/28/58	Pales Verdes Flat Rock Point	Noon	Clear	25	3500	Under canopy
3/31/58	North Point Loma	Midmorning	Scattered clouds	70	2300	Under canopy

From North (1962).

a uniform salinity of 33.55 $^o/oo$ that has a standard deviation of only ± 0.15 $^o/oo$ (Lynn, 1967). No long-term trends were discovered; seasonally the minimum temperatures and salinities occur in February and March and the maximum values between June and September.

Models of the dispersion of conservative materials (SCCWRP, 1973; Hendricks and Young, 1974a) have been constructed by the Southern California Coastal Water Research Project. Hendricks and Young (1974) noted that simple diffusion models only hold for a unidirectional flow pattern. Current measurements are necessary at all depths for at least a year to determine the distribution pattern at any one location.

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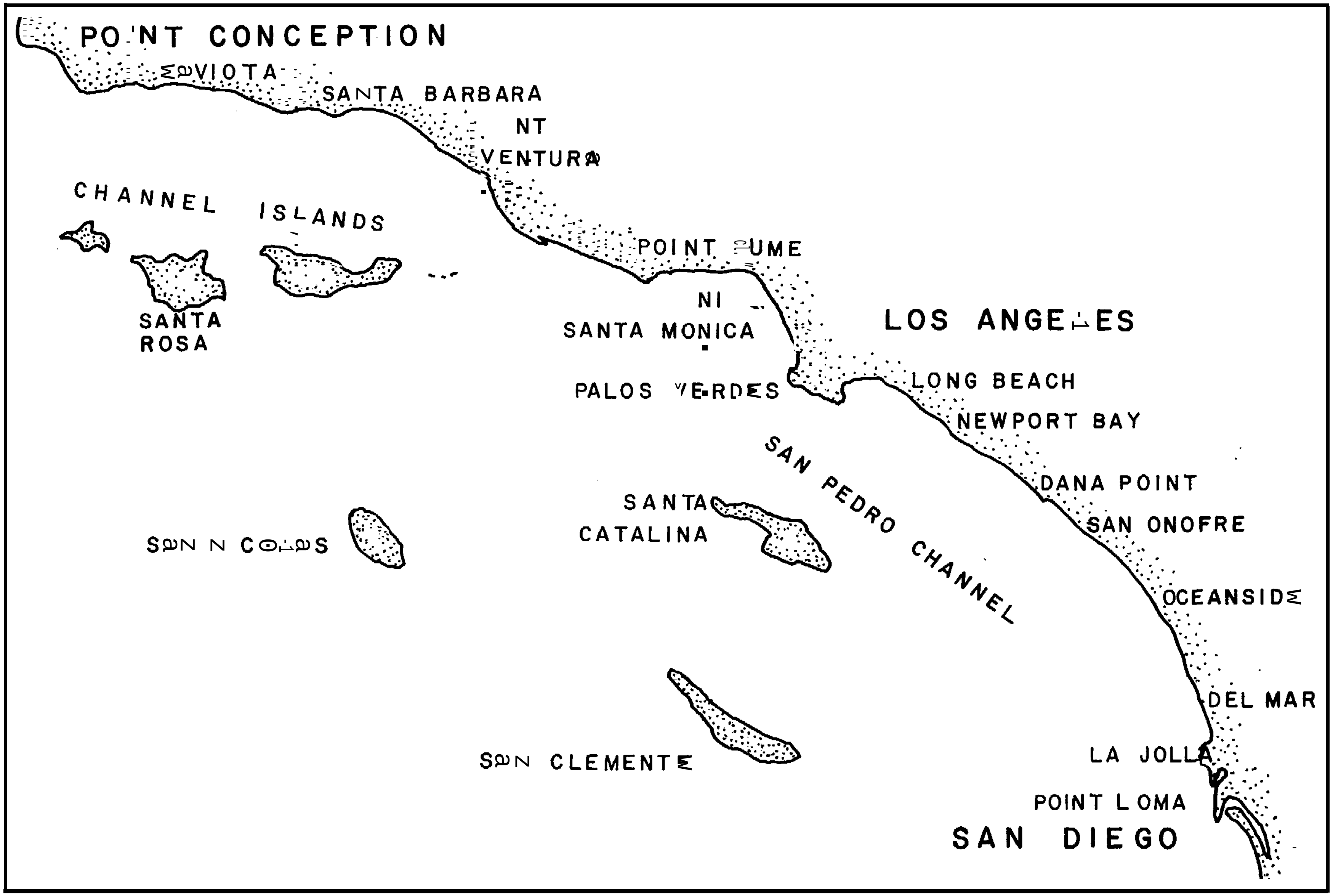


Figure 3-1. Location map.

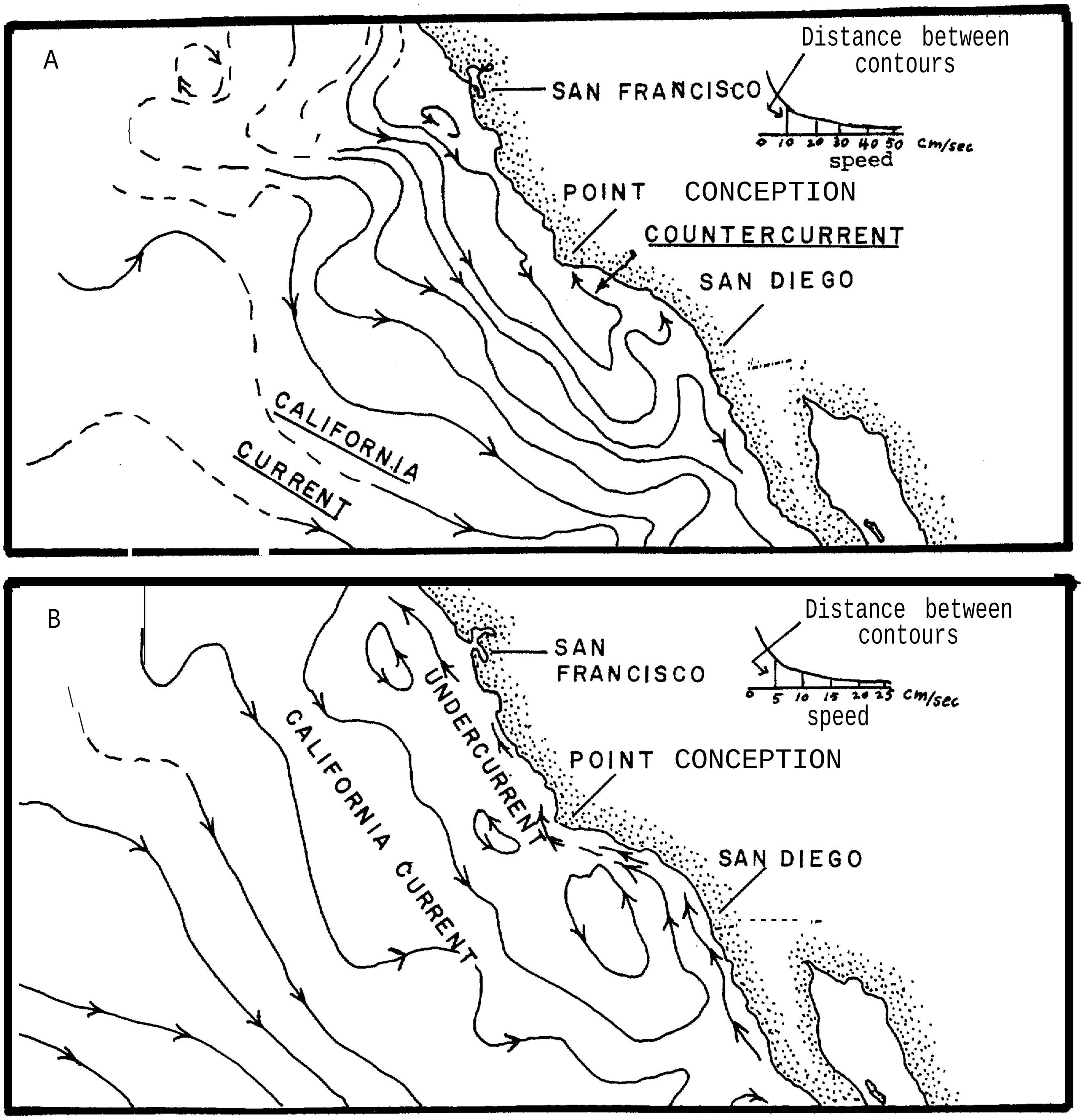


Figure 3-2. Mean July (1950-1965) geostrophic flow relative to the 500 decibar surface. (A) currents at surface and (B) currents at depths of 200 m. From Schwartzlose and Reid (1972).

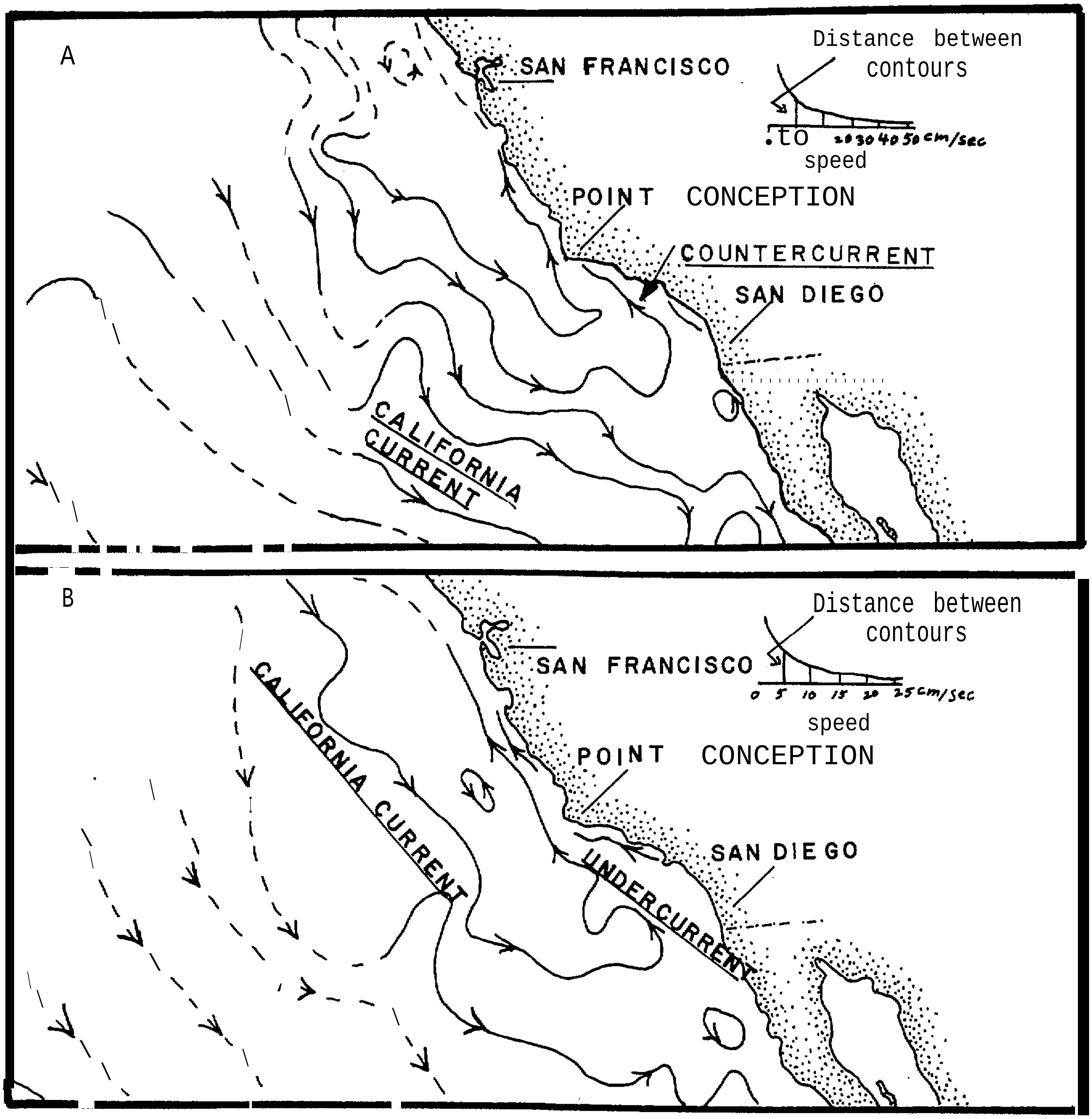


Figure 3-3. Mean January (1950-1965) geostrophic flow relative to the 500 decibar surface. (A) Currents at the surface and (B) currents at depths of 200 m. From Schwartzlose and Reid (1972).

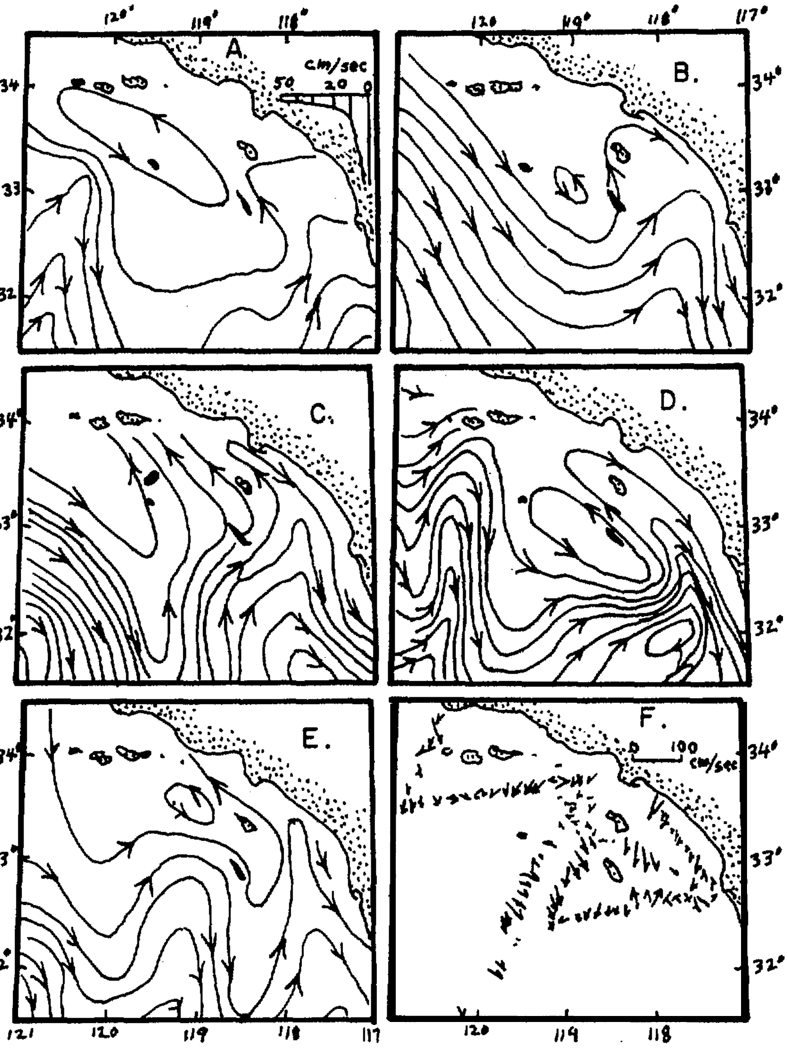
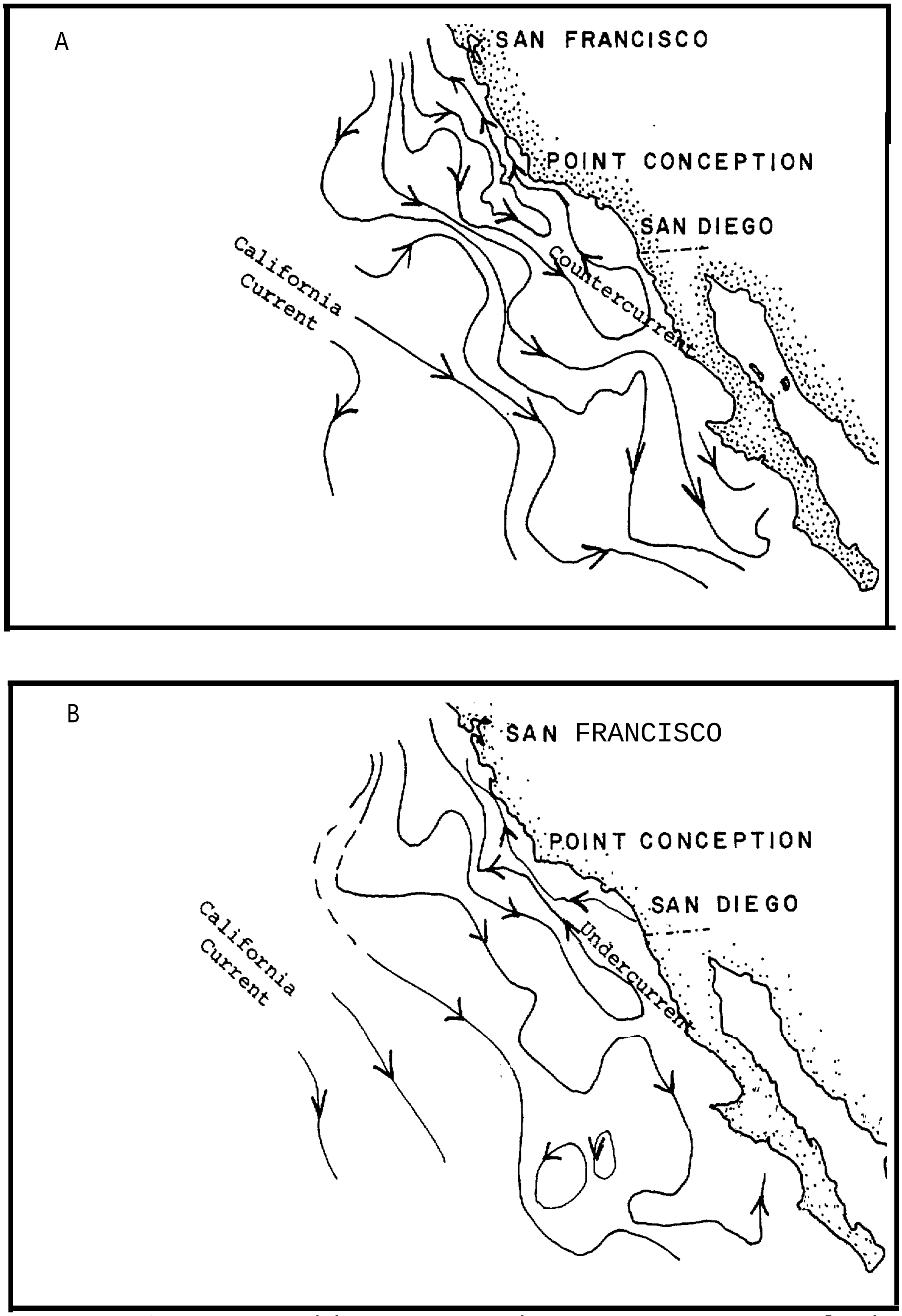


Figure 3-4. Geostrophic surface currents calculated relative to 300 meters for five cruises: (A) February, 1950; (B) May, 1950; (C) July, 1950; (D) January, 1951; and (E) March, 1952. Speeds are relative to contour spacing as shown in A. F shows geomagnetic electrokinograph records of currents in January and March, 1952. From Emery (1960).



gure 3-5* Geostrophic currents in January, 1964, relative to the 500 decibar surface. (A) Currents at surface and (B) currents at a depth of 200 m. From Schwartzlose and Reid (1972).

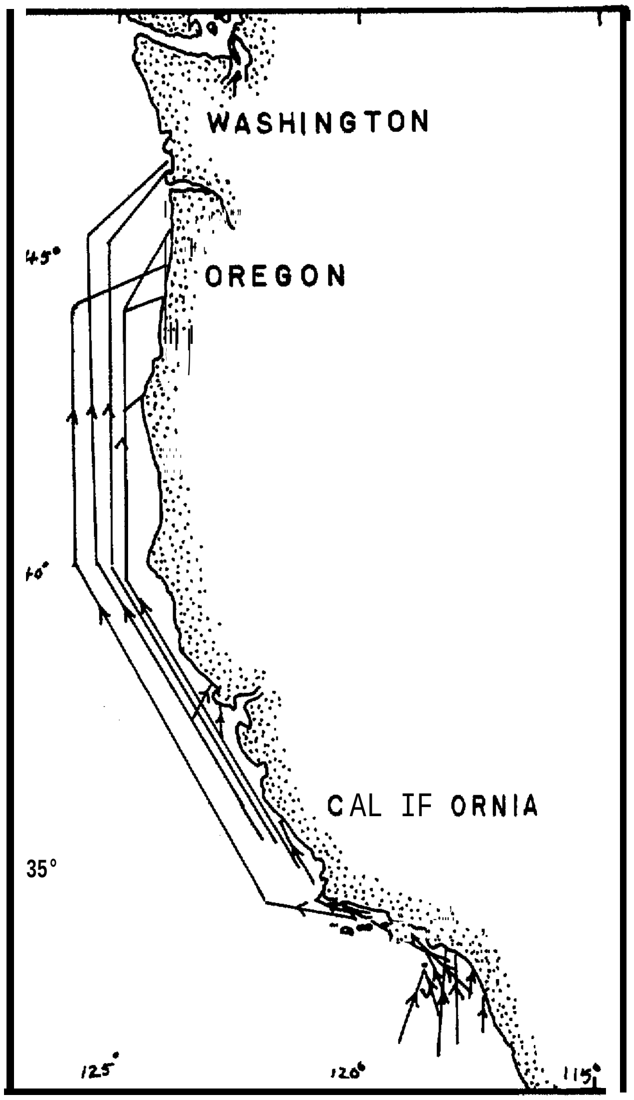


Figure 3-6. Drift bottle results from November, 1957, showing unusually strong countercurrents. From Schwartzlose (1963).

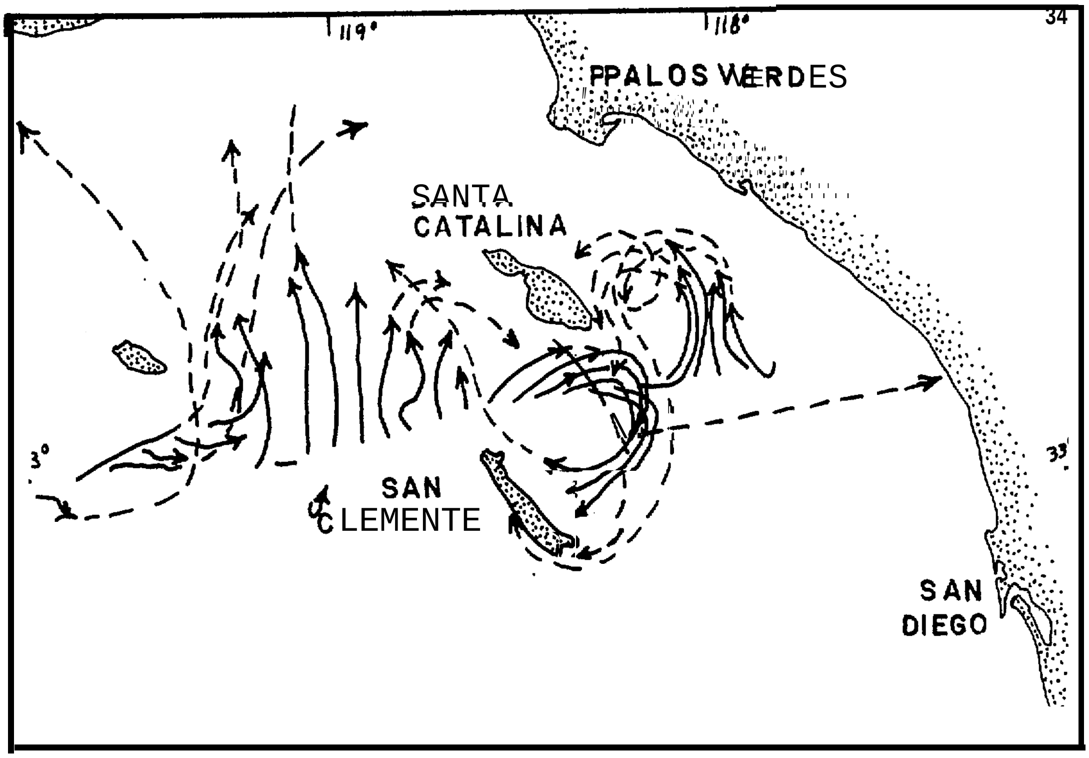


Figure 3-7. Drogue current measurements at a depth of 10 m off Southern California during October, 1958. From Schwartzlose and Reid (1972).

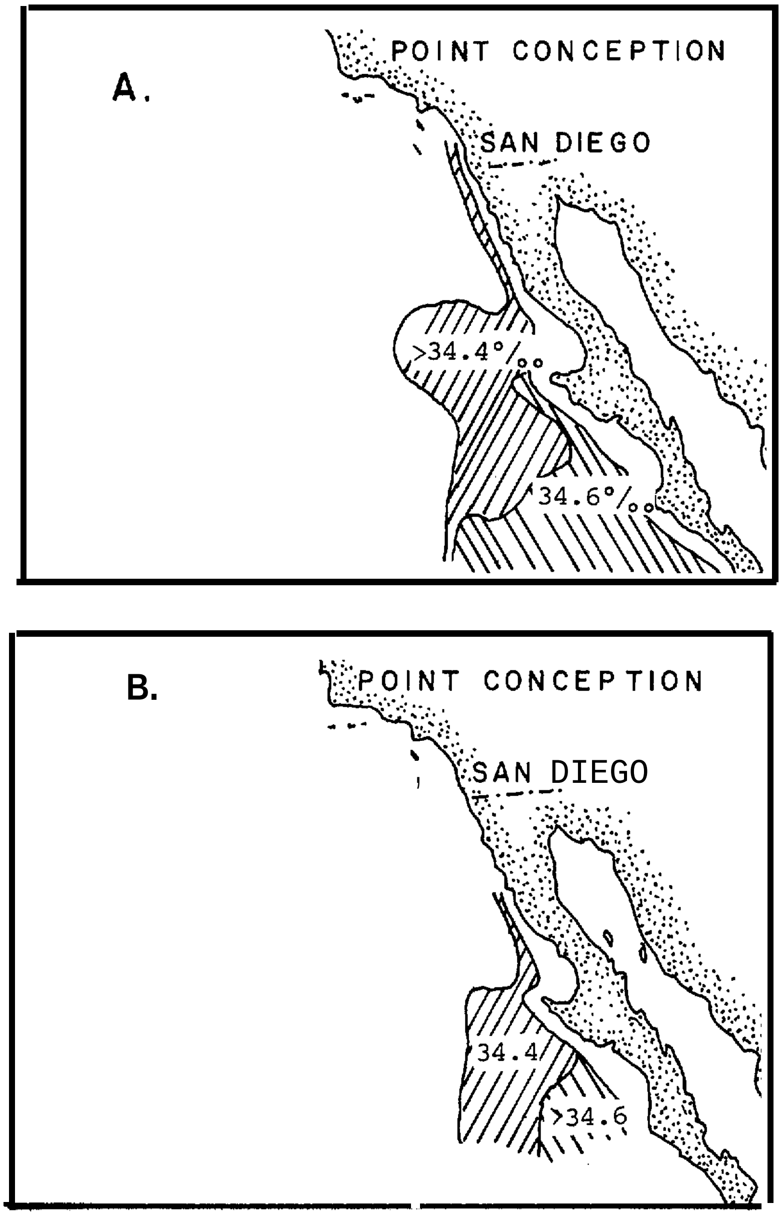


Figure 3-8. California Undercurrent distribution. plotted using salinity of greater than 34.4 ‰ on the 26.54 σ_t surface. From Wooster and Jones (1970) .

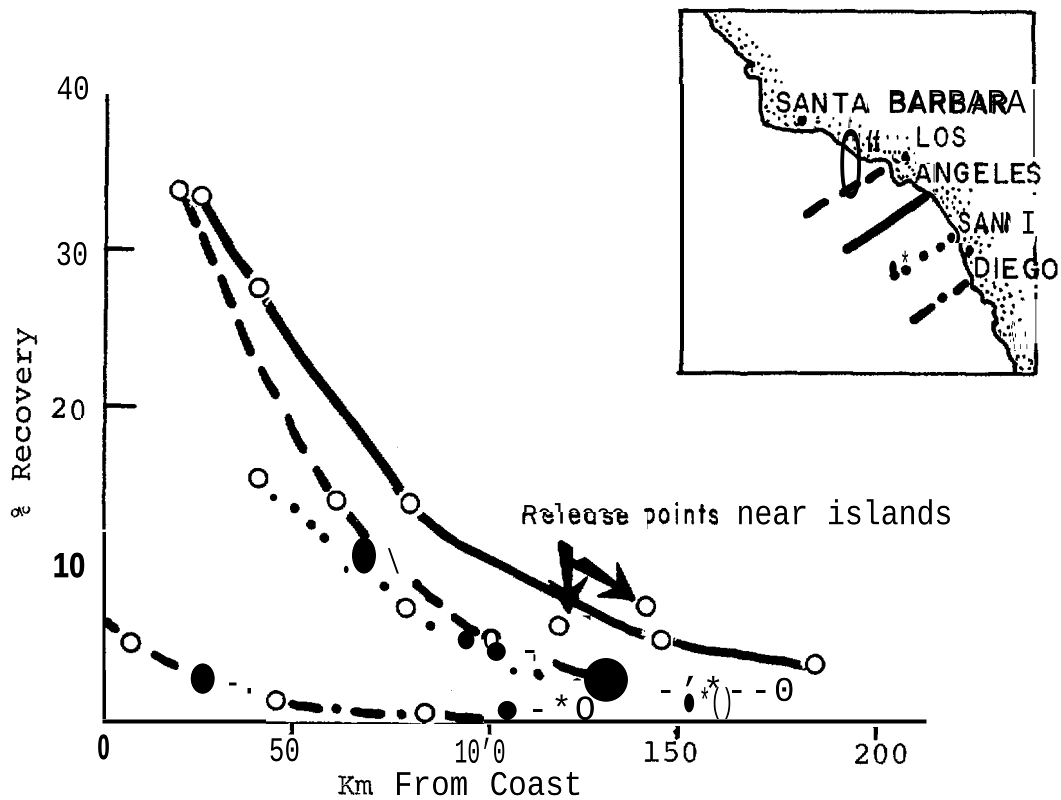


Figure 3-12. Drift-bottle recoveries from releases at various distances offshore. From Schwartzlose and Reid (1972).

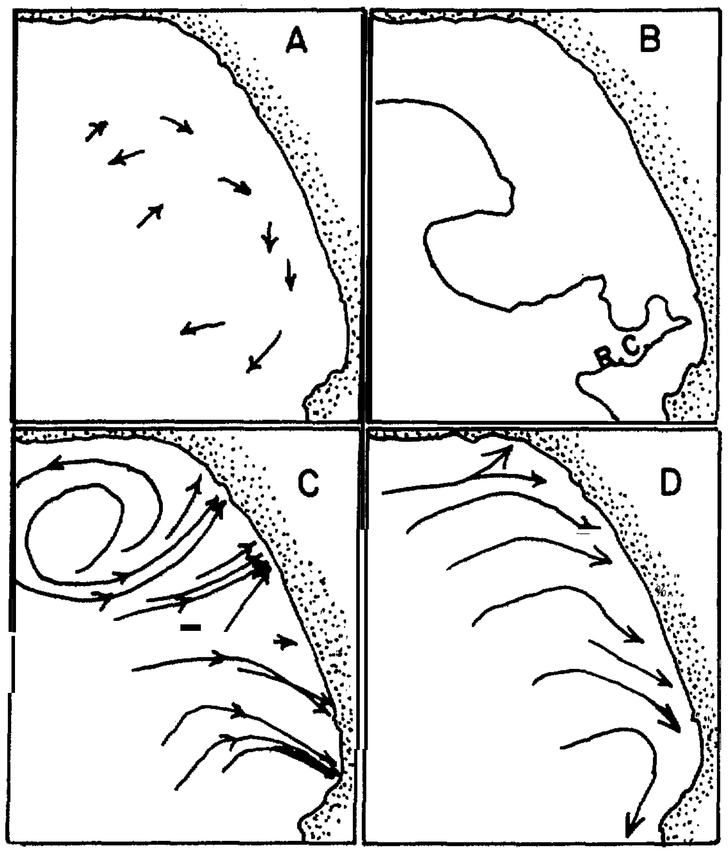


Figure 3-13. Currents in Santa Monica Bay. (A) Surface currents in March, 1956; (B) continental shelf area and Redondo Canyon; (C) surface currents from drift cards in February, 1956; and (D) surface currents from drift cards in August, 1956. From Stevenson, Tibby and Gorsline (1956).

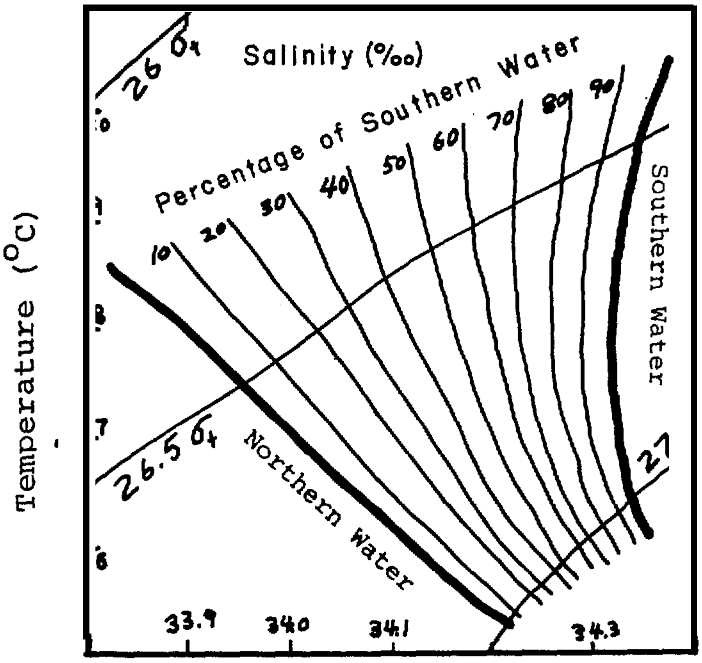


Figure 3-10. Temperature-salinity diagram showing northern water, southern water, and percentages of mixing. Density is given in σ_t. From Sverdrup and Fleming (1941).

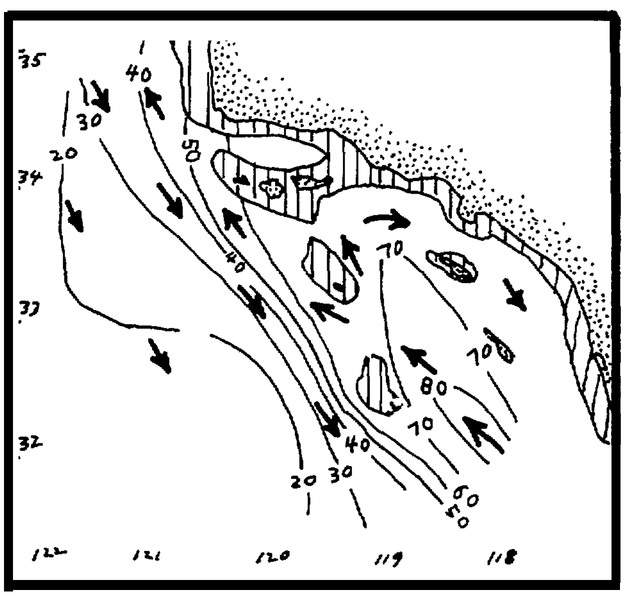


Figure 3-11. Horizontal distribution of southern water at depths of 200 to 400 m. Contours are in percentage of southern water. From Sverdrup and Fleming (1941).

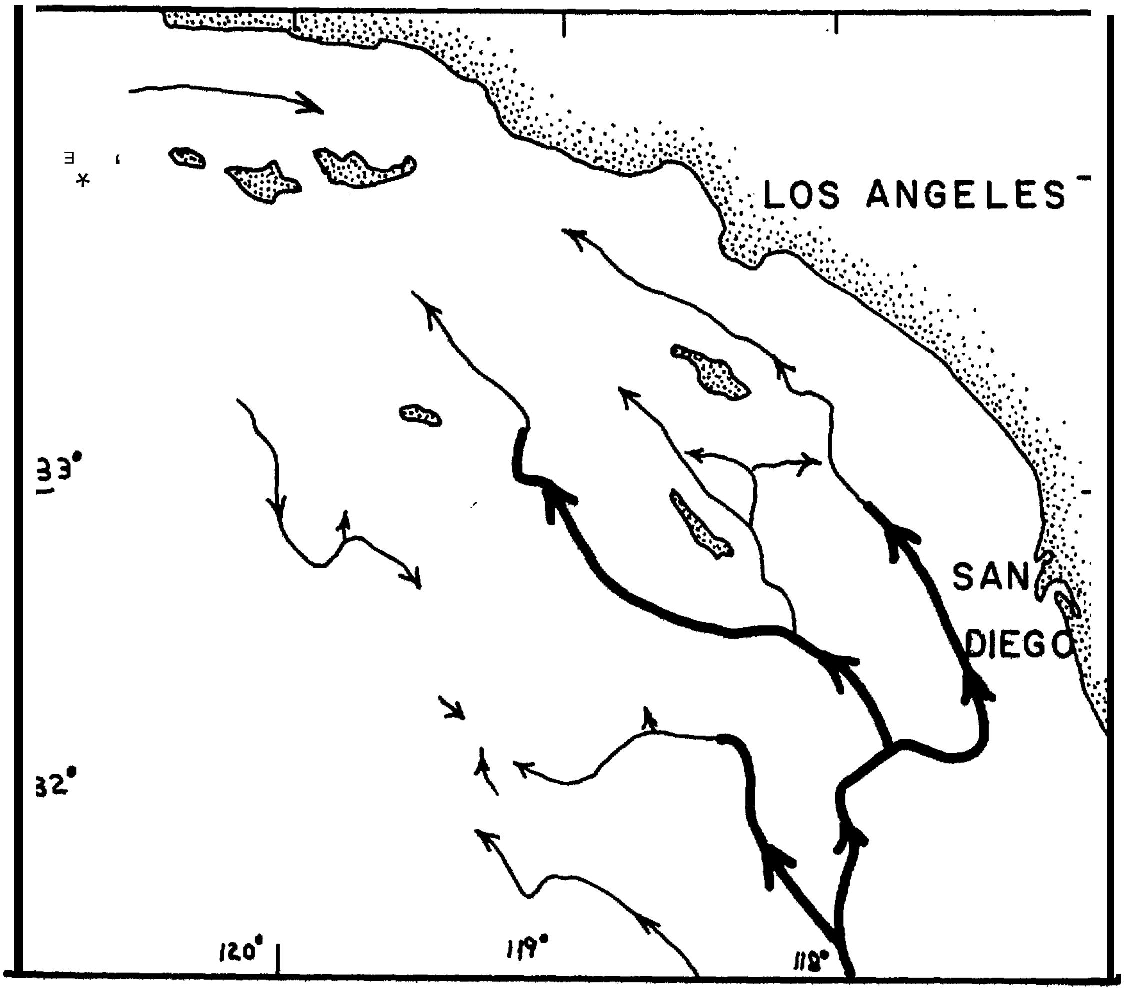


Figure 3-9. Flow lines of California Undercurrent in the California Borderland. From Emery (1960).

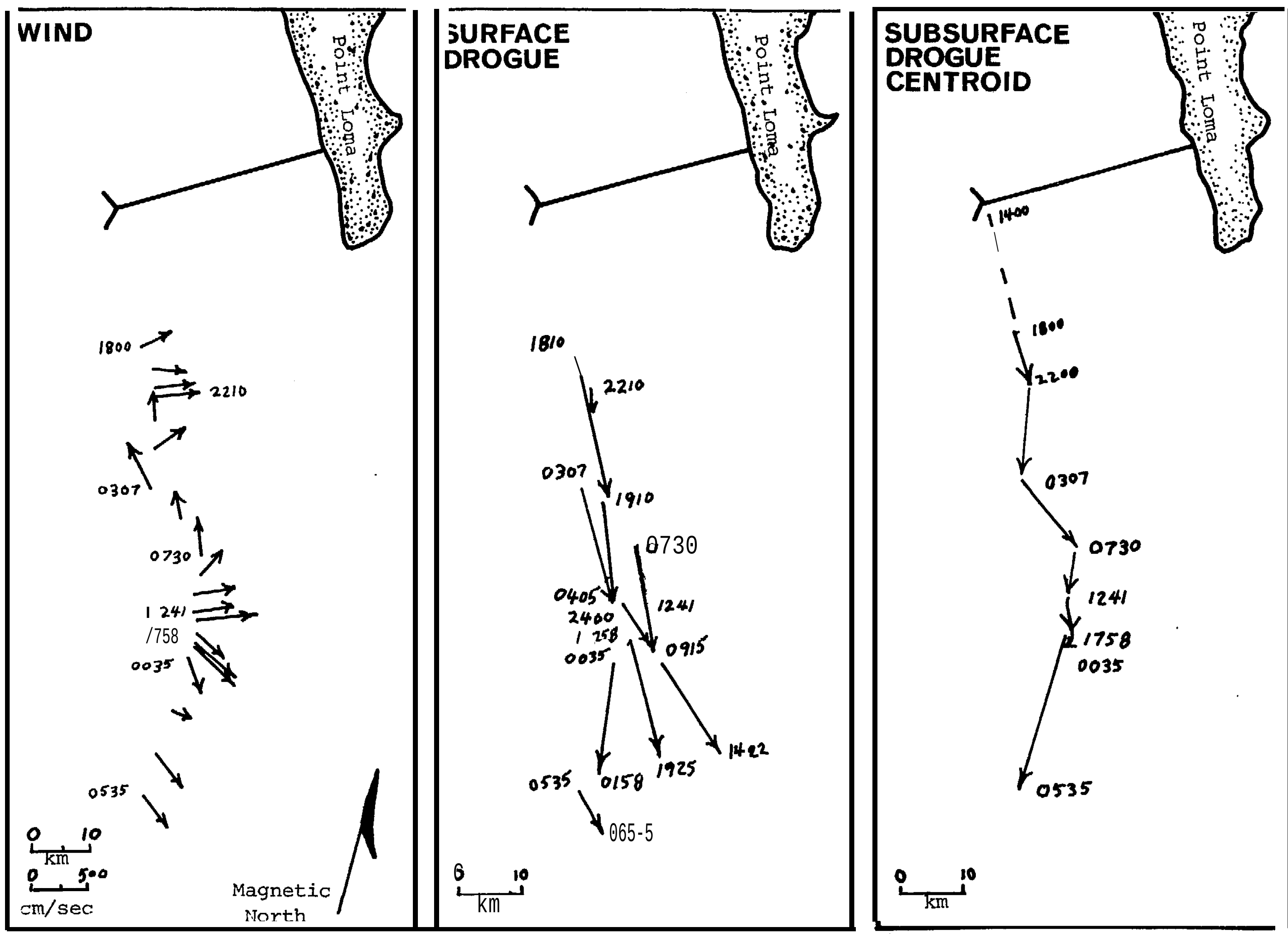


Figure 3-14. Wind, surface currents and subsurface currents, Point Loma, May 1972. From Hendricks and Harding (1974).

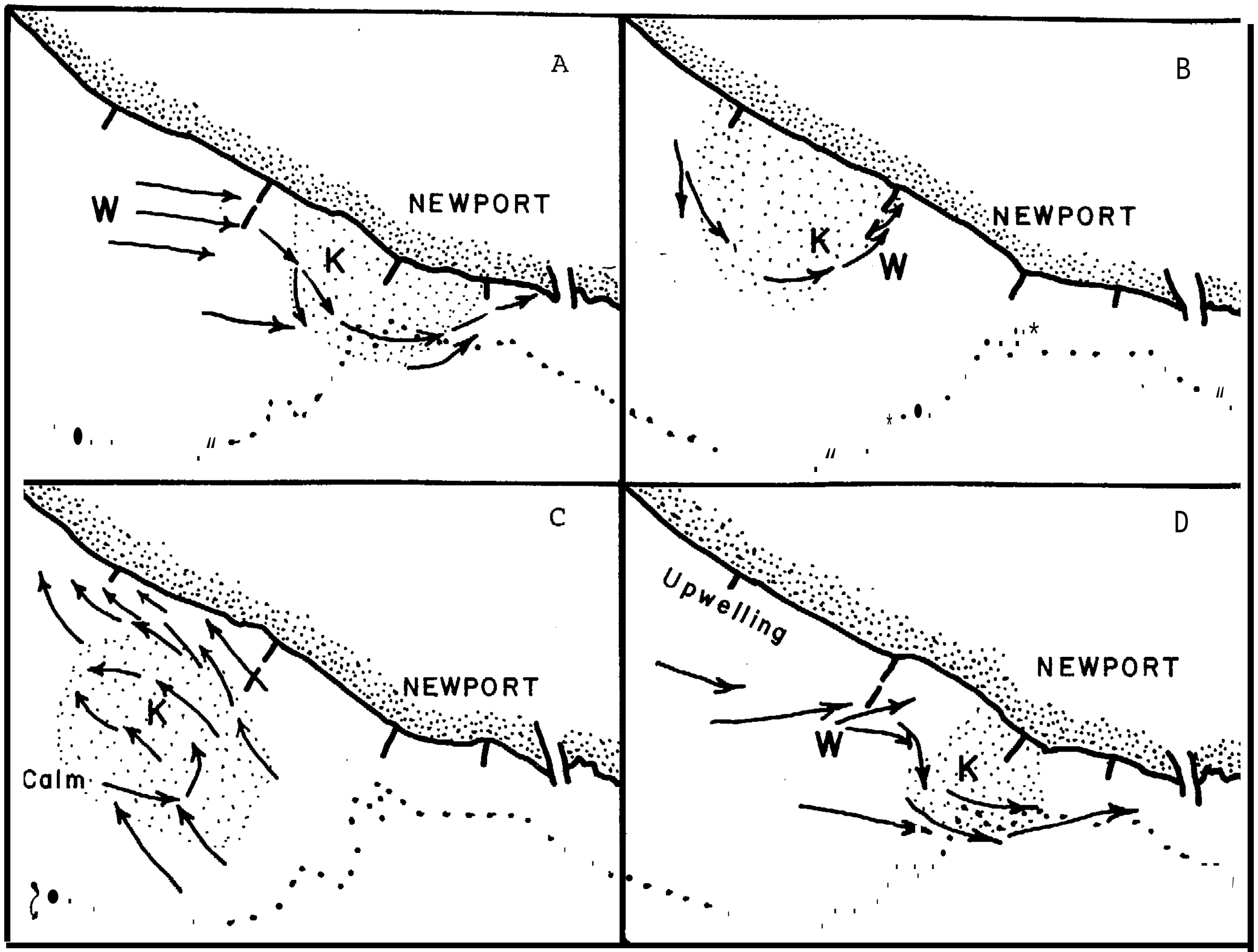


Figure 3-15. Cold spots and associated currents, Newport Shelf. (A) No upwelling, wind drift with fully developed “cold spot” centered on canyon; (B) no wind, no upwelling, “cold spot” shifted to west; (C) no breeze or S.E. breeze, “cold spot” shifts to west and seaward; and (D) upwelling and wind drift with fully developed “cold spot” centered near canyon. From Stevenson (1959).

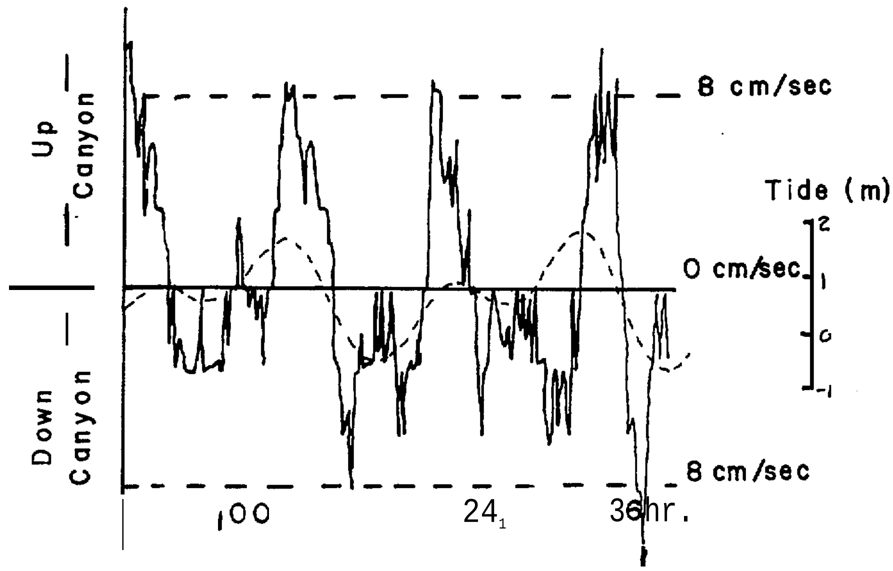


Figure 3-16. Flow directions and tidal periods at a depth of 247 m in Newport Canyon. From Shepard and Marshall (1973).

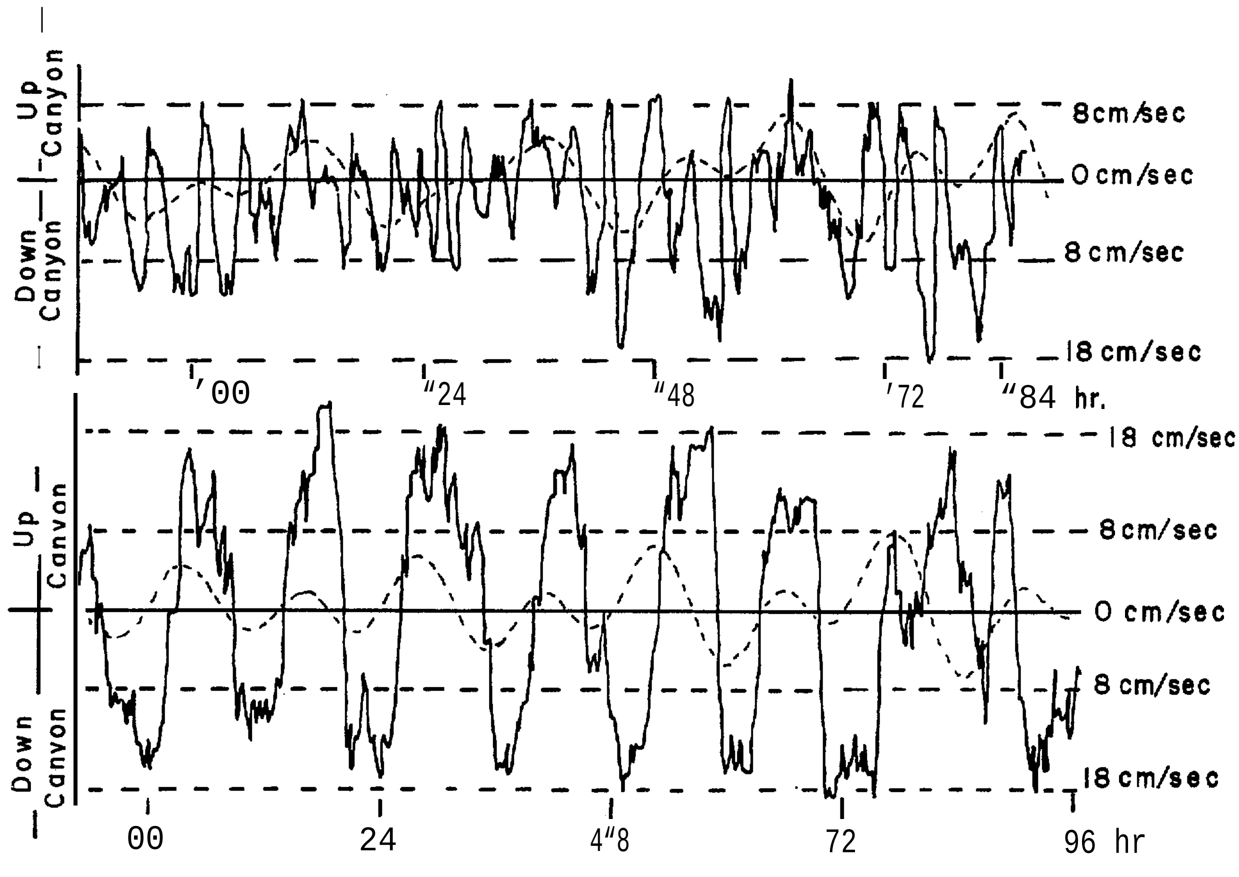


Figure 3-17. Flow directions and tidal periods in a shallow station (A) depth 206 m, and a deep station (B) depth 375 m in La Jolla Canyon. From Shepard and Marshall (1973).

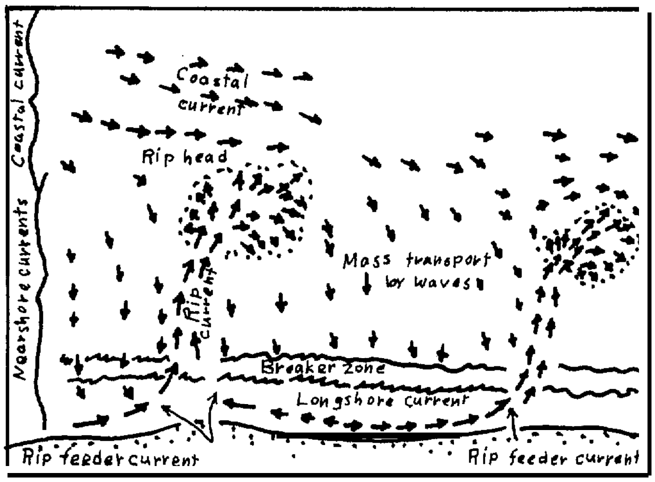


Figure 3-18. Nearshore circulation patterns. From Shepard and Inman (1951).

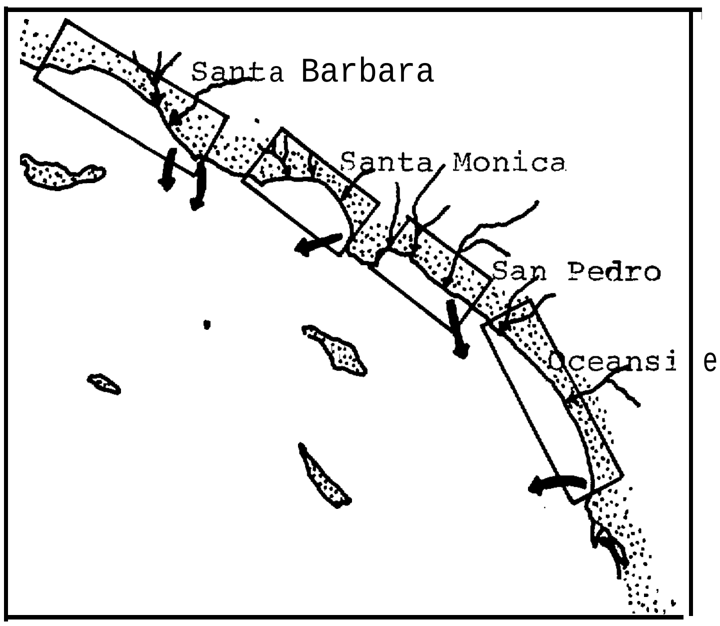


Figure 3-19. The compartmentalization of beaches in the Southern California Bight with the loss of sand into the heads of submarine canyons (thick arrows) at the southern end of each compartment. From Inman and Frautschy (1966).

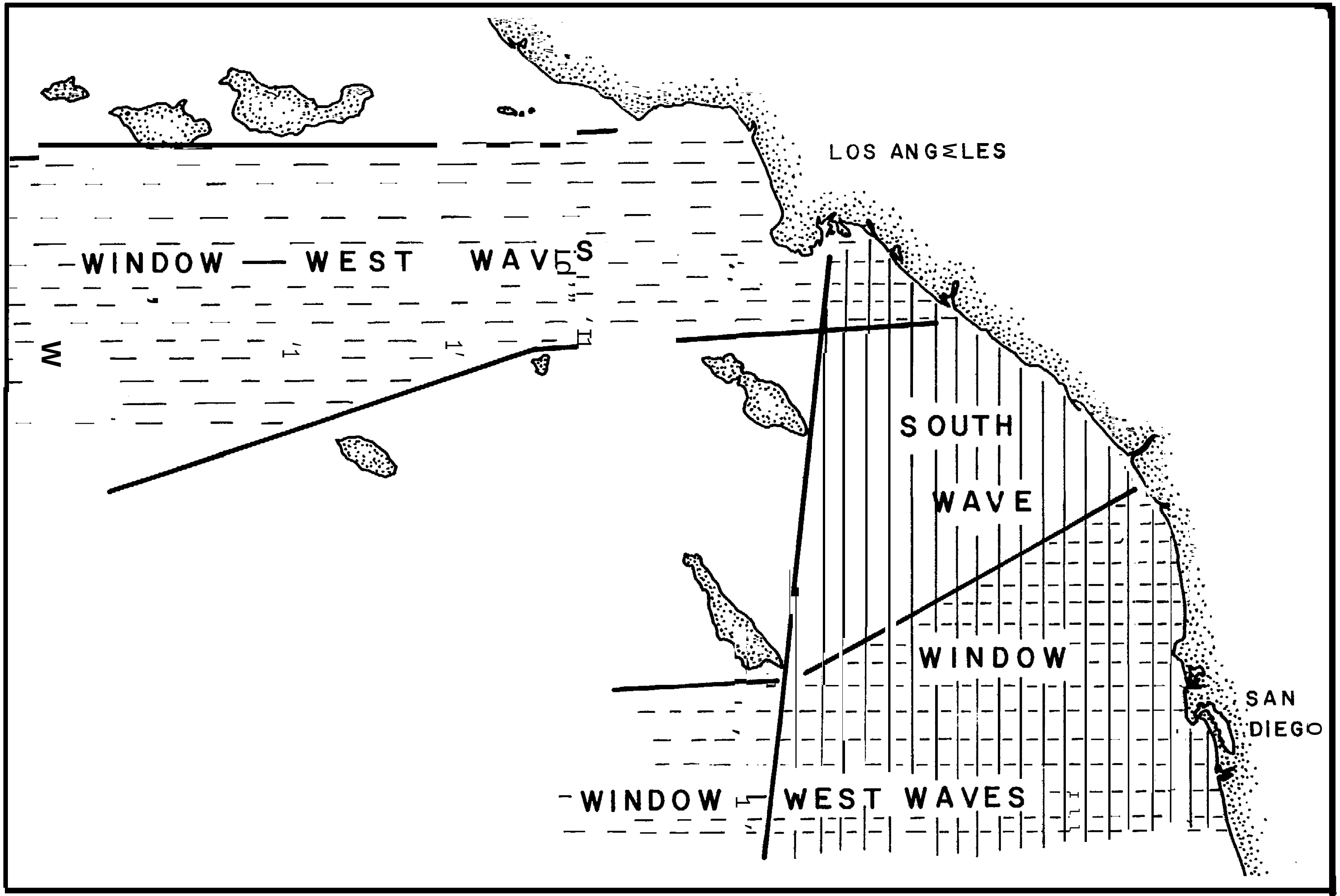


Figure 3-20. Wave windows to the coast in the Southern California Bight.

Figure 3-21. Computer display of 1964 Alaska tsunami. From Chen (1973) .

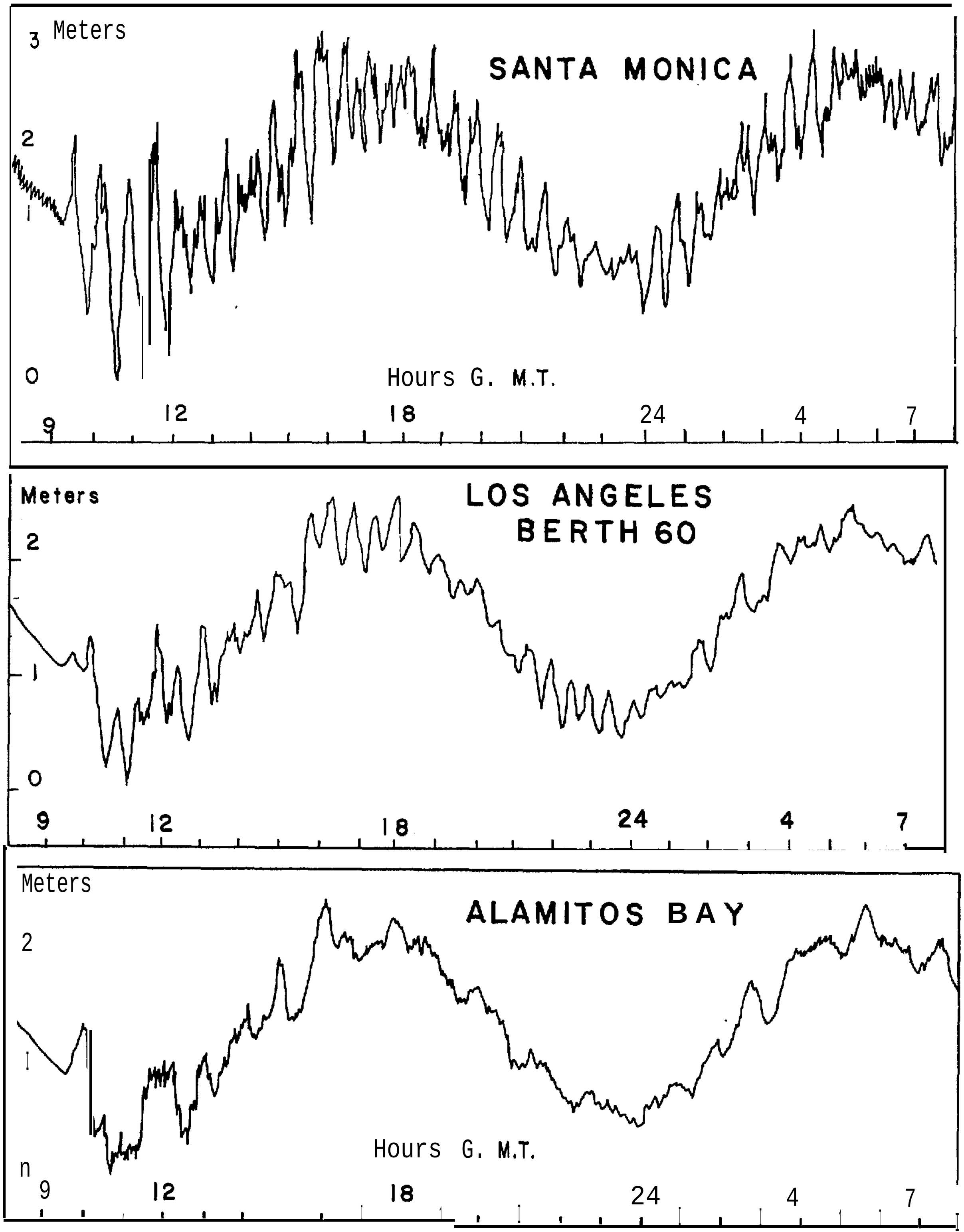


Figure 3-22. Tide gauge records showing oscillations from tsunami of March 28, 1964. From Cox (1972).

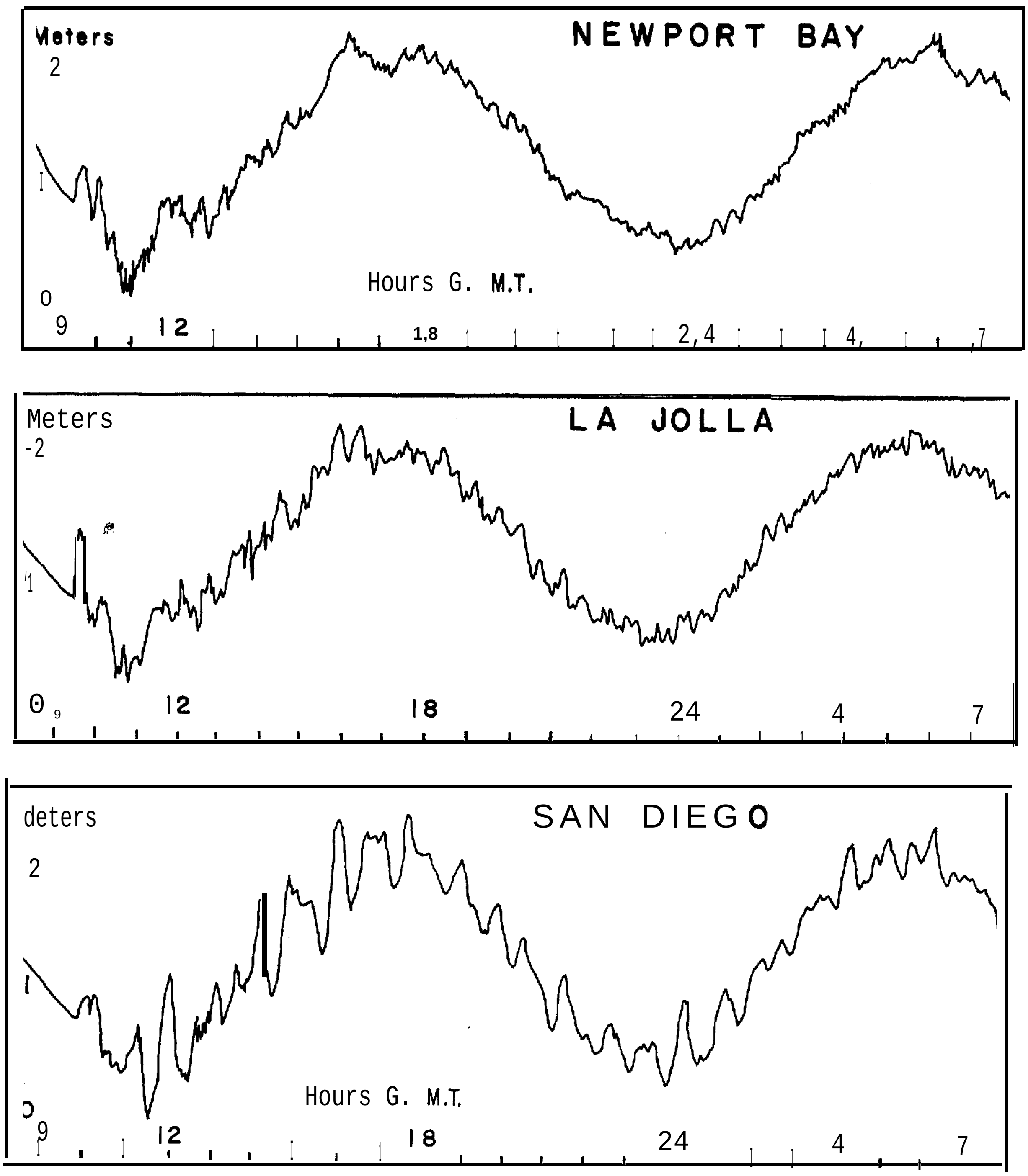


Figure 3-23. Tide gauge records showing oscillations from tsunami of March 28, 1964. From Cox (1972).

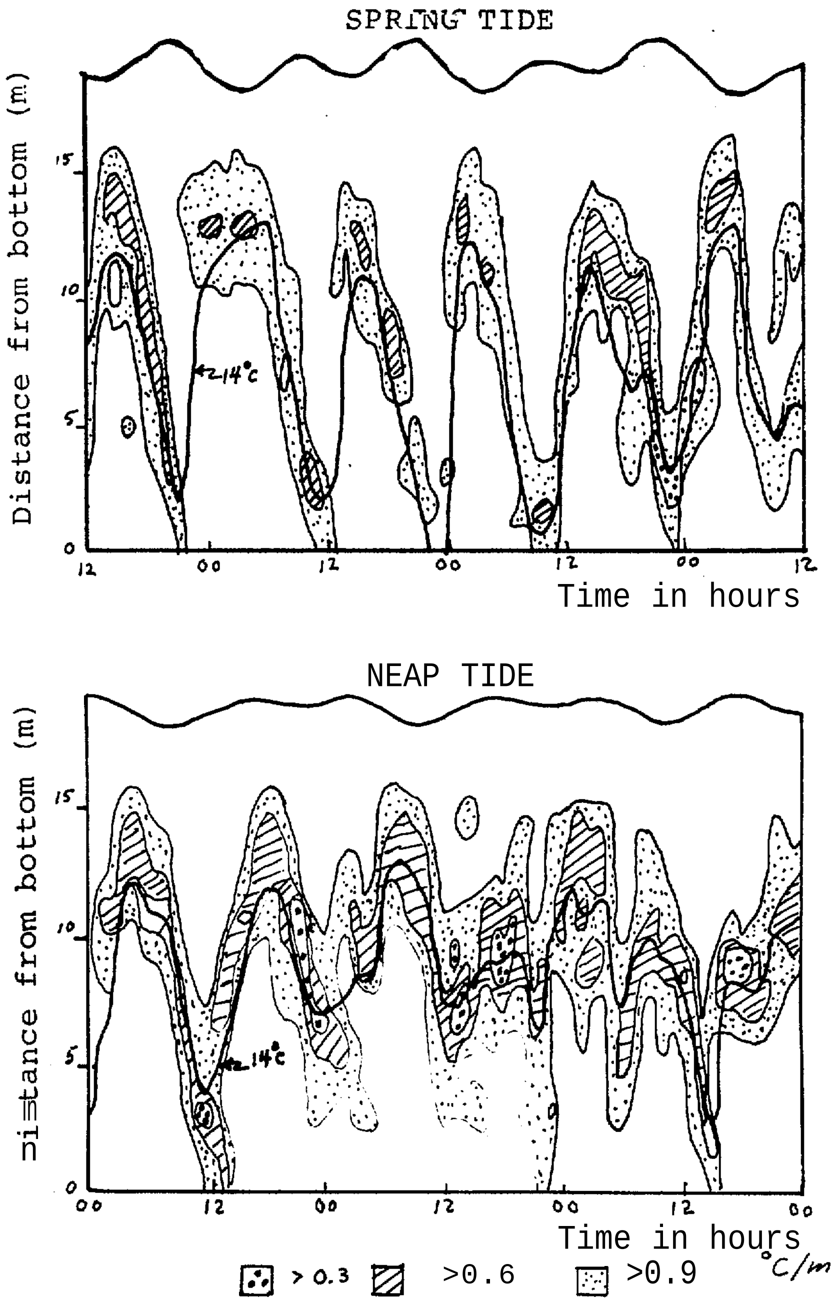


Figure 3-24. Contours of vertical temperature gradients during spring and neap tides in May, 1955. From Cairns (1968).

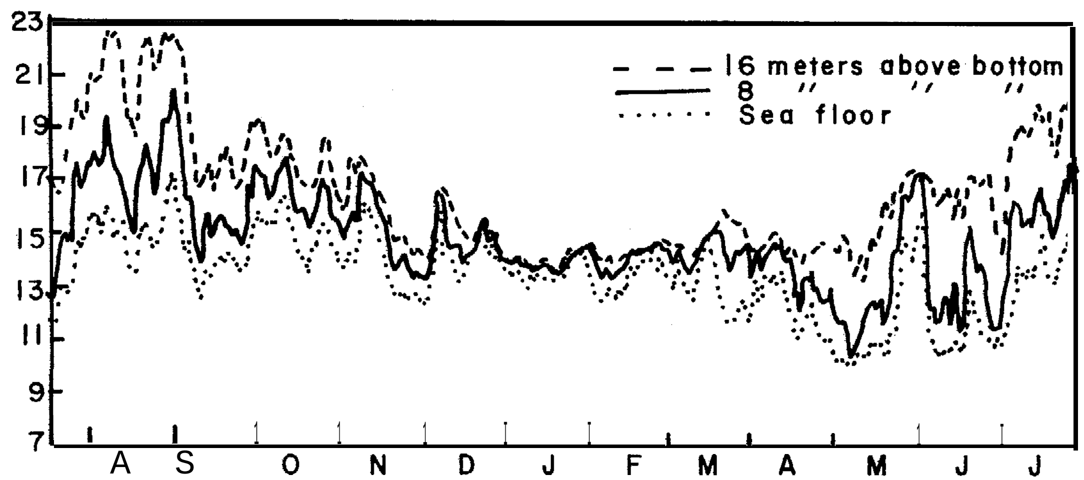


Figure 3-25. Annual record of daily averaged temperatures at three depths above the sea floor. Mean water depth 18 m. From Cairns and Nelson (1970).

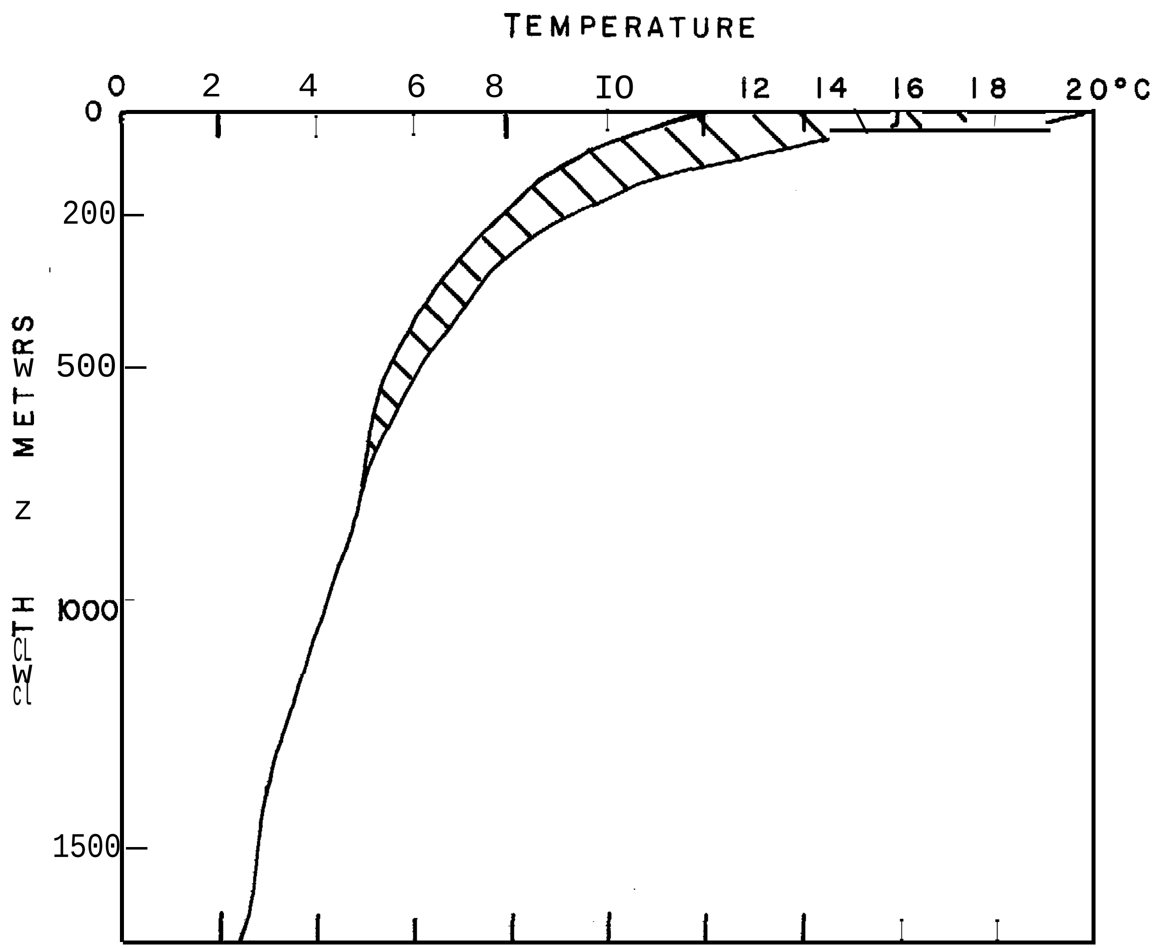


Figure 3-26. Temperature-depth diagram for the Southern California Bight.

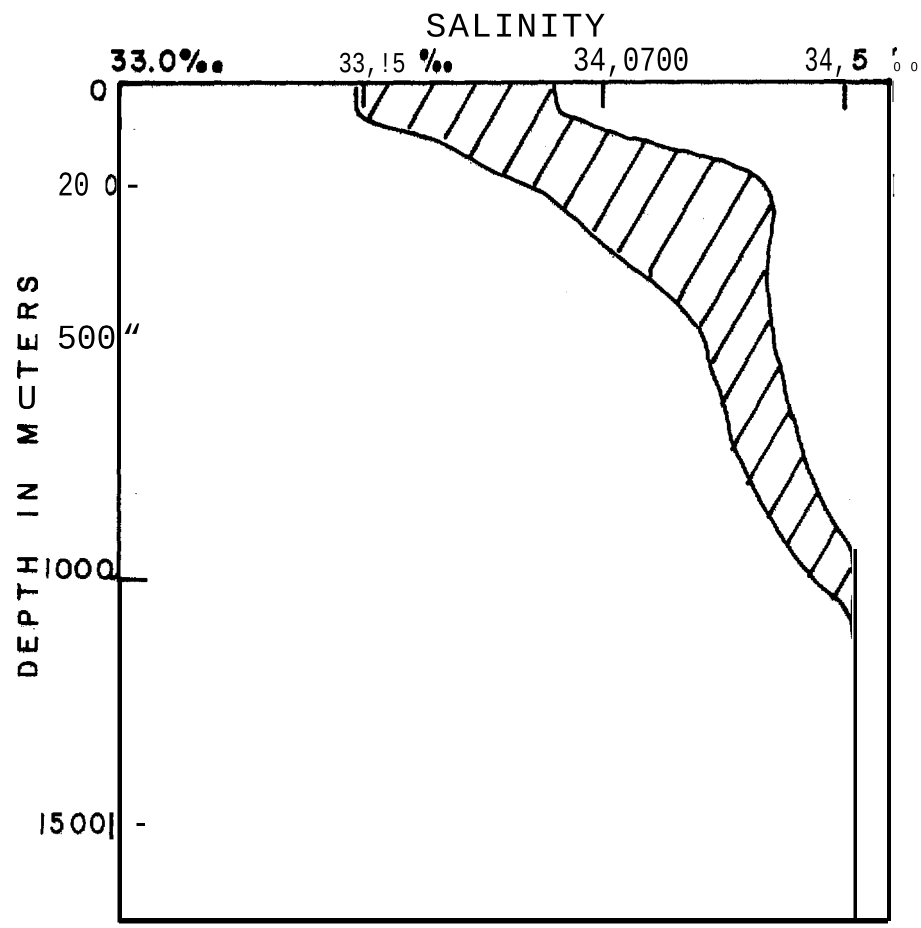


Figure 3-27. Salinity-depth diagram for the Southern California Bight.

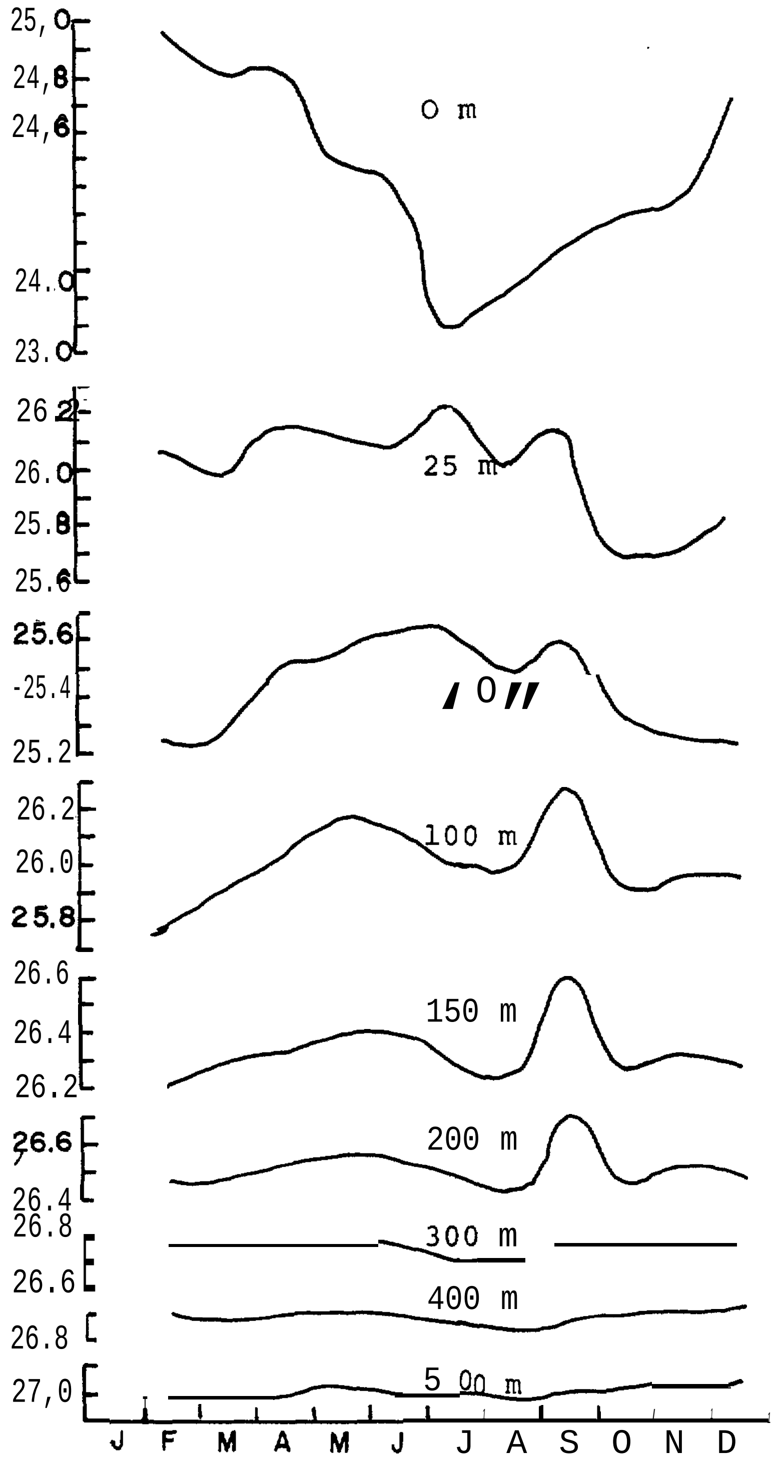


Figure 3-28. Annual variations in water density at different depths in California coastal region. Density given in σ_t. From Muromtsev (1958).

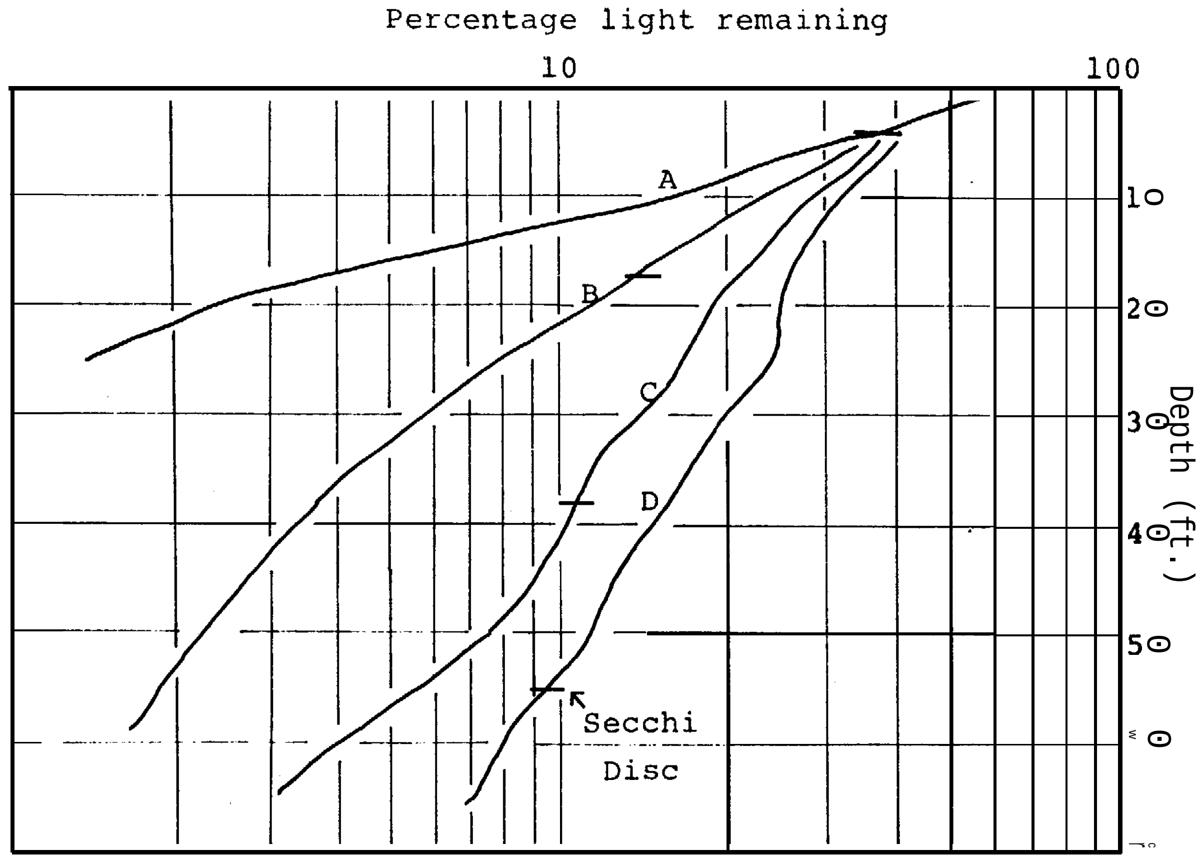


Figure 3-29. Representative hydrophotometer light transmission curves in Southern California Bight. From Allan Hancock Foundation (1965).

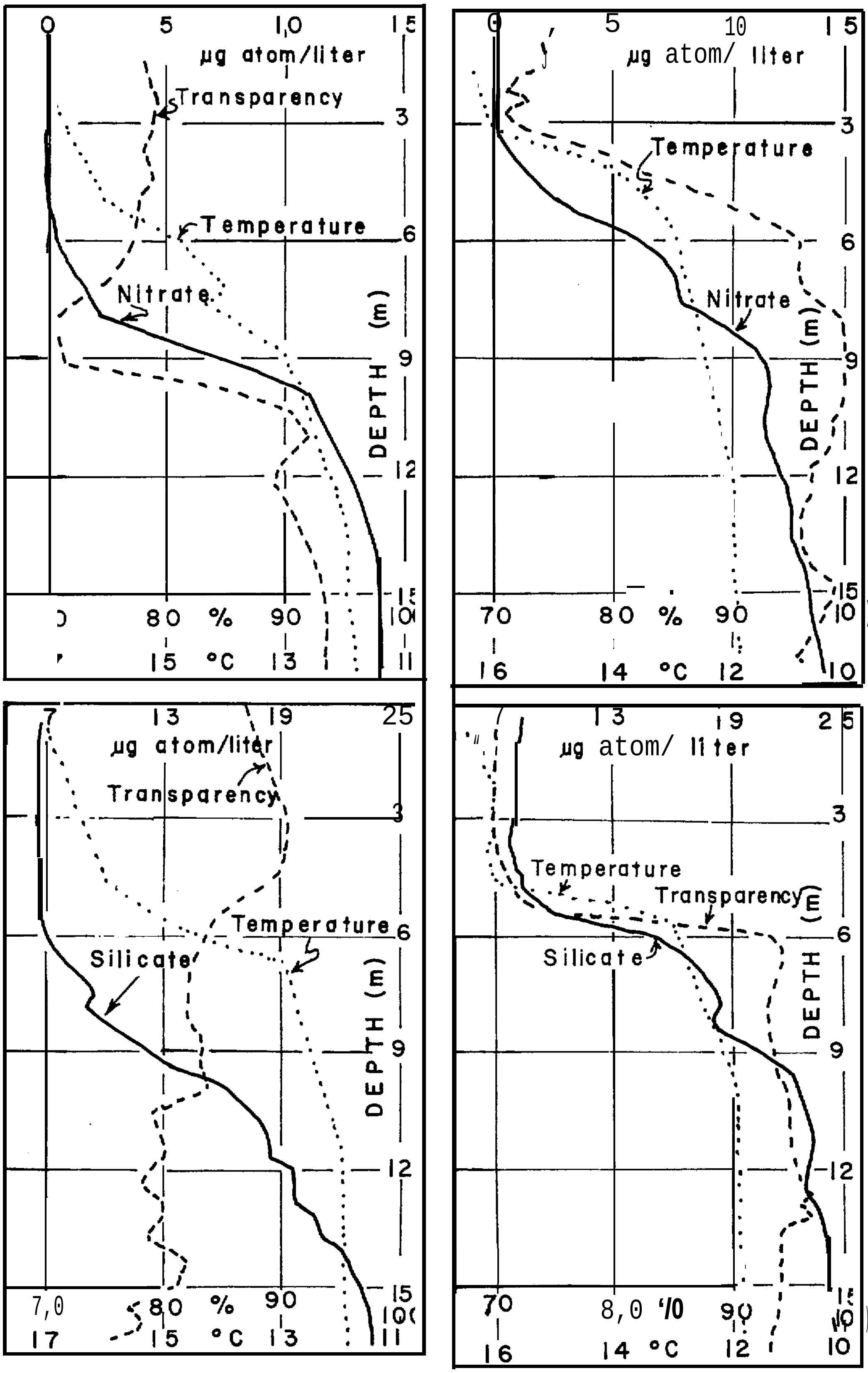


Figure 3-30. Comparison of vertical transparency, temperature, nitrate and silicate distributions in May, 1965, off San Diego. From Armstrong and LaFond (1966).

4. CHEMICAL OCEANOGRAPHY

Kwan Ming Chan

1. Temperature and Salinity

1.1 Water Masses and current circulation pattern

The major water mass off Southern California is the California Current, which is an eastern boundary current of a large anticyclonic gyre in the Eastern North Pacific Ocean. The water carried southward by the California Current is low temperature, low salinity, but high dissolved oxygen content subarctic water. North of Point Conception, the mean current speed is 12.5-25 cm/sec (Schwartzlose and Reid, 1972) and the total volume of transport above the 1500 decibar surface is probably about 10×10^6 m^3/sec (Sverdrup, Johnson and Fleming, 1942) to 12×10^6 m^3/sec (Pavlova, 1967), in which more than 90% is within 800 km of the coast of central California and is located above 300 m depth (Sverdrup and Fleming, 1941). There is no true western edge to this current as it gradually mixes with the high temperature and salinity water of the Central Pacific (Jones, 1971). Seaward of the continental borderland, and some 150 miles southwest of Los Angeles, the California Current flows in a southeasterly direction (Allan Hancock Foundation, 1965).

East of the California Current and over the Continental borderland, the water motion is dominated by a large eddy centered more or less around the Santa Rosa-Cortes Ridge. The eddy is a nearly permanent feature of the flow in the study area, and has been found to be well developed in winter and weak in the spring (Schwartzlose, 1963; Reid et al., 1958). The motion is counter-clockwise, requiring 10-20 days for a half-revolution and the northwestward flow has been known as the Southern California Counter Current (Sverdrup and Fleming, 1941; Emery, 1954). The observed speed and the estimated volume of transport of the Counter Current are comparable with that of the California Current. The water in the Counter Current is a mixture of offshore California Current surface water and upwelled water, and very often with an admixture of water of southern origin. In the study area, the water is primarily from the Counter Current and the properties of the water will vary depending on the degree of mixing of the above current and water, and the extent of modification as a result of heating and cooling, dilution, evaporation, biological activity and, towards the coastal area, waste discharges.

Studies of short-term flow pattern with drogues have indicated that the large counterclockwise eddy is associated with many small eddies in the California Channel Island area (S10 Report 62-67. I-962). The residence time of the Counter Current, "based on a mean path of 500 km, and a mean speed of 7 cm/see, is about 3 months (Jones, 1971).

1.2 Temperature and salinity of the water in the upper 100 m

The characteristics of the water in the upper 100 m depend on the following factors:

(i) Local climate - thewm, dry summer and mild, wet winter. The minimal precipitation and runoff in the months between July and December cause the surface salinity to be slightly higher during this period. However, due to the density difference and the stratification of the water, the effects of evaporation and dilution seldom extend to below 10 m (Lynn, 1967).

(ii) Wind mixing. In summer, due to the formation of thermoclines and the intense stratification of the surface water, there is a maximum difference in temperature between the surface and the 60 m level. In fall, the thermocline breaks down and strong wind mixing increases the temperature of the bottom water to the maximum values.

(iii) Upwelling. The cold and higher salinity water from depth strongly modifies the seasonal pattern of variation of temperature and salinity of the water in summer.

(iv) Current. The California Current forms a tongue of cold and low salinity water, while the Counter Current brings in relatively warm and high salinity water. However, due to heat exchange with the atmosphere by evaporation, and the mixing with colder upwelled water, the temperature increase due to the northward movement of the Counter Current becomes relatively-small (Fig. 4-1) (Jones, 1971).

The seasonal pattern of water temperature, salinity, and density down to the depth of about 100 mwere surveyed by the Allan Hancock Foundation (1965). The results (Fig. 4-2, 4-3) show that it is almost isothermal and isohaline between the surface and 60 m (200 feet) in winter. The vertical temperature difference between these two levels is about 3°C, except nearby San Diego. January may be taken as the typical winter condition of the study area. Fig. 4-1 shows that there is a weal eddy around the Channel Islands and the low temperature and salinity nature of the water is attributed to the California Current.

In spring, the surface water temperature increases slightly, while the temperature at 60 m level decreases. The California Current moves closer to shore and due to the configuration of the coastline, the water of the California Current is entrained and contributes to the Counter Current. The difference in temperature between the surface and at 60 m is about 7 - 10°C. However, in some areas, e.g., in the vicinity of Redondo Beach and Point Fermin, the temperature difference is much smaller. This, together with the lowering of surface temperature, indicates local upwelling.

The temperature differences between the surface and at 60 m increase to a maximum in summer. This is due to the intense solar heating and the formation of a seasonal thermocline. The vertical thermal gradient averages 0.59°C/m from April through early September at the Naval Oceanographic Tower, which is located 1.6 km off shore from the Mission Beach. The sharpest gradient maybe as great as 1.27°C/m in late June (Cairns and Nelson, 1970).

In autumn, the Counter Current is still strong and due to the decrease in upwelling, the surface water temperature is raised to a maximum in several coastal areas, and retards summer warming. Also the break-down of the seasonal thermocline decreases the temperature differences between the surface and the 60 m (200 feet) level. The upper 60 m forms an almost homogeneous, or a well mixed layer, which increases seaward to 120 mand decreases towards the coast to 20-30 m (Kin'dyushev, 1970).

The annual range of surface salinity is in the order of 0.5 to 0.8 °/oo. In the study area, the California Current brings in water of low salinity (approximately 32.5 °/oo) from the north side, which gradually mixes with water of higher salinity from the deeper depths in coastal upwelling areas. The mean surface salinity ranges between 33.3 to 33.6 O\oo (Kin'dyushev, 1970). The direct influence on the surface salinity by evaporation and precipitation can be considered to be minimal (Reid et al., 1964).

Beginning about 23 km west of' the coast at 32° 33' N, a shallow salinity minimum, lying between 50-70 m with salinity about .12°/00 less than the upper homogeneous layer, was observed by Reid et al., (1964). This was explained as a consequence of horizontal mixing of the surface water with the more saline water to the west.

To eliminate any transient conditions of runoff and diurnal heating and cooling, Lynn (1967) used the 10 m depth record of temperature and salinity to analyze the properties of the water off the coast of California. The regression curves show that the seasonal temperature minimum occurs about March and the maximum occurs during early September. In regions of upwelling and those influenced by upwelled waters, the occurrence of temperature minimum and maximum are delayed (Fig. 4-4, 4-5). The salinity pattern (Fig. 4-6, 4-7) is considerably less regular than that of the temperature. The minimum is in spring and the maximum in fall. In the upwelled regions, the maximum salinity is in summer, shortly after the minimum temperature is attained.

1.3 Temperature and salinity characteristics of the water below 100 m

The water below the surface mixed layer has less complex temperature-salinity variations (Fig. 4-8) (Stevenson, 1959 and 1961). The most important influence is from the water of southern origin, known as the Southern Water (Under Current), which is in contrast to the water near the surface of northern origin, known as the Northern Water. The Southern Water has a higher temperature and salinity than the deep water of the California Current located at the same depth. It extends into the study area (Fig. 4-9) (Sverdrup, et al. , 1942), where most of it is trapped by the Santa Rosa-Cortes Ridge. Part of it moves northward along the seaward side of the ridge. In late fall and early winter, the northwest flow at 5-10 cm/sec (Jones, 1971) reaches surface near Point Conception and is called the Davidson Current. From its horizontal distribution, the depth of 50% Southern Water can be computed by mapping the dynamic topography of the 300 decibar level with respect to the 800 decibar level (Emery, 1960). Incomplete mixing of the waters is sometimes revealed by both temperature and salinity inversions (Gunnerson, 1957; Roden, 1964; Reid et al., 1958). At a depth between 300 and 600 m, the shelf water has a temperature of 6° to 9°C and salinities of 34.1 to 34.4°/00, and relatively low oxygen and high phosphate content (Stevenson, 1961).

The water of the basins below the sill depths is essentially uniform in temperature and salinity (Fig. 4-10) (Emery, 1954). A longitudinal section through San Clemente, San Nicolas and Santa Cruz Basins shows that the temperature is from 2.6° to 3°C and salinity, from 34.4 to 34.5°/00 (Fig. 4-11). The salinity within the basins is about the same as that of the open sea at the same depth of the basin sills, and it remains nearly uniform from the sill to the bottom depth of each basin.

Due to mixing and turbulence, there is a slight temperature decrease of no more than 0.13°C in the first hundred meters below the sill of several basins. Below that depth there is a slight increase of temperature with depthof less than 0.01°/100 m which can be partly attributed to adiabatic heating (Emery, 1954). The other factor involved is the heat flux from the earth into the water. Measurements in San Pedro Basin showed that the value was 1.8 1 cal cm^{-2} see-l, which is higher than the world average of 1.2 cal cm^{-2} sec^{-1} (LaFond and Lafond, 1973). Such kind of heat flux would cause the development of convection cells and increase the positive temperature gradients within a few meters above the sea floor.

2. Dissolved oxygen

2.1 Distribution pattern of dissolved oxygen

The amount of dissolved oxygen in surface waters depends on both temperature and salinity. In the open coastal waters of Southern California, with an annual surface water temperature range of about 5° to 6*c and salinity variation of 0.5 to 0.8 ‰, the temperature effect is apparently several times greater than that of salinity (Allan Hancock Foundation, 1965). Therelationship between the content of dissolved oxygen and temperature of the water entering the study area (Fig. 4-12) shows that the Northern Water has a higher dissolved oxygen content and lower temperature, while the water from the south side tends to have lower dissolved oxygen and higher temperature. The general decrease in dissolved oxygen with lower temperature is related to the greater depth of the water from which the samples were collected. It is due to the oxidation of organic matter, respiration, bacterial activities, and chemical reactions. A similar relationship between an increase in inorganic phosphate with decrease in dissolved oxygen below the surface also exists (Fig. 4-13) . This is apparently related to the regenerative process in which oxygen is utilized to oxidize the decaying organic matter. The dissolved oxygen content of the coastal waters down to a depth of about 90 m was surveyed by the Allan Hancock Foundation (1965). The surface water was found to be at the saturation level. The biggest difference in dissolved oxygen content of the surface water is between that in the months of April and November (Fig. 4-14). The higher dissolved oxygen content in April is attributed to the increase in photosynthetic activities of the phytoplankton. However, in several places, a reduction of the dissolved oxygen content becomes apparent. This is primarily caused by local upwelling, which could become intense in the summer season. Over the shelf area, the oxygen content is generally homogeneous to a depth of about 33m. At 100 m, the dissolved oxygen content is reduced to only about 5 to 6 mg/liter.

Close to the 30 m level, dissolved oxygen concentration may increase to an excess of 8 mg/liter. During the 1958-1960 season, such an oxygen maximum rose to the surface in San Pedro Bay, along the coast off San Clemente, and off San Diego (Fig. 4-15). The oxygen maximum, which rarely occurs in winter or spring, is possibly caused by photoplankton or an "entrapment" of oxygenby the water during the cold periods (Redi, et al., 1958). In winter, due to wind mixing and the break-down of the seasonal thermocline, the dissolved oxygen values in the upper homogeneous layer are fairly constant and are at or above saturation values. In spring the surface dissolved oxygen concentration begins to decrease. However, below 30 - 40 m, the dissolved oxygen content does not decrease until in July or August when the seasonal thermocline becomes fully developed. Thus a subsurface maximutn usually occurs from late spring until winter as shown in

Figure 4-16 . The effect of photosynthesis is believed to be less important than the entrapment process in the dissolved oxygen content of the subsurface layer.

From 200 to 300 mand locally as deep as 500 m, the water, as indicated by its temperature-salinity relationship, consists of a mixture of 50% Southern Water and 50% Northern Water types. However, the dissolved oxygen contents do not follow the percentage of mixing of Northern or Southern Water. In fact, the observed values in the inshore continental slope areas are often less than the computed ones, based on the percentage of mixing. Such a decrease in oxygen content is caused by the oxidation of organic matter settling through the water from the area of high production near the surface. Accordingly the nutrient content, due to the regenerative processes, is inversely proportional to the oxygen content (Fig. 4-13).

From 500 to 700 m the dissolved oxygen concentration decreases to a minimum of about 0.7 mg/L. It increases with depth below 700 meters and reaches 3 mg/L at 2000 meters. The oxygen minimum layer is consistently found below the salinity-minimum layer wherever it is present. Off the west coast of the United States the oxygen minimum layer originates between 28°N and the Equator, and it extends westward like a wedge (Sverdrup, et al., 1942).

The water in the marine basins has approximately the same oxygen content as the water outside the basins at the same depth as the basin sills. The shallower basins have sills at the depth of the oxygen minimum layer and so their oxygen concentrations are only about 0.7 mg/L, while deeper basins have dissolved oxygen of 2 mg/L (Fig. 4-16) (Rittenberg, et. al., 1955). Minard (1968) compared the temperature, salinity, and oxygen content of the Santa Monica and San Pedro basins in 1937 and 1954 with that of 1968 and noted that there were no significant long term changes. However, using Santa Barbara Basin as a model, Sholkovitz and Gieskes (1971) demonstrated that the replacement of basin water with colder, more saline, and more oxygenated seawater is a dynamic, and perhaps a seasonal process Vertical mixing is sufficient to maintain aerobic condition and the residence time of the basin water is about 5 years. Current measurements show that the flow at the bottom of' San Pedro Basin is normally very weak, less than 0.05 cm/sec, but strong surges can occur (LaFond and LaFond, 1973).

2.2 Characteristics and the amount of waste of high oxygen con-Sumption discharged from various sources

Most waste waters contain organic substances of high oxygen consumption. The indicators of the oxygen consumption potential are usually measured in terms of biochemical oxygen demand (BOD), chemical oxygen demand (COD), or total organic carbon (TOC). BOD measures only-part of the organic matter under decomposition, as well as sulfide, thiosulfate, ferrous iron, and perhaps ammonia. The COD test is more useful for industrial wastes and especially in measuring the efficiency of sewage treatment processes. The total organic carbon can also be a very useful parameter, if it is determined quantitatively.

In the study area the main input of biologically oxidizable organic rotter is from municipal waste dischargers. The oxygen consumption potentials from various sources are as shown in Table 4-1. Since the discharges from the Joint Water Pollution Control Project (JWPCP) has the highest 5-day BOD, COD as well as ammonia and organic nitrogen concentration, and discharges the greatest volume of effluent, it is the most important contributor of oxidizable organic matter. It must be noted that part of the industrial waste also discharges into the municipal sewage system. Comparing both BOD and COD values, the industrial waste waters and the surface runoff combined are only 2% and 13% respectively of that through the municipal discharges (1973).

The industrial waste is discharged primarily to the San Pedro Bay area, which received 70% of the total COD in 1971-1972. As for the surface runoff, both the Ballona Creek and the Dominguez Channel carried the highest concentration of TOC and COD in 1971-72 and can be accounted for most of the discharge of oxygen consuming substances. More than 90% of BOD and COD are discharged to the area from Santa Monica Bay to Newport Bay.

Table 4-1

OXYGEN CONSUMPTION POTENTIAL OF THE DISCHARGES FROM VARIOUS SOURCES, 1971-1972, IN M TONS/YR.

Area	5-day BOD Muni.	BOD Indust.	COD Muni.	COD Indust.	Surface Runoff
Pt. Mugu-Palos Verdes Pt.	59,000		154,000	18,000	8,000
Pales Verdes Pt.-Pt. Fermin	160,000		311,000		
Pt. Fermin-Newport Bay	36,000	6,000	113,000	43,000	14,000
Newport Bay-Del Mar	2,000		5,000		1,000
Del Mar-Mexican Border	28,000		77,000		
Total	285,000	6,000	660,000	61,000	23,000

Data from SCCWRP Table 4-28, P. 101 (1973).

2.3 Replenishment of dissolved oxygen in marine basins

In the study area, another important oxygen consumption potential is in the bottom-most layer of the basin water. The concentration of dissolved oxygen in the basin water is less than half the average concentration at sill depth (Fig. 4-17). Such a reduction of oxygen is due to the presence of organic detritus material. If no replenishment were to occur, oxygen would be depleted and stagnant oxygen-free waters would result. Due to the high productivity of the surface layer of the water, the amount of organic matter sinking through the water is large, although most of it is eatenup by scavengers. The amount of organic matter which reaches the bottom and becomes buried is about 4.9 mg cm^{-2} $year^{-1}$ (Emery and Hulsemann, 1962). In the Santa Catalina Basin, the use of free dissolved oxygen is about 3ml cm^{-2} $year^{-1}$ of sediment surface. Since oxygen is present in the bottom-most layer of the basin water, the supply of dissolved oxygen through advection and renewal processes must be sufficient to satisfy the amount used in the decomposition (Emery, 1960). The presence of oxygen in the Santa Catalina Basin also allows nitrate, formed in the upper zone of oxidized sediment, to be denitrified in the reduced subsurface zone. This results in a greater net loss of nitrogen than in Santa Barbara Basin, where the absence of an oxidized zone makes this type of cycling of nitrogen impossible (Kaplan and Rittenberg, 1965).

3. Nutrients

3.1 Characteristics and the distribution pattern of nutrients

In the euphotic zone of the sea, the photosynthetic production of organic matter by photoplankton depends on the availability of inorganic nutrients. Both nitrogen and phosphorus, and in certain cases, silica, are known as the micronutrients (Riley and Chester, 1971). They are present at the micromolar level and during the blooming of phytoplankton growth they may be completely exhausted. Under such conditions, the rate of production of organic matter in the sea becomes severely limited. However, precipitation, land drainage, upwelling, and the decomposition of organic materials will replenish these micronutrients in the sea water. Such processes, together with the turbulence and mixing would raise the micronutrient concentration in the receiving body of water.

In the coastal zone of Southern California, the activities of man in altering the landscape by agricultural development, urbanization, and the discharge of sewage, industrial wastes, and waste treatment plant effluents often accelerate the nutrient input to the sea. Such processes, if uncontrolled, may cause the deterioration of the marine environment known as eutrophication. The relationships between the growth of phytoplankton and the enrichment or utilization of nutrients are very complicated (Moberg, 1928), and often involve an interrelationship study of climatic, physical, and geographical factors as well. In view of the complexity of the subject matter and its importance to the water qualities in the marine environment, in recent years several coastal ecological research projects have engaged in the study of the distribution of the micronutrients off Southern California.

The principal characteristics and the general distribution of phosphate and silicate from surface to 100 mare as follows (Fig. 4-18, 4-19) (Allan Hancock Foundation, 1965):

(i) The distributions of phosphate and silicate are relatively uniform in the entire coastal water of Southern California.

(ii) In general, lower values and smaller vertical concentration gradients occur in fall and winter.

(iii) In several places, relatively large increases in phosphate and silicate concentrations at subsurface levels occur in the April to June period.

The concentration of phosphate in the coastal waters of Southern California is relatively high in comparison with that of the Gulf of Maine and the English Channel (Reid, et al., 1958). This is due to the great replenishment of phosphate by upwelling during the period of heavy plant growth in summer. The amount of phosphate from upwelling can easily counterbalance the maximum rate of consumption, which has been estimated to be in the order of 0.012 mg l^{-1} $month^{-1}$ (Reid, et al., 1958). However, the surface phosphate values do not show the effects of upwelling as clearly as have temperature and salinity. In several places at the appropriate times, higher phosphate concentrations occur as the result of upwelling, but the pattern is not so regular or simple as those of temperature and salinity.

There was relatively little reliable data concerning the distributionof nitrogeneous nutrients in the study area prior to 1965, because satisfactory analytical technique, especially for nitrate, was not available. A general survey of the distribution of nitrate in the shelf area by the Allan Hancock Foundation showed that the surface nitrate concentration was in the order of 0.01 to 0.16 mg/L. There was an increase from 0.2 to 0.4 mg/L at 100 m.

The distribution of nutrients in the Santa Monica Basin and the Santa Catalina Basin has been measured by Rittenberg get al., (1955) and Minard (1968). The concentrations of phosphate and nitrate are nearly uniform below about 800 m, and there is relatively little variation from basin to basin. This is due to the almost constant concentration of both phosphate and nitrate in the open sea. Silica becomes uniform with depthat about 1000 m. Thus, the concentration of silica depends on the sill depth. A basin with a deeper sill will have a higher silica concentration. (Table 4-2) (Minard, 1968).

3.2 Nutrient enrichment and eutrophication near outfall areas

3.2.1 Sources of nutrient enrichment. The study area is well known for its relatively high productivity because of the upwelling water along the coastal areas which supplies the limiting nutrients, usually nitrogen, from the deeper depths. Assuming an average upwelling rate of 40 m/month during a three-month period from April to June, and an average nitrogen concentration of 0.2 mg/L in the upwelled water (SCCWRP, 1973), the supply of nitrogen over an area of 1 km^2 is 24 M tons. If upwelling occurs along 25% of the coast from Point Dume to the U.S. - Mexico border and within a zone of 60 km from the shore, the total annual supply of nitrogen is approximately 120,000 M tons. This is substantially greater than the total amount discharged from the municipal wastewater, industrial wastewater, and surface runoff (Table 4-3). However, in contrast to upwelling, the supply from waste discharges tends to be relatively constant throughout the year, localized, and in the case of municipal wastewater, diffused below the euphotic zone.

Table 4-2

NUTRIENT CONCENTRATIONS NEAR THE FLOOR OF THE MARINE BASINS

Location	Basin	Depth m	Total-P mg/L	Ortho-P mg/L	Total Org-N mg/L	NO_3-N mg/L	SiO_2-Si mg/L	Ref.
33°51.7'N 119°07.5'W	Santa Monica	833	0.13	0.10	0.11	0.22	2.57	Merz, 1959
33°48.7'N 118°55.4'W		876	0.14	0.12	0.13	0.28	2.62	"
33°45.4' N 118°51.5'W		880	0.18	0.08	0.23	0.38	2.38	"
33°45.5'N 118°34.8'W	San Pedro	770	0.09	0.11	0.11	0.34	2.38	"
33°38.1'N 118°2. 'W		871	0.16	0.09	0.10	0.40	2.43	"
33°34.3'N 118°24.8'W		848	0.22	0.11	0.12	0.25	2.66	"
33°31.0'N 118°21.0'W		872	0.11	0.12	0.12	0.33	2.62	"
Average			0.15	0.10	0.11	0.31	2.51	"

(continued)

Table 4-2 (cont'd)

NUTRIENT CONCENTRATIONS NEAR THE FLOOR OF THE MARINE BASINS

Location	Basin	Depth m	Total-P mg/L	Ortho-P mg/L	Total Org-N mg/L	NO_3-N mg/L	SiO_2-Si[2] mg/L	Ref.
33″45 N 118°46 W	Santa Monica	884		0.10		0.49	4.41	Merz, 1959
33°29.8'N 118°22.1'W	San Pedro	915		0.10		0.49	2.02	"
	Santa Monica	938		0.10		0.49	4.49	Emery, 1954
	Santa Catalina	1357		0.09		0.49	4.63	
	E. Pacific	750		0.10		0.48	3.70	Merz, 1959

Table 4-3

RATE OF INPUT OF NUTRIENTS FROM DISCRETE SOURCES, 1971-72, in M TONS/YR

Area	Dissolved Silica	Nitrate Nitrogen	Ammonia Nitrogen	organic Nitrogen	Total Nitrogen	Phosphate
(i) Muni. wastewaters						
Point Mugu - Pales Verdes Point	12,000	290	8,100	6,400	14,800	3,200
Pales Verdes Point - Petit Fermin	9,000	112	41,000	13,700	55,000	7,300
Point Fermin - Newport Bay	5,500	48	5,900	2,600	8,600	1,180
Newport Bay - Del Mar	1,000	4	350	123	590	240
Del Mar - Mexican Border	3,500	333	3,100	1,700	5,100	810
Total	31,000	487	58,450	24,023	84,090	12,010

(continued)

Table 4-3 (cent'd)

RATE OF INPUT OF NUTRIENTS FROM DISCRETE SOURCES, 1971-72, in M TONS/YR

Area	Dissolved Silica	Nitrate Nitrogen	Ammonia Nitrogen	organic Nitrogen	Total Nitrogen	Phosphate
(ii) Surface runoff						
Point Magu - Pales Verdes Point	800	210	102	260	570	64
Point Fermin - Newport Bay	900	400	100	560	1,070	165
Newport Bay - Del Mar	300	180	37	52	270	35
Total	2,000	790	239	872	1,910	264
(iii) Indust. waste						
Point Fermin - Newport Bay			9,500		10,000	

Data from SCCWRP, Table 4-28, p. 101 (1973).

3.2.2 Eutrophication near outfall areas. The enhancement of nutrient input in the outfall areas increases chlorophyll concentration and phytoplankton growth in comparison with those from non-outfall areas. Associated with such enhanced phytoplankton production are high concentrations of chlorophyll a, adenosine triphosphate (ATP), and particulate organic carbon and nitrogen (Fig. 4-20, 4-21). There are no appreciable differences in the concentrations of nutrients or dissolved organic constituents, e.g., dissolved organic carbon, nitrogen and phosphorus, and vitamins B_{12}, B_1 (thiamine) and biotin, between outfall areas and the normal coastal background. This may be due to rapid uptake of nutrients, or simply the effective dispersal of these substances from the outfall regions (Eppley, et al., 1972).

3.2.3 Rates of uptake of nitrogenous nutrients. Near the sewage outfall areas, the ammonia concentration may be increased to 30 μ moles N/L (0.42 mg/L) at the depth of 30 - 40 m (Eppley, 1971). Ammonia profiles obtained at a position slightly downstream from the outfall diffusers show that the ammonia concentration pattern can be used to estimate the dilution, thickness, and the vertical position of the effluent from the outfall systems (Hendricks and Harding, 1974) . The decrease in ammonia concentration downstream of the effluent could not be explained by a simple diffusion model. Uptake by motile phytoplankton would give abrupt changes in ammonia concentration profiles. McCarthy (1972) studied the relative utilization rate of different nitrogen species by matural phytoplankton at different locations. Off Whites Point, the water was the most productive with respect to all three nitrogen forms; i.e. high utilization rates of nitrate, ammonia and urea. The average percentage of total nitrogen productivity accounted for by urea is about 28%. However, when the ammonium concentration is in excess of 0.5 - 1.0 μg at N/L (7 - 14 μg/L) the uptake of both nitrate and urea are suppressed. A considerable amount of nitrogenous nutrients turns over each day. High biomass occurs near the Whites Point sewage outfall, where the high rate of input and high utilization rate prevent nutrient accumulation. The average ratio of carbon utilized (from ^{14}C productivity) to nitrogen utilized from ^{15}N productivity) is 12.4, corresponding to an enrichment in carbon. This may be due to phytoplankton growth limiting concentrations of nitrogenous nutrients.

3.3 The atomic ratios of biologically important substances

In the offshore water the vertical profile of inorganic and organic nutrients has a layering pattern (Hol.m-Hansen, et al.., 1966), which can be studied using the atomic ratios of both the dissolved and particulate constituents.

3.3.1 Oxidized carbon:nitrogen:phosphorus. The amount of oxidized carbon can be calculated from the apparent oxygen utilization assuming a constant respiratory quotient or photosynthetic quotient (Redfield, Ketchum, and Richards, 1963). Table 4-4 shows that the average ratio of carbon oxidized:nitrate:phosphate is about 100:18.4:3. The N:P ratio by atoms is about 15:1 in the top 200 m, which is expected in the case of complete oxidation of oceanic phytoplankton. This ratio is lower for the rest of the water column to the depth of 1,300 m.

3.3.2 Oxidized carbon: silicon. The ratio between oxidized carbon and silicon decreases rapidly below 200 m from 100:60 to about 100:106. This is because much of the oxidized carbon has been removed from diatom residues by about 900 m, but the liberation rate of silicon may be approximately constant with time. The production of carbon dioxide per mole of silicate dissolution decreases from about 4 moles in the near surface to about 0.2 mole in the deeper waters, which corresponds to the dissolution of frustules containing less than 10% organic matter (Holm-Hansen, et al., 1966).

3.3.3. C:N:P in dissolved and particulate organic compounds. The average ratio by weight of carbon to nitrogen to phosphorus in dissolved organic compounds is 100:11:1.1, which is poorer in nitrogen and considerably poorer in phosphorus as compared with those in the water samples. However, in comparison with those reportedby Holmes, et al. (1967) and Williams (1969), it is still some 30% richer in nitrogen (Table 4-4). The average ratio of C:N:P for organic particulate matter is 100:8:2, which has even less nitrogen with respect to carbon. However, the average carbon:nitrogen ratio is very close to those given by Emergy (1960) for sediments in the same area. The average particulate C:N ratio for red water in La Jolla Bay is 100:14.1, which is definitely richer in nitrogen.

The average ratio of dissolved organic carbon to oxidized carbon in the water is 20:100 and the corresponding ratio for organic nitrogen to oxidized nitrogen is about 15:100. This suggests some 16% of the carbon and 13% of the nitrogen have passed through a dissolved organic stage before being completely oxidized. Beneath the euphotic and the immediate subeuphotic zone, at about 200 m, all these ratios become nearly constant, which may be due to the slow oxidation of dissolved organic matter in comparison with the rate of oxidation of any fresh detrital plankton remaining in the water. The percentage of dissolved organic carbon not associated with either nitrogen or phosphorus exceeds 50% of the total organic carbon. Those carbons unaccounted for in either dissolved or particulate organic matter are probably non-nitrogenous material or an inert organic residue with a very high carbon to nitrogen ratio (Holm-Hansen, et al., 1966).

4. pH

4.1 Distribution pattern of pH

The range of pH for the shelf water varies from about 7.5 to 8.6. The Allan Hancock Foundation showed that the pH of 65% of the 200 water samples collected had pH within the range of 8 to 8.2. At about 70 - 100 m, pHofthe seawater decreases to a range of values between 7.6-7.8 (1965). High pH values at or near the sea surface are due to the equilibrium with the carbon dioxide in the atmosphere, but the maximum pH values maybe caused by the photosynthetic activity of plants, which reduces the content of carbon dioxide in seawater. Below the euphotic zone, pH decreases as the concentration of carbon dioxide increases as a result of respiration and decomposition. In the oxygen minimum layer, pH approaches a limiting value of 7.5. Below the oxygen minimum layer, there is a gradual increase in pH with depth. The pH of the water below the sill depth in the marine basins in the coastal borderland depends on the sill depth. Those basins having deeper sill depth will have higher pH values. The Santa Monica Basin has sill depth of 737 m, and the pH of the basin below sill depth ranges between 7.68 - 7.77, while the Catalina Basin, which has sill depth of 982 m, the corresponding range is 7.70 - 7.89 (Rittenberg, et al., 1955).

4.2. Changes in pH in bottom basin water due to carbonate dissolution

The change in pH of the bottom layer of the marine basin water has been used to estimate the amount of calcium carbonate dissolution (1971). A plot of pH vs dissolved oxygen content (Figure 4-22) of the basin water shows that within 15 m. of the basin floor pH increases about 0.1 unit with no accompanying change in dissolved oxygen (Rittenberg, et al., 1955). Seawater pH changes can be attributed to the increase in carbon dioxide related to oxygen utilization as well as to the release of carbon dioxide as a result of calcium carbonate dissolution. Park (1968) showed that for seawater of normal alkalinity,

$$\text{APH} = 2\ \text{A}\ O_2(\text{m moles/L}) + 2.4\ \Delta CaCO_3(\text{m moles/L})$$

The mean increase of 0.1 pH units in the water within 15 m of the basin floors can be attributed to the dissolution of 0.04 m moles of calcium carbonate per liter of seawater. If such a dissolution rate occurs over

Table 4-4

ATOMIC RATIOS OF NUTRIENTS

Depths	C:N:P (by weight)			Oxidized C silicate	N: P (by atoms)	
	Oxidized	Dissolved organic	Particulate Organic		Oxidized	Dissolved
(i) Santa Catalina Basin						
0-75	100:21.0:3.2	100:14 :1.6	100:18:3	100:52	14.5:1	20:1
75-150	100:20.9:3.1	100:13 :1.1	100:11:2	100:59	15.0:1	27:1
150-220	100:19.8:2.8	100:15.5:0.8	100:10:1.7	100 :59	15.6:1	42:1
220-330	100:17.4:2.8	100:12 :1.2	100: 9:1.7	100:62	14.0:1	22:1
330-450	100:17.9:3	100:16.5:1.5	100:10:1.7	100:69	13.5:1	25:1
450-750	100:18.2:2.0	100: 9.5:1.0	100: 9:1.5	100:85	13.7:1	22:1
750-975	100:18.8:3	100: 6 :1	100: 7:2.5	100:106	13.8:1	14:1
975-1200	100:18.5:3.1	100:10 :0.9	100:10:3	100:114	13.4:1	24:1
1200-1300	100:17.9:3.1	100:13.5:1.4	100: 7:4	100:117	12.6:1	23:1
Average	100:18.4:3	100:11 :1.1	100: 8:2	100:93	13.6:1	22:1

Table 4-4 (cent'd)

ATOMIC RATIOS OF NUTRIENTS

Depths	C:N:P (by weight) Oxidized	C:N:P (by weight) Dissolved Organic	C:N:P (by weight) Particulate organic	Oxidized C silicate	N:P (by atoms) Oxidized	N:P (by atoms) Dissolved
(ii) San Diego Trench, Cruise 10-67						
0		100:10 .9:1.5				18.6:1
10		100: 5.8:1.0				11.8:1
50		100:11.1:2.6				22.2:1
100		100:11.0:1.2				4.8:1
200		100: 2.6:5.4				0.8:1
300		100: 1.9:1.1				4.3:1
400		100: 2.0:1.4				3.2:1
500		100: 2.9:0.3				20.6:1
Average		100: 6.0:1.8				10.8:1
(iii) San Diego Trench, Cruise 15-67						
5		100: 8.8:0.5				83.3:1
10		100: 6 :0.2				56.6:1
20		100: 7.5:0.5				31.5:1
50		100: 6.3:1.0				13.5:1
Average		100: 7.1:0.6				46.2:1

Table 4-4 (cent 'd)

ATOMIC RATIOS OF NUTRIENTS

Depths	C:N:P (by weight) Oxidized	C:N:P (by weight) Dissolved Organic	C:N:P (by weight) Particulate Organic	Oxidized C silicate	N:P (by atoms) Oxidized	N:P (by atoms) Dissolved
(iv) Red Tide (off Newport Beach, Nov. 67)						
0		100:11 .0:1.2				20.9:1
0		100:11.4:1.4				18 :1
5		100:10.3:1.1				19:8:1
20		100:13.9:2.2				13.6:1
Average		100:11.6:1.4				18.0:1
(v) Offshore, La Jolla Bay						
1		100:10.6:1.0	100: 7.3			9:1
12		100: 4.4:5.6	100:12.8			2:1
Average		100: 7.5:3.3	100:10			5:1

Table 4-4 (cent'd)

ATOMIC RATIOS OF NUTRIENTS

Depths	C:N:P (by weight)			Oxidized C silicate	N:P (by atoms)	
	Oxidized	Dissolved Organic	Particulate organic		Oxidized	Dissolved
(vi) Inshore, red patch, La Jolla Ray						
1		100: 7 :0.5	100:16.3			12:1
7		100: 8 :1.7	100: 9.2			7:1
12		100: 6.9:4.7	100:17.0			3:1
Average		100: 7.3:2.2	100:14.1			7.1

Data for (i), from Holm-Hansen, et al. (1966}, Table 1, p. 557
(ii), (iii) and (iv), calculated from values reported by Williams (1969), Table 1, p. 158
(v) and (vi) calculated from values reported by Holmes (1967), Table 1, p. 505

the whole Southern California borderland, an annual biochemical transfer of calcium carbonate is about 200×10^{10} g/year. This is comparable with the total amount of biological production of 346×10^{10} g/year and the amount of deposition on basin floor, on the slopes and on the shelf of 125×10^{10} g/year, and the amount transfer by rivers of 16×10^{10} g/year (1971). The high rate of dissolution is believed to be due to the rapid flushing of carbon dioxide rich waters from the North Pacific Ocean oxygen minimum layer throughout the study area. The above is supported by the observations (Ben-Yaakov & Kaplan, 1971) that the water west of the borderland is undersaturated with calcium carbonate in the oxygen minimum layer, from which California basin waters are derived (1960), while the water is supersaturated both above and below the oxygen minimum layer.

5* 'Trace Metals

5.1 Trace metal concentrations in seawater

The concentration range and the distribution of trace metals in seawater, though poorly known, are of great importance to the study of the marine environment. Some of these metals, such as copper and iron are physiologically essential to biological productivity but they become toxic when their threshold limits of concentration are exceeded. Some of these trace metals also can be concentrated and/or transformed to a state toxic to humans through the marine food chain.

The information concerning the general concentration level of trace metals in the study area is limited to the following elements:

Cobalt	0.1 - 0.2 µg/L	(Brooks, et al., 1967)
Copper	1.6-9 µg/L	(Brooks, et al., 1971; Williams, 1969)
Iron	1.9 -44.3 µg/L	(Brooks, et al., 1967)
Mercury	0.03 µg/L	(SCCWRP, 1973)
Nickel	0.4 - 2.5 µg/L	(Brooks, et al., 1967)
Lead	0.4 -18.2 µg/L	(Brooks, et al., 1967; Chow & Peterson, 1966)
zinc	1.1 -41.2 µg/L	(Brooks, et al., 1967)

For most of these, the levels are consistent with those reported in other parts of the world's ocean, except for lead. (Ref. Chapter 6).

5.2 Characteristics of the input of trace metals

The trace metals input to the study area are classified as diffused and discrete sources (SCCWRP, 1973) (see Chapter 6). Their distribution pattern by area is summarized in Table 4-5, and their characteristics are discussed below.

5.2.1 Discrete Sources. The most important discrete source is from the municipal wastewater discharge. The concentration and the annual emission rates are described in Chapter 6. Galloway (1972 a,b,c) showed that the magnitude of mobilization of copper into the ocean from the municipal wastewater discharge and industrial sources were comparable to that of natural weathering.

The total amount of trace metal input through surface runoff is roughly correlated with the suspended silt concentration. When storm water samples of Los Angeles River were filtered through 0.45 µ filters, more

Table 4-5

MASS INPUT OF TRACE METALS IN THE STUDY AREA (M TONS/YR)

Area	Ag	Cd	co	Cr	Cu	Hg	Ni	Pb	Zn	Fe	Mn
(i) Municipal wastewaters											
Pt. Mugu - Palos Verdes Pt.	1.1	25	3	148	190	2.1	147	31	330	660	16
Pales Verdes Pt. - Pt. Fermin	10.2	15.4		440	290	0.5	123	128	1220	5100	67
Pt. Fermin - Newport Bay	3.6	10.9		41	66	0.2	34	40	101	230	17
Del Mar - Mexican border		2.5		19	20	0.1	8	12	22		
Total	14.9	53.8	3	648	566	2.9	312	211	1673	5990	100
(ii) Surface runoff											
Pt. Mugu - Palos Verdes Pt.	0.4	0.2	0.4	5	3		1	21	21	1190	15
Pt. Fermin - Newport Bay	0.5	0.4	0.9	7.3	6	.05	4	57	52	11900	39
Newport Bay - Del Mar	0.02	0.1	0,3	0.8	0.9	.01	.7	3	4	700	15
Total	0.92	0.7	1.6	13.1	9.9	.06	5.7	82	77	13790	69

Table 4-5 (Cont'd)

MASS INPUT OF TRACE METALS IN THE STUDY AREA (M TONS/YR)

Area	Ag	Cd	Co	Cr	Cu	Hg	Ni	Pb	Zn	Fe	Mn
(iii) Ocean Vessel											
		0.1		1	357	3.6		8.8	152		
(iv) Ocean Dumping											
	1.5	14	14	28	28	1.5	28	28	56	280	28
(v) Aerial Fallout											
					400	8	40	3400	2200	40	
(vi) Advective Transport											
	6000	2000	8000	4000	60000	600	140000	6000	200000	60000	40000

Data from (SCCWRP, 1973)

than 75% of the metals, except nickel and copper, were found to be retained with the residues (SCCWRP, 1973). Maximum trace metal transport through surface runoff occurs during peak flow periods after the storms. As shown in Table 4-5, the inputs of iron, manganese and cobalt through surface runoff are comparable to or higher than those from municipal wastewater discharges. For the other, except lead, the rate of input is less than 10% of that from municipal wastewaters.

5.2.2 Diffused sources. The diffused sources in the study area include ocean dumping, aerial fallout, vessel waste and advective transport.

Refinery and chemical wastes represent the major sources of trace metal input to the study areas as ocean dumping. In 1971 about 1800 M tons\ year of refinery waste, and 1000 M tons/year of chemical and miscellaneous waste were being dumped. Assuming these wastes contain 0.5 to 1% by weight of trace metal content, the total amount of trace metal input to the coastal waters would range from about 1.5 M tons/year for silver and mercury to about 280 M tons/year for iron (SCCWRP, 1973).

The sources and the mass flux of trace metals in airborne particles are discussed in Chapter 6. SCCWRP (1973) estimated the rate of input of various metals based on the data of rain washout and found that both lead and manganese are in significantly higher concentrations. The input of lead from aerial fallout was independently estimated by Chow and Earl (1970) using the fallout data in La Jolla. The total annual input to the entire Southern California coastal region from both rain washout and dry fallout is approximately 1,000 and 2,400 M tons respectively. If 10,000 M tons of lead are released to the atmosphere by gasoline combustion, as much as 1/3 of this amount may fall directly into the coastal. waters.

Ocean going vessels and recreational crafts use antifouling paint, primers and sacrificial anode, which will release additional amounts of trace metals, especially zinc, copper and lead to the coastal waters (SCCWRP, 1973) (see Chapter 6).

The most important diffused source is from current transport. The mean concentration of trace metals in the California Current is as low as that in the open ocean. Due to its large volume, the total amount of trace metals transported annually is very large in comparison with all other sources. The combined total of various trace metals from all other sources is less than 4% of the amounts in the California Current except for chromium and lead, which are about 20%, and iron, about 54%, of the amount from current transport (SCCWRP, 1973).

Assuming a steady-state mass balance of the upper mixed layer of the Southern California borderland, the budget of any trace metal may be written as:

Transport by Current = (all sources of input) - (sedimentation)

= (concentration difference between the inflow and outflow water) x (flow rate).

Theoretically, the budget of any trace metal can be verified by measuring the difference in concentration between the inflow and outflow waters of the Southern California borderland. However, such differences are usually very small. Estimate of the maximum differences in mercury concentration is in the order of 0.005 to 0.006 µg/L or about 20% of the background mercury concentration in the open ocean waters, which is approximately the detection limit for mercury in seawater (Young, 1971).

5.3 Dispersion patternof trace metals from the outfall systems

Although the amounts of trace metals discharged from the outfall system are quite large, they are diluted as expected at a 100 to 1 ratio. The four metals listed in Table 4-6 show some decreasing concentrations at increasing distances from the outfall, but the general distribution pattern has not been mapped. Except for lead and cadmium, the concentrations of trace metals in the sea water collected near the outfall systems are consistent with the levels reported in other parts of the world's ocean. However, core samples from the sediment around the outfall have very high concentrations of most of the trace metals, except iron and manganese. Mercury, cadmium and lead are highly enriched in the surface sediment layer, especially off Whites Point area (SCCWRP, 1973; Galloway, 1972b) .

The degree of damage to the marine biota due to high enrichments of trace metal concentrations in the sediments is still relatively unclear. Investigations based on analyses of trace metals in clover sole liver tissue showed that specimens from near the outfall did not contain significantly higher metal concentrations. In certain cases, e.g. selenium in albacore liver, silver in clover sole livers, the specimens had higher concentration than that for other fishes (SCCWRP, 1973) (See Chapter 11). More studies are required to understand the mechanisms of uptake and transport of trace metals in the marine environment.

5.4 Degree of trace metal complexation in the coastal water

The toxicity of a trace metal depends not only on the total amount of the metal present, but also the form of the metal and the degree of chelation, The typical example is mercury, which can exist andbe transformed into different forms in the marine environment. Young (1971) reviewed the chemistry and biochemistry of mercury in aquatic ecosystems, and indicated that inorganic forms are converted to the highly toxic organomercurials by microorganisms in sediments under both aerobic and anaerobic conditions. When benthic organisms are present, mercury-rich sediment in the deep layers released the methylated form to the sea water. Fish accumulate all forms of mercury, including methylated mercury directly absorbed from water through the gills.

Apparently, the variations in toxicity of trace metals depend on the degree of complexation with the natural chelators in sea water. Newly upwelled water must be organically conditioned to make trace metals

Table 4-6

CONCENTRATIONS OF 4 TRACE METALS (µg/L) IN RECEIVING WATERS AROUND 'IWO LOS ANGELES WASTEWATER OUTFALL SYSTEMS

Trace Metal	Effl. (x.01)	JWPCP Outfall Diff. *	Interm. **	Control	Effl. *** (x.01)	Diff.	Interm.	Control	Normal ranges
Cd	.3	.56	.23	.20	.5	.33	.26	.74	.1
Cu	5.2	1.5	1.2	.74	2.3	1.6	.83	1.9	.1-23
Pb	1.6	< .16	< .16	<.12	.6	.73	.80	< .16	.03-.3
Zn	24	9	8.8	6*8	4.6	5*3	8.0	18.0	.7-52.5

Data from SCCWRP (1973)

* Diff. = Samples taken just above the bottom and close to the diffusers
** Interm. · Samples taken from near-bottom and subthermocline levels at stations approximately half as far from the diffusers as the "Control" stations
Control = Samples taken 2 or more kilometers from the discharge
*** Effl. X .01 = metal concentrations that could be expected at a 100-to-l seawater dilution of final effluent, assuming metal-free dilution water.

available before phytoplankton blooms can occur (Barber and Ryther, 1969; Barber et al., 1971). In the study area, copper has been found to associate with dissolved organic matter in-seawater (Williams, 1969).

There is no direct correlation between organically associated copper and the concentration of organic carbon, nitrogen or phosphorus . However, nearshore surface samples are relatively high in inorganic copper. The percentage of organically associated copper in the total copper varies from 5 to 28% and shows no significant variation in concentration with depth. One red tide sample collected off Newport Beach showed very low organically associated copper. The exact nature of these organically associated copper compounds may be complexes with phospholipids, carotenoids, or other lipid soluble fractions (Slowey, et al., 1967).

The availability of trace metals for phytoplankton blooms has been interpreted as the reduction of copper toxicity by the organic-conditioning compounds (Steem-Nielsen and Wium-Andersen, 1970). Bioassays show that copper at levels as low as 1 ppb can be inhibitory to <u>T. pseudonana,</u> a marine diatom. Since the total copper concentration is often greater than 1 ppb, the results suggest that the variation of trace metal toxicity may be affected by the degree of complexation (Davey et al., 1974).

6. Chlorinated Hydrocarbons

6.1 Effects and concentration levels of chlorinated hydrocarbon residues in marine organisms

The presence of the residues of polychlorinated biphenyls (PCB), and DDT compounds in the California coastal environment are widespread. Marine organisms caught from the waters off Southern California consistently contain higher concentrations of DDT residues than in those areas receiving extensive agricultural drainages (Risebrough, et al., 1970). Once the residues are incorporated into the marine food chain, their concentrations may be magnified to the ppm level. The muscle tissues of fishes from Santa Monica Bay were found to contain up to 35 ppm of DDT residues (1970). Fish-eating birds of Southern California have relatively high levels of DDT (Risebrough, et al., 1970), and fish from nearshore area off Los Angeles have extremely high (100 to 1000 ppm) levels of DDT in their tissues (Munson, 1972). (See chapter 13 and 11).

It is now well known that chlorinated hydrocarbons exert a broad range of adverse physiological effects on a wide variety of life forms, e.g., rockfish from Santa Monica Bay containing high pesticide residues in liver had no ovarian development during spawning period (Macgregor, 1972). Sublethal effect may occur evenat 0.01 ppb in sea water (Nat. Acad. Sci., 1971).

Engel, et al., (1970) noted an inhibition of enzyme activity of the quahog clam at 2 ppb. Some species have the ability to accumulate higher body burdens of pesticides without showing any apparent adverse effects. Butler (1969) reported that oysters with a body burden of 25 ppm showed no observable adverse effects, but 50% mortality occurred to fish and shrimp within 2 days after feeding on those same oysters. Although PCB is about 100 times less toxic than DDT, contamination with either of these toxins renders fish unsuitable for human consumption as well as causing deterioration of water quality in the coastal zone.

6.2 Characteristics and the dispersion patternof chlorinated hydrocarbons

The major source of chlorinated hydrocarbons to the study area as surveyed by SCCWRP (1973) are primarily from municipal wastewater dischargers (Table 4-7). Concentrations of chlorinated hydrocarbons in marine organisms have been found to be high in the vicinity of the outfalls, where the effluent is ultimately diffused and mixed with the coastal seawater. The amount of DDT discharged at the outfall of the Los Angeles County Sanitation District's Joint Water Pollution Control Plant (JWPCP) at Whites Point includes the industrial effluent of the Montrose Chemical Company, which is the

Table 4-7

MASS INPUT OF CHLORINATED HYDROCARBONS (kg/yr)

Area	Total DDT		Total PCB		Dieldrin	Total CHC	
	Muni.	Runoff	Muni.	Runoff	Runoff	Muni.	Runoff
Point Mugu-Palos Verdes	88	21	570	18	9	860	49
Pales Verdes - Pt. Fermin	19000		6,000			25,000	
Pt. Fermin-Newport Eay	75	88	3,000	214	20	3,100	322
Newport Bay-Del Mar		2		3		[illegible]7	6
Del Mar-Mexican Border	22		110				140
Total	19185	111	9,680	235	29	28,961	517

Data from (SCCWRP, 1973)

Muni. = Municipal wastewaters

Runoff = Surface Runoff

largest DDT manufacturer in the United States.

About 99% of the total DDT and about 62% of the total PCB from municipal sewage comes directly from the outfall of JWPCP. The OCSD effluent contains about the same concentrations of DDT as found in those from the Terminal Island and Pt. Loma facilities. Ocean dumping is another important source of DDT and PCB in the study area. The annual emission rates were approximately 14 M tons/yr of DDT and 28 M tons/yr of PCB.

The chlorinated hydrocarbon concentration in samples collected from the Los Angeles River seems to be proportional to the amount of storm flow (Figure 4-23). The concentrations of silt and chlorinated hydrocarbons increase when the storm flow reaches its peak and decreases when the storm flow subsides. The flow-weight mean concentrations of total DDT, PCB and dieldrin in storm water indicate that the total chlorinated hydrocarbons in the Los Angeles River waters are significantly higher than that from the Santa Clara, Ballona Creek and Santa Ana Rivers (Table 4-8). The input (71-72) by surface runoff (storm water plus dry weather flow) were approximately 120 kg DDT, 250 kg PCB, and 31 kg Dieldrin. However, the total chlorinated hydrocarbons was only 1% of those from the municipal wastewater discharges (SCCWRP, 1973).

The aerial fallout of chlorinated hydrocarbons is difficult to esthate. Probably the amount from dry fallout is much greater than that from rainfall washout. If the fallout rate of total chlorinated hydrocarbons is about 0.1 $\mu g/m^2/day$, with most of the material divided almost equally between DDT and PCB (McClure, 1973), the annual aerial fallout rate of chlorinated hydrocarbons would be shout 2 M tons of DDT and 2 M tons of PCB (SCCWRP, 1973).

The total amount of chlorinated hydrocarbons transported by the California Current is about 5 times the other sources combined, but its concentration is about 0.01 μg/liter (SCCWRP, 1973).

Table 4-8

AVERAGE CONCENTRATION OF CHLORINATED HYDROCARBONS (µg/L)
IN STORM WATERS, 1971-72 *

Stream	Volume ** (10^6 cu m)	Total DDT	Total PCB	Dieldrin	Total Identified Chlorinated Hydrocarbons
Santa Clara River	22.7	0.15	0.22	0.016	0.39
Ballona creek	4.1	0.43	0.36	0.21	1.0
Los Angeles River	9.7	0.88	2.5	0.13	3*5
Santa Ana River	1.8	0.12	0.24	0.053	0.41

* Flow-weighted mean.

** Accumulated storm flow from which samples were obtained for chlorinated hydrocarbon analyses.

From SCCWRP, Ecology of the Southern California Bight, table 4-24, p. 4-24, p. 95.

6.3 Distribution of concentration of pesticide residues in marine organisms nearby the outfalls

Polychlorinated DDT and PCB are very resistant to degradationby microorganisms because they possess a high partition coefficient between water and lipids of marine organisms. Thus, most chlorinated hydrocarbons entering the sea will be accumulated in the food cms. Average PCB concentrations in the lipids of thin-shelled eggs of the Brown Pelicans (Pelecanus occidentals) were about 200 ppm. The concentrations of total DDT and PCB in muscle tissue of clover sole ranged from 0.05 to 24 ppm and 0.02 to 2.4 ppm respectively. The specimens from the Whites Point, Hyperion, and OCSD outfalls had higher DDT residue contents than those collected from Santa Catalina Island (SCCWRP, 1973). About 60% of clover sole captured during 1971-72 in trawls between Redondo Canyon and the Western entrance of the Los Angeles Harbor exceeded the maximum total DDT concentration (5 mg/kg weight) permitted by the U.S. Food and Drug Administration in fish to be offered for sale. Munson (1972) compared the DDT/PCB ratio indifferent species of organisms caught from the orange County and San Diego coastal waters. The average ratio of DDT/PCB for samples from San Diego was one, while samples from Orange County had a ratio of 0.35. The large amount of PCB added to the marine environment by sewer outfalls in the Los Angeles-Orange County area caused such a difference (Schmidt, Risebraugh & Giess, 1971). The lowest levels of DDT and PCB were found in the abalone, which is a strict herbivor. The whelk and the spring lobster, both scavenger-carnivores had the highest concentrations of DDT and PCB. All these results indicate a significant contamination of the marine food chains by chlorinated hydrocarbons in the outfall areas.

6.4 Distribution pattern of pesticide residues in the sediment layer

No measurement of chlorinated hydrocarbon input to the study area was made prior to 1970. However, there are indications that the input has been considerable for a long period of time. Maximum concentrations of 100 mg/kg DDT and 10 mg/kg PCB were observed for surface sediment collected immediately to White Point outfall (SCCWRP, 1973). In general, the concentrations of chlorinated hydrocarbons declined both to the north and to the south of the outfall system, although the decline was found to be more rapid to the south. DDT and PCB concentrations in the surface sediment layers were much higher than those in the deeper layers. Sediments taken 15 cm below the surface of the bottom and over 6 km from the outfall contained 310 ppb chlorinated hydrocarbons, almost entirely DDT (Carry and Redner, 1970). This value is probably much less than the amount originally laid down at that stratum, since anaerobic bacteria can break these pesticides down to water soluble products. Of five samples taken off the top ‘2.5 cm of sediment and within 8 km of the Whites Point outfall, the lowest amount of chlorinated hydrocarbons found was 16 ppm. Using this value as a low estimate for the concentration in the sediments within a rectangle extending along the shore 8 km in both directions and out to the sea 8 km from shore, and assuming a sediment density of 2 g/c.c., the amount of chlorinated hydrocarbons input is 102 M tons. A year of input at the highest measured rate of 290 kg/day would be requiredto account for these surface sediments (Burnett, 1971).

Since DDT residues are associated with the finer, more mobile particles, they are easily carried away by strong currents to a distance far away from the outfall. Resuspension of chlorinated hydrocarbon residues during storms or periods of upwelling and mixing has been found to be possible (see Chapter 6).

7. Suspended particulate matter

7.1 The nature and the distribution of suspended particulate matter

The suspended particulate matter in the sea can be divided as inorganic or organic material having a diameter greater than 0.5 µm, while those passing through a 0.5 µm membrane filter are true dissolved matter together with colloidal. The organic suspended materials are mainly oily substances or of natural origin, such as plankton or organic detritus material, which are mainly carbonaceous and nitrogenous remains of organisms. Usually the amount of the dissolved organic matter in the sea exceeds the particulate organic fraction by a factor of 10-20 and only l/5 of the particulate matter, on the average consists of living cells (Riley, 1963). The inorganic materials are mainly terrigenous detritus derived from rivers and the adjoining shelves and marine sediments, that have been stirred up and mixed with overlying water.

The distribution and the concentration of the suspended matter in a water column depend on the rate of supply and the influence of transporting agencies, e.g., currents and waves, on the material. The carbonaceous and nitrogenous remains of organisms have a density close to that of water and are usually transported together with very fine-grained inorganic particles, principally silts and clays. The relative abundance of organic and inorganic constituents in the suspended particulate matter is a function of the relative rate of supply and deposition, which will vary with seasons and depths. In the study area, the concentration of organic matter varies from 4 to 26% for surface samples and 3 to 12% for samples from deep depths (Drake and Gorsline, 1973). The supply of organic detritus material. is considered to be abundant because of the moderately high productivity of the water. This is evident from the higher organic contents of the sediments, when compared with sediments of equal fineness from elsewhere (Revelle and Shepard, 1939).

Typical distribution patterns of suspended sediment and plankton in the water of the study area were obtained by Gunnerson and Emery (1962). Sectional patterns (Fig. 4-24) show that plankton concentration varies inversely with depth while suspended sediment concentration varies inversely with distance from shore. The inorganic sediment consists of feldspar, quartz and biotite with minor amounts of hornblende, muscovite and opaque minerals. The median diameter of this suspended sediment was about 30 µm. Localized high concentrations of 2 µm diameter sediment, greater than 100 grains/ml, occur near the bottom at depths between 200 to 275 m. Plankton distribution (Fig. 4-24) is similar to that of suspended sediment. This type of entrainment and sinking of plankton along with the suspended sediment must originate within the upper 50 m on the continental shelf.

7.2 Characteristics and the amount of suspended matter discharged

In the study area, besides the supply of terrigenous materials from Los Angeles River, San Gabriel River and Santa Ana River, a relatively large amount of particulate material is discharged from the municipal and industrial wastewaters. The following is a summary of their annual rates of supply.

7.2.1 Surface runoff. It is difficult to estimate the amount of suspended terrestrial material supplied annually to the coastal ocean of Southern California. The complicating factors include the extremely variability of the total runoff and rates of discharge, not only from year to year, but between different storms in the same year. Suspension concentrations of samples collected near the mouth of Los Angeles River ranged from 1.5 g/L to 8.7 g/L (Rodolfo, 1970). The average annual discharge of suspended matter from Los Angeles Basin, San Gabriel Basin and Santa Ana-San Jacinto Basin based on runoff record of 1927-1967, was 717×10^4 M tons (Rodolfo, 1970). SCCWRP report estimated about 74,000 M tons of silt were discharged in 1971-72, but during the above period, the surface runoff was equivalent to about 50% of the long-term average (Table 4-9) (SCCWRP, 1973).

Most of the suspended silt was discharged during the storm seasons. The flood control and the concrete channel linings effectively eliminate the suspended silt discharged from the rivers, such as the Los Angeles River, San Gabriel River and the Santa Ana River.

7.2.2 Municipal wastewater and Industrial wastewater. Most of the suspended solids, about 60%, are discharged from JWPCP at Whites Point (Table 4-9). Qualitative analyses of the sediment samples around the outfalls shows that silt was most common and its color was black with strong hydrogen sulfide odor. Apparently most of the suspended solids are settled around the outfall area (SCCWRP, 1973).

7.3 Transport of suspended particulate matter

Most of the suspended matter derived from land is transported seaward either as eolian dust or as turbidity currents diffused along the shelf floor. Sediments may be stirred up by surface waves, rip currents, internal waves (LaFond, 1962; Gunnerson and Emery, 1962) and storms (Beers and Gorsline, 1971) (Fig. 4-25). In the study area, the largest supply of suspended silt is from Santa Ana River. Observations showed that most of the suspended material was restricted within a few kilometers of the coastline

Table 4-9

MASS INPUT OF SILT AND SUSPENDED SOLIDS IN THE STUDY AREA

M TONS/YEAR, 1971-1972

Area		Silt	Total Suspended Solids	Volatile Suspended Solids
Point Mugu - Pales Verdes	(i)		61,000	37,000
	(ii)	12,000		
	(iii)		2,800	
Pales Verdes- Point Fermin	(i)		169,000	106,000
Point Fermin- Newport Bay	(i)		28,000	21,000
	(ii)	45,000		
	(iii)		12,800	
Newport Bay- Del Mar	(i)		2,000	1,000
	(ii)	17,000		
Del Mar- Mexican Border	(i)		14,000	11,000
Total	(i)		274,000	176,000
	(ii)	74,000		
	(iii)		15,600	

(i) Municipal waste waters
(ii) Surface runoff
(iii) Industrial waste waters

Data from (SCCWRP, 1973)

and tended to travel longshoreward rather than seaward (Manheim, Meade, and Bond, 1970). Surveys of the Newport area showed that concentrations above the thermocline over the shelf ranged from 3to 6.2 mg/L (Drake and Gorsline, 1973). Surface concentrations rapidly decreased beyond about 3 km from the shore to values that are essentially equivalent to those over the outer shelf. Light-transmission profiles across the shelf and slopes north and south of the canyon and along the canyon axis show uniform supply of fine particles with little evidence of turbidity flow (Moore, 1969). Nepheloid layers of high concentration of suspended matter were present over the mainland shelf and slope. The thickness ranged from a few meters to 200 m and the peak particle concentrations was 5 to 7 mg/L (Drake and Gorsline, 1973).

In the surface layer, the suspended matter is predominantly fine silt and clay that has been kept in suspension by wave and rip currents. The mechanism which brings the suspended material to the ocean floor has been suggested by Moore (1969) as a turbidity flow by gravity. Calculations based on density difference of the pycnocline layer (Postma, 1968; Drake and Gorsline, 1973) showed that the suspended matter concentrations should be at least of 1 - 2 g/L in order to penetrate the thermal density stratification. Light-transmission profiles (Fig. 4-26) show that suspended particulate matter settles to the thermocline. The subsurface maxima over the shelf are 'closely related to the density gradients and the microstructure of thermoclines. The maximum concentrations of suspended matter are less than 10 mg/L. Thus, under the normal conditions, turbidity current flow originating above the shallow thermocline is unlikely (Drake and Gorsline, 1973).

An alternative may be a combination of settling and gravity flow. Amass of turbid water descends by gravity until it reaches a layer with the same density. The flow then stops, but the particles continue to move by settling until they again moved by gravity flow (Postma, 1968). Complete understandings of the mechanisms of transport and the estimation of the rate of sedimentation in the borderland would require further research and studies.

8. Oily substances

8.1 Nature and distribution of oily substances on beaches and in the water

Oily substances are organic compounds, extracted fran polluted water by a suitable solvent, and consist of mineral oils, hydrocarbon derivatives, and vegetable or animal oils such as fatty acids. Alternatively they can be defined as oil comprising a highly complex mixture of hydrocarbons and their oxygen, nitrogen and sulfur derivatives, and grease, which originates in household and industrial wastes of solvent-extractable material. of animal and vegetable origin (McKee, 1956). Some of the saturated hydrocarbons and olefinic hydrocarbons in the oily substances occur naturally in many marine organisms and can be considered as harmless to the marine environment, while some aromatic hydrocarbons are acute poi sons for man as well as for all other organisms.

Oily substances in the marine environment may be derived fran oil production, industrial wastes, municipal waste, spill during transportation, and accidents. The non-anthropogenic source of oil is probably from submarine seeps. However, oil emitted by submarine seeps and deposited on beaches has characteristic component groups which are different f rom the other sources. In 1959, Rosen, Musgrove and Lichtenberg, analysed the characteristics of coastal oil samples from Manhattan Beach, Hermosa Beach, Coal Oil Point (northwest of Santa Barbara) , Redondo, Wilmington-Long Beach, Seal Beach and Ventura area (Rosen and Musgrove, 1959) . The oil samples collected by divers f rom the slick above the seeps were compared with crude oil samples by adsorption chromatography and infrared spectra methods. Among these samples, the seep oils contained more ether-insolubles (asphaltenes) , less neutrals, less aliphatics, more aromatics and Oxys . The general distribution of oily substances on beaches and in nearshore waters was surveyed by Merz (1959) by using chloroform extraction method. Most of the samples contained less than 0.6 g/m^2 or just a trace amount. Heavy deposits were found at Coal Oil Point (2.1 kg/m^2), Gaviota (3.7 g/m^2) and the southern end of Santa Monica Bay (.9-5.5 g/m^2). Water samples collected near the pier of Santa Monica Bay contained less than 0.1 ppm oily substances. Survey of beach deposits by Allen (1971) showed that approximately 86% of tarry beach deposits found between El Segundo and Redondo Beach could be identif ied as originating from the nearby offshore natural oil seeps.

8.2 Characteristics arid the amount of oily substances from various sources

SCCWRP (1973) classified the industrial waste dischargers into three groups: oil field brine, tanker and line ballast, and refinery and petrochemicals. Along the southern California coast, the estimated average concentrations of oil and grease from oil field brine and tanker and line ballast are 12 and 14 mg/L respectively (SCCWRP, 1973). Assuming these characteristics are representative of all similar industrial wastes, approximately 1400 M tons/year of oil and grease are contributed by discrete industrial waste discharges into the coastal ocean. The discharge into San Pedro Bay alone is approximately 800 M tons/year, because of the concentration of fish canneries, oil tanker mooring facilities, refinery and petrochemical industries, and other chemical industries.

The quantities of oil and grease discharged from municipal wastewater are summarized in Table 4-10. The largest contribution is from the JWPCP. The total from municipal discharge is almost 30 times that from discrete industrial waste discharge.

In the coastal areas, oily wastes are conveyed by municipal or industrial sewers to the ocean. IfLand, waste brines may be ponded for evaporation, held for release during high stream flows, or recharged into oil or brine-bearing strata. Ultimately part of the oil and grease discharged will find its way to the ocean through surface runoff. SCCWRP (1973) showed that the average oil and grease concentration in storm flows and dry weather flows varied from 1.5 to 49 mg/L. The concentrations of oil and grease reported in samples from Los Angeles-Santa Ana River basins (24 to 49 mg/L) were much higher than the concentrations reported for the Ventura-Santa Clara River basins (4 mg/L).

Most refinery wastewater, oil drilling wastes, and chemical wastes are finally disposed by ocean dumping. SCCWRP (1973) reported that approximately 480,000 M tons of petroleum refining wastes were dumped between 1946 and 1971, corresponding to an average of about 18,000 M tons/year. However, the reported annual dumping rate has dropped to about 1800 M tons/year since 1968. More than 3×10^6 M tons of oil drilling mud and cuttings were also dumped in the San Pedro Channel between 1966 and 1970, but they have been prohibited and discontinued since 1970. Since there is no quantitative information on these types of wastes, the annual rate of emission of oil and grease is difficult to determine.

8.3 Fate of oily substances in the sea

The fate of oily substances in the sea have been reported by Hoult (1969) and Nelson-Smith (1972). Once in the ocean, they tend to be dispersed and to a lesser extent evaporate into the marine

Table 4-10

MASS INPUT OF OIL AND GREASE INTO THE STUDY AREA
IN 1971-1972

Area	Municipal Wastewaters	Surface Runoff	Industrial Waste
	in M tons/yr.		
Point Mugu - Pales Verdes Pt.	14,000	1,400	1,300
Pales Verdes Pt. - Point Fermin	35,000		
Point Fermin - Newport Bay	7,400	2,400	800
Newport Bay - Del Mar	800	500	
Del Mar - Mexican Border	5,800		
Total	63,000	4,300	2,100

Data from (SCCWRP, 1973)

atmosphere. Volatile, low-molecular weight constituents with boiling point up to about 300°C evaporate quickly leaving behind more viscous residue, which ultimately may sink to the sub-surface mine environment. Some may be adsorbed into non-buoyant particulate matter or become emulsified by the physical action of waves and breaking water (Garrett, 1970). The extent of biological utilization and decomposition is uncertain at present. The heavier components will be deposited on the bottom forming a coat of sludge that smothers benthic organisms (Garrett, 1970). After an oil spill, the period for an area to return to ecological stability depends on a number of variables; e.g., populations of marine organisms and wildlife, configuration and flushing characteristics of the area, composition and behavior of oil spilled, etc (Straughan, 1970, 1972). In the case of S/S Tampico Maru, which went aground about 180 km. south of the U.S. border, seven years were required for the bay to return to a state resettling a "normal" ecosystem. Complete recovery may need an even longer time (Neushul, 1970).

9. Organic substances

9.1 Nature and the amount of organic substances discharged from various sources

Organic substances found in sea water are present in either dissolved or particulate form. The usual concentration range of dissolved organic matter in seawater is 0.3- 3 mg C/L. The non-living particulates of organic matter are aggregates formed mainly by adsorption of dissolved organic matter on bubbles and other naturally occurring substances (Riley, 1973). Their sizes range from about 5 to several mm in diameter and have been reported as "marine snow" in both near-surface and deep water environment. They are very fragile and serve as supplementary food for zooplankton. In the coastal environment, such as southern California, organic substances present in seawater also originate from anthropogenic sources as waste water. The major constituents of these wastes are carbohydrates, sugars, amino acids, non-amino acid nitrogenous compounds, organic acids, esters, anionic surfactants, and miscellaneous organic compounds. Once released into the ocean, they take an active part in chemical and biochemical processes in seawater and in the sediment layers (Hunter, 1970).

Quantitative information concerning the input of organic substances from the municipal sewage wastewater dischargers is summarized in SCCWRP report (1973). Organic nitrogen with an annual discharge of almost 25,000 M tons is the most abundant.

Since the total nitrogen from the municipal wastewaters is about 84,000 M tons/year, the percentage of organic nitrogen is about 30%. The only other major source of organic nitrogen is from surface runoff, but it is only about 4% of that from the municipal discharges . The other organic constituents, e.g., phenols, are probably diluted to an insignificant level after discharged from the sources. Thus, the organic nitrogenous compounds are a potential source of nitrogen, which may ultimately influence the productivity in the euphotic zone of the coastal waters.

9.2 Fate and the deposition of organic substances in the sediment

Any organic substance, regardless of form and origin, will be subject to decomposition once released to the ocean. The larger particulate type materials will tend to precipitate and settle rapidly as organic matter in the sediment. In the study area, the concentration of organic matter in the sediment ranges from essentially zero in sands through low concentration in the sediments of the shelves and bank tops to an average high value of 7% in the sediments of the basin floors (Emery, 1960). The rate of destruction of the organic matter in the sediments varies with the rate of sedimentation and the oxygen content of the overlying waters. In the study area, out of the original 100 grams (dry weight) per square meter of organic matter produced near the surface annually, only about 6.4% to 4.2% escapes oxidation or scavengers as it falls through the water column and is deposited on the sea floor (Emery, 1960. Most of the organic matter is rejuvenated within the top 2 m by biological action. Thus, when deposition is slow, oxidation can be complete, whereas when sedimentation is relatively fast, more organic matter escapes decomposition and is buried. Radiocarbon measurements indicates that organic matter accumulates at a rate of about 1.5 mg cm^{-2} year-l in the marine basins (Emery, 1960).

9.3 Distribution of dissolved organic compounds

Most of the dissolved organic carbon in the sea exists as a complex material (Gelbstoff), which is very resistant to bacterial attack. The other fraction consist of molecular aggregates or large molecules, e.g., proteins, carbohydrates, lipids, etc., or smaller molecules, e.g., vitamins, amino acids, sugars, urea or as dissolved gases. The low concentration level in the sea may imply these substances have a high rate of turn-over and participate actively in biochemical processes. In the study area only the dissolved free amino acids (DFAA) has been studied in detail (Clark, et al., 1972) to evaluate the effects of continuing man-made organic enrichment from the outfalls. The most abundant ones were ornithine, serine and glycine with peak concentration values of about 1 μ moles/L or 115 μg/L. The total DFAA levels were very high at the sewage outfall off Whites Point and Point Loma, at a level about twice the value found in surface samples from other parts of the world. Bottom water samples contained more DFAA than surface waters at both sites, with significantly more near an outfall than 24 kmaway Prom it, e.g., 2.4 vs. 1.6 μ moles/L. The interstitial water samples collected at Whites Point have even higher concentration ofDFAA, with mean value of about 3 μ moles or 345 μg/liter. Proportions of individual amino acids to the total DFAA were similar in virtually all samples. The only exception is glutamic acid, which was usually less than 6% of the total DFAA but accounted for about 15% of the DFAA in surface waters at Point La Jolla and Bird Rock. Ornithine, glycine, alanine, serine, and aspartic acid together contributed. more than 50% of the total with glycine and serine usually most abundant .

The DFAA content may vary considerably with currents, mixing, thermal stratification, and exposure to organisms. Abalone Cove is three times farther from the discharge area than Whites Point. During periods when currents carry wastes directly toward Abalone Cove, DFAA levels might even be lower at Whites Point. The concentration of DFAA in the study area is greater than in water samples obtained from the American east coast, the Irish Sea, the North Sea and the Norwegian Sea. However, these Atlantic sites have less upwelling, lower productivity and may have less influence from major sewage outfalls. Thus it is difficult to evaluate the overall coastal enrichment by the sewage outfall system based only on the information of DFAA alone.

10. Chemical Forces Modeling

10.1 Methods of modeling chemical forces

The behaviour of chemical forces in the marine environment depends on their chemical nature and the ways in which they may be altered by marine biochemical processes. The distribution and variation in intensity of these forces are affected by physical processes, e.g., currents, in the ocean. All these processes, physical and biological, which strongly influence the chemical forces are extremely complex and inmost cases are only partially understood. However, there is a strong need for making management decisions and regulations which rely heavily on a good understanding of these chemical forces as well as an ability to predict with a certain degree of accuracy their behaviour during any modifications of the environment.

The best tool available is the construction of models. At present, with the facilities of high speed and large capacity computers, it is possible to introduce factors which account for the various parameters in the interacting physical, biological and chemical processes in the ocean.

Simulation of chemical forces in a complex coastal. environment can be achieved either statistically or deterministically. The statistical model is generally based on empirical or statistical relationships among the observed parameters. For example, a chemical force, F may be influenced by the concentration of marine organisms (B), depth of thermocline (T), concentration of one or several chemical parameters (P), etc. The empirical model could be constructed to predict the influence of this chemical force:

$$F = f(B, T, P, \ldots)$$

The mathematical function can be in a polynomial form or any other form. The coefficients and exponents in the empirical function can be evaluated on the basis of field data. Such a function should not be used for extrapolation and provides little insight to the mechanisms of the processes within the system. The number of parameters may be reduced by dimensional analysis by combining them into non-dimensional quantities, e.g., length scale and Froude number (Baumgartner and Callaway, 1972.)

Alternatively, modeling of a chemical force can be achieved by expressing it in terms of the physical mechanisms and biological influences within the process. The resulting differential equation, with the necessary boundary conditions and sufficient details to represent all the factors involved, will be the basic quantitative formulation of the chemical force. For example, the three dimensional advection-diffusion equation can be used to describe the time rate of change in concentration of a chemical substance (Lal, 1966):

$$\frac{\partial c}{\partial t} = \nabla . A \nabla C + V . \nabla C + \Sigma S$$

where C = concentration of the chemical substance or may be described as the magnitude of the chemical force

A = coefficient of eddy diffusion

V = vector current velocity

Σ S = sum of introduction and depletion of the chemical substance in seawater.

Σ S represents the sum of all sources and sinks, including the biological factor, which may be treated as a particle with a vertical migration pattern. In steady state, $\frac{\partial c}{\partial t} = 0$, and for a conservative chemical substance $\Sigma S = 0$. However, in most cases the above formulation contains coefficients or terms, or both, which are difficult to define with high degree of accuracy. The ultimate choice depends on knowledge of the entire process and on how much detail is required for a specific purpose.

Applications of the simplification to one or two dimensional cases to simulate chemical pollutant transport have been published by Brandsma et al. (1973) and SCCWRP (1973). The following sections summarize the modeling methods and the results in each of these cases.

10.2 Pollutant transport in Marina del Rev

The special geometry of Marina del Rey permits an approximation of the advection-diffusion formula by a one-dimensional equation. The simulation is in Lagrangian form so as to follow individual element of fluid as it moves along the one-dimensional channels in response to tidal flows (Brantsma, et al., 1973). The water is assumed to be homogeneous vertically and horizontally. The model constructed shows that the Marina is sensitive to variations in locations and the length of time during which pollutants are injected. In the case of instantaneous discharge, the timing of pollutant injections relative to tidal phases is very important in determining what proportion of the material will be flushed out within a given time. The solid boundaries of the side basins severely restrict convective and dispersive transport of pollutants. At these locations, a build up of pollutants to high concentrations could occur if the injections have a long duration. Flushing capabilities of the Marina will be increased if there is sufficient discharge momentum from continuous external inflows at its landward extremities.

10.3 Dispersion Model of the Southern California Bight

The Southern California Bight is considered to be divided into a two-dimensional array of boxes or cells. The distribution of a conservative chemical substance is estimated by applying the two-dimensional advection-diffusion equation, and neglecting vertical diffusion. The total advective change is obtained by summing the changes in concentration for each cell. face. The diffusion term can be considered as the result of simultaneous and equal volume exchange of flows between adjacent cells. The source (waste-water discharge, surface runoff, aerial fallout, etc) and the sinks (e.g., deposition in the sediments), can be expressed in terms of mass rate per year. Some substances, e.g., suspended solids concentration, etc., are removed in proportion to their concentration at a constant effective "decay" rate. 'I'his relatively simple model shows that for nearshore mean transport velocities on the order of 0.04 m/see, the corresponding residence time for the effluent from the five major sewer dischargers is 4 to $4\frac{1}{2}$ months. The average dilution of the effluent in the Bight ranges from about 1,000:1 in the general region near the outfall to 10,000:1 or more at the outer islands (SCCWRP, 1973).

The model was testedby comparing the observed concentrations of three trace materials - residues of dichlorodiphenyl dichloroethylene (DDE), lead and cadmium - in intertidal mussels with the relative changes in the predicted concentrations. The results were inconclusive because the difference in concentrations could be due to a number of factors e.g., the waste discharges is submerged, while the mussels essentially sample the surface water. Some anomalies may be due to possible absorption of pesticide residues of dichlorodiphenyl dichloroethylene (DDE) onto floatable or its incorporation into phytoplankton. Suitable testing would be by direct comparison of predicted and observed concentrations in the ocean waters.

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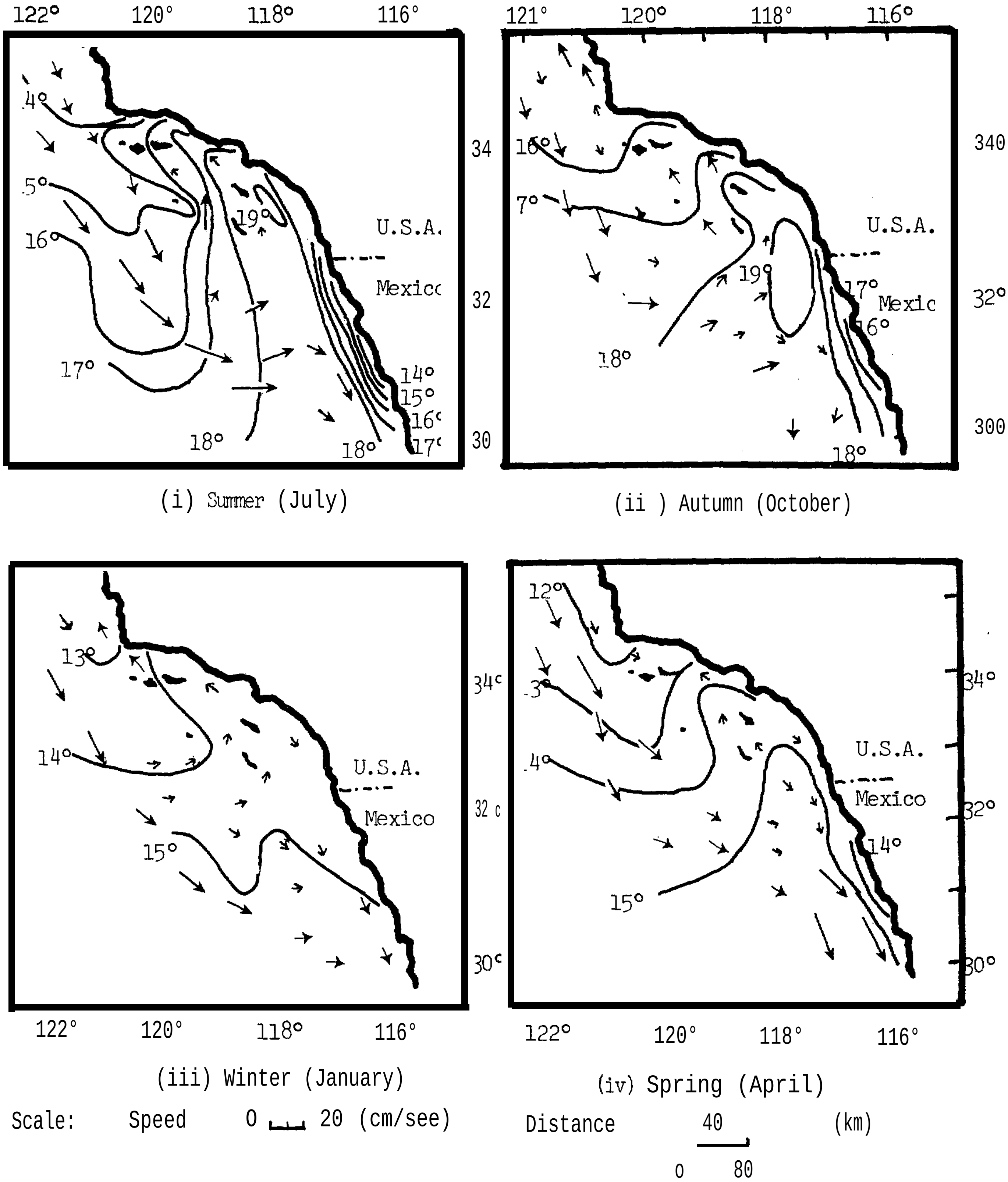

Figure 4-1. Average geostrophic surface flow (arrows) and surface isotherms (°C) in the Southern California Bight. From Jones (1971), Fig. 5-8.

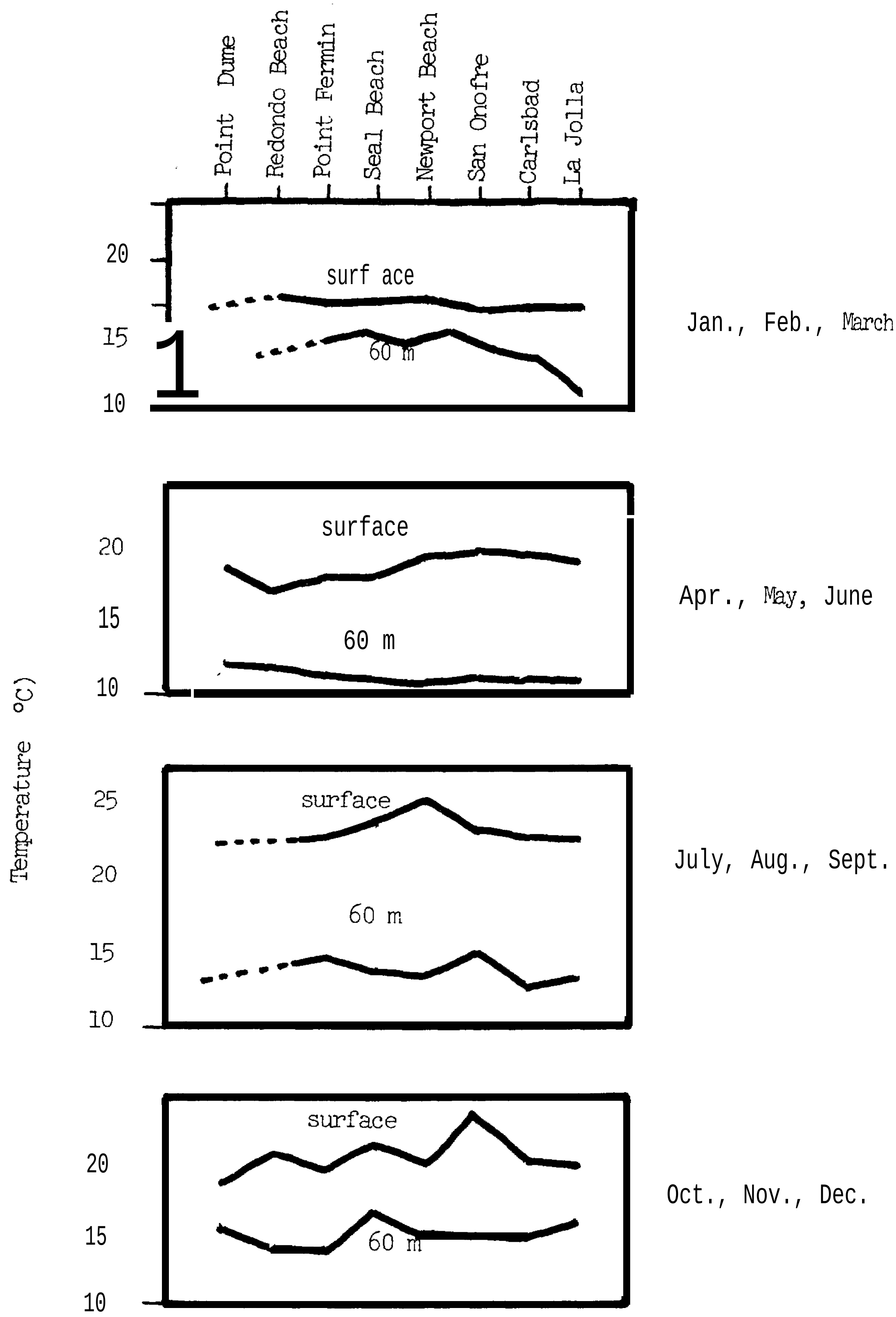

Figure 4-2. Latitudinal distribution of mean temperature by seasons. From Allan Hancock Foundation, Fig. 3.4, p. 64, (1965).

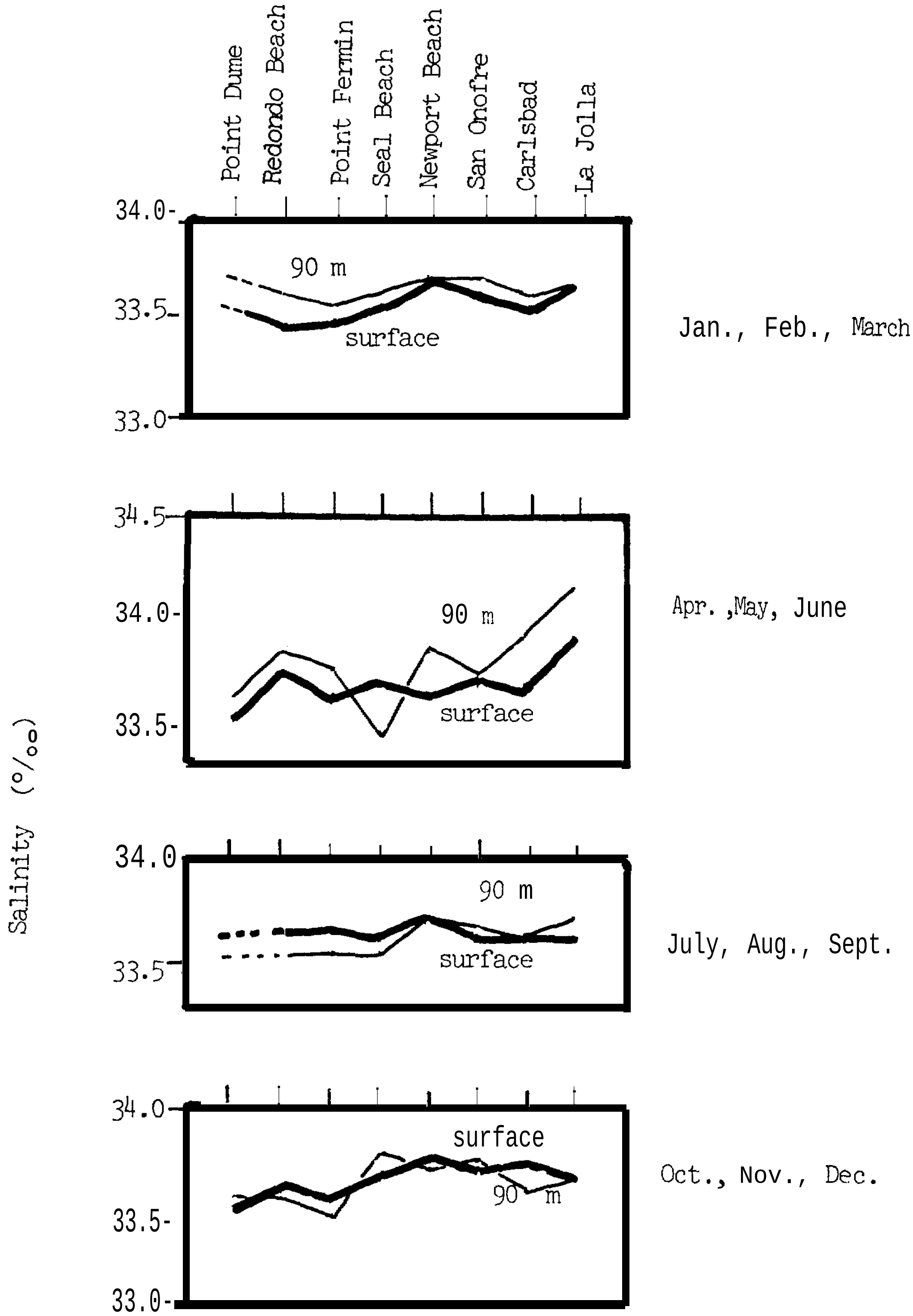

Figure 4-3. Latitudinal distribution of mean salinity by seasons. From Allan Hancock Foundation (1965), Fig. 3.6, p. 67.

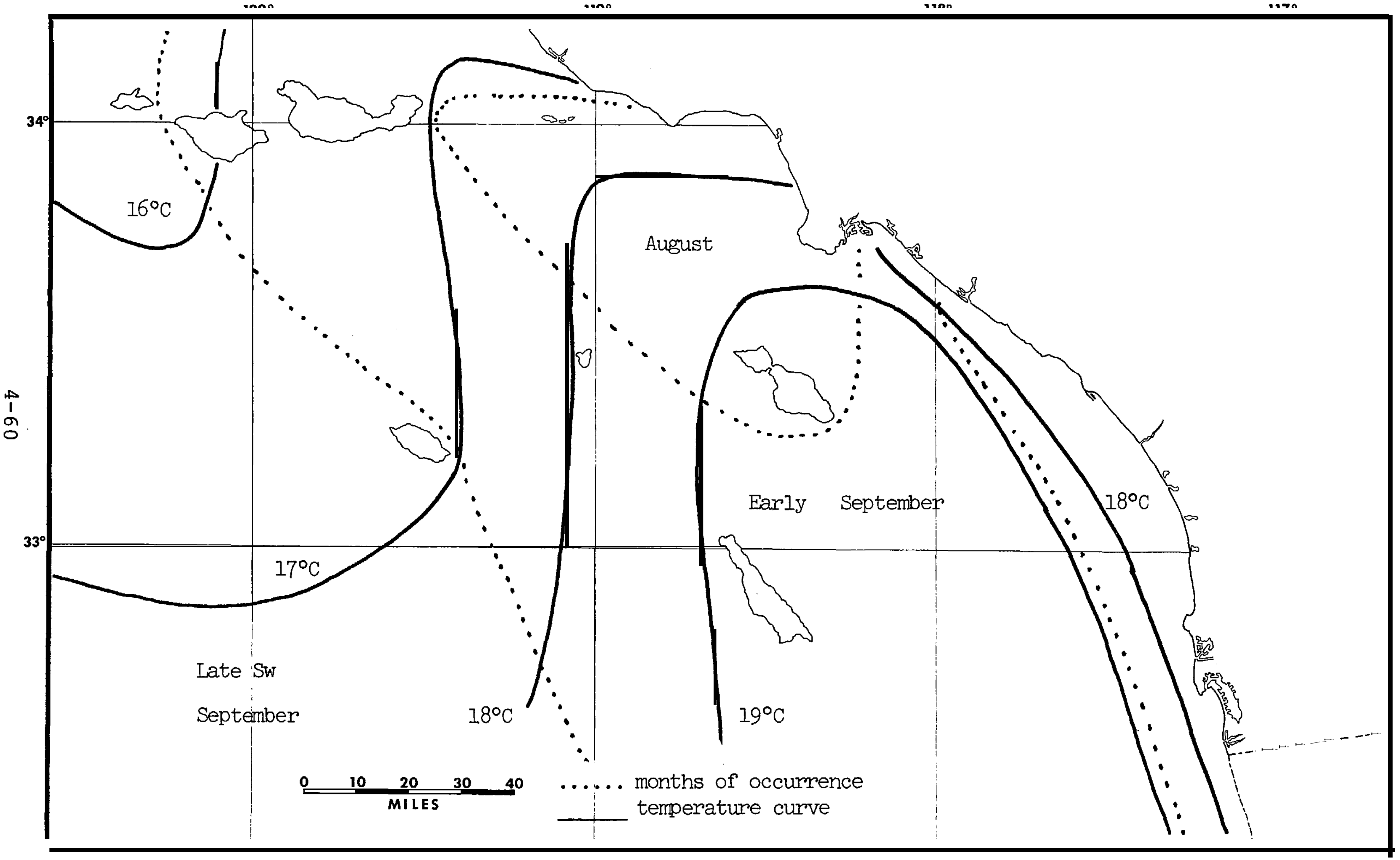

Figure 4-4. Temperature maximum regression curves and corresponding months of occurrence. From Lynn(1967),Fig. 11,p.167.

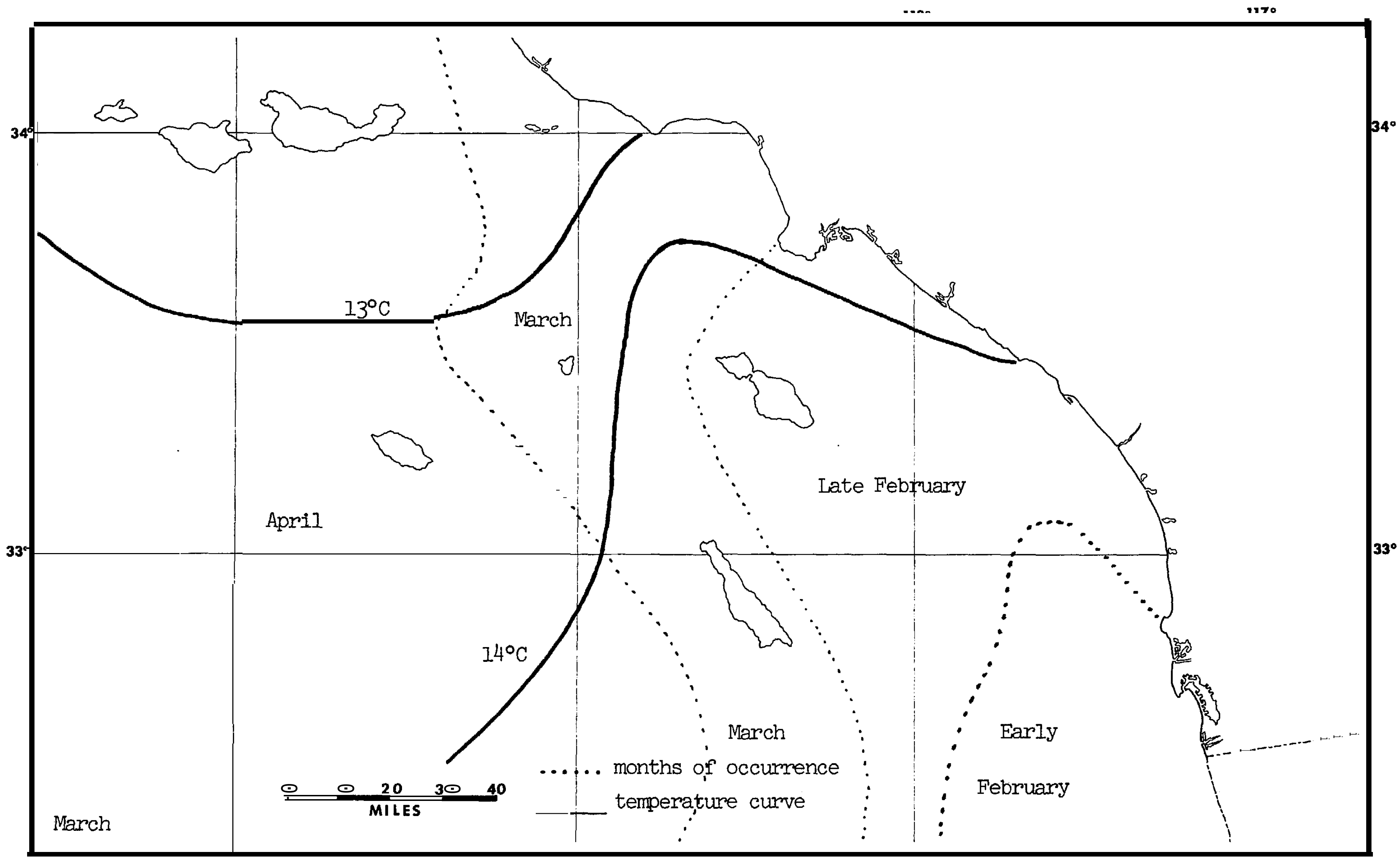

Figure 4-5. Temperature minimum regression curves and corresponding months of occurrence. From Lynn(1967),Fig. 11, p.167.

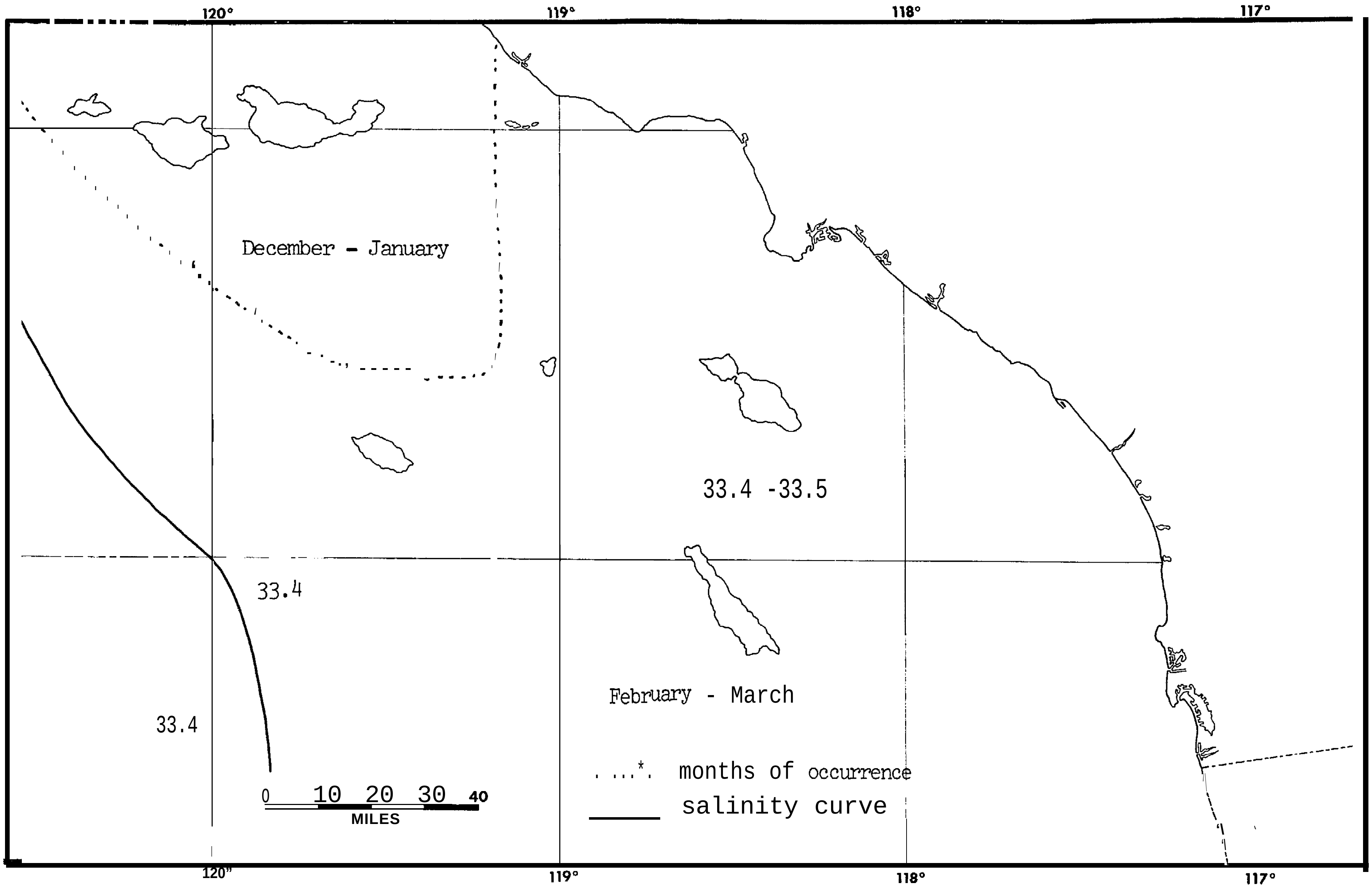

Figure 4-6. Salinity minimum regression curves and corresponding month of occurrence. From Lynn (1967), Fia. 12, p. 168.

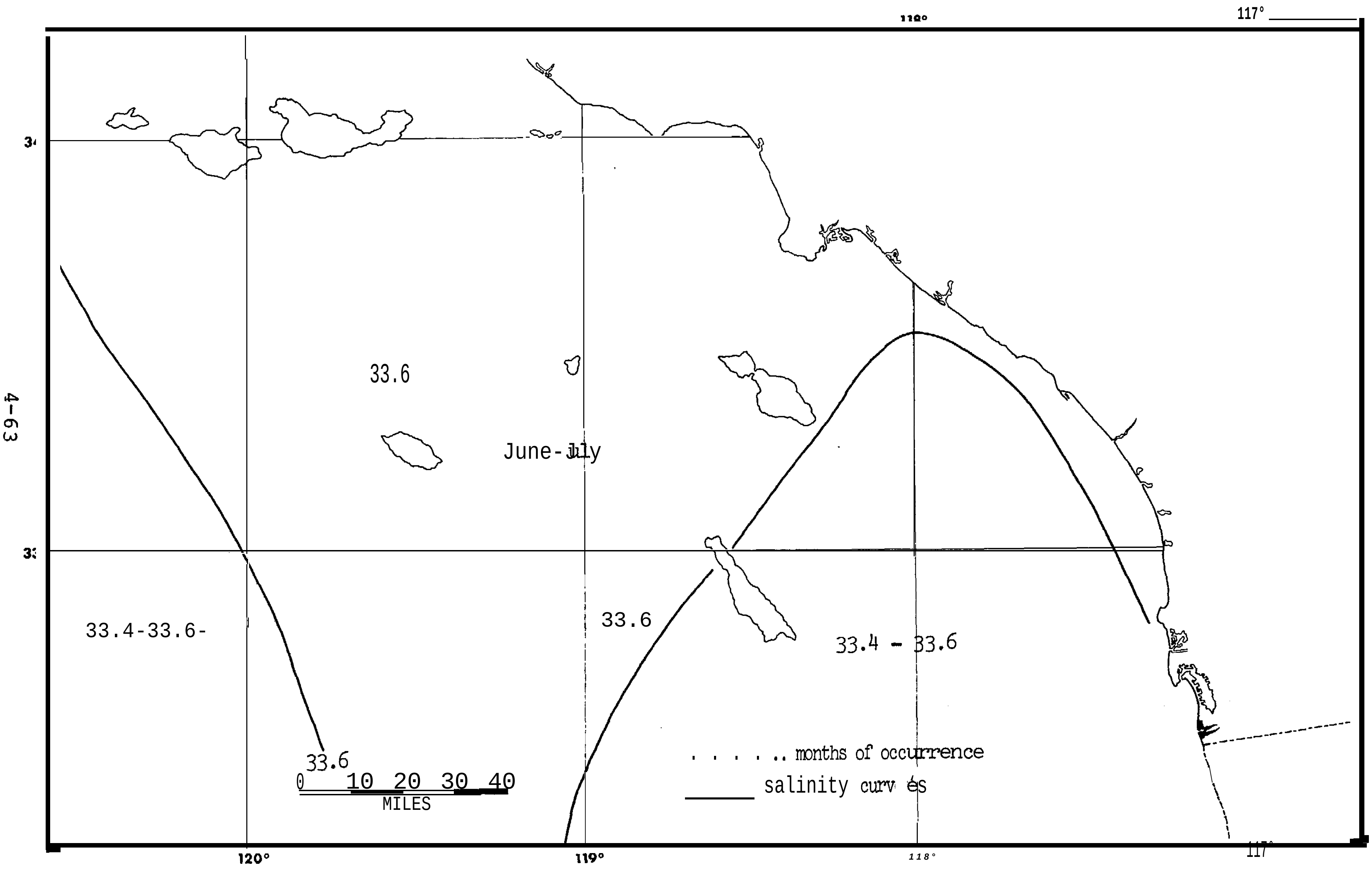

Figure 4-7. Salinity maximum regression curves and corresponding month of occurrence. From Lynn (1967), Fig. 12, p. 168.

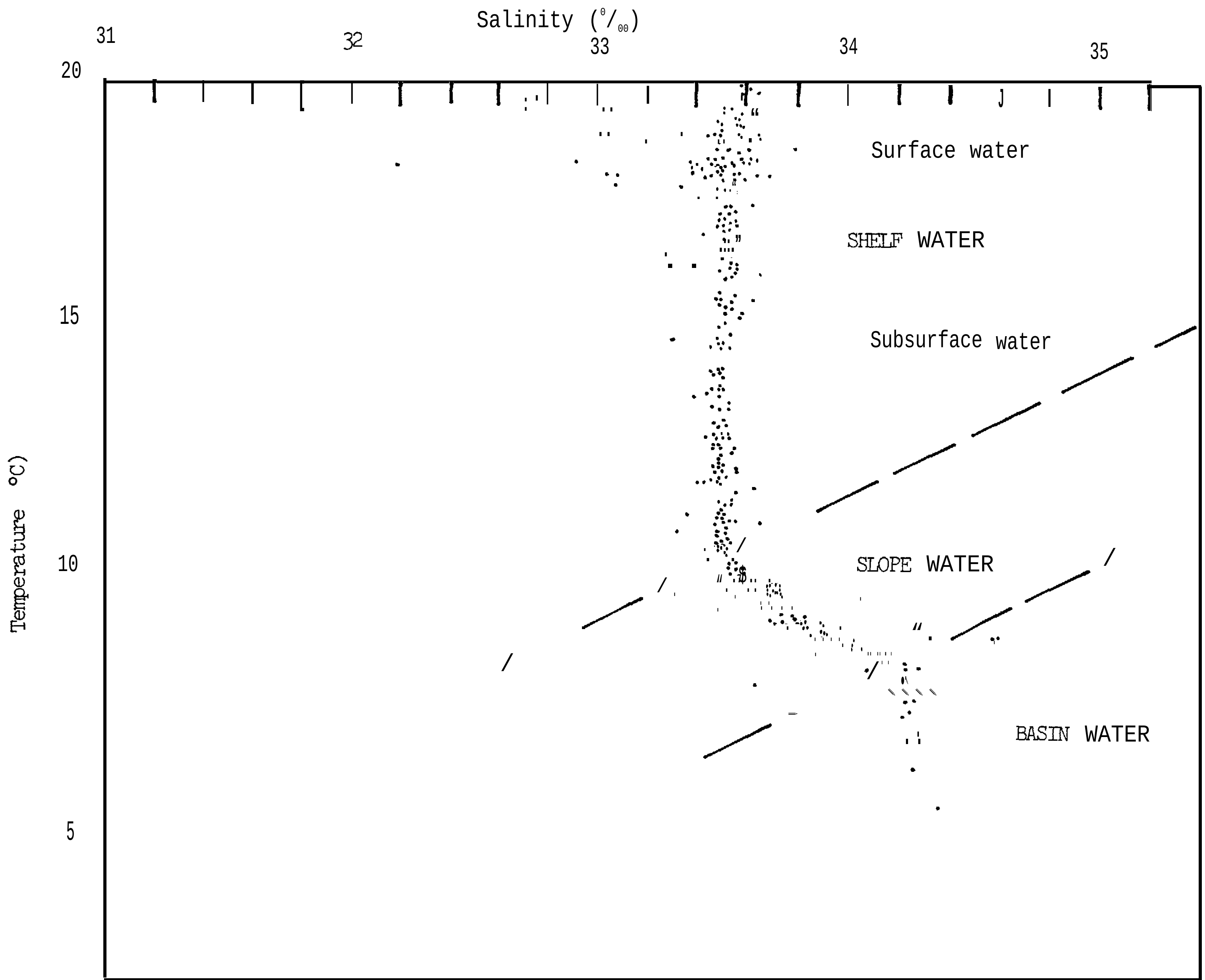

Figure 4-8. Temperature - Salinity diagram of the water in the offshore area. From Stevenson (1961).

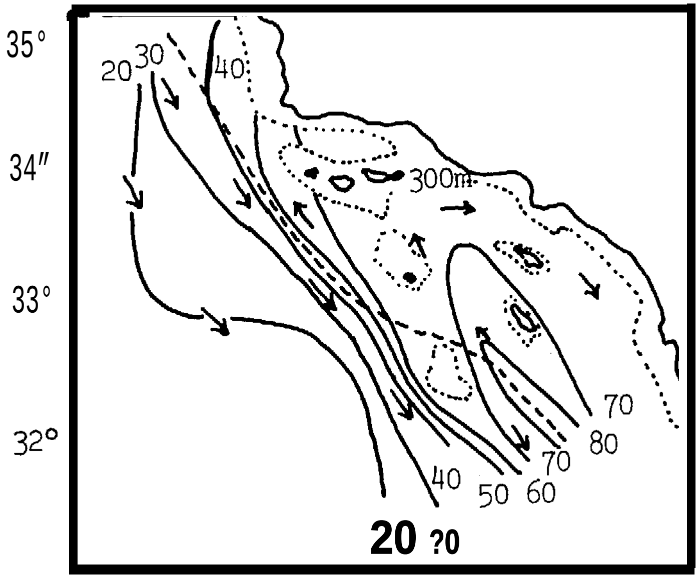

Figure 4-9. Horizontal distribution of Southern Water between 200 and 400 m depth. The 300 m isobath has been plotted to indicate the possible effect of the topography on the flow of Southern Water east of Cortes Ridge. The heavy dashed line separates flow to the south from flow to the north. The numbers are given in %. From Sverdrup and Fleming (1941) Fig. 34, p. 295.

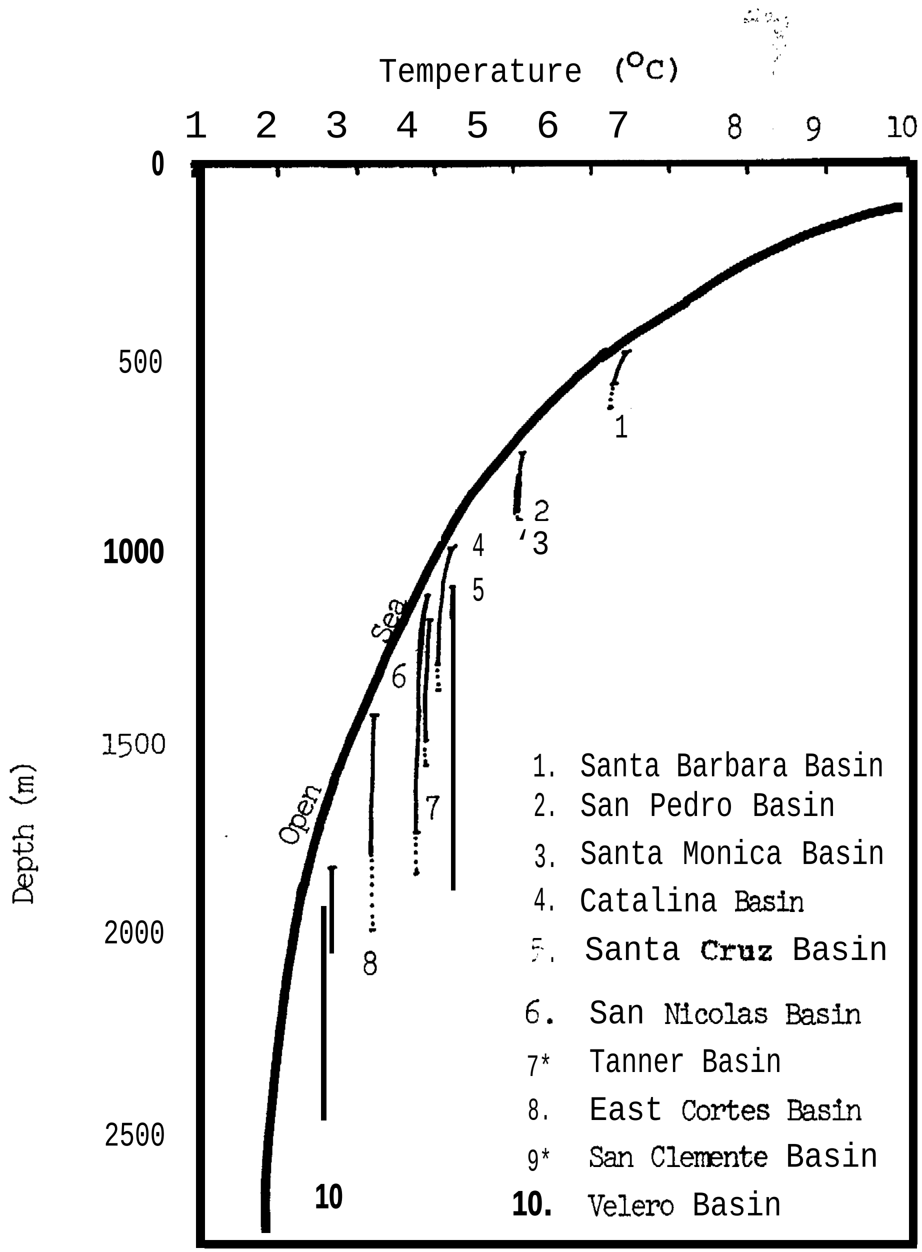

Figure 4-10. Temperature - depth curves for the open sea (31° 46'N, 120° 15'W) and for basin water-below sills. Short horizontal lines indicate sill and bottom depths of basins. The dashed lines indicate water below lowest sample bottle plus difference in depth between station location and deepest part of basin. From Emery (1954), Fig. 2, p. 5.

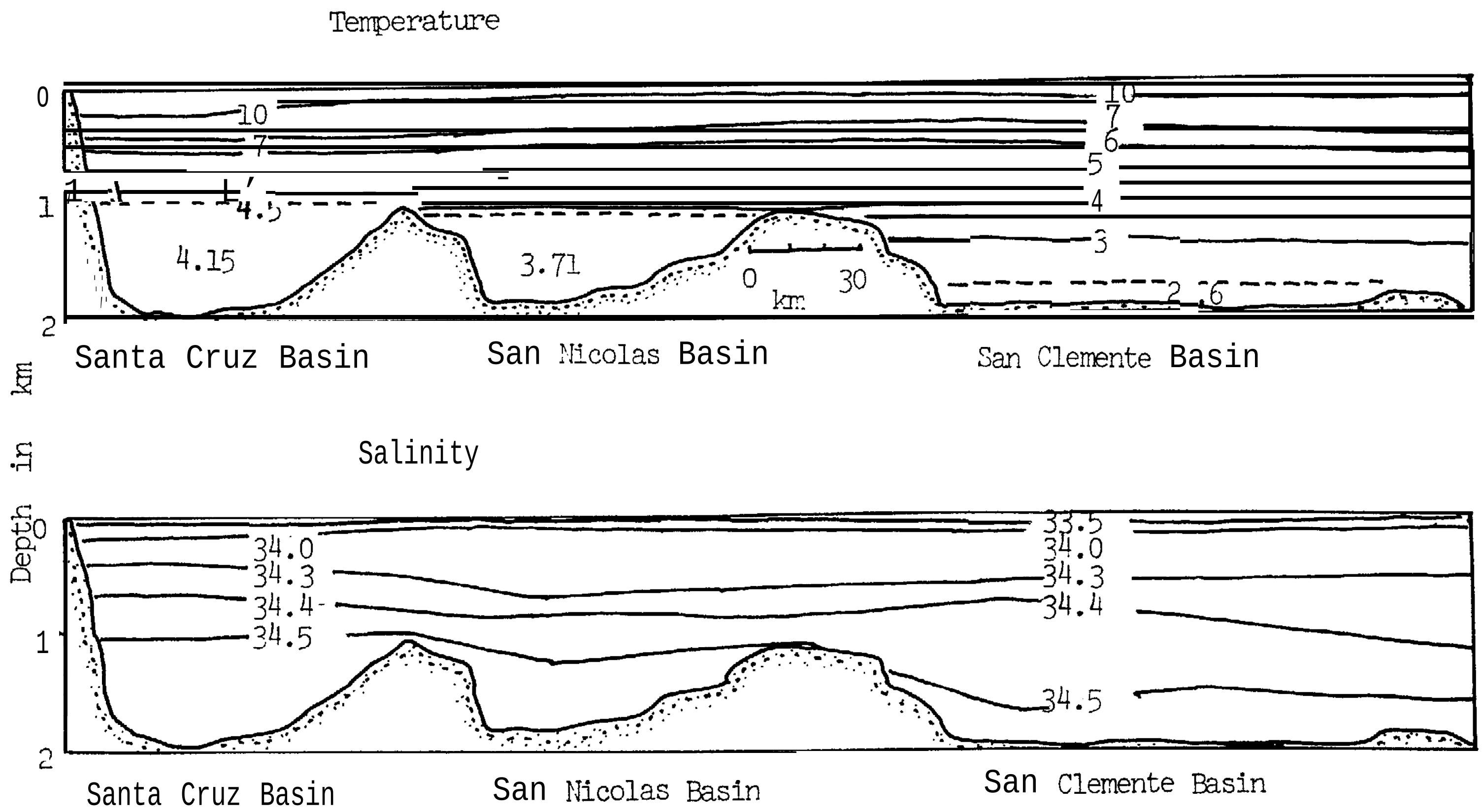

Figure 4-11. Longitudinal section through San Clemente, San Nicolas, and Santa Cruz Basins. Isotherms in °C and isohalines in °/00 . Horizontal dashed lines indicate effective sill depths. Water at extreme right is assumed to be like that of Velero Basin. From Emery (1954), p. 7.

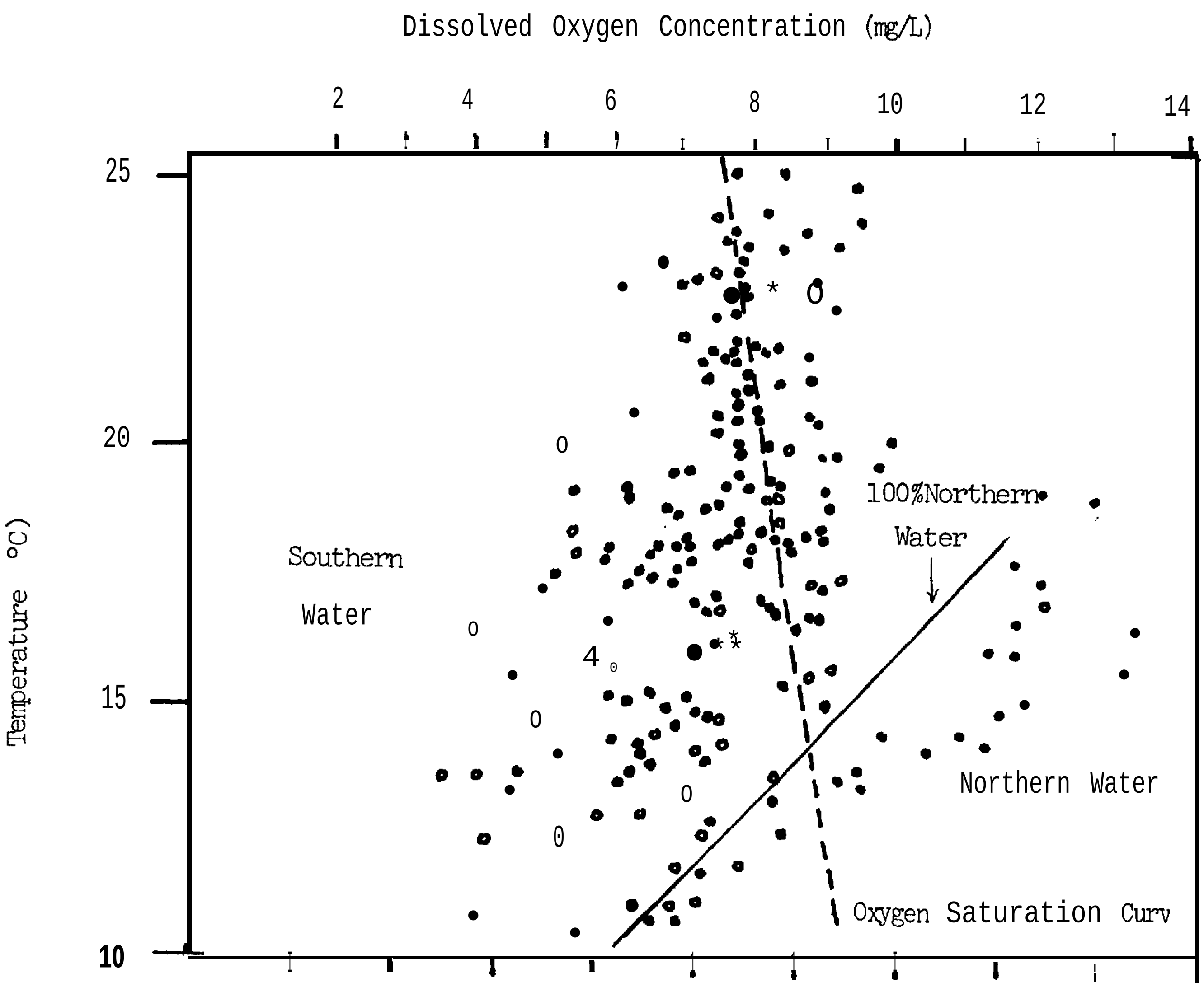

Figure 4-12. Temperature vs Dissolved Oxygen concentration graph for Northern and Southern Waters. From Allan Hancock Foundation (1965), Fig. 3.1, p.55.

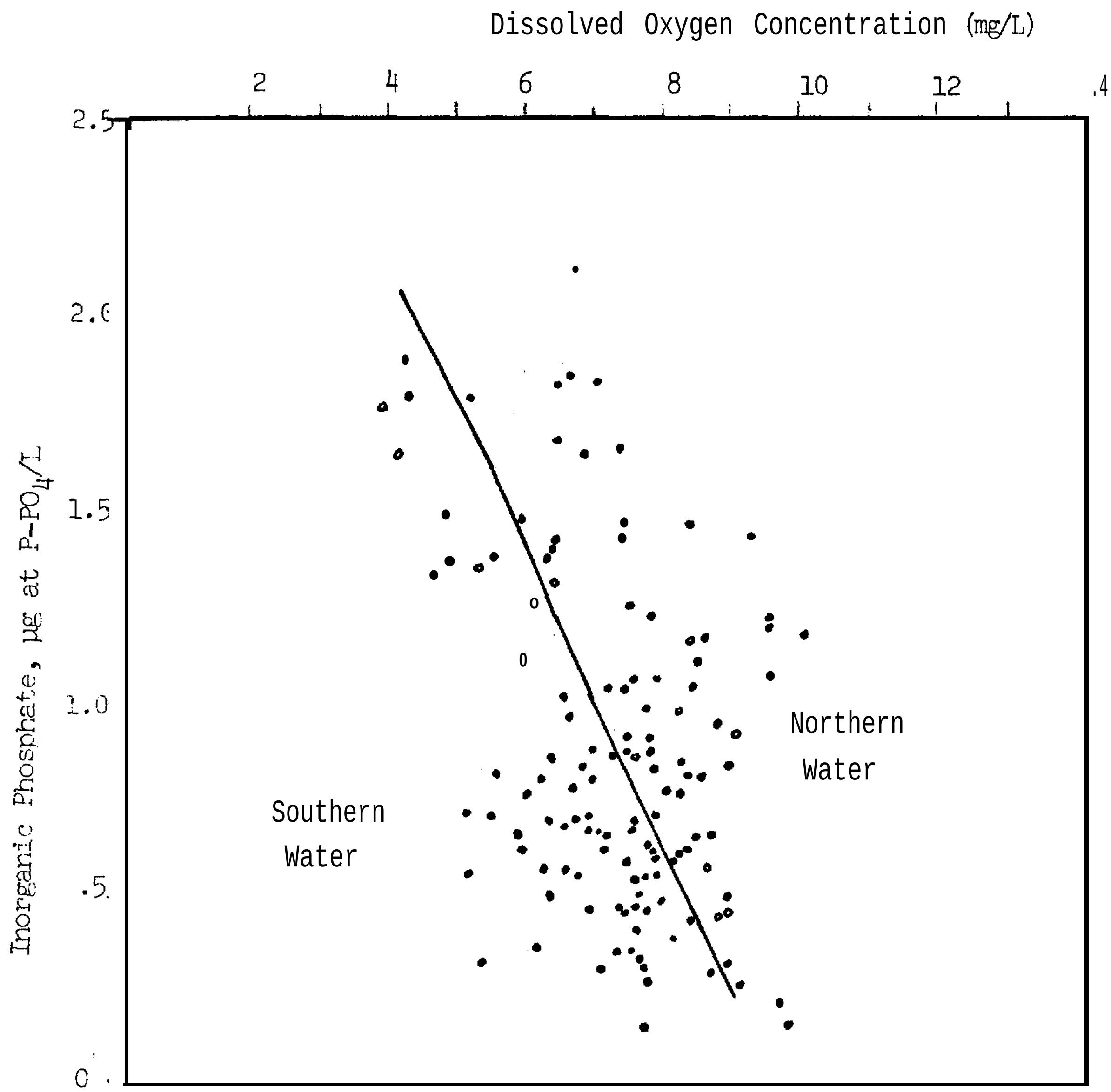

Figure 4-13. Phosphate vs Dissolved Oxygen graph for Northern and Southern Waters. Data collected in 1957-1960. From Allan Hancock Foundation (1965),Fig.3.2, p.56.

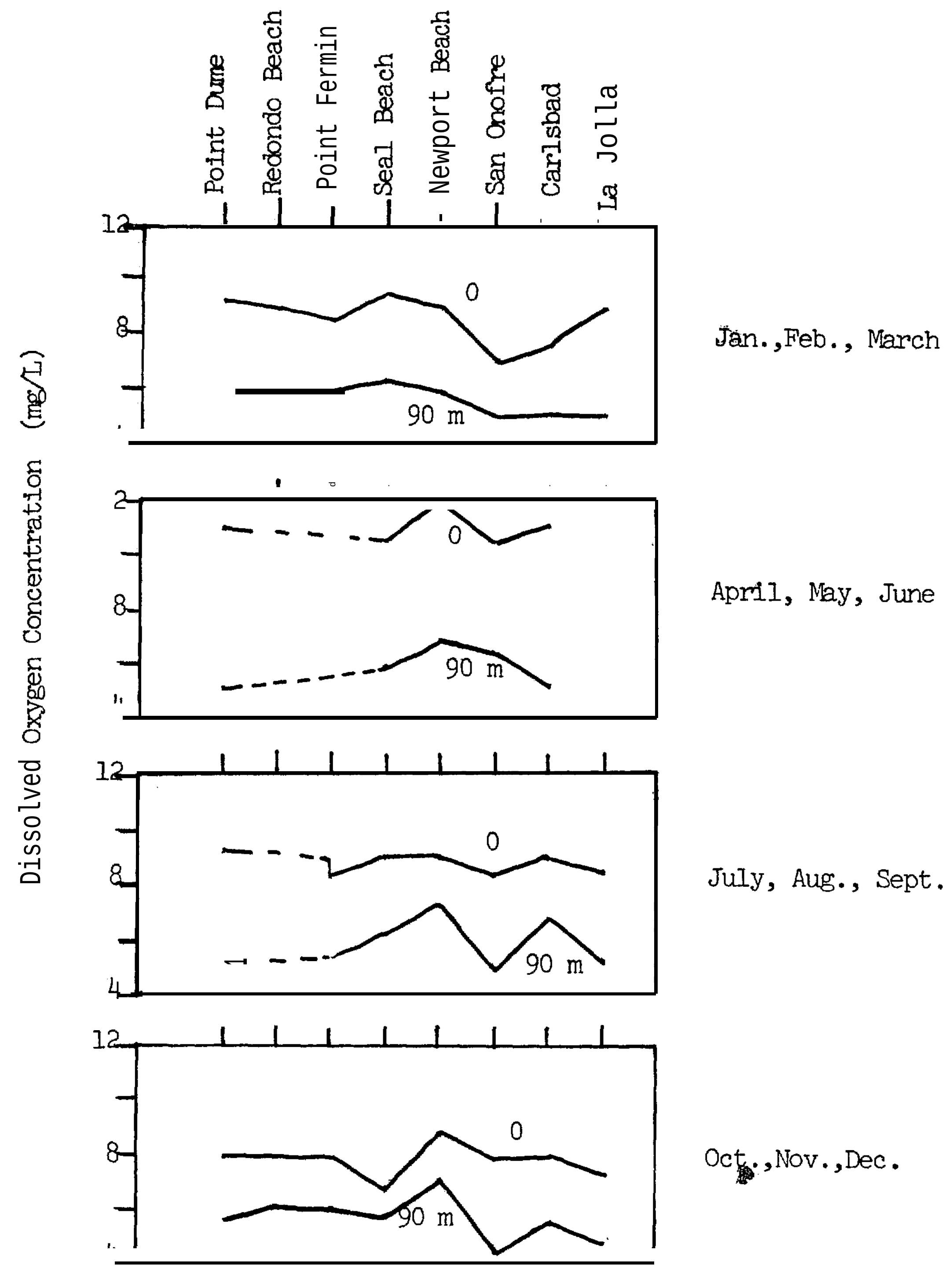

Figure 4-14. Latitudinal distribution of mean dissolved oxygen by seasons. From Allan Hancock Foundation (1965),Fig.3.9.

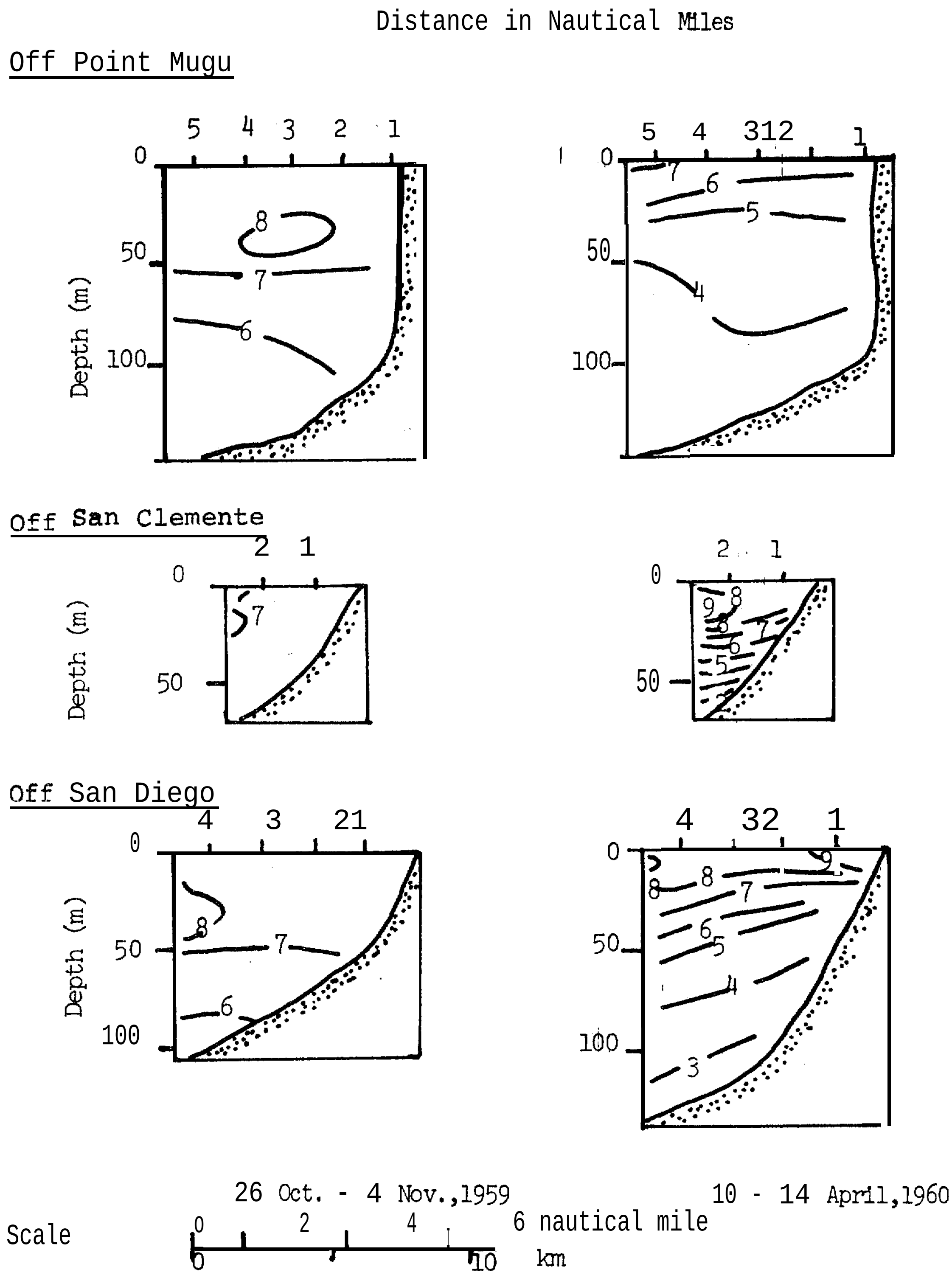

Figure 4-15. Vertical distribution of dissolved oxygen (mg/L) showing subsurface intrusion of water of high oxygen content and the rising of oxygen maximum to the surface. From Allan Hancock Foundation (1965], Fig. 3.11, p. 76.,

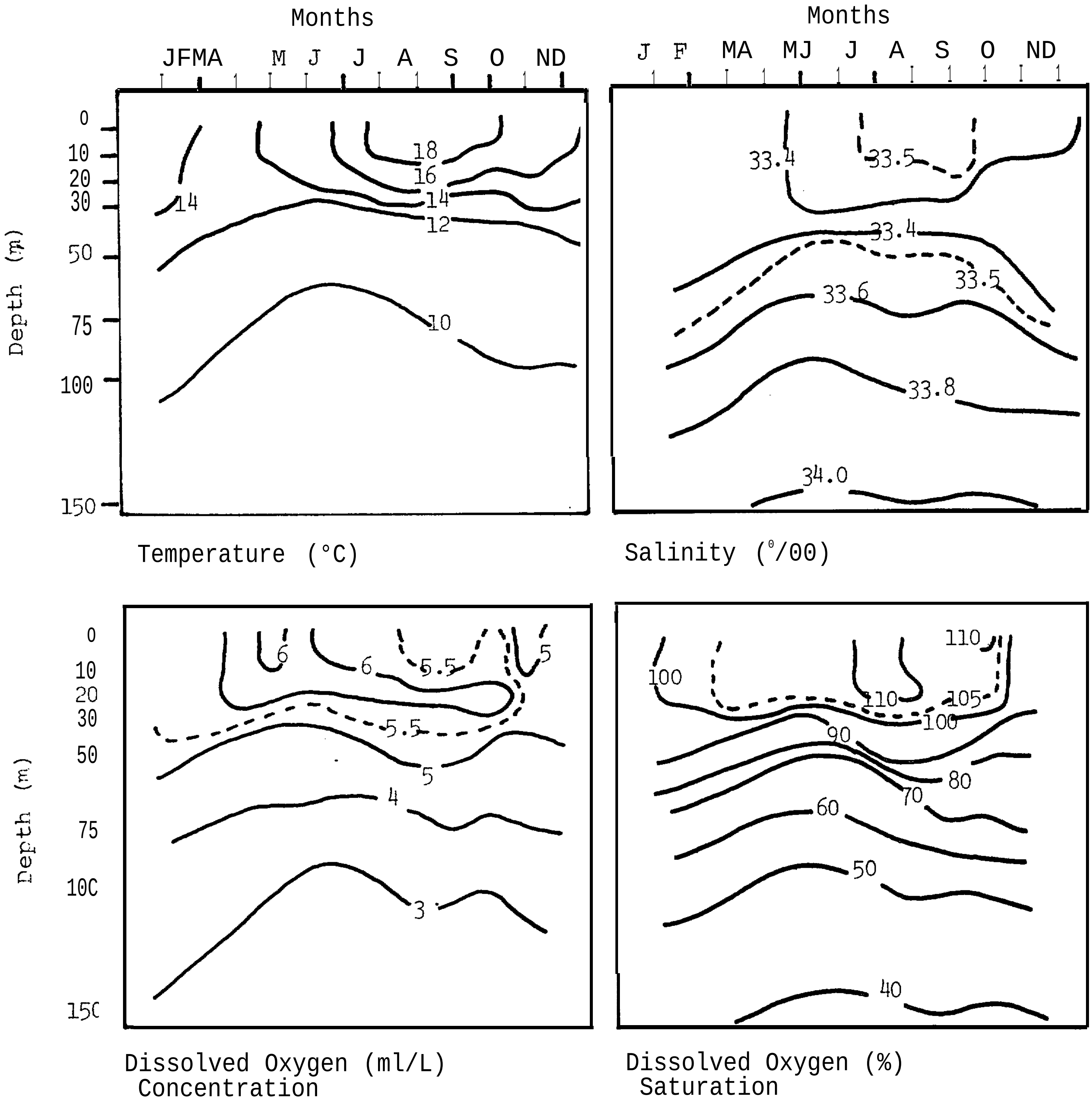

Figure 4-16. Average seasonal variations of temperature, salinity, dissolved oxygen concentration and saturation in the upper 150 m at 33° 12'N, 118° 24' W (in Channel Islands area). From Reid (1962), Fig. 32.

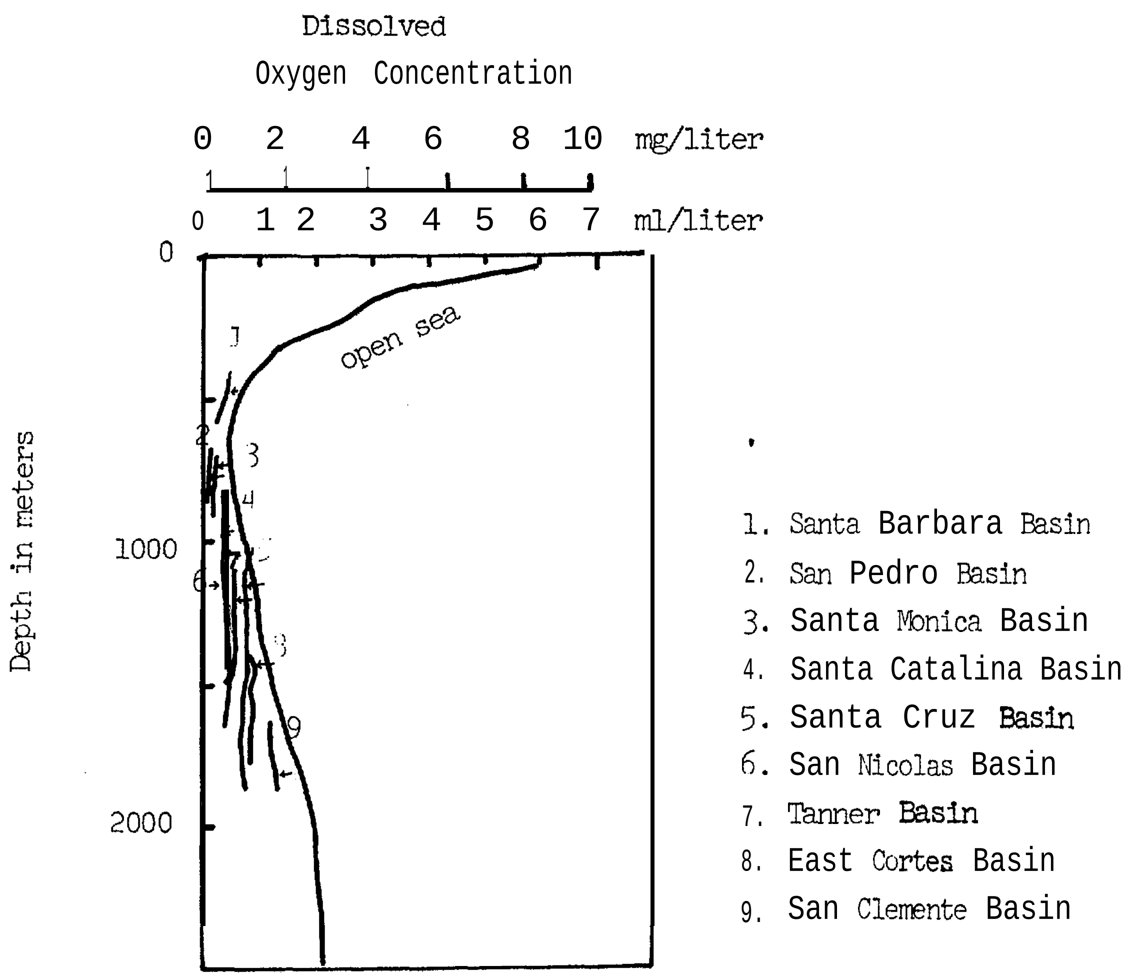

Figure 4-17. Oxygen vs depth curves for open sea and for waters below basin sills. Arrows indicate sill depths. From Rittenberg, Emery, and Orr (1955), Fig. 2.

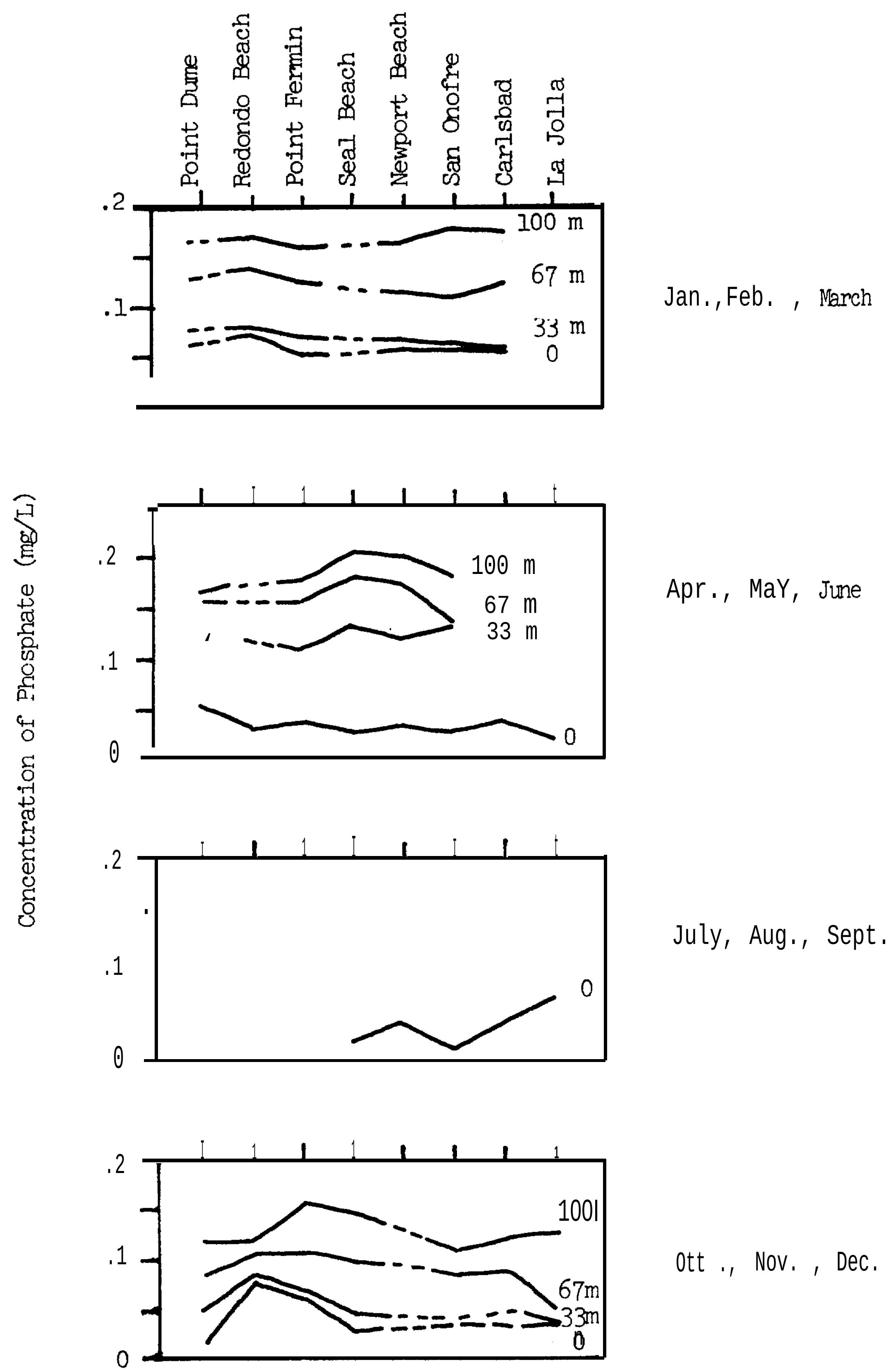

Figure 4-18. Latitudinal distribution of mean phosphate by seasons. From Allan Hancock Foundation, Fig. 3.14, P. 80 (1965) .

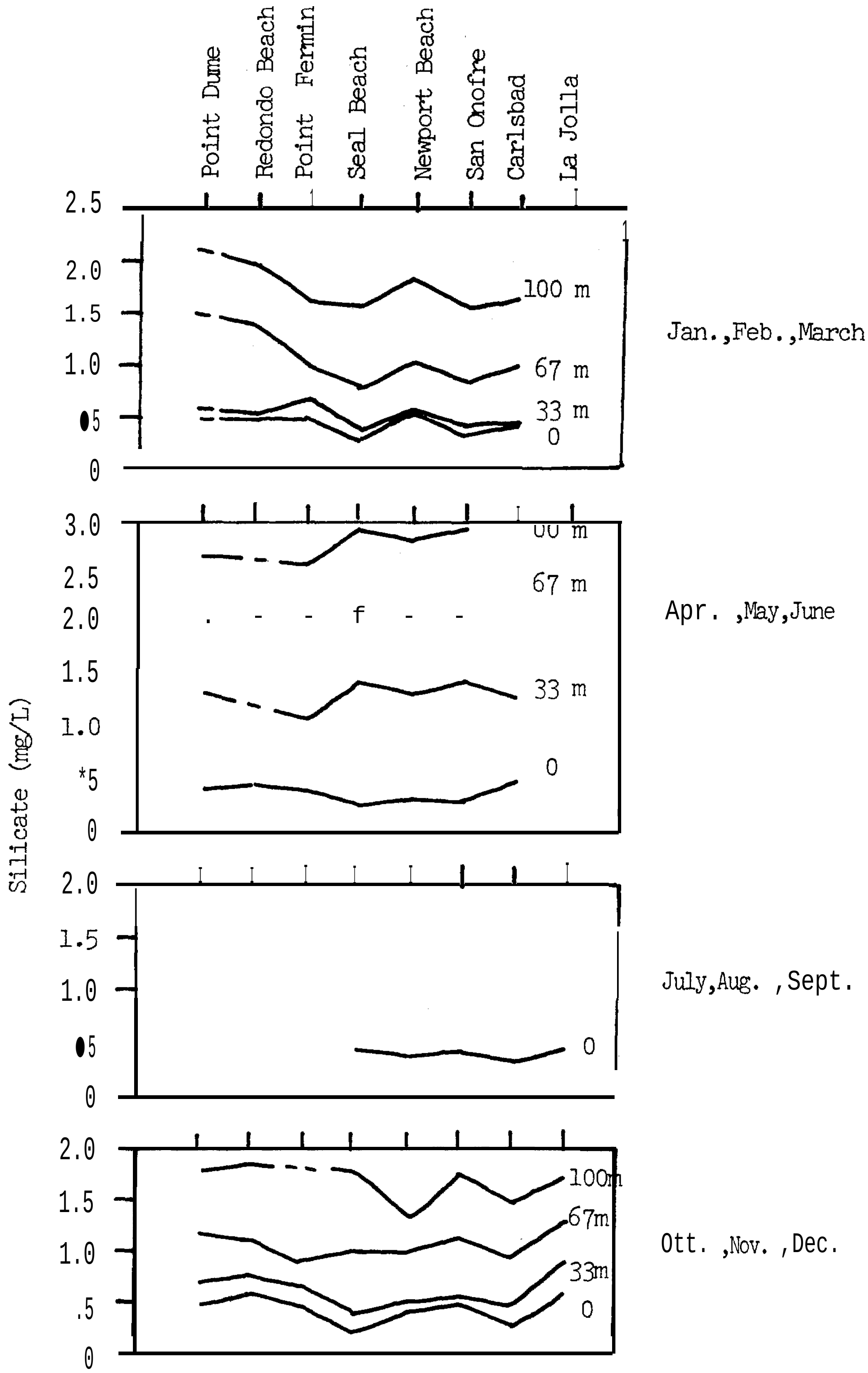

Figure 4-19. Latitudinal distribution of mean silicate by seasons. From Allan Hancock Foundation (1965), Fig. 3.15, p. 81.

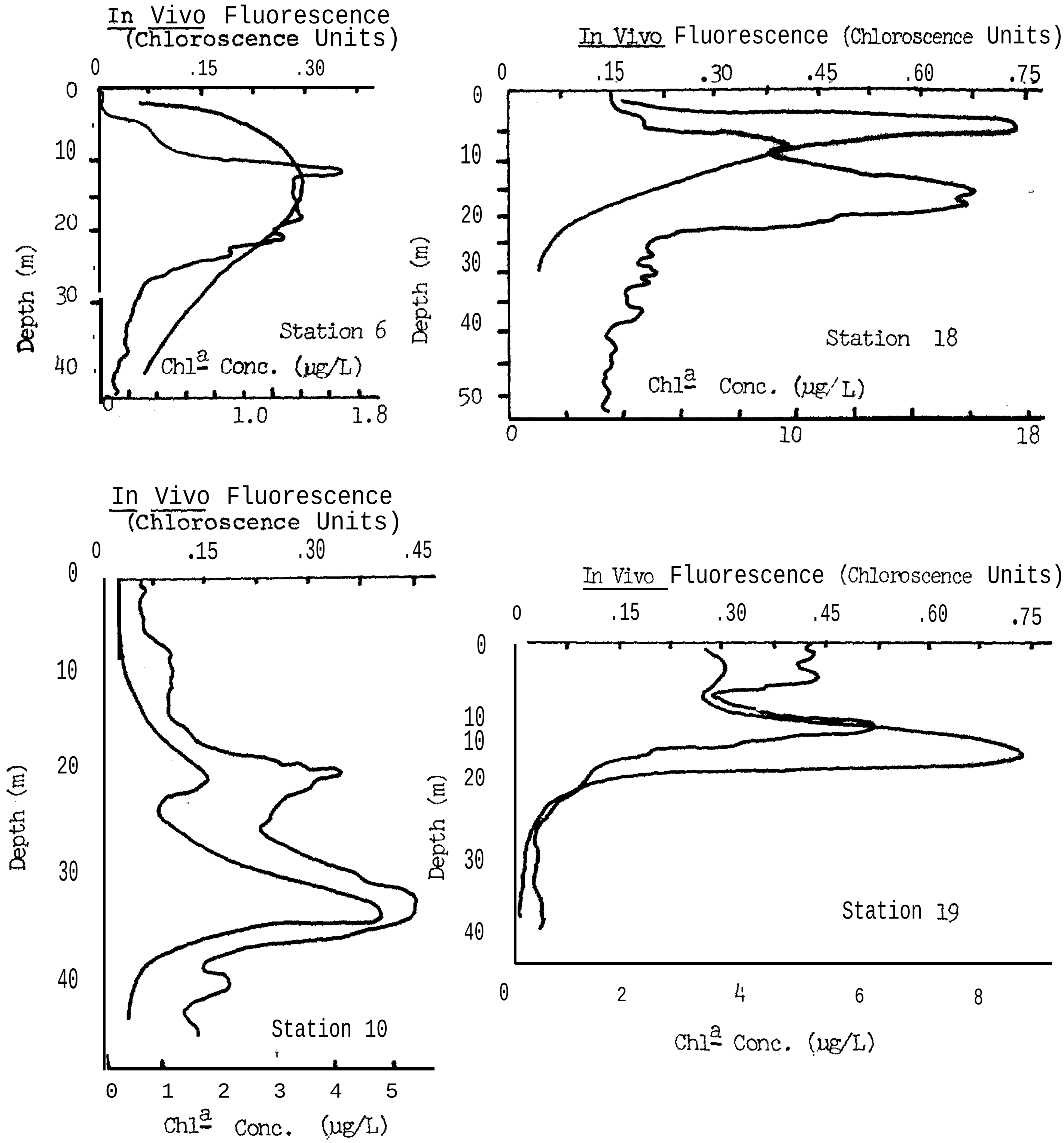

Figure 4-20. Concentrations of chlorophyll a in waters from Stations 6 and 10 (non-outfall) and 18 and 19 (outfall). Smooth lines are drawn based on data from discrete samples. "Chloroscence" units for continuous profiles are relative chlorophyll concentration. From Eppley, et al. (1972), Fig. 2, p. 76.

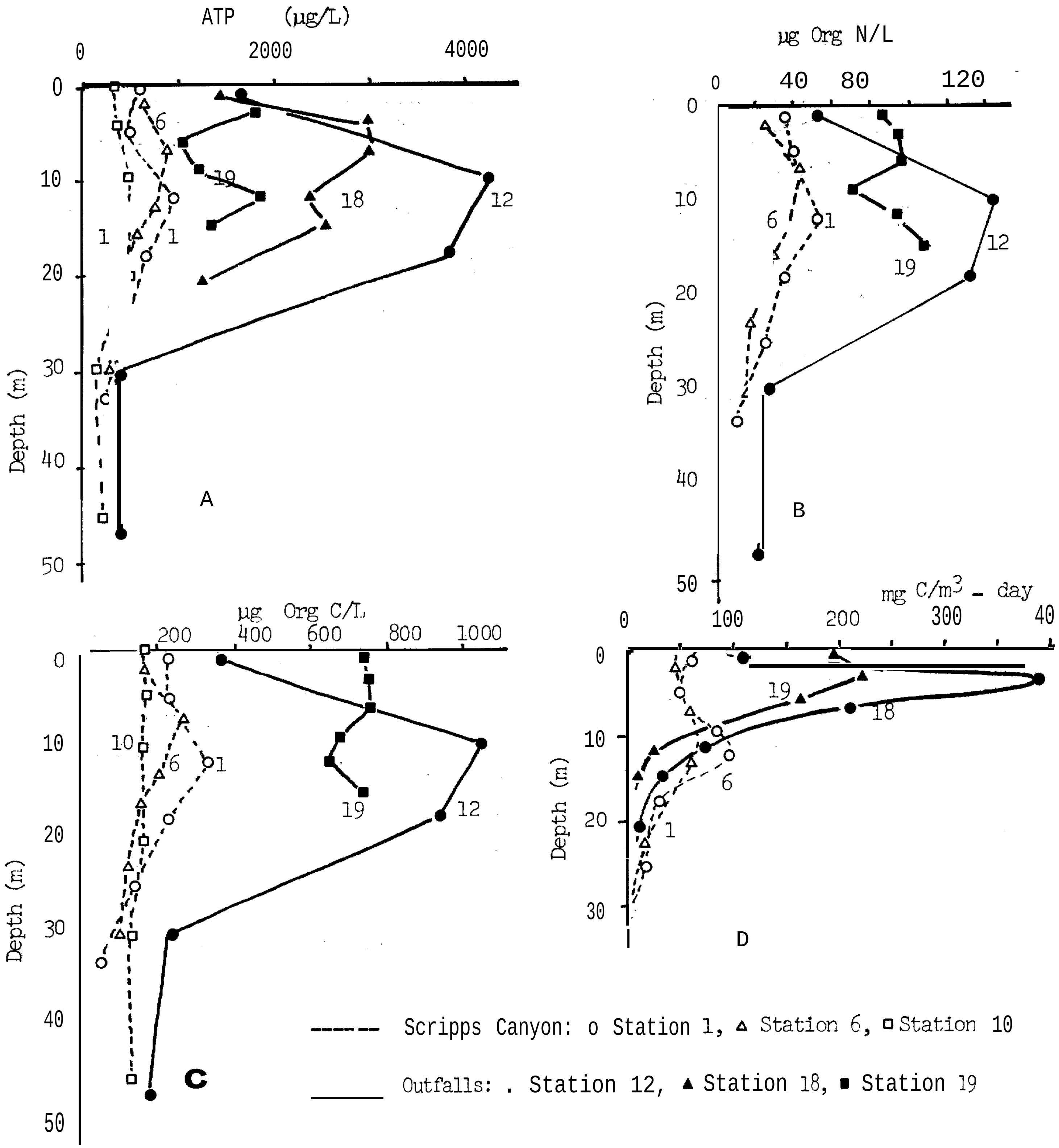

Figure 4-21. Comparison of (A) ATP, (B) particulate organic carbon, (C) particulate organic nitrogen and (D) primary "production in waters from non-outfall and outfall area. From Eppley, et al. (1972), Fig. 3-6, p. 77.

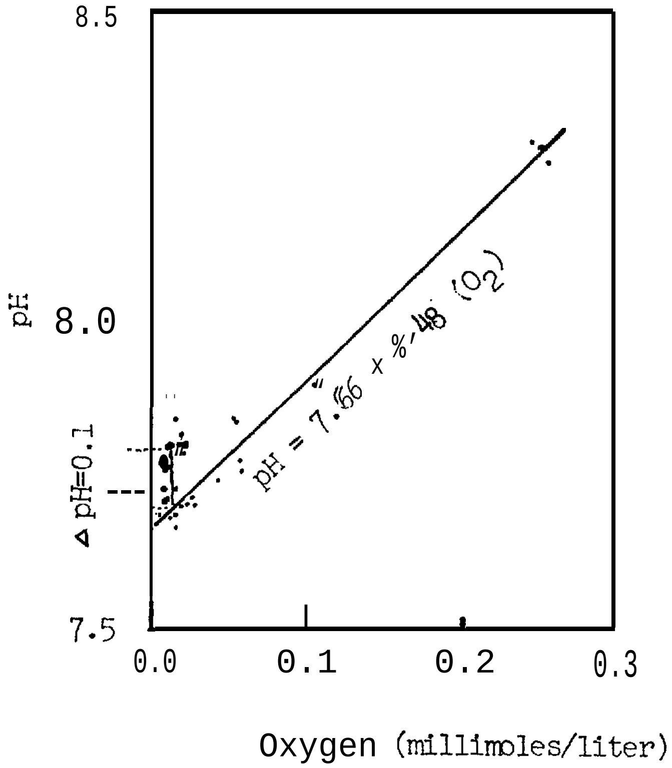

Figure 4-22. Oxygen content versus pH for Southern California basin waters (data from Rittenberg, et al., 1955). The regression line slope for samples-more than 15 m above the basin floors approximate Park's (1968) equation for changes in response to apparent oxygen utilization along; the increased pH at a constant oxygen content near the basin floors also corresponds to Park's equation. The mean increase of 0.1 pH units in water within 15 m of the basin floors can be attributed to the dissolution of 0.04 m moles calcium carbonate per liter. From Smith (1971), Fig. 2, p. 804.

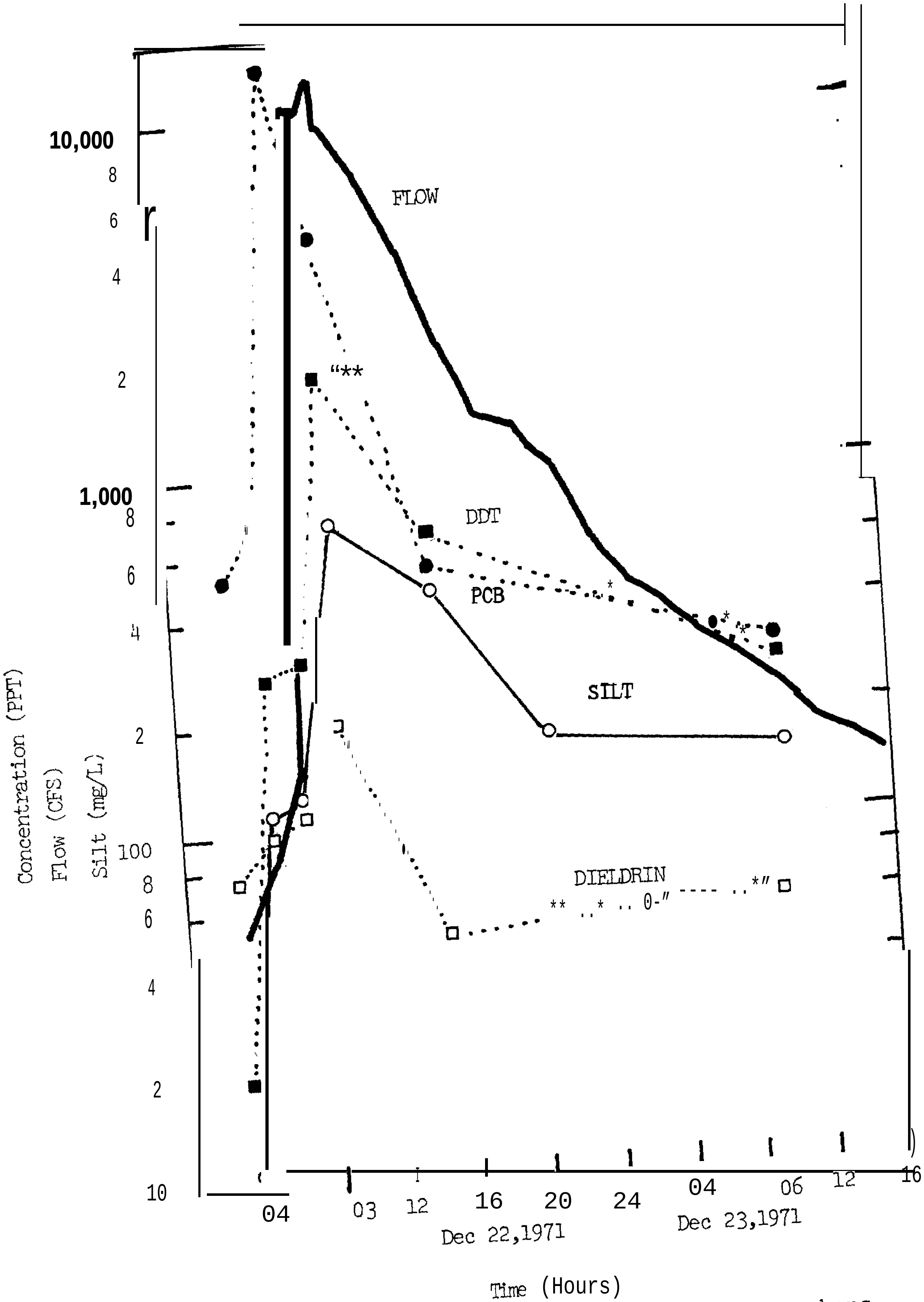

Figure 4-23. Concentrations of chlorinated hydrocarbons in Los Angeles River Stormwaters, 22-23 Dec. 1971. From SCCWRP (1973), Fig. 4-5, p. 4.

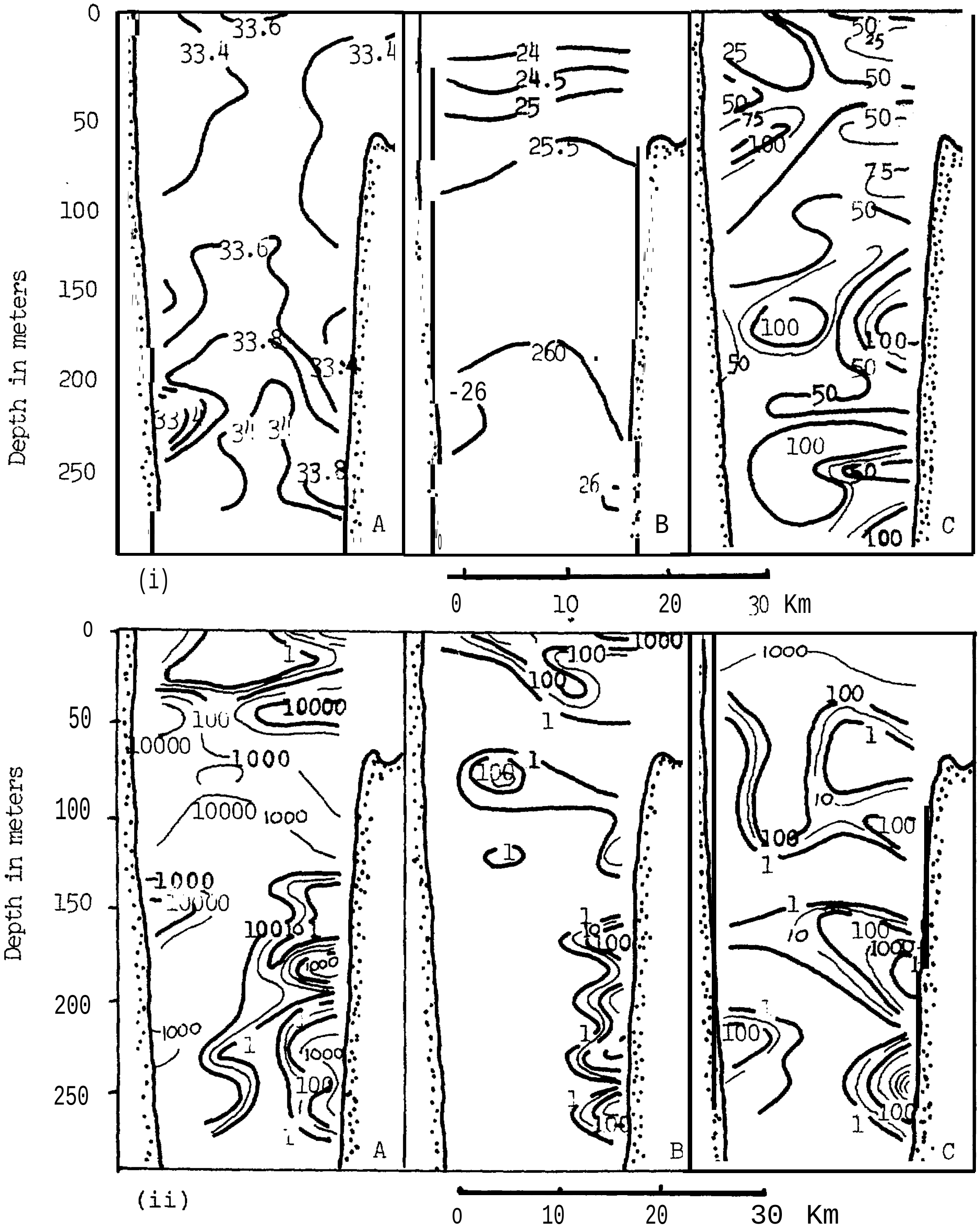

Figure 4-24. (i) Distribution of water properties on Aug. 6, 1958. A, salinity in $^{o}/oo$; B, σ_t ; and C, suspended sediment, 30 μ diameter, in grains/ml. (ii) Distribution of organisms on Aug. 6, 1958. A, diatoms in cells/L; B, dinoflagellates in cells/L; and C, Foraminifera in cells/L.

The vertical section is from Santa Catalina Island to San Pedro Bay. From Gunnerson and Emery (1962), Fig. 3-4, p. 16-17.

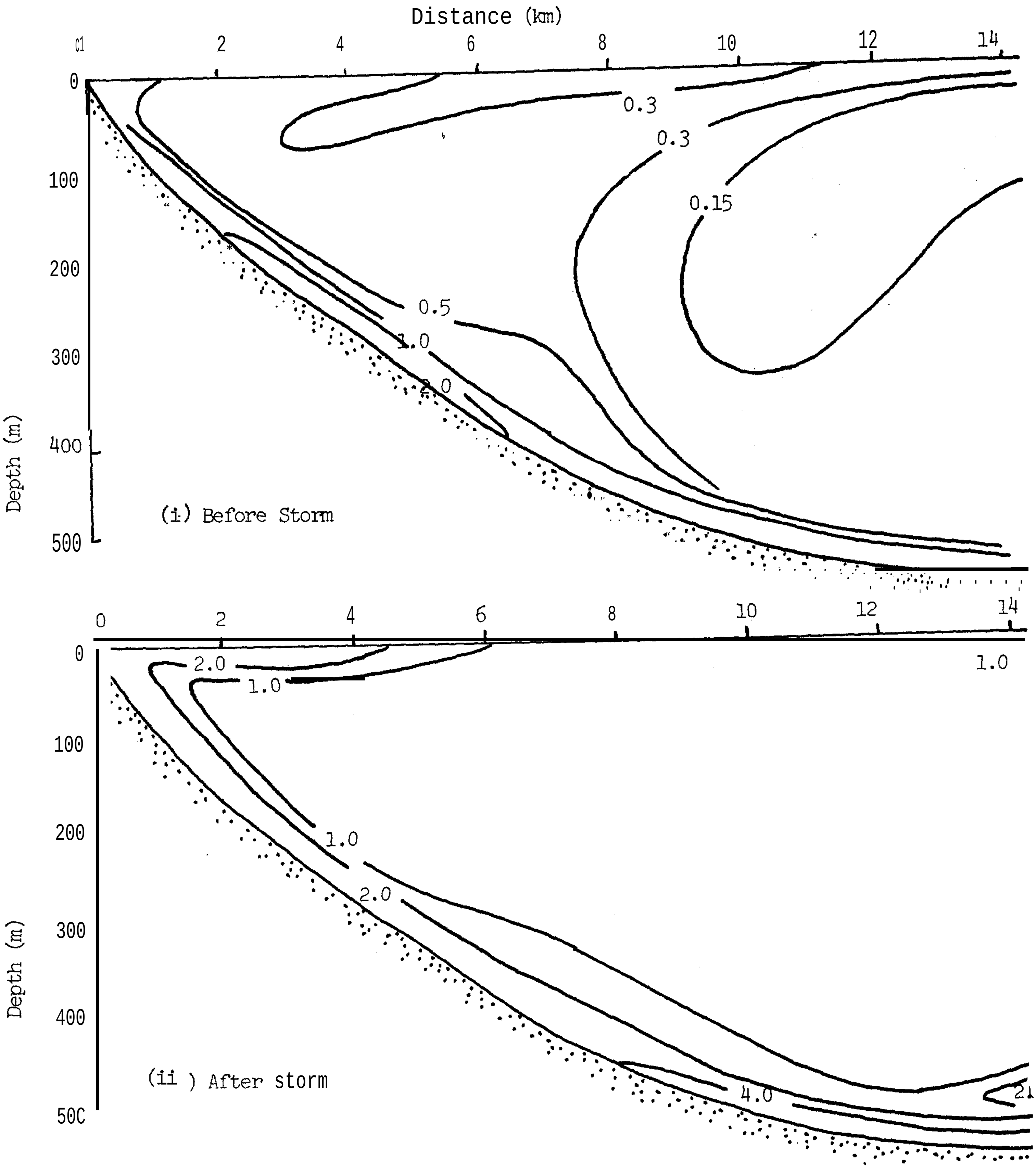

Figure 4-25. Distribution of total suspended material (mg/L) along a section of Redondo Canyon (i) before (ii) after a storm. From Beer and Gorsline (1971), Fig. 7-8.

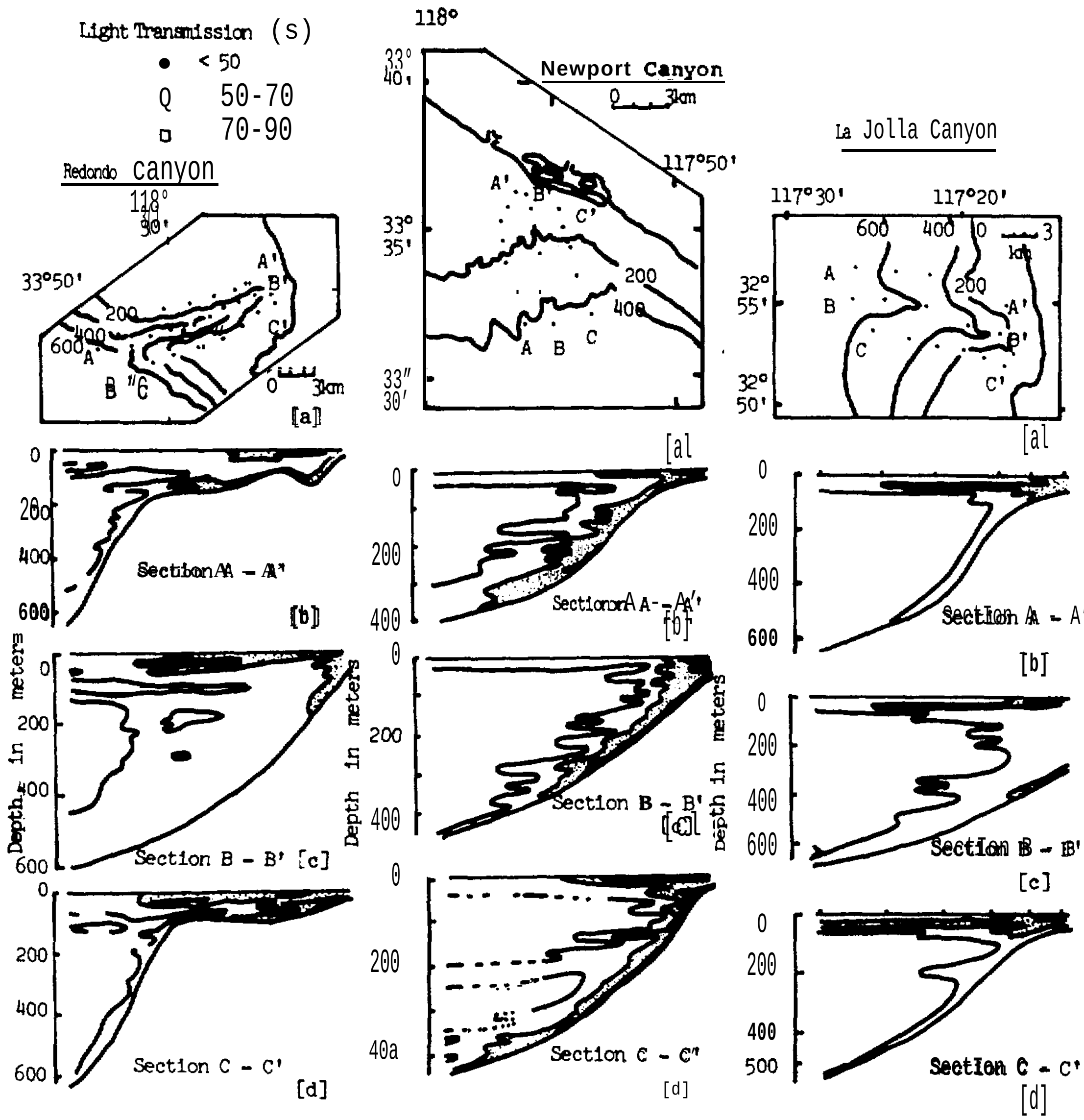

Figure 4-26. Station locations and light transmission profile across shelf and slope of (i) Redondo Canyon, Newport Canyon and La Jolla Canyon. From Drake and Gorsline (1973), Fig. 3-5.

5. HYDROGRAPHY OF HARBORS, LAGOONS AND SLOUGHS

Neil J. Maloney and Kwan-Ming Chan

1. General Features

The project area includes 18 lagoons and harbors that fall into the following general categories: (1) Salt marsh lagoons, (2) man-made small boat harbors, (3) man-made deep water harbors, (4) continental shelves protected by breakwaters, and (5) estuaries of intermittent streams. The importance of these small embayments in terms of biological productivity and resources are discussed in Chapters 13, 14 and 21. Man has physically altered these bodies of water by construction for industrial, recreational, and residential purposes; and chemically altered the water by adding pollutants of various types.

The larger embayments remain open to the ocean and receive tidal flushing. Seasonal storm run-off, power plant coolant water, and sewage outfalls increase the flushing rate. The health of a bay depends upon the relationship between the pollutant inflow and the flushing. Pollution sources in the coastal ocean are discussed in Chapter 6.

The small lagoons are cut off from the ocean by barrier spits for long periods of time. They do not receive tidal flushing and may revert to fresh or hypersaline water depending on the local run-off conditions. These lagoons are highly vulnerable to pollution because they are not diluted by tidal action.

Figure 5-1 shows the locations of the harbors and lagoons discussed in this chapter.

2. Marina Del Rey

Marina Del Rey is a small boat harbor modified from an estuarine salt marsh. It is located between Santa Monica and El Segundo (Figure 5-1) . The harbor consists of a dredged channel and eight small boat marina basins, and occupies 1.8 km^2 of water (Figure 5-2). Two man-made jetties maintain a permanent ocean entrance, and an offshore breakwater weakens the offshore wave action. The mean water depths are 7.5 m in the main channel and 3.5 m in the marina basins.

2.1. "Tidal Flushing

Mixed semi-diurnal tides with diurnal ranges from 1 to 3 m occur in the harbor. Some 20% to 40% of the bay water is exchanged with the ocean each day. Complete flushing, estimated by the tidal prism method (Dyer, 1973), normally takes about three complete tidal cycles. Storm run-off into the harbor increases the flushing rate. The transverse nature and the numerous obstructions in the marina basins probably cause some local stagnation of water.

The offshore position of the breakwater (Figure 5-2) may divert some of the ebb tide from Ballona Creek into Marina Del Rey Harbor and add pollutants. Local storms result in occasional large flows in the creek, and some of the pollutants flushed out of the creek bed could return to pollute the harbor.

2.2 Water Conditions

Bowerman and Chen (1971) conducted a survey of the hydrographic conditions and some of the potential sources of water contamination. The following paragraphs are a summary of their findings.

Temperatures ranging from 10.9 to 15.5°C were encountered in late February and early March of 1971. Surface and bottom temperature differences were about 1°C, indicating good mixing. Water temperatures closely follow the seasonal and diurnal fluctuations of air temperature due to the shallowness of the harbor. Homothermal conditions are frequently observed along the main channel, while greater temperature differences occur in the basins due to the poorer tidal flushing. The harbor water temperatures are almost identical with the coastal ocean water temperatures.

Salinities measured over the same time period ranged from 29 ‰ to 34 ‰ averaging about 33.4 ‰ They found only 0.2 ‰ difference between the top and bottom water which also indicates excellent mixing. The lowest salinities indicate some fresh water influx at the entrance and in the most inland basin. The highest salinities were found in the main channel. The salinities are probably much lower during rainy periods and slightly higher during the late summer.

The pH ranged from 7.4 to 8.1, increasing from the back basin towards the entrance. The water clarity, measured with a secchi disk was 1.5 to 3.1 m, much less than for open ocean water.

Typical dissolved oxygen values ranged from about 5 mg/l to 8 mg/l, with mean values of 6.5 mg/l along the main channel. Red tide, the blooming of dinoflagellates, occasionally decreased the dissolved oxygen to around 2.5 mg/l at 1.5-m below the surface (see Chapter 7). Reaeration by turbulence and photosynthesis can improve the conditions and increase dissolved oxygen to saturation level. (Figure 5-3)

The lowest dissolved oxygen values occurred at the harbor entrance. There is no problem with the dissolved oxygen in the harbor except during the red tide season.

2.3 Pollutants

The general level of heavy metal concentrations in the sediments was relatively low when compared with other coastal waters (Table 5-l). The concentration range for mercury was less than 0.3 ppb; lead 0.1 to 0.2 ppm; cadmium 2.5 to 5.0 ppb; and antimony 1.0 to 0.3 ppm. The primary sources of these heavy metals are apparently from storm drains. However, these heavy metals have a short residence time in the water and settle within a short distance from the source of the discharge.

Table 5-1

CONCENTRATION OF HEAVY METALS IN SOUTHERN CALIFORNIA COASTAL WATER [1]

		Lead in ppb	Cadmium in ppb	Mercury in ppb
Marina Del Rey		100-700	2.5-5.0	0.03
San Pedro	Top	180-266	6.0-11.0	0.03
Harbor	Bottom	192-266	6.0-11.0	0.03
Long Beach	Top	144-160	6.5-6.5	0.03
Harbor	Bottom	160	6.5-7.2	0.03
Santa Monica	ToP	120-160	10.0-11.0	0.03
Bay	Bottom	160-240	10.0-11.0	0.03

[1] From Bowerman and Chen (1971)

The concentration of pesticide residues i-n the water was well below 1 ppb. However, as in the case of heavy metals, accumulation in the sediment was evident, especially nearby the storm drain sites.

The environmental conditions of the Marina on the whole were moderately satisfactory. Heavy metals were in comparatively low concentration. The concentration of chlorinated hydrocarbons was relatively low and is considered to be at a harmless level. Dissolved oxygen was reduced to hazardous level during the blooming of red tide but otherwise it is above the minimum level of 3 to 4 mg/l.

2.4 Bottom "Sediments

The bottom sediments consist of mud in the marina basins and sandy mud in the channel. Sediments are transported into the harbor from the ocean by longshore currents and the flood tide. The highest concentration of organic material occurs in the sediments at the harbor entrance. Bowerman and Chen feel that this sediment washed out of Banana Creek during storms and was transported into the Marina by the tides.

Changes of depth of +0.7m in the main channel since 1962, are common (Bowerman and Chen, 1971) . These changes may be the result of different flow patterns created by the construction of the breakwater.

3. Ballona Creek Slough

Ballona Creek enters the ocean in a man-made channel located just south of Marina Del Rey (Figure 5-2). It is an intermittent stream that runs during storm periods. The estuary is small, ranging in depth from 8 m to 0 m. It has almost normal ocean temperatures and salinities except during high run-off periods when the creek flushes out the channel. Bowerman and Chen (1971) measured temperatures of 11.9° to 14.8°C, salinities of 33.2 ‰ to 34.0 ‰ Secchi disk depths of 1.6 to 3.4 m and pH values of 7.7 to 7.9.

The bottom sediments consist of black, anaerobic sandy muds. Bowerman and Chen (1971) conclude that the creek is the major source of organic material for the region. It is a potential source of pollutants to the ocean when flood waters flush the sediments into the ocean. Further discussion of the pollution potential is presented in Chapter 6.

4. King Harbor

King Harbor is a man-made small boat marina. The outer harbor

Table 5-2

VOLUME OF MUNICIPAL, INDUSTRIAL DISCHARGERS AND SURFACE RUN-OFF TO THE SAN PEDRO BAY [2]

Dischargers		Flow Volume $1 \times 10^6\ m^3/day$
Municipal waste, Terminal Island City of Los Angeles		30.7
Industrial waste discharges		
Los Angeles Harbor:		177.3
Outer Harbor	29.5	
Fish Harbor	7*2	
Main Channel	5.7	
West Basin-S.W. Slip	110.4	
East Basin	23.1	
Consolidated Slip	0.9	
Cerritos Channel	0.5	
Long Beach Harbor:		128.1
Cerritos Channel	42.7	
Channel Two	62.4	
Channel Three	4.9	
S.E. Basin	17.4	
Dominguez Channel		39.0
Los Angeles River Tidal Prism		26.5
Los Cerritos Channel		0.8
San Gabriel River Tidal Prism		13.6
Average daily flow from surface run-off 1971-72		$m^3/year$
Dominguez Channel		10.7×10^6
Los Angeles River		68×10^6
San Gabriel River		10.6×10^6

[2] SCCWRP 1973

water and sediment received from the river have been greatly reduced over the years by the construction of dams upstream and the general lowering of the ground-water table. River flow has the greatest effect on the eastern portion of the harbor.

Soule and Oguri (1972) measured the tidal currents in the harbor and found a high level of incursion and little circulation in some of the basins of the inner harbor. The circulation of the outer harbor is complex with rotary and cross channel tidal currents, which are modified by the local winds. The tidal currents are less than 0.6 m/sec (Reish, 1959; currents of 3 m/sec have been measured (Soule and Oguri, 1972).

The outer harbor has a fetch of about 17.7 km in an east-west direction (Figure 5-5), and small waves with periods of 1 to 3 seconds are formed in the harbor. Infrequent low 30 second to 45 minute seiches occur during times of persistent winds. In addition to these waves formed in the bay, wave energy is transmitted through the porous breakwater, resulting in some 10 to 20 second swell.

5.2. Water characteristics

Los Angeles-Long Beach Harbor is a well mixed body of water with temperatures and salinities that are similar to coastal - ocean water. Reish (1959) measured temperatures ranging from 13°C to 24°C, and Soule and Oguri (1974) found extremes of 8.1°C and 26°C. Soule (1974) shows that the warmest months are July through September and the coldest are December through February. The warmest summer temperatures occur in the inner harbor, and the coldest winter temperatures in the outer harbor. Temperature differences between the surface and the bottom ranged from 0°C (excluding a few small temperature inversions) to 10.6°C, with most stations ranging between 1°C and 5°C (Soule and Oguri, 1974). Summer warming of the surface water in the inner harbor caused the maximum differences.

Salinity readings ranged from 31 °/oo to 37°/00 with the maximum salinities occurring in the summer and the minimum salinities occurring during the winter storms in the inner harbor (Soule and Oguri, 1974). The vertical salinity variations ranged from 0.0 °/oo to 2.5 °/oo as the harbor is well mixed.

Both dissolved oxygen and the biochemical oxygen demand have been used to indicate the water quality of the harbor waters. The dissolved oxygen content is known to be closely related to the diversity of the bottom fauna (L. A. Water Pollution Control Board, 1952), except in the inner Fish Harbor, where there are few or no animals but the dissolved oxygen is moderately high due to good circulation of tidal water. The solid materials present in the waste discharge settle to the bottom.

The dissolved oxygen content of the harbor water, especially of the inner harbor, was almost depleted during the late 1930's. During World War II and the subsequent boom period, huge quantities of chemical and organic waste water were discharged into the Dominguez Channel. Surveys in October 1947 found there was no dissolved oxygen at the surface in the eight samples from the inner harbor. Recovery of dissolved oxygen and decrease in concentrations of sulfide in the harbor water are due to a series of pollution abatement measures. The most important one is the prohibiting of the discharge of oil refinery wastes into the channel (Clark 1971, L.A. Water Quality Board, 1967, Chapter 6, Reish, 1971) (Table 5-3).

Soule and Oguri (1974) measured dissolved oxygen concentrations between 1 and 12 ppm during the period from 1971 to 1973. The inner harbor had the poorest quality water.

The variation in pH is from 6.3 to 8.7 (Soule and Oguri 1974) . The low values were recorded in May 1973; if these data are excluded then all pH values exceed 7.2. Median pH values in Long Beach Harbor are 7.9 for the surface and 7.8 for both surface and deep water in Los Angeles outer Harbor. The inner harbor has lower pH values, averaging about 7.4.

5.3 Water Quality

Los Angeles-Long Beach Harbor is polluted by (1) sewage outfall, (2) industrial effluents, (3) oil well and tanker spills, and (4) brines from the oil field. Additional pollutants enter the harbor from Los Cerritos Channel, Dominguez Channel, Los Angeles River and the San Gabriel River during high run-off periods. Lower water quality in the harbor is the result of this pollution. Life is sustained in all parts of the harbor.

The characteristics and the constituent concentrations of these discharges and the run-off was summarized by SCCWRP (1973) . Two of the most important factors causing pollution in the harbors are the configuration and the direction of current or tidal flow. Dominguez Channel, Consolidated Slip, and West Basin have narrow entrances, and this has decreased the efficiency of tidal flushing action. The flood tide enters the harbor in an easterly direction and proceeds up either side of Terminal Island (Soule and Oguri, 1972). Ultimately the tidal currents meet in Cerritos Channel near Badger Avenue Bridge and result in zero flow exchange at this point (Clark, 1971) .

Measurements of suspended sediment in the water show great variations ranging from 1 ppm to 115 ppm. The higher values were obtained around the fish canning operations in Fish Harbor (L. A. Water Pollution Control Board 1952).

Table 5-3

DISSOLVED OXYGEN AND SULFIDE CONTENT, LOS ANGELES INNER HARBOR (ppm)

Station	Ott. 47[1] D.O.	Ott. 47[1] Sulfide	Nov. 54[2] D.O.	Oct. 66[3] D.O.	Oct. 67[3] D.O.	Jan. 69[1] D.O.	Feb. 70[1] D.O.	Feb. 71[1] D.O.
7	-	-	3.7	4.5	2.7			
26	-	-	2.3	2.4	1.7			
30	none	0.1				0.2	1.7	6.7
41	none	0.6				0.2	0.1	7.0
47	none	1.3				0.2	0.1	6.5
49	none	3.1	0.5			0.2	0.1	6.4
50	none	2.1	1.0	0.4	0.2	0.1	0.2	5.7
51	-	4.4	0.0			0.0	0.1	5.6
54			0.0		0.9			

[1] Clark, 1971

[2] Reish, 1959

[3] Crippen and Reish, 1969

The water quality of the inner harbor has improved since 1949. Although there is exchange of water between the inner and outer harbors, the dilution and mixing involved allow the water in the outer harbor to remain relatively healthy (Reish, 1972).

Oguri (1974) studied the primary productivity in the outer Los Angeles Harbor for the period of 1971 through August, 1973. Higher productivity, 50 mg C/hr/m^3, and assimilation ratios were observed inside the breakwater than were observed outside especially during the red tides. The inhibitory effects of high concentration of waste materials in the area may have decreased the productivity and assimilation.

5.4 Bottom Sediments

The bottom of the inner harbor is covered with a layer of organic mud or sludge that is anaerobic and toxic. The outer harbor is covered with various sediment types; Long Beach Harbor contains sediments from the Los Angeles and San Gabriel Rivers. Toxic heavy metals and chlorinated hydrocarbons occur in the bottom sediments.

6. Alamitos Bay

Alamitos Bay, located in Long Beach, is a spit-fronted embayment that has been dredged into a small boat harbor with marinas and a marine stadium (Figures 5-1 and 5-6). The San Gabriel River which once ran into the bay has been channelized south of the harbor. The mean lower low water depths are 5 to 7 m at the entrance, 5 to 6 m in the main harbor, and 3 m in the marina basins and the marine stadium. Two jetties maintain a permanent ocean entrance. The bay has been developed into a residential community with dredged channels and cement bulkheads.

6.1 Tidal Flushing

The bay has an area of about 1.38×10^6 m^2, and tidal prisms of between 1.4×10^6 and 2.1×10^6 m^3. Twenty to thirty percent of the bay water is exchanged with the ocean during a daily tidal cycle. Complete flushing of the bay should take less than four days; restricted circulation in some of the marinas probably causes local stagnation.

Surface run-off enters the bay through Los Cerritos Channel into the marine stadium and through local storm drains. The main channels of the bay are about 133 m wide and 7 m deep. Water is pumped from the bay and Los Cerritos Channel by the Southern California Edison Company at its Alamitos Power

Generating Station and by the City of Los Angeles at its Hynes Steam Plant facility. After circulation in these plants, the warm water is discharged into the San Gabriel River and then it flows out into the coastal. ocean. There are no direct sewage discharges into Los Cerritos Channel.

The minimum dry weather flow in Los Cerritos Channel is about 230 m^3 per day, consisting of street drainage and several industrial waste discharges of airplane wash water and cooling water from facilities at Long Beach Airport and filter backwash water from the Long Beach municipal water treatment plant. One storm drain empties into Alamitos Bay, near the southwest corner.

6.2 Water characteristics

The hydrographic conditions of Alamitos Bay have been described by Reish and Winter (1954) and the Los Angeles Water Quality Board (1967). The following paragraphs summarize their results.

The surface water temperatures ranged from 16.8°C to 27°C with the highest temperatures occurring in July, 1952. Salinity values were in the same range as in ocean water. The pH ranged from 7.6 to 8.2 with a mean of between 7.9 and 8.0. Dissolved oxygen values were above 5 ppm at most stations. The lowest concentrations were present in Los Cerritos Channel. Table 5-4 tabulates the chemical data from Alamitos Bay.

Table 5-4

RANGES OF WATER CHARACTERISTICS
ALAMITOS BAY, 1954 AND 1967[3, 4]

	Temperature (°C)	Dissolved Oxygen (ppm)	Transparency (meters)	PH	Cl°/oo
July 1952	20-27	3.9--9.1	0.8-2.2	7.6-	18.4-
1967	16.8-19.9	3.0-6.0	1.6-2.6	8.2	18.9

[3]From Reish and Winter (1954)

[4]From Los Angeles Water Quality Board (1967)

The data from both surveys show that there is no apparent adverse effect from waste discharges. Although the configuration of the bay limits free exchange of water with the coastal ocean, the tidal flushing is sufficient to dilute and disperse the waste discharged into the bay at the present level of usage.

The bottom sediments consist of fine, gray mud with abundant organic material (Reish and Winter, 1954). Organic black mud is accumulating over the gray clay in the marina basins. This suggests that pollutants are accumulating in the bottom sediments. Dr. Reish at California State University, Long Beach, has more recent unpublished data on some aspects of the harbor which supplements published literature (not available for inclusion) .

7. San Gabriel River

The San Gabriel River enters the ocean in a man-made, 80 m wide, flood control channel that is located between Alamitos and Anaheim Bays (Figure 5-7) . An entrance is maintained between the two jetties. The greatest water depths from 3 to 4 m, occur at the entrance.

7.1 Tidal Flushing

Flow from the San Gabriel River and Coyote Creek transports 8.3 x 10^6 m^3/day of Southern California Edison Power Plant coolant water and various industrial wastes (Reg. Water Qual. Control Bd., L.A., 1967). The Los Angeles County Sanitation District has calculated the flushing resulting from the waste water inflow and the tides. Their methods and results are explained in the following excerpt from a letter received from Franklin D. Dryden:

"Using a model developed within the Districts, we have calculated the detention time of water in the stretch of the San Gabriel River between the confluence of the river with Coyote Creek and the first Southern California Edison discharge point located between Seventh Street and Westminster Avenue (see enclosed map). This is a distance of 6,550 feet (2,150 m). Below this point, the input of cooling water from the Southern California Edison Power Plant and the Los Angeles Department of Water and Power Plant is 8.3 x 10^6 m^3/day causing the flow below the power plants to be constantly on the ebb tide. The flow into the tidal prism consists of about 0.16 x 10^6 m^3/day of wastewater from the San Jose Creek WRP, the Los Coyotes WRP, and the Long Beach WRP plus about 0.03 x 10^6 m^3/day of fresh water from Coyote Creek for a total of 0.2 x 106 m^3/day. The large quantity of cooling water discharged from the power plants allows for a dilution ratio of saline cooling water to fresh water of 47:1. It is felt that any further calculation of detention time for our wastewater below the power plant discharges would be insignificant.

"For the detention time of freshwater in the" stretch previously described, I have included a graph showing the detention times for three steady state conditions over a wide range of flow rates. Under present conditions the maximum detention time of 0.2 x 10^5 m^3/day of fresh water in the San Gabriel River between the Southern California Edison discharge and the upper end of the tidal prism is 14.5 hours occurring at Mean Higher High Water."

7.2 Water characteristics

Reish (1954) measured temperatures of between 18.5°C and 28.5°C in 1952. The temperatures were higher in the summer and the inland water was warmer than the ocean water. Salinities in the channel were slightly lower than the coastal ocean. Brackish water was encountered above the railroad bridge. Normal levels of dissolved oxygen were found below the bridge, while above the bridge, the concentrations were reduced to zero, indicating that the upper reaches of the estuary were badly polluted.

Los Angeles Water Quality Control Board, Los Angeles (1967) measured temperatures of 20°C to 30.8°C and dissolved oxygen concentrations of 3.2 ppm to 7.8 ppm, averaging 5.1 ppm.

The Los Angeles County Sanitation District is performing a continuing study of the water quality in the river. Their data on the water characteristics during 1972 are tabulated in Table 5-5.

Table 5-5

WATER CHARACTERISTICS IN
SAN GABRIEL RIVER ESTUARY, 1972

Location	Temperature (°C) Min. - Max.	Specific Cond. (µmho/cm)	Dissolved Oxygen (mg/1)
Southern California Edison Power Plant	10 to 29	440 to 50,000	4.5 to 9.5
Westminster Ave.	14 to 30	34,300 to 50,400	4.2 to 8.3
Entrance	16 to 32	36,800 to 50,500	4.7 to 8.6
Coastal ocean near entrance	12 to 26	42,800 to 52,900	4.5 to 8.8

The power plant coolant is warming the river mouth above the normal ocean temperatures. The low temperatures correlate with winter storm run-off in the river as do the lowest salinity (specific conductance) values. Dissolved oxygen values are sufficient to support life in the estuary.

7.3 Bottom sediments

Reish (1954) found black organic sand covering the channel bottom seaward of Pacific Coast Highway and black mud up channel from the highway. Hydrogen sulfide was present in the mud and organic matter was abundant in all samples. This sediment was probably washed out to sea during the flood of 1969. Sampling by the Los Angeles County Sanitation Districts in 1972, recovered black, organic sands and muds, and discovered areas of clean cement channel.

The Sanitation District analyzed the sediment samples for heavy metals and organic matter and obtained the results shown in Table 5-6.

Table 5-6

METALS AND ORGANIC MATTER ANALYSES
BOTTOM SEDIMENT
SAN GABRIEL RIVER MOUTH, 1972

Organic nitrogen	0.01 to 2.03 %N
Organic matter	0.18 to 36.5 %
Cadmium	0.52 to 2.72 ppm
Chromium	10.1 to 81.3 ppm
Copper	?.44 to 53.00 ppm
Lead	38.4 to 122.00 ppm
Manganese	2.90 to 264.0 ppm
Nickel	7.37 to 16.5 ppm
Zinc	11.3 to 233.00 ppm
Total chlorinated hydrocarbons	0.002 to 0.58 ppm

8. Anaheim Bay Complex

The Anaheim Bay Complex is located between the San Gabriel River and Newport Bay (Figure 5-l). It is a, compound embayment; it includes an outer deep water harbor, an inner deep water harbor, two salt marsh lagoons, and two small boat harbors (Figure 5-8).

The outer harbor is triangular, formed by two long breakwaters and a dredged main channel. Its depths. range from 5 to 17 m, averaging about 13 m below mean lower low tide. The harbor has an area of 0.38 X 10^6 m^2 and daily tidal prisms of between 1.19 x 10^6 and 0.85 x 10^6 m^3. An ocean entrance 133 m wide and more than 13 m deep is maintained which provides free tidal access to the ocean. Water is also exchanged with the inland portions of the bay complex.

The inner harbor is a dredged deep water basin. It connects with the outer harbor through a 133 m wide, 13 m deep channel and with inland portions of the bay through a restricted passage 50 to 67 m wide, 4 m deep. The surface area of the inner harbor is 0.39 x 10^6 m^2, and it has a daily tidal prism of between 0.86 x 10^6 and 0.57 x 10^6 m^3.

The Anaheim salt marsh consists of broad tidal flats and narrow tidal channels. It encompasses an area of 2.76 x 10^6 m^2, of which 0.53 x 10^6 m^2 are under water at high tide. Low tide covers about seventy percent of the high tide area (Chan and Lane, in press).

The area occupied by Huntington-Sunset harbors was formerly a salt marsh lagoon. It has been dredged to a mean depth of 3.3 m to provide marinas for small boats. The harbor has an area of 0.62 x 10^6 m^2 and tidal prisms of between 1.69 x 10^6 and 0.85 x 10^6 m3.

Sunset Bay and Huntington Harbour have been developed as residential marinas. The southeasterly end of Bolsa Bay salt marsh is separated from the marinas by tide gates. These three bays consist of a total of about 2 km^2 of water surface at high tide. At low tide, much of the bay, especially the inner-most part of the bay, is exposed marshland, mud-flats and channels. South of Anaheim Bay is a naval harbor, which has the only opening into the Pacific Ocean (Resources Agency, State Water Qual. Control Bd., 1967).

Bolsa Bay, consisting of narrow tidal channels and salt marsh tidal flats, empties into Huntington Harbour through restricted channels. It has a tidal prism of about 0.17 x 10^6 m^3.

The annual mean salinity of the four stations ranged from 33.18 to 33.43 ‰, with a slight increase in salinity from inside the bay to the ocean. The major salinity fluctuations are due to the influence of seasonal freshwater discharge from the flood channels and land drainages, during the winter and spring. All four stations had higher salinity in late July and early September (Figure 5-9).

There was an apparent decline in dissolved oxygen content of the water in winter. The annual mean dissolved oxygen concentrations for Stations One through Four were 4.95, 5.10, 5.17, and 5.70 ml/l. The greater fluctuations and lower mean values for Station One were due to its shallower depth and greater influence from surface run-off and sewage discharge (Figure 5-8).

The inorganic phosphate level ranged from 0.3 microgram-at/liter in late March at Station Four to the maximum of 3.24 microgram-at/liter at Station Three in early September (Figure 5-9). In general, Station Four had consistently lower inorganic phosphate levels than Station One, while Stations Two and Three were at intermediate levels. The annual mean inorganic phosphate levels were 1.65, 1.57, 1.65, and 1.31 microgram-at/liter for Stations One through Four, respectively. This trend is opposite to that encountered for dissolved oxygen, whose concentration at Station One may be interpreted by the intense consumption by oxidation of decaying materials and the limited exchange of oceanic water between the back of the bay and the coastal ocean.

The hydrographic condition of Anaheim Bay shows that there is no adverse effect caused by storm run-off or discharges. However, Anaheim Bay has only one direct access to the coastal ocean. The reduction in tidal exchange towards the inner bay area is revealed from the noticeable difference in hydrographic conditions as well as change in abundance and species composition of marine life.

Golshal (1971) noted that silt was dredged from the outer harbor. Mud is probably now accumulating on the bottom of the harbor away from the entrance.

8.3 Water Characteristic, Anaheim Salt Marsh

Anaheim Salt Marsh lies within the naval base and, as a result, has been protected from development.

Chan and Lane (in press) estimate the mean tidal level at 1.5 m; about 50% to 60% of the high tide volume is exchanged with Anaheim Harbor on a daily tidal cycle. Tidal flushing

8.1 Tidal Flushing

Freshwater discharges into the bay are through man-made flood control channels and normal street drainage. The total amount is significant only during heavy rainfall in the winter seasons. Waste discharges directly into Anaheim Bay are limited to chlorinated, settled sewage from the U.S. Naval Weapons Station at Seal Beach and oil field brine from the Signal Oil and Gas Company. The total volume is very small by comparison to the tidal exchange. Thus the circulation within Anaheim Bay is dominated by tidal flushing. Wind mixing and surface run-off are only secondary to tidal effects (Chan and Renshaw, 1972).

Moffatt and Nichol (1973) measured tidal prisms of 5.29 x 10^6 m^3 when the daily tidal range was 2.7 m, and 3.54 x 10^6 m^3 when the range was 1.8 m. The tidal prism is 16% to 20% of the low tide volume. They estimate that the main channel flushes in 3 to 4 days and the back channels in 10 to 20 days.

Flushing rate calculations in the salt marshes and small boat harbors is complicated by the water passing back and forth through Anaheim Harbor where the Naval Station is located. Thus water returning on the flood tide possibly could contain higher levels of contamination than the water that left on the ebb tide.

Moffatt and Nichol (1973) found maximum tidal currents of 1.5 m/see. The average currents are much lower than this.

8.2 Water Characteristics, Anaheim Harbor

Slawson (1972) measured hydrographic properties of Anaheim Bay (Figure 5-8). He established three stations in the harbor and one on the continental shelf. The following paragraphs are summarized from his results.

The annual surface water temperature range was about 9°C, from a minimum of 13.0°C in January to 22°C in August. The seasonal temperature patterns for each station were almost identical and the variation in temperature from station to station at any time seldom exceeded 1.5 C (Figure 5-9). In general from June through January the ocean had slightly warmer temperatures than the inner harbor, but this was reversed from February through May. Such observations show that the temperature characteristics of the bay are similar to the open coastal ocean. However, due to its shallower depth, the water is slightly cooler in winter and warmer in summer, of the salt marsh is calculated to take about three tidal cycles. Note that while the salt marsh is flushing out, Anaheim Harbor water is coming into the area and could pollute the salt marsh. The maximum tidal currents measured by Chan and Lane were 1.5 m/see.

There are considerable diurnal and seasonal variations in the water temperature. Chan and Lane measured temperatures ranging from 11°C to 26°C in the tidal channels. Daily temperature fluctuations are one to three degrees. The upper marsh water is warmer in the summer and colder in the winter than the lower marsh water.

Summer salinities are 34.2 °/oo to 34 °/oo. These salinities are higher than those measured in Anaheim Harbor. The salinities are reduced to less than 30 °/oo during the rainy period of the winter and spring (Chan and Lane, in press). The best flushing occurs during the periods of peak run-off. The highest salinities occur in the salt marsh tidal flats as a result of evaporation and excretions of salt by the plants. Chan and Lane found that the salinities there are usually over 35 °/oo and several tide pools had salinities in excess of 40 O/OO.

Dissolved oxygen values range from 6 ppm to 11 ppm with daily variations of 1 to 2 ppm. Chan and Lane found no areas of stagnant anaerobic conditions; there is some lowering of the dissolved oxygen concentrations in the west arm of the salt mar sh.

Nutrients are abundant in the spring but scarce during the other months. Chan and Lane measured 0.6 to 3.6 µg-at P/l of phosphorus, 0.2 to 0.7 µg-at N/l of nitrogen and 4.4 to 28.3 µg-at Si/l of silicon. The nitrogen to phosphorus ratio is low suggesting that some of the nitrogen is tied up as ammonia and organic nitrogen compounds. All nutrients were maintained at low levels throughout the year.

The bottom sediments consist of silty sand and sand with median diameters of 2 to 0.2 mm in the channels and black, silt-clay mud on the tidal flats. Organic carbon makes up 0.5% to 8.2% of the sediment; the highest concentrations occur in the muds.

8.4 Water Characteristics, Huntington Harbour

Huntington Harbour is located southeast of Anaheim Bay. Prior to the development of a residential marina, Huntington Harbour was a low-lying salt marsh. The outlet to the coastal ocean is through Anaheim Bay, and tidal flushing is very slow and inefficient. Wind mixing and storm run-off are secondary to tidal flushing in promoting water mixing and circulation. Based on an average tide differential of 1.8 m, the tidal exchange will replace Huntington Harbour waters on the average of once every 3 or 4 days. In the back channel area it will require 10 to 20 days (Molina Engineering, 1972). The following is a summary of the general hydrographic data primarily obtained by the Department of Harbors and Beaches, City of Huntington Beach (1973).

Surface water temperature within Huntington Harbour varies as a function of distance from the ocean and the season. The average increase in temperature toward the inner harbor is about 1°C/400 m. The average winter temperature is about 15.6°C while the average for summer months is about 21.1°C. The average temperature difference between surface and bottom water is less than 0.5°C. Temperature inversions occur during and after peak storm run-off periods. The run-off water forms isolated, cold and low salinity water lenses, which gradually dissipate after several tidal cycles.

Hardy (1970) studied Sunset Harbor and found the water temperatures ranged from 14.6°C to 20.2°C, with salinities similar to ocean water. In Huntington Harbour, the yearly average of dissolved oxygen is definitely reduced, being 6.3 mg/liter compared with 7.6 to 8.5 mg/liter for coastal water off Huntington Beach. The average dissolved oxygen concentration decreases from the outer harbor toward the inner harbor. This is also influenced by storm drain discharge of water with high oxygen consumption potential. Very often after a rainstorm, the storm drain run-off depresses the dissolved oxygen values to less than 2.5 mg/liter. Such a state of oxygen depletion remains 12 to 36 hours after the subsidence of the run-off (Jackson, 1973).

The pH values of the harbor surface water are in the range from 8.0 to 8.1. A slight lowering of pH occurs near the storm drain sites. BOD of the water is slightly above 1.3 mg/liter. No measurable amounts of sulfide, ammonia and chromium are found. The concentrations of nutrients are low except in the back channel area near Warner Avenue and the Huntington Harbour Corporation administration offices, where nitrate concentrations of 1.5 mg/l to 6 mg/l and phosphate concentrations of 0.3 to 1 mg/l are common (Jackson, 1973).

Huntington Harbour receives run-off from inland drainage areas, which are predominantly urbanized. The primary inflow is from Bolsa Chica Channel and the breakdown of the various sources of urban run-off into the harbor is as follows:

Sources	Contribution of Total
Huntington Harbour (entire land area)	1.5%
East Garden Grove-Wintersburg Channel, Sunset Channel and Warner Culvert	39.5%
Bolsa Chica Channel	59.0%

The run-off from these sources, although turbid, will remain in the Harbour for several days because of its density differential with the seawater. During the peak run-off period, the storm water carries not only large quantities of nutrients but also a tremendous mass of sediments. As a result there is almost a linear relationship between the sediment particle size and the distance from the sources of the drain outlet. Clays and finer silts become predominant in the dead-end channels, and the benthic infauna is also relatively depauperate (Kauwling, 1972).

9. Santa Ana River Slough

The Santa Ana River enters the ocean through a flood control channel located between Huntington Beach and Newport Beach (Figure 5-10). Long-shore transport of sand and the small size of the tidal prism have resulted in the partial to complete closure of the entrance with a sand bar. The slough is not important biologically, bunt periodic flooding flushes the sediment in the channel into the ocean where it could pllute the shelf area. Chapter 6 contains information on the run-off and pollution of the Santa Ana River.

10. Newport Bay

Newport Bay is compound, the outer harbor a spit-formed bay and the back bay a drowned valley estuary (Figure 5-10). The outer harbor was originally a salt marsh lagoon that has been dredged to form small boat marinas with piers and cement bulkheads. The ocean entrance was deepened and is maintained with jetties and by dredging. The back bay remains a tidal-channel salt marsh estuary. Portions of the main channel have been deepened and a few salt marshes have been lost to residential and marina development.

10.1 Tidal Flushing

Newport Bay has an average tidal prism of about $10.47 \times 10^6 m^3$.

The tides are mixed with daily ranges varying from 3 to over 10 feet. Water depths range from 6 to 7 m below mean lower low tide in the main channel and average about 5 m in the outer harbor. The back bay is much shallower averaging about 1.3 m at low tide. Tidal flats make up about 30% of the back bay area.

Tidal flushing is estimated to require 3 to 4 days. The strongest tidal currents occur at the Pacific Coast Highway Bridge and at the harbor entrance. Stevenson and Emery (1958) measured currents of up to 1.8 m/see, and the Harbor Department has recorded currents of up to 2.5 m/see. Maloney (unpublished) found velocities of up to 1.0 m/see. The currents in most portions of the bay are less than 0.3 m/see.

10.2 Water Characteristics

Water temperatures recorded in Newport Bay range from 10.4°C to 36.8°C. The outer harbor has temperatures similar to the coastal ocean water while the back bay is warmer during the summer. Murphy (1972) recorded temperatures of 12°C to 24°C around Lido Island in the outer harbor. Maloney (unpublished) found temperatures of 13°C to 15°C throughout the entire bay in December, 1971, and April, 1973. Readings taken in April, 1973, show the presence of 23°C to 25°C water in the outer harbor, which was 10°C higher than the coastal ocean water and 6°C above the back bay water. The reason for this anomalous condition is not understood.

The maximum daily temperature range found by Maloney was 4°c. Surface and bottom temperatures were within one degree of each other indicating good mixing.

Salinities range from normal marine values in the outer bay to slightly brackish or brackish in the back bay. The outer harbor contains well mixed ocean water in contrast with the back bay which is somewhat diluted by San Diego Creek and is completely flushed out during high run-off periods. Murphy (1972) measured salinities of 29.2 ‰ to 33.4 ‰ around Lido Island. In three tidal cycle studies of Newport Bay, Maloney found back bay salinities down to 24.2 ‰. Vertically the salinity is well mixed with differences of less than 1 ‰ between the top and bottom water.

Lower Newport Bay was surveyed by the Department of Fish and Game in 1953 and the condition of the Bay water was found to be satisfactory. Dissolved oxygen was present in the surface and at depths. Readings ranged from 5.5 to 8.1 ppm. The lower values were observed in the fish cannery slip and the west end of the bay.

Dissolved oxygen concentrations generally range from 4.5 to 12.0 mg/l with most of the bay having more than 6 mg/l. The lowest values occur around Lido Peninsula, in the turning basin, and in the marina located to the east of the main bay. Murphy (1972) measured dissolved oxygen concentrations of 2.3 to 15.9 ppm around Lido Island.

The transparency of the water ranged from 2 to 7.3 m with the lower values observed in the inner bay area (Calif. Dept. Fish and Game, 1953).

In August, 1966, a more detailed study of Newport Bay was conducted by the State Department of Public Health. The range of dissolved oxygen was between 3.6 to 7.5 ppm in the outer harbor and 5.2 to 5.7 ppm in the back bay. Lower values occurred in the dead-end channels. The general range of values was less than that found by the Department of Fish and Game in Lower Newport Bay during January, 1953. Such differences may be partially due to the seasonal variation in temperature. On the other hand, the Secchi disk depths recorded were also lower, from 1.2 to 2.8 m in the outer harbor and from 1.3 to 1.5 m in the back bay. Although no sewage debris has been recorded, oil, and trash are frequently found, probably due to the heavy boating use.

The pH of the bay waters averaged 7.78. The highest pH was 8.79, measured at a temperature of 33°C in shallow water. The lowest was 7.22, measured one hour before dawn over fine grained mud. Besides photosynthesis, respiration and temperature of the water, other environmental factors, such as depth of water, height of tide, abundance of plants and animals, and sediment types also are important in causing variations of pH values. However, the average of all periods measured showed a net increase of pH during the day and a decrease at night. The range in pH was found to be greater in the upper end of the bay than at the mouth. The Upper Bay stations averaged 1.2 points higher during the day and 1.0 point lower at night. The lowest pH reading always occurred just prior to sunrise because of the lowest temperature and the highest carbon dioxide concentration.

Hardy (1970) found that the nitrate concentrations ranged from 1.4 to 5.8 mg/l, and the phosphate from 0.12 to 0.36 mg/1 in the back bay. The values increase towards San Diego Creek. The nitrate and phosphate values are lowest during the spring plankton bloom and then increase after the blooms (Murphy, 1972).

The coarsest sediments cover the channel bottoms and the finest sediments are found on the tidal flats and in the boat slips. Stevenson and Emery (1958) sampled sand in the narrow channels. Hardy (1970) found soft, light gray silty mud covering the bottom of the back bay and scoured hard sand at the bridge. Periodic floods on San Diego Creek are filling the head of the back bay.

The water quality in the bay is fairly good. In the past the main polluters have been the fish canneries on Lido Peninsula, but now motor boats also contribute to the pollution.

The State Department of Health found the concentrations of silver, chromium, and cadmium are generally of the same order of magnitude throughout Newport Bay (Table 5-7). The remaining five metals varied significantly in concentration, with the west end of the lower bay exhibiting the highest levels of these elements. The one station consistently showing the highest concentrations was number twelve, Davey's Locker. Located at the end of the Rhine Channel, it had the highest concentrations of mercury, arsenic, copper and zinc. Station eleven was highest for lead. The upper bay and lower main bay had much lower levels of these five metals. Of the five, zinc was found in the highest concentrations at nine of the ten stations, and copper the highest at the remaining station. The chlorinated hydrocarbon concentrations were found to be in agreement with base line values found in California river sediments.

Environmental influences were investigated, including human activities, which possibly contribute to the concentrations of heavy metals at each station. A significant factor appears to be boat hull paint, which commonly contains arsenic, copper, mercury, and zinc. Station twelve, where these metals are found in the highest concentrations, is also the area where most boat maintenance yards are located (see Chapter 6).

Street drainage appears to be a significant factor affecting lead concentrations; the highest levels of this metal are found where storm drains discharge to channels with restricted circulation. Automobile exhaust fallout is a likely source.

The ecological significance of the concentrations of heavy metals and chlorinated hydrocarbons encountered is not known. Additional investigations are needed to shed light on this question.

When the concentrations of heavy metals in Newport Bay are compared with those found in the literature for California benthic sediments, a few interesting comparisons may be made. The mercury concentration at Station twelve, Davey's Locker, The phosphate concentration is high in winter followed by a secondary peak in June. The maximum concentration of phosphate occurs during heavy rain and probably represents the enrichment from land run-off. The secondary peak resulted from remineralization by zooplankton as the May blooming causes a sharp drop in phosphate concentration from December to April (Figure 5-27) . A similar pattern of remineralization and utilization also is observed for silicate. The seasonal cycle for different nitrogen species was rather complicated. The major factors are (i) influence of pollution; (ii) oxidation; (iii) utilization. The high concentration of ammonia occurred at the surface of the bay suggesting the major source of ammonia is from pollution (Figure 5-28). Since ammonia in sea water is rapidly oxidized to nitrite and subsequently to nitrate, the seasonal variation of these nitrogen species is not so obvious and the resulting pattern is one of cyclic fluctuations. Superimposed on these fluctuations is the seasonal utilization and the preferential uptake of ammonia by phytoplankton.

As a result of modifications of the bay area, which may be traced back to the early beginning of the 20th century, the tidal prism was reduced, and the subtidal volume of the bay increased. At the same time, the rate of discharge of wastes from the municipal and industrial sewage, ships and small craft caused a marked deterioration of water quality. Water quality sampling in the bay during the 1950's and early 1960's showed that 80% of the bay had dissolved oxygen concentrations below the levels for continued sustenance of fish and wildlife (Browning, Speth and Gayman, 1973). Water clarity, as measured by Secchi disks, was less than four feet. Extensive sludge deposits blanketed bay bottoms around the U.S. Navy installation and waterfront area. The termination of San Diego Municipal waste discharge into the bay area in 1963 helped to improve the water quality conditions. Water sampling in the late 1960's revealed dissolved oxygen concentrations generally between 4 and 7 mg/liter, Secchi disk depth 2 to 4 m. The regulations imposed by the Regional Water Quality Control Board-San Diego continued to improve the water quality in most areas. Nevertheless, there are still several pollution sources, e.g. , surface run-off, thermal and saline effluents, shipyard and military wastes, which directly or indirectly will deteriorate the water quality of the bay water. Zinc, mercury and lead have been concentrated in the bottom.

22. Tia Juana Lagoon

Tia Juana Lagoon is a channel-salt marsh lagoon that occupies between 4 and 8 km^2 (Figure 5-29). It maintains an open channel to the ocean, and receives periodic influxes of fresh water from the Tia Juana River. Sewage enters the lagoon from the drainage system. The lagoon is shallow and the flushing should take three to four days when the entrance is open. No data is available for the water characteristics of the lagoon.

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is protected from the ocean by a breakwater (Figure 5-4). This portion of the bay has a mean lower low tide depth of 6 to 10 m and is open to tidal flow. The inner harbor was constructed by dredging out basins which are 3 to 5 m deep and are somewhat restrictive to tidal flow. King Harbor has an average tidal prism of about 0.5 X 10^6 m^3. Roughly 20% of the bay water is exchanged with the ocean on each daily tidal cycle. The overall flushing time, using the tidal prism method, is about six days (Dyer, 1973). The flushing is probably poorest in the restricted portions of the inner harbor and the deepest areas of the outer harbor.

There are no fresh water sources in King Harbor except for local run-off, and the salinity of the bay is close to that of the adjacent ocean water. Other chemical properties of the harbor water are unknown.

The Redondo Beach Generating Station uses bay water as a coolant and then returns the heated water to the bay. Duffy (1969) measured temperatures ranging from 13.6°C to 22.6°C in King Harbor, and discovered a 4°C thermocline at the outfall. The Edison Company has found the temperatures at the outfall to be 3°C to 9°C higher than the surface temperature outside the harbor. The water conditions were described as healthy in 1968 (Duffy, 1969).

The bottom sediments consist of fine sand in the channel and silt and mud lateral to the channel and in the marinas. The outfall is covered with yellow sand.

There needs to be more study of the circulation patterns, tidal flushing, and water chemistry of King Harbor.

5. Los Angeles-Long Beach Harbor

Los Angeles-Long Beach Harbor is a man-made deep water port located in San Pedro Bay (Figure 5-l), The outer portion of the harbor was formed by the construction of three breakwaters on the continental shelf in 1928 (McQuat, 1950) . The inner portion of the harbor is a salt marsh lagoon that was dredged to form channels and marinas in some places and filled to create islands in other areas (Figure 5-5) (see Chapter 19). Four additional 10 acre islands have been formed to provide locations for petroleum production (see Chapter 19).

Shipping and industrialization increased as Los Angeles became a large city. This together with the development of an oil field in the harbor caused it to become highly polluted. Strengthened controls on pollution have improved the water quality in the harbor. The Allan Hancock Foundation of the University of Southern California is presently monitoring the physical, chemical and biological system in Los Angeles-Long Beach Harbor; and the Army Corps of Engineers is completing an environmental impact report related to channel deepening.

Los Angeles-Long Beach Harbor is hydrographically one body of water that is divided geographically into the following areas:

	Area Km^2 Outer' "Harbor	Area Km^2 Inner Harbor
Los Angeles	3.69	3.09
Long Beach	8.02	0.85

The bay has an area of 62 km^2 (Reish, 1959) and an average mean lower low tide depth of 12 m. The outer harbor is deeper than the inner harbor.

5.1 Tidal Flushing

Mixed semi-diurnal tides with diurnal ranges of 1 to 3 m occur in the harbor. The average mean tidal range is 1.2 m and the mean daily change is about 2.3 m. A theoretical tidal exchange of 8.6% has been calculated in the western part of the Los Angeles Harbor. By way of comparison, Reish (1959) estimated that 20% of the water in the harbor is . exchanged with the ocean on each complete tidal cycle. The calculated overall tidal exchange rates fluctuate between 8% and 25%; 10% of the outer harbor water and 25% of the inner harbor water. 'The flushing rate of the harbor estimated by the tidal prism method, neglecting discharges, is about 90 tidal cycles. The actual flushing rate is probably somewhat better than this estimate, but it is safe to say that the harbor is very poorly flushed.

The daily total volume of water exchange between the harbor and the open ocean based on semi-diurnal tidal pattern is about 8.7 X 10^6 m^3/day. Part of the volume exchange is re-circulated through the tidal cycle. Due to the configuration of the harbor, there is less flushing action in the inner harbor than the outer harbor area. The volume of exchange is about 20 times the discharges from the municipal and industrial wastes (Table 5-2).

River water enters the bay from the Los Angeles River and Dominguez Channel during the rainy winter season. The San Gabriel River lies to the east of San 'Pedro Bay and the river water can enter the bay during periods of high run-off whenever the wind is' from the east or the south. The Los Angeles River has a 2163 km^2 drainage basin; the amounts of

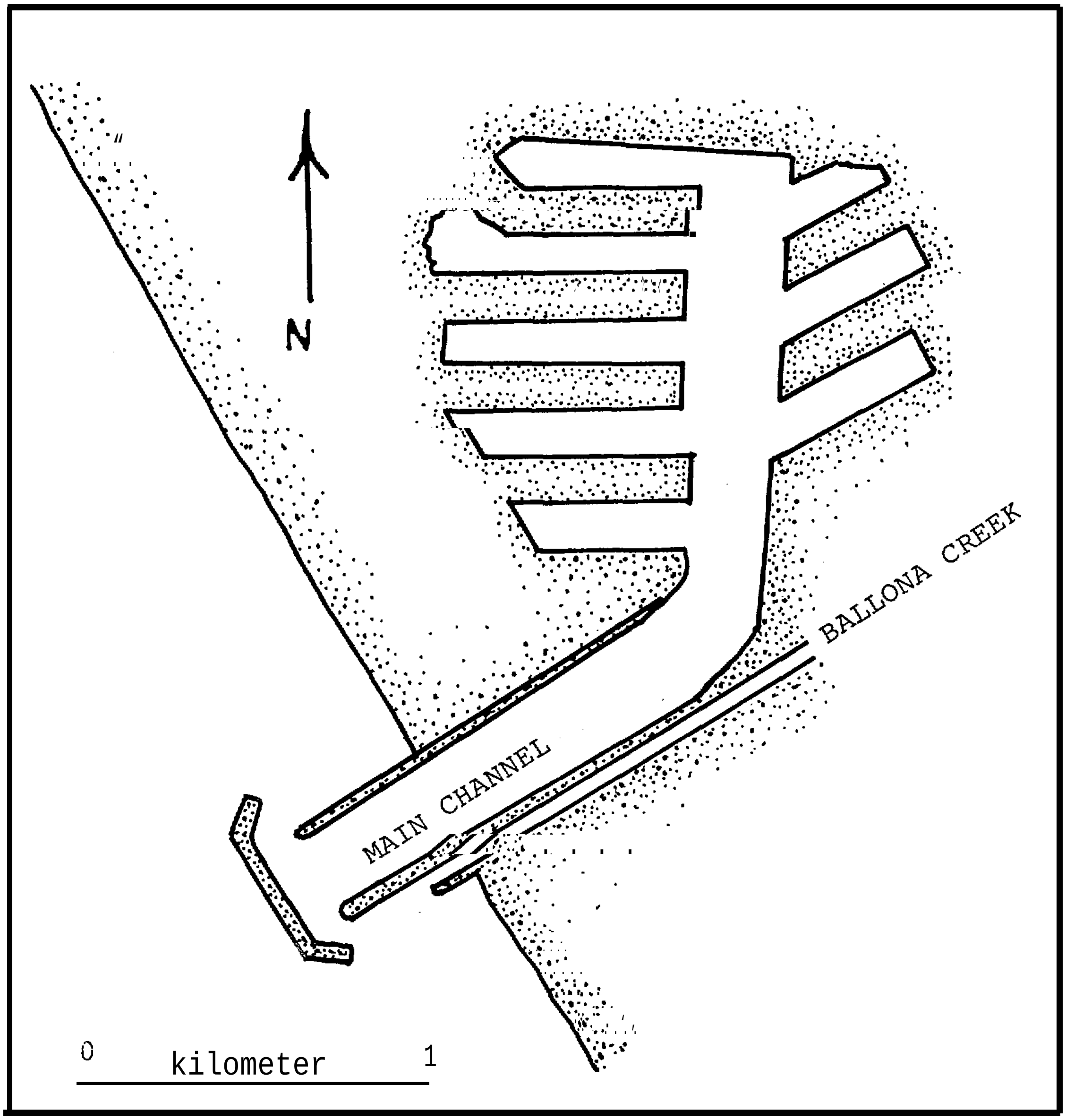

Figure 5-2. Sketch map of Marina del Rey Harbor and Ballona Creek.

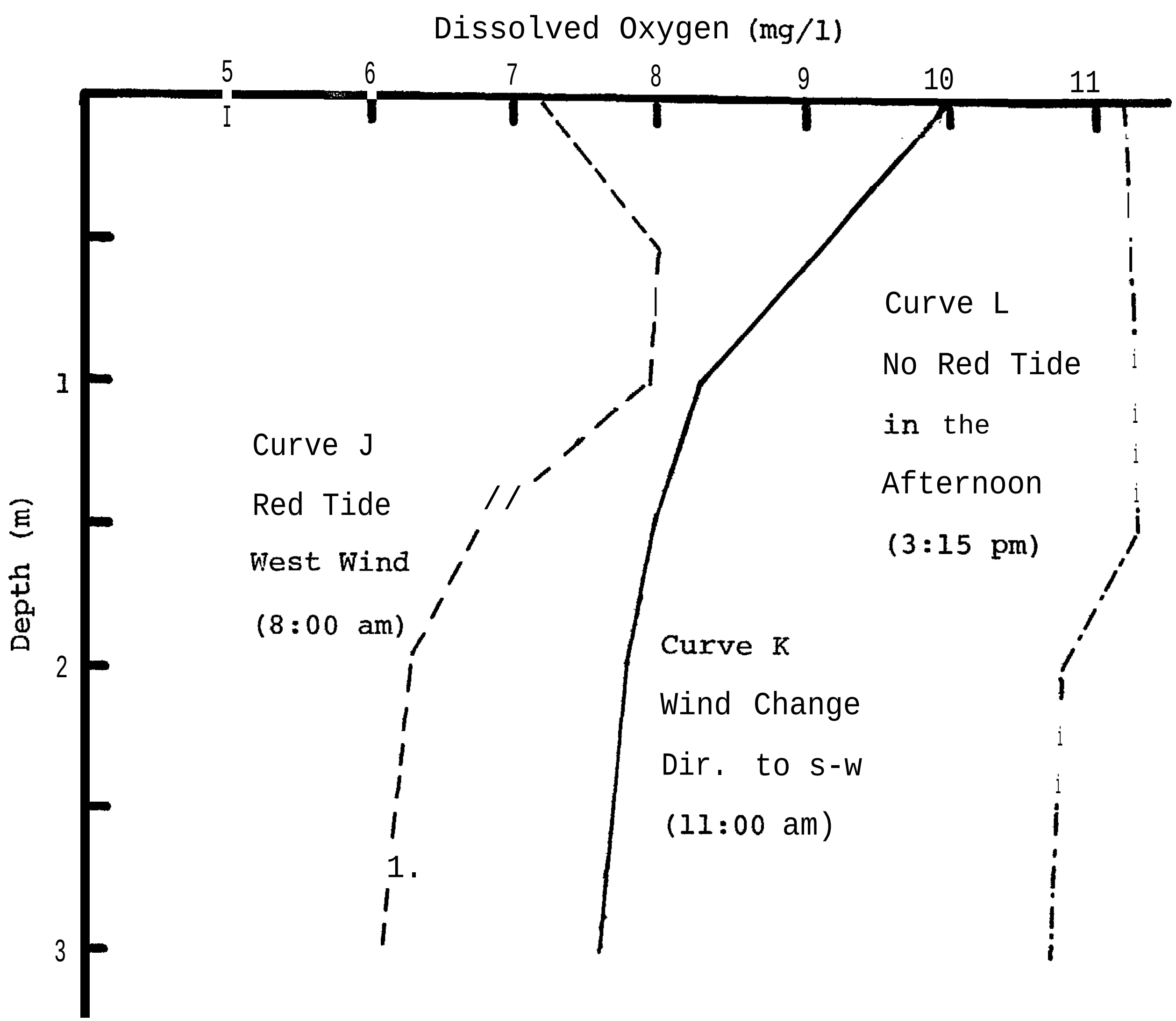

Figure 5-3. Dissolved oxygen concentration showing the effects of red tides and re-aeration by the wind. From Bowerman and Chen (1971).

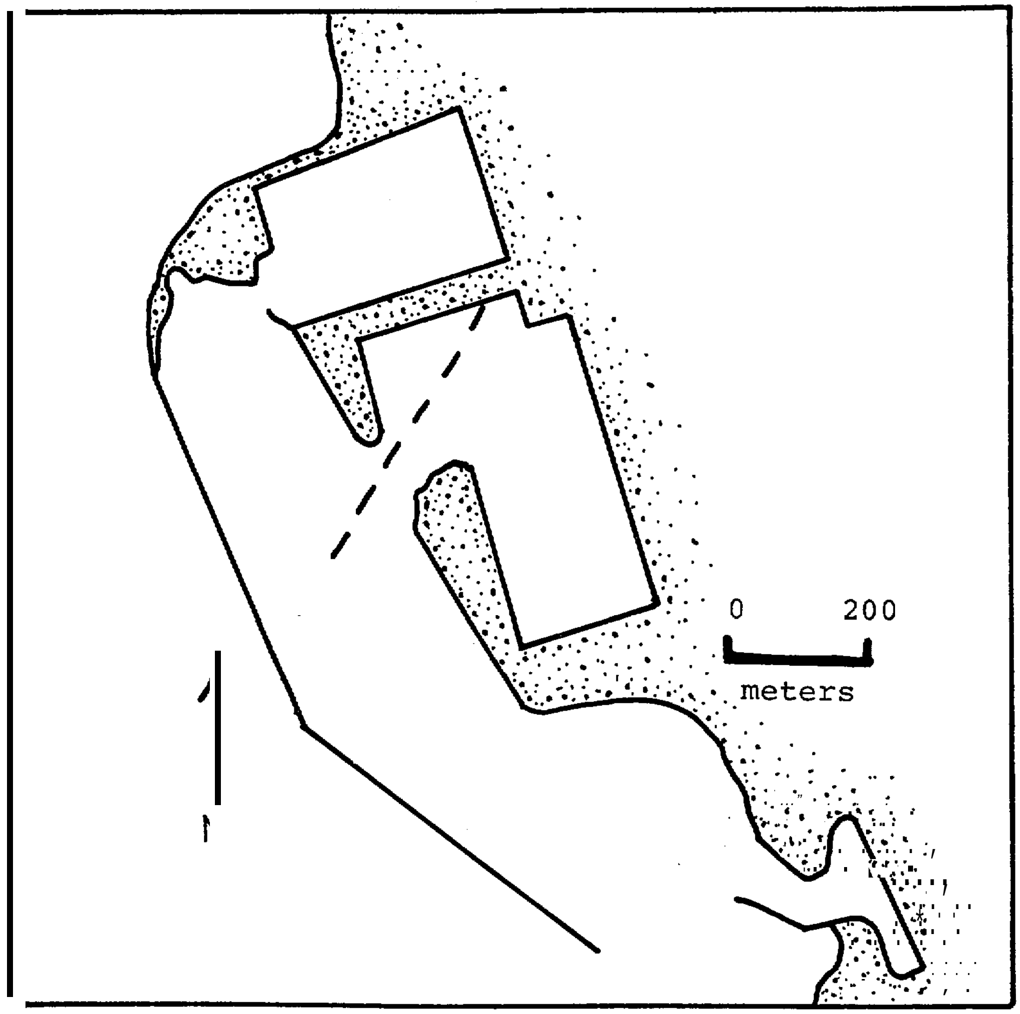

Figure 5-4. Map of King Small Boat Harbor. The dot shows the location of the generating station coolant outfall.

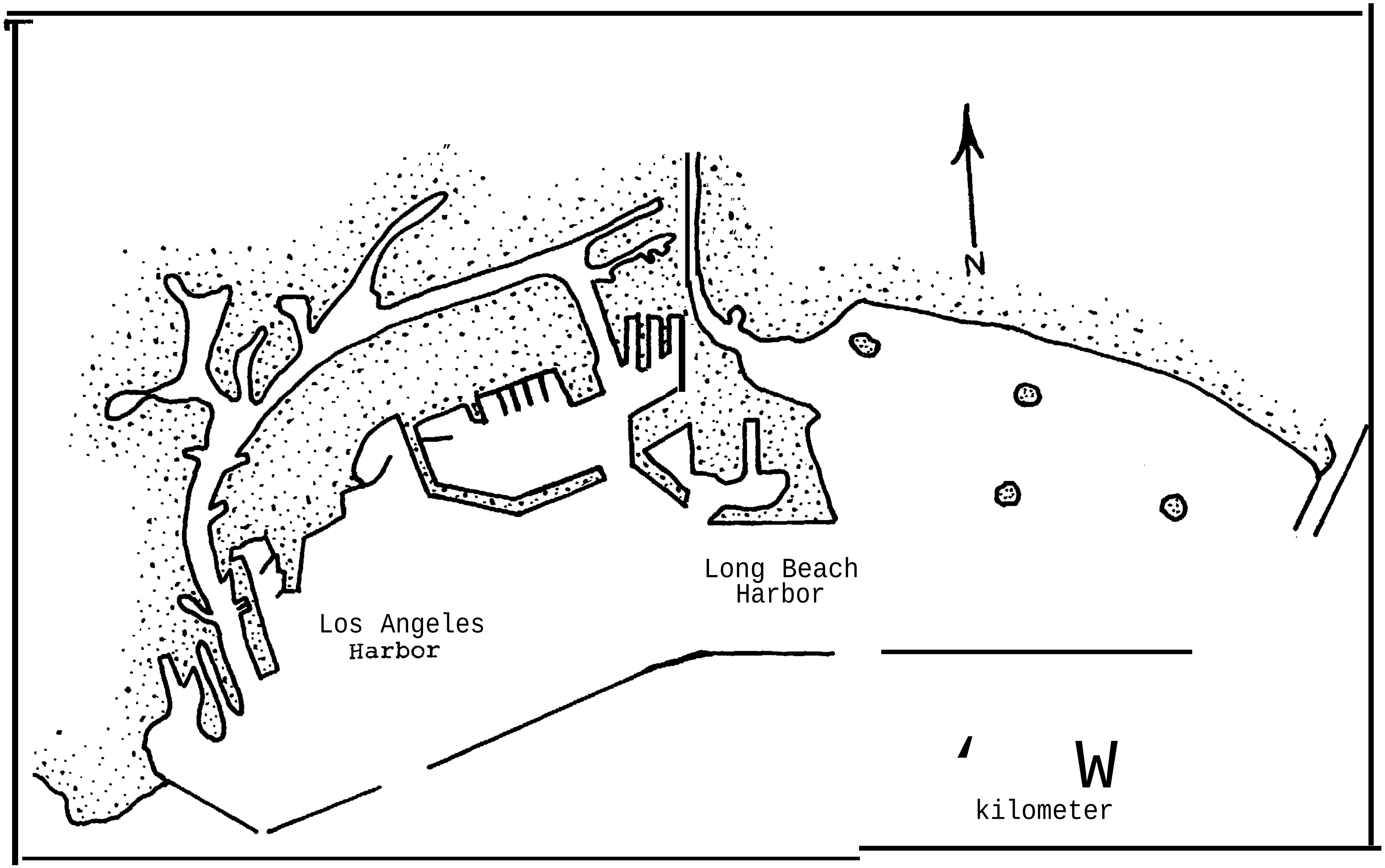

Figure S-5. Map of Los Angeles-Long Beach Harbors.

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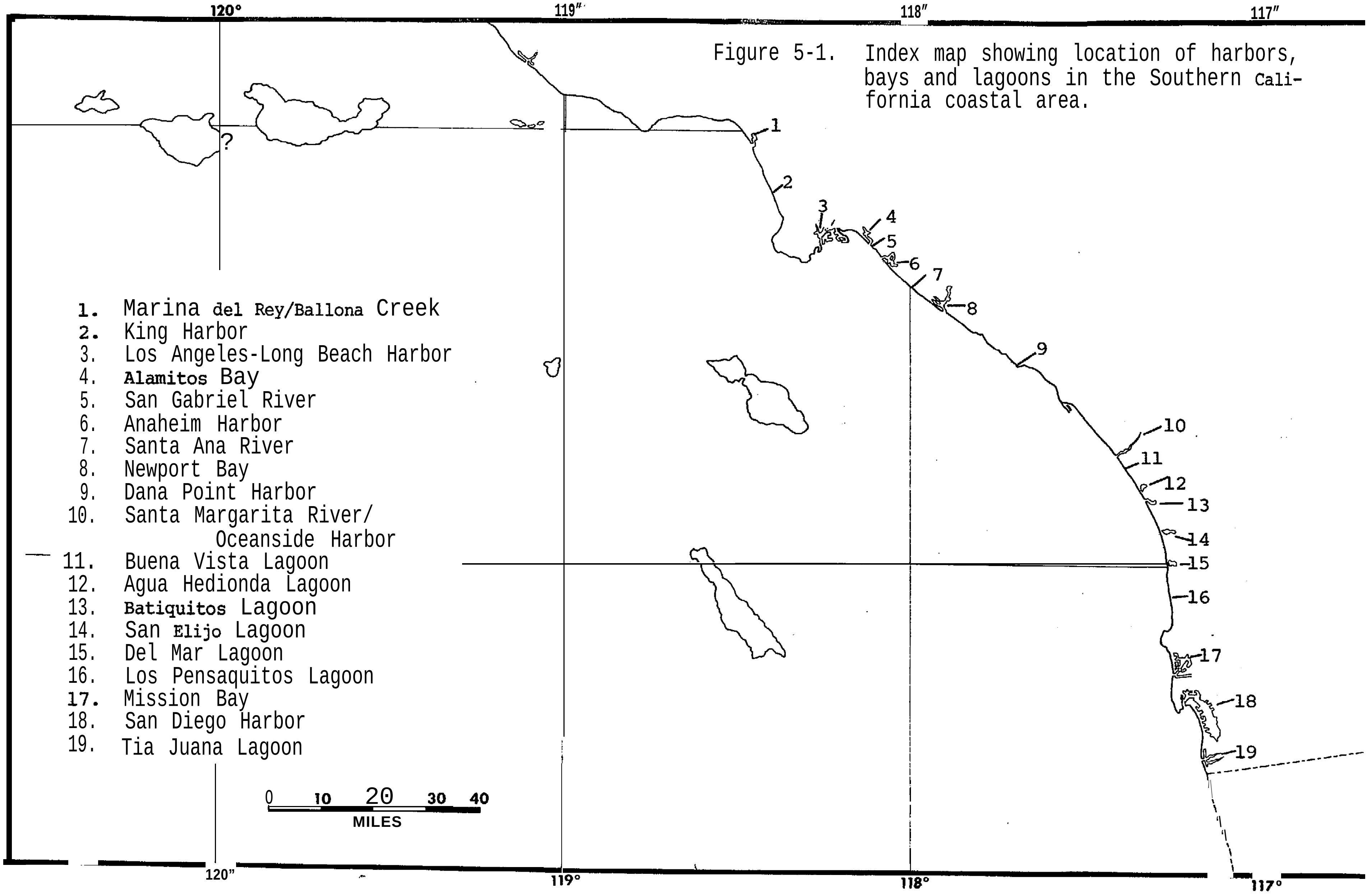

Figure 5-1. Index map showing location of harbors, bays and lagoons in the Southern California coastal area.

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Table 5-7

CHEMICAL ANALYSES MUD SAMPLES
Newport Bay, Orange County - September 1, 1971
(mg/kilograms - dry basis)

Station	Location	Total Assayed Heavy Metals	Hg	As	Pb	Ag	Cr (total)	Cu	Cd	Zn	Chlorinated Hydrocarbons DDE	Chlorinated Hydrocarbons DDT
2	Onyx Avenue Balboa Island	122.48	1.08	3.0	18.	0.6	16.	24.	0.8	59.	0.05	None detected
6	Balboa Bay Club Swim Area	233.9	1.30	4.8	23.	1.2	29.	38.	1.6	135.	0.02	None detected
8	Newport Blvd. Bridge	354.7	1.50	3.0	142.	0.6	14.	46.	0.6	147.	0.01	None detected
9	43rd Street Beach	474.83	4.84	5.6	43.	1.0	31.	140.	1.4	248.	0.02	None detected
10	38th Street Beach	141.38	0.98	2.2	84.	0.6	12.	46.	0.6	95.	0.001	None detected
11	33rd Street Channel End	531.25	2.45	3.5	172.	0.8	16.	110.	1.5	225.	0.01	None detected
12	Davey's Locker End of Rhine	1221.2	11.90	10.0	44.	1.0	29.	713.	2.3	410.	None detected	None detected
25	Vaughn's Launching Ramp	201.02	0.12	3.9	21.	1.0	26.	22.	3.0	124.	0.1	0.002
26	Ski Launch Area	183.47	0.17	3.5	30.	1.0	21.	22.	1.8	104.	0.05	None detected
4	Bayshore Camp Swim Area	12.925	0.025	0.8	2.	0.0	2.	3.	0.1	5.	0.01	0.003

for example, (11.90 mg/kg) was over 500 times the concentration found in bottom sediments collected off La Jolla by Klein and Goldberg (1969) and presumed by SCCWRP, in their report on mercury in the environment, to be a base level value. The concentration of mercury at this station is ten times that found 1.8 km from the Los Angeles County Joint Water Pollution Control Plant-White's Point outfall (Klein and Goldberg, 1969). Of the stations in Newport Bay, only two compare favorably with the base line value cited above. These are station 25, Vaughn's Launching Ramp, and station 26, Ski Launch Area.

Copper concentrations found in sediments from Davey's Locker were also higher than those obtained by SCCWRP off the JWPCP outfall at White's Point.

Base line values for most of the heavy metals are not readily available at the present time. Further investigation, however, should reveal more information with which to compare heavy metal concentrations in Newport Bay.

The levels of the chlorinated hydrocarbons DDT and DDE obtained in Newport Bay were found to be in reasonable agreement with values of .01 to .50 ppm observed in California river sediments investigated by Bailey, Asce, and Hannum in 1967.

11. Dana Point Harbor

Dana Point has a new man-made harbor, created from a former tidepool-continental shelf region (Figure 5-11). The harbor has an area of roughly 0.1 x 10^6 m^2, and an average tidal prism of 0.13 x 10^6 m^3. There is no freshwater inflow. The wave energy is stopped by a long breakwater. The tides have free access to the ocean; however, restricted channels in the marina may reduce the tidal action. The water quality in Dana Point Harbor is thought to be good.

12. Santa Margarita Lagoon

Santa Margarita Lagoon is closed to the ocean and varies greatly in size due to variable run-off. It includes 3.24 km^2 that are highly modified by marine amphibious vehicles from Camp Pendleton. Two sewage treatment plants put 950 m^3 of secondary treatment effluent into the lagoon per day. No details on the water chemistry are available. There is no tidal flushing.

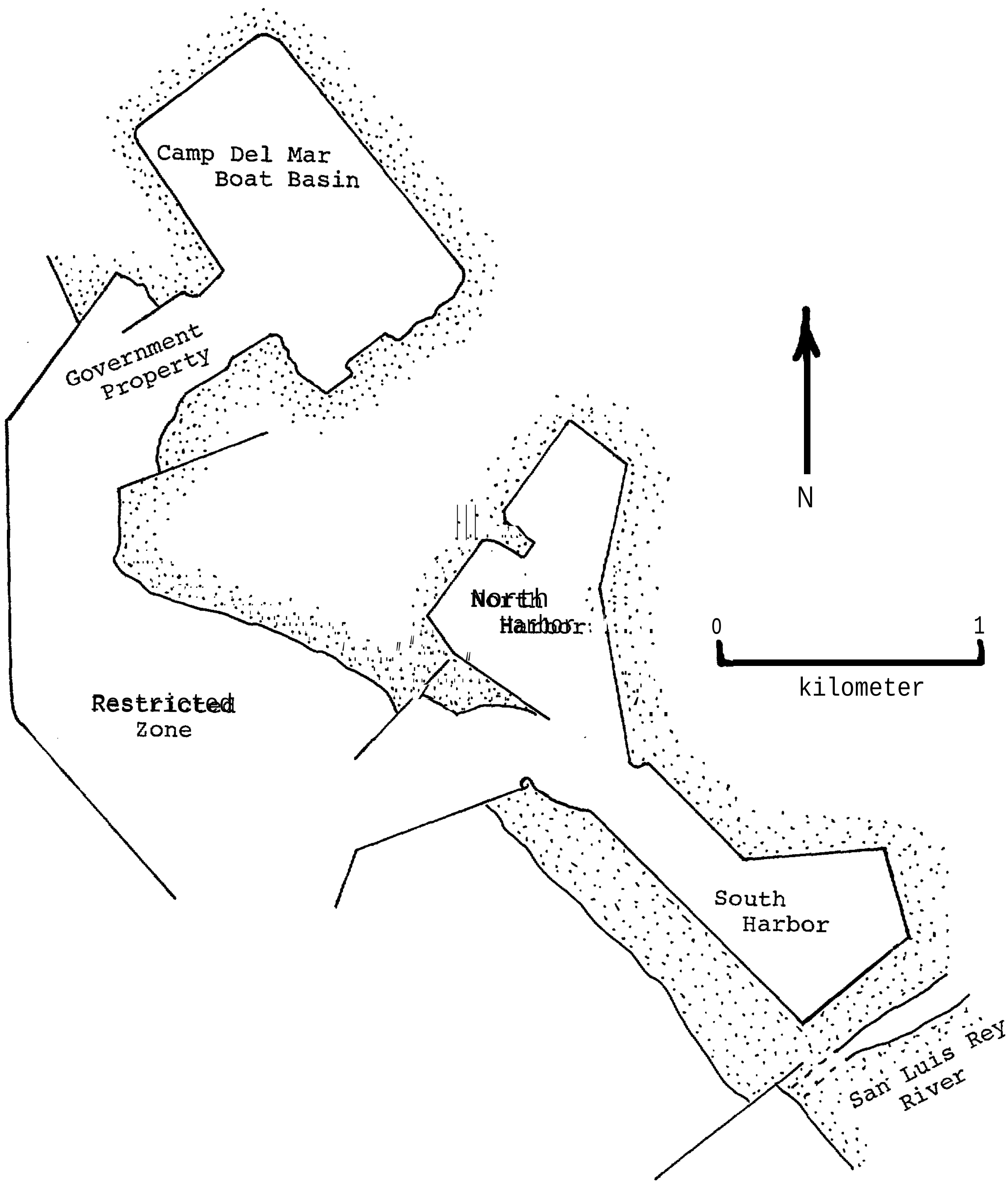

Figure 5-12. Map of Oceanside Harbor.

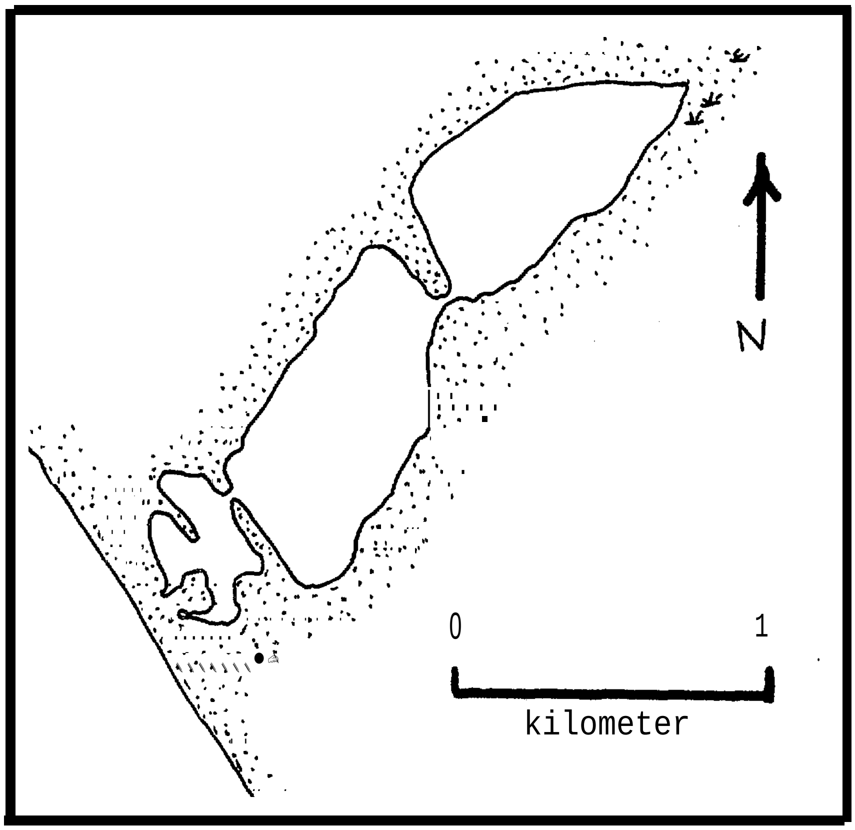

Figure 5-13. Map of Buena Vista Lagoon.

21. San Diego Bay

San Diego Bay is a large spit-fronted lagoon that has been dredged into a deep water harbor (Figure 5-25). The bay is about 22.5 km long and 4 km across at its widest point. Maximum depth exceeds 20 m, but aside from dredged channels, most of the bay is less than 13.3 m deep. The western entrance of the bay is protected by Point Loma, a narrow peninsula, and Zuniga Jetty.

Originally San Diego Bay was an estuary. In 1957, the U.S. Army Corps of Engineers diverted the flow of San Diego River away from the bay. Since then the bay may be more accurately described as a neutral type lagoon with annual evaporation approximately balanced by the fresh water input from all sources (Lackey and Clendenning, 1965; Miller and Nusbaum, 1952).

21.1 Currents and Tidal Flushing

The daily tidal range varies from about 1 to 3.2 m and averages 1.8 m. The tidal prism is about 84.9 x 10^6 m^3 and about 30% of the bay water is exchanged with the ocean during each tidal cycle. The flushing rate, estimated by the tidal prism method, is about four days (Dyer, 1973). The flushing is poorest in the deep channels of the north bay, the restricted marinas, and the south inland part of the bay where the water is recirculated from the main harbor. Tidal currents of up to 1.5 m/see occur near the entrance (Calif. Dept. Fish and Game, 1951). Local winds cause waves with maximum heights of about one meter.

Since the tidal exchange is not very efficient, the flushing action decreases towards the southern portion of the bay. If the tidal flushing were greatly reduced, the southern end of the bay soon would become highly saline and overheated during the summer, and the dissolved oxygen would be depleted rapidly.

21.2 Water Characteristics

Where tidal flushing action is strongest, near the entrance and the northern portion of the bay, the water temperature normally ranges from 11.7°C in winter to 23.9°C in summer (Ford, 1968; Ford, Chambers, and Merino, 1972; Marine Advisors, 1963). The water temperature in the Southern San Diego Bay is 6°C to 8°C higher than those in the North Bay during the summer months (U.S. Dept. Interior, 1968). This is partly due to the intense solar heating and partly from the waste heat in power plant cooling waters (Applied Oceanographers, 1970) .

The salinity of the water, from 32 °/oo to 37 °/oo, is similar to that in the coastal ocean. The amount of municipal and industrial wastes entering the" 'bay has been reduced by the diversion through a long ocean outfall in 1963. The amount of dilution from fresh 'water run-off "is very small, especially during the summer months. Consequently the tidal exchange is the most important factor causing the bay water to have rather uniform salinity. Local variations in salinity are primarily due to heavy rainfall or hyper-saline effluent from the water desalination facility (U.S. Dept. Interior, 1968).

The concentration of dissolved oxygen in the San Diego Bay was studied in detail by the San Diego Regional Water Pollution Control Board in 1952. The general distribution pattern is summarized in Figure 5-26. A gradual decline in dissolved oxygen from the entrance to the southern end of the bay is apparent, Such a decrease of dissolved oxygen can be accounted for only by the higher rate of oxygen utilization than the replenishment by photosynthesis, mixing, and diffusion. Although the tidal exchange daily introduces oxygen saturated ocean water, only a small amount is actually available for the stabilization of pollution in the central and southern areas. Miller and Nusbaum (1952) divided the bay area into three zones and evaluated the resources and the existing demand in San Diego Bay (Table 5-9). Among the three different zones, A has a surplus of dissolved oxygen, B is close to the limit of loading, and C probably has an oxygen deficit. The lower dissolved oxygen in the South San Diego Bay is due to a combination of excessive warming of bay waters, poor circulation and intense utilization by oxidation of organic matter or other waste materials.

Table 5-9

OXYGEN RESOURCES AND DEMAND IN SAN DIEGO BAY, 1952

Resources	Z ONE		
	A	B	C
(i) Atmospheric aeration assuming 4 ppm (kg/day)	26,501	18,310	17,900'
(ii) Oxygen produced by biological activity (kg/day)	37,860	35,220	8,040
(iii) Oxygen available by tidal exchange (kg/day)	362,720	76,810	0
Total(kg)	424,680	130,360	25,950
Demand			
(i) Mean oxygen demand in Bay waters (kg/day)	60,450	69,900	16,090
(ii) Daily 24-hour oxygen demand from wastes (kg/day)	360	9,220	130
Total (kg)	60,810	79,130	16,220

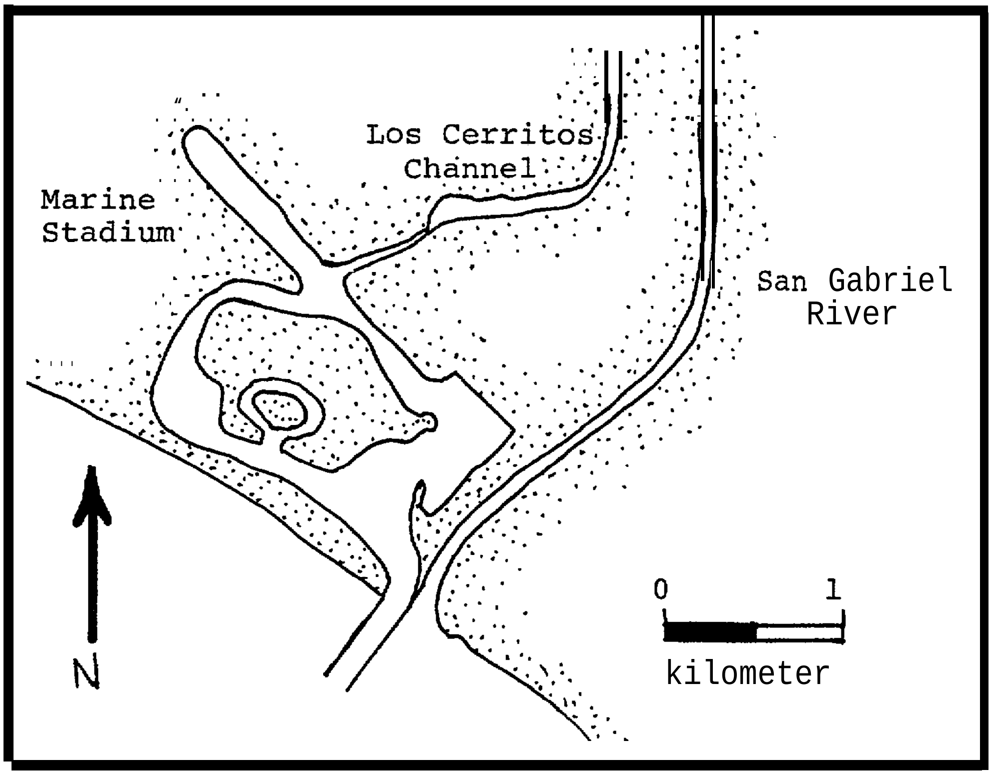

Figure 5-6. Map of Alamitos Bay and San Gabriel River Mouth.

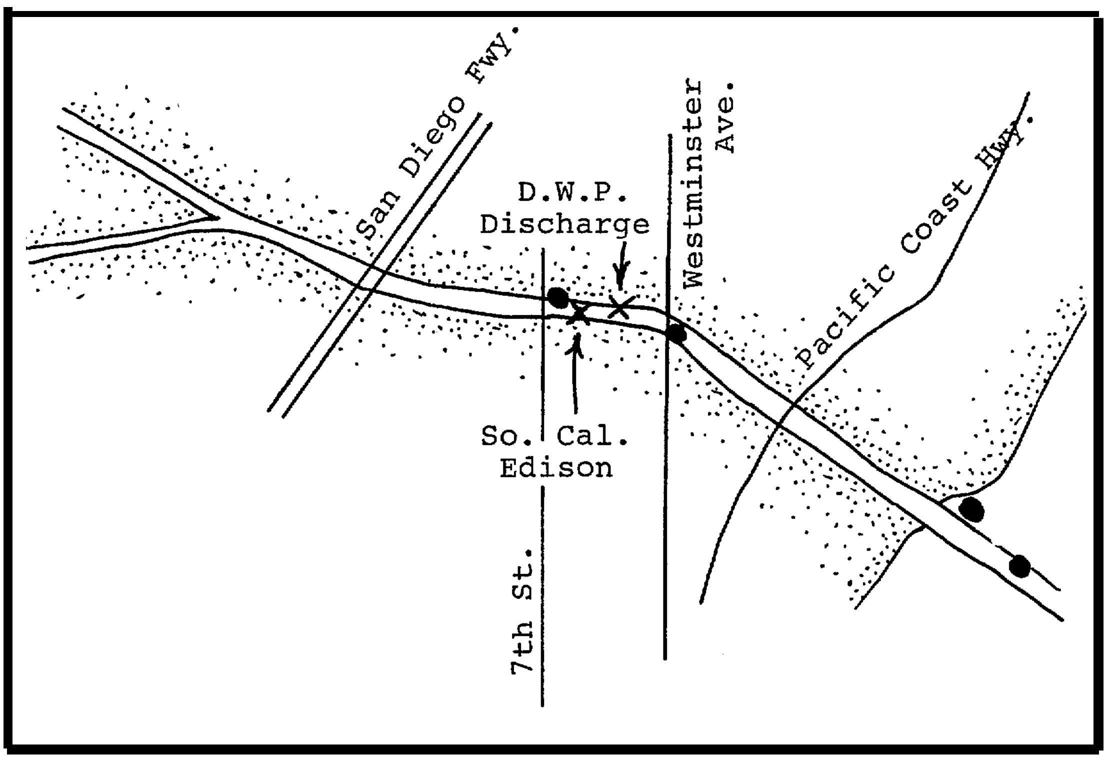

Figure 5-7. Map of San Gabriel River Slough. The black dots locate the Sanitation District sampling stations listed in Table 5-5.

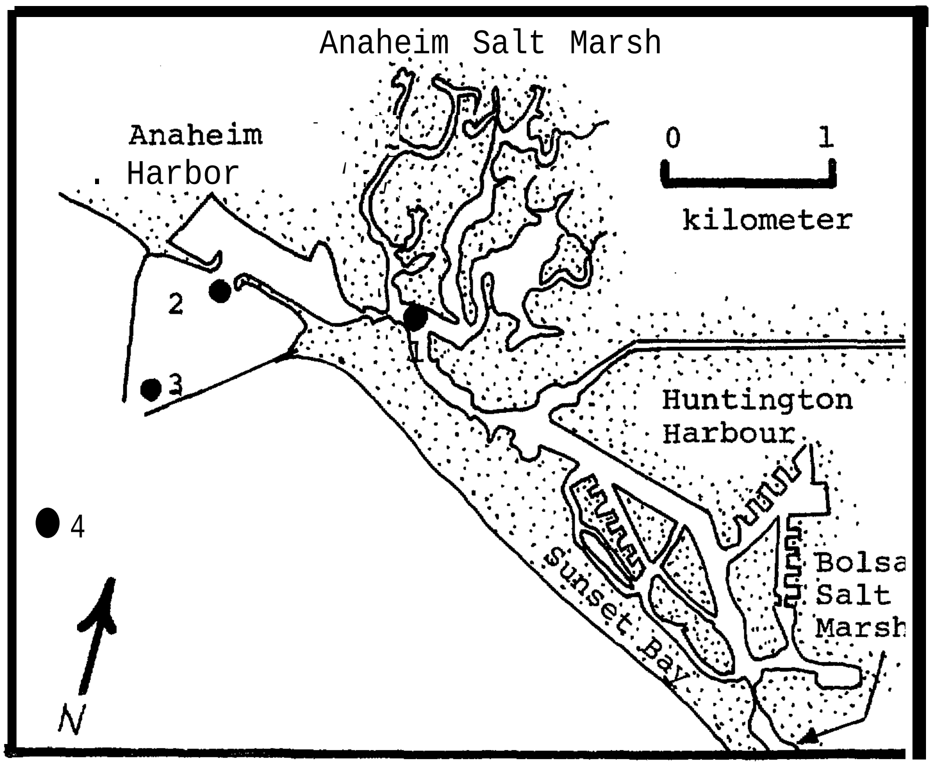

Figure 5-8. Map of Anaheim Bay Complex. Black dots locate hydrographic stations. From Slawson (1972).

prism is about 12.9 x 10^6 m^3 (Table 5-8). Tidal currents of up to 1.1 m/see have been measured at the entrance when the tidal range was 2.1 m. Roughly 36% of the lagoon's water is exchanged with the ocean each tidal cycle (U.S. Army Corps Engr., 1973).

Mission Bay is exposed to south and northwest swell. Diffracted waves and wave surges have caused erosion and sedimentation in the bay. The tidal channels are about 2.7 m deep with sandy bottoms. Silt occurs in the quiet water areas, and clay is found in the eastern-most portion of the bay.

20.2 Water Characteristics

The following chemical oceanographic information is from a set of continuous recording instruments located in the tidal stream of the marshland on the north shore of the bay (Bradshaw, 1968). The variation of environmental conditions in the marshland is more extreme than in the bay. Variations due to tidal action and the amount of vegetation affect either directly or indirectly, all chemical parameters of the water.

The mean monthly water temperatures for 1964 varied from 12.7°C in January to the maximum of 24.1°C in June. The maximum recorded temperature was 33°C in July, and the coldest temperature, 4.9°C, was in December. On the whole, the mean monthly water temperature was slightly above the mean air temperature, except in October and November. Compared with the oceanic temperatures, the monthly range of temperature is about 2 to 5 times the corresponding range observed from Scripps Institute Pier.

During flood tide the marshland is covered by the bay water with salinity of about 34 ‰. After residence on the marshland, much of the water is evaporated, and the water develops higher salinity, up to 50 ‰. Records of September and October, 1964, showed that salinity greater than 35 ‰ occurred 64% of the time. The fluctuation of salinity closely corresponds to the tidal cycle, varying from 34 ‰ at flood tide to 50 ‰ during the ebb.

There is no consistent seasonal pattern of dissolved oxygen concentration in the marshland. Observed values range from 0% to 275% saturation level. The diurnal variations of dissolved oxygen are much greater than the seasonal variations, and are closely related to the pH variations.

The pH values of the water over the marshland vary from a ' minimum of 6.7 in June to a maximum of 8.5 in April. The monthly mean values vary only slightly, from 7.3 to 7.6. If 7.6 is taken as the value affecting the carbonate equilibrium of seawater? about 50% of the time the marsh environment is favorable for deposition of calcium carbonate and the remainder of the time for its dissolution.

Mission Bay receives relatively little sewage input, and so the nutrient levels are very low (Table 5-8 and Figures 5-14 and 5-15) . The phosphate levels, as surveyed in 1970, were generally low (0.3-1.2 µg-at P/l) (Figure 5-23), and nitrate and nitrite were also uniformly low (less than 2.5 ug-at N/ 1). In several locations, ammonia values were relatively high and variable. The extremely high ammonia values and a wide range of 17-720 µg-at N/1 seem to be atypical for the bay (Bradshaw and Mudie, 1972).

Fairbanks (1969) showed that the total nitrogen in the Quivira Basin reached a maximum concentration in September and remained at low concentration levels from January to June (Figure 5-24). When the total inorganic nitrogen was divided into its components, the total nitrogen maximum was primarily due to ammonium. Nitrite was at its annual minimum during that month. The secondary maximum in total inorganic nitrogen was due to large concentrations of nitrate. The cycling of nitrogen appeared to follow the sequence of . maximum concentration of ammonia in September, then nitrite maximum in November and finally nitrate maximum in December. Such cycle pattern is most pronounced at the 3 and 6 m depths and may be due to the effect of bacterial oxidation. The silicate concentration pattern showed that high concentration occurred in May, as a result of an influx of nutrient rich bottom waters and poor uptake by small diatom populations. During winter the silicate concentration remained at a relatively low level, which was related to the winter diatom bloom. Approximately 80-90% of the May phytoplankton bloom consisted of dinoflagellates, which do not require silicate in frustule formation. On the whole the silicate cycle in Quivira Basin was different from cycles reported for other geographic areas and was primarily due to the dinoflagellate bloom of May. The seasonal pattern of phosphate also reflected the effect of plankton utilization and remineralization process. The zooplankton population began to increase about a month before the phosphate began to increase (see Chapter 14) . The low phosphate concentration of July, due to phytoplankton utilization, was followed by an increase in August, due to remineralization of bound phosphate. On the whole the phosphate concentrations for Quivira Basin were comparable with that of coastal water near San Diego and in San Diego Bay.

Table 5-8

SUMMARY OF LAGOON CHARACTERISTICS

	Type of Lagoon	Effluent Discharge Rate (m^3 X 10^3/day)	Type of Effluent	Lagoon Vol. at MHHW (m^3 X 10^6)	Tidal Prism (m^3 x 10^6)	Salinity Range $^o/_{oo}$	Nutrient Concentrations Factor[3]
Mission Bay	Open	0.00543	Untreated	35.658	12.9048	32-35	0.147×10^3
Agua Hedionda	Open	0.00543	Untreated	2.2923	0.8490	32-35	2.23×10^3
San Diego Bay	Open	0.94522	Untreated	424.50	84.9000	32-35	5.63×10^3
Los Penasquitos	Variable[1]	3.78371	Secondary	0.0792	0.0198	15-40	9.55×10^3
Buena Vista	Closed	0.01887	Irrigation	0.8122	0[2]	2-5	0.64×10^3
Batiquitos	Variable	0.0873	Secondary & Irrigation	0.4924	0[2]	4-27	4.6×10^3
San Elijo	Variable	7.56742	Secondary	1.9782	0[2]	2-14	91.5×10^3
Del Mar	Variable	0.75561	Secondary	0.1557	0[2]	5-55	1.27

[1] Normally kept open artificially and thus treated as open lagoon for calculation of nutrient concentration factor.

[2] Normally closed and thus tidal prism is effectively zero.

[3] Ratio of concentration of pollutant in lagoon to concentration of pollutant in sewage

18. Del Mar' (San Dieguito) Lagoon

Del Mar Lagoon has an area of 0.85 km^2. It is permanently closed to the ocean, but has San Dieguito Creek entering at its head (Figure 5-20). Salinities range from fresh to hypersaline (Table 5-8). Bradshaw and Mudie (1972) note high phosphorous and nitrogen concentrations (Figures 5-14 and 5-15). This results from the 0.74 x 10^3 m^3/year of secondary sewage effluent that is put into San Dieguito Creek.

19. Penasquitos Lagoon

Penasquitos Lagoon occupies 1.4 km^2 of which 0.4 km^2 are tidal flats (Figure 5-21). The tidal channels cover 40 acres. Bridges restrict the circulation at two places. A narrow ocean entrance is maintained over much of the year by bull-dozing a cut through the sand spit. Los Penasquitos Creek enters at the upper end of the lagoon.

The tidal channels have low tide depths of 0.3 to 9.0 m, averaging about 0.67 m. Bradshaw and Mudie (1972) show that the tidal prism varies from zero when the entrance is closed, to 0.02 x 10^6 m^3. The lagoon is poorly flushed (Table 5-8).

Water temperatures range from 10°C to 30°C, and salinities from 0 ‰ to more than 40 ‰. These extremes result from seasonal changes, rainfall run-off, sewage outfall, and the condition of the entrance. Sewage discharge into the lagoon equals about 3.8 x 10^3 m^3/day. Bradshaw and Mudie (1972) measured orthophosphate-phosphorous concentrations of 3 to 300 mg-at P/l and ammonia-nitrogen concentrations of 0.5 to 20 mg-at N/l (Figures 5-14 and 5-15). The low nitrate to phosphate ratio probably is an indication of sewage pollution in the lagoon.

20. Mission Bay

Mission Bay is a semi-developed salt marsh lagoon that covers an area of 10.8 km^2 (Figure 5-22). It has a permanent entrance to the ocean that is maintained by two jetties. The San Diego River has been channeled to the south and no longer flows into the bay. Development projects and construction have modified the whole bay for boating and recreational facilities. The freshwater inflow to the bay is primarily from minor creeks, washes, and storm gutters along the shore. As a result of dredging, the bay has been converted to a navigable marine park.

20.1 Tidal Flushing

The diurnal tidal range varies from 1 to 3.5 m and the tidal

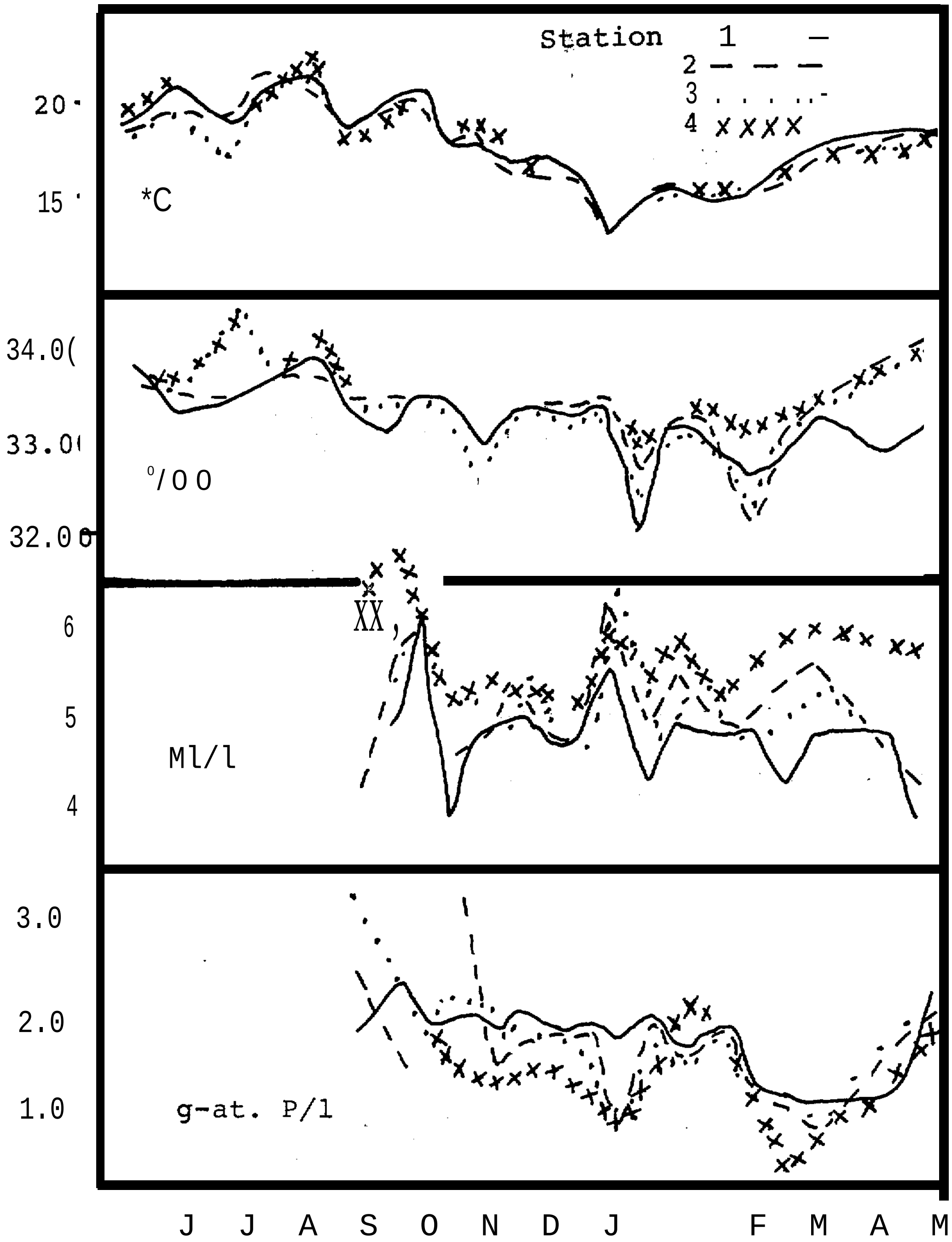

Figure 5-9. Surface temperatures, salinities, dissolved oxygen, and inorganic phosphate contents in Anaheim Bay from September 1969 through May 1970. The stations are located on Figure 5-8. From Slawson (1972).

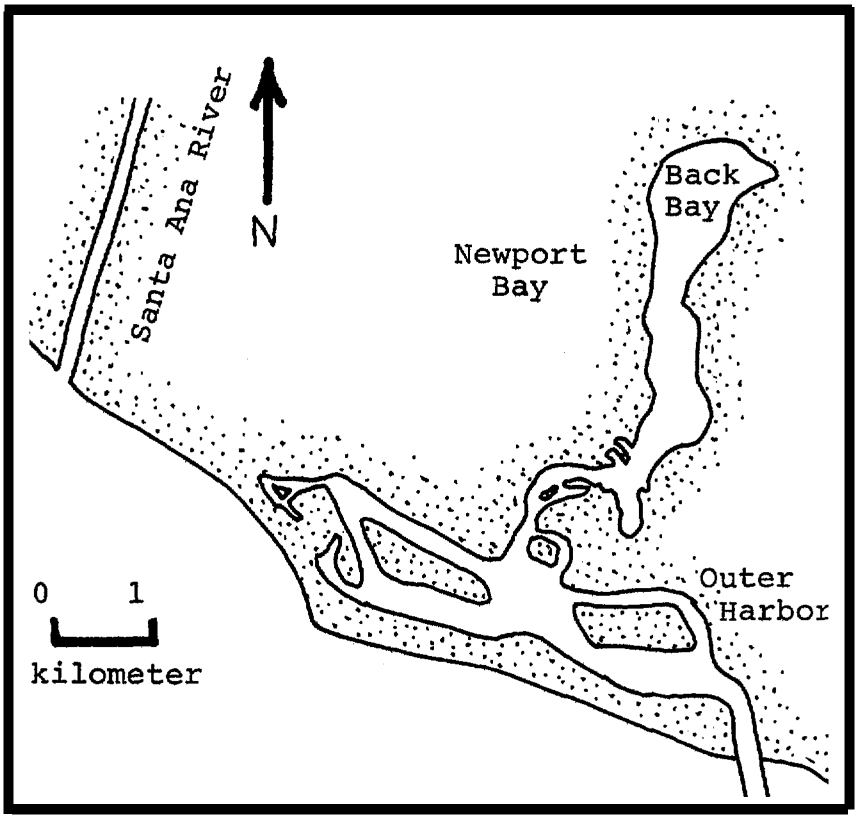

Figure 5-10. Map of Santa Ana River Slough and Newport Bay.

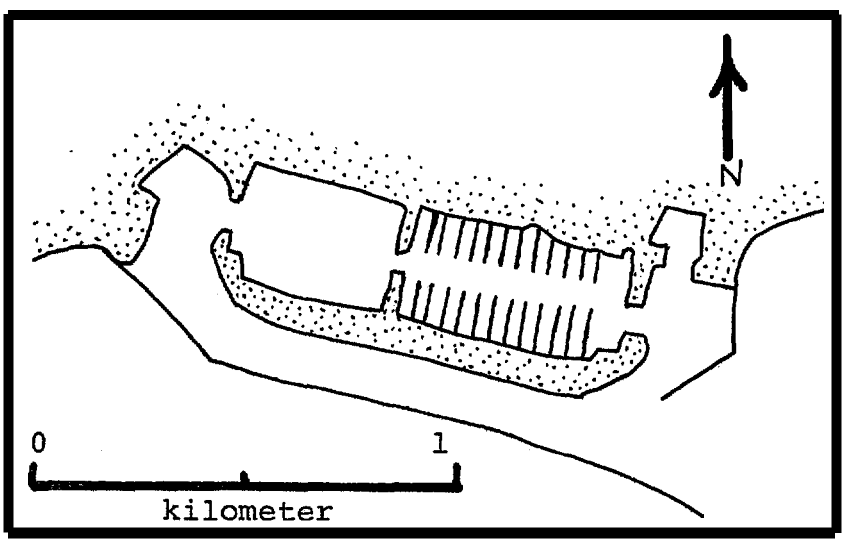

Figure 5-11. Map of Dana Point Harbor.

13. Oceanside Harbor and San Luis Rey River

Oceanside Harbor is complex (Figure 5-12), consisting of Camp Del Mar Boat Basin, an outer harbor and Oceanside Small Craft Harbor. The harbor complex occupies an area of 0.64 x 10^6 m^2 and has an average tidal prism of about 0.85 x 10^6 m^3. The harbor entrance to the ocean is kept open with three jetties and periodic dredging. No streams flow into the harbor. The water characteristics are probably similar to the coastal ocean conditions.

San Luis del Rey River is an intermittent stream that has been channeled south of the harbor complex (Figure 5-12). It is cut off from the ocean most of the year by a sand bar and is flushed only during high run-off periods. The water characteristics of the lagoon are probably variable depending on the run-off condition and the length of time it is separated from the ocean.

14. Buena Vista Lagoon

Buena Vista Lagoon is a brackish coastal lagoon that is closed to the ocean by a sand bar. The lagoon is divided into three ponds by bridges (Figure 5-13) . It occupies an area of 1.42 km^2 and has a volume of 0.79 x 10^6 m^3 (Bradshaw and Mudie, 1972). There is neither tidal prism nor flushing. Salinities range from 2 $^o/oo$ to 7 $^o/oo$ (Table 5-8). Irrigation effluent averaging 0.019 x 10^3 m^3 per day flows into the lagoon. Prior to 1966, 7.6 x 10^3 m^3 per dav of secondary sewage effluent was discharged into the lagoon. The water depths are shallow,ranging from 0.67 to 2.0 m. Bradshaw and Mudie (1972) measured phosphorous concentrations of 2 to 100 mg-at P/l and 0.2 to 1.5 mg-at/l of ammonia-nitrogen. The high phosphate values relative to the nitrogen values suggest that the lagoon water is somewhat polluted (Figures 5-14 and 5-15) .

15. Agua Hedionda Lagoon

Agua Hedionda Lagoon includes about 2 km^2 of which about 1 km^2 is under water (Figure 5-16) . An entrance with the ocean is maintained by dredging. Maximum depths of 1.8 m are found in the tidal channels. Bridges divide the lagoon into outer, middle and inner ponds.

The tidal prism is about 0.85 x 10^6 m^3 and 20% to 50% of the lagoon is exchanged with the ocean during each tidal cycle. Normal ocean salinities of 32.4 $^o/oo$ to 34.1 O\oo occur in the lagoon (Bradshaw and Mudie, 1972). Water temperatures of 22.1^{o}C to 26.3^{o}C have been recorded, and the dissolved oxygen values range from 3 to 8 ml/1 with the surface water having the highest values (Table 5-8). Phosphate values of 0.5 to 0.6 μg-at P/l suggest that there is little pollution from organic material. The ammonia-nitrogen concentrations range from 0.5 to 5.0 μg-at N/l.

16. Batiquitos Lagoon

Batiquitos Lagoon is a salt marsh complex that occupies 600 acres (Figure 5-17). San Marcos Creek flows into the head of the lagoon during the rainy season, and the entrance to the ocean occasionally is open. There is no tidal flushing when the entrance is closed, and only variable flushing at other times. Salinities are normally brackish ranging from 4 $^{o}/oo$ to 27 $^{o}/oo$, but evaporation and transpiration over the salt marsh tidal flats may increase the salinity locally to 45 $^{o}/oo$. Secondary sewage effluent amounting to 0.08 x 10^3 m^3 enters the lagoon causing excess algae growth, especially during the wet season.

Bradshaw and Mudie (1972) measured orthophosphate-phosphorus levels of between 4 and 50 mg-at P/l and ammonia-nitrogen concentrations of 0.5 to 10 mg-at N/l (Figures 5-14 and 5-15). The nutrients are most abundant during the winter. An extensive sludge bed still exists in the lagoon from an earlier period of greater sewage discharge.

17. San Elijo Lagoon

San Elijo Lagoon occupies an area of 2.47 km^2. The railroad and freeway bridges segment the lagoon into three ponds (Figure 5-18). Escondido Creek runs into the head of the lagoon and an ocean entrance is open only about a third of the year. Thus the tidal prism varies from zero to about a million cubic meters. Until 1973, there was a large volume of secondary treatment sewage (7.56 x 10^3 m^3/year) coming into the lagoon, making it brackish with salinities of 2 $^{o}/oo$ to 14 $^{o}/oo$ and giving it high nutrient concentrations (Table 5-8). Figure 5-19 shows the concentration levels of phosphate, ammonia, and nitrate with distance down Escondido Creek to the ocean. Bradshaw and Mudie (1972) found that two-thirds of the sewage effluent from the City of Escondido, 22 km upstream, reaches the lagoon. The sewage effluent is no longer flowing into Escondido Creek and as a result the entire chemical nature of the lagoon will change. The chemical nature of the lagoon should be monitored to determine these changes.

Table 6-10

SUMMARY OF MUNICIPAL WASTE WATER DISCHARGED AND REUSED IN THE SOUTHERN CALIFORNIA COASTAL BASIN AS OF 1972*

County	Sources (No. of Plants)	Daily (MGD)	Yearly (TAF)
		Reused	
Santa Barbara	5	2.15	2.14
Ventura	6	3.87	4.33
Los Angeles	9	26.34	29.50
Orange	6	4.46	4.99
San Diego	12	4.34	4.86
		Discharged to Land or Water Course	
Santa Barbara	8	6.74	7.55
Ventura	11	10.58	11.85
Los Angeles	19	14.50	16.24
Orange	7	0.73	0.82
San Diego	25	12.80	14.34
		Discharged into Saline Waters	
Santa Barbara	5	15.04	16.85
Ventura	3	14.05	15.74
Los Angeles	3	707.35	792.22
Orange	9	140.87	157.77
San Diego	3	94.56	105.91
		Total	
Santa Barbara	13	23.94	26.81
Ventura	20	28.50	31.92
Los Angeles	31	748.19	837.96
Orange	22	146.06	163.58
San Diego	40	111.71	125.11
	131	1,058.40	1,185.38

*State of California, Department of Water Resources. "Inventory of Waste Water Production and Waste Water Reclamation Practices in California, 1970, 1971. Bulletin No. 68-71, November 1972.

Table 6-11

MUNICIPAL WASTE WATER DISCHARGES TO
SOUTHERN CALIFORNIA COASTAL WATERS, 1972*

County / Facility	Fig. 6-16	Flow MGD	Flow TAP
Santa Barbara			
Carpenteria Sanitary District	M-1	1.27	1.42
Goleta Sanitary District	M-2	5.53	6.19
Montecito Sanitary District	M-3	0.56	0.63
Santa Barbara, City of	M-4	7.62	8.53
Summerland Sanitary District	M-5	0.07	0.08
Ventura			
Oxnard, City of	M-6	9.85	11.03
Port Hueneme, City, of	M-7	2.30	2.58
San Buenaventura, City of Seaside Plant	M-8	1.90	2.13
Los Angeles			
Los Angeles, City of			
Hyperion Plant	M-9	333.16	373.13
Terminal Island Plant	M-10	9.09	10.18
Los Angeles C. San. Districts			
Joint Water Pollution Control Plant	M-n	365.05	408.91
Orange			
Dana Point Sanitary District	M-12	0.30	0.34
Laguna Beach, City of	M-13	2.86	3.20
Orange Co. San. Districts			
Plant No. 1	M-14	48.26	54.05
Plant No. 2	M-15	86.36	96.72
San Clemente, City of	M-16	0.53	0.59
San Juan Capistrano, City of	M-17	0.25	0.28
South Laguna San. District	M-18	1.05	1.18
Sunset Beach San. District	M-19	0.14	0.16
San Diego			
San Diego, City of			
Point Loma Plant	M-20	93.91	99.58
San Diego County Dept. of Spec. Dist. Serv.			
Encina Water Pollution Control Facility	M-21	4.51	5.05
San Elijo Water Pollution Control Facility	M-22	1.14	1.28

* State of California Department of Water Resources, Inventory of Water Reclamation and Waste Water Reclamation Practices in California, 1970-1971, Bull.63-71, Nov 1973.

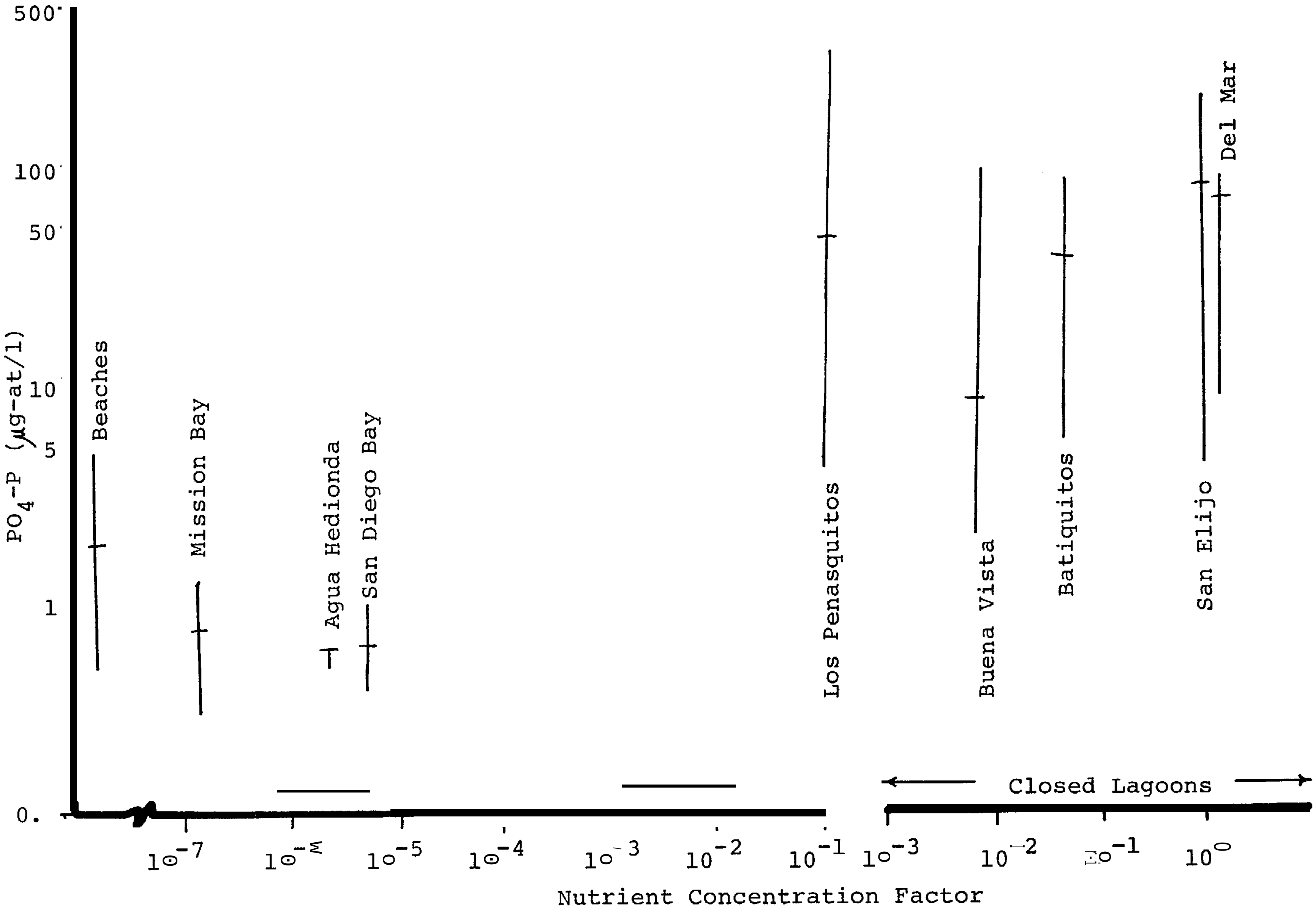

Figure 5-14. Summation of orthophosphate-phosphorus data from San Diego County lagoons and nearshore waters, Fall, 1970. From Bradshaw and Mudie (1972).

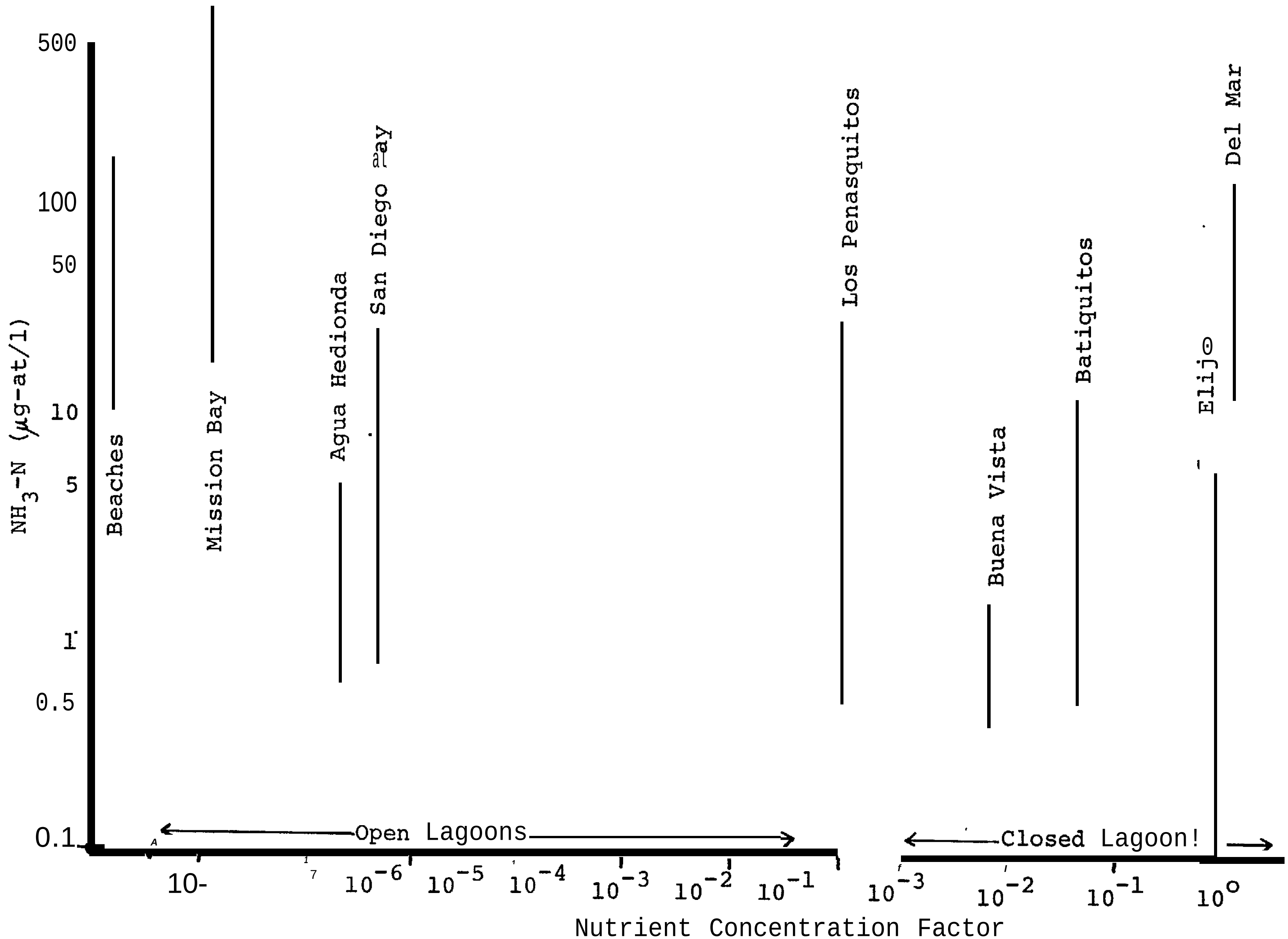

Figure 5-15. Summation of ammonia-nitrogen data from San Diego County lagoons and nearshore waters, Fall, 1970. From Bradshaw and Mudie (1972).

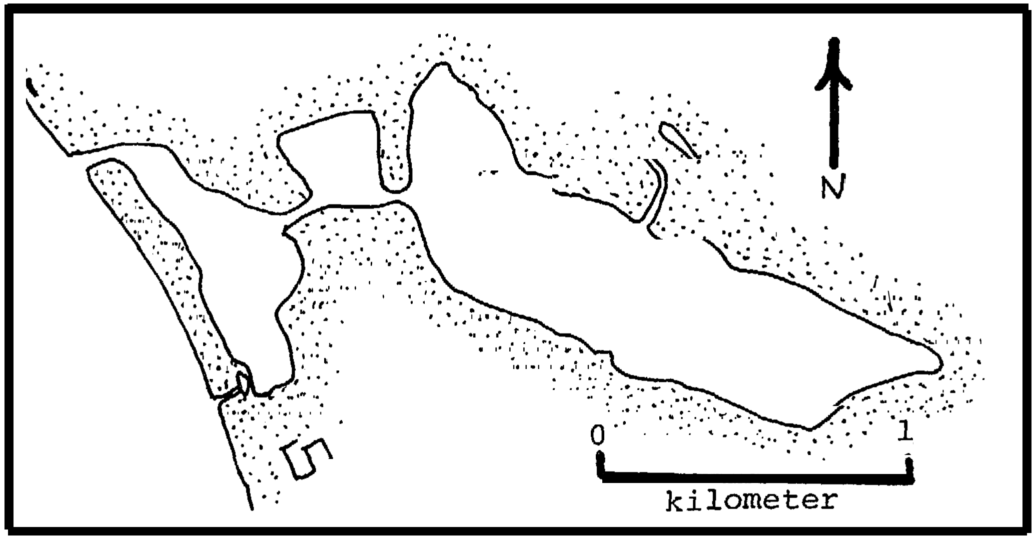

Figure 5-16. Map of Agua Hedionda Lagoon.

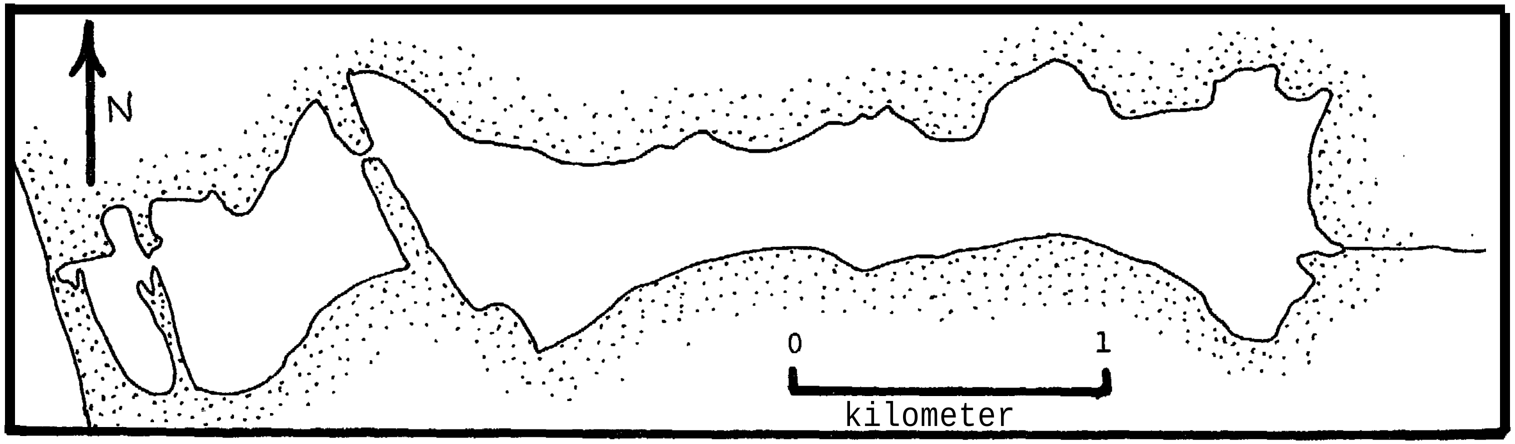

Figure 5-17. Map of Batiquitos Lagoon.

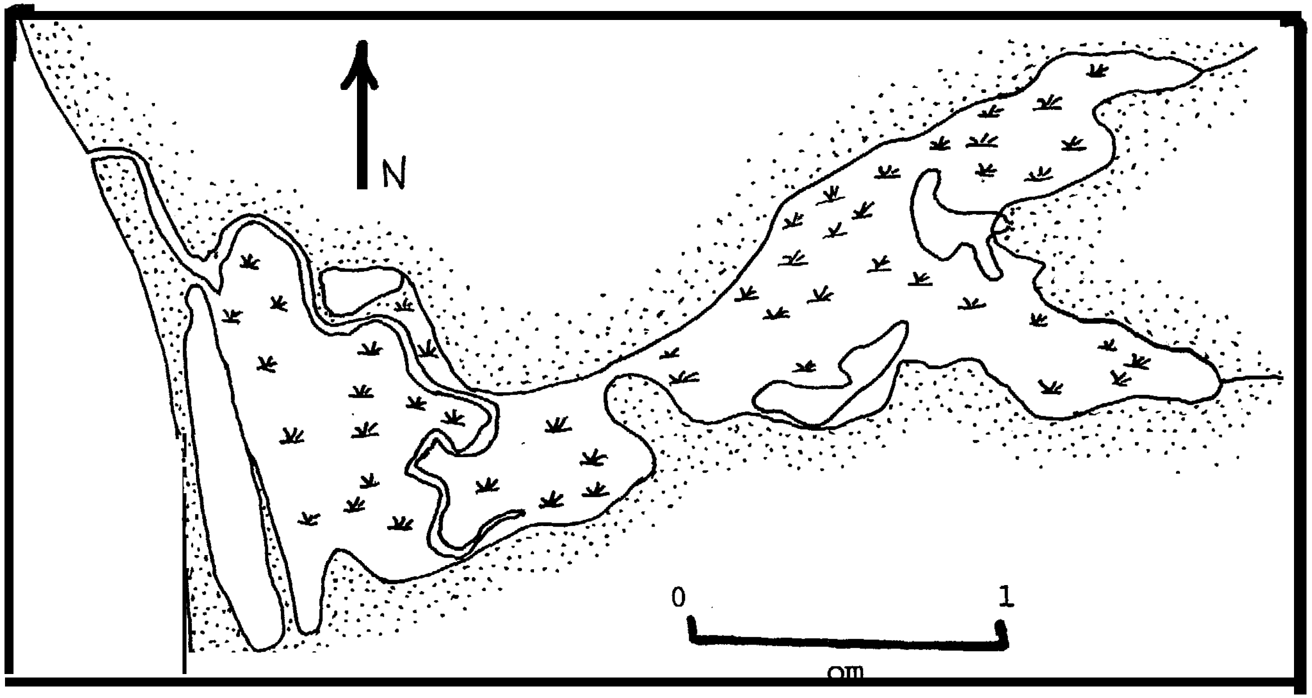

Figure 5-18. Map of San Elijo Lagoon.

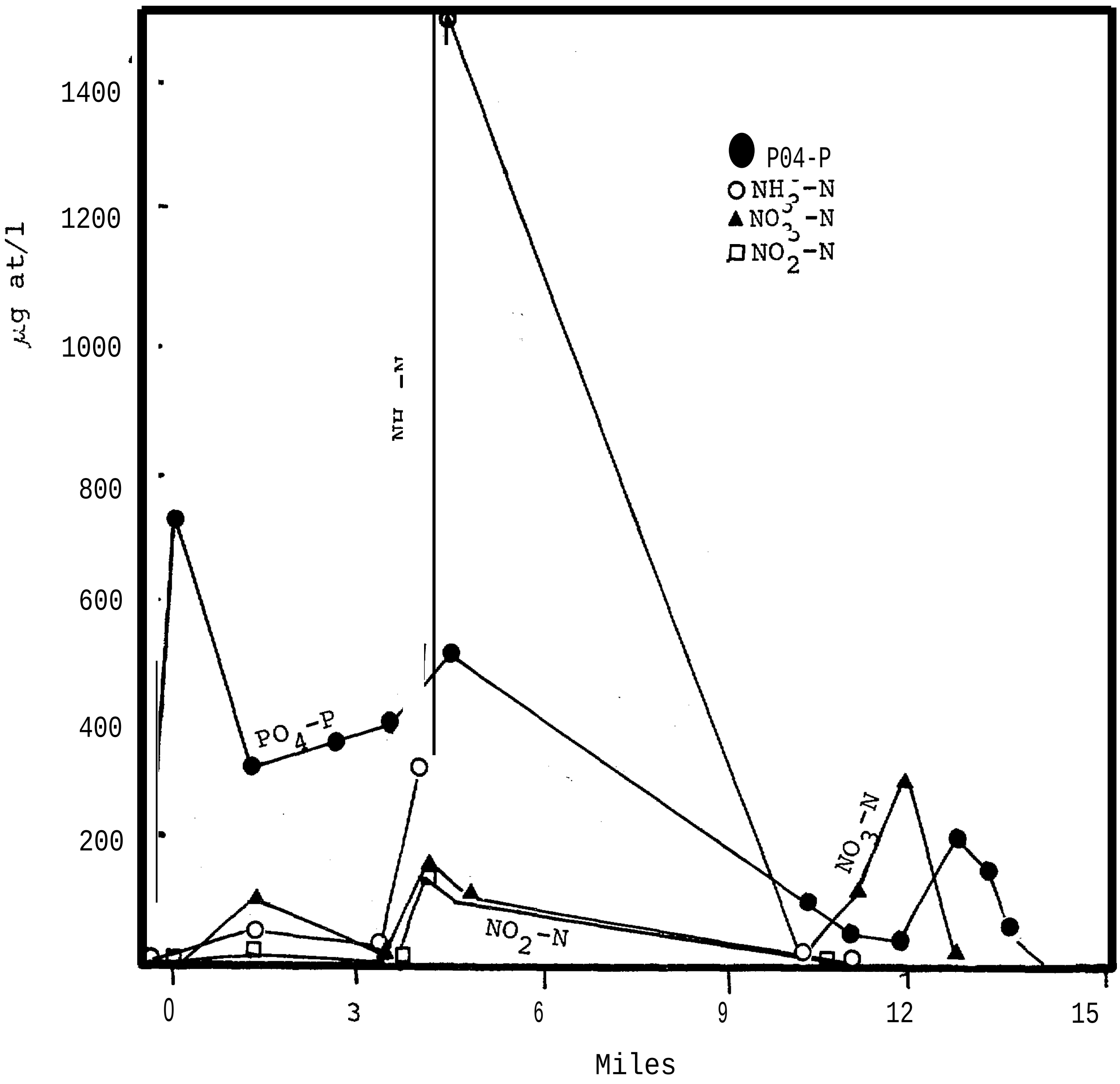

Figure 5-19. Distribution of nutrients down Escondido Creek from the sewage discharge towards San Elijo Lagoon. From Bradshaw and Mudie (1972).

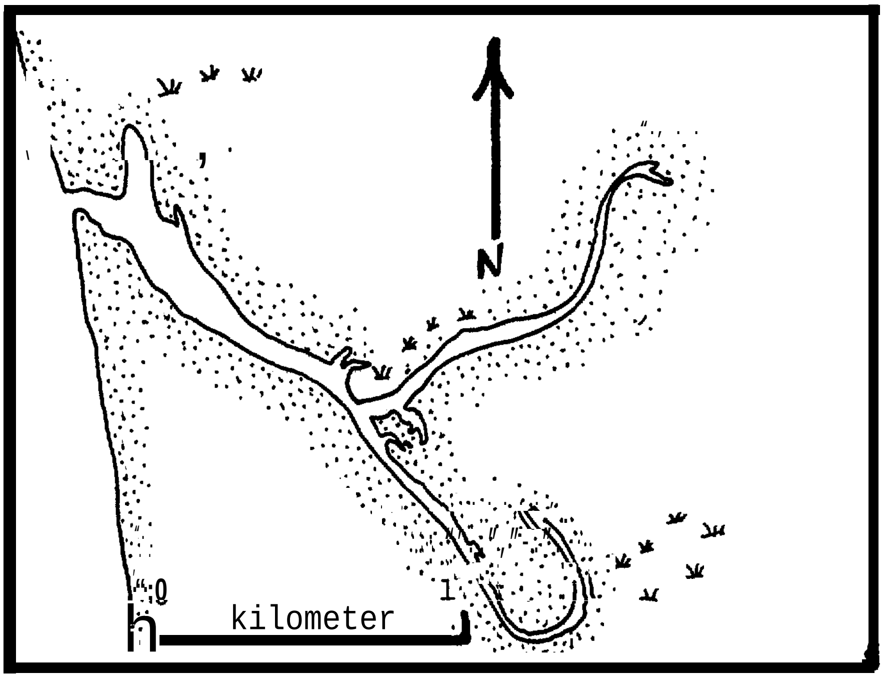

Figure 5-20. Map of Del Mar Lagoon.

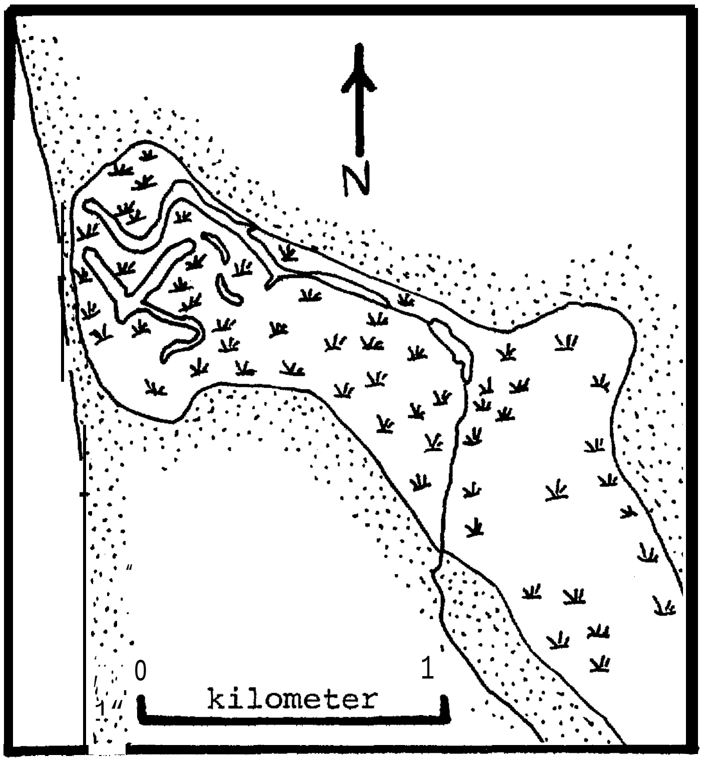

Figure 5-21. Map of Los Penasquitos Lagoon.

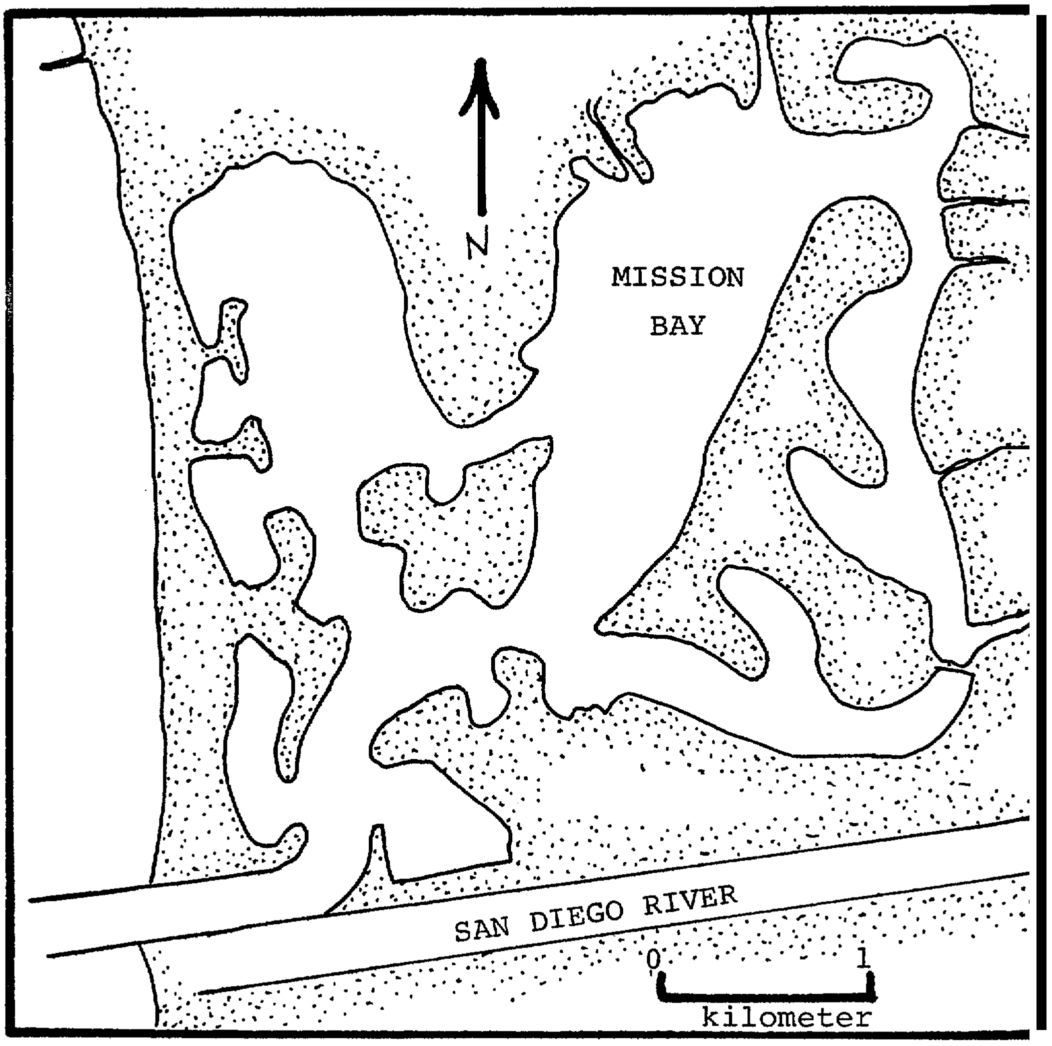

Figure 5-22. Map of Mission Bay.

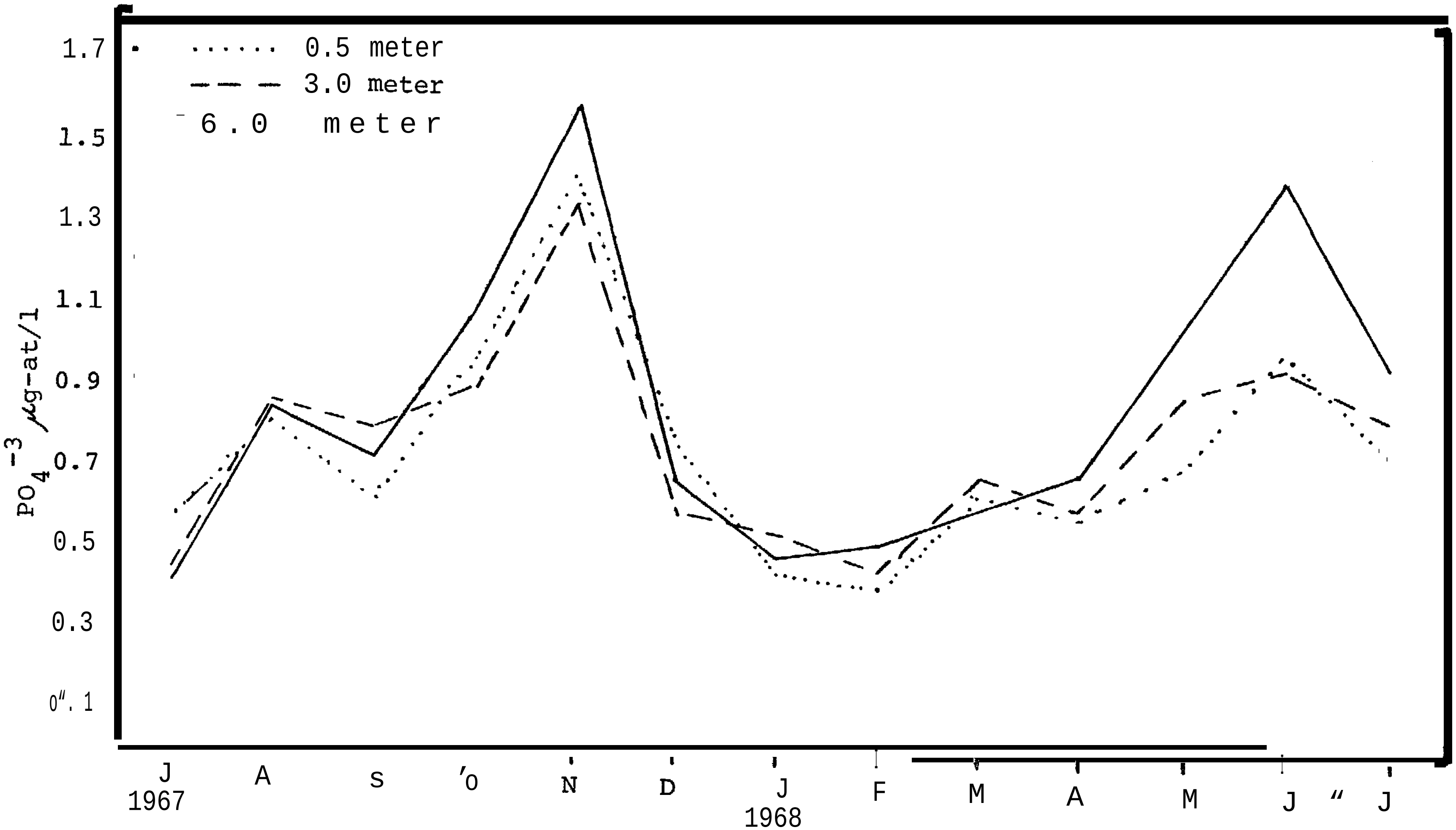

Figure 5-23. Mean monthly PO_4^{-3} concentrations for three depths in Quivira Basin from July 1967 through July 1968. From Fairbanks (1969).

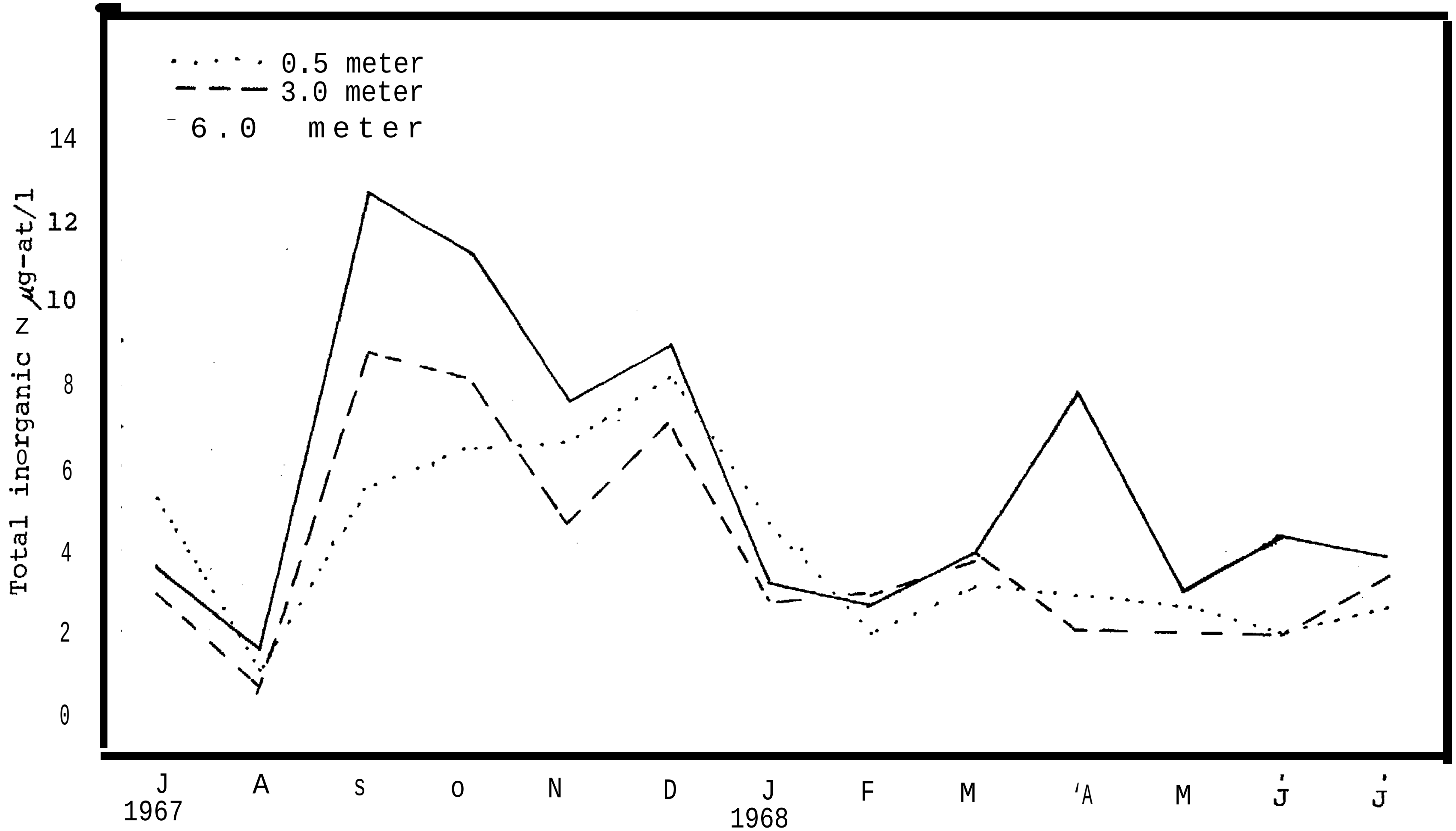

Figure 5-24. Mean monthly concentrations of total inorganic nitrogen for three depths in Quivira Basin from July 1967 through July 1968. From Fairbanks (1969).

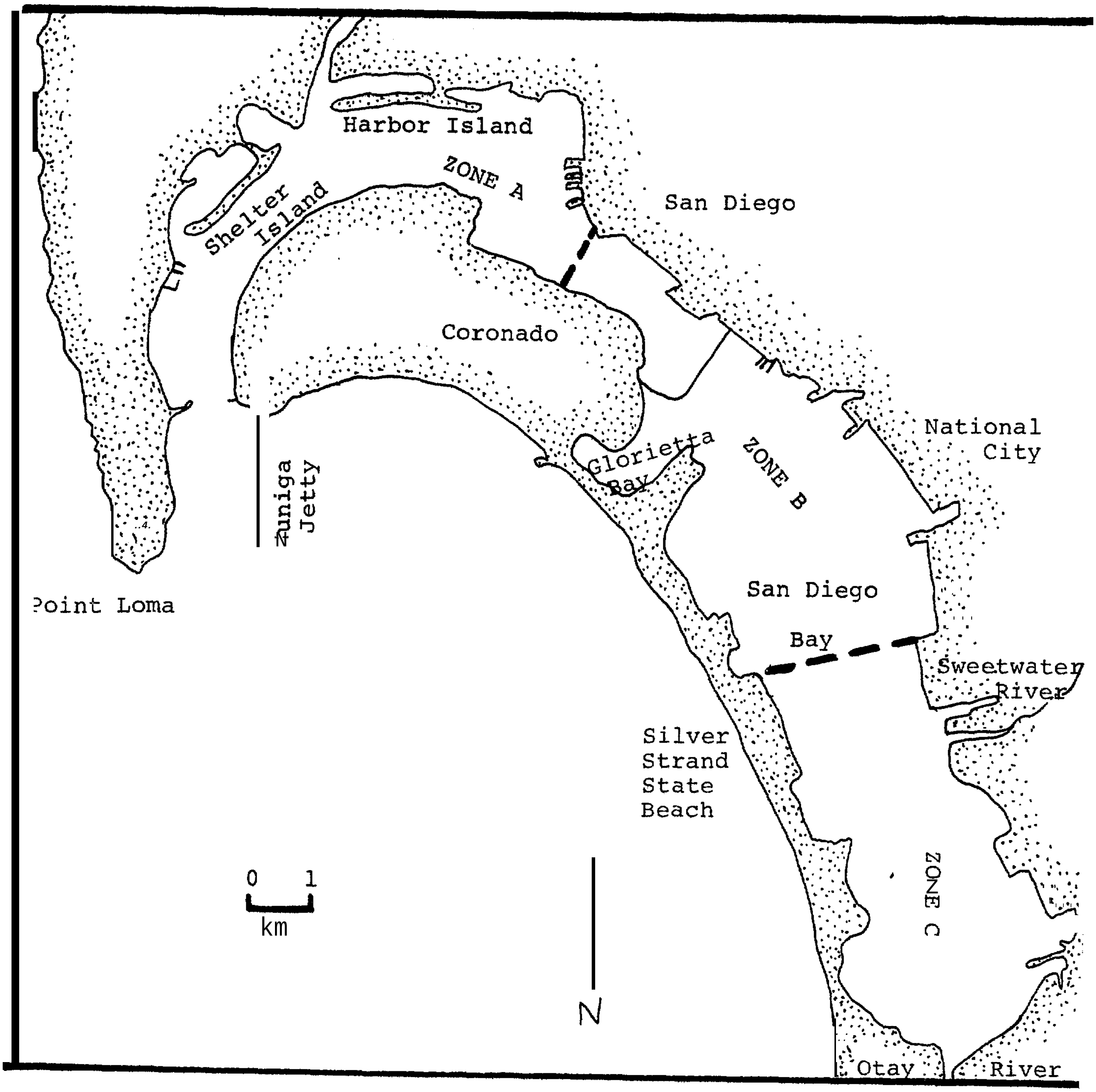

Figure 5-25. Map of San Diego Bay showing the Northern, Central and Southern Zones of the Bay.

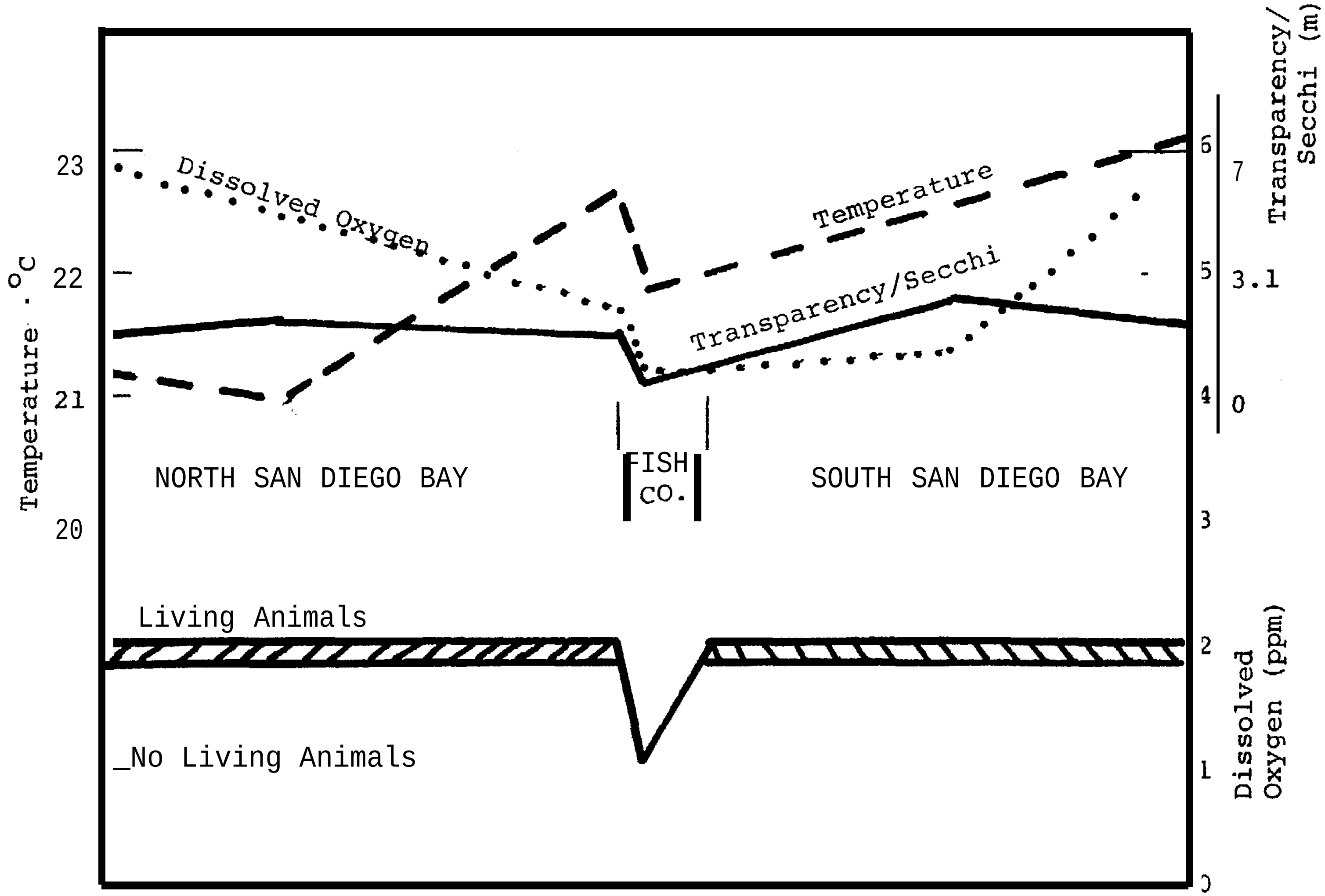

Figure 5-26. Graphic representation of a section of water from North San Diego Bay to the fish canneries and the South San Diego Bay. From San Diego Regional Water Pollution Control Board (1952).

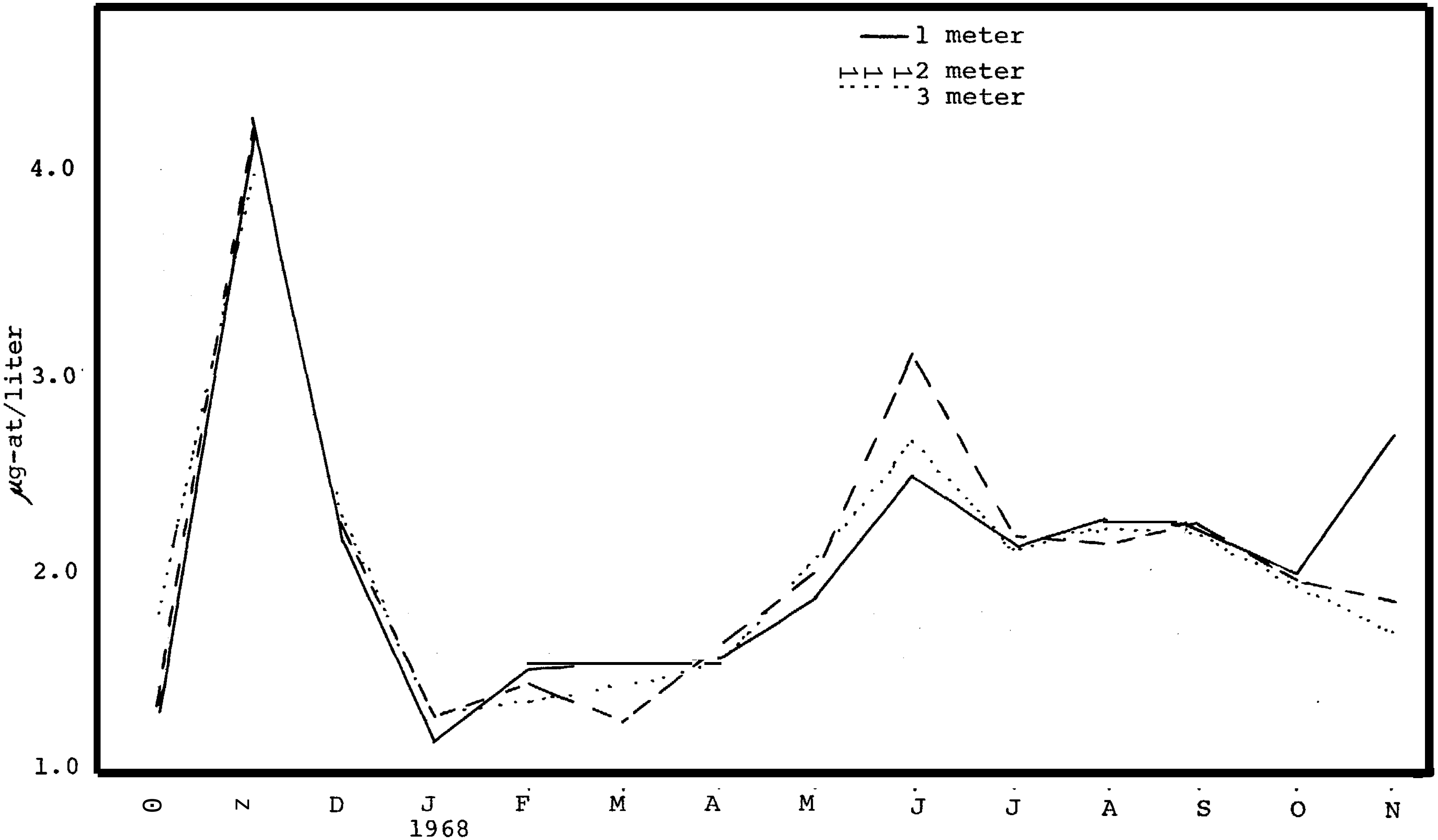

Figure 5-27. Temporal changes in available phosphate in San Diego Bay.

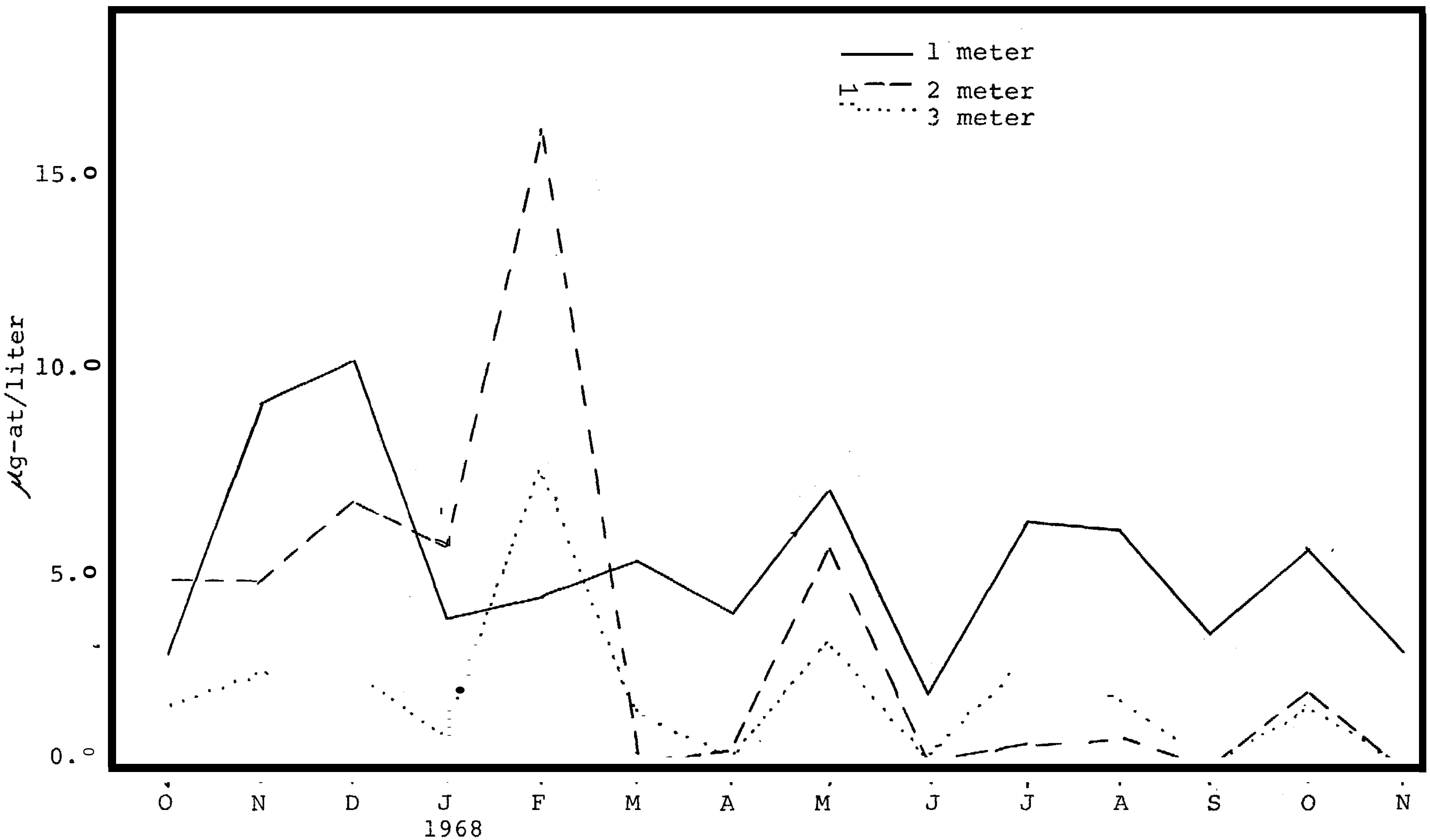

Figure 5-28. Temporal changes in available ammonia in San Diego Bay.

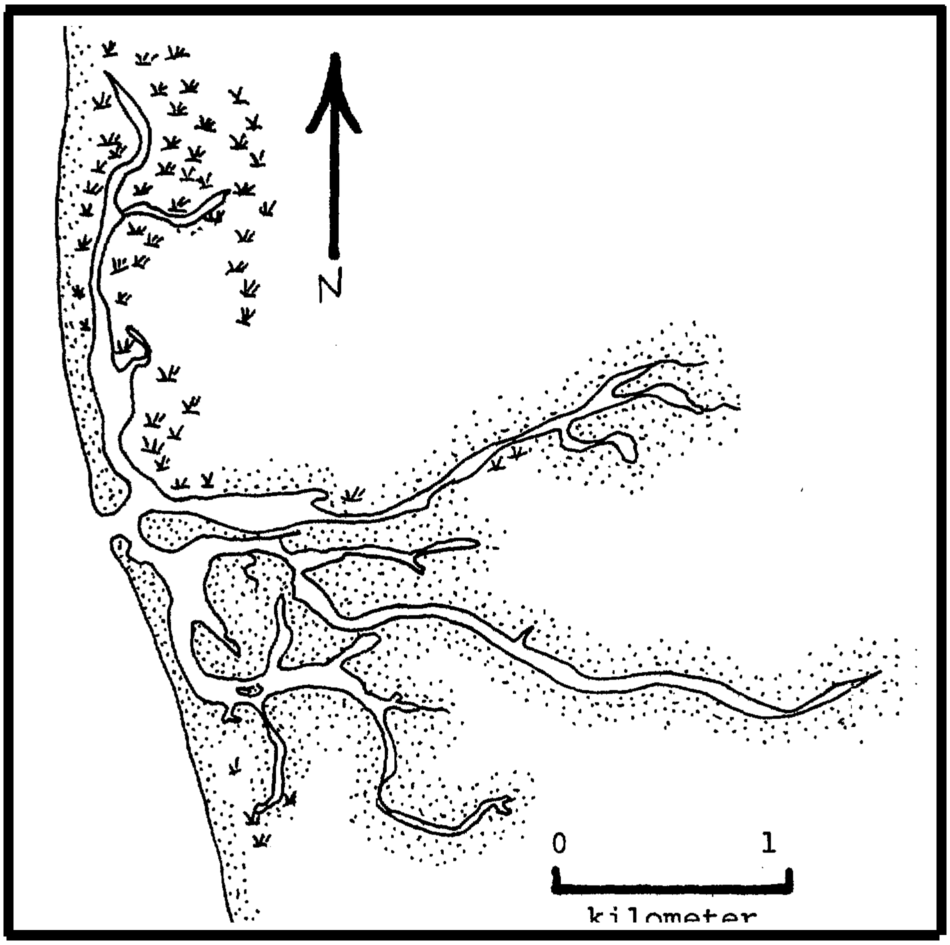

Figure 5-23. Map of Tia Juana Lagoon.

6. POLLUTION SOURCES

Willard 11. Reed
Theodore P. Bakker

1. Introduction

The waters in the coastal study region are generally made less suitable for further beneficial uses when waste materials are discharged into them. Water pollution, the process of adding wastes to a body of water thus lowering the quality, becomes contamination when the addition of such materials renders the water unfit for further beneficial use. The introduction of pollutants into the marine environment can occur as discharges from municipal waste water treatment plants, industrial plants, electrical generating stations, and waterborne vessels. Additionally, pollutants can enter the marine environment as surface runoff, aerial fallout, flaking and dissolution of antifouling vessel paints, and direct ocean dumping from barges and other vessels. Substances introduced include sewage sludge, waste water treated only to remove floatable and suspended solids, garbage, chlorine, phosphates and nitrates, heated water, chlorinated hydrocarbons and heavy metals.

Not all the constituents present in a waste discharge are considered pollutants or contaminants since they may have a beneficial effect on some of the organisms within the water environment (Cronin 1971). For example, some fish thrive in areas near sewage treatment plant ocean outfalls due to discharges of large quantities of nutrients which serve as food for the living organisms upon which the fish prey. Along with these nutrients are found such pollutants as mercury and chlorinated hydrocarbons which have been found to accumulate but which do not biodegrade in the bodies of all the marine organisms which ingest the nutrients discharged at these outfalls (Cronin 1971). Accumulations of these non-biodegradeable pollutants eventually occur in the predators or large fish that consume the small living organisms.

Every year approximately 1,000 mgd (1,100 X 10^3 acre/feet) of partially treated municipal waste water (California Water Resources 1972), 129 mgd (144.6 X 10^3 acre/feet) of industrial waste water (California Water Quality 1973), and 18,347 mgd (20,560 X 10^3. acre/feet) of heated cooling water (Power Company 1972-73) are discharged to the coastal waters of the study area. It has been estimated that about 2,000 times the above total quantity of waste water enters this coastal ocean area every year due to water movement produced by the ocean currents (SCCWRP 1973).

Tn this section of the report contributions made to the coastal waters from the air, land, and fresh water environment will be discussed in some detail. Since most of the data concerning discharges are not immediately available for publication, some of the information may be valid for the years 1972 and 1973 instead of 1974. This section of the report will be concerned only with known discharges of pollutants to the coastal study area. It will not attempt to predict the quality of the ocean water due to the fact that physical chemical reactions and biological conversions are continually taking place within this water body. This dynamic condition makes it nearly impossible to predict water quality at any location or point in time.

1.1 Paths Taken By Discharges To The Study Area.

Materials may enter the coastal ocean waters from either discrete sources or diffused sources.

1.1.1 Discrete Sources. The materials travel directly to the study area by conduits, such as pipelines and open channels, which convey municipal waste waters, industrial wastes, and storm runoff to the coastal waters from inland sources.

1.1.2. Diffused Sources. The materials are conveyed to the coastal study area by paths, which are not well defined, such as aerial fallout of dust and lead particulate, ocean dumping from boats or barges, solution of protective coatings and ferrous metals from boats and ships, etc.

Identification and measurement of materials discharged from discrete sources to the coastal basin is much easier to accomplish than those materials derived from diffused sources. This report will present data mainly derived from discrete sources because of the scarcity of diffused sources data.

Some possible sources of additional information would be needed to complete or update the chapter. These include: the U. S. Navy, oil companies operating offshore sites, California State Air Resources Board, etc. They would supply statistics on ocean dumping, oil salt solution discharges, ballast discharges, fallout of particulate from the atmosphere, etc.

Discharges from discrete sources are mainly derived from municipal waste water collection and treatment systems, industrial plant waste water effluents, and storm runoff drainage conduits (Figure 6-l).

1.2. Physical Systems Receiving Pollutants

That portion of the Southern California Bight covered by this study and the tributary area bounded on the north, east and south by the Transverse and Peninsular ranges and the U. S. Mexican border are inter-related by several varied and/or extreme geographic-oceanographic-geomorphic, climatic and demographic conditions (Figure 6-2).

Its location on the east coast of the North Pacific provides it with the California Current, and a uniquely shaped coastline that significantly alters the current (Chapter 3), makes it ideal for major trade with all who share the Pacific (Chapter 19), makes it a desirable place to live, sets the stage for major earthquake activity and related terrestrial and oceanographic problems (Chapter 1) .

The shape of the central section of the North American Pacific coastline is altered below the Pt. Arguello-Pt.Conception area so that a natural embayment, the Southern California Bight, is formed (SCCWRP 1973). From Pt. Conception south, the continental slope continues its nearly straight southeasterly course while the coastline curves eastward creating a highly irregular continental shelf which varies in width from 90 to 300 kilometers (SCCWRP 1973). This variation from the 19 kilometer average continental shelf width is accompanied by a geological arrangement of numerous 'islands, and submarine geological features of the area are a continuation of the terrestrial area bounded by the study. Such filled inland basins as Ventura, San Fernando, Los Angeles, and San Gabriel, shown in Figure 6-3, contribute to the filling, pollution, and other problems experienced by such submarine basins and troughs as Santa Barbara, Santa Monica, Los Angeles, San Pedro, San Diego, Santa Cruz, Santa Catalina, San Clemente, San Nicolas, East Cortes, Tanner, and West Cortes, shown in Figure 6-4. As noted by Emery and others, these basins can be grouped into parallel belts Traveling in the northwest to southeast alignment, the basins get deeper within belts and deeper belt to belt proceeding in a seaward direction. This is partially indicated by profiles shown in Figure 6-5. The groups are: (1) land forms, Ventura, San Fernando, Los Angeles, and San Gabriel; (2) submarine belts, (a) Santa Barbara (on the northern border of the study area),Santa Monica, San Pedro, San Diego, (b) Santa Cruz, Santa Catalina, San Clemente, (c) San Nicolas, East Cortes and No Name (just south of the study area), (d) Tanner, West Cortes and Velero (just south of the study area), (e) Long Basin (just south of the study area (Emery 1960; C&GS Chart #5101). The longer dimensions of these basins, with the exception of Santa Barbara - Ventura - San Fernando - Los Angeles - San Gabriel, parallel the Peninsular Ranges while the exceptions parallel the Transverse Ranges (Figures 6-2,3,4).

The highly irregular continental shelf containing the channel islands of San Miguel, Santa Rosa, Santa Cruz, Anacapa, Santa Barbara, Santa Catalina, San Nicolas, San Clemente, and the submarine basins cited above produces an "eddy" in the flow of the California Current (Chapter 4).

The eddy develops the Southern California Counter Current (SCCWRP 1973) , which in turn contributes greatly to the oceanographic uniqueness of the bight. These currents shown in Figure 6-6 create a region where the mixing of northern and southern waters and the bringing together of nutrient rich northern water and local organisms provides enriched breeding ground for such organisms. Figure 6-7 indicates the relationship of the northerly bottom flows as they exchange water between basins and help to maintain the oxygen levels reported by Emery, SCCWRP, Vaughn, and others (Chapter 4). Emery (1960) and Williams (1962) describe 3 types of basins whose characteristics depend on the rate of exchange of water, relative levels of sill depths and evapotranspiration. Southern Californiars climate, inter-basin sill configurations, and mixing studies indicate that perhaps at least the near shore basins' characteristics in the Southern California Bight are defined by a combination of the three basin types, those where evaporation exceeds precipitation. In these basins down-welling resulting from evaporation induced density currents plus water flowing in and out over the sills plus internal standing waves is believed to account for most of the mixing and exchange rates (Emery 1960; and Williams 1962). Emery estimates that currents of up to 5 cm/sec (10 fpm) are induced in the Santa Monica Basin by these standing waves which in the Catalina Basin have amplitudes ranging from 20 to 200 meters with periods of 2 to 18 hours (Emery 1960).

No one has accurately measured the rate of water replacement in the various basins though it has been approximated by calculating or estimating the oxygen demand of the bottom sediments and the dissolved oxygen above the bottom (Rittenberg; Emery and Orr, 1955; Emery 1960). Using 3.5% organic carbon as the content of the upper 30 cm of original bottom sediments, an annual sediment deposit rate of .091 grams per square centimeter and 50% oxidation of all organic carbon in the upper 30 cm, Emery, Rittenberg, and Orr predicted that the oxygen supply must be replaced every 2 years (within one order of magnitude) . They based this on the requirement of 3.0 mℓ oxygen being necessary to oxidize the organic carbon in the top 30 cm of Santa Catalina Basin. Rittenberg had predicted a 20 year minimum replenishment rate for the Santa Barbara basin using a requirement of 1.5 mℓ oxygen for the NH3 - NO nitrogen regenerating requirements. The lack of measurable differences between the oceanic and basin oxygen contents at sill depths indicate that the minimum for oxygen replenishment is less than 20 years (Emery 1960).

Emery finds that the dissolved oxygen at sill depth in the inner basins range from 0.2 to 0.3 mg/ℓ and at the outer basins range from 1.3 to 2.0 mg/ℓ. Emery reported approximately 40 μg-atom/ℓ nitrates for the Santa Monica Basin. Vaughn, discussing a sampling cruise made for Los Angeles City Sanitation District in March and April of 1970, reported dissolved oxygen values of about one-half Emery's and nitrate values of about one-half Emery's (Table 6-l). Differences of averages were: dissolved oxygen - Vaughn 0.1 mg/ℓ, Emery 0.2 to 0.28 mg/ℓ; nitrates - Vaughn 20 μg-atom/ℓ, Emery 40 μg-atom/ℓ. Phosphate-phosphorous averaged somewhat higher: Vaughn 4-5 μg-atom/ℓ, Emery 3 μg-atom/ℓ. These and other differences including estimated time required for replenishment differences led Vaughn to estimate 5 years as the required replenishment rate for the Santa Monica-San Pedro Basin complex. Emery found (and Vaughn agrees) that the small difference in temperature (approximately 0.13°C) in the first 100 meters below the sill in each basin is indicative of mixing.

Sverdrup has shown surface water off Southern California to be northern water while the water flowing at sill depth (Figures 6-6 and 6-7) is southern water. Intermediate waters are a mixture of northern and southern waters. Waters below the sill depths are unique to a particular basin and are generally fairly uniform from the sill depth downward. The effects of wastes influent to these waters are hard to evaluate because of the complex physical, chemical, and biological characteristics made more complex by flow patterns found in the continental shelf water (SCCWRP 1973).

In discussing the geology of the Santa Barbara Basin, Emery and Rittenberg (1952) estimated that at the present rate of sediment inflow, the basin would fill to the surface in 1.5 million years. The deeper Santa Monica Basin can be estimated to fill to the surface in 2.0 million years. Using Emery's procedure, Vaughn estimated that with the 1970 Hyperion discharge rates, it would take 5 million years to fill the Santa Monica Basin to sill depth with compacted sludges. If the discharge ratios of Hyperion and LACoJWPCD, 450/750, and basin volume ratio, 19/50, were applied, it could be estimated that it would take 1.1 million years to fill the San Pedro Basin to sill depth. (450/750 x 19/50 x 5 = 1.1 m.yrs) . These figures provide some perspective of the filling effects of the wastes (pollutants) now being discharged into the two basins.

Another consideration would be the relative oxygen demand and nitrogen loading imposed on the receiving waters by natural and man-made means. The total sediment deposited by the three natural processes (wind, runoff, and precipitation) is approximately 10^{12} grams per year while the sludge deposited by direct injection is 10^{10} grams per year or 1%. The oxygen demand of the sludge is 10^{7} grams per year, .1{1000 of that of the natural deposits. The nitrogen regenerated from the bottom represents about 1% of that generated in the upper waters and about 0.4% of the phytoplankton needs. The nitrogen to be regenerated in the sludges is less than that of the natural bottom materials and therefore will not be noticed by the biological needs of the waters.

Table 6-1

SANTA MONICA BAY DEEP WATER BASIN SURVEY*

Date 1970	Samp. No.	Cl	DO	p	NO -N	Temp.	Depth	Location	Long. W	Lat. N
3-25	(1			0.06	0.13			Redondo Canyon		
"	(2			0.055	0.13			Redondo Canyon		
"	(3	18,920	5*3	0.075	0.17	10.53	330 ft	S.M. Basin Deep		
"	(4	19,088	3.2	0.08	0.24	9.09	660 ft	" "		
"	1(5	19,151	1.6	0.10	0.28	7.53	980 ft	" "		
"	(6	19,172	0.8	0.12	0,32	6.41	1470 ft	" "		
"	(7	19,144	0.5	0.11	0.35	6.13	2200 ft	" "		
"	(8	19,249	0.2	0.15	0.31		2800 ft	" "		
"	(9	19,263	0.1	0.13	0.28	5.3	2800 ft	" "		
"	(lo		8.2				Surface	" "		
4-1	(1	19,382	0.9	0.19	0.33	6.18	1700 ft	Dume Canyon	118°48.5′	33°58.4′
"	(6	19,582	0.6	0.13	0.35	6.39	1440 ft	" "	"	"
"	2(5	19,496	2.9	0.11	0.25	7.70	950 ft	" "	"	"
"	(3	19,382	1.3	0.11	0.28	8.54	660 ft	" "	"	"
"	(4	19,353	4.5	0.10	0.19		330 ft	" "	"	"
4-1	(7	19,353	0.1	0.15	0.33	5.40	2750 ft	6.5K off Pt Dume	118°49.8′	33°53.8′
"	(9	18,669		0.14	0.27		2750 ft	" "	"	"
"	(Solid Sample									
"	(l	19,525	0.3	0.19	0.36	5.51	2250 f	" "	"	"
	3(11	19,353	0.3	0.14	0.38	6.01	1900 ft	" "	"	"
"	(10	19,297	0.8	0.11	0.33	6.71	1400 ft	" "	"	"
"	(13	19,397	1.7	0.14	0.31	8.32	1000 ft	" "	"	"
"	(12	19,240	3.4	0.10	0.23	9.59	500 ft	" "	"	"
4-1	(15	19,410	1.0	0.14	0.35	7.12	1500 ft	S.M. Canyon	118°40.5′	33°54.3′
"	4(14	19,410	1.3	0.14	0.33	7.57	1300 ft	" "	"	"
"	(16	19,325	2.3	0.18	0.27	8.20	900 ft	" "	"	"

Table 6-1 (cent)

SANTA MONICA BAY DEEP WATER BASIN SURVEY (cent)

Date 1970	Samp. No.	Cl	DO	p	NO -N	Temp.	Depth	Location	Long. W	Lat .N
4-1	(18	19,410	0.1	0.19	0.31	4.99	2900 ft	S.M. Canyon	118°41.3′	33049.5′
"	(17	19,468	0.2	0.33	0.33	5.30	2400 ft	“ "	"	"
"	(20	19,439	0.45	0.10	0.35	6.08	2000 ft	“ "	"	"
“ 5	(19	19,382	0.8	0.16	0.33	6.89	1500 ft	“ "	"	"
"	(22	19,297	2.2	0.18	0.27	8.01	1000 ft	“ "	"	"
"	(21	19,297	3.9	0.1″0	0.22	9.81	500 ft	“ "	"	"
4-2	(102	19,496	0.7	0.13	0.33	6.90	1500 ft	Sill outlet to Canyon off Snta.Brbra.Isl.	118°59′	33°34′
" 6	(101	19,410	1.1	0.11	0.27	8.10	1000 ft	“ "	"	"
"	(104	19,353	2.0	0.10	0.27	8.42	800 ft	“ "	"	n
"	(103	19,211	4.6	0.8	0.17	10.38	300 ft	“ “	"	"
4-2 “ 7	(106	19,525	0.1	0.16	0.34	5.32	2800 ft	S.M. Basin Edge & Island	118°59′	33°43′
"	(105	19,525	0.1	0.19	0.28	5.48	2300 ft	“ "	"	"
4-2	(111	19,696	0.1	0.16	0.29	5.30	2700 ft	S.M., Bay at Bottom of Canyon	118°37′	33°47′
" 8	(110	19,667	0.5	0.17	0.36	5.54	2200 ft	“ "	"	"
n	(113	19,525	0.5	0.13	0.36	6.45	1700 ft	“ “	"	"
"	(112	19,496	1.1	0.10	0.30	7.50	1200 ft	“ n	n	"
4-2	(122	19,468	0.7	0.11	0.34	6.77	1600 ft	Redondo Cnyn	118°30.0′	33°48.3′
"	(121	19,468	1.3	0.11	0.28	7.28	1200 ft	“ "	n	"
“ 9	(124	19,297	2.1	0.10	0.27	8.77	800 ft	“ "	"	n
"	(123	19,240	3.7	0.08	0.21	9.88	400 ft	“ "	"	"
n	(125	19,097		0.08	0.01		Surface	“ "	n	"

* Data taken from Investigation Into The Receiving Environment For Digested Sludge Solids, John P. Vaughn, 1971.

The sources Of natural terrestrial sediments are limited to stream, wind, water, direct injection seacliff erosion, from the ocean to organic remains and chemical precipitant. Those of land origin are transported to the bight by wind, water, and direct injection. Once in the marine environment, sediments are transported by wind above the water, on the water by fresh-water rafting, by diffusion through the water, and by turbidity current once it reaches the shelf or basin wall (Fig.6-8). These sediments, which are approximately 84% detrital, 13% calcium carbonate, and 3% organic matter, are being subjected to changes induced by mainland construction of such as water supply reservoirs, flood debris basins, urban paving, storm drains, river-channel linings, highways, seawalls, breakwaters, groins, jetties, etc.

Airborne sediments come chiefly on the Santa Ana winds which are experienced only a few days each year. Samples collected on the R.V. Velero IV on November 4, 1950 amounted to 135 mg per sq. yd.

During his investigation of fallouts from such winds, Babcock in 1957 collected 2.4 grams per sq. yd. or approximately .3 mg per sq. cm. of material. Assuming an average of 5 Santa Ana winds per year and allowing for the decrease in velocity to zero by the time the continental slope is reached, Emery calculates that 1.5 mg/cm²/yr or 0.6 million tons per year are deposited on the coastal waters. Figure 2-36 depicting the Santa Ana wind pattern and the northwest winds of Figure 2-35 and the wind roses' of Figures 2-25 and 2-26 as well as Figures 6-28 and 6-29 will help to illustrate the phenomena.

The harbors of the Southern California Bight are ideally located for domestic and foreign trade. Los Angeles and Long Beach Harbors are well protected by the channel islands and the damping effect of the bottom configuration (SCCWRP 1973). The Southern California coast is nearly ideal for the development of small craft harbors and there are 14 major marinas and 3 major seaports in the area of study. These widely diverse "harbors" can be grouped into 5 general classifications: commercial, industrial, recreational, fishing, and refuge. The largest harbors of the bight, Los Angeles, Long Beach, and San Diego, serve all 5 functions while intermediate harbors such as Santa Barbara, Port Hueneme, and Newport Bay serve two or three of the functions. Smaller harbors such as Anaheim Bay, Camp Pendleton, Santa Monica, Playa Del Rey, Redondo Beach, Alamitos Bay, Sunset Bay, Bolsa Chica, and Mission Bay serve only one or two of the five purposes.

ocean commerce and recreational use of the Southern California Shelf has resulted in over 290 shipwrecks worthy of note. Of the 290 ships of varying size wrecked in the area of study (Emery 1960), 45% are within 30 mi. (48 km) of Los Angeles-Long Beach Harbors and 25% of the total occurred in the

Santa Barbara channel. Twenty-five ships were lost before the turn of the century but most have been lost since World War I.

The land area tributary to the coastal. waters is a popular place to live. one-half (nearly 11 million people) of the state's population live in the drainage basins that feed the bight. This represents better than 5% of the U.S. population (U.S. Census 1970). Nearly one-half of the state's water supply is imported into the area to supply the demands created by such a dense population. Together, these conditions produce many problems related to the coastal waters. Den se populations generate problems. Present concern of concentrated industrial, commercial, and domestic wastes is for certain of these wastes: oils and greases, particulate, persistent pesticides, trace metals and metallic compounds (SCCWRP 1973). Such wastes are discussed under sections 3, 4, 5, 6, 7. Airborne wastes are discussed under section 8.

The area being studied lies in a highly faulted, very active earthquake belt (Chapter 1) , (Figure 6-9 from U. S. Department of Commerce Building Science Series 40). The San Andreas Fault, inland and approximately parallel to the California Coast, nearly parallels the peninsula ranges on the east of the study area and jogs westward in a configuration that almost parallels the Transverse Range to the northeast of the study area (United States Department of Commerce Building Science Series 40, Figure 6-10). The relative northwesterly movement of the western side of the fault and the southeasterly movement of the eastern side produces a zone of compression in the offset (paralleling the Transverse Range) that is ultimately felt throughout the bight and adjoining tributary land area (Figure 6-11). It is apparent from Figure 6-11 that the effects of the 1971 San Fernando Earthquake extended into the coastal area under study.

The subsidence experienced in the Long Beach-Los Angeles Harbors area over the period 1928-1962 (Figure 6-12) was accelerated at the times of significant earthquake activity as noted on the graph of subsidence rate versus time for the period 1946-1962 (Figure 6-12). It is reasonable to assume that other geological and man-made structural features of the bight have been or will be similarly effected.

Conditions in harbors, bays, marshes, and other estuarine areas of the bight are discussed in Chapters 5 and 14. Mention of pollution in the Los Angeles Harbor here is used to illustrate the effects of control of the source of pollutants entering the Southern California waters.

1.3. Historical Los Angeles Harbor Pollution

Clark, in a survey of the Improvement of Water Quality in Los Angeles Harbor, reported on the improvements resulting from the termination of domestic and industrial wastes. He reports that the first serious attempt at water quality control in Los Angeles Harbor came in 1938 when the discharge of oils, flammable liquids, related materials or bilge waters containing such substances was prohibited. In 1944, the City of Los Angeles introduced control over the discharge of wastes to storm drains. No immediate improvement was noticed and in 1947, an Advisory Committee with several sub-committees was formed to recommend corrective measures.

The Los Angeles Regional Water Pollution Control Board (1948) submitted the "Second Interim Report of the Technical Subcommittee on Harbor Pollution" which verified the pollution of Cerritos Channel, the northerly area of Consolidated Channel, by organic wastes, oil, suspended matter, and hydrogen sulfides. It reported sludge beds from 6 to 8 feet thick. (The City of Long Beach, which had been dumping screened domestic sewage into the channel, stopped discharging there in 1948 and the sludge beds disappeared by 1951.)

The effects of industrial waste (petroleum) is also illustrated by the results of a general strike of oil workers in September of 1948 which caused a discontinuance of operations at major plants discharging effluent into Dominguez Channel. Six stations reporting dissolved oxygen and sulfide concentration during the active and inactive periods indicated reported increase of D.O. from 0 to 8.0 ppm and decrease of sulfides from 4.4 to 0 ppm (Table 6-2). See Figure 6-13 for location of sampling stations. A program of curtailing discharge of domestic, petroleum and other industrial wastes has greatly improved the quality of the water in inner Los Angeles Harbor. Sampling at selected station as reported by Clark illustrate the improvement (Table 6-3).

Installation of equipment to reduce the amounts of pollutants discharged into Dominquez Channel began in 1969 and was completed in 1970.

Table 6-2

COMPARISON OF DISSOLVED OXYGEN AND SULFIDE CONTENT
LOS ANGELES INNER HARBOR
REFINERIES ACTIVE VERSUS REFINERIES INACTIVE
(in parts per million)*

	October 30, 1947 (Refineries Active)		September 29, 1948 (Refineries Inactive)	
Station No.**	Dissolved Oxygen	Sulfide	Dissolved Oxygen	Sulfide
LA 30	None	0.1	4.9	None
41	"	0.6	8.0	"
47	"	1.3	7.6	"
49	"	3.1	4.6	"
50	"	2.1	4.1	"
51	"	4.4	2.3	"

* Data taken from E. K. Clark, Improvement of Water Quality in Los Angeles Harbor, (unpublished research paper), CSULB, 1971/72.

** See Figure 6-13 for location of water quality sampling stations .

Table 6-3

DISSOLVED OXYGEN AND SULFIDE CONTENT IN LOS ANGELES INNER HARBOR ATTAINED THROUGH REDUCTION IN POLLUTANTS DISCHARGED INTO DOMINGUEZ CHANNEL
(in parts per million)*

	January 1969		February 1970		February 1971	
Station No.**	D.O.	Sulfide	D.O.	Sulfide	D.O.	Sulfide
LA 30	0.2	0.0	1.7	0.0	6.7	0.0
41	0.2	0.0	0.1	0.0	7.0	0.0
47	0.2	0.0	0.1	0.0	6.5	0.0
49	0.2	0.0	0.1	0.0	6.4	0.0
50	0.1	0.0	0.2	0.0	5.7	0.0
51	0.0	0.0	0.1	0.0	5.6	0.0

* Data taken from E. K. Clark, Improvement of Water Quality in Los Angeles Harbor, (unpublished research paper) CSULB, 1971/72.

** See Figure 6-13 for location of water quality sampling stations.

2. Surface Runoff

All the rainfall that does not infiltrate into the soil, evaporate from water surfaces, or transpire from plants is called surface runoff or possibly storm runoff. In the study area, it is assumed that all the surface runoff will enter the ocean from natural or man-made conduits. When no rainfall occurs these natural or man-made conduits may still convey surface water called dry-weather flow. These dry-weather flows mainly are derived from the following sources: springs, wells, street washings, industrial wastes, waste water reclamation plant discharges, reservoir releases, etc. The quantities of runoff have been measured for most of the major streams but the quality measurements of significant constituents found in these streams generally have not been made. This type of information should be available for each major stream and conduit conveying runoff. The only information of this type available at the present time was found in SCCWRP 1973, and from recorded data maintained by the Water Quality Section of the Los Angeles County Flood Control District (LACFCD 1972-1973).

Tables 6-4, 6-5, and 6-6 show average constituent concentrations in storm flows, dry-weather flows, and mass emission rates respectively for selected streams in the 1973 SCCWRP Report. Four rivers were selected for the storm runoff studies while 11 perennial streams were used for the dry-weather flow studies. It should be noted that some of the values given are only good estimates as quality measurements were not made during all of the storm flows or during the entire duration of the storm in some cases. Streams were sampled only once during dry-weather flows because they were assumed to be of relatively constant concentration during the whole year (SCCWRP 1973).

An item of interest is suspended solids concentration of the storm water flows in the four streams as shown in Table 6-4. The Santa Clara and Santa Ana Rivers show concentrations of 7,600 and 1,800 mg per liter respectively while the Los Angeles River and Ballona Creek show concentrations of 300 and 390 mg per liter respectively. This is due primarily to the degree of lining of the channel involved and upstream river basin improvements. Streams with little or no lining produce high concentrations of suspended material. The total quantity of silt or sand carried by these streams per time period is also largely influenced by the amount of flood control improvements made in the runoff basins. The building of flood control reservoirs and the lining of stream channels have decreased sediment transport in some streams to the extent that beach sand has to be replaced by man-made devices. As an example, the Santa Clara River produced 199,000 metric tons of silt during the 1971-1972 time period as shown in Table 6-6 (SCCWRP 1973). The total surface runoff for the Santa Clara River was found to be only 26 X 10^6 cubic meter compared with approximately 68 X 10^6 cubic meters for the Los Angeles River in 1971-1972.

Table 6-4

AVERAGE CONSTITUENT CONCENTRATIONS (mg/ℓ) IN STORM WATER OF FOUR STREAMS*

	Santa Clara River	Ballona Creek	Los Angeles River	Santa Ana River
<u>Soluble Constituents</u>				
Organic nitrogen	1.1	3.9	3.0	1.1
Ammonia nitrogen	0.4	1.6	1*1	0.2
Nitrite nitrogen	0.1	0.4	0.5	0.1
Nitrate nitrogen	2.3	5.2	3.7	1.3
Phosphate phosphorus	0.43	0.52	0.85	0.82
Dissolved Silica (SiO_2)	11	9.6	11	5.3
Total organic carbon	22	45	45	30
<u>Soluble Plus Insoluble Constituents</u>				
Chemical oxygen demand	180	260	120	62
Oil and Grease	1.5	23	12	7
Detergents (MBAS)	0.1	0.4	0.3	0.06
Phenols	0.03	0.09	0.09	0.05
Cyanide (CN)	0.09	0.16	0.04	0.03
<u>Silt Constituents</u>				
Silt	7600	390	300	1800
Organic carbon	100	64	31	28
Organic nitrogen	3.9	3.0	2.0	1.5
Phosphate phosphorus	2.0	0.84	0.65	0.71

* Data taken from the 1973 Southern California Coastal Water Research Project Report

Table 6-5

GENERAL CHARACTERISTICS OF DRY WEATHER FLOWS (mg/ℓ) IN SOUTHERN CALIFORNIA, 1971-7.2*

	Ventura River	Santa Clara River	Calleguas Creek	Pico Drain	Ballona Creek	Dominguez Channel
Soluble Constituents						
Organic nitrogen	2.9	2.2	2.4	2.4	1.9	1.2
Ammonia nitrogen	9.1	0.0	6.3	0.0	3.5	0.0
Nitrite nitrogen	0.l	0.1	0.1	0.2	0.2	0.0
Nitrate nitrogen	6.3	4.1	2.4	2.2	1.7	0.1
Phosphate phosphorus	3.7	0.06	4.2	1.6	0.49	0.33
Dissolved silica (SiO_2)	17	26	32	28	27	10
Soluble plus Insoluble Constituents						
Chemical oxygen demand	39	120	100	62	33	190
Oil and grease	4	4	4	49	34	34
Detergent (MBAS)	0.14	0.02	0.08	0.32	0.26	0.72
Phenols	0.002	0.001	0.001	0.01	0.00	24
Cyanide (CN)	0.004	0.007	0.018	0.00	0.08	0.00
Silt Constituents						
Silt	64	930	50	54	51	14
Organic nitrogen	1.0	6.8	1.1	0.16	1.2	1.3
Phosphate phosphorus	---	---	---	0.29	0.42	0-.09

Table 6-5 (cent)

GENERAL CHARACTERISTICS OF DRY WEATHER FLOWS (mg/ℓ) IN SOUTHERN CALIFORNIA, 1971-72*

	Los Angeles River	San Gabriel River	Coyote Creek	San Diego Creek	San Juan Creek
Soluble Constituents					
Organic nitrogen	2.9	1.7	2.2	1.7	0.7
Ammonia nitrogen	0.0	10.2	0.0	3.5	0.0
Nitrite nitrogen	0.2	0.3	0.7	5.9	0.0
Nitrate nitrogen	0.5	1.2	2.2	10.7	2.5
Phosphate phosphorus	0.55	0.69	0.14	1.83	0.03
Dissolved silica (SiO_2)	18	25	12	21	17
Soluble plus Insoluble Constituents					
Chemical oxygen demand	36	58	46	110	13
Oil and grease	39	24	34	36	30
Detergent (MBAS)	0.16	0.34	0.74	0.28	0.13
Phenols	0.00	0.00	0.00	0.01	0.00
Cyanide (CN)	0.009	0.00	0.032	0.004	0.004
Silt Constituents					
Silt	60	32	14	1,620	4.4
Organic nitrogen	0.42	1.6	0.57	2.9	0.57
Phosphate phosphorus	0.07	0.59	0.15	1.3	0.10

* Data taken from the 1973 Southern California Coastal Water Research Project Report

Table 6-6

CONSTITUENT MASS EMISSION RATES (M TONS/YR)
FROM SURFACE RUNOFF IN SOUTHERN CALIFORNIA, 1971-72*

Stream	Flow (10^6 Cu m/yr)	Silt	Total Organic Carbon	Chemical Oxygen Demand	Oil And Grease	Dissolved Silica (SiO_2)	Nitrate Nitrogen	Ammonia Nitrogen
S.Brbra Grp.								
storm	2.5	200	200	100	<50	50	16	23
Dry Weather	1.2	100	100	<100"	<50	<50	8	11
Ventura R.								
storm	3	200	200	100	<50	50	20	27
Dry Wthr.	11.7	700	900	500	<50	200	75	107
Santa Clara R.								
storm	26	199,000	2,800	4,800	50	300	63	11
Calleguas Cr.								
storm	0.7	<100	<100	100	50	50	2	4
Dry Weather	2.7	100	100	300	50	80	7	17
Malibu Cr.								
storm	3.4	1,000	300	400	50	<50	15	4
Pico Drain								
storm	1.2	500	100	300	<50	<50	7	2
Dry Weather	3.6	200	100	200	180	100	9	1
Ballona Cr.								
Storm	26	10,000	2,800	6,600	600	250	151	42
Dry Wthr.	15.7	800	200	500	530	420	30	55
Dominguez Ch.								
storm	5.3	100	100	1,000	180	50	1	<1
Dry Weather	5.4	100	100	1,000	190	50	1	<1
L.A.River								
storm	48	14,000	3,600	5,700	590	50	204	53
Dry Wthr.	20	1,200	200	700	790	36	14	<1

Table 6-6 (cent)

CONSTITUENT MASS EMISSION RATES (M TONS/YR)
FROM SURFACE RUNOFF IN SOUTHERN CALIFORNIA, 1971-72*

Stream	Flow (10^6 cu m/yr)	Silt	Total Organic Carbon	Chemical Oxygen Demand	Oil And Grease	Dissolved Silica (SiO_2)	Nitrate Nitrogen	Ammonia Nitrogen
S.Gabriel R.								
Storm	10.3	3,000	800	1,300	130	110	44	11
Dry Weather	0.3	<100	<100	<100	<50	50	1	3
Coyote Cr.								
Storm	27	8,000	2,000	3,200	330	290	110	30
Dry Weather	4	100	100	200	140	50	12	<1
Santa Ana R.								
storm	10.4	18,000	600	600	70	50	15	2
S.Diego Cr.								
Storm	2.5	4,000	100	300	90	50	42	9
Dry Weather	8	13,000	400	900	290	170	133	28
San Juan Cr.								
Storm	0.2	<100	<100	<100	<50	<50	1	<1
Dry Weather	2.1	<1oo	<100	<1oo	60	50	5	1
Total								
Storm	167	258,000	13,000	24,500	2,100	1,330	690	218
Dry Wthr.	75	16,000	2,200	4,400	2,300	1,510	290	224
TOTAL	242	274,000	15,200	28,900	4,400	2,840	980	442

Table 6-6 (cent)

CONSTITUENT MASS EMISSION RATES (M TONS/YR)
FROM SURFACE RUNOFF IN SOUTHERN CALIFORNIA, 1971-72*

Stream	Organic Nitrogen	Total Nitrogen	Phosphate Phos - phorous	Detergent (MBAS)	Cyanide (CN)	Phenols
S.Brbra Gp.						
Storm	10	49	9	0.4	<0.1	<0.1
Dry Weather	5	24	4	0.2	<0.1	<0.1
Ventura R.						
storm	12	59	11	0.4	<0.1	<0.1
Dry Weather	46	230	43	1.6	0.1	<0.1
Santa Clara R.						
storm	132	206	64	2.6	2.4	0.8
Calleguas Cr.						
Storm	2	8	3	‘0.1	<0.1	<0.1
Dry Weather	9	33	11	0.2	0.1	<0.1
Malibu Cr.						
Storm	17	36	5	1.0	0.1	0.3
Pico Drain						
storm	8	17	2	0.5	0.2	0.1
Dry Weather	9	19	7	1.2	<0.1	<0.1
Ballona Cr.						
Storm	180	370	36	10.3	4.1	2.3
Dry Weather	49	134	14	4.1	0.1	CO*1
Dominguez Ch.						
storm	13	14	2	3.8	<0.1	127
Dry Weather	13	14	2	3.9	<0.1	130
L.A.River						
storm	242	500	72	14.5	1.9	4
Dry Weather	67	81	13	3.2	0.2	<0.1

Table 6-6 (cent)

CONSTITUENT MASS EMISSION RATES (M TONS/YR)
FROM SURFACE RUNOFF IN SOUTHERN CALIFORNIA, 1971-72*

Stream	Organic Nitrogen	Total Nitrogen	Phosphate Phos-phorous	Detergent (MBAS)	Cyanide (CN)	Phenols
S.Gabriel R.						
storm	52	107	16	3.1	0.4	1
Dry Weather	1	5	3	0.1	<0.1	<0.1
Coyote Cr.						
storm	140	280	40	8.1	1.1	2
Dry Weather	11	23	1	3.0	0.1	<0.1
Santa Ana R.						
Storm	27	44	16	0.6	0.3	1
San Diego R.						
Storm	12	63	8	0.7	<0.1	<0.1
Dry Weather	37	198	27	2.2	<0.1	<0.1
San Juan Cr.						
storm	<1	1	<1	<0.1	<0.1	<0.1
Dry Weather	<3	8	<1	0.3	<0.1	<0.1
Total						
storm	840	1,750	283	46	10.4	139
Dry Weather	250	760	126	20	0.6	130
TOTAL	1,090	2,510	409	66	11.0	269

* Data taken from 1973 Southern California Coastal Research Project Report.

2.1. Runoff Studies For Four Los Angeles County Streams

Dry-weather flow and storm flow studies have been made on Ballona Creek, Los Angeles River, San Gabriel River, and Santa Clara River during the 1972-1973 time period. Flow rate and constituent concentration data for dry-weather flows are shown in Tables 6-7 and 6-8. This information was furnished by LACFCD 1972-1973 in monthly reports. It should be noted that both dry-weather flow rates and concentrations are averages for the months of July, August, and September in 1972. The dry-weather mass emission rates presented in Table 6-8 were calculated using these average monthly flow rates and the average monthly constituent concentrations found in Table 6-7.

The constituents are discharged to the ocean by these streams in proportion to the dry-weather flow rates with one or two exceptions. One exception is the mass emission of total dissolved solids from Ballona Creek as compared with the Los Angeles River. Ballona Creek discharges nearly the same quantity of dissolved solids (60.3 metric tons per day) to the ocean as the Los Angeles River (87.9 metric tons per day) while the flow rate for Ballona Creek is only about 1/3 of the flow rate in the Los Angeles River, 13.6 cubic feet per second as compared to 38.0 cubic feet per second. Although the San Gabriel River has a flow rate of more than 4 times that of the Santa Clara River, 28.3 cfs vs. 6.5 cfs, the mass emission rate of nitrates are nearly equal, 0.69 M tons per day vs 0.60 M tons per day. This may be explained by the fact that the Santa Clara River watershed is largely agricultural in nature while that of the San Gabriel River is largely residential. Excess fertilizers found in the Santa Clara Valley agricultural drainage system build up the concentration of nitrates in the waters of the Santa Clara. The relatively high mass emission rate of phosphate in the San Gabriel River can only be explained by the discharge of reclaimed domestic waste water from the satellite waste water treatment plants operated by the Los Angeles County Sanitation Districts. Domestic waste water generally has" high concentrations of phosphates due to use of detergents containing phosphate builders. The discharge of these nutrients, nitrates, and phosphates will encourage the growth of small organisms, such as algae, in the estuaries of the study area (Chapter 12).

Storm runoff data for these four Los Angeles County streams are presented in Table 6-9, and Figures 6-14 and 6-15. Flow rates for these streams are shown for the November 11, 1972 and January 16, 1973 storm only (LACFCD 1972-1973). Constituent concentrations of the eight grab samples are shown in Table 6-9. In that a representative sampling that will reflect the actual concentration of constituents for the entire storm is unavailable, mass emissions have not been calculated. From Table 6-9 it should be observed that the

Table 6-7

AVERAGE CONSTITUENT CONCENTRATIONS IN DRY-WEATHER FLOWS IN FOUR LOS ANGELES COUNTY STREAMS (mg/ℓ)*, SUMMER 1973**

	Ballona Creek	Los Angeles River	San Gabriel River	Santa Clara River
Average Monthly Flow Rate, cfs	13.6	38.0	28.3	6.5
Total Dissolved Solids (TDS)	1846	962	1120	1093
Chemical Oxygen Demand (COD)	69	86.7	87.7	32.7
Biochemical Oxygen Demand (BOD)	10.3	14.3	6.7	4.0
Nitrate	12.1	8.5	10.2	38.6
Phosphates	1.8	3.8	22.4	1.0

* Data shown are averages of monthly concentrations from Los Angeles County Flood Control District (LACFCD) monthly reports.

** Summer months are July, August, September, 1973.

Table 6-8

AVERAGE CONSTITUENT MASS EMISSION RATES (M TONS/DAY)* IN DRY WEATHER FLOWS IN FOUR LOS ANGELES COUNTY STREAMS, SUMMER 1973**

	Ballona Creek	Los Angeles River	San Gabriel River	Santa Clara River
Total Dissolved Solids (TDS)	60,3	87.85	76.14	17.07
Chemical Oxygen Demand (COD)	2.3	7.92	5.96	0.51
Biochemical Oxygen Demand (BOD)	0.34	1.31	0.46	0.06
Nitrates	0.40	0.78	0.69	0.60
Phosphates	0.06	0.35	1.52	0.02

* Mass Emission rates are products of average monthly flow rates and average monthly concentrations furnished in LACFCD monthly reports.

** Summer months are July, August and September 1973.

Table 6-9

CONSTITUENT CONCENTRATIONS IN STORM FLOW GRAB SAMPLES* IN 4 LOS ANGELES COUNTY STREAMS (mg/ℓ), WINTER 1972-1973**

	Ballona Creek		Los Angeles River		San Gabriel River		Santa Clara River	
	11-11-72	1-16-73	11-11-72	1-16-73	11-11-72	1-16-73	11-11-72	1-16-73
Total Dissolved Solids (T. D. S.)	399	67	197	92	323	105	650	402
Suspended Solids (S.S.)	280	262	265	1,190	60	107	2,500	9,280
Biochemical Oxygen Demand, (BOD)	19	7	30	14	13	9	30	32
Nitrates	15.7	5.2	11.1	0	7.4	0	18.0	0
DDT,µg/ℓ	0.19	0.22	0.35	0.30	0.11	0.21	0.37	0.09
T.I.C.H.,µg/ℓ	0.33	0.43	0.38	0.45	0.27	0.22	0.47	0.14

* A grab sample is taken during every storm
** Data source is the Los Angeles County Flood Control District (LACFCD)

first major storm of the rainy season (November 11, 1973) produces very high concentrations of nitrates which have been building up during the dry season. This also is true for both DDT and TICH (Total Identified Chlorinated Hydrocarbons) in the Santa Clara River drainage basin. All of these above-named constituents are commonly found in an agricultural area such as the Santa Clara River drainage basin. Chlorinated hydrocarbon measurements were made in both the Los Angeles and San Gabriel Rivers during dry-weather flow conditions. For the Los Angeles River, the DDT and TICH concentrations were found to be less than 0.01 micrograms per liter and 0.09 micrograms per liter respectively. The concentrations for the San Gabriel River were respectively 0.05 μg per liter and 0.25 μg per liter for the same time period (July, August, and September of 1972).

3. Municipal Waste Discharges

3.1 Waste Water Flow Rates

As of January 1, 1972, 131 municipal waste water treatment plants were operating and either discharging municipal waste water to the coastal basin, spreading it on the land, discharging the waste water to streams and flood control channels, or reusing the treated waste water for industrial, agricultural, and recreational purposes (California Water Resources 1972). Table 6-10 shows that the total average waste water flow rate discharged from those plants was 1058.40 mgd during the year 1971. On the average, 41.14 mgd (3.9% of this treated waste water was reused for agricultural, industrial, and recreational beneficial uses and was therefore not discharged directly to a surface stream, a flood control channel, or the ocean itself during the year 1971) (California Water Resources 1972). Approximately 91.8 percent (971.87 mgd) of the daily average flow is discharged directly into saline water from the municipal treatment facilities while only 4.3 percent (45.35 mgd) is discharged to either the land or a flowing stream of some type. The location of the major ocean discharge points in the study area are shown in Figure 6-16. As of January 1, 1972 there were 22 major municipal dischargers of waste water in the coastal area that on the average discharged nearly 1,000 mgd of partially treated municipal sewage into the coastal basin (California Water Resources 1972). These discharges are more fully broken down in Table 6-11. The five service areas that generate the flows for 15 of the major waste dischargers are shown in Figure 6-17. Six of these major dischargers generate 946 mgd or 97 percent of all the municipal waste water directly discharged to the coastal waters of the study area. These six dischargers are Los Angeles County Sanitation District's Joint Water Pollution Control Plant (365 mgd), City of Los Angeles Hyperion Treatment Plant (333 mgd), Orange County Sanitation District's Plants 1 and 2 (135 mgd), City of San Diego Point Loma Plant (94 mgd), Terminal Island plant (9.1 mgd), and City of Oxnard Treatment Plant (9.9 mgd) (Tables 6-10,11,12) .

Of these 6 major municipal treatment plants, the Los Angeles County Sanitation District's Joint Water Pollution Control Plant receives the greatest quantity of treated and untreated industrial wastes. Los Angeles City Hyperion and Orange County Sanitation District's Plants 1 and 2 also receive significant quantities of industrial wastes. The presence of some industrial wastes reduces the potential of giving complete secondary (biological) treatment to the waste waters discharged to these plants. Toxic materials present in some of these industrial waste waters retard micro-organism activity, thereby reducing the efficiency of biological treatment. Less than 15 percent of all the municipal wastes being discharged directly to the ocean now receive more than conventional primary (physical) treatment on a continuous basis (California Water Resources 1972). Most of the plants are capable of chlorinating the effluents should conditions require this type of treatment. The Hyperion Treatment Plant operated by the City of Los Angeles disposes of its digested sludge by means of a seven mile outfall in Santa Monica Bay. The other agencies use either effluent sludge disposal methods or land disposal for the digested sludge generated in their plants.

Yearly average flow rates produced by the five major waste water dischargers and the Terminal Island Treatment Plant outfall are presented in Figure 6-18 (SCCWRP 1973 and California Water Resources 1973). The Terminal Island Treatment Plant, operated by the City of Los Angeles, serves the Los Angeles Harbor area. Waste water flow rates have increased consistently over the period shown in Figure 6-18 due to expansion of the service areas and growth of population and industrial activities within the areas. The decrease in flow rates shown in Figure 6-18 for both Hyperion and the Los Angeles County Joint Water Pollution Control Treatment Plants in 1969 may be due to addition of waste water reclamation plants to the systems.

Figure 6-19 shows the relationship between Hyperion Treatment Plant waste water flow rates and some of the major constituents found in the effluent discharged by means of the 5 mile outfall line to Santa Monica Bay (California Water Resources 1972). During the 1961 to 1972 time period very little correlation is shown between effluent flow rates and mass emission rates for constituents, such as SiO_2, NH_3-N, PO_4-P, Oil and Grease, Metals (Cu, Cr, Ni, Zn). Normally, control of treatment is based upon degree of BOD and suspended solids removed within the plants, which would account for the approximate correlation between effluent flow rates and mass emission rates. Thus, for any constituent except suspended solids and oxygen demand, it would usually be incorrect to assume that the mass flow rate of this constituent would vary proportionally with the total discharge rate.

3.2 Waste Water Effluent Quality Characteristics

Table 6-12 presents the most commonly measured effluent constituent concentrations for the 6 major waste water dischargers in the coastal basin. More rigorous control and sampling programs are conducted in the larger plants producing data for more of the constituents. Operators of smaller plants normally conduct only routine sampling programs resulting in less data concerning these plant effluents. There appears to be a serious discrepancy in the concentration of every constituent except cyanide when comparing the Hyperion waste water effluent and that of the Los Angeles County Joint Water Pollution Control Plant. The suspended solids concentrations are 85.7 mg/ℓ and 286 mg/ℓ respectively. The 5-day BODS are 17.3 mg/ℓ and 61.5 mg/ℓ. This apparent discrepancy should be clarified to avoid incorrect conclusions. The Los Angeles County Joint Water Pollution Control Plant is operated in

Table 6-12

GENERAL CHARACTERISTICS (mg/ℓ) OF FINAL EFFLUENT
FROM SIX MAJOR MUNICIPAL WASTEWATER DISCHARGERS, 1972*

	Oxnard	Hyperion	JWPCP	Terminal Island	Orange County	Point Loma
Flow (MGD)	9.9	330.0	360	9.1	140	92.8
Suspended solids	76	85.7	286	139	146	115.0
BOD_5		113	273	153	174	180
Grease and Oil	6.4	17.3	66.0	23	39	25.5
Ammonia nitrogen		16.0	44.0	27.9	33	19.0
Organic nitrogen				10.4		
Total nitrogen		17.3	61.5			
Total phosphate		20.0	52.0	26.1		
Detergent (MBAS)				9.0		
Cyanide	0.006	0.28	0.20	0.04	0.136	0.0
Phenolic compounds	0.16	0.1	2.00	0.08	0.099	0.255

* Data from State of California, Department of Water Resources Inventory of Waste Water Production and Waste Water Reclamation Practices in California, 1970, 1971, Bulletin No. 68-71, November 1972.

quite a different manner than is the Hyperion Plant. It receives a large quantity of industrial wastes, and all the sludge from the satellite water reclamation plants is sent here for processing. A portion of the treated sludge is discharged into the final effluent from the plant. At Hyperion Treatment Plant, the quantity of industrial wastes is somewhat less. This plant treats only the sludge from its own influent and discharges the treated sludge to the ocean through separate 7-mile sludge-outfall line. One - third of the total flow receives secondary or biological treatment at Hyperion, while all treatment at the Los Angeles County Joint Water Pollution Control Plant is primary (physical) in nature.

Mass emission rates of the most commonly measured constituents for the 6 major municipal waste dischargers, presented in Table 6-13, are measured in thousands of metric tons per year (California Water Resources 1972). This table shows that the Los Angeles County Joint Water Pollution Control Plant and Los Angeles City Hyperion Treatment Plant, with average flow rates of 365 mgd and 333 mgd respectively, also respectively produce 142 thousand metric tons and 39 thousand metric tons of suspended solids per year. Thus, the Joint Water Pollution Control Treatment Plant discharges 61.5 percent and the Hyperion Treatment Plant 16.9 percent of the total suspended solids discharged by the six major municipal waste dischargers. The Joint Water Pollution Control Treatment Plant and Hyperion Treatment Plant also discharge 54.1 percent and 20.5 percent respectively of the total BOD discharged by five of the major municipal waste dischargers (not including the Oxnard Plant) . The principal reason that the Hyperion Treatment Plant effluent contains much less BOD and suspended solid matter is that a large portion of the organic matter is conveyed into Santa Monica Bay separately.

A comparison of the mass emission rates of suspended solids and BOD for Hyperion Treatment Plant and the Orange County Sanitation District's Plants 1 and 2 shows that Hyperion Treatment Plant discharges 39 thousand metric tons of suspended solids and Orange County Sanitation District's Plants 1 and 2 discharge 32.25 thousand metric tons of suspended solids or 16.9 percent and 14.0 percent respectively of the total suspended solids discharged by the 6 major municipal waste dischargers (Table 6-13). Concerning BOD discharges, Hyperion discharges 51.4 thousand metric tons and Orange County Sanitation Districts discharge 38.44 thousand metric tons which are 20.5 percent and 15.3 percent respectively of the total BOD discharged by the 6 major municipal waste dischargers. Since the flow rates from these plants are 333.16 mgd and 135 mgd respectively, it can be seen that much of both the suspended material and BOD are removed from the plant effluent in the Hyperion Treatment facility. This suspended material and BOD from Hyperion is discharged to the coastal ocean waters (Santa Monica Bay) but is not shown in

Table 6-13

CONSTITUENT MASS EMISSION RATES (1,000 M TONS/YR)
FROM MUNICIPAL WASTEWATER DISCHARGERS, 1972*

	Oxnard	Hyperion	JWPCP	Terminal Island	Orange County	Point Loma
Suspended solids	1.01	39.04	142.14	1.92	32.25	14.73
BOD_5		51.4	135.68	2.11	38.44	23.06
Grease and oil	0.08	7.88	32.80	0.32	8.61	3.27
Ammonia nitrogen		7.29	21.87	0.39	7.29	2.43
Organic nitrogen				0.14		
Total nitrogen		7.88	30.57	0.53		
Total phosphate		9.11	25.84	0.36		
Detergent(MBAS)				0.12		
Cyanide	0.00008	0.1276	0.0994	0.0006	0.0300	0.0
Phenolic compounds	0.0021	0.04556	0.9940	0.001	0.02187	0.0327

* Data from State of California, Department of Water Resources, Inventory of Waste Water Production and Waste Water Reclamation Practices in California, 1970, 1971, Bulletin No. 68-71, November, 1972.

the quantities in Table 6-13.

Los Angeles County municipal plants produce 79.2 percent of the suspended solids and 75.5 percent of the BOD produced by the 6 major waste dischargers. Since Orange County Sanitation District's Plants produce 14.0 percent of the suspended solids and 15.3 percent of the BOD discharged by the 6 major dischargers, the total combined suspended solids and BOD contributed by Los Angeles County and Orange County plants is found to be 93.2 percent and 90.8 percent of the total respectively. These two counties contain the major portion of both population and industrial development of the entire study area.

3.3 Trace Metals

The average concentrations of trace metals found in the six major municipal waste dischargers' final effluents are listed in Table 6-14 (California Water Resources 1972). The Orange County Treatment Plants' effluent discharges a waste water that contains the highest concentration of cadmium (0.05 mg per liter). Silver was found in the highest concentration (0.02 mg per liter) in the effluent from the Terminal Island Treatment Plant operated by the City of Los Angeles in the harbor area. The Joint Water Pollution Control Plant operated by the Los Angeles County Sanitation Districts had the highest concentrations of chromium (0.77 mg per liter), copper (0.55 mg per liter), lead (0.29 mg per liter), mercury (0.009 mg per liter), nickel (0.26 mg per liter), and zinc (1.85 mg per liter) confirming the fact that it receives waste water from a highly industrialized section in the study area (Table 6-14).

Trace metal mass emission rates have been calculated from trace metal concentrations and average flow rates for the six major waste water dischargers. The emission rate for each trace metal is presented in metric tons for each major waste water discharger in Table 6-15. Except for cadmium, the Los Angeles County Sanitation District Joint Water Pollution Control Plant supplies the major portion of the trace metals to the waters of the study area. Orange County Sanitation District's two treatment plants discharge 11.044 metric tons of cadmium (41.5 percent) to the waters of the study areas per year, Table 6-15. The Los Angeles County Sanitation District's Joint Water Pollution Control Plant discharged 64.4 percent of the chromium, 59.2 percent of the copper, 61.0 percent of the lead, 75.0 percent of the mercury, 49.3 percent of the nickel, 57.5 percent of the silver, and 76.2 percent of the zinc to the waters of the study area during 1971. The Los Angeles City Hyperion and Terminal Island Treatment Plants together discharged 17.6 percent of the cadmium, 19.7 percent of the chromium, 15.1 percent of the copper, 14.0 percent of the lead, 20.3 percent of the mercury, 32.4 percent of the nickel , 5.6 Percent of the silver and 11.1 percent of the zinc into the waters of the study area. These figures do not include the trace metals discharged to Santa Monica Bay

Table 6-14

AVERAGE CONCENTRATIONS (mg/ℓ) OF TRACE METALS IN FINAL EFFLUENTS OF MUNICIPAL WASTEWATER DISCHARGERS, 1972*

	Oxnard	Hyperion	JWPCP	Terminal Island	Orange County	Point Loma
Cad ium	0.008	0.01	0.019	0.01	0.050	0.0102
Chromium	0.54	0.24	0.77	0.56	0.318	0.135
Copper	0.059	0.15	0.55	0.11	0.471	0.110
Lead	0.08	0.07	0.29	0.08	0.227	0.062
Mercury	0.001	0.0026	0.009	0.0019	0.00072	0.00085
Nickel	0.050	0.18	0.26	0.21	0.192	0.04
Silver	0.011	0.001	0.015	0.02	0.014	0.012
zinc	0.25	0.28	1.85	0.39	0.54	0.25

* Data taken from State of California Department of Resources, Bulletin No. 68-71, November 1972.

Table 6-15

TRACE METAL MASS EMISSION RATES (M TONS/YR)
OF MUNICIPAL WASTEWATER DISCHARGERS, 1972*

	Oxnard	Hyperion	Terminal Island	JWPCP	Orange County	Point Loma
Cadium	0.106	4.556	0.1382	9.443	11.044	1.307
Chromium	7.157	109.339	7.731	382.687	70.242	17.295
Copper	0.782	68.337	1..519	273.348	104.038	24.093
Lead	1.060	31.891	1.104	144.129	50.141	7.943
Mercury	0.013	1.185	0.026	4.473	0.159	0.109
Nickel	0.663	82.004	2.899	129.219	42.410	5.125
Silver	0.146	20.456	0.276	7.455	3.092	1.537
zinc	3.313	127.562	5.384	919.442	119.279	32.029

* Data taken from State of California, Department of Water Resources, Bulletin No. 68-71, November 1972.

by means of the seven mile sludge outfall line. From the 3 major waste water municipal dischargers located in Los Angeles County, it should be noted that 53.2 percent of the cadmium, 84.1 percent of the chromium, 74.3 percent of the copper, 75.0 percent of the lead, 95.3 percent of the mercury, 81.6 percent of the nickel, 63.2 percent of the silver, and 87.2 percent of the zinc is discharged into the marine waters of the study area. This definitely indicates that Los Angeles County is the most highly industrialized sub-area in the study area because trace metal wastes in significant quantities are usually generated in industrial areas not in residential or agricultural areas.

3.4 Chlorinated Hydrocarbons

Chlorinated hydrocarbon insecticides are some of the world's most widely distributed synthetic chemicals. DDT, best" known member of this family was first synthesized in the late 19th century. Its usefulness as a pesticide was discovered during World War II (Revelle 1974). After 1945 its use expanded geometrically on a world-wide basis. It helped to control many diseases that had plagued man until that time.

Chlorinated hydrocarbons have been found to destroy other living creatures as well as insects. So they can, in regard to their general toxicity, be called biocides, a biocide being a compound that will have an adverse effect upon the general well-being of an animal (Greenwood 1973).

Chlorinated hydrocarbons consist primarily of carbon, hydrogen, oxygen, and chlorine. DDT is almost completely insoluble in pure water, approximately 1 microgram per liter, but quite soluble in organic matter (Wurster 1971). Other chlorinated hydrocarbons are more or less soluble in water than DDT but they generally have similar volubility characteristics in that they are all quite insoluble in water and soluble in organic materials.

Chlorinated hydrocarbons are highly effective pesticides, however produce a serious problem in our air and water environments. They both kill insects and persist for relatively long periods of time after they are applied (they do not lose their effectiveness) (Greenwood 1973). Chlorinated hydrocarbons are thought to have half-lives of between 10 and 20 years (Revelle 1974). (One half-life is the time necessary for one-half of the quantity applied to disappear). When a pesticide such as DDT is applied to a crop to destroy the insects, it will not only be active for one year but for many years. It can thus be conveyed to a receiving body of water in the active state by rainfall and storm runoff. Eventually it will concentrate in the ocean and be absorbed by the marine life found in the ocean primarily because it is more soluble in the organic matter making up this marine life. The fact that predators ingest the smaller forms of marine life tends to concentrate the DDT in the tissues of these living organisms (Chapter 11.). This is called magnification or concentration (Wurster 1971). The two major sources of chlorinated hydrocarbons in the ocean, therefore, are storm water runoff and industrial waste discharges. Smaller quantities may be derived from direct fallout from the air and from rainfall onto the ocean. In this section of the report, we will be concerned only with chlorinated hydrocarbons derived from municipal waste dischargers. The primary sources of the chlorinated hydrocarbons in the municipal waste flows are industries.

The concentrations and mass emission rates of DDT, PCB (polychlorinated biphenyls) and TICH (Total Identified Chlorinated Hydrocarbons) for the major municipal waste dischargers are given in Tables 6-16 and 6-17 respectively.

Polychlorinated biphenyls (PCB) are also forms of chlorinated hydrocarbons which are similar in structure to DDT. They are found primarily in lubricants, hydraulic fluids, waxes, adhesives, transformer fluids, and asphalt (Revelle 1974). From Table 6-16 it can be seen that Hyperion sludge had a concentration of 28.7 micrograms per liter in 1971 while the effluent from Los Angeles County Sanitation District's Joint Water Pollution Control Plant showed only a concentration of 10.1 micrograms per liter.

The DDT concentrations in the effluent from Los Angeles County's Joint Water Pollution Control Plant were much greater than any of the other effluents. This was considered to be due to discharges of large quantities of DDT from one industrial manufacturer. The discharge of this industrial waste has been discontinued but occasionally relatively high concentrations of DDT are found in JWPCP discharges due to disturbances of sludge in the major trunk lines by cleaning operations.

Table 6-18 shows the 1973-74 concentrations of various types of chlorinated hydrocarbons found in the final effluent of the Los Angeles County Sanitation District's Joint Water Pollution Control Plant (LACSD 1973-1974). Concentrations are given in micrograms per liter for DDT, PCB, and TICH. It can be seen that TICH concentration exceeded 20 micrograms per liter only in the September 4, 1973 composite sample (24 hours). This high value compares with the average value of 44.8 micrograms per -liter for the year 1971. An average of the TICH for the year 1973 is 10.7 micrograms per liter which is less than one-fourth the average of 52.0 micrograms per liter found in 1971. The major source of chlorinated hydrocarbons now is considered to be the sediments found in the large size trunk sewers (LACSD 1973-1974).

Table 6-16

AVERAGE CONCENTRATIONS OF CHLORINATED HYDROCARBONS (μg/ℓ) IN FOUR MAJOR MUNICIPAL WASTEWATER TREATMENT PLANT EFFLUENTS, 1971*

Discharger	Flow (mgd)	Total DDT	Total PCB	Total Identified Chlorinated Hydrocarbons
Hyperion Effluent	335	0.16	0.08	1.26
Sludge	5	2.07	28.7	39.0
JWPCP	371	41.9	10.1	52.0
Terminal Island	8.1	0.96	0.38	1.37
Point Loma	90	0.2		

* Data from Southern California Coastal Water Research Project Report (SCCWRP) 1973. (As updated per L.A. County Sanitation District)

Table 6-17

CHLORINATED HYDROCARBON MASS EMISSION RATES (KG/YR)
FROM MUNICIPAL WASTEWATER DISCHARGERS, 1971*

Discharger	Flow (mgd)	Total DDT	Total PCB	Total Identified Chlorinated Hydrocarbons
Oxnard	12	2	3“	5
Hyperion	340	88	570	860
JWPCP	371	21,000	5,000	26,000
Terminal Island	8	10	4	15
Orange County San.Dist.	130	65	3,000	3,100
Pt. Loma	90	24	110	140
TOTAL	951	19,200	9,700	29,000

* Data from Southern California Coastal Water Research Project Report (SCCWRP) 1973. (As updated per L.A. County Sanitation District)

Table 6-18

1973-1974 CONCENTRATIONS OF CHLORINATED HYDROCARBONS (μg/ℓ) IN FINAL EFFLUENT, 24-HOUR COMPOSITE SAMPLES AT THE LOS ANGELES COUNTY SANITATION DISTRICT'S JOINT WATER POLLUTION CONTROL PLANT*

Date	Total DDT	Total PCB	TICH
January 2, 1973	4.82	1.1	6.0
February 5, 1973	2.67	0.86	3.6
March 5, 1973	8.03	1.7	9.7
April 2, 1973	7.34	2.66	10.2
May 1, 1973	12.03	4.54	16.7
June 4, 1973	10.81	N.D.	10.8
July 2, 1973	6.10	2.06	8.16
August 6, 1973	10.07	N.D.**	10.42
September 4, 1973	20.3	2.08	22.8
October 2, 1973	5.66	3.57	9.23
November 7, 1973	5.47	2.77	8.24
December 3, 1973	5.33	7.12	12.4
January 15, 1974	4.20	8.03	12.2
February 4, 1974	2.51	2.35	4.93

* Data from Los Angeles County Sanitation Districts (LACSD) Laboratory Analysis of JWPCP Effluent 1973-1974. (As updated per L.A. County Sanitation District)

** Not Detectable

4. Industrial' Waste Discharges

Industrial wastes are discharged into waters of the ocean study area in many ways. Some of the industrial wastes are discharged into municipal waste water collection sewers, conveyed to a treatment facility, treated and then discharged to the receiving body of water by an outfall conduit. A large majority of the low volume industrial wastes are disposed of in this manner. Another method of industrial waste disposal is discharge to a storm drain system. Strict quality control of this type of activity is exercised by state and municipal agencies to ensure that biological degradation of the waste material does not take place in the storm water conveyance system. Cooling water is an example of a waste that may be discharged by this means. Industrial waste may be discharged to the ocean by direct means from the industrial facility through a conduit. An example is the discharge of oil brine solutions to the ocean from an oil field. This section is concerned with direct discharges of industrial wastes to the ocean waters. Municipal discharges and surface runoff are discussed in other sections of the chapter.

Investigations into both the quantity and the quality of industrial wastes formerly discharged into the ocean have shown that much recent activity has been directed toward the use of deep well injection of a major proportion of the oil brine wastes that are produced in large quantities by Southern California oil producers (California Water Quality Control Board 1973). Flow rates (1973) of discrete industrial waste dischargers and discharge termination dates are presented in Table 6-19. Locations of the major industrial waste dischargers are shown in Figure 6-20.

The concentration of constituents" in oil brine waste such as total suspended solids, oil and grease and chemical oxygen demand have been averaged in the 1973 SCCWRP Report and found to be approximately 60 mg per liter, 12 mg per liter, and 3,000 mg per liter respectively (SCCWRP 1973). If the assumption is made that all oil brine waste has a uniform concentration for every constituent, the 5 major producers in the approximate 1.94 mgd discharge of oil brine waste are introducing 0.434 metric tons of suspended solids, 0.087 metric tons of oil and grease and 21.7 metric tons of chemical oxygen demand into the ocean everyday. Intermittent discharges from ship ballast tanks and oil spills occurring during loading and unloading operations have not been measured.

4.1 Industrial Waste Discharges Into Los Angeles Harbor

Since Los Angeles is the most highly industrialized city in the study area, the industrial waste discharges into the Los Angeles Harbor were of major concern in this report. A wide range of industries are located near the Los Angeles Harbor as is noted in Table 6-20. Fish canneries, marine oil

Table 6-19

INDUSTRIAL WASTE DISCHARGES ON SOUTHERN CALIFORNIA COAST

Ref.	Discharger	Type of Waste	Flow Rate, M	Termination
I-1	Mobil Oil Co. Sea Cliff	Oil Brine	0.135	9-30-74
I-2	Norris Oil Co. Rincon	Oil Brine	0.0016	8-1-74
I-3	Phillips Petroleum, Punta Garda	Oil Brine	0.405	6-1-74
I-4	McDonnell-Douglas, Venice	Cooling Tower Bleed Off	0.65	
I-5	Standard Oil El Segundo	Refinery Cooling Water	72.0	
I-6	Signal Oil & Gas, Huntington Beach	Oil Brine	0.6	6-1-74
I-7	Standard Oil Huntington Beach	Oil Brine	0.8	7-1-75
		TOTAL	74.5916	

* Data from Regional Water Quality Control Boards 1973.

Table 6-20

DISCRETE INDUSTRIAL WASTE DISCHARGERS INTO LOS ANGELES HARBOR*

Discharger	Average Flow MGD	Type of Discharge	Typical Constituent Concentrations, mg/ℓ BOD	COD	Susp. Solids	Oil & Grease	T.D.S.
Outer Harbor-Fish Harbor							
#8 Cannery "B", Plant #4	2.69	Cannery Waste	365	634	193	211	33,700
#9 Los Angeles Harbor Dept. Outfall	6.21	Cannery Waste	645	968	237	320	33,700
Cannery "B", Plant #4 Condenser	0.45	Cooling	5	8	-	0to10	34,000
Marine Terminals							
Mobil Oil	0.007	Ballast, Rainwater	135	149	16	14	5,800
Standard Oil	0.06	Ballast, Rainwater	165	305	64	45	11,800
Time Oil	0.002	Line Flushing, Rainwater	75	188	100	26	600
Union Oil	0.014	Ballast, Rainwater	80	634	<10	12	30,000
Navy Fuel Dock	0.05	Ballast, Rainwater	9	50	144	19	16,000
Shell Oil	0.01	Ballast, Rainwater	270	568	52	39	1,520
Refineries to Chemical Plants							
Union Oil	43.2	Cooling		10	5	5	34,000
Union Carbide	0.17	Miscellaneous	105	-45	40	15	3,460
U.S. Borax	0.52	Cooling, Boilers	50	220	110		30,000
Collier Carbon	0.003	Ammonia Conversion	100	-20	12		972
Heavy Industry							
Todd Shipyards	0.53	Cooling, Boilers	105	283	-	23	2,764
Bethlehem Steel	0.045	Cooling, Boilers	10	202	132	38	33,000
National Metals	0.43	Cooling					

* Data taken from Regional Water Quality Control Board and City of Los Angeles

terminals, refineries, chemical plants, metal fabricators, and shipyards are the major types of industry located in the Los Angeles Harbor area (LACHD 1973 and California Water Quality Control Board 1973). Each discharges significant quantities of industrial wastes to the Los Angeles Harbor. Average flow rates for the year 1973 and typical constituent concentrations are given in Table 6-20.

Three major companies operate 5 fish canning plants in the Los Angeles Harbor area, designated Cannery A, Cannery B, and Cannery C here. Mass emission rates of constituents, such as suspended solids, BOD, COD, and oil and grease are shown in Table 6-21 (LACHD 1973). These rates are calculated in metric tons per year. Assumptions are made that the canneries operate 5 days per week and that concentrations of constituents are constant throughout the year. The fish canning wastes are quite small (8.9 mgd) but the effect on the quality of the water in Los Angeles Harbor is quite severe due to the small volume of ocean water available for dilution of the pollutants (Chapter 5). Dissolved oxygen levels are at times depressed to less than 1.0 mg per liter (California Water Quality Control Board 1973). Concentrations and mass emission rates of the more important trace metals discharged by all the canning plants are presented in Table 6-22.

Industrial wastes are also generated in other industrial centers in the study area such as San Diego and Long Beach but insufficient data is presently available to present in this section of the report. Locations of various industrial waste discharge are indicated in Figure 6-20.

Table 6-21

CONSTITUENT MASS EMISSION RATES (M TONS/YR) FROM DISCRETE INDUSTRIAL WASTE DISCHARGES TO THE LOS ANGELES HARBOR, 1973*

Industrial Waste Source	Suspended Solids	BOD	COD	Oil and Grease
Cannery "B", Plant #4	502	949	1,648	549
Los Angeles Harbor Department Outfall	1,423	3,873	5,809*	1,921
Cannery, Total	1,925	4,822	7,457	2,470

* Data from California Water Quality Control Board and Los Angeles Harbor Department 1973.

** COD assumed to be 1.5 (BOD)

Table 6-22

TRACE CONSTITUENTS DISCHARGED FROM THREE CANNERIES INTO THE LOS ANGELES HARBOR, 1973*

Trace Constituent	Average Concentration mg per liter	Mass Emission Rate, Metric Tons Per Year
Mercury	0.006	0.005
Cadmium	0.102	0.88
Nickel	0.31	2.67
Zinc	0.30	2.58
Chromium	0.12	1.03
Copper	0.05	0.43
Phenols	0.22	1.89

* Data from California Water Quality Control Baord and Los Angeles Harbor Department, 1973.

5. Thermal Discharges

Unwanted heat produced by man's activities may be discharged to either the air, water, or land environments producing an undesirable effect known as thermal pollution. This section is primarily concerned with the effects created in the water environment by industrial dischargers. Most of the heat discharged to the ocean study area is supplied by power generation stations. It is estimated that more than three-fourths of the waste energy discharged to water bodies in the United States is derived from power generating stations.

The quantity of waste heat produced by a steam electrical plant depends upon many parameters, the most important being plant size and efficiency. These two factors are not completely independent as large plants usually are more efficient than small ones. The plant efficiency determines how much of the primary energy is converted directly to electrical energy. The remaining energy expended is discharged either to the air environment or the water body. Here it is assumed that 15 percent of the heat wasted by fossil-fueled plants is discharged to the atmosphere. For nuclear fueled plants, the assumption is made that all waste heat is discharged to the water environment. Thermal efficiencies of the fossil-fueled, thermal power plants operating in Southern California range between 17.5 and 36 percent. The San Onofre nuclear plant operated with a thermal efficiency of 32 percent in 1972-73 (Power Companies 1972-1973). For a plant operating at 17.5%, 4.71 total units are wasted to the environment for every unit of electrical output (San Diego Gas and Electric, P. 16, Station B, San Diego Bay). Of these 4.71 units of waste heat, 4.00 are discharged to the water environment and 0.71 units are discharged to the air environment.

The ocean study area contains seventeen major thermal power generating stations with a total capacity of 12,457 mega watts (Table 6-23). Only one of these stations, San Onofre, uses nuclear energy as an energy source. The remainder of the installations burn either natural gas or liquid fossil fuel to produce heat. Approximately 480 megawatts of the total generation capacity is developed by turbine peaking units located at the Huntington Beach, Mandalay and Alamitos installations operated by the Southern California Edison Company (Power Companies 1972-1973). Units at those installations are not water-cooled so do not contribute to the heat load placed upon the waters located in our study area. The locations of the major power generating installations are shown on Figure 6-21 (Power Companies 1972-1973).

Power companies in this area have furnished 1972-1973 operational data for their major installations. This data was used to compute the total quantity of thermal energy discharged to the ocean study area. The total annual thermal power generated by the 16 power stations (not including the Southern

Table 6-23

THERMAL DISCHARGES BY POWER GENERATING STATIONS IN THE SOUTHERN CALIFORNIA COASTAL AREA AS OF 1972-1973*

Station Location	Capacity MW_e	Load Factor F (%)	Overall Efficiency E (%)	Waste Heat Per Unit of Electrical Energy, Q	Waste Heat to Cooling Water Per Unit OutputrQw
Fossil-Fuel Type					
L/A.Dept.Of Water And Power					
T-1 Harbor,Wilmington	445	22	29.0	2.45	2.08
T-2 Haynes,Seal Beach	1591	73	37.0	1.70	1.45
T-3 Scattergood,Playa 1&2	358	72	35.0	1.86	1.58
del Rey 3	315				
Sub-total	2709				
Southern California Edison Co.					
T-4 Alamitos 1-4,Seal Beach	990	50	32.0	2.13	1.81
T-5 Alamitos 5-7,Seal Beach	1081	59	36.0	1.78	1.51
T-6 El Segundo, El Segundo	1020	54	35.0	1.86	1.58
T-7 Huntington Beach	991	55	35.0	1.86	1.58
T-8 Long Beach,Long Beach	212	1	---	---	---
T-9 Mandalay,Oxnard	551	54	36.0	1.78	1.51
T-10 Redondo Beach 1-6	292	29	27.0	2.70	2.30
T-n Redondo Beach 7&8	1310	54	35.0	1.86	1.58
T-12 Ormond Beach	1500	47	35.0	1.86	1.58
Sub-total	7947				
San Diego Gas and Electric					
T-13 Encino,Carlsbad	325	68	33.2	2.01"	1.71
T-14 Silver Gate,San Diego	237	31.1	26.4	2.79	2.37
T-15 South Bay,San Diego Bay	713	63.0	32.1	2.12	1.80
T-16 Station B,San Diego Bay	96	9.1	17.5	4.71	4.00
Sub-total	1371				
Nuclear-Fuel Type					
T-17 San Onofre,San Clemente	430	60.0	32.0	2.01	1.71
Total	12457				

* Data from Los Angeles City Dept. of Water and Power, San Diego Gas & Electric and Southern California Edison Company, Operational Power Plant Data, Unpublished 1972-1973.

Table 6-23 (cent)

THERMAL DISCHARGES BY POWER GENERATING STATIONS IN THE
SOUTHERN CALIFORNIA COASTAL AREA AS OF 1972-1973*

Station Location	Plant Waste Heat, H Max imum H_m	Plant Waste Heat, H Average	Norma l Average Temp. _	Cooling Flow Maximum R_{max} $(10^6 m^3/day)$
bo	0.93	0.20	4.1	4.68
T-2 Haynes, Seal Beach	2.30	1.68	10.0	4.77
T-3 Scattergood, Playa 1&2 del Rey 3	0.57	0.41	8.0	1.47
Sub-total	3.80	2.29		10.92
Southern California Edison Co.				
T-4 Alamitos 1-4, Seal Beach	1.79	0.89	6.25	5.92
T-5 Alamitos 5-7, Seal Beach	1.63	0.96	5.90	5.73
T-6 El Segundo, El Segundo	1.61	0.87	6.75	4.94
T-7 Huntington Beach	1.56	0.86	7.04	4.60
T-8 Long Beach, Long Beach	---	---	0.06	
T-9 Mandalay, Oxnard	0.83	0.45	6.58	2.62
T-10 Redondo Beach 1-6	0.67	0.19	3.71	3.74
T-n Redondo Beach 7&8	2.07	1.12	5.40	7.93
T-12 Ormond Beach	2.37	1.11	7.84	6.25
Sub-total	12.53	6.45		41.73
San Diego Gas and Electric				
T-13 Encino, Carl-shad	0.56	0.38	9.40	1.22
T-14 Silver Gate, San Diego	0.56	0.17	5.22	2.23
T-15 South Bay, San Diego Bay	1.28	0.81	4.73	5.61
T-16 Station B, San Diego Bay	0.38	0.03	1.66	4.80
Sub-total	2,78	1.33		13.86
Nuclear-Fuel Type				
T-17 San Onofre, San Clemente	0.91	0.55	6.35	3.00
Total	20.02	10.62		-6K-51-

* Data from Los Angeles City Dept. of Water and Power, San Diego Gas & Electric and Southern California Edison Company, Operational Power Plant Data, Unpublished 1972-1973.

California Edison Company Plant at Long Beach) is estimated to be 55 X 10^9 Kw/hrs in the 1972-1973 time period (Table 6-23). This total quantity of energy is estimated using an average capacity factor of 50 percent.

Heat wastes tabulated in Table 6-23 were calculated using operational data furnished by the three major electrical energy generators, Los Angeles City Department of Water and Power, San Diego Gas and Electric Comapny, and Southern California Edison Company. The capacity-weighted mean efficiency for all of these plants is calculated to be 32.7 percent (not including the Long Beach plant of Southern California Edison Company). Thus, for each unit of electrical energy produced in the study area by an average plant, 2.06 units of heat are wasted to the air and water environments. Since we assume that 15 percent of the total waste is lost to the air in a fossil-fueled plant and 85 percent is transferred to the water, approximately 0.31 units of heat is discharged to the atmosphere and 1.75 units of heat are discharged to the water environment for every unit of electrical energy produced in these steam-gathering plants.

In Table 6-23 some estimates of heat discharges to the water bodies are presented for the 17 major plants. Some assumptions made in these calculations are that thermal discharges are proportional to electrical output, that cooling water flow varies with plant capacity, that 15 percent of waste heat produced in fossil fuel plant is discharged to the atmosphere and that the average temperature increase is proportional to the capacity factor for each plant. From Table 6-23 it may be seen that the total maximum instantaneous waste heat discharged from these 17 plants is calculated to be 2.00 X 10^7 KW. The average annual waste heat discharged to the ocean water is calculated to be 1.06 X 10^7 KW assuming that the capacity factors for each plant are as presented in Table 6-23.

The maximum rate of instantaneous cooling water flow has been estimated to be 69.5 X 10^6 cubic meters per day (10.43 billion gallons per day). The quantities of cooling water flow rates required for all the plants involved are shown in column 8 of Table 6-23. This assumes that the plants are operating at full capacity which is not always the case.

The estimated quantities found in columns 4, 5, 6, 7, and 9 are calculated using the following relationships:

Column (4): $Q = [1-\sim/E$

Column (5): $Q_\omega = Q-(.15)Q$ for fossil-fueled plants only

Column (6A): $H_{max} = MWe \times Q_w \times 10^3$

Column (6B): $H_{aug} = H_{max} \times F$

Column (8): $R_{m\omega} = H_{max} \times (20.7/T)$

6. Boat Wastes

In contrast to discrete or point pollution sources, the wastes produced by boats are spread out or diffused throughout the waters of the study area. Very little information is available concerning the quantities of pollutants discharged to the waters of the study area. The best source of information presently available for boat waste data is the 1973 Southern California Coastal Water Research Project (SCCWRP) Report. Many of the pollution quantities are estimates in this report and should be used with this fact in mind. All boats in the study area are used either for recreational, commercial , or naval purposes. Figure 6-22 shows the locations of the major recreational boat anchorages in the study area (see also Fig. 19-17) . Commercial and naval vessels are considered to concentrate their activities in the San Diego and the Los Angeles-Long Beach Harbor waters, Chapter 19. In this section of the study, an evaluation is made concerning the quantities of metals discharged to the ocean by both recreational, commercial, and naval vessels. It is assumed that the sources of these metals are protective coatings and fuel used in powering these vessels. SCCWRP conducted a study of the quantities of metals discharged to the ocean from recreational vessels anchored at Marina del Rey and assumed that all recreational vessels in the study area would discharge metals to the water as was found to be the case in Marina del Rey.

There were about 35,000 recreational boats of the 16 to 65 foot class harbored in the marinas of the study area in 1971 (SCCWRP 1973). A numerical breakdown of these boat mooring locations are given in Table 6-24. The locations of these marinas are shown in Figure 6-22. In this SCCWRP study it was found that each boat used 2.4 gallons of anti-fouling paint per year on the average. Making the assumption that each boat in the study area would use this much paint also, this means that these 34,860 boats would use 83,700 gallons of anti-fouling paint per year. It was assumed also that each gallon of paint weighed 8.6 Kg. This means that about the total annual paint usage was approximately 720,000 Kg (SCCWRP 1973).

A study conducted by the San Diego Regional Water Quality Control Board in 1972 (SCCWRP 1973) found that annual paint usage for San Diego based commercial and naval vessels was 30,000 gallons (8.6 kg/gal) of anti-fouling paint, 23,000 gallons (5.2 kg/gal) of red primer and 10,000 gallons (4.1 kg/gal) of zinc chromate primer (SCCWRP 1973). It was estimated that approximately 10 percent of these protective coatings were being lost to the bay water by sandblasting operations (SCCWRP 1973). The remainder of these coatings was disposed of in landfills. Making the assumption that comparable duplicate paint removal operations were taking

Table 6-24

NUMBERS AND LOCATIONS OF BOATS MOORED IN SOUTHERN CALIFORNIA MARINAS, 1971***

Location Point *	Marina	No. of Boats**
H-1	Santa Barbara Harbor	750
H-2	Ventura Harbor	930
H-3	Oxnard, Channel Islands Harbor	930
H-4	Los Angeles, Marina del Rey	5,500
H-5	Redondo Beach, King Harbor Marina	1,400
H-6	San Pedro Bay, Los Angeles Harbor	3,400
H-7	San Pedro Bay, Long Beach Harbor	2,530
H-8	San Pedro Bay, Long Beach Marina	2,300
H-9	Huntington Beach, Huntington Harbor	3,200
H-10	Newport Bay, Newport Beach Harbor	8,000
H-n	Dana Point Harbor	550
H-12	Oceanside Harbor	550
H-13	San Diego, Mission Bay	1,500
H-14	San Diego Bay	3,320
	TOTAL	34,860

* Location Points on Figure 6-22
** Size of Boats is 16 to 65 feet
*** Data Source is Southern California Coastal Water Research Report 1973.

Table 6-26

SOLID AND LIQUID WASTES DUMPED INTO THE OCEAN WATERS OF SOUTHERN CALIFORNIA, 1931 THROUGH 1971*

Waste Type	Dumping Site Location	Record Period	Estimated Total Discharge During Record Period M	Estimated Annual Discharge (M tons/yr)
Refinery Wastes	3	1946-71	480,000	1,800
Chemical Wastes	2,3	1965-71	2,800	470
	4	1947-71	5,700	210
	7	1960-67	140	
Filter Cake	8	1969-70	320,000	
Oil Drilling Wastes	2	1966-70	3,000,000	
Refuse and Garbage	4	1931-71	47,000	1,200
	5	1944-70	7,400	
	9	1947-68	90,000	
Radioactive Wastes	10,14	1946-68		
Military Explosives	6,11,12	1945-70		
Miscellaneous Wastes				250

* Source of data, The Ecology of the Southern California Bight: Implications for Water Quality Management, Southern California Coastal Water Research Project, 1973.

Table 6-25

TRACE MATERIAL MASS EMISSION RATES (M TONS/YR) FROM RECREATIONAL, COMMERCIAL AND NAVAL VESSELS INTO THE SOUTHERN CALIFORNIA OCEAN WATERS*

	Recreational Vessels			Commercial and Naval Vessels			
Trace	Anti-fouling Paint	Zinc Anode	Fuel	Anti-fouling Paint	Zinc Chromate Primer	Red Lead Primer	Tota 1
Arsenic	1.4			0.1			1.5
Cadmium		0.1					0.1
Chromium					1.0		1.0
Copper	360			26			386
Mercury	3.6			0.3			3.9
Lead			3.5	-		6,0	9.5
Zinc		160			4.1		164.1
PCB	3.6			0.3	0.1	0.1	4.1

* Data source is Southern California Coastal Water Research Project 1973.

Ocean dumping is presently regulated by the Environmental Protection Agency under the Marine Protection Research and Sanctuaries Act of 1972. There is presently (1974) only one dumping permit for offshore California, issued to H-10 Water Taxi, Ltd. of San Pedro, California for disposal of foreign vessel generated wastes.

23.7+2.4 metric tons/day (Huntzicker 1974). Huntzicker found that approximately 25 percent (5.9+1.1 metric tons/day) of the Pb is retained in the vehicles, while the remaining 75 percent (17.8+2.6 metric tons/day) was exhausted into the atmosphere. Of the latter amount, approximately 17.2 metric tons/day are in particles and the remainder is in the vapor phase, presumably as tetraethyl lead. Of the Pb which remains in the car, one-third to one-half is in the oil filter (Huntzicker 1974). This may enter the environment by disposal either in sanitary sewage systems, or in sanitary landfills. The remainder of the Pb is in the exhaust system, and some may enter the atmosphere during scrap smelting operations.

Deposition of Pb particles is dependent on particle size. For example, very large particles (Dp>10µm) settle rapidly. Smaller particles may remain airborne for a long period, but some eventually deposit in the urban area by convective diffusion to surfaces. Distances of deposition have been termed far deposition and near deposition. Of the 18 metric tons/day which are exhausted, approximately two-thirds are deposited within the basins while one-third is removed by advection (Chapter 9) . The resultant mass balance (Table 6-27) indicates input and output routes (applies to dry weather which is the situation for 90% of days in Los Angeles) (Huntzicker 1974).

Table 6-27 MASS BALANCE FOR AUTOMOBILE EMITTED LEAD

Input (Metric Tons/Day)	Output (Metric Tons/Day)	
Auto Exhaust = 17.8+2.6	Near Source Deposition	9.8+2.3
	Far Deposition	2.0+1.0
	Removal By Wind	5.8+3.1

Most of the Pb which deposits on the land is immobilized in the soil, but the three output routes are not necessarily sinks. For example, Pb that deposits on the streets can be washed off by rain into storm sewers which empty into the ocean, or Pb which is blown out of the basin serves as an input to other geographical regions.

8.1.2 Zinc (Zn). The two major sources of atmospheric Zn in the Los Angeles Basin are tire dust and metallurgical emissions. Through oxidation and wear of tires on the nation's highways, approximately 8 lbs per year per driver of rubber polymers (434,000,000 lbs or 197,000 metric tons) were converted to dust and gas in 1968 (Environmental Protection Agency 1971). Tire dust contains approximately 1.5 percent by weight Zn (Rogers 1948). Pierson (1972) has estimated that approximately 6.4 X 10^8 kg or 6.4 X 10^5 metric tons of tire dust are generated in the United States each year. The Los Angeles Basin accounts for 4.5 percent of the automobiles and trucks in the country. Using 1968 EPA data approximately 78.9 metric tons/day of tire dust or

.015 X 78.9 = 1.18 metric tons/day of Zn is generated in the Los Angeles Basin. This is in agreement with Huntzicker's (1974) estimate of 1.2 metric tons/day particulate emissions from metallurgical operations. The two major sources are Zn melting (1000 lbs/day) and brass melting (2000 lbs/day). In the first case the primary effluent is ZnO which corresponds to .37 metric tons/day of Zn. In the case of brass melting, 59 percent of the stack emissions is ZnO which is equivalent to .43 metric tons/day of Zn (Huntzicker 1974). According to the State of California Implementation Plan for Achieving and Maintaining the National Ambient Air Quality Standards (1972), the ratio of Orange County metallurgical emissions to Los Angeles County metallurgical emissions is 0.07. Consequently when the Zn metallurgical emissions are scaled by 1.07, the total for the whole Los Angeles Basin is .86 metric tons/day.

Deposition characteristics of Zn are similar to those of Pb. Huntzicker found that the large particle end of the distribution is attenuated because of non-ideal sampling conditions. The presence of a large mode at an equivalent, unit density diameter greater than 10μm is apparent. As a consequence, the mode assigned to tire dust particles was assumed to have a diameter greater than 7 μm. Metallurgic emission Zn concentration is determined from the Zn/Pb ratio of particle size concentration. The resultant mass balance (Table, 6-28) demonstrates input and output.

Table 6-28 MASS BALANCE FOR Zn

Input (Metric Tons/Day)		Output (Metric Tons/Day)	
Metallurgical		Near Source Deposition	1.10+.05
Fire Dust	1.20	Far Deposition	.63+.37
Other Automotive	.15	Removal By Wind	.57∓.47
	2.20		2.30+.89

8.1.3 Nickel (Ni) and Cadmium (Cd). The flows of Ni and Cd are not as well understood as that of Pb and Zn. The primary source of airborne Ni is probably the combustion of fuel oil in the Los Angeles Basin (Huntzicker 1974). The Los Angeles County Air Pollution District reports that 13 metric tons/day of particulate emissions are generated by power plants. Friedlander (1973) has reported that Ni contents of fuel oil fly ash is 2 percent by weight, with the resultant emission of Ni, .26 metric tons/day (Huntzicker 1974).

Fallout measurements made primarily during the summer show that approximately .9 metric tons of Ni are depostied daily over the basin. During the winter fuel oil consumption increases and it is estimated on the basis of the National Air Surveillance Network data that fallout and airborne Ni fluxes increase by approximately 60 percent (Huntzicker 1974).

The difference between known input and output routes is .12 metric ton, s/day which could probably be attributed to near source fallout: although Huntzicker does not have the data to support this contention.

Emission data for Cd is unavailable. Huntzicker, utilizing the concept that Cd is usually present in Zn ores, found that the basin-wide Cd fallout rate approximated 5 Kg/day. These Cd emissions are assumed to occur during the smelting of Zn ores; however, Cd emissions do not scale to Zn fall-Outs .

8.2 Input Routes To Coastal Waters

The input routes to the coastal waters include: atmospheric - deposition, rainout-washout, rainy weather runoff, dry weather runoff, discharge of treated, sewage and direct discharge. With the exception of sewage discharge and direct discharge, all routes originate in the atmosphere. Direct discharge was not considered by Huntzicker and will not be discussed here due to lack of available data.

8.2.1 Atmospheric Deposition. This route is a function of local meteorology. The prevailing wind pattern during the year is onshore flow during the flow. At night weak offshore drainage winds converge with normal onshore flow (Bell 1960). The western edge of the convergence zone is poorly defined but may extend as far offshore as the eastern edge of Santa Catalina Island. Thus , Santa Catalina can occasionally receive Los Angeles air, but except under Santa Ana conditions the islands which are further offshore do not receive Los Angeles air (Huntzicker 1974). Davidson, Huntzicker, and Friedlander believe that of the airborne metals originating in the Los Angeles Basin, fallout occurs in an area of 4,400 sq. kilometers, extending 55 kilometers from the coast and 80 kilometers along the coast. The "final draft" of the California Coastal Zone Conservation Commission, South Coast Regional Commission, Coastal Zone Plan Element 1, agrees with these findings.

8.2.2 Rainout and Washout. Airborne trace metals input to the coastal waters with rainfall is calculated by Huntzicker from the average annual rainfall over the coastal waters and trace metal content of the rainfall.

8.2.3 Runoff And Sewage. In addition to the direct input by rainout-washout, rainstorms will wash trace metals into the storm sewers and ultimately into coastal waters. Huntzicker calculated removal using: the accumulation of the trace metal in street dirt (source of runoff) , rain year (7 cycles, 26 dry days, 1 day heavy rain), type of road, nature of locality and traffic. (Each determined per unit time). Rainy weather runoff contributed more to removal than dry weather runoff.

8.2.4 Input to Coastal Waters: Mass Flux. Davidson, Huntzicker and Friedlander tabulated results of the pathways of the trace metals to coastal water:

Table 6-29
MASS FLUX (METRIC TONS/YEAR) TO COASTAL WATERS

	Pb	Zn	Ni	Cd
Fallout	130	60	13	-r
Rainout-Washout	30	70	1	
Dry-Weather Runoff	10	7	0.3	0.4
Stormy Weather Runoff	160	140	14	1.4
Sewage Discharge	230	1300	280	27

8.3 Transport of Wind Blown Trace Metals to Remote Regions.

A portion of the trace metals originating in the Los Angeles Basin are removed by wind before depositing in coastal waters. Deposition sites have been measured in the San Gabriel-San Bernardino Mountains, north of Los Angeles, in the Mojave Desert, north of the mountains, and in the Coachella Valley, 180 kilometers east of Los Angeles. During the summer, wind patterns blow from Los Angeles in the daytime converging near Palm Springs with up-valley winds from the southeast. At night, the winds are down-valley but Los Angeles air is draining toward the west. During the winter and spring, daytime winds blow primarily from the Los Angeles area (Huntzicker 1974).

Huntzicker determined deposition in the mountains, deserts, and coastal waters areas represented 28 percent of the trace metals leaving Los Angeles. While the difference of 72 percent is transported beyond a radius of 150 kilometers from the city and that these quantities exceed the total trace metals emissions in the surrounding semi-urban and non-urban areas.

The San Diego County Air Pollution Control District has tracked Los Angeles originated air pollution movement out over the Southern California coastal waters to San Diego, Figures 6-24, 6-25, 6-26, and 6-27. The winds preventing or supporting this form of pollution movement are indicated in Figures 6-28 and 6-29. A detailed study of these and other data incorporated with new studies of air-water interaction is needed to better' define the deposition at sea during such periods.

California Air Quality Data Publications report the maximum hourly concentration of oxidant, carbon monoxide, sulfur dioxide, nitrogen dioxide, nitric oxide, oxides of nitrogen, hydrocarbons, particulate and lead in the eleven air basins of the State. The particulate matter portion of these publications is reproduced in Table 6-30.

It should be noted that over one-half the population (nearly 11 million people) of the State of California reside in these portions of Los Angeles and San Diego Counties that contribute to the pollution of the area. This is over 5 percent of the U. S. population (Figure 6-30). Contributions of airborne pollutants provided to the Southern California coastal waters by this large segment of the nation's population are a matter of speculation at this point. Very little data is available from which to approximate the quality and quantity of contamination.

9. Regulation of Pollution Sources

The State Water Resources Control Board through nine Regional Water Quality Control Boards regulates all sources of discharge into the ocean, tidal waters, bays, harbors, estuaries, fresh waters and groundwaters of California. The three Regional Boards having jurisdiction in the study area are Los Angeles, Orange and San Diego.

The Air Resources Board controls vehicular emissions and four Air Pollution Control Districts (Ventura, Los Angeles, Orange and San Diego) in the study area control industrial emissions.

Ocean dumping is regulated by the Environmental Protection Agency.

Table 6-30

PARTICULATE MATTER
MICROGRAMS PER CUBIC METER BY HIGH VOLUME
AIR SAMPLING METHODS, 1973*

Days of Month	January L.A.	January S.D.	February L.A.	February S.D.	March L.A.	March S.D.	April L.A.	April S.D.
1			936	83	410	83	91	
2	713	69		223		223	647	
3		84	343				98	301
4	1041		42				811	
5			362		519		82	
6		70			17		321	
7	398		139		49	139	579	
8	322	178	77		161	77		302
9	70	64	1072		229		82	
10	450				45		1391	
11	138		220		304			
12	1612				195	195	628	
13		462			1040			259
14			300	105		105	426	
15	50		499				119	
16	1442		630		156		644	
17	726		394	303	794	303	536	
18		273			488		469	165
19			74					
20	320						78	
21			978		177		76	
22	1069			217	50	217	1431	
23		306	109		789			262
24	558		371					72
25	59				209		126	
26			552		85		589	
27	426		336	295	44	295	991	
28	1059	168			537		614	164
29					935			
30	106	69					271	
31	38				100			
No.Of Samples ≥100 µg/m	32	7	25	5	25	5	42	5

* Data from State of California, Air Resources Board, Air Quality Data, 1973.

Table 6-30 (cent)

PARTICULATE MATTER
MICROGRAMS PER CUBIC METER BY HIGH VOLUME
AIR SAMPLING METHODS, 1973*

Days of Month	Month & Basin							
	May		June		July		August	
	L.A.	S.D.	L.A.	S.D.	L.A.	S.D.	L.A.	S.D.
1			545		498		283	57
2	743	133	50	136	72		1152	
3	192	219	721		2151		194	
4	1291		86		214		283	
5	53		779				413	
6			1051		584			158
7	1029			305	259	139	40	
8	404	301	76		59		1584	
9	138		1916		1228			
10	1213				112		610	
11	148		686		992		62	
12	981		55	140			642	156
13		176	290			178	313	
14			319		177		1257	
15	320		1232	96	1252		565	
16	1454		827		674		491	
17	1250		289	153			64	
18	127	233	96	116	46		479	377
19			121		364	146	6 5	
20	476		106		272		3982	
21	105		2625		1783			
22	1729			178	173			
23		170		70	586		176	
24	322	81	231		327		623	398
25	242		413			250	510	
26			875		601		645	
27	1056		772	250	1937	94	142	
28	1715	183			1 2	4	718	
29					261			
30	232	74					682	303
31					1195	274		
No. Of Samples >100µg/m	70	7	71	4	81	5	66	6

* Data from State of California, Air Resources Board, Air Quality Data, 1973.

Table 6-30 (cent)

PARTICULATE MATTER
MICROGRAMS PER CUBIC METER BY HIGH VOLUME
AIR SAMPLING METHODS, 1973*

Days of Month	September L.A.	September S.D.	October L.A.	October S.D.	November L.A.	November S.D.	December L.A.	December S.D.
1	1385				376			134
2	143				29	104		
3			324	5	916			
4	472		698		268	89		47
5	346	294		259	884		299	60
6			786					
7	2048				130			41
8			358		442			
9	630		321		660	169		
10			221	145				48
11	286	202			607		444	
12	244		982					
13	1548	95			567		346	
14	625		337		43	75		438
15			126	87				
16			315					
17	774	267			543		429	
18			677		351			
19	2350		538		71	188		270
20			152	121	40	83		
21	371				404		60	312
22	195				33			
23		222			638		767	
24	474		2424		212	78		131
25	2202		103	138	528			
26	98		62	88				
27	356				41		63	
28	98		586		571			133
29	1345	419	511		1022	140	406	271
30			1166	499	247		103	
31								
No.Of Samples ≥100μg/m	80	6	44	5	34	3	3	12

* Data from State of California, Air Resources Board, Air Quality Data, 1973.

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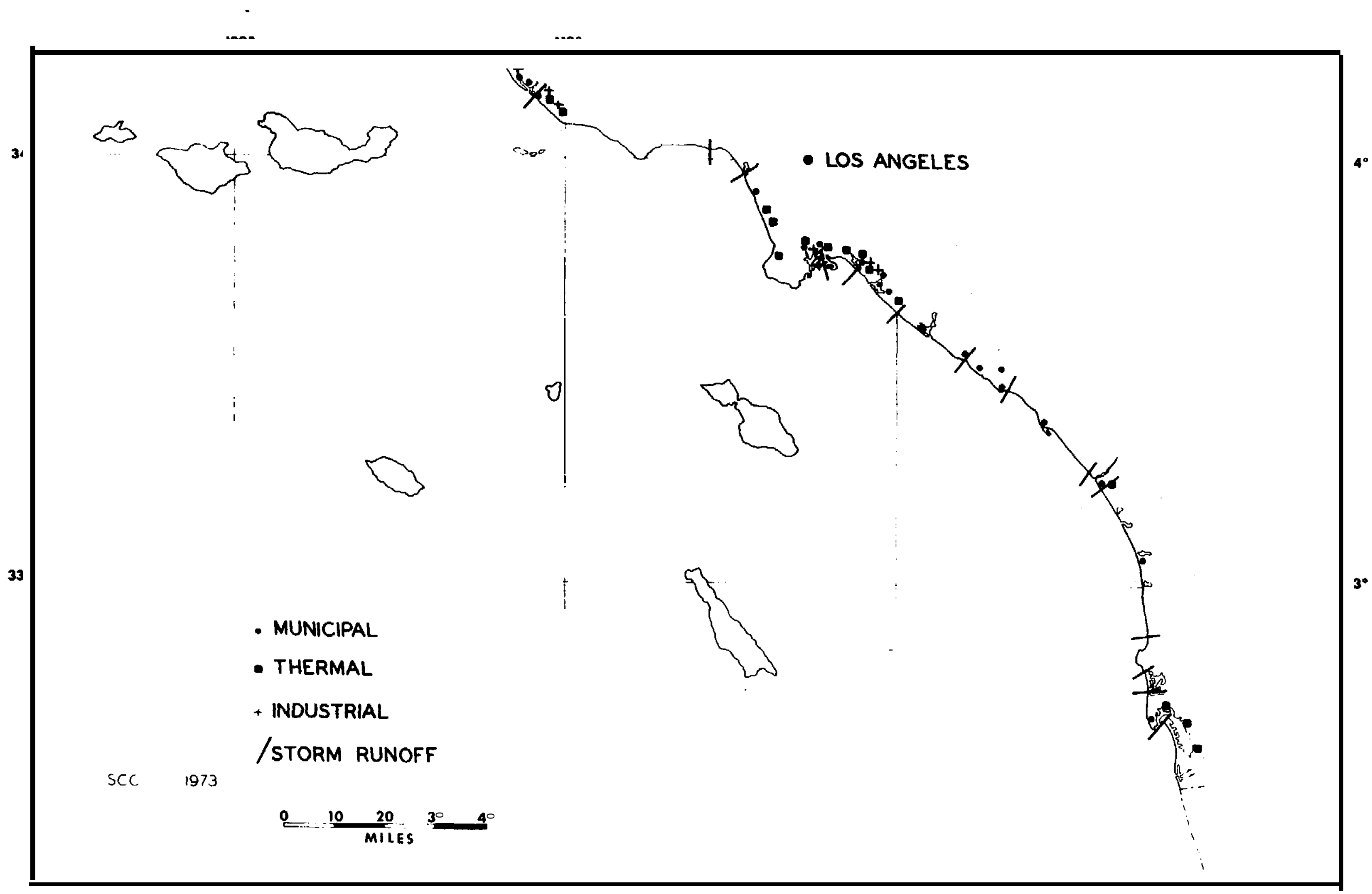


FIG. 6-1 LOCATION OF MAJOR DISCRETE WASTE WATER SOURCES

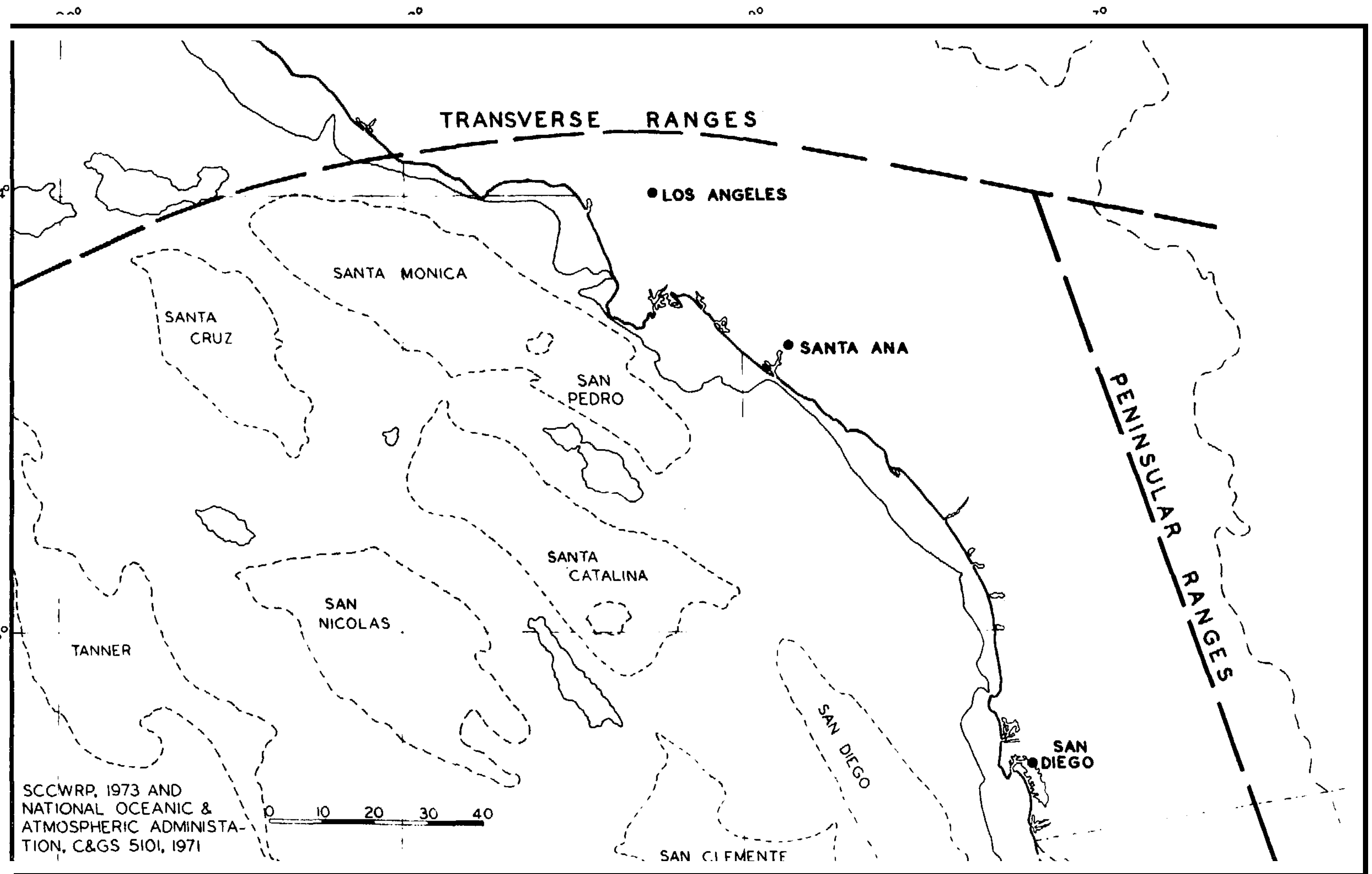


FIG. 6-2 MAP SHOWING TRANSVERSE & PENINSULAR RANGES, BAYS AND BASINS

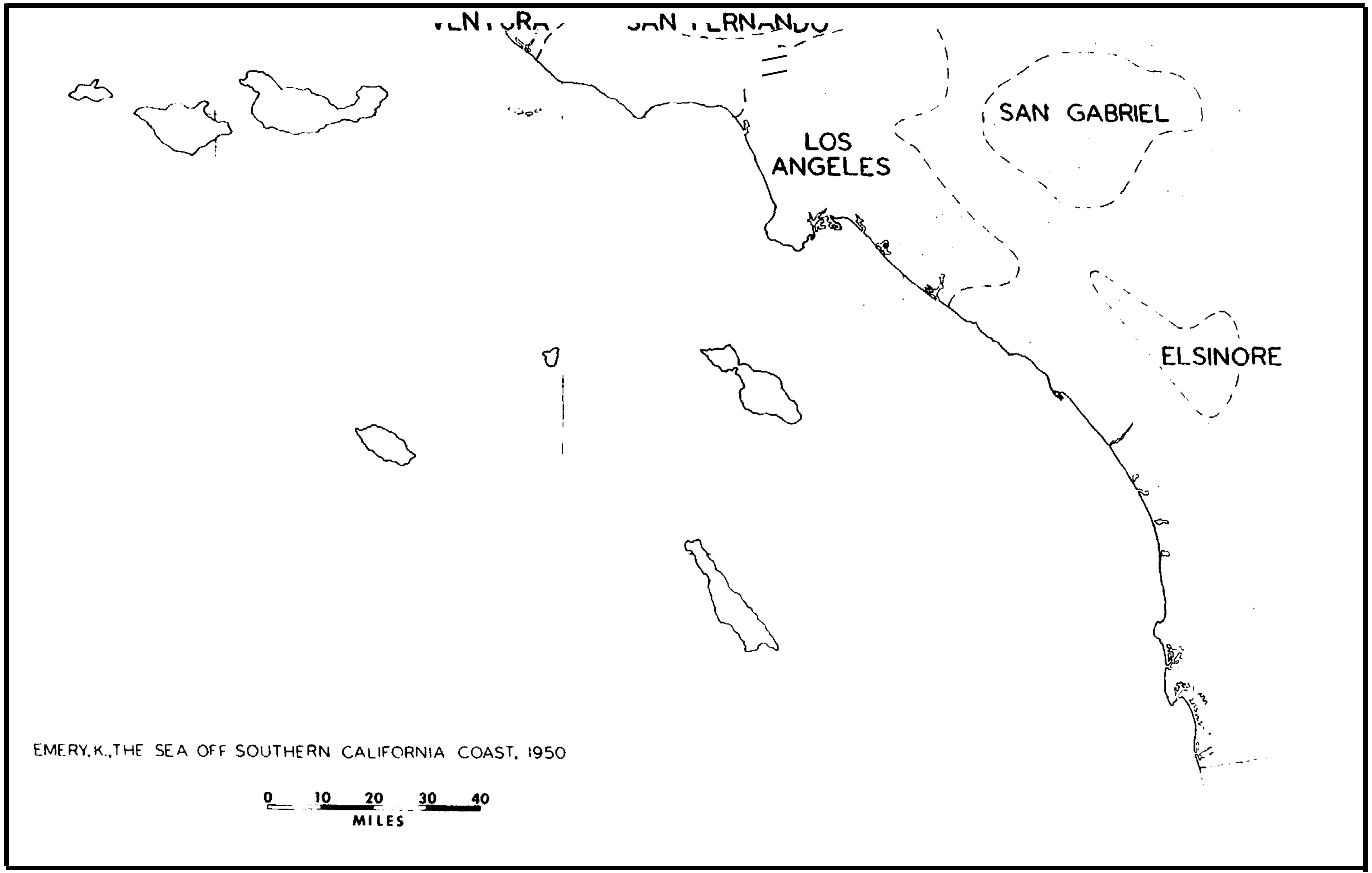


FIG. 6-3 FORMER MARINE BASINS

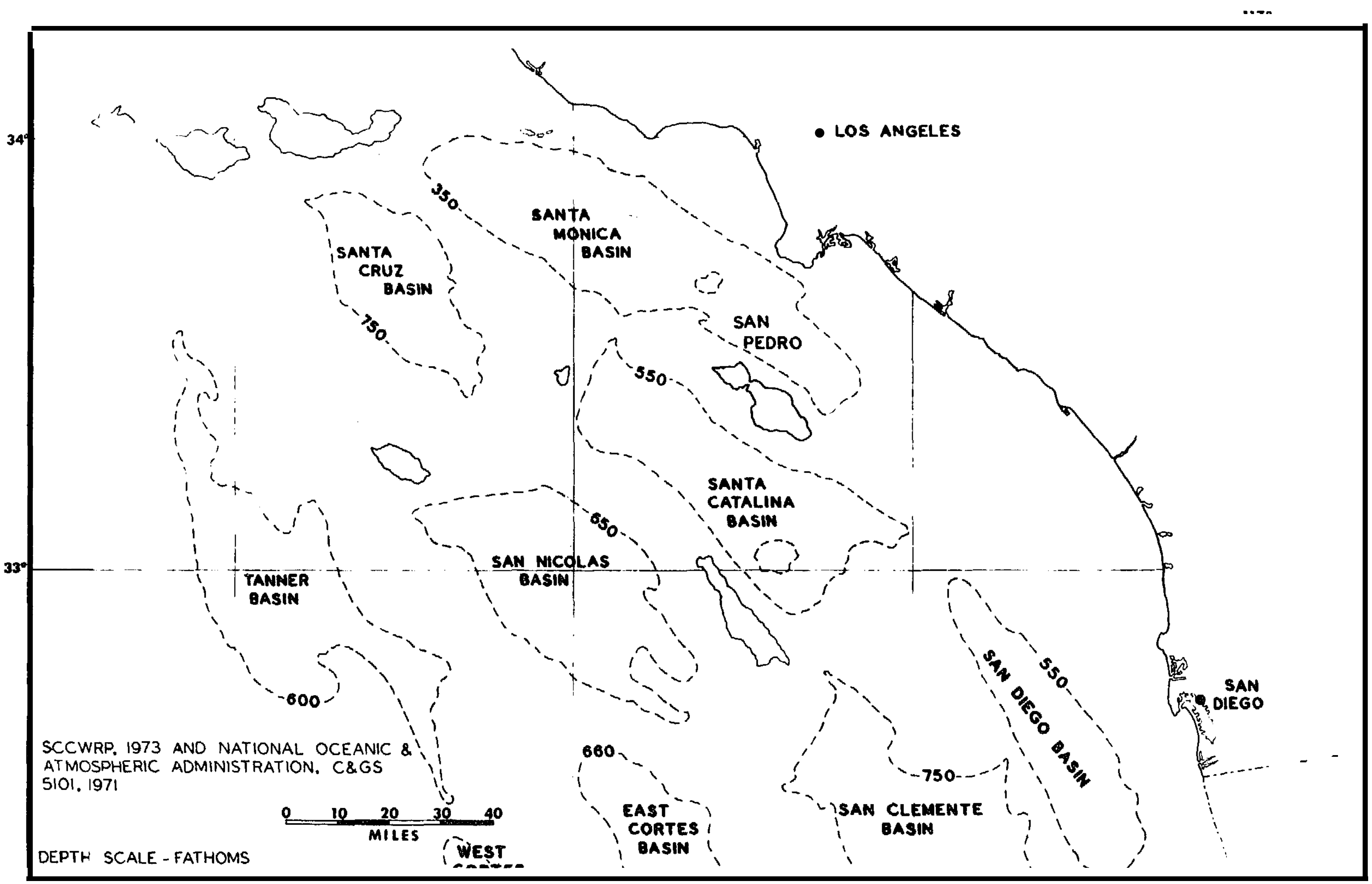


FIG. 6-4 BASINS OF SOUTHERN CALIFORNIA

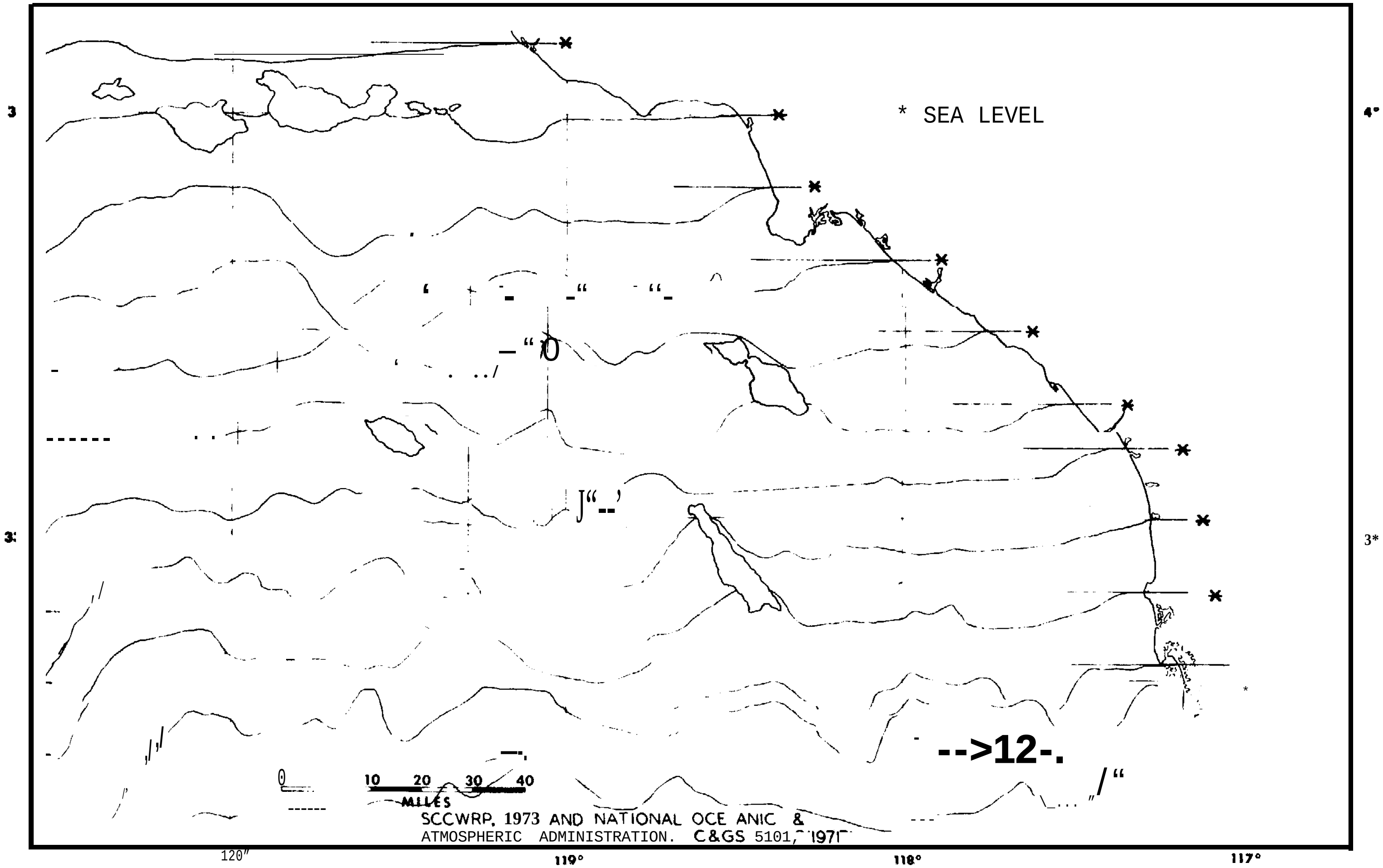


FIG. 6-5 PROFILES OF OCEAN FLOOR

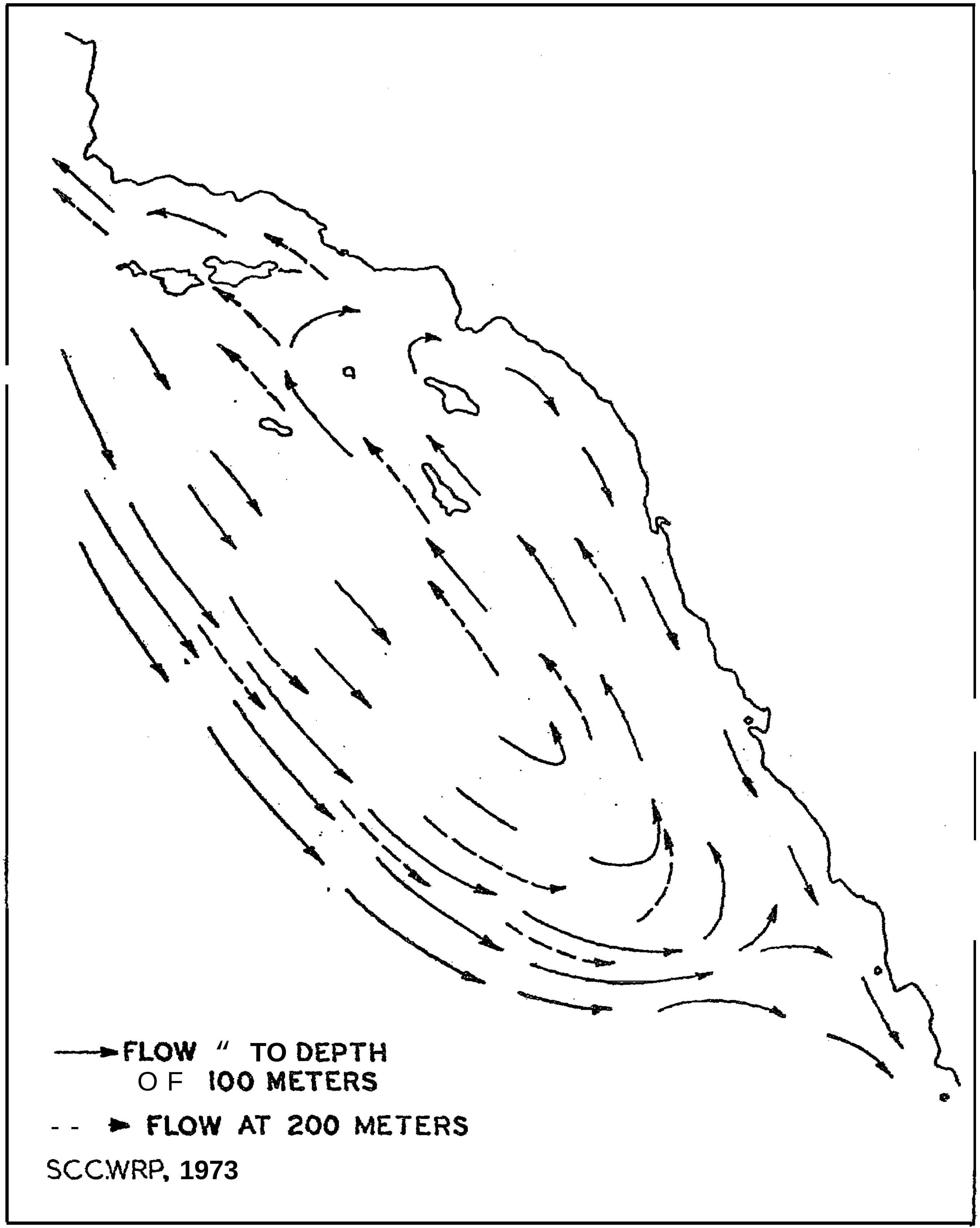


FIG. 6–6 CURRENTS OF SOUTHERN CALIFORNIA

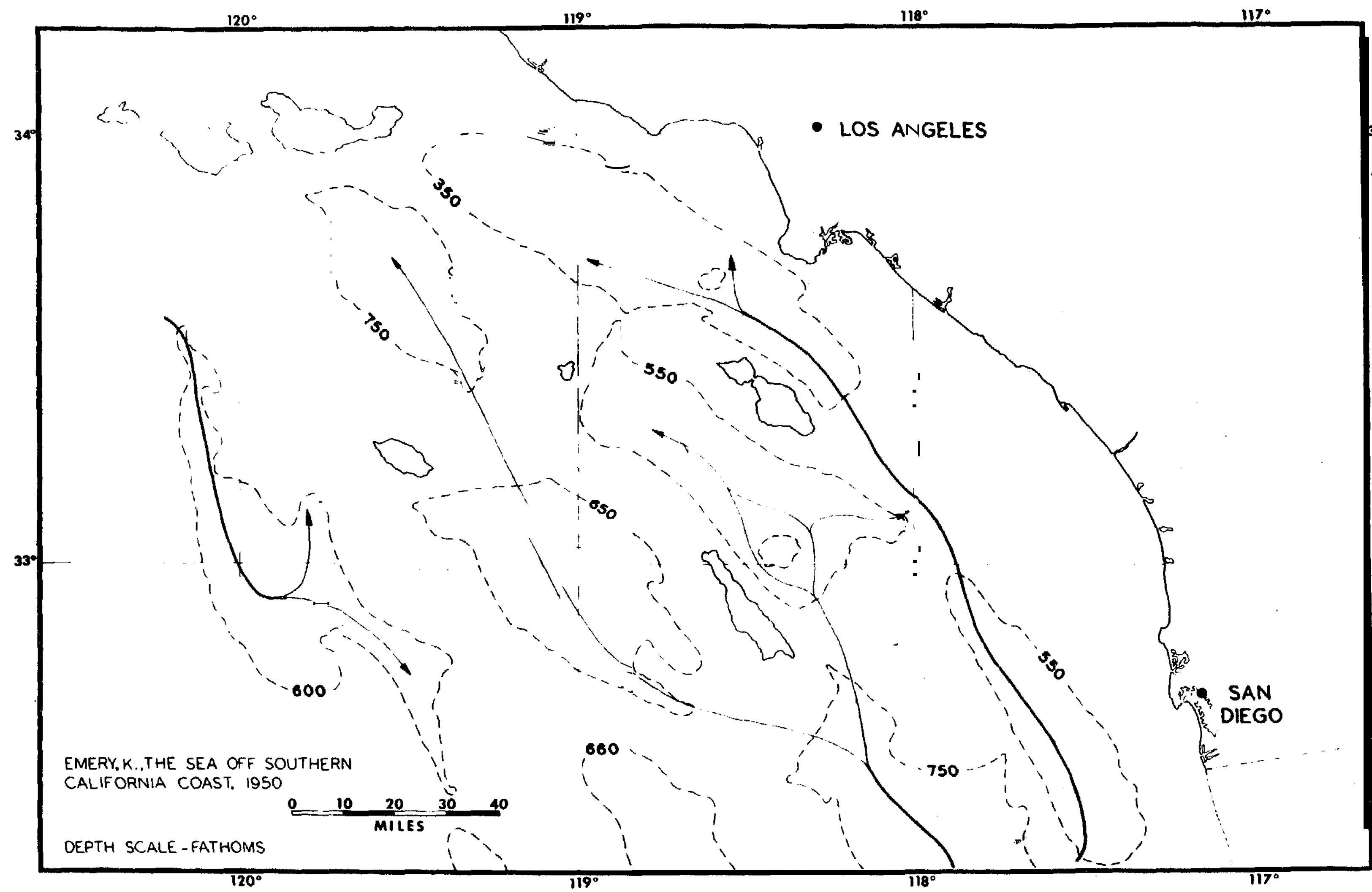


FIG. 6-7 WATER FLOWS FROM BASIN TO BASIN OFF SOUTHERN CALIFORNIA COAST

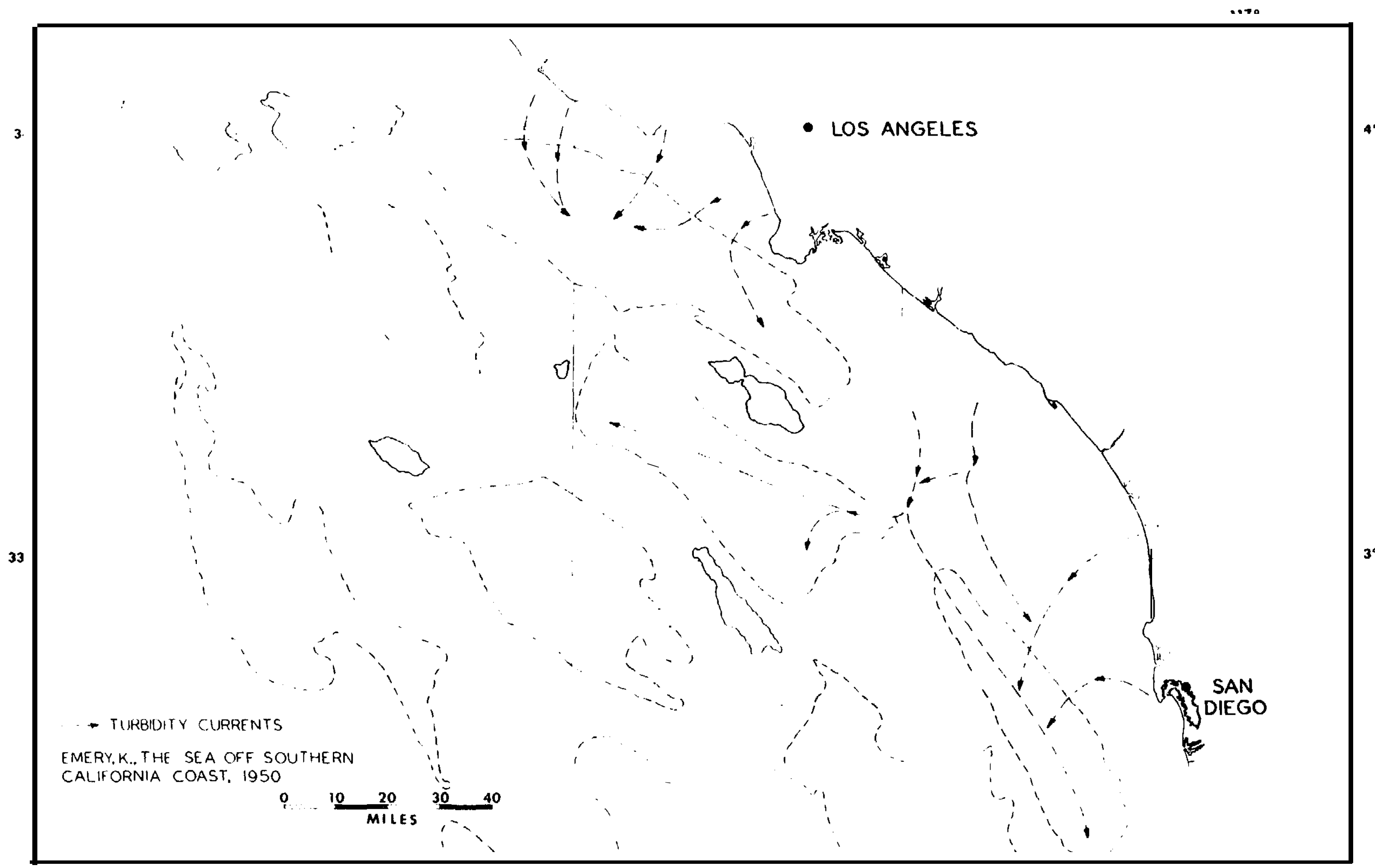


FIG. 6-8 TURBIDITY CURRENTS OFF THE SOUTHERN CALIFORNIA COAST

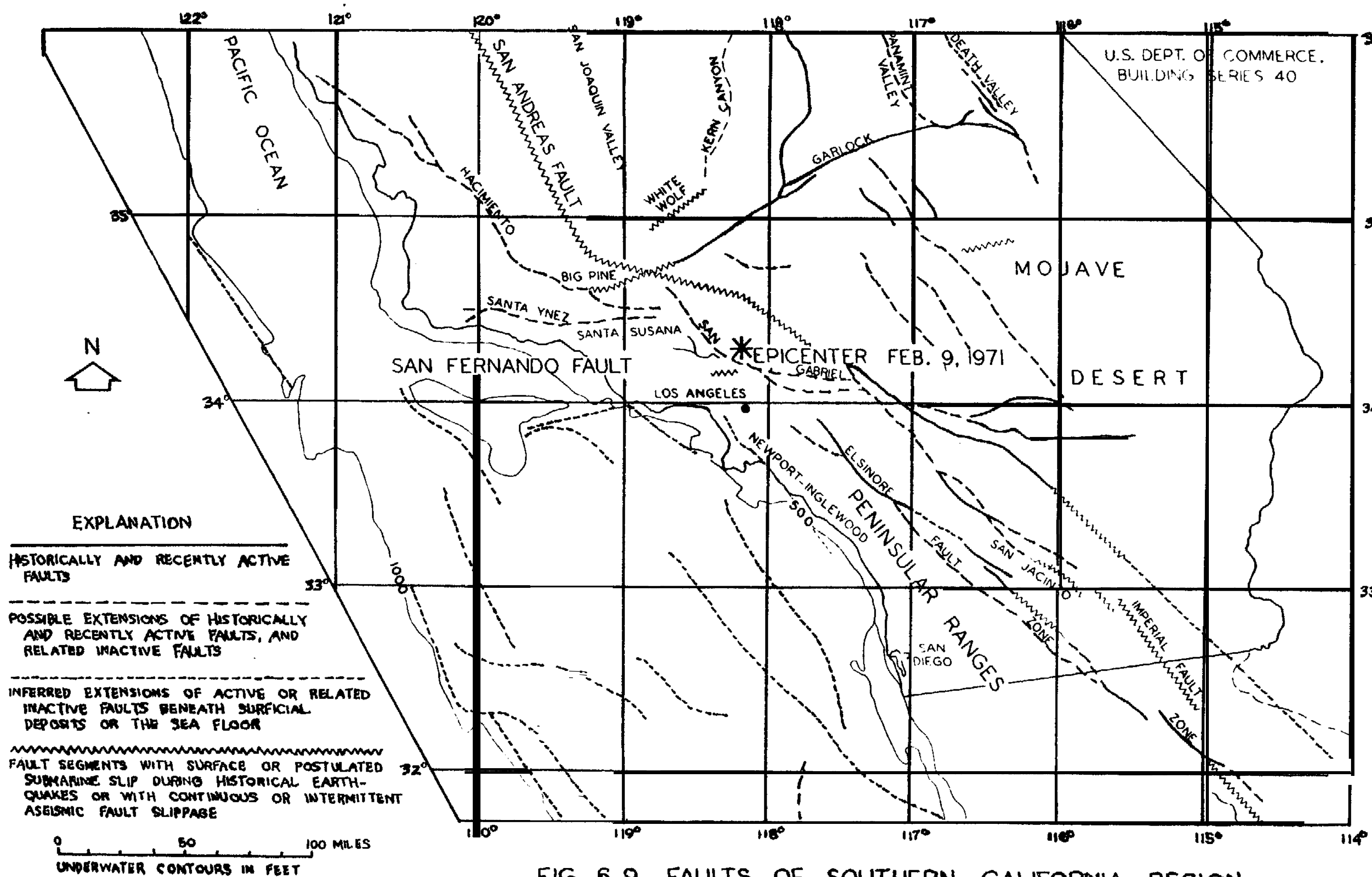


FIG. 6.9 FAULTS OF SOUTHERN CALIFORNIA REGION

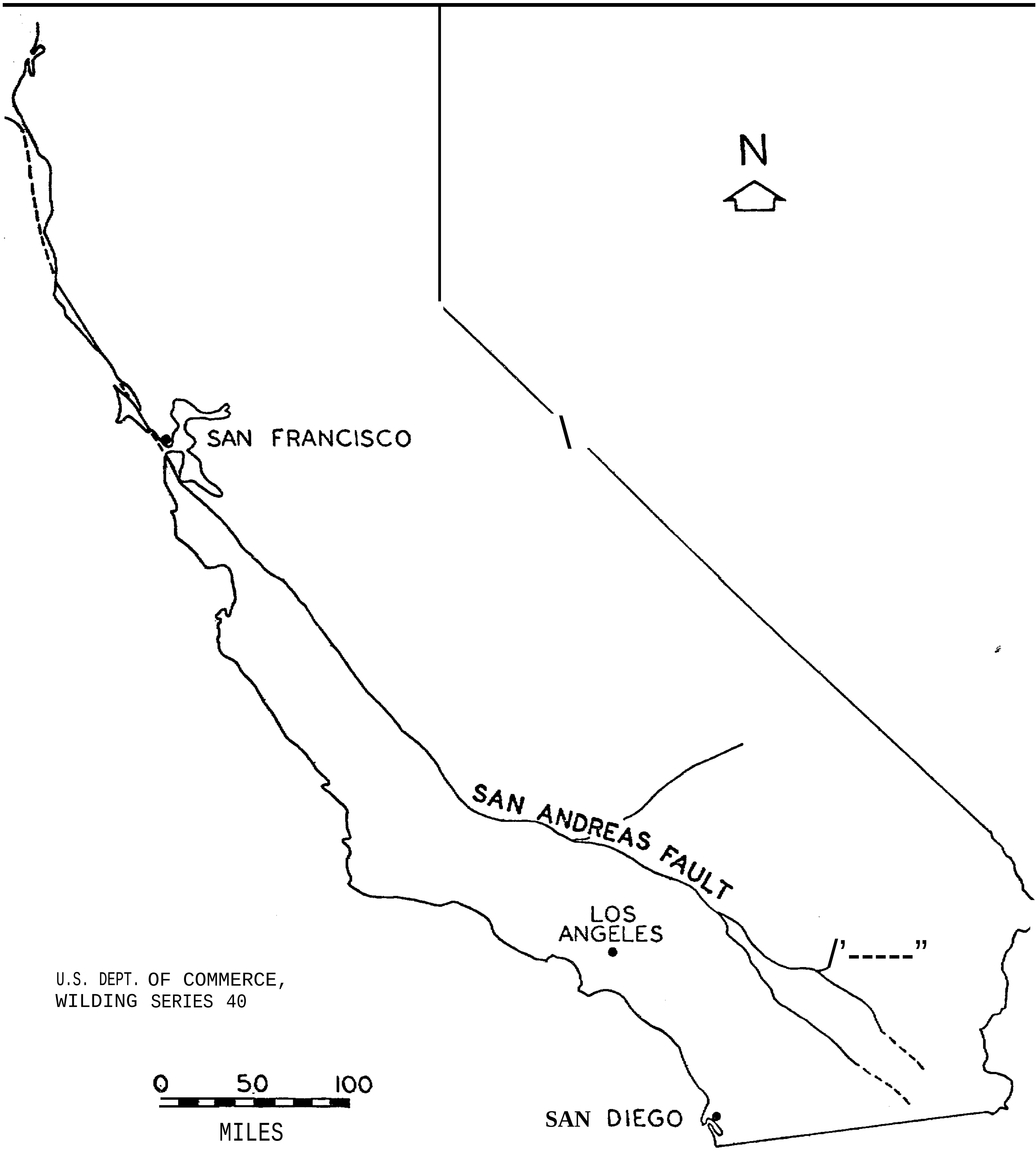


FIG. 6-10 SAN ANDREAS FAULT

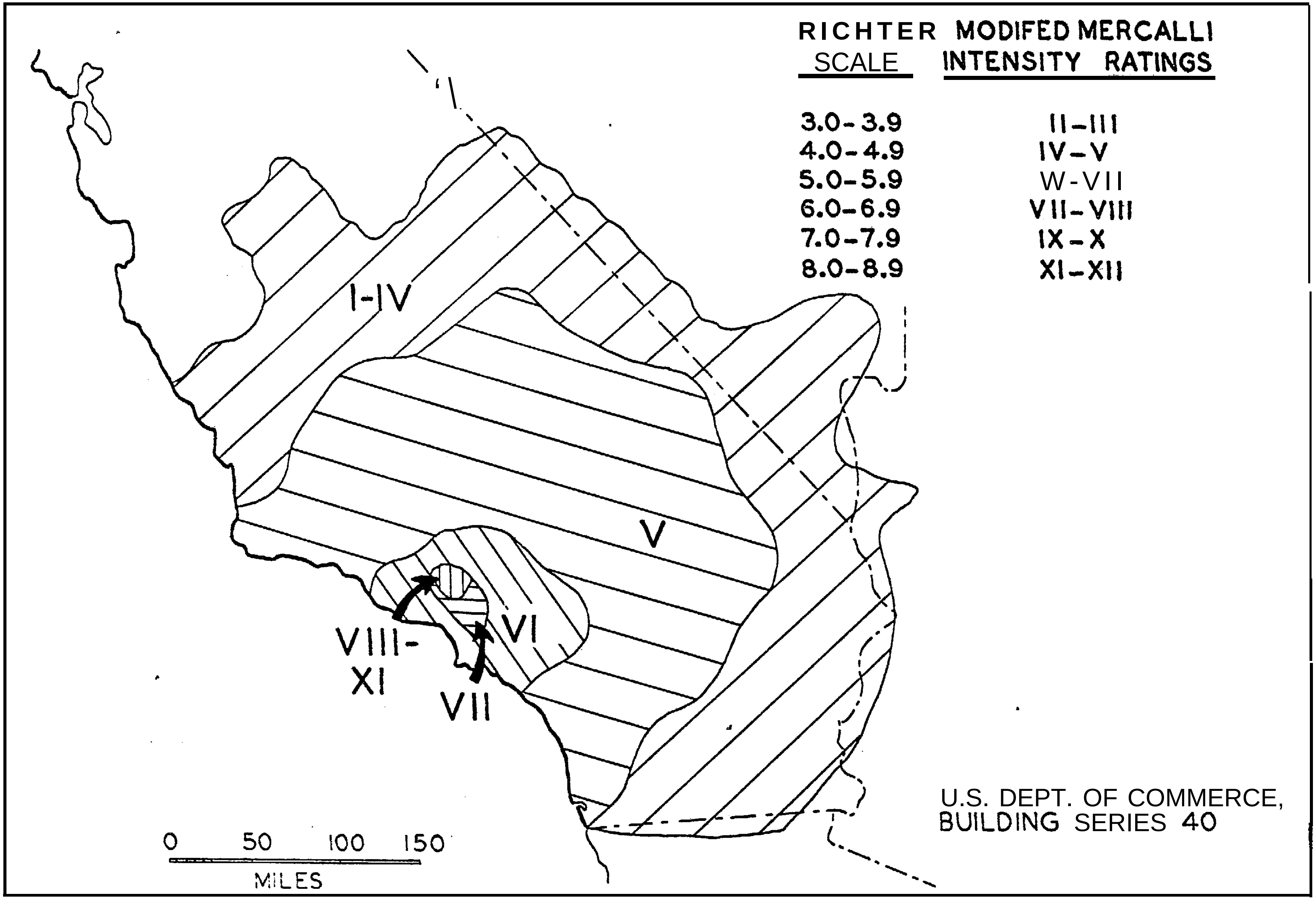
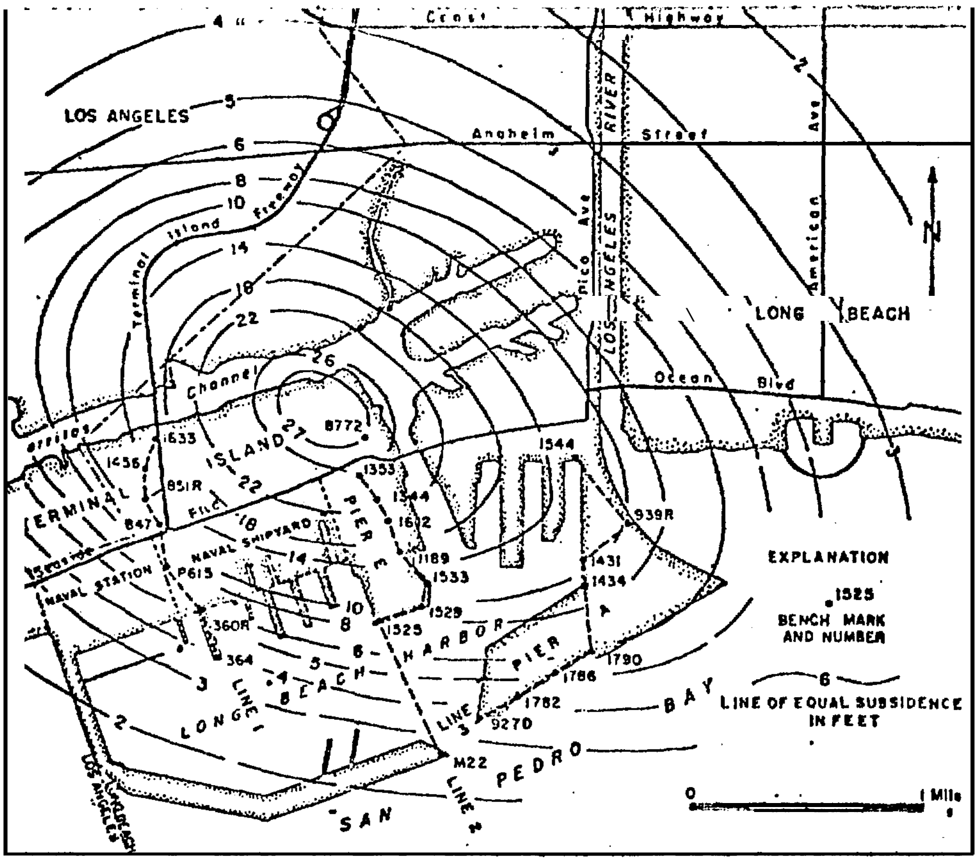
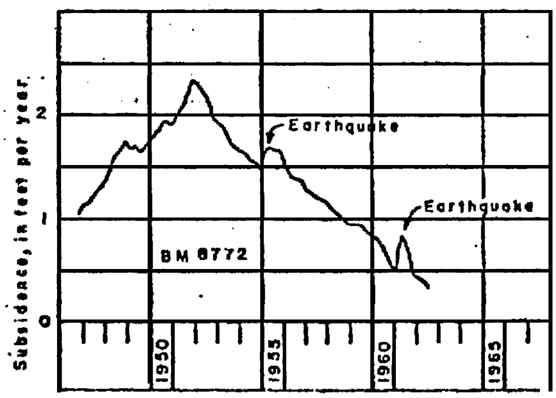


FIG. 6-11 INTENSITY AND AREA AFFECTED BY THE SAN FERNANDO EARTHQUAKE OF 1971

6-28





SOURCE: LONG BEACH HARBOR DEPARTMENT

FIG. 6-12 SUBSIDENCE OF LONG BEACH AREA

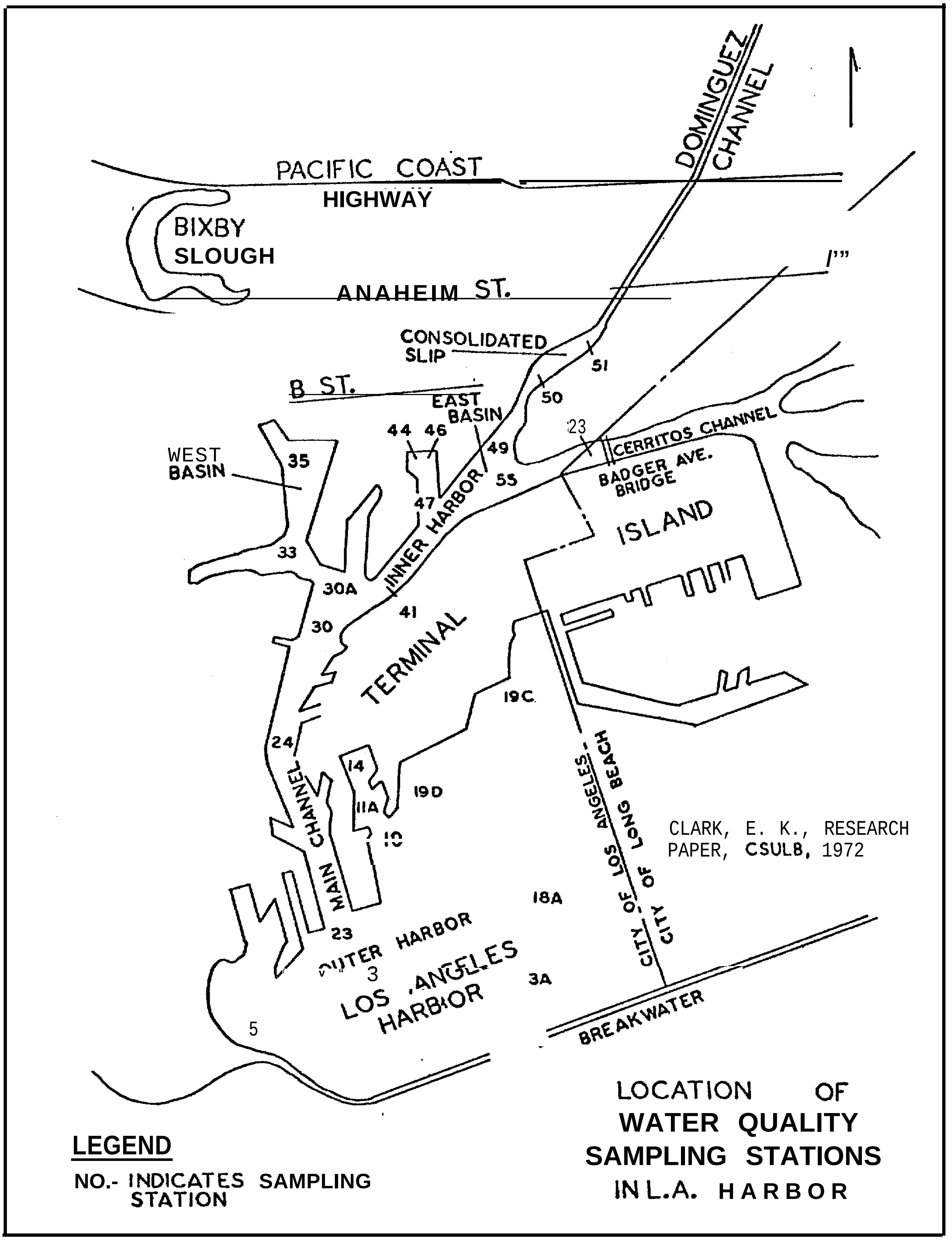


FIG. 6-13 LOS ANGELES HARBOR SAMPLING

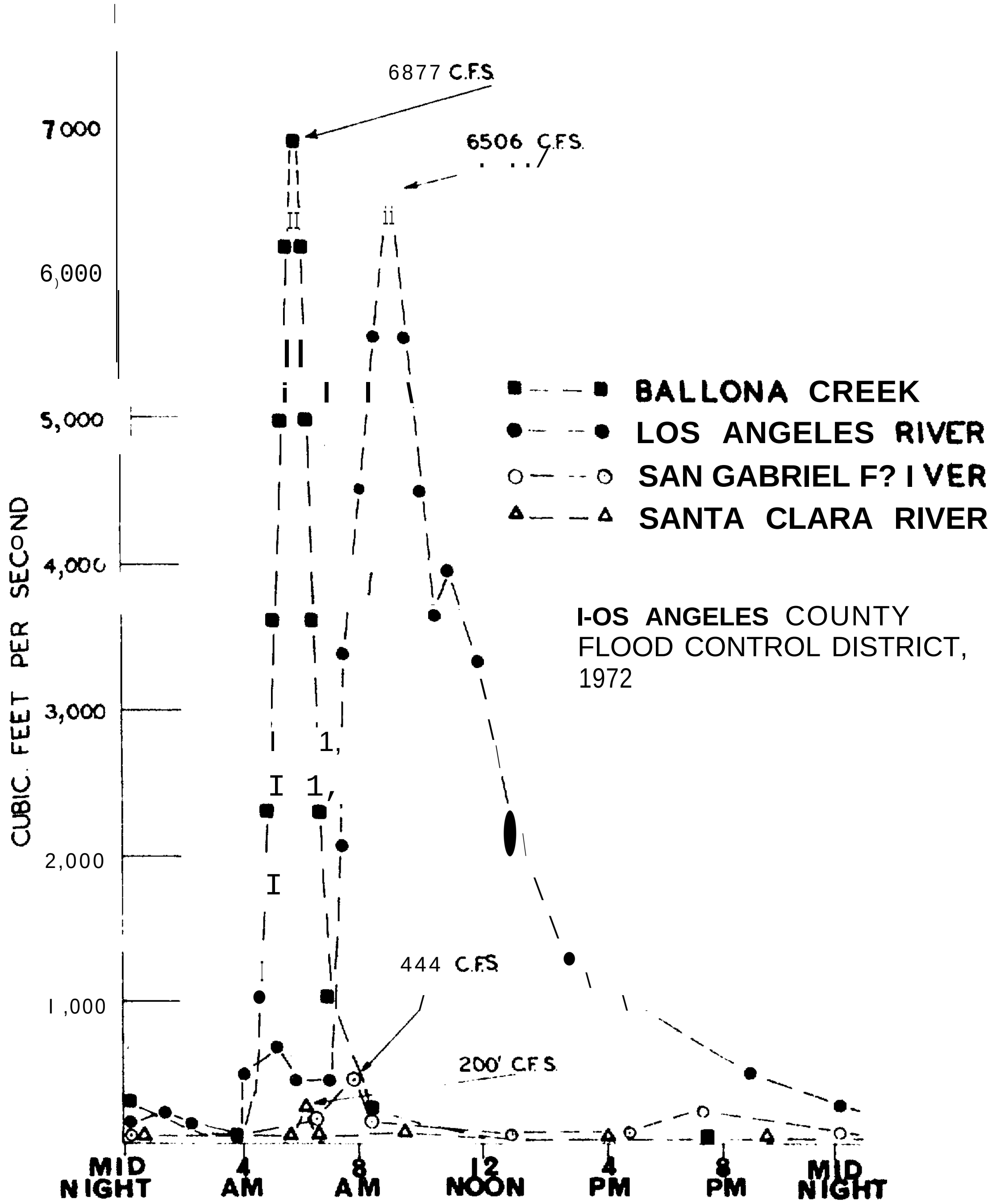


FIGURE 6-14 STORM FLOW RATE
4 LOS ANGELES COUNTY STREAMS
NOVEMBER 11, 1972

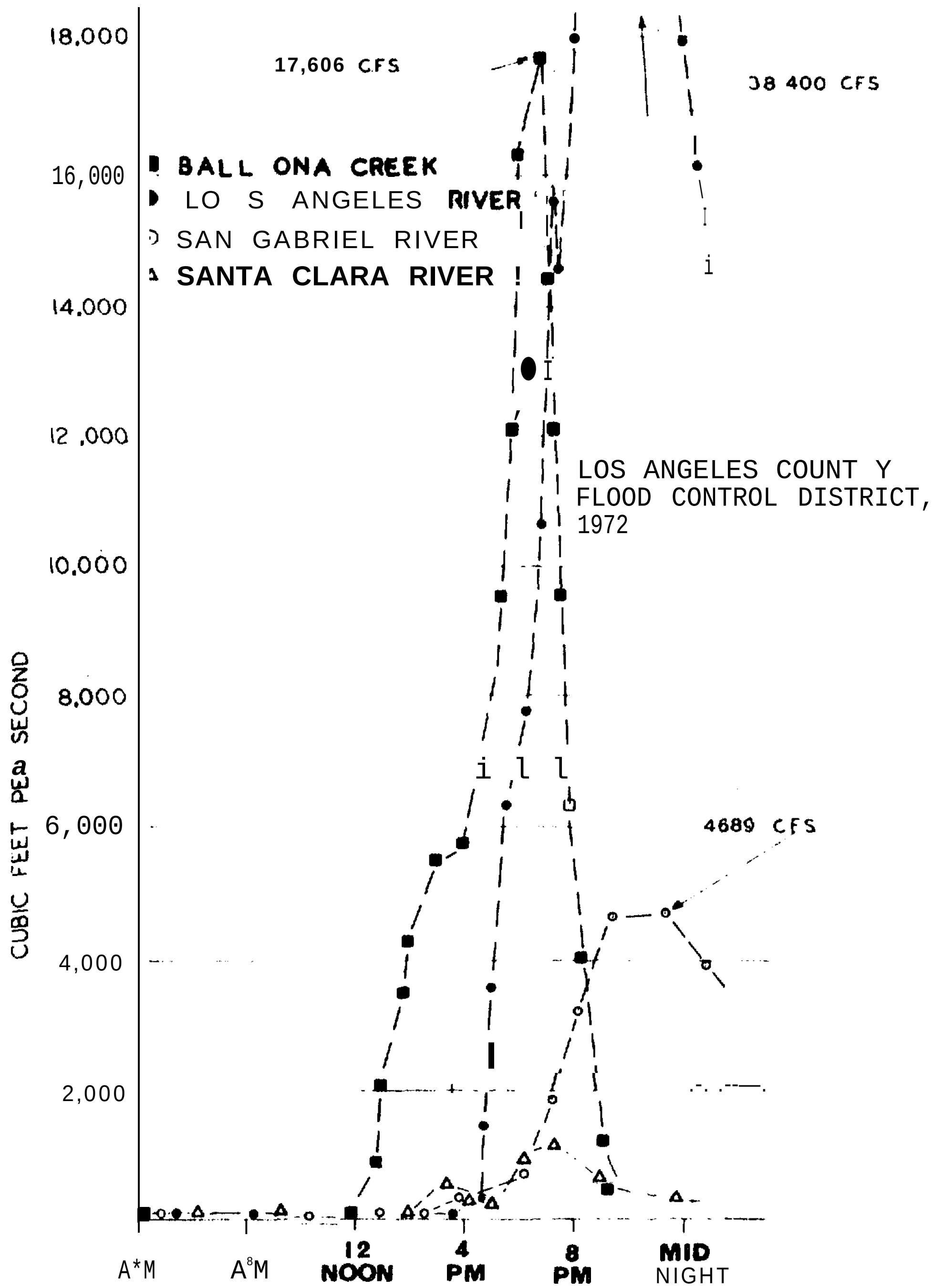


FIGURE 6-15 STORM FLOW RATES
4 LOS ANGELES COUNTY STREAMS
JANUARY 16, 1973

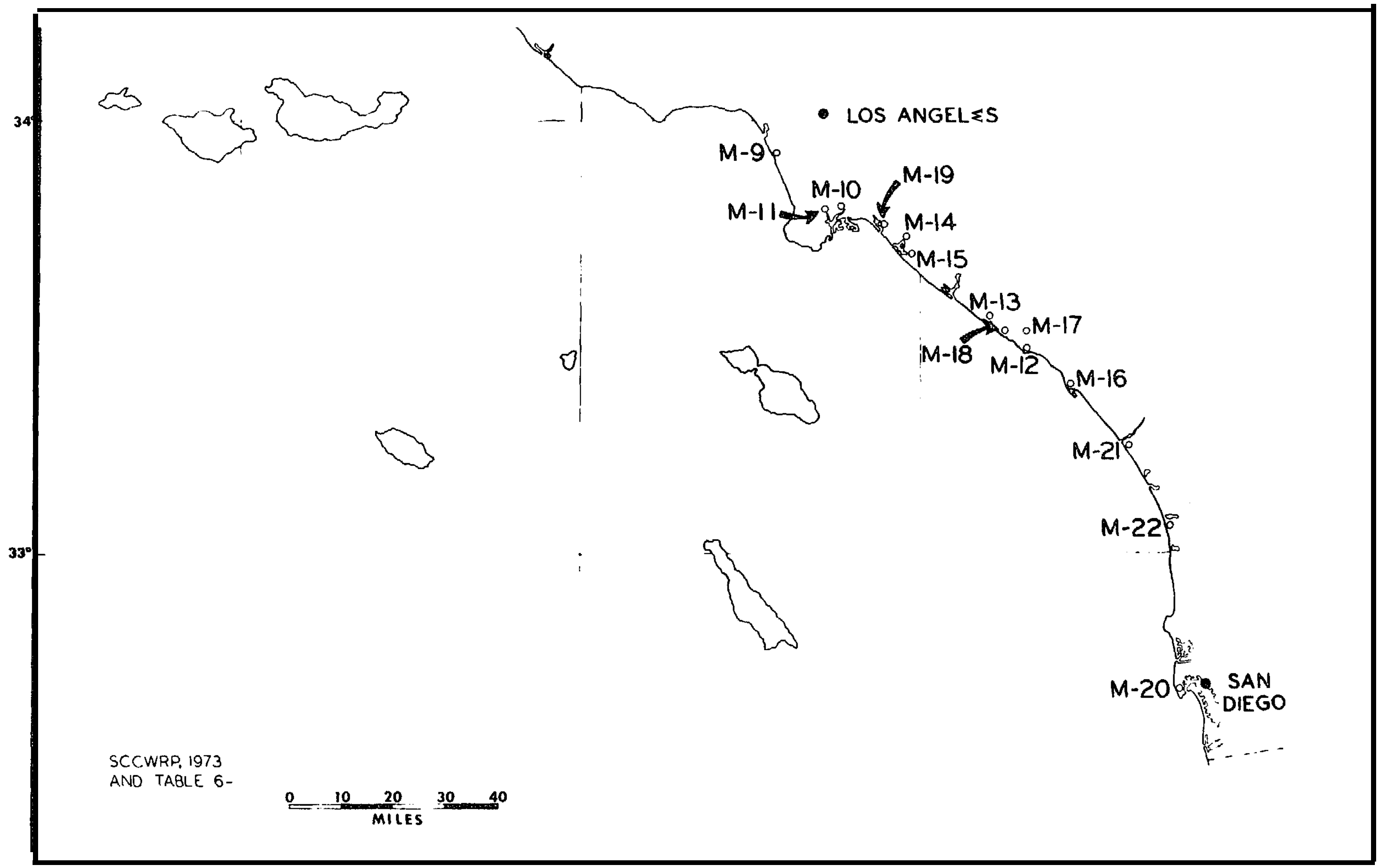
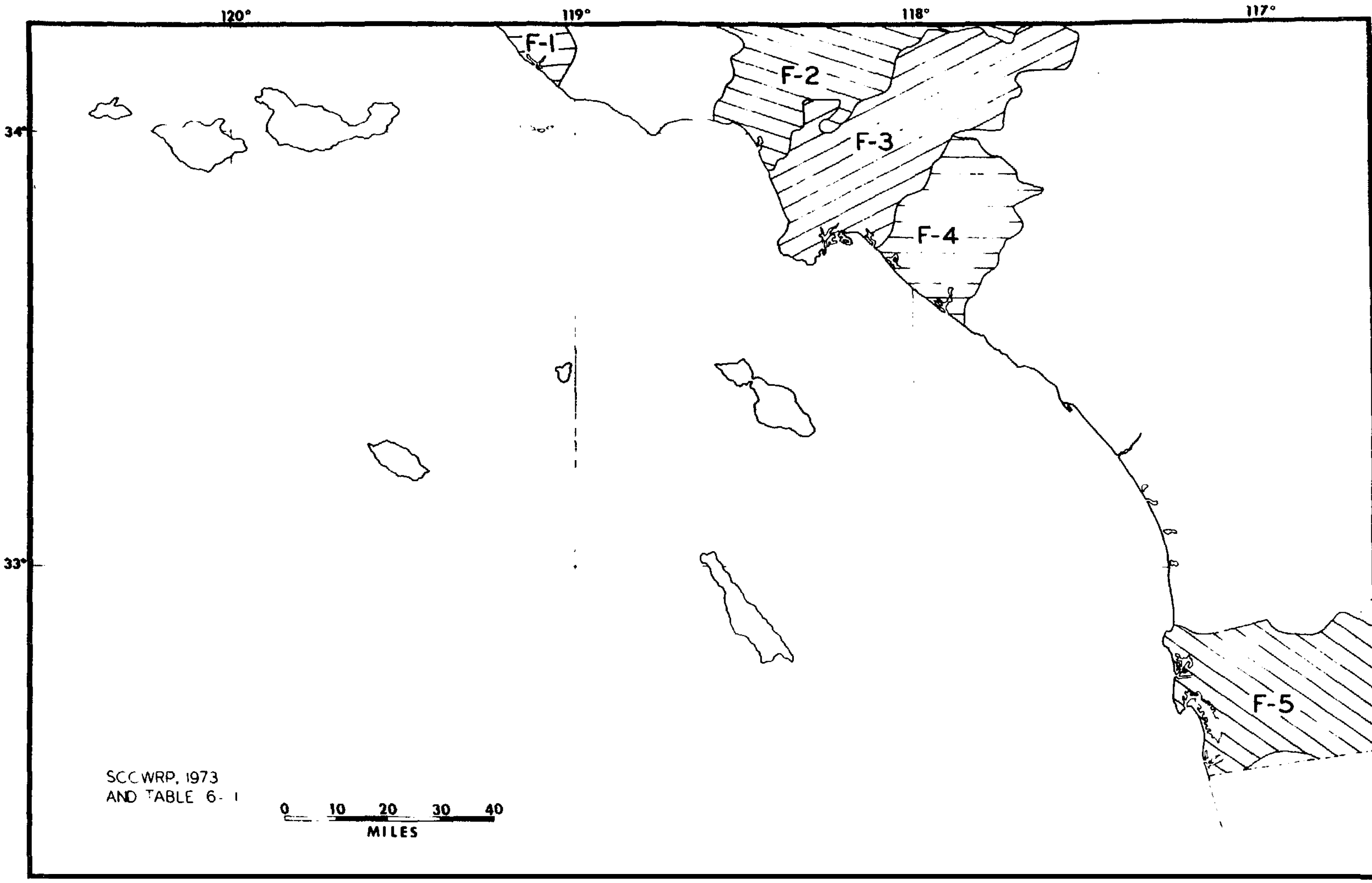


FIG. 6- MAJOR MUNICIPAL WASTE DISCHARGES ON SOUTHERN CALIFORNIA COAST



G 6 MA OR OU FA AREA ON O H RN ORN OA

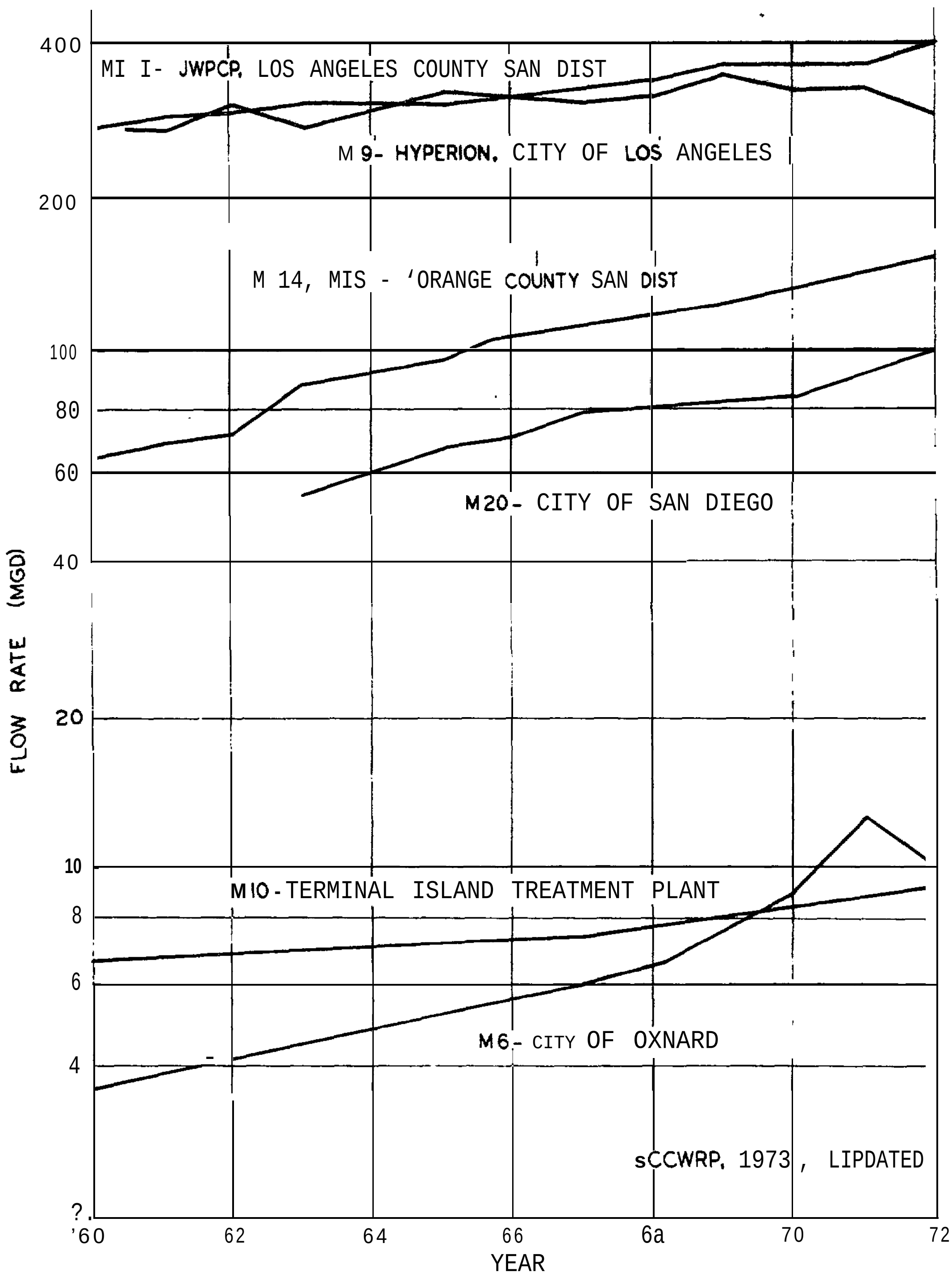


FIG. 6-18 EFFLUENT FLOW RATES FROM SIX MAJOR MUNICIPAL WASTEWATER TREATMENT PLANTS, 1960-72

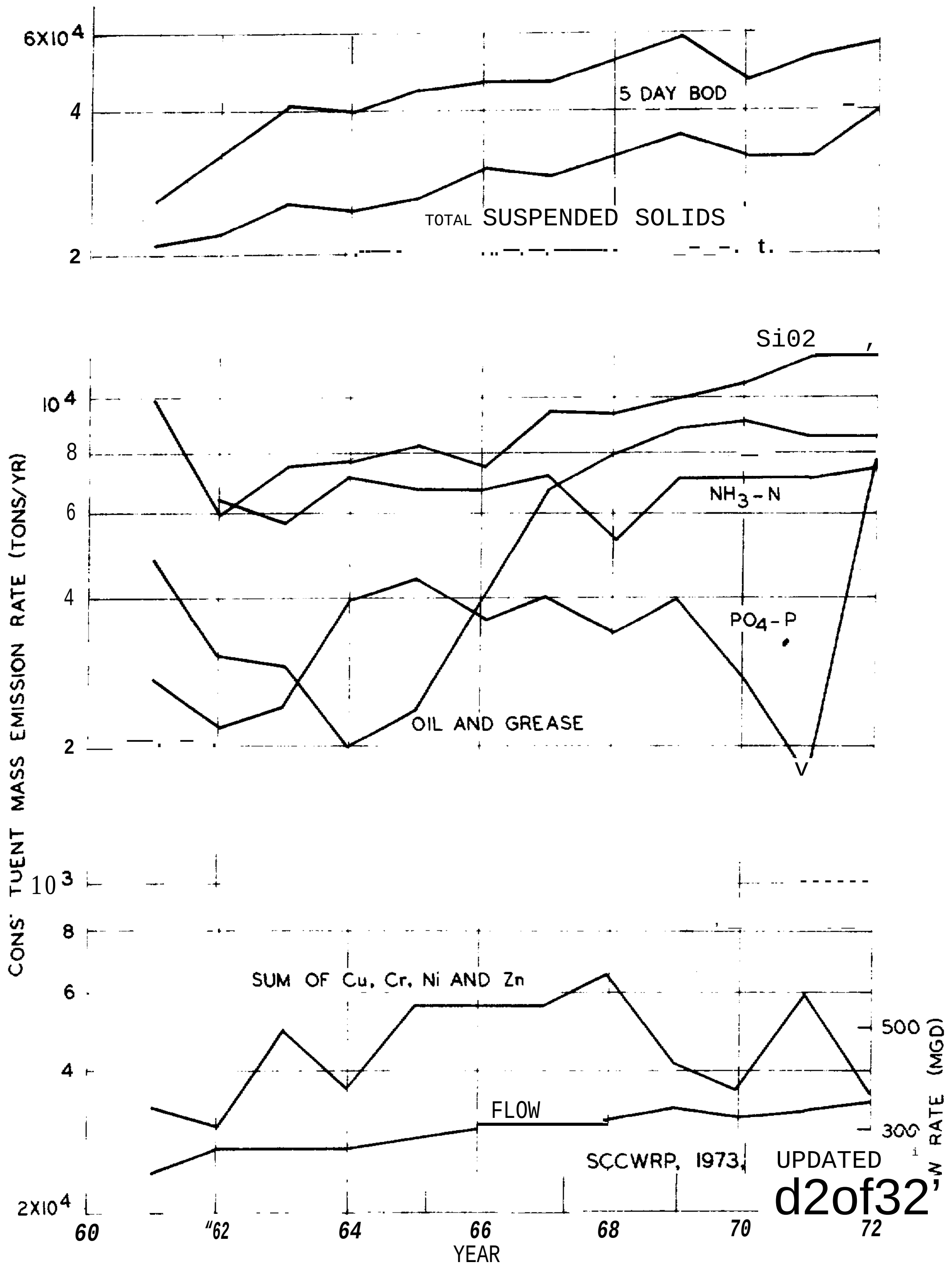


FIG. 6-19 **CONSTITUENT MASS EMISSION RATES FROM THE HYPERION 5-MILE EFFLUENT OUTFALL. 1961-72**

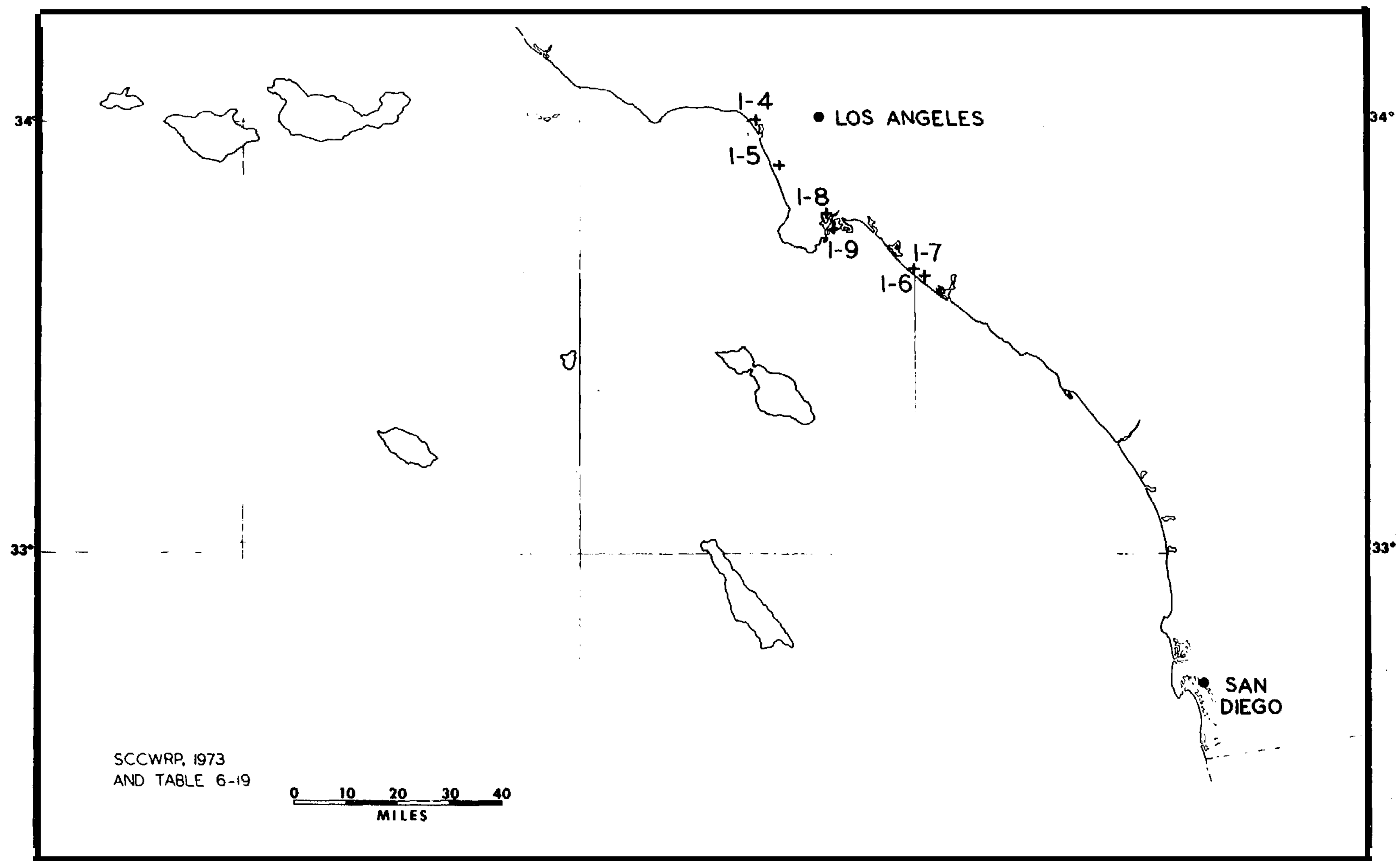


FIG. 6-20 INDUSTRIAL WASTE DISCHARGES ON SOUTHERN CALIFORNIA COAST

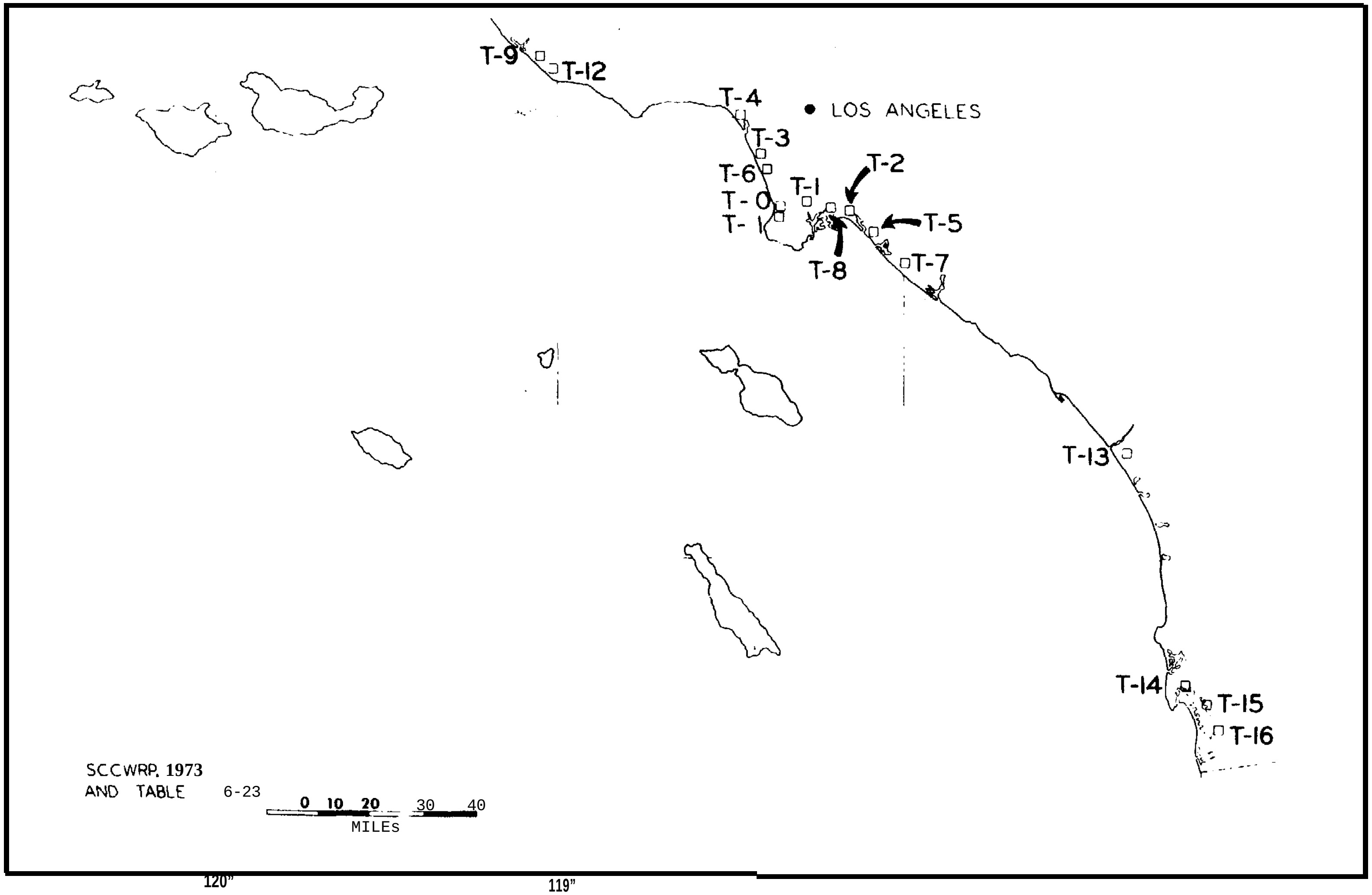


FIG. 6-21 **THERMAL DISCHARGES ON SOUTHERN CALIFORNIA COAST**

6-9
w
o

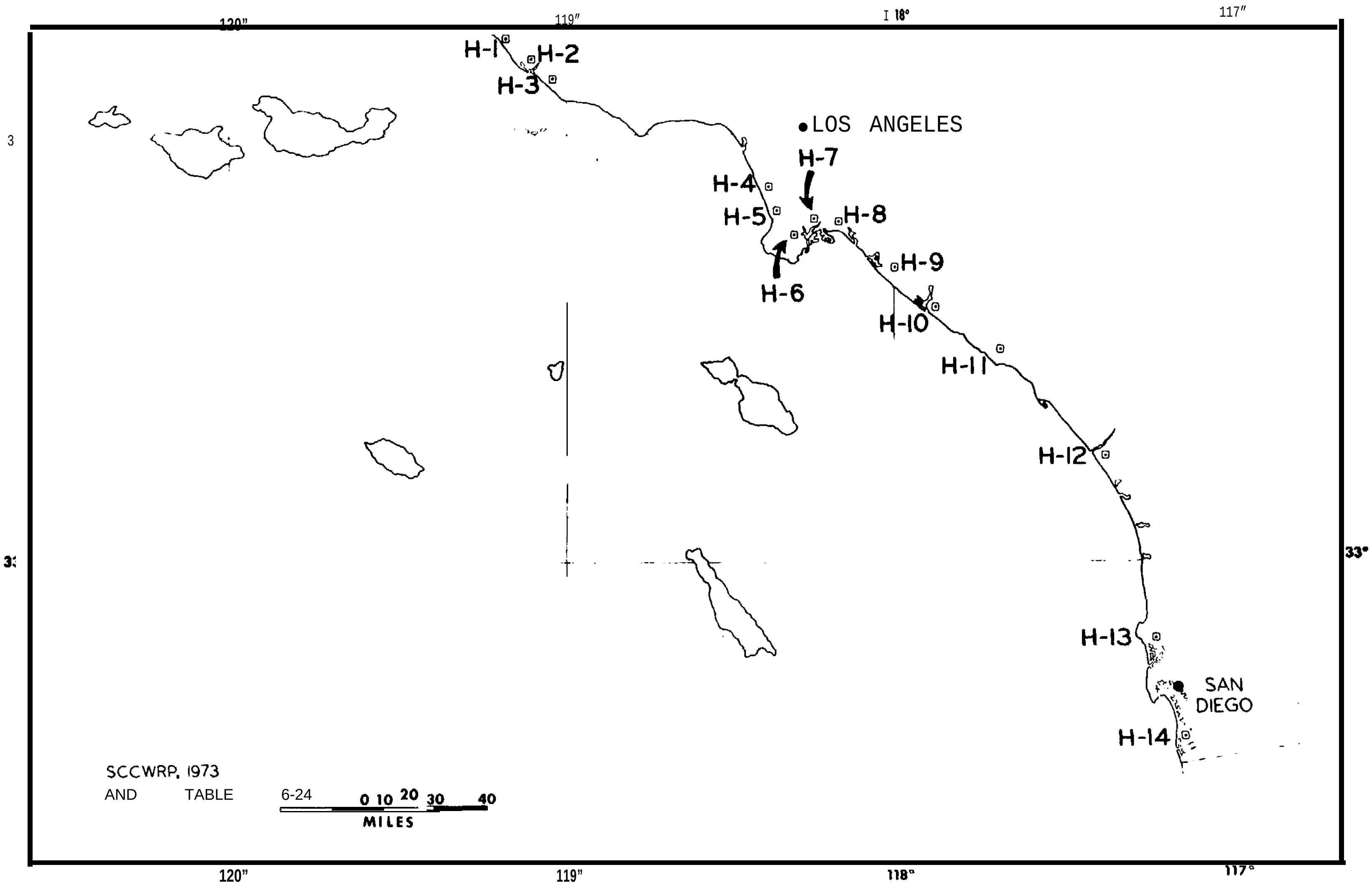


FIG. 6-22 MAJOR RECREATIONAL BOAT HARBORS ON SOUTHERN CALIFORNIA COAST

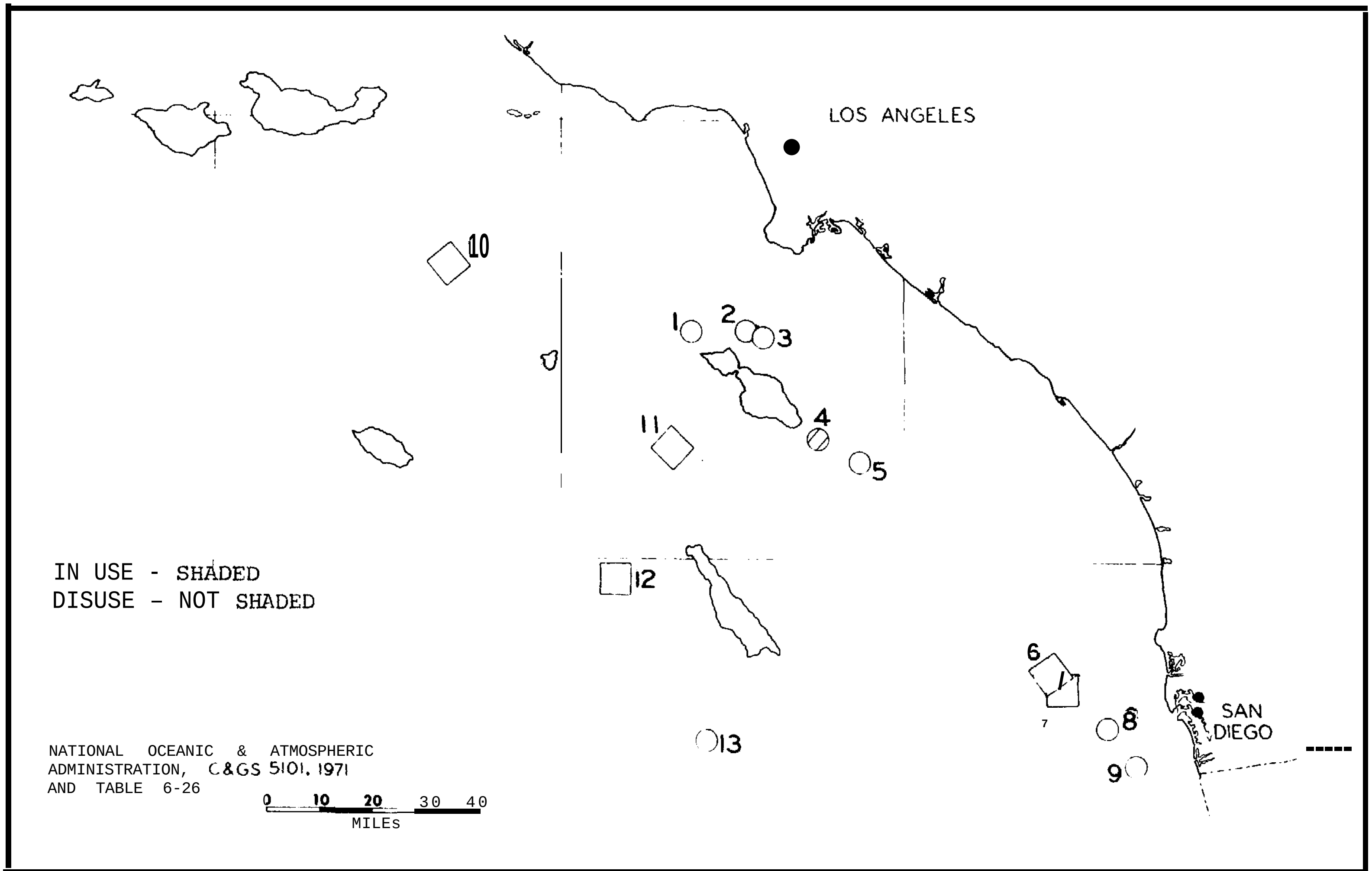


FIG. 6-23 DESIGNATED OCEAN DUMPING SITES

6-w2

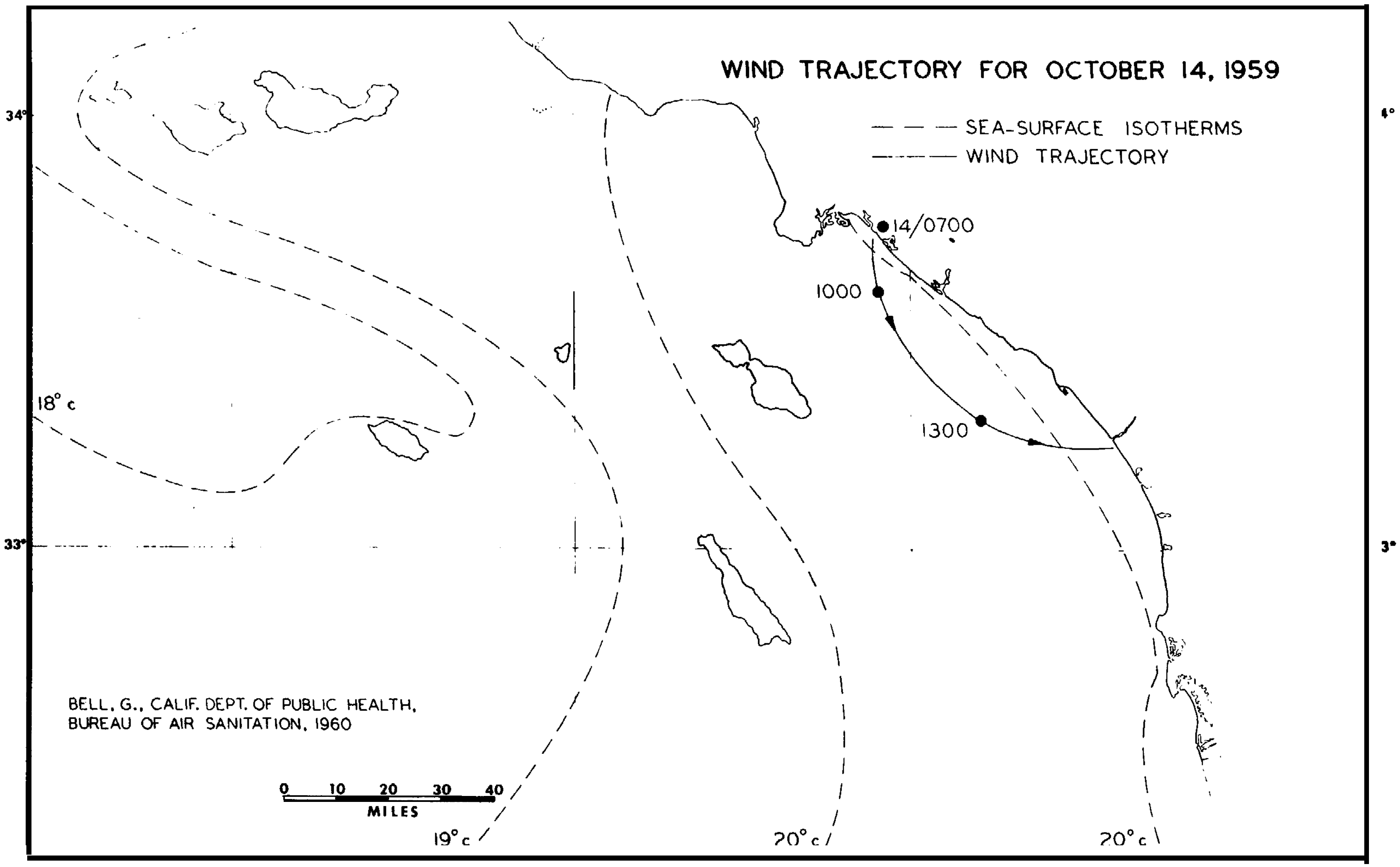
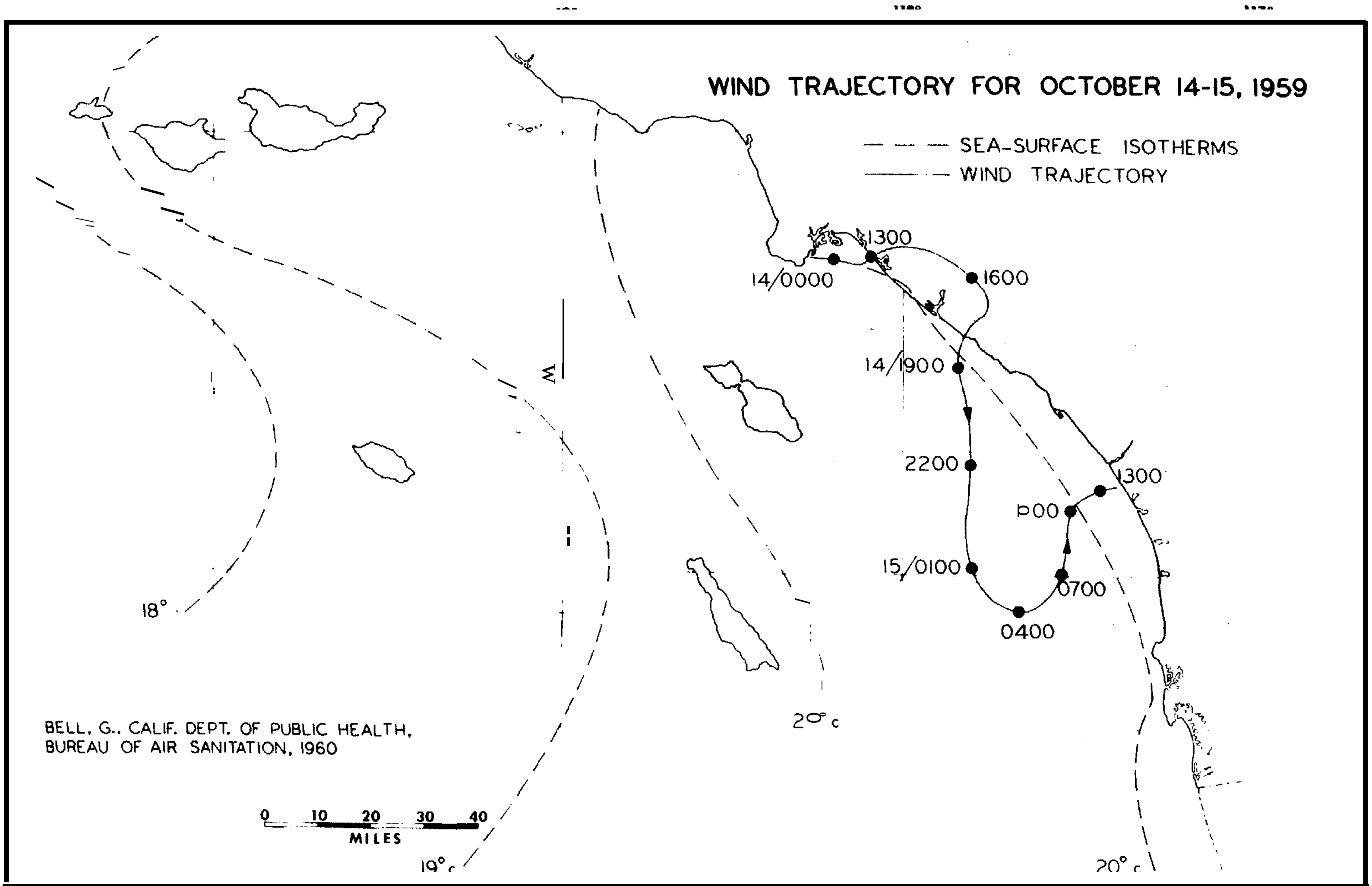

WIND TRAJECTORY FOR OCTOBER 14, 1959
SEA-SURFACE ISOTHERMS
WIND TRAJECTORY
14/0700
1000
1300
18° c
19° c
20° c
20° c
34°
33°
BELL, G., CALIF. DEPT. OF PUBLIC HEALTH,
BUREAU OF AIR SANITATION, 1960
0 10 20 30 40
MILES

FIGURE 6-24



WIND TRAJECTORY FOR OCTOBER 14-15, 1959
SEA-SURFACE ISOTHERMS
WIND TRAJECTORY
14/0000
1300
1600
14/1900
2200
15/0100
0400
0700
1300
18°
19°c
20°c
20°c
BELL, G., CALIF. DEPT. OF PUBLIC HEALTH,
BUREAU OF AIR SANITATION, 1960
0 10 20 30 40
MILES

FIGURE 6-25

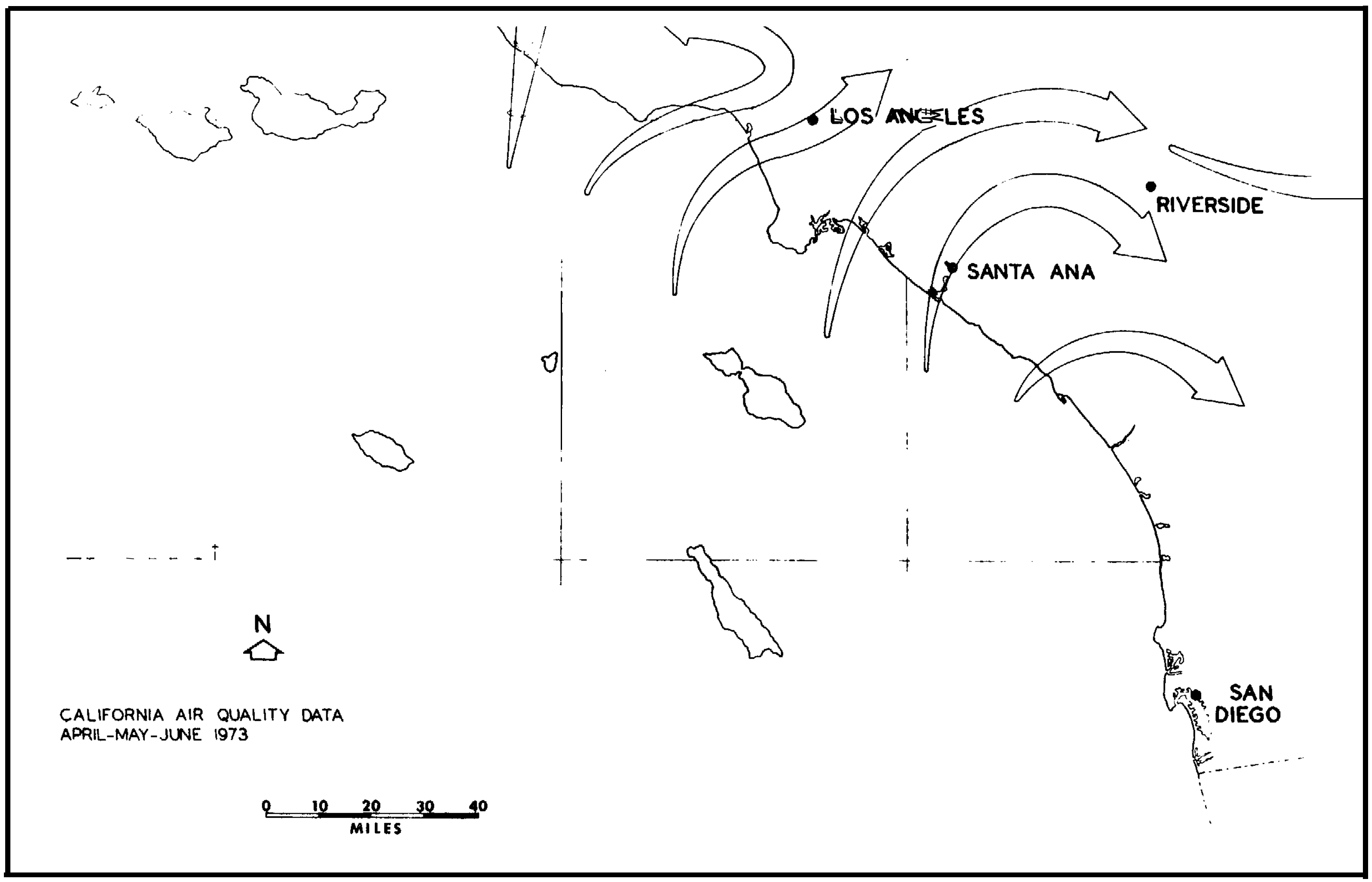


FIG. 6-28 SOUTH & SOUTHWESTERLY WINDS (SEPT. 6, 1973 - MILD, STABLE WITH SMOG)

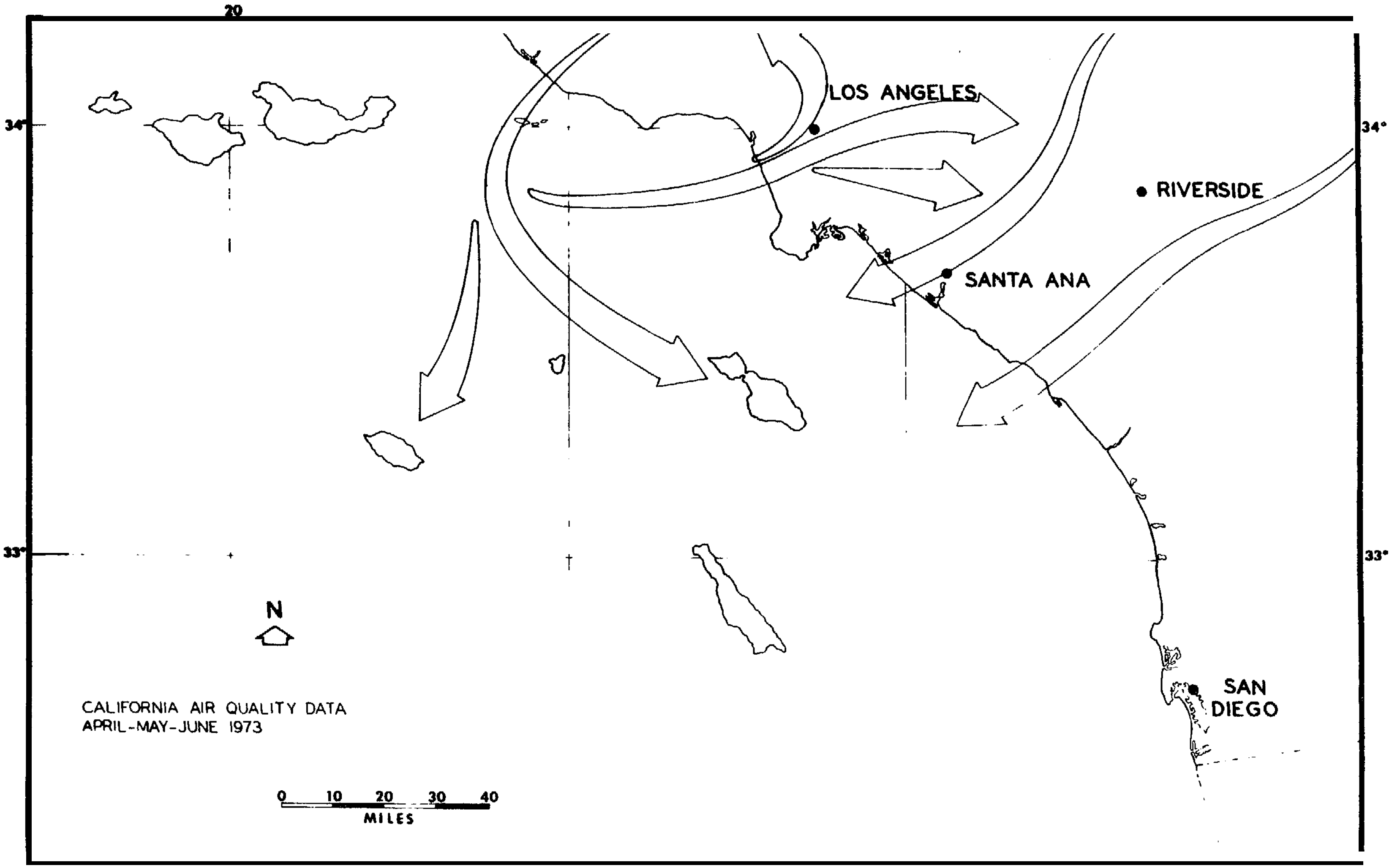


FIG. 6-29 STRONG CONTINENTAL NE WINDS AND WEAK RETURN FLOW. SANTA ANA-TYPE WIND CONDITION

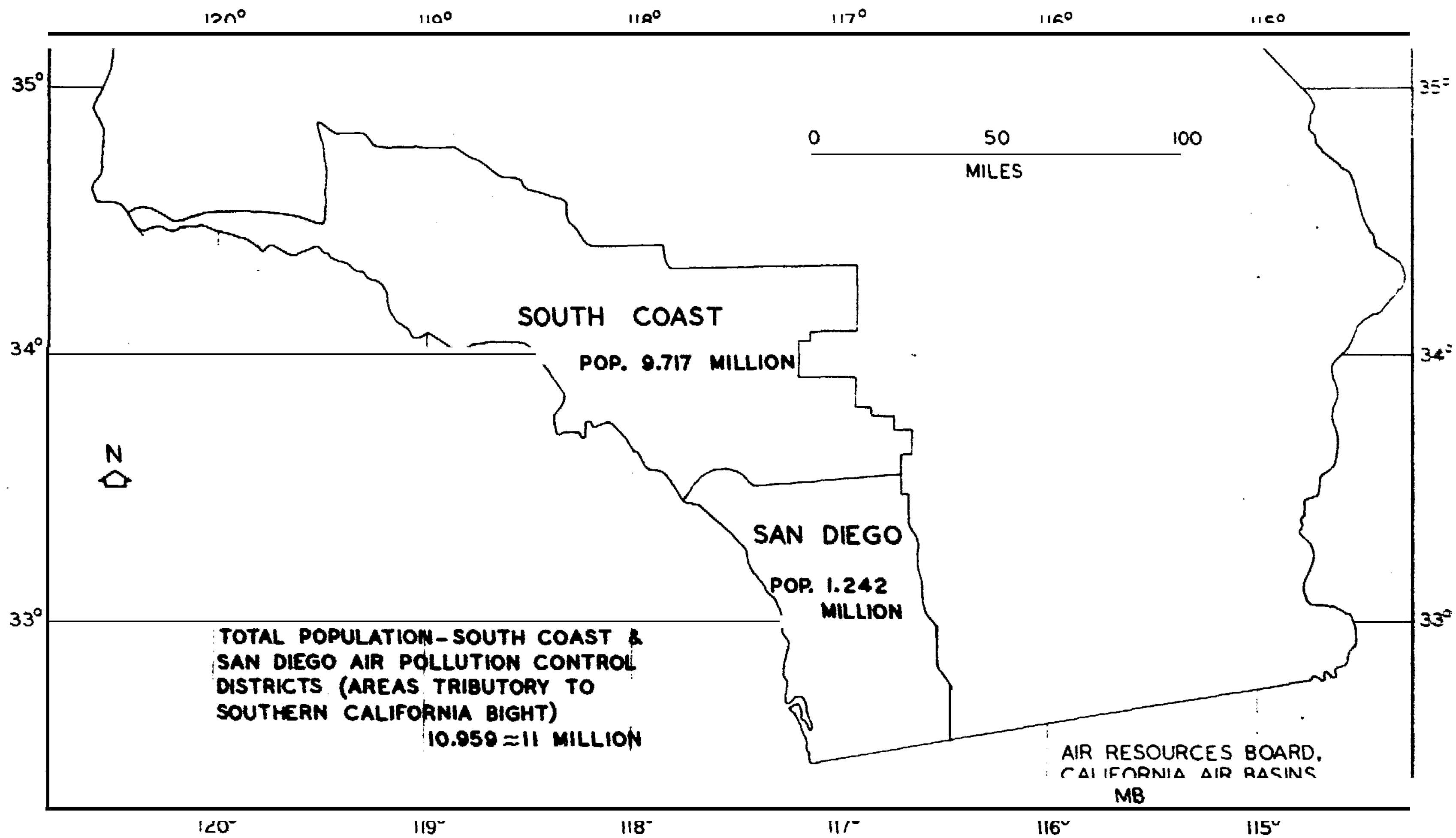


FIG. -30 AIR BASINS ON SOUTHERN CALIFORNIA COAST

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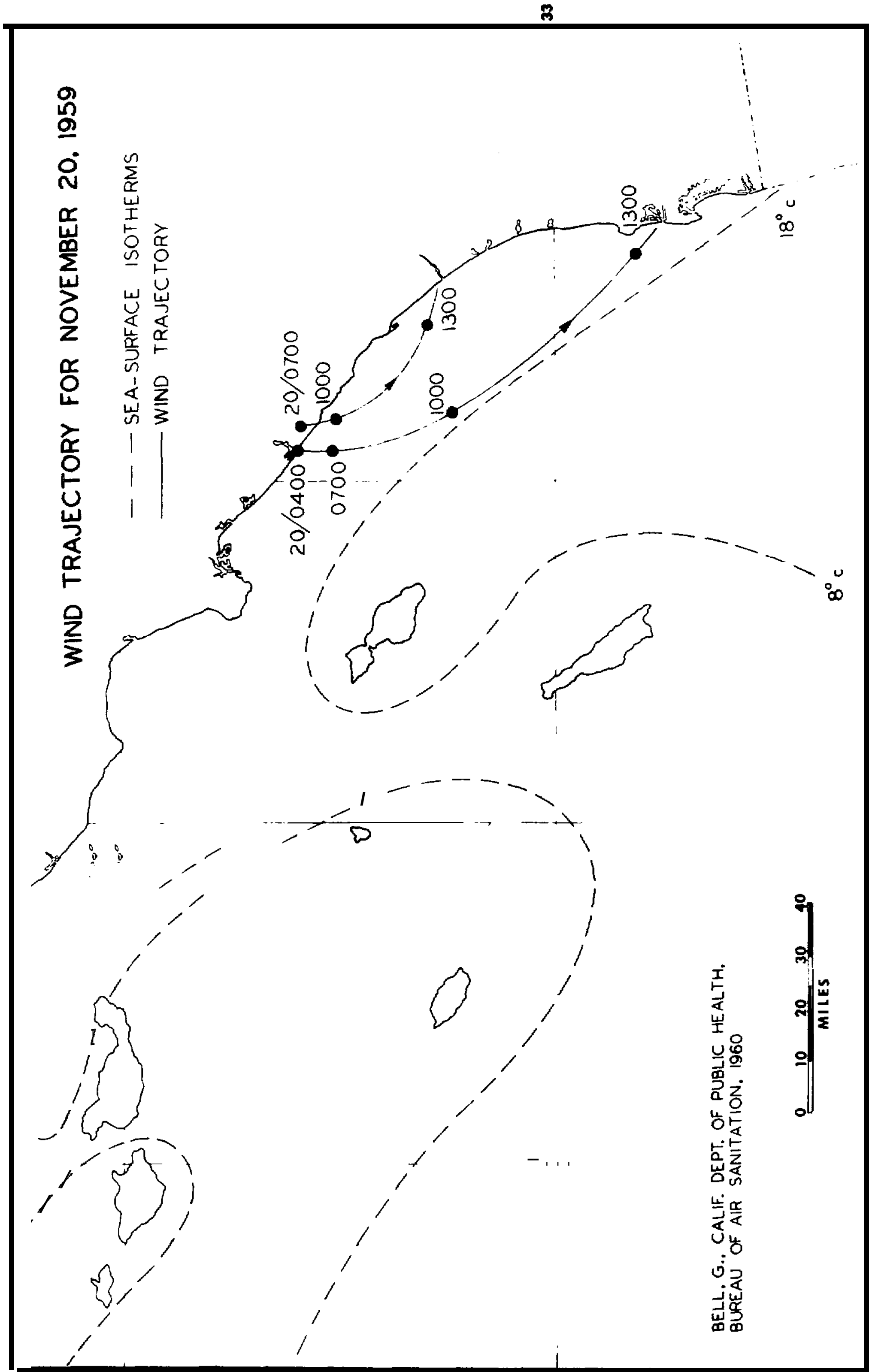
WIND TRAJECTORY FOR NOVEMBER 20, 1959
SEA-SURFACE ISOTHERMS
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BELL, G., CALIF. DEPT. OF PUBLIC HEALTH,
BUREAU OF AIR SANITATION, 1960
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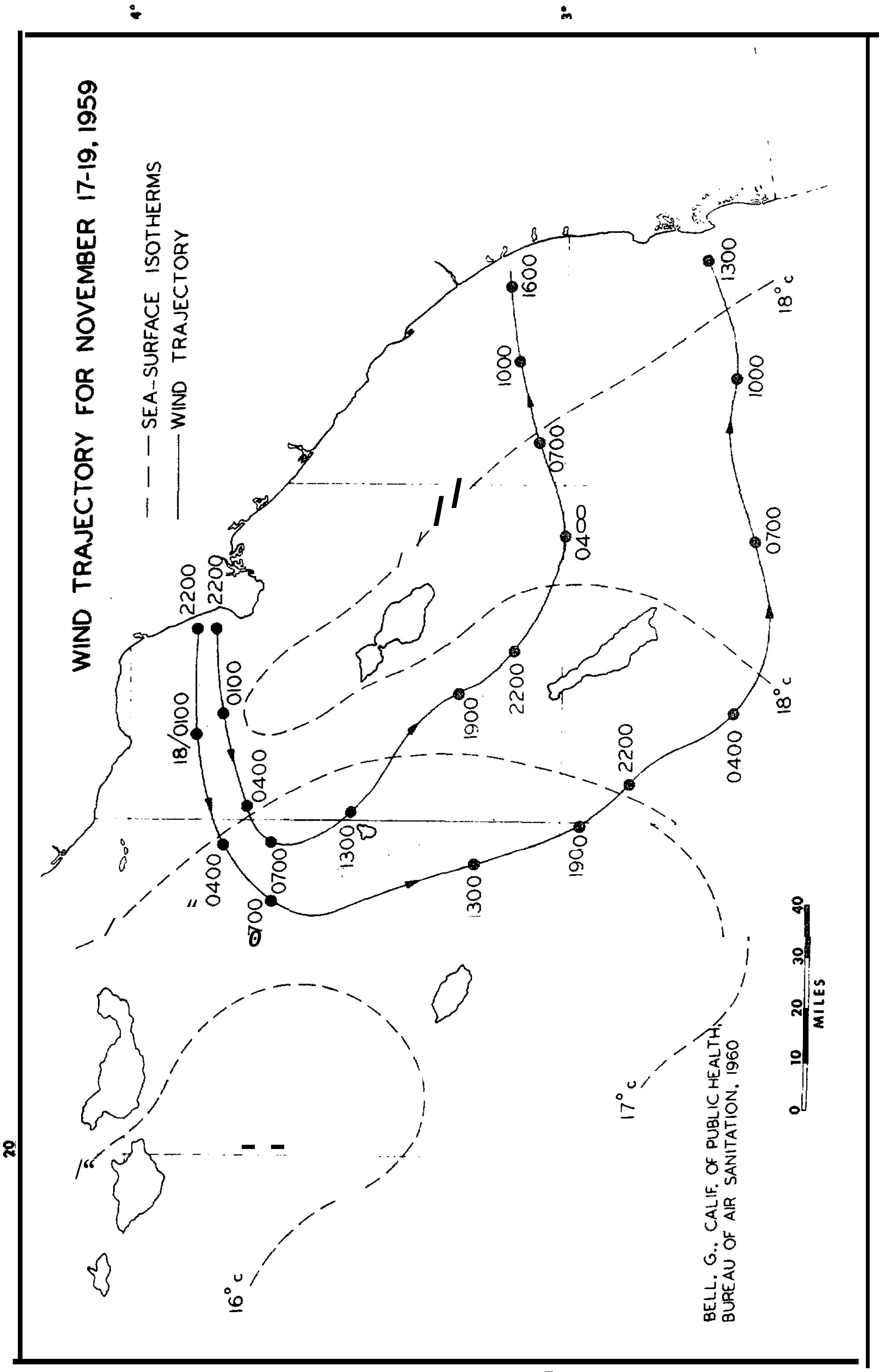
FIGURE 6-26



WIND TRAJECTORY FOR NOVEMBER 17-19, 1959
SEA-SURFACE ISOTHERMS
WIND TRAJECTORY
16°c
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BELL, G., CALIF. OF PUBLIC HEALTH,
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FIGURE 6-27

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