SAND BUDGET
FOR CAPITOLA BEACH,
CALIFORNIA

Richard Glenn Anderson

United States
Naval Postgraduate School

THESIS

SAND BUDGET FOR CAPITOLA BEACH, CALIFORNIA

by

Richard Glenn Anderson

Thesis Advisor: Warren C. Thompson

March 1971

Sand Budget for Capitola Beach, California

by

Richard Glenn Anderson
Lieutenant Commander, United States Navy
B.S., United States Naval Academy, 1963

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OCEANOGRAPHY

from the

NAVAL POSTGRADUATE SCHOOL
March 1971

ABSTRACT

The beach at Capitola, California has a history of short-term variations about a nominally wide beach. This pattern was interrupted in 1965 when the beach was greatly depleted following the construction of Santa Cruz Harbor. The beach remained small until the construction of a groin and subsequent sand fill at Capitola in 1970.

The annual sand budget developed for Capitola Beach shows a net gain of 1,300 cu. yds. The sand sources are littoral drift, 300,000 cu. yds., river discharge, 8,000 cu. yds., and seacliff erosion, 3,800 cu. yds., while sand loss is due to littoral drift, 310,500 cu. yds.

The observed short-term variations in the beach are reflected in the monthly sand budget. The budget permits evaluation of the effect on the beach of varying each source due to the construction of artificial barriers. It is concluded that the harbor construction at Santa Cruz was responsible for the sand depletion at Capitola Beach in 1965.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

The author wishes to express his sincere appreciation to those whose efforts made this study possible. My particular thanks go to my advisor, Professor Warren C. Thompson, for his sound advice and assistance throughout the study. The San Francisco District Office of the U. S. Army Corps of Engineers and the City of Capitola provided tremendous interest and assistance in the collection of data for this study. Additional thanks are extended to Miss Sharon Raney of the Naval Postgraduate School Computer Facility for her programing assistance and to Mr. Jack Mellor of the Naval Postgraduate School Oceanography Department for his assistance in the field work.

I. INTRODUCTION

A. PURPOSE AND SCOPE

Cardinal own

The objective of this study is to determine the factors that control the sand supply to the beach at Capitola, California, and to explain the large variability that has characterized this beach. The approach taken has been to establish a sand budget for the beach in which the sand sources and losses have been determined quantitatively, both on a monthly basis and on an annual basis, so that variations in the sources and losses could be examined.

The volume of sand on Capitola Beach has exhibited great seasonal variability over the years. Prior to 1965, in spite of this variability, there had generally been a beach of sufficient size for recreation and protection of beach front businesses from storm waves. Since 1965, however, the beach has been considerably smaller and has been nonexistant at times.

The depletion of the beach at Capitola was preceeded by the construction of a small boat harbor at Santa Cruz, California during the period 1962-1964. Whether or not this construction had any effect on Capitola Beach is one of the points considered in this study. The history of the beach problems at Capitola have been partially documented by the U. S. Army Corps of Engineers [1958 and 1969]. The San Francisco District Office of the Corps has a photographic file on Capitola Beach which is included for reference in Appendix D.

In April 1970, a groin was constructed at the eastern or downcoast end of the beach and 20,000 cubic yards of sand were placed on the beach. The effects of the groin and its influence on the beach will also be discussed, although only a preliminary evaluation of the groin is possible at this time.

B. DESCRIPTION OF THE AREA

The coast of northern Monterey Bay is characterized by seacliffs ranging in height from 30 feet to 70 feet. They form the landward margin of a broad, alluvium-covered marine terrace fronting the Santa Cruz Mountains. The roughly east-west orientation of this coastline provides protection from winter swell from the northwest but exposes it to local storm waves and swell from the southwest quadrant.

The community of Capitola is located four miles east of the city of Santa Cruz on Monterey Bay, California (Figure 1). Capitola Beach (Figure 2), at the mouth of Soquel Creek, is an isolated beach about 400 yards in length, flanked by 40-foot seacliffs. The volume of sand on the beach is of primary importance to the community since the beach is heavily used in the summer season. In addition, commercial structures on the ocean front are protected from ocean storms by the presence of the beach.

Soquel Creek enters Monterey Bay near the west end of the beach and about 100 yards east of Capitola Wharf. The creek is intermittent and flows only in the winter rainy season from October to April. During the remainder of the year, a wave-built bar fronts the creek mouth and a small lagoon forms at the back of the beach.

The seacliffs to the west of the beach, called Opal Cliffs, average 40 feet in height. They are composed of horizontally stratified marine siltstones of the Pliocene Purisima Formation overlain by deposits of Pleistocene alluvium. Opal Cliffs extend from Capitola southwest to Soquel Point, a distance of about two miles. From Soquel Point the coast trends northwest to the city of Santa Cruz two miles upcoast. This section of coastline has cliffs similar to those described above but which

are interrupted by three small stream-cut valleys fronted by sandy beaches.

The seacliffs on the east side of Capitola Beach extend for about one mile to New Brighton State Beach, a very wide, sandy beach. The coastline begins to curve at New Brighton Beach and changes its orientation to southeast. As will be discussed in detail later, the orientation of the coastline between Capitola and New Brighton Beaches is such that littoral drift is eastward or downcoast in all months of the year.

II. SHORELINE SECTORS STUDIED

The shoreline under study in this paper extends from Santa Cruz Harbor to the groin at Capitola Beach. It was divided into three sectors: Santa Cruz, Opal Cliffs, and Capitola Beach (Figure 1). Capitola Beach is the sector of primary interest while the other two sectors have a direct influence on Capitola Beach. Each of the three sectors has a generally straight shoreline but of different orientation. Therefore littoral drift, to be discussed later, was assumed to be constant throughout a given sector.

The Santa Cruz Sector was selected as a littoral unit because the net annual downcoast drift into this sector at Santa Cruz Harbor is known from field surveys by the Army Corps of Engineers [1969]. Since the net annual littoral drift for the entire study area was found to be downcoast and since the sectors are contiguous, it is possible to begin the development of a sand budget at Capitola Beach with a knowledge of the actual littoral transport into the study area.

The Opal Cliffs Sector has a common boundary with the Santa Cruz Sector at Soquel Point. Therefore the littoral drift out of the Santa Cruz Sector is the littoral drift into the Opal Cliffs Sector. Since the littoral transport was assumed to be constant throughout each sector, the littoral drift out of the Opal Cliffs Sector and into the western boundary of the Capitola Beach Sector is known.

The Capitola Beach Sector is defined by the physical limits of the beach. Sand sources to this sector are littoral drift from the west and sediment discharge from Soquel Creek, while sand losses are attributed to

littoral drift downcoast. No sand enters Capitola Beach from the coastal segment lying eastward of the groin.

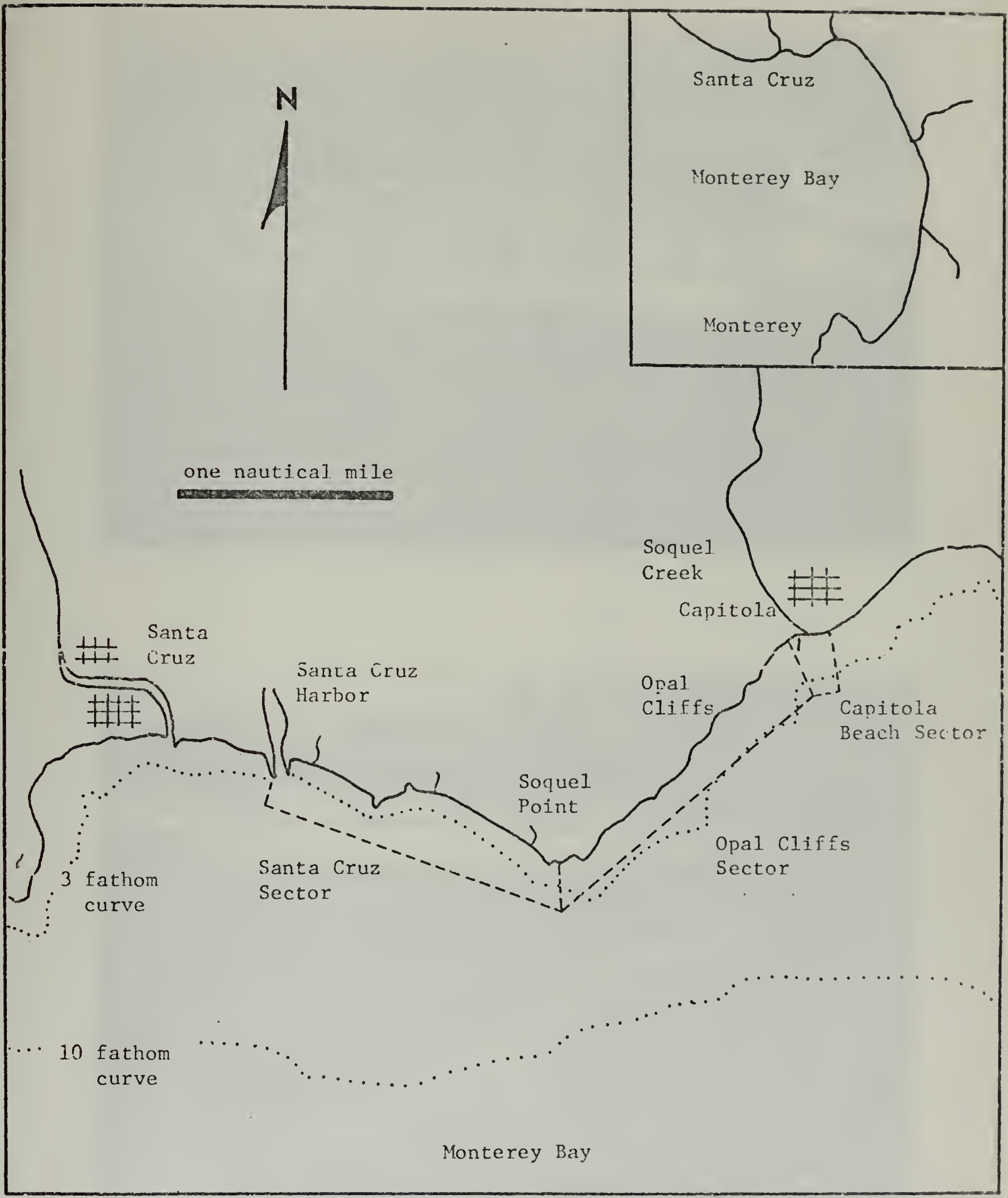


Figure 1. Area of Study and Sector Limits

Figure 2. Photographs of Capitola Beach, December 1970 (photographs by the author)

III. DETERMINATION OF POTENTIAL LITTORAL DRIFT

Field measurements of littoral drift were not made during this study. The only known drift measurements in the area are those made by the Army Corps of Engineers at Santa Cruz Harbor. Accordingly, for the purpose of compiling the sand budget for each of the three coastal sectors, the littoral sand transport in each sector was determined by computing the longshore component of wave power in the surf zone using deep-water statistical wave data. The shoreline sectors in this study have essentially straight coastlines and the bottom contours in each sector are reasonably uniform. Therefore the littoral drift calculations for each sector are considered to represent the littoral drift at any shoreline location within that sector.

Since littoral drift was computed using statistical wave data, the concept of "potential littoral drift" or "potential drift" is introduced. The potential drift represents the drift that would be expected to occur under the influence of waves if an unlimited supply of sand were available. It is evident that the actual drift cannot exceed the potential drift since by definition the potential drift is the maximum drift which can be supported by the existing wave conditions. However should the supply of sand to a beach be less than the potential drift, the excess energy in the waves will remove sand from the beach in an attempt to transport at full capacity.

The wave data used to determine the potential littoral drift passing through a littoral sector were taken from a report prepared for the Army Corps of Engineers by National Marine Consultants (NMC) in 1960. This

report provides statistical wave data on a monthly basis for seven offshore stations along the California coast. The wave data were hindcasted from 6-hourly synoptic weather charts of the North Pacific Ocean covering a three-year period. These data are presented in the form of tables giving the frequency of occurrence of deep-water waves by height, period, and direction. The frequency of occurrence of wind waves and swell are tabulated separately. The data from NMC Station 3, located about 80 miles northwest of Capitola, were used in this study with certain modifications that are described later.

The littoral drift rate in a given sector was determined by first computing the longshore component of wave power, P_e, per unit length of beach using a formulation presented by Bowen and Inman [1966] where:

$$P_e = E_o C_o n_o \left(\frac{b_o}{b_b}\right) \sin \alpha_b \cos \alpha_b$$

$K_r = \sqrt{\frac{b_o}{b_b}}$

The subscript "o" refers to deep-water and "b" to the surf zone. E_o is wave energy per unit area in deep water, and is given by $\frac{1}{8} \rho g H_o{}^2$, where ρ is density of seawater, g is acceleration of gravity, and H_o is deep-water wave height. $C_o n_o$ is the group velocity in deep-water and equals $\frac{1}{2} \frac{gT}{2\pi}$ where T is wave period. b_o and b_b refer to the distance between a given pair of wave orthogonals in deep water and at the surf zone, respectively. The breaker angle with the shoreline is represented by α_b, where positive angles indicate downcoast drift and negative angles upcoast drift.

The littoral drift rate, S, was then obtained using the following relationship from Bowen and Inman:

P_e - ft-lb/sec/ft of beach

$Q_S = 7.5 \times 10^3 P_e$

$$S \left[\frac{ft^3}{sec}\right] = 1.13 \times 10^{-4} P_e \left[\frac{lb\cdot mass\text{-}ft}{sec^3}\right]$$

This relationship was determined from field and laboratory measurements.

A computer program was written to utilize the modified NMC monthly wave data in calculating the potential drift per month, D, due to both swell and wind waves. The transport equation used in the computer program was:

$$D \left[\frac{yard^3}{month}\right] = S \left[\frac{ft^3}{sec}\right] \times \left[\frac{1\ yd^3}{27\ ft^3}\right] \times \left[\frac{\begin{array}{c}\text{time in seconds}\\ \text{from NMC data}\end{array}}{\text{month}}\right] \times [\text{percent}]$$

The "percent" in the above equation represents the values of frequency of occurrence contained in the NMC tables. The program yielded the littoral drift contribution for each set of wave conditions for which a frequency of occurrence is given, and then summed these to give the total transport in a particular month due individually to both swell and wind waves. These results allow the reader to distinguish between the effects of wind waves and swell. The littoral drift computations are presented in Tables I and II and the computer program in Appendix A.

It was necessary to modify the NMC wave data in two ways to make it consistent with wave conditions known to occur in the vicinity of Capitola. First, it was necessary to alter the frequency of occurrence of wind waves from the south-southeast due to the limited fetch in the bay. The wind waves from the south-southeast contained in the NMC data were hindcasted at Station 3 using a 200 nautical mile fetch. The height and period of the NMC waves were reduced to values consistent with a five nautical mile fetch. The frequencies of occurrence, which were not altered, were then placed under these new height-period combinations.

The NMC report does not include data on Southerly Swell resulting from storms off Mexico and Central America or in the Southern Hemisphere. Since Southerly Swell has an important effect on littoral drift in the Santa Cruz-Capitola area, its addition to the NMC data was considered essential.

No hindcast data on Southerly Swell are available for the California coast. However, a coarse estimate is possible of the dimensions and frequency of occurrence using lifeguard observations made daily at Newport Beach, California over a five-year period. These observations were made available by the Los Angeles District Office of the Army Corps of Engineers. Taking into account that the lifeguard observations were of breakers occurring under local conditions of refraction at Newport Beach, and that there is an additional travel distance to Monterey Bay, it was estimated that an average period of 15 seconds and a deep-water height of 2 feet satisfactorily describe these swell conditions.

The frequency of occurrence of this height-period combination, obtained by averaging the five years of Southerly Swell observations, was apportioned equally to each of three directions, southwest, south-southwest and south, and added on a monthly basis to the NMC data. Appendix B contains the lifeguard observations at Newport Beach and the changes and additions made to the NMC data.

Refraction diagrams for the Capitola-Opal Cliffs-Santa Cruz shoreline sectors used to determine breaker angles and values of b_o/b_b from the deep-water wave data were largely obtained from the San Francisco District Office of the U. S. Army Corps of Engineers. The author also constructed some refraction diagrams to provide additional data. A list of the refraction diagrams used is contained in Appendix C. Refraction

graphs showing curves of b_o/b_b and breaker angle for the shoreline sectors studied are also contained in Appendix C.

The results of the littoral drift computations show that, in the Capitola and Opal Cliffs Sectors, the drift is downcoast (west to east) because of the orientation of those sections of shoreline. The breaker angles in these sectors vary from 0° to $+45^\circ$, and b_o/b_b from 0.00 to 0.95. b_o/b_b has a similar range in the Santa Cruz Sector; however, the breaker angles vary from -10° to $+ 22^\circ$. Almost all waves from southerly directions cause an upcoast component of littoral drift in this sector, which at times predominates.

It is significant to emphasize here that the computations indicate that the littoral drift in the Capitola Beach Sector is downcoast in all months of the year. The limited fetch in Monterey Bay southeast of Capitola precludes any significant wave action which might cause a drift reversal. This point is important in that future consideration given to beach protection and planning on Capitola Beach need only consider uni-directional littoral drift.

TABLE I

Potential Littoral Drift [yds^3] for Each Sector Due to Swell and Wind Waves

MONTH	SANTA CRUZ		OPAL CLIFFS		CAPITOLA BEACH	
	Swell	Wind Waves	Swell	Wind Waves	Swell	Wind Waves
January	119,464	-34,922	19,269	44,874	17,093	45,644
February	148,326	-71,289	45,935	107,298	31,954	92,418
March	48,682	-9,597	17,732	21,589	14,563	22,467
April	43,938	8,742	5,238	15,928	5,568	13,414
May	7,922	2,252	10,790	7,969	9,432	7,457
June	-6,156	6,611	5,772	723	4,580	727
July	-7,764	3,295	5,981	344	4,714	441
August	-6,032	2,852	4,734	136	3,780	262
September	-480	-707	6,488	3,807	4,996	4,294
October	20,463	-3,703	5,161	7,458	3,416	8,218
November	20,988	975	1,403	1,752	1,503	2,127
December	54,958	2,763	8,382	7,154	5,080	6,385
TOTAL	444,309	-92,728	136,385	219,032	106,679	203,854

NOTE: Negative sign indicates upcoast drift.

TABLE II

Net Monthly Potential Littoral Drift [yds^3]

MONTH	SANTA CRUZ	OPAL CLIFFS	CAPITOLA BEACH
January	84,542	64,143	62,737
February	77,037	153,233	124,372
March	39,085	39,321	37,030
April	52,680	21,166	18,982
May	10,174	18,759	16,889
June	455	6,495	5,307
July	-4,469	6,325	5,154
August	-3,180	4,870	4,042
September	-1,187	10,295	9,290
October	16,760	12,619	11,634
November	21,963	3,155	3,631
December	57,721	15,536	11,465
ANNUAL	351,581	355,917	310,533

NOTE: A negative sign indicates upcoast drift.

IV. SAND SOURCES AND LOSSES

The sources and losses of sand to Capitola Beach, and the methods by which the supply and loss rates were determined, are described in this chapter. Capitola Beach has two sources of sand--littoral drift and sediment discharge from Soquel Creek. The littoral supply of material to Capitola Beach consists of sand transported into the study area past Santa Cruz Harbor and the material derived from seacliff erosion within the study area. Known sand losses to the beach are through littoral drift. Sand exchange with the offshore area is possible and is also discussed. The littoral calculations to be referred to were those discussed in the previous chapter. Determination of the sources and losses to the study area were calculated on both a monthly and an annual basis and are presented in the tables at the end of this chapter.

A. LITTORAL DRIFT

The largest supply of material to Capitola Beach arrives as littoral drift from the coastal sectors to the west (upcoast). The annual drift rate is considered to equal the net flow of littoral material past Santa Cruz Harbor, augmented by material eroded from the seacliffs between the harbor and Capitola Beach.

In November 1962, the West Jetty at Santa Cruz Harbor began impounding sand on its upcoast side. The newly formed beach appeared to reach an equilibrium condition in two years. Beach surveys taken at this site by the Army Corps of Engineers [1969] over this two-year period showed that approximately 600,000 cubic yards of sand were impounded, thus yielding an average net downcoast drift rate of 300,000 cubic yards annually past the harbor entrance.

An additional 2,000 cubic yards of sand is estimated to be added to this annual drift due to erosion of the seacliffs in the Santa Cruz Sector. Computation of the amount of material derived from seacliff erosion is discussed in Section C of this chapter. Thus, the total net annual drift out of this sector at Soquel Point and into the Opal Cliffs Sector is 302,000 cubic yards. The monthly apportionment of this source was based on the littoral calculations for the Santa Cruz Sector (Table III).

It is assumed that all of the littoral material transported downcoast to Soquel Point is transported around the point and therefore represents the littoral source to the Opal Cliffs Sector. The validity of this assumption is based on the observation that no sinks for sand are evident offshore along the Santa Cruz Sector. In addition, the ability of sand to be transported effectively around promintories on the California coast was demonstrated by Trask [1955].

Littoral drift calculations were made for the Opal Cliffs Sector to determine the monthly distribution of littoral material passing through this sector and into the Capitola Beach Sector (Table II). The littoral material in the Opal Cliffs Sector consists of material resulting from transport eastward around Soquel Point, plus the addition of sand derived from seacliff erosion within the sector.

The loss of sand from Capitola Beach is primarily due to littoral drift. Monthly littoral drift calculations for this sector indicate that the drift is continuously downcoast or to the east (Table II).

B. SOQUEL CREEK

Soquel Creek is the only stream drainage of any consequence between Santa Cruz Harbor and Capitola Beach. It drains an area of 42.4 square

miles. The geology of the drainage area is represented by a thick sequence of Tertiary marine sedimentary strata overlapping a granite basement of Mesozoic age. The granite exposed in the watershed is generally highly decomposed and soft.

Sediment transport rates have not been measured on Soquel Creek, but an estimate of the average annual supply of sand to the beach has been made by the San Francisco District Office of the Army Corps of Engineers [1969]. This was done using an estimate of sediment yield of 0.6 acre-feet/square mile/year from measurements made on San Francisquito Creek in San Mateo County and assuming a 20 percent sand yield from the total sediment transported. Thus the Corps determined that Soquel Creek provides an annual input of 8,000 cubic yards of sandy material to the beach.

The average sand contribution by months was estimated by relating the sediment transport to the creek discharge. Straub [1942] gives an empirical relationship between the sediment load and the square of the stream discharge. Thus the monthly sand contribution was obtained by multiplying the annual sand contribution by the monthly percent distribution of the square of the creek discharge (Table IV). The average monthly stream discharge measurements, over a 36-year period (1925 to 1961), for Soquel Creek were used for this purpose [Corps of Engineers, 1963].

The annual supply of sand from Soquel Creek to Capitola Beach is seen to be less than 3 percent of that provided by littoral drift. Accordingly, any inaccuracies in apportioning the creek supply by months are not considered of significance in the mean monthly sand budget picture for the beach.

miles. The geology of the drainage area is represented by a thick sequence of Tertiary marine sedimentary strata overlapping a granite basement of Mesozoic age. The granite exposed in the watershed is generally highly decomposed and soft.

Sediment transport rates have not been measured on Soquel Creek, but an estimate of the average annual supply of sand to the beach has been made by the San Francisco District Office of the Army Corps of Engineers [1969]. This was done using an estimate of sediment yield of 0.6 acre-feet/square mile/year from measurements made on San Francisquito Creek in San Mateo County and assuming a 20 percent sand yield from the total sediment transported. Thus the Corps determined that Soquel Creek provides an annual input of 8,000 cubic yards of sandy material to the beach.

The average sand contribution by months was estimated by relating the sediment transport to the creek discharge. Straub [1942] gives an empirical relationship between the sediment load and the square of the stream discharge. Thus the monthly sand contribution was obtained by multiplying the annual sand contribution by the monthly percent distribution of the square of the creek discharge (Table IV). The average monthly stream discharge measurements, over a 36-year period (1925 to 1961), for Soquel Creek were used for this purpose [Corps of Engineers, 1963].

The annual supply of sand from Soquel Creek to Capitola Beach is seen to be less than 3 percent of that provided by littoral drift. Accordingly, any inaccuracies in apportioning the creek supply by months are not considered of significance in the mean monthly sand budget picture for the beach.

C. SEACLIFF EROSION

Opal Cliffs extend from the wharf at Capitola to Soquel Point, a distance of 10,000 feet, with an average height of 40 feet. The lower part of these cliffs is composed of a horizontally bedded, friable, massive marine siltstone of the Pliocene Purisima Formation, the upper surface of which is a wave-cut terrace. This is overlain by coarsely stratified Pleistocene alluvium consisting of poorly consolidated sands and conglomerates with some clay facies.

A study was conducted to determine the yield of sand material from cliff erosion. Oblique photographs were taken of the cliff section from a helicopter to determine the thickness of the upper and lower layers and also the length of shoreline protected by artificial works. Figure 3 gives the reader an idea of the nature of the seacliff at two different locations along Opal Cliffs. The location of the photographs is indicated on Figure 4.

Sections of the seacliffs are protected from erosion primarily by the placement of rip-rap over the years at the base of the cliffs. Some private property owners have used additional means to protect their property, such as seawalls or concrete poured over the cliff. Figure 4 shows the type and extent of protection. From this it was determined that 5,600 feet of cliff length is directly exposed to erosion.

Six sediment samples were taken from the several sedimentary facies exposed in the cliff for the purpose of estimating the contribution of sand-sized materials from cliff erosion. Each sample was dried, dissociated, weighed, and sieved using 2.00 mm and 0.061 mm sieves. The material in the size range between the two sieves was considered to be erodable material available to the beach as sand. The Purisima siltstone and the

fine facies of the overlying alluvium yielded no sand-sized material. The conglomerate and sand facies of the upper alluvial layer yielded 48 percent and 98 percent, respectively, of sand-sized material. Estimation of the relative volume of each sediment facies exposed in the seacliff yielded a value of 0.145 cubic yards of sand available per cubic yard of seacliff eroded annually.

Santa Cruz County surveys, made in 1907, 1958, and 1967, of East Cliff Drive between Santa Cruz and Soquel Point indicate an average seacliff erosion rate generally in excess of 2 feet per year. However, the Opal Cliffs Sector is more sheltered and an estimated rate of erosion was taken here as 1.5 feet per year. This is consistent with the experience of a realtor and resident along the Opal Cliffs Sector, who reported (verbal communication) a landward retreat of his property of 60 feet in 40 years.

Taking the erodable length of seacliff as 5,600 feet, the average height as 40 feet, the average annual rate of cliff retreat as 1.5 feet, and the sand content per cubic yard of eroded material as 0.145 cubic yards, it was determined that 1,800 cubic yards of sand is available annually from cliff erosion. This mean annual supply was then partitioned on a monthly basis in direct proportion to the potential drift distribution for the Opal Cliffs Sector on the basis of the assumption that the cliff erosion is directly proportional to wave energy.

Seacliff erosion results from wave action and from slumping due to water saturation and to rain wash. These processes reach their maxima in the winter season. In view of the fact that the annual sand contribution from seacliff erosion amounts to well under one percent of the annual littoral drift rate, the monthly proration of the 1,800 cubic

yards of seacliff-derived sand according to the computed monthly wave energy is considered reasonable.

The mean monthly estimate of sand provided by erosion of Opal Cliffs is presented in Table V. This material is all carried eastward by littoral drift along the base of the seacliffs out of the Opal Cliffs Sector and into the Capitola Beach Sector.

The Santa Cruz Sector also contains seacliffs which are adding sediment to the littoral stream in that sector. Using an erodable cliff length of 5,000 feet, an erosion rate of 2 feet per year, and the same sand-yield figure of 0.145 cubic yards quoted above, it was determined that the total annual yield of these seacliffs is 2,000 cubic yards. As was stated in Section A, this amount was added to the downcoast drift in the Santa Cruz Sector in calculating the sand transport downcoast around Soquel Point.

D. ONSHORE-OFFSHORE SAND EXCHANGE

It is recognized that in addition to alongshore sand transport, beach sand is shifted onshore and offshore with the character of the incident waves. Widening or narrowing of the exposed beach accordingly does not necessarily mean that the sand budget for the beach is suffering a net increase or decrease. Onshore-offshore exchange of sand is considered here to be a reversible process independent of the alongshore transport. However, the possibility of an irretrievable net loss to the shelf offshore, or a net supply from the offshore shelf should be considered. It is recognized that major storms may carry sand seaward to depths where it may not be later returned, or it may be partially returned to the beach by long, low swell over a long period of time. Onshore-offshore rates of

exchange of sand are believed to be minor in the study area compared to alongshore transport, and are not treated here.

TABLE III

Monthly Distribution of Littoral Sand Transport in the Santa Cruz Sector

MONTH	POTENTIAL DRIFT DOWNCOAST (cu.yds)	PERCENT OF TOTAL POTENTIAL	MATERIAL TRANSPORTED DOWNCOAST (cu.yds)
January	84,542	23.4	70,700
February	77,037	21.3	64,400
March	39,085	11.1	33,400
April	52,680	14.6	44,000
May	10,174	2.8	8,500
June	455	0.1	300
July	0	0	0
August	0	0	0
September	0	0	0
October	16,760	4.6	14,000
November	21,963	6.1	18,400
December	57,721	16.0	48,300
ANNUAL	360,417	100.0	302,000

NOTE: Only the downcoast drift is of importance here. Therefore upcoast drift in July, August and September was not included.

TABLE IV

Monthly Distribution of Sand Discharge from Soquel Creek

MONTH	AVERAGE RUN-OFF (acre-ft)	$[\text{AVERAGE RUNOFF}]^2$	PERCENT OF $[\text{AVERAGE RUNOFF}]^2$	SAND DISCHARGE (cu. yds.)
January	4,844	23,300,000	15.30	1,230
February	7,549	56,800,000	37.40	2,990
March	5,692	32,300,000	21.20	1,700
April	4,016	16,100,000	10.60	848
May	1,260	1,590,000	1.04	42
June	561	315,000	0.21	0
July	341	116,000	0.08	0
August	206	42,500	0.03	0
September	172	29,600	0.02	69
October	386	149,000	0.10	8
November	1,528	2,340,000	1.52	123
December	4,374	19,000,000	12.50	1,000
ANNUAL	30,900	152,082,100	100.00	8,000

NOTE: The mouth of Soquel Creek is closed from mid-May to mid-September. The sand transported during these months is considered to be made available to the beach in September.

TABLE V

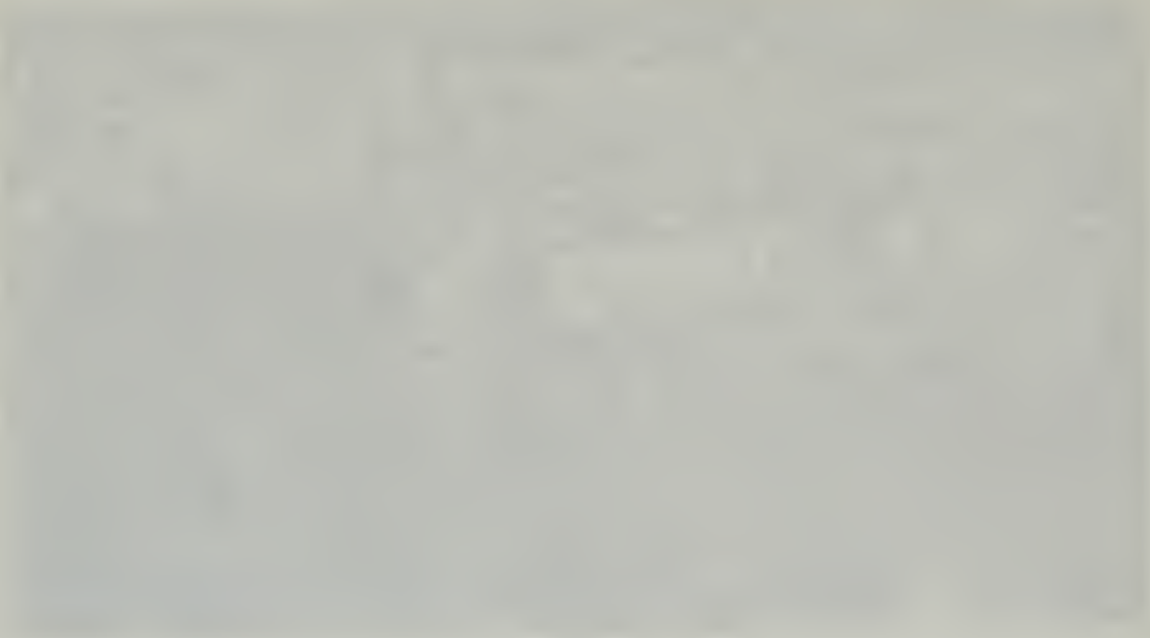
Monthly Distribution of Sand-sized Material Eroded from Opal Cliffs

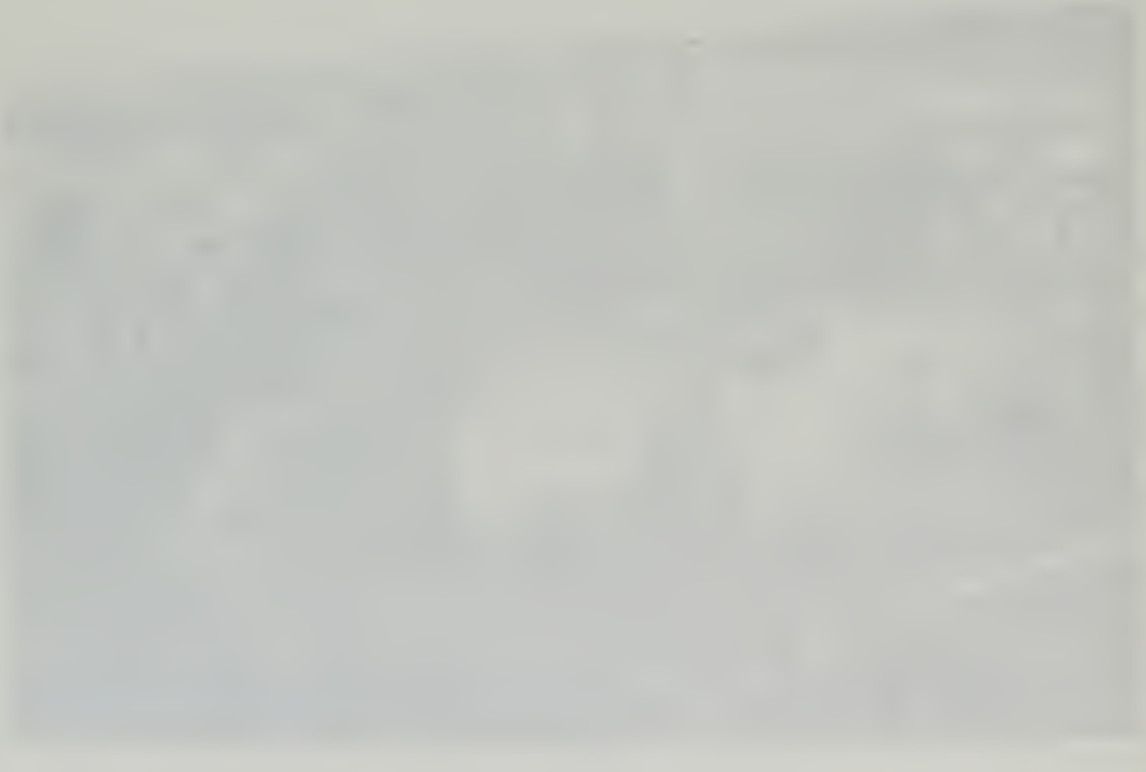
MONTH	POTENTIAL DRIFT (cu.yds.)	PERCENT OF TOTAL POTENTIAL	ERODED MATERIAL (cu.yds.)
January	64,143	18.0	324
February	153,233	43.1	776
March	39,321	11.0	197
April	21,166	5.9	108
May	18,759	5.3	95
June	6,495	1.8	32
July	6,325	1.8	32
August	4,870	1.4	25
September	10,295	2.9	52
October	12,619	3.5	63
November	3,155	0.9	17
December	15,536	4.4	79
ANNUAL	355,917	100.0	1,800

A

B

Figure 3. Aerial Photographs of Opal Cliffs
(photographs by the author)





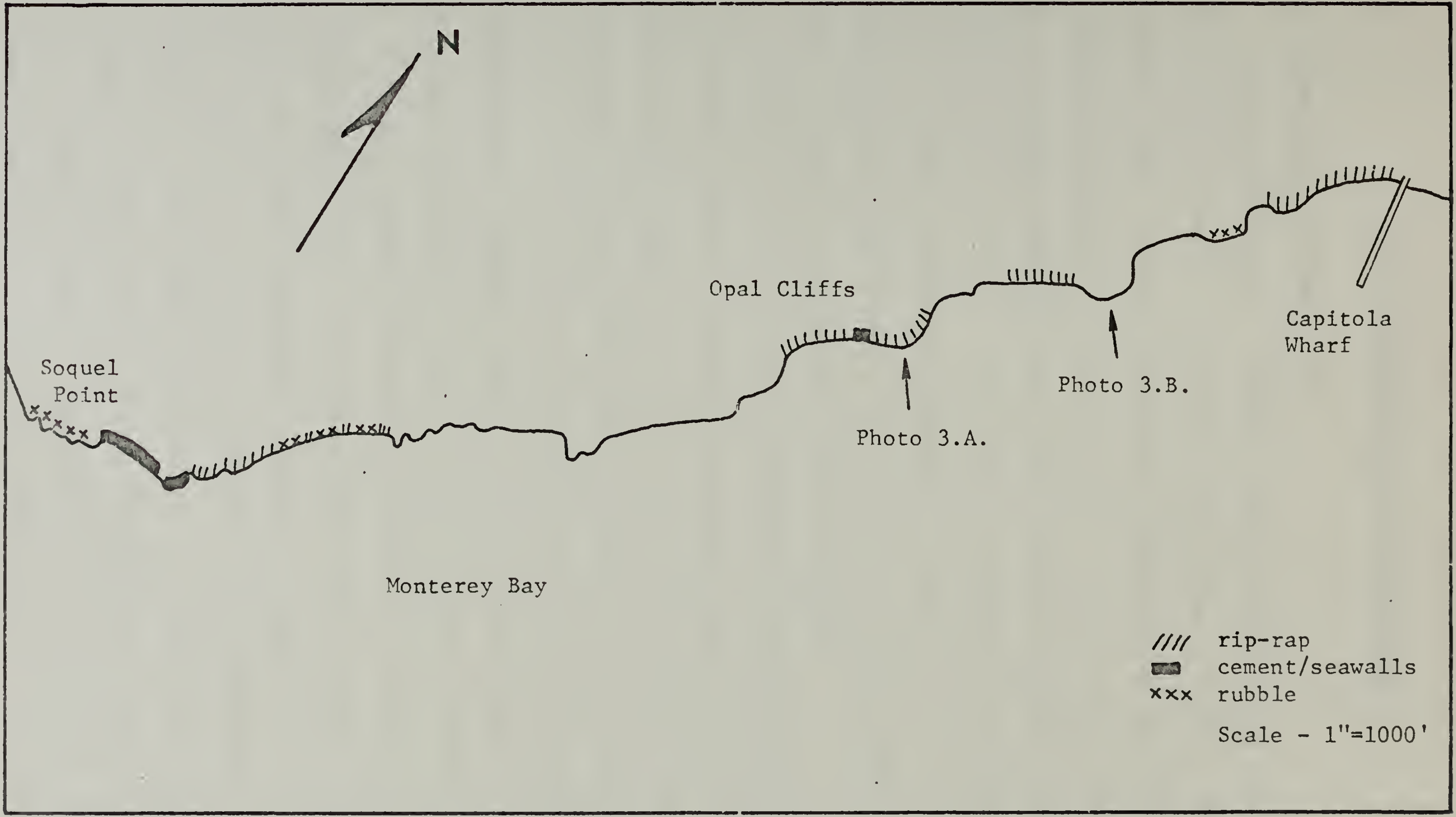


Figure 4. Erosion Protection in the Opal Cliffs Sector

V. SAND BUDGET FOR CAPITOLA BEACH

A. SAND BUDGET DETERMINATION

The sand budget for a coastal sector consists of an accounting of all gains and losses to the sector over a given period of time. At Capitola Beach the sand loss has been identified as potential littoral transport, downcoast, out of the sector. The sand gains were found to be by sediment discharge from Soquel Creek and littoral transport from the sectors to the west. The latter is composed of a measured transport at Santa Cruz Harbor, augmented by sand derived from erosion of the seacliffs between Santa Cruz Harbor and Capitola Beach. No gains from or losses to the offshore area are assumed.

Before the budget could be developed for Capitola Beach, it was necessary to make an additional assumption about the material transported around Soquel Point from the Santa Cruz Sector. The drift computations in Table II show that the potential drift in the Santa Cruz Sector is nearly equal to that along the Opal Cliffs Sector on an annual basis. However, because of the different coastline orientations of the two sectors, the monthly drift potentials are very different.

It was therefore assumed that the material transported around Soquel Point from the Santa Cruz Sector, when in excess of the drift potential along the Opal Cliffs Sector, is deposited nearshore on the east side of Soquel Point temporarily. Thus reservoiring of sand was assumed to occur there in some months. It was further assumed that this temporary deposit is then used to supplement the littoral drift when the drift potential along the Opal Cliffs Sector exceeds the amount of material transported around Soquel Point from the Santa Cruz Sector.

Verification of the assumption of local reservoiring of sand adjacent to the point came from discussions with local residents. Divers report crevices having depths of 15 to 20 feet in a very rocky bottom off Soquel Point; whereas, over this same area, at other times, surfers report walking on sand bottom (personal communication).

The mechanical process of determining the sand budget for a given month required the summation of sources starting with the known littoral drift at Santa Cruz Harbor. The potential littoral drift out of the Capitola Beach Sector for the month was then subtracted from this summation to yield the net gain or loss for the beach. The monthly and annual sand budgets for Capitola Beach are tabulated in Table VI and are graphically presented in Figure 5. To gain a better understanding of the derivation of Table VI, the budget for the month of April will be discussed in detail.

In April there is estimated to be 44,000 cubic yards of sand available to the Opal Cliffs Sector resulting from littoral transport out of the Santa Cruz Sector. An additional 108 cubic yards is available to the Opal Cliffs Sector from seacliff erosion, bringing the total sand volume available to 44,108 cubic yards. However, this sector has the drift potential to transport only 21,166 cubic yards. It was thus assumed that only this amount is transported through the Opal Cliffs Sector and that the remaining 22,942 cubic yards of excess sand is stored off Soquel Point. Some of this stored sand is seen to be used in May when the drift potential in the Opal Cliffs Sector exceeds the sand supply around Soquel Point from the Santa Cruz Sector.

The littoral material available to Capitola Beach from the Opal Cliffs Sector in April is 21,166 cubic yards, as indicated above. The sediment

discharge from Soquel Creek adds 848 cubic yards, bringing the total input to the Capitola Beach Sector to 22,014 cubic yards. The downcoast loss from the beach, on the other hand, represented by the potential downcoast drift, is 18,982 cubic yards. This results in a net gain for the beach in April of 3,032 cubic yards. The remainder of the table was determined in the same manner.

B. SAND BUDGET INTERPRETATION

Examination of the mean monthly budget for Capitola Beach (Table VI and Figure 5) shows that there are relatively large net sand gains by the beach in some months, notably December, January, April and May, and large net losses in others, particularly March, August and September. These results are consistant with the history of large seasonal variations observed in the beach. The permanence, or annual stability, of the beach, on the other hand, may be explained by the fact that the budget shows a net annual gain of approximately 1,300 cubic yards of sand.

The sand budget was derived for statistically average conditions of monthly wave occurrence and stream runoff. The possible effects on the beach of variations in the budget due to abnormal wave conditions, stream runoff, and the construction of artificial works along the coast are now examined.

The littoral drift calculations for the Santa Cruz and Opal Cliffs Sectors show that an eroding condition exists in these areas since littoral drift potential exceeds sand supply. Thus the maximum amount of littoral material possible from these sectors is supplied to Capitola Beach. However, the drift potential at Capitola Beach is approximately equal to the sum of the sources. Accordingly, an increase in wave

conditions would be expected to increase the potential drift at a greater rate than the increase in supply of sand to the beach, thereby giving rise to beach erosion at Capitola Beach to satisfy the potential drift.

Winter storms from the south, producing waves of more than average intensity or frequency of occurrence, could have the additional effect of stopping the littoral transport around Soquel Point by causing a drift reversal in the Santa Cruz Sector. It is expected that this would not only reduce the immediate sand supply to Capitola Beach, but also that in succeeding weeks and months, since it would prevent the storage of sand off Soquel Point which is used to supplement the littoral drift in the Opal Cliffs Sector. As a result, Capitola Beach would be expected to erode in order to satisfy the potential drift downcoast, and to remain depleted until replenished by above normal drift or stream supply at some later time.

Soquel Creek provides 8,000 cubic yards of sand annually to Capitola Beach during an average runoff year which represents about three percent of the total sand supply to the beach. However, the runoff and the sediment supply vary considerably from year to year, and during floods can be quite large in an interval of only a day or two. A major flood, such as the one in December 1955, may provide the beach with a supply of sediment that could possibly last for several years (Figure 6). The December 1955 flood was determined by the Corps of Engineers [1963] to be a once in 30-year event. The peak river discharge during that flood was 12,000 cubic feet per second, as compared with the average December discharge of 10.6 cubic feet per second (no figures on sediment transport are available). A series of years of unusually low runoff, on the other hand,

may result in a generally depleted beach condition over an extended period.

Man has the potential to alter the sediment supply of Soquel Creek by the construction of dams. In 1963 the U. S. Army Corps of Engineers [1963] had proposed that a flood control dam be constructed on Soquel Creek. The resulting reduction in the sand supply to Capitola Beach would, according to the sand budget computations, transform the relatively stable beach into one with an annual deficit of up to 6,700 cubic yards (1,300 gain minus 8,000 loss), depending on the location of the dam.

There are three types of coastal works in the study area which may have had or are now having an effect on Capitola Beach. The construction of Santa Cruz Harbor is considered to have been a factor only during the harbor construction period, 1962 to 1964; whereas, the newly installed groin at Capitola Beach and the rip-rap and seawall protection of Opal Cliffs are currently affecting the beach.

The construction work at Santa Cruz Harbor between 1962 and 1964 is believed by the author to have been a major factor in the observed reduction in the size of the beach at Capitola which became evident in 1965 (Figure 7). As was stated previously, while some 600,000 cubic yards of sand were being impounded west of the West Jetty at Santa Cruz Harbor, 400,000 cubic yards of dredged sandy material from the harbor area were deposited on the beach immediately downcoast during this two-year period. This left a net annual deficit of 100,000 cubic yards in the sand supply to Capitola Beach, representing a reduction in the annual supply of 30 percent. Since the downcoast littoral drift potential at Capitola Beach remained unaffected, an erosion condition of significant proportions existed at the beach for two years, resulting in a very depleted beach.

Surveys made in October 1965 and October 1966 by the U. S. Army Corps of Engineers of the beach formed west of the West Jetty at Santa Cruz Harbor showed that the rate of accretion had slowed as the new beach reached equilibrium, thus indicating that sand is being transported downcoast past the harbor entrance. At the same time it was observed that some sand was being deposited in the harbor channel. This sand has been returned to the littoral stream each year by dredging the channel and placing the spoil downcoast of the harbor entrance. It is therefore concluded that the littoral conditions at the present time downcoast of Santa Cruz Harbor are essentially the same as they were prior to the construction of the harbor, and that the harbor construction did cause the general depletion of the beach at Capitola during the two-year period when the West Jetty beach was being formed.

The effect of rip rap and seawalls placed over the years to reduce seacliff erosion in the study area, and thereby diminish the sand supply, is determined to be of minor importance to the sand budget at Capitola Beach. Assuming that the seacliffs were completely protected from erosion, the reduction in sand supply to the beach is estimated at approximately 3,800 cubic yards annually, which represents only 1.2 percent of the computed average annual littoral transport. Thus the construction of seawalls to protect property along the seacliffs is not considered to have a detrimental effect on the beach.

The groin constructed in April 1970 at the east end of Capitola Beach extends only to the minus one-foot contour (MLLW). Thus it is not an efficient littoral barrier. However, the purpose of the groin and the accompanying artificial beach fill of approximately 20,000 cubic yards was to provide the community with a recreational and protective

beach front. This has been accomplished. Capitola Beach will still be expected to experience the monthly variations discussed earlier; however, because of the greater sand reservoir created by the groin, losses and gains to the beach now represent a smaller percentage of the existing beach.

The groin will not completely prevent sand losses from the beach during large storms. However, if a large amount of sand is lost, a greater length of the groin is exposed and for a short time it may be expected to become a littoral barrier to help rebuild the beach. It may be recalled that sand transport is downcoast under all wave conditions, so that the groin, being located on the downcoast end of the beach, should prevent severe sand depletion in the future.

In August 1970, a cooperative beach surveillance program was begun by the author, the San Francisco District Office of the U. S. Army Corps of Engineers, and the City of Capitola. Beach surveys were made in August, September and November. Visual observations of wave and beach conditions are being made daily by personnel from the city offices. Preliminary results indicate that the groin and beach fill are satisfying the installation requirements. The small changes which have occurred on the beach to date are as expected and consistent with the computed average monthly budget.

TABLE VI

Sand Budget for Capitola Beach
(all values are in cubic yards)

MONTH	DOWNCOAST DRIFT FROM SANTA CRUZ SECTOR	CLIFF EROSION OPAL CLIFFS SECTOR	DRIFT POTENTIAL IN OPAL CLIFFS SECTOR	SAND STORED AT SOQUEL POINT	LITTORAL MATERIAL AVAIL. TO CAPITOLA BEACH	SEDIMENT DISCHARGE BY SOQUEL CREEK	TOTAL SUPPLY TO CAPITOLA BEACH	DRIFT POTENTIAL AT CAPITOLA BEACH	NET GAIN(G) OR LOSS(L) AT CAPITOLA BEACH
January	70,700	324	64,143	56,430	64,143	1,230	65,373	62,737	2,636(G)
February	64,400	776	153,233	0	121,606	2,990	124,596	124,372	224(G)
March	33,400	197	39,321	0	33,597	1,700	35,297	37,030	1,733(L)
April	44,000	108	21,166	22,942	21,166	848	22,014	18,982	3,032(G)
May	8,500	95	18,759	12,778	18,759	42	18,801	16,889	1,912(G)
June	300	32	6,495	6,615	6,495	0	6,495	5,307	1,188(G)
July	0	32	6,325	322	6,325	0	6,325	5,154	1,171(G)
August	0	25	4,870	0	347	0	347	4,042	3,695(L)
September	0	52	10,295	0	52	69	121	9,290	9,169(L)
October	14,000	63	12,619	1,444	12,619	8	12,627	11,634	993(G)
November	18,400	17	3,155	16,706	3,155	123	3,278	3,631	353(L)
December	48,300	79	15,536	49,549	15,536	1,000	16,536	11,465	5,071(G)
ANNUAL	302,000	1,800				8,000		310,533	1,267(G)

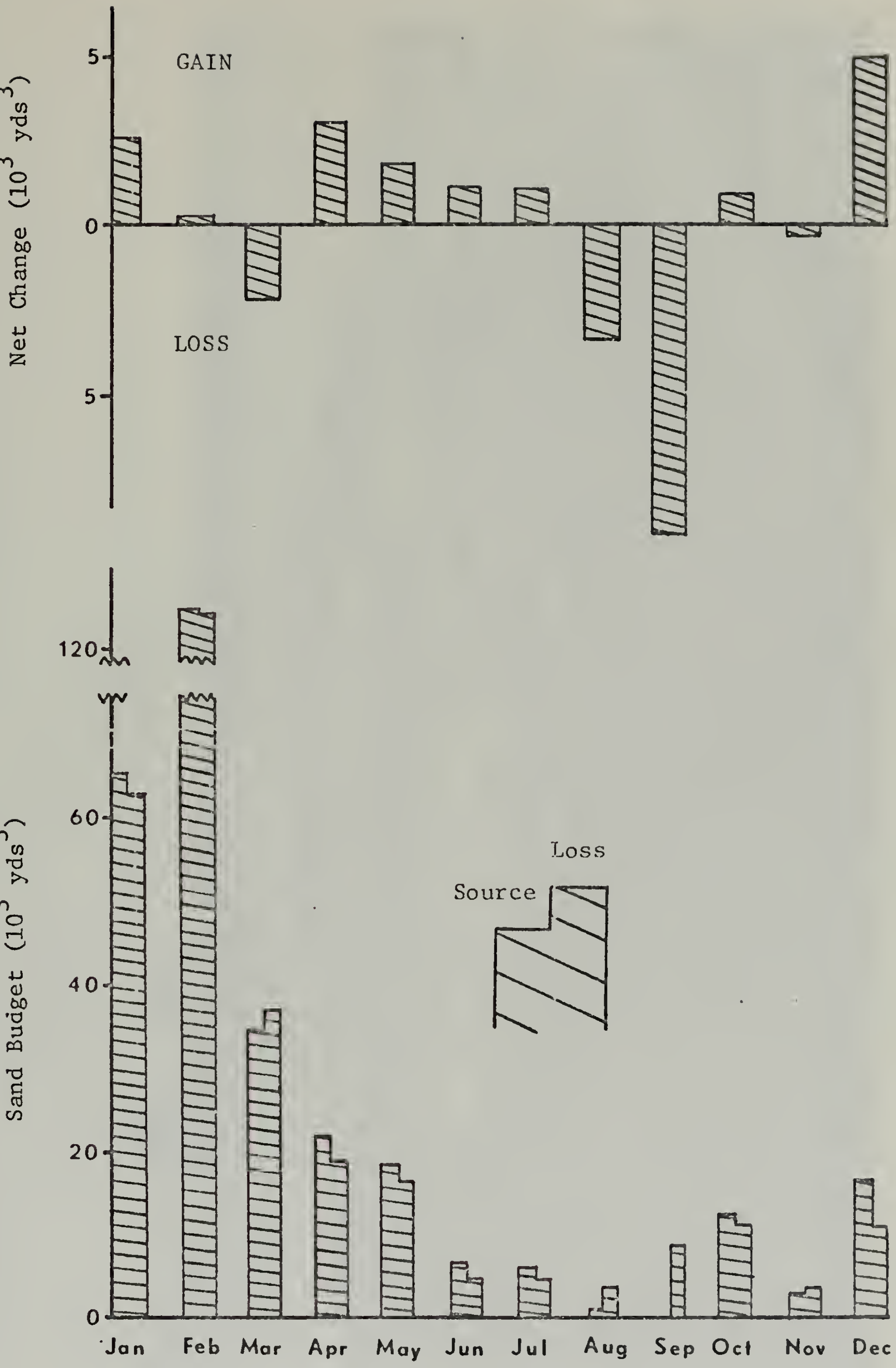


Figure 5. Sand Budget for Capitola Beach

Figure 6. Capitola Beach after a Major Flood, December 1955
(photograph by W. C. Thompson)

Figure 7. Depletion of Capitola Beach, December 1965
(photograph by Corps of Engineers)

VI. SUMMARY OF CONCLUSIONS

There are approximately 310,000 cubic yards of sand moving past Capitola Beach annually, of which 96 percent is littoral transport from the areas upcoast. The littoral drift at Capitola Beach is downcoast in all months of the year. Monthly or seasonal variations in the magnitude of the drift can be expected due to the varying wave conditions. These drift variations are evident in the computed sand budget, while seasonal beach changes are a matter of recorded history.

The sand budget developed in this study is believed by the author to be applicable to Capitola Beach—past, present and future. Past instances of an extremely small or non-existent beach can be considered to be the result of an abnormal occurrence. The construction of the harbor at Santa Cruz and the resulting interruption of the littoral drift was clearly such an occurrence. A similar, though less severe, effect may be expected to result from the construction of a flood-control dam on Soquel Creek.

The protection of the seacliffs from erosion does prevent some sand from reaching the beach. However, the small volume lost to the beach as a result of this protection is of minor consequence when compared with the potential economic losses of valuable seacliff property should the erosion of the cliffs proceed unchecked.

It is recommended that the beach surveillance program be continued for another year and that beach surveys be conducted bi-monthly. This would serve the dual purpose of documenting the effect of the groin and also validating the sand budget computed for this beach. A sand budget

prepared on a monthly basis would appear to have valuable application to other beaches.

APPENDIX A

LITTORAL DRIFT COMPUTER PROGRAM

Computer Program to Calculate Littoral Drift from Swell Statistics

```
C THIS PROGRAM WAS DEVELOPED SPECIFICALLY TO UTILIZE THE NMC
C WAVE DATA IN COMPUTING LITTORAL DRIFT ON A MONTHLY BASIS.
C THIS PROGRAM MAY BE USED TO CALCULATE THE LITTORAL DRIFT
C ANYWHERE ALONG THE CALIFORNIA COAST BY USING THE NMC DATA
C APPLICABLE TO THE LOCATION AND THE REFRACTION DATA FOR THE
C LOCATION.
      DIMENSION HST(14,8),HPC(14,8),RSQ(8,9),A(8,9),D(13),NC
     1ARD(9,12)
      REAL AMON(12)/'JAN ','FEB ','MAR ','APR ','MAY ','JUN
     1','JUL ','AUG ','SEP ','OCT ','NOV ','DEC '/
      REAL PER(8)/5.,7.,9.,11.,13.,15.,17.,19./
C THESE ARE THE VALUES OF WAVE PERIOD USED.
      REAL WAV(14)/2.,4.,6.,8.,10.,12.,14.,16.,18.,20.,22.,2
     14.,26.,28./
C THESE ARE THE VALUES OF WAVE HEIGHT USED.
      REAL TIME(12)/1129.,892.,1110.,736.,759.,621.,498.,569
     1.,815.,1061.,1012.,1129./
C THESE TIMES COME FROM THE NMC DATA FOR EACH MONTH.
      DO 100 I=1,14
      DO 100 J=1,8
  100 HST(I,J)=PER(J)*WAV(I)**2
      READ(5,200)((NCARD(I,J),I=1,9),J=1,12)
C THIS TELLS THE COMPUTER THE NUMBER OF DATA POINTS TO BE
C EXPECTED FOR EACH HEIGHT-PERIOD-DIRECTION-MONTH COMBIN-
C ATION.
  200 FORMAT(9I5)
      READ(5,300)((RSQ(I,J),I=1,8),J=1,9)
C THESE ARE THE VALUES OF
  300 FORMAT(8F5.2)
      READ(5,400)((A(I,J),I=1,8),J=1,9)
C THESE ARE THE BREAKER ANGLES.
  400 FORMAT(8F5.1)
      CONST=64.2*32.2**2*3600.0*1.13/(32.0*3.14*27.0<10.0**4
     1)
C THIS CONSOLIDATES ALL CONSTANTS AND CONVERSION FACTORS.
      DO 700 L=1,12
      D(L)=0.0
      DO 600 K=1,9
      NC=NCARD(K,L)
      IF(NC.EQ.0.)GO TO 600
      DO 600 I=1,NC
      READ(5,500)(HPC(I,J),J=1,8)
C THESE ARE THE PERCENT FREQUENCIES OF OCCURRENCE FROM THE
C NMC DATA.
  500 FORMAT(8F5.1)
      DO 600 J=1,8
      D(L)=D(L)+CONST*HST(I,J)*HPC(I,J)*RSQ(J,K)*COS(A(J,K)*
     10.01745)*SIN(A(J,K)*0.01745)*TIME(L)/100.0
  600 CONTINUE
      WRITE(6,650)AMON(L),D(L)
  650 FORMAT(1X,'THE LITTORAL DRIFT DUE TO SWELL FOR ',A4,'
     1IS ',F15.4,'CUBIC YARDS IN THE SANTA CRUZ SECTOR.')
  700 CONTINUE
      STOP
      END
```

```
C THIS PROGRAM WAS DEVELOPED SPECIFICALLY TO UTILIZE THE NMC
C WAVE DATA IN COMPUTING LITTORAL DRIFT ON A MONTHLY BASIS.
C THIS PROGRAM MAY BE USED TO CALCULATE THE LITTORAL DRIFT
C ANYWHERE ALONG THE CALIFORNIA COAST BY USING THE NMC DATA
C APPLICABLE TO THE LOCATION AND THE REFRACTION DATA FOR THE
C LOCATION.
      DIMENSION HST(14,8),HPC(14,8),RSQ(8,9),A(8,9),D(13),NC
     1ARD(9,12)
      REAL AMON(12)/'JAN ','FEB ','MAR ','APR ','MAY ','JUN
     1','JUL ','AUG ','SEP ','OCT ','NOV ','DEC '/
      REAL PER(8)/5.,7.,9.,11.,13.,15.,17.,19./
C THESE ARE THE VALUES OF WAVE PERIOD USED.
      REAL WAV(14)/2.,4.,6.,8.,10.,12.,14.,16.,18.,20.,22.,2
     14.,26.,28./
C THESE ARE THE VALUES OF WAVE HEIGHT USED.
      REAL TIME(12)/744.,680.,744.,720.,744.,720.,744.,744.,
     1720.,744.,720.,744./
C THESE TIMES COME FROM THE NMC DATA FOR EACH MONTH.
      DO 100 I=1,14
      DO 100 J=1,8
  100 HST(I,J)=PER(J)*WAV(I)**2
      READ(5,200)((NCARD(I,J),I=1,9),J=1,12)
C THIS TELLS THE COMPUTER THE NUMBER OF DATA POINTS TO BE
C EXPECTED FOR EACH HEIGHT-PERIOD-DIRECTION-MONTH COMBIN-
C ATION.
  200 FORMAT(9I5)
      READ(5,300)((RSQ(I,J),I=1,8),J=1,9)
C THESE ARE THE VALUES OF
  300 FORMAT(8F5.2)
      READ(5,400)((A(I,J),I=1,8),J=1,9)
C THESE ARE THE BREAKER ANGLES.
  400 FORMAT(8F5.1)
      CONST=64.2*32.2**2*3600.0*1.13/(32.0*3.14*27.0<10.0**4
     1)
C THIS CONSOLIDATES ALL CONSTANTS AND CONVERSION FACTORS.
      DO 700 L=1,12
      D(L)=0.0
      DO 600 K=1,9
      NC=NCARD(K,L)
      IF(NC.EQ.0.)GO TO 600
      DO 600 I=1,NC
      READ(5,500)(HPC(I,J),J=1,8)
C THESE ARE THE PERCENT FREQUENCIES OF OCCURRENCE FROM THE
C NMC DATA.
  500 FORMAT(8F5.1)
      DO 600 J=1,8
      D(L)=D(L)+CONST*HST(I,J)*HPC(I,J)*RSQ(J,K)*COS(A(J,K)*
     10.01745)*SIN(A(J,K)*0.01745)*TIME(L)/100.0
  600 CONTINUE
      WRITE(6,650)AMON(L),D(L)
  650 FORMAT(1X,'THE LITTORAL DRIFT DUE TO WIND WAVES FOR ',
     1A4,'IS ',F15.4,'CUBIC YARDS IN THE SANTA CRUZ SECTOR.'
     2)
  700 CONTINUE
      STOP
```

APPENDIX B

MODIFICATIONS MADE TO NMC WAVE DATA

Alterations to NMC Data for Limited Fetch Wind Waves

The frequencies of occurrence given below replace the data for wind waves from the south-southeast.

		WAVE PERIOD (SEC)		
MONTH	WAVE HEIGHT (FT)	5	7	9
January	2	2.4		
	4	4.0	2.2	0.5
	6	0.8	1.8	
February	2	1.4		
	4	2.3	0.9	0.3
March	2	1.3		
	4	0.6		
	6		0.8	
April	2	0.6		
	4	1.4	0.8	
	6		0.3	
May			No Change	
June			No Change	
July			No Change	
August			No Change	
September			No Change	
October	2	1.1		
	4	0.3	1.3	
November			No Change	
December	2	2.2		
	4	0.8	1.6	
	6		0.3	

Addition of Southerly Swell Statistics to NMC Data

NUMBER OF DAYS OF OCCURRENCE OF SOUTHERLY SWELL OBSERVED AT NEWPORT BEACH, CALIFORNIA

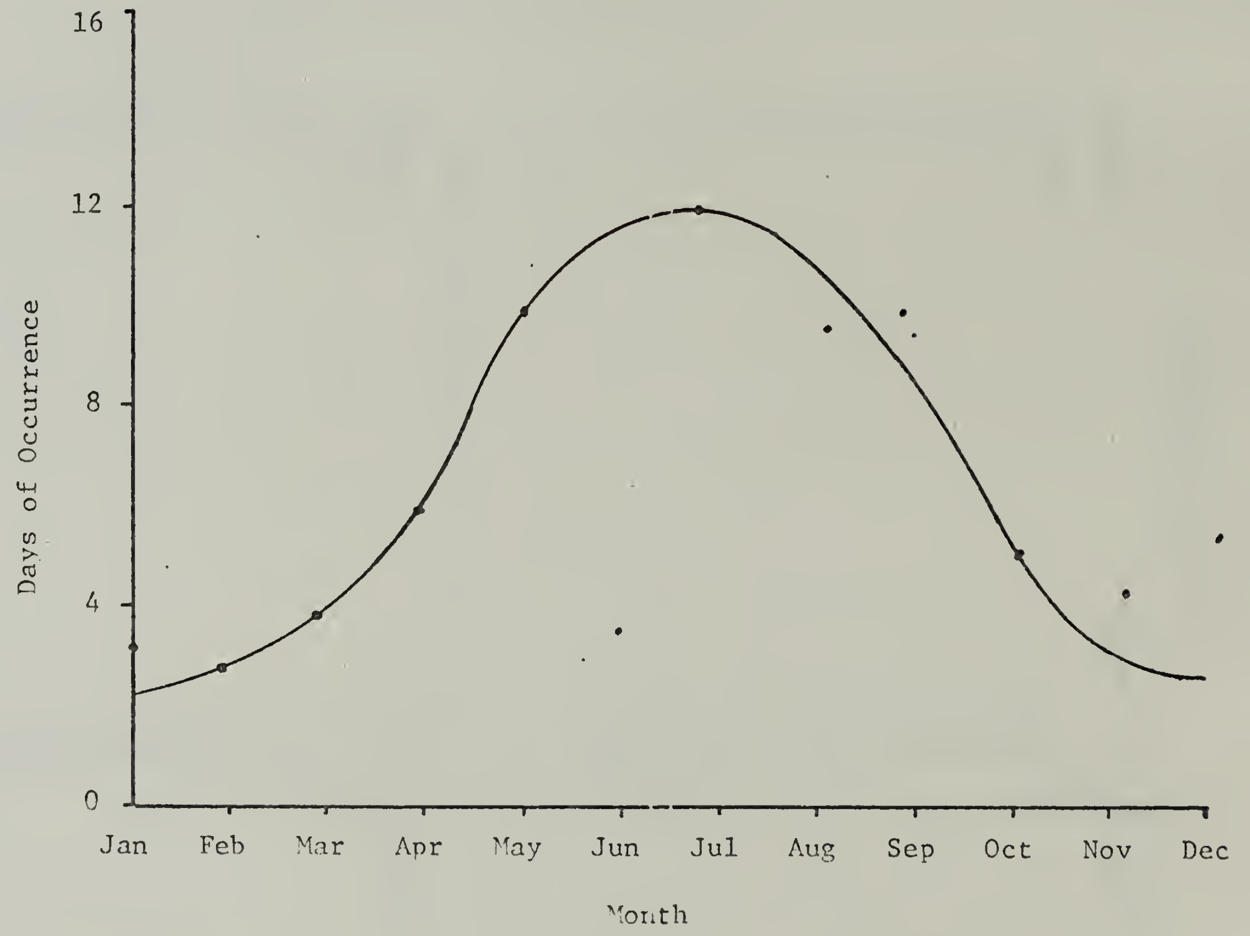
Month	1965	1966	1967	1968	1969	5-year Average
January	12	2	-	-	2	3.2
February	11	-	-	-	4	3.0
March	8	-	3	2	6	3.8
April	7	8	-	9	5	5.8
May	11	18	6	12	6	10.6
June	-	8	4	-	7	3.8
July	11	11	12	8	18	12.0
August	-	25	9	11	2	9.4
September	6	6	13	14	10	9.8
October	-	-	4	12	9	5.0
November	4	-	6	-	-	2.0
December	-	-	-	-	-	0.0

Data from Corps of Engineers, Los Angeles District Office

CHANGES TO NMC DATA

Month	Hours of Swell (from 5-yr avg)	$\frac{\text{Hrs Swell}}{\text{Time in NMC data}} \times 100$	% Swell in NMC Data	% to be added
January	76.8	6.8	0.9	5.9
February	72.0	7.9	1.5	6.4
March	91.2	8.1	1.5	6.6
April	139.0	18.8	1.1	17.7
May	254.0	32.2	2.7	29.5
June	278.0	44.6	0	44.6
July	288.0	57.6	0	57.6
August	226.0	39.9	0	39.9
September	235.0	28.8	0	28.8
October	120.0	11.8	0	11.8
November	48.0	4.7	0	4.7
December	75.0	6.7	0	6.7

NOTE: The June observation was abnormally low. Thus the value used for this month was taken from the following distribution curve.



Frequency of Occurrence of Observed Southerly Swell at Newport Beach, California

APPENDIX C

The refraction diagrams listed below were used in drawing the refraction graphs that follow.

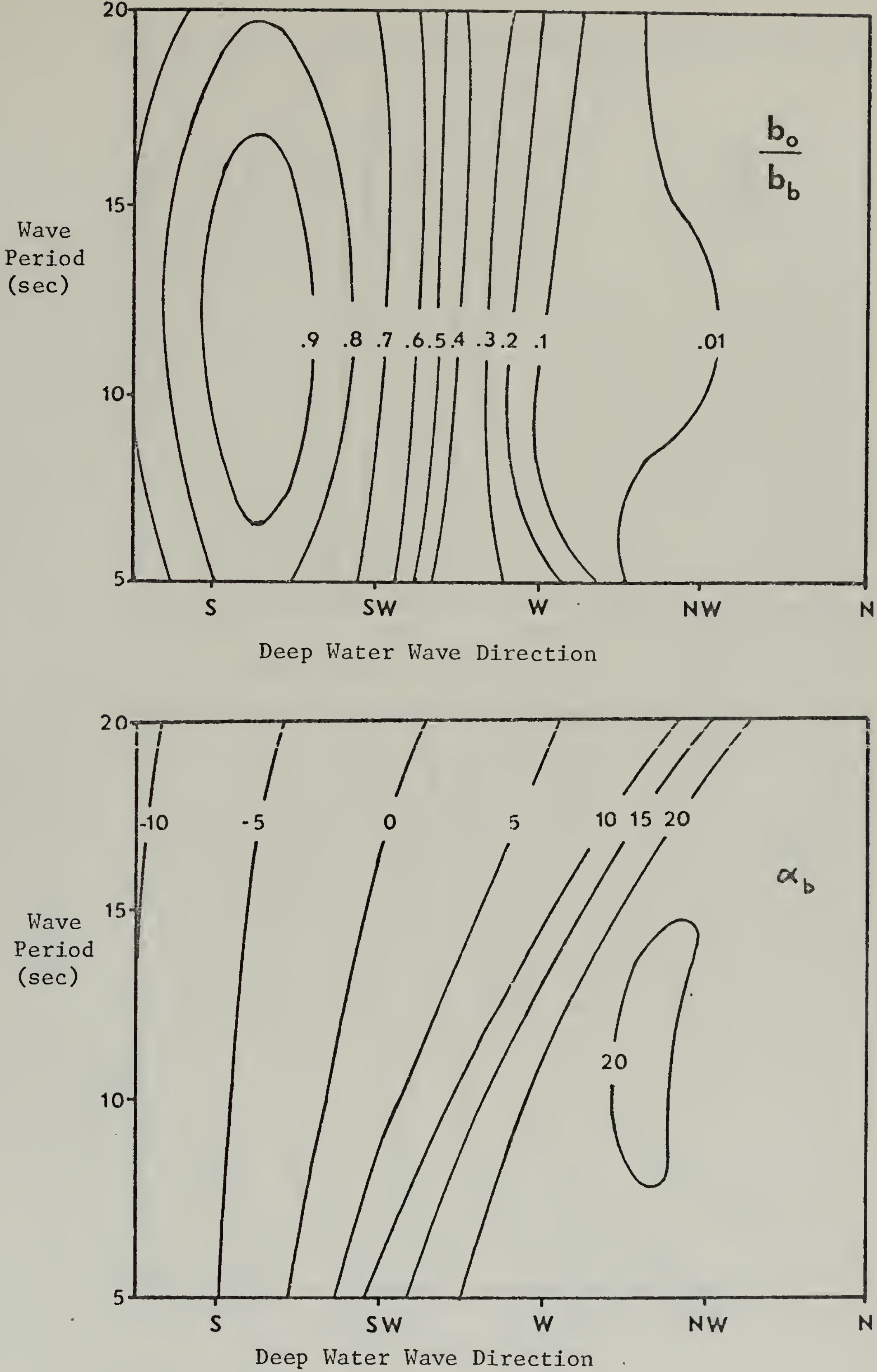
SANTA CRUZ SECTOR

Period	Deep Water Direction
16 sec	180 deg
12	183
12	200
12	248
12	270
12	292
12	315
8	225
8	270
8	315
6	225
6	240*
6	270
4	160*
4	240*

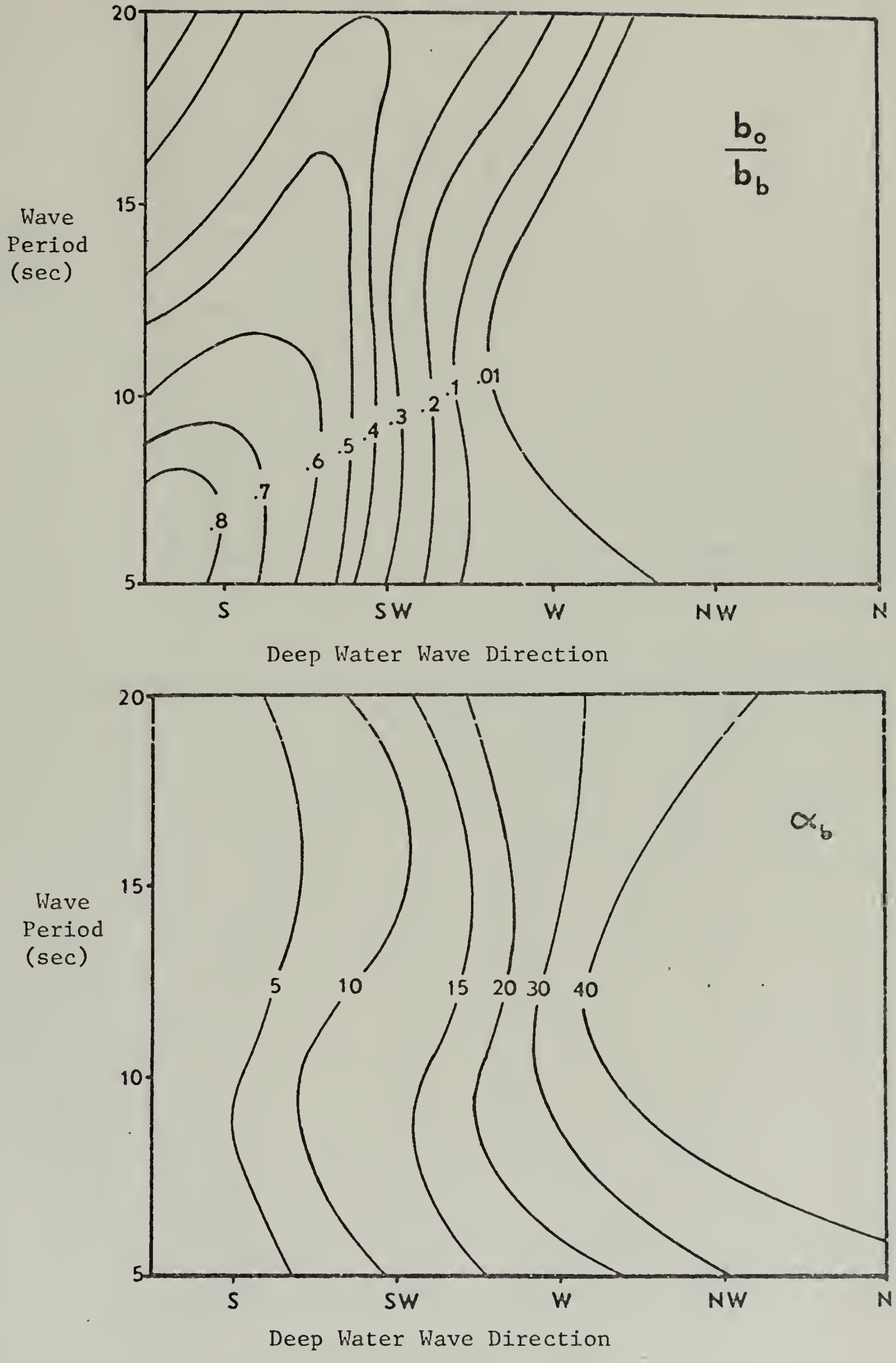
OPAL CLIFFS AND CAPITOLA BEACH SECTORS

Period	Deep Water Direction
16 sec	215 deg
16	240
16	270
16	320
14	180*
12	200
12	225
12	250
12	270
10	190*
8	163*
8	190
8	212
8	240
8	270
6	270*
4	180*
4	200*
4	230*

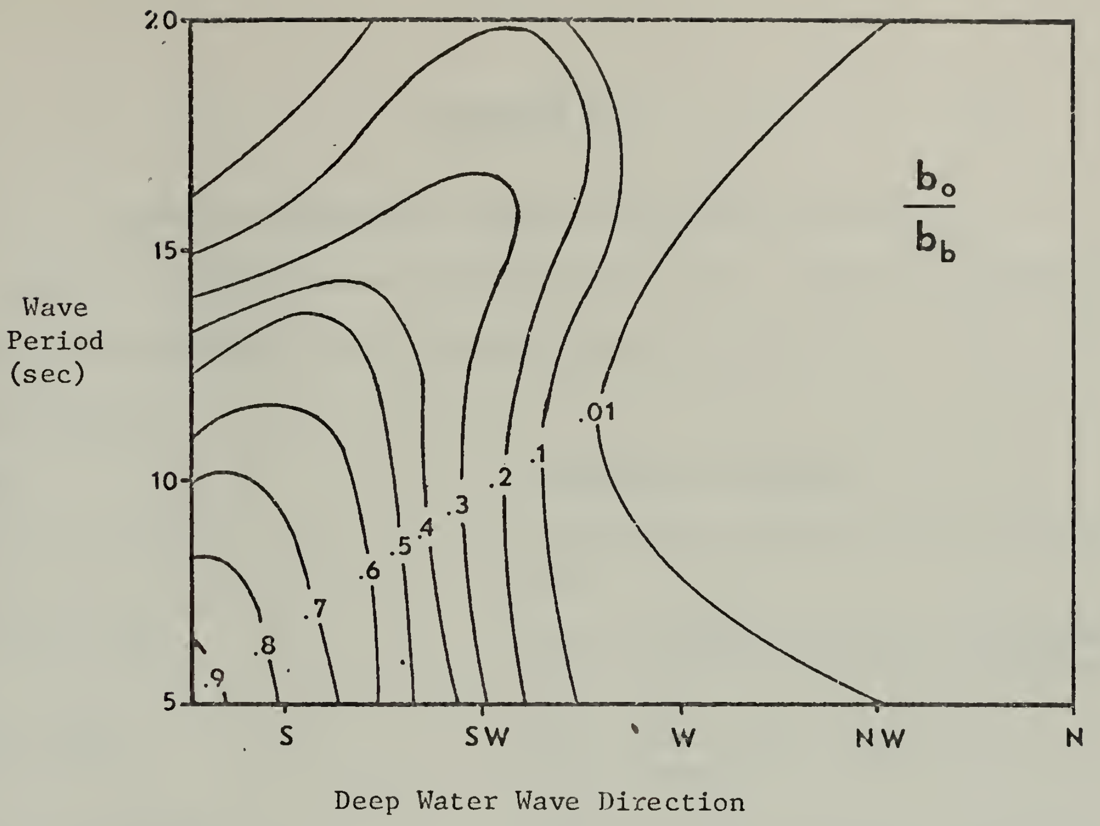
*constructed by the author



Refraction Graph for the Santa Cruz Sector



Refraction Graph for the Opal Cliffs Sector



Refraction Graph for the Capitola Beach Sector

APPENDIX D

LIST OF PHOTOGRAPHS AVAILABLE OF CAPITOLA BEACH

These photographs were taken at various times from 1904 through 1970, and are on file in the San Francisco District Office, U. S. Army Corps of Engineers.

Date	Description of Beach
4 October 1902	Wide beach extending west of Capitola Wharf.
14 June 1945	Two photographs showing a wide beach which extends west of Capitola Wharf.
Late 1946	Aerial photograph indicating a limited beach.
29 December 1955	Shows a very wide beach at Capitola Wharf.
30 May 1957	Wide beach.
31 May 1957	Wide beach.
10 April 1958	Very wide beach but very low profile (taken at low tide).
21 May 1959	Two photographs showing a beach of moderate width.
13 February 1960	Two photographs showing a very low profile and limited beach (taken at low tide).
11 May 1965	An aerial photograph showing a small beach at the mouth of Soquel Creek.
28 October 1965	Three photographs showing a very small amount of sand at the mouth of Soquel Creek.
30 November 1965	An aerial photograph showing the same situation as October 1965.
6 December 1965	Two photographs showing the same as October and November 1965.

APPENDIX D

LIST OF PHOTOGRAPHS AVAILABLE OF CAPITOLA BEACH

These photographs were taken at various times from 1904 through 1970, and are on file in the San Francisco District Office, U. S. Army Corps of Engineers.

Date	Description of Beach
4 October 1902	Wide beach extending west of Capitola Wharf.
14 June 1945	Two photographs showing a wide beach which extends west of Capitola Wharf.
Late 1946	Aerial photograph indicating a limited beach.
29 December 1955	Shows a very wide beach at Capitola Wharf.
30 May 1957	Wide beach.
31 May 1957	Wide beach.
10 April 1958	Very wide beach but very low profile (taken at low tide).
21 May 1959	Two photographs showing a beach of moderate width.
13 February 1960	Two photographs showing a very low profile and limited beach (taken at low tide).
11 May 1965	An aerial photograph showing a small beach at the mouth of Soquel Creek.
28 October 1965	Three photographs showing a very small amount of sand at the mouth of Soquel Creek.
30 November 1965	An aerial photograph showing the same situation as October 1965.
6 December 1965	Two photographs showing the same as October and November 1965.

11 August 1966	Two photographs showing a very narrow beach.
18 January 1967	Aerial photograph showing small beach centered at mouth of Soquel Creek.
29 January 1967	Shows same as 18 January photograph but taken at low tide.
April-May 1967	Four photographs showing a moderate beach of very low profile at low tide.
12 April 1969	Moderate beach.
11 July 1969	Seven photographs showing a very narrow beach east of the concrete flume and a small beach west of it.
24 April 1970	Nine photographs covering the construction of the groin at the east end of Capitola Beach.
November 1970	Six photographs showing a wide beach.

BIBLIOGRAPHY

1. Bascom, W. J., "Characteristics of Natural Beaches", *Proc. Fourth Conference on Coastal Engineering*, p. 163-180, Council on Wave Research, Univ. of Cal., 1954.

2. Bowen, A. J. and D. L. Inman, *Budget of Littoral Sands in the Vicinity of Point Arguello, California*, U. S. Army Coastal Engineering Research Center, Tech. Memo. No. 19, December 1966.

3. California Division of Mines, *Geological Map of California, Santa Cruz Sheet, 1:250,000*, State of California, Dept. of Nat. Res., Div. of Mines, Ferry Bldg., San Francisco, 1959.

4. Dorman, C. E., *The Southern Monterey Bay Littoral Cell: A Preliminary Sediment Budget Study*, M.S. Thesis, Naval Postgraduate School, Monterey, California, 1958.

5. National Marine Consultants, *Wave Statistics for Seven Deep Water Stations Along the California Coast*, prepared for the Los Angeles and San Francisco Districts, U. S. Army Corps of Engineers, 1960.

6. Straub, L. G., *Mechanics of Rivers: Hydrology*, p. 614-636, Dover Publications, 1942.

7. Trask, P. D., *Movement of Sand Around Southern California Promontories*, U. S. Army Corps of Engineers, Beach Erosion Board, Tech. Memo. No. 76, June, 1955.

8. U. S. Army Corps of Engineers, *Santa Cruz County, California, Beach Erosion Control Study*, 85th Congress, 1st Session, House Document No. 179, U. S. Government Printing Office, 1958.

9. U. S. Army Corps of Engineers, *Survey Report for Flood Control and Allied Purposes on Soquel Creek, Santa Cruz County, California*, U. S. Army Engineer District, San Francisco, California, 1963 (Rev. 1966).

10. U. S. Army Corps of Engineers, *City of Capitola, Beach Erosion Study, Santa Cruz County, California*, U. S. Army Engineer District, San Francisco, California, 1969.

11. Wiegel, R. L., *Oceanographical Engineering*, p. 341-381, Prentice-Hall, Inc., 1964.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Documentation Center Cameron Station Alexandria, Virginia 22314	2
2.	Library, Code 0212 Naval Postgraduate School Monterey, California 93940	2
3.	Department of Oceanography Naval Postgraduate School Monterey, California 93940	3
4.	Professor Warren C. Thompson, Code 58Th Department of Oceanography Naval Postgraduate School Monterey, California 93940	5
5.	LCDR Richard G. Anderson, USN 1001 Halsey Drive Monterey, California 93940	2
6.	Library (Attn: Mr. Maddox) Coastal Engineering Research Center 5201 Little Falls Road, N. W. Washington, D. C. 20016	1
7.	Commanding Officer U. S. Army Corps of Engineers Navigation and Shoreline Planning Division 100 McAllister Street San Francisco, California 94102	
	Attn: Mr. Robert Sloan	2
	Library	1
8.	City Manager, City of Capitola 420 Capitola Avenue Capitola, California 95010	3
9.	Chairman, Board of Supervisors Santa Cruz County Santa Cruz, California 95060	1
10.	Commanding Officer U. S. Army Corps of Engineers P. O. Box 274 Los Angeles, California 90053 Attn: Chief, Shore Protection Branch	1

11. Dr. Edward B. Thornton 1
Department of Oceanography
Naval Postgraduate School
Monterey, California 93940

12. Commanding Officer 1
U. S. Army Engineering Division, South Pacific
630 Sansome Street
San Francisco, California 94111
Attn: Mr. Orville T. Magoon

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1 ORIGINATING ACTIVITY *(Corporate author)*

Naval Postgraduate School
Monterey, California 93940

2a. REPORT SECURITY CLASSIFICATION

Unclassified

2b. GROUP

3 REPORT TITLE

Sand Budget for Capitola Beach, California

4 DESCRIPTIVE NOTES *(Type of report and, inclusive dates)*

Master's Thesis; March 1971

5. AUTHOR(S) *(First name, middle initial, last name)*

Richard Glenn Anderson

6 REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
March 1971	61	11

8a. CONTRACT OR GRANT NO.

b. PROJECT NO.

c.

d.

9a. ORIGINATOR'S REPORT NUMBER(S)

9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*

10 DISTRIBUTION STATEMENT

Approved for public release: distribution unlimited.

11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY

Naval Postgraduate School
Monterey, California 93940

13. ABSTRACT

The beach at Capitola, California has a history of short-term variations about a nominally wide beach. This pattern was interrupted in 1965 when the beach was greatly depleted following the construction of Santa Cruz Harbor. The beach remained small until the construction of a groin and subsequent sand fill at Capitola in 1970.

The annual sand budget developed for Capitola Beach shows a net gain of 1,300 cu. yds. The sand sources are littoral drift, 300,000 cu. yds., river discharge, 8,000 cu. yds., and seacliff erosion, 3,800 cu. yds., while sand loss is due to littoral drift, 310,500 cu. yds.

The observed short-term variations in the beach are reflected in the monthly sand budget. The budget permits evaluation of the effect on the beach of varying each source due to the construction of artificial barriers. It is concluded that the harbor construction at Santa Cruz was responsible for the sand depletion at Capitola Beach in 1965.

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Sand Budget						
Capitola Beach, California						
Littoral Transport						
Monterey Bay, California						

DD FORM 1 NOV 65 1473 (BACK)

S/N 0101-807-6821