REPORT ON THE BEACH EROSION IN THE REPUBLIC OF LIBERIA

November 1978

JAPAN INTERNATIONAL COOPERATION AGENCY

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Preface

The Government of Japan, at the request of the Government of the Republic of Liberia, decided to cooperate in identifying the causes of the beach erosion which had become a serious problem in the country and to recommend necessary measures for the problem. The Japan International Cooperation Agency (JICA) conducted a survey by sending to Liberia a team headed by Dr. M. Tominaga, The Ministry of Construction to conduct a survey for a period of three weeks from May 5th to May 25th, 1978.

The survey team examined the sites of beach errosion and collected the data necessary for analysing the causes of the problem and had a series of discussions with the authorities concerned of the Liberian Government. The team submitted a preliminary report on the survey to the Liberian Government during its stay in the country.

The present report has been prepared in Japan as a result of more detailed analysis of the data collected and the discussions conducted in Liberia. I hope this report will contribute to control of the beach erosion in Liberia and further promote the friendly ties between our two countries.

I would like to express my sincere appreciation to the officials concerned of the Government of Liberia for their kind and valuable cooperation offered to the survey team.

November, 1978

Shinsaku Hogen

President

Japan International Cooperation Agency

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Contents

1. Introduction

1.1 Objectives

The objectives of the team were: (1) to obtain information on beach erosion in the Republic of Liberia, (2) to find the causes of erosion, and (3) to recommend effective countermeasures by investigating the beaches and gathering data. And to give an advisory opinion about the investigation required to plan constal protection works. However, this report deals with only the beaches of Monrovia, Buchanan, and Greenville which require urgent countermeasures. Still general causes of erosion and countermeasures are described so that they may be of use as a reference for similar problems in the future.

The members of the team were as follows.

DR. M. TOMINAGA, Ministry of Construction
MR. H. HASHIMOTO, Ministry of Construction
MR. T. KIHARA, Ministry of Transport
MR. Y. MORITA, Ministry of Construction
MR. K. FUKUCHI, Japan International Cooperation Agency

1.2 Itinerary

The itinerary during the investigation is briefly shown in Table 1.

Table 1

Date	Day	Activity
5	Fri	Depart from Tokyo
6	Sat	Arrive in Monrovia
8	Mon	Previous arrangement with the Ministry of Public Works Courtesy
		Visit to the Japanese Embassy
		Visit to Ministry of Lands and Mines
		Obtaining maps at Liberian Cartographic Service
9	Tue	Obtaining data at Liberian Hydrological Service
		Investigation of erosion around Monrovia
10	Wed	Visit to LAMCO in Buchanan
		Request for the data
		Investigation of erosion in Buchanan
11	Thu	Visit to Liberian Cartographic Service
		Visit to the National Port Authority
		Visit to the Monrovia city-corporation
12	Fri	Visit to the Department of Meteorology
		Obtaining data at Liberian Hydrological Service
13	Sat	Data analysis

Date	Day	Activity
15	Mon	Visit to the Liberian Cartographic Service
		Visit to the Department of Meteorology
		Submit interim report to Minister G.J. Tucker of the Ministry of Public Works
		Return of group-head Dr. Tominaga to Japan
16	Tue	To Greenville by air
		Investigation of erosion
17	Wed	Data analysis
18	Thu	Aerial investigation of St. John River and of the coasts of Monrovia and Roberts Port Town
19	Fri	Obtaining the meteorological data at the Ministry of Commerce, Industry & Transportation
20	Sat	Data analysis
22	Mon	Report Writing
23	Tue	Investigation of the places of sand removal (Monrovia)
		Investigation of the conference hall of OAU
24	Wed	Interim report to Minister G.J. Tucker
		Visit to Japanese Embassy
25	Thu	Depart from Monrovia
27	Sat	Arrive in Tokyo

2. Summary

The summary of the report is given hereunder.

2.1 Characteristice of The Coast

1) The coast stretches about 560Km from N4°20' W8°25' to N6°55' W11°30', with monotonus and continuous sandy beach of 20m-50m width.

2) There are outlets of six relatively large rivers on the coast, and in the west of those outlets the coast line changes its direction clockwise: SE-NW to S-N

3) The waves are mostly swell, less than 1m in height and 9-10 sec. in period. The wave direction is inclined at small angle to the South to the perpendicular of the coast line.

4) The tidal range is about 1m and the tidal current is parrellel to the coast line.

5) The littoral transport is continuously in the direction of SE to NW, considering the following factors:
   (1) The wave direction to the coast line
   (2) At the headlands, the beach is wider in SE side than in NW side.
   (3) Sand deposits are found in SE side of river outlets, breakwaters and headlands, while erosion is in NW side of those places.

6) The sand is supplied from the coast of Ivory Coast and the rivers in Liberia, and flows out offshore at the headlands, and to the coast of Sierra Leone.

7) The littoral transport changes with the angle of the waves to the coastline, and it is estimated that the littoral transport along the Liberian coast will be 50,000m^3 per year from the rate of beach erosion and the energy of the waves, and that the effective volume of sand from the river will be 1.6×10^6 m^3 per year.

8) Seasonal and yearly variation of river discharge and wave conditions cause changes in the topography of coast line near the river outlets and headlands.

2.2 Causes of Beach Erosion

The causes of erosion in the places which the mission visited are (1) due to the change in the balance of littoral transport and (2) due to the drifting of the river outlets.

The causes of the change in the balance of littoral transport are blockage of sand draft by construction of breakwaters, removal of sand from the beach for construction materials and possible reduction of sand supply from the rivers after the construction of dams.

2.3 Countermeasures for Beach Erosion

1) Control of littoral transport by construction of structures such as groins, and detached breakwaters.
2) Artificial sand by-pass and sand nourishment at places where the sand drift is blocked by structures.
3) Strict control of sand removing from the beach near the housing area.
4) House construction control near the river outlets.
5) Combination of the above items 1 - 4.

2.4 New Kru Town in Monrovia

1) Comparing the aerial photograph taken in 1952 with the map of 1969 (Scale 1:7500), the shoreline is eroded about 100M in the stretch of 3 Km. Many houses were washed away.
2) The causes will be stoppage of sand drift by construction of breakwaters of the Freeport.
3) The countermeasures will be construction of groins in the North side of New Kru Town beach, combined with sand nourishment.
4) In the future, the dredged sand of the Freeport can be dumped in the South side of the beach for sand nourishment.

2.5 West Point in Monrovia

1) The erosion is taking place in the North side of West Point. West Point is situated in the South of the breakwater and a place of accumulation i in updrift. The River Mesurado must have been flowing along the South breakwater, but the outlet has shifted southward by the influence of sand deposit alongside the breakwater.
   This change of river outlet is causing erosion at West Point.
2) The countermeasures will be construction of a jetty in the North of West Point in order to stabilize the outlet position of the Mesurado.

2.6 ELWA and Old Congo Town in Monrovia

1) Comparing the aerial photograph taken in 1952 with the map of 1969

(Scale 1:7500), the shoreline is eroded about 40m.

2) The causes of erosion will be removal of sand from the beach near the Congo Town and Cooper's Beach.

3) The countermeasure will be control of sand removal from the beach.

2.7 Buchanan

1) The beach at Buchanan used to have possibility of erosion but the erosion has become severe after completion of the breakwaters.

2) Dumping of tailing materials helped to restore the beach but the erosion started to take place after dumping of tailing material was discontinued.

3) While sand is deposited in the East of the break-water, the sand was removed for construction purposes.

4) The causes of erosion will be mainly blockage of sand drift by the breakwaters.

5) The countermeasures will be construction of groins in the North of Buchanan City and sand nourishment.

2.8 Greenville

1) The beach and sand bank was heavily eroded in September 1977 and the sand bank was cut in May this year. Part of the road and several houses were washed away.

2) The probable causes of erosion will be:
   (1) Shifting of the outlet of the River Sinoe
   (2) Blockage of sand drift by the breakwater
   (3) Dredging work of the Greenville Port.

3) The countermeasures will be to stabilize the outlet position of the Sinoe by constructing a jetty on the west side of eroded area.

2.9 General Comments

The construction of structures for prevention of beach erosion requires a large amount of fund, and moreover those structures will not arrest the erosion completely.

Therefore the following measures will be more efficient to cope with the beach erosion problem:

1) To centralize the management of the Liberian beach in one organization.

2) To workout a systematic plan for construction and expansion of ports, zoning of housing area, designation of beaches for sand removal.

3) To conduct environmental assessment prior to construction of structures, such as ports and dams.

4) To control house construction on the beaches, outlets of rivers, where erosion is likely to take place.

3. Natural Conditions

In order to clarify the causes of beach erosion, and to find appropriate countermeasures, it is necessary to obtain information about the natural conditions. Beach erosion is a phenomenon which is caused by the shift of balance in the littoral transport and therefore the direction and rate of sand carried by waves and currents must be studied taking the natural conditions into account.

Natural conditions are: topography, geological features. meteorological conditions, waves and tides, and others. By investigating the topography and geological features near the beach, it is possible to obtain information about topographical changes in the past and to forecast future changes. The main external forces which generate littoral drift are wave and current, and the information about these are necessary to obtain knowledge about the transport characteristics of the sand. The rivers are considered to be the main source of sand to the beach, and therefore the characteristics, particularly the rate of transport at the outlet, must be known. Therefore, the problem using data about the natural conditions will be discussed in the first place.

3.1 Topography

The Republic of Liberia is located at the west coast of the African continent, and is situated approximately in the north latitude of 4°20'–8°30', and in the west longitude of 7°40'-11°30'. The country is bordered by Sierra Leone and Guinea to the northwest, and Ivory Coast to the east, and the Atlantic Ocean to the southwest.

Its land area is about 110,000 square kilometers. The coast stretches about 560 kilometers from N4°20' W8°25' to N6°55' W11°30' as shown in Fig.3.1. The coast is topographically fairly monotonous, having few islands and big bays, and its average direction is S40°W.

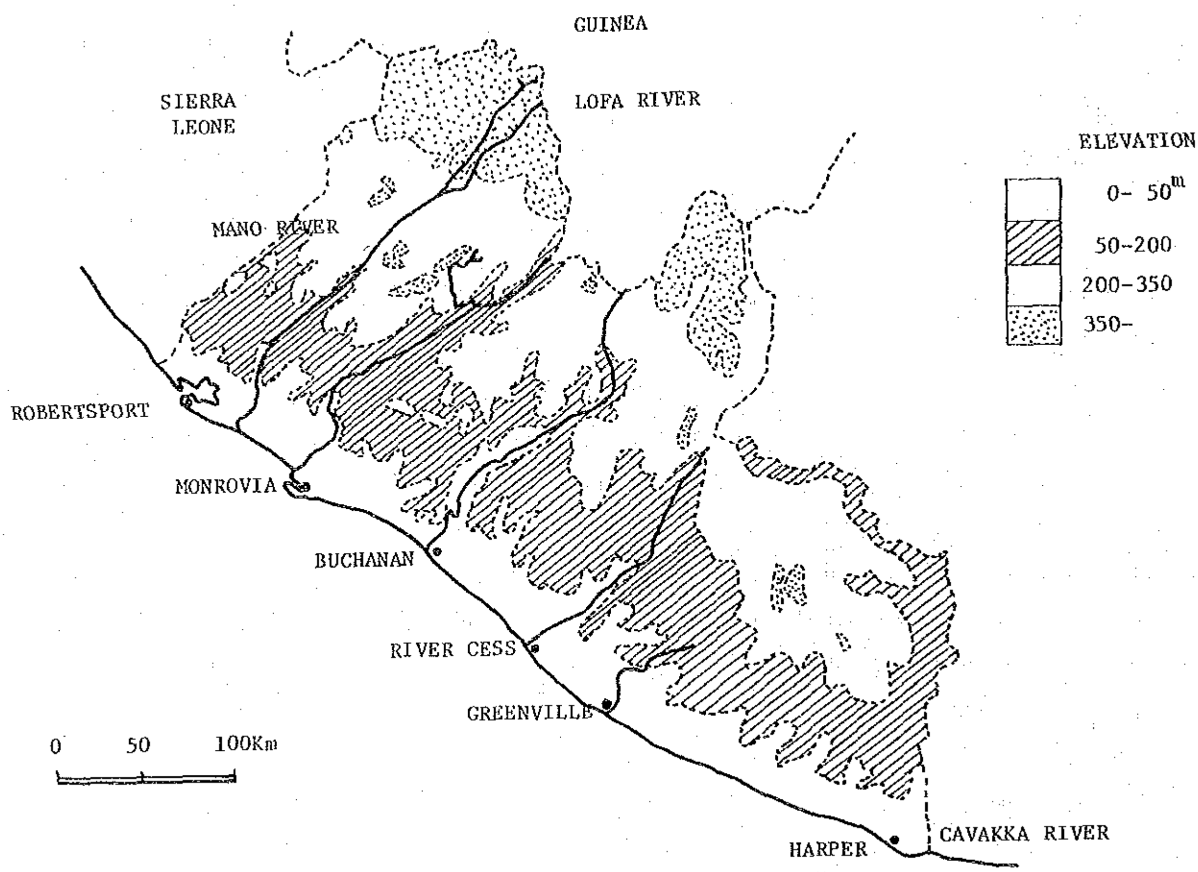


Fig. 3.1 Map of Liberia

Along the coast lies forests of 10-30 meters in height with a width of 15-40 kilometers and coastal plains of savanna. The rivers are sinuous, with marshes of mangroves or long narrow inlets. Further inland, the hills of 180-300 meters in height develop into mountains near the national border.

Only six rivers are conspicuous among the many which flow into the Atlantic Ocean. There are four large ports, namely, Monrovia, Buchanan, Greenville, and Harper along the coast. Along with Robers Port Town, these form the major towns facing the sea.

Along the coast many headlands composed of reefs or cliffs are found with sand beaches in between. The direction of the coastline differs depending on which side of the headland it belongs to. On the south east side, the coastline advances while on the north west side it retreats. The topographies around Cape Mount, Cape Mesurado, and Cape Palmas are exemplified in Fig. 3.2 - Fig. 3.6.

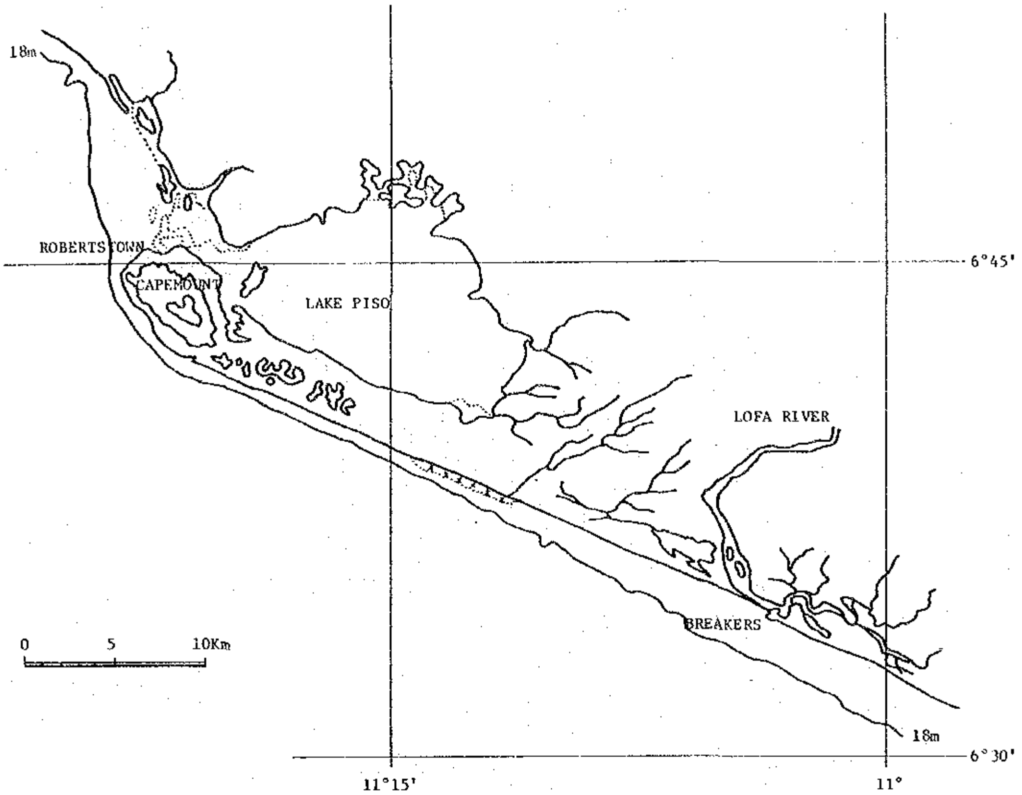


Fig. 3.2 Pattern of Coastline (No.1)

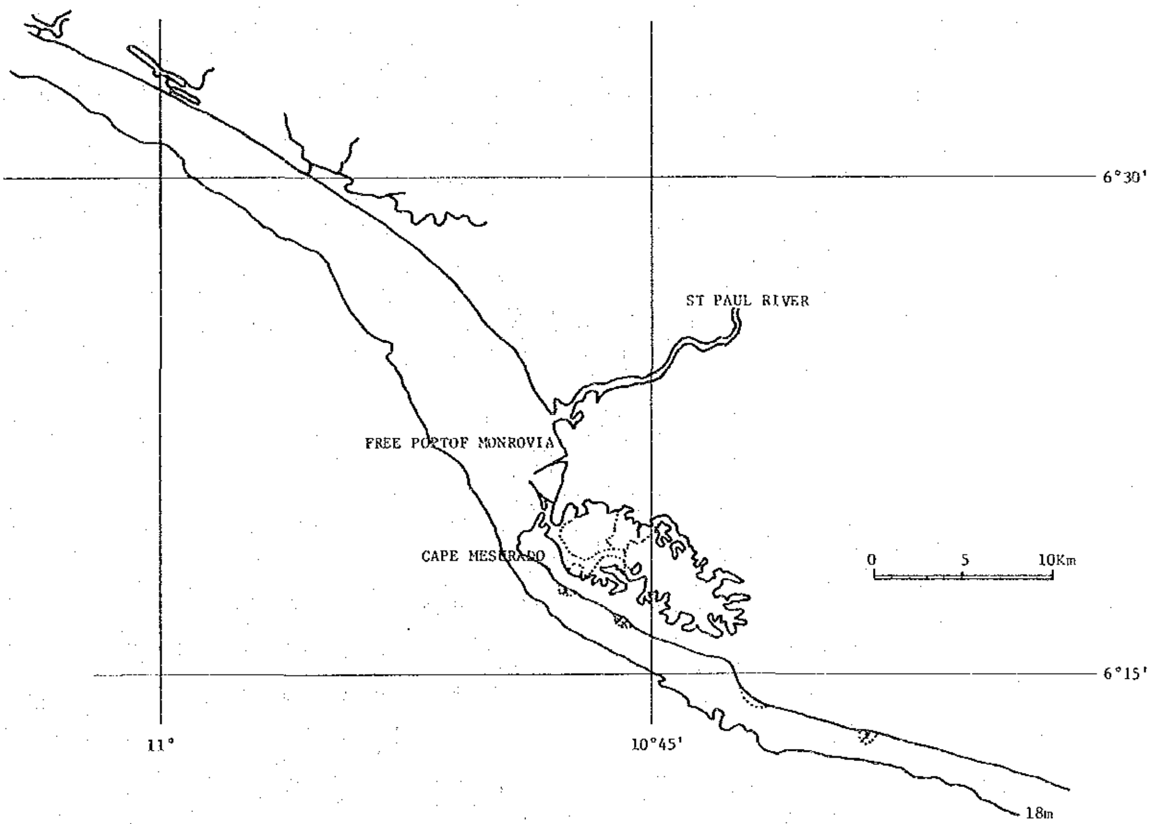


Fig. 3.3 Pattern of Coastline (No.2)

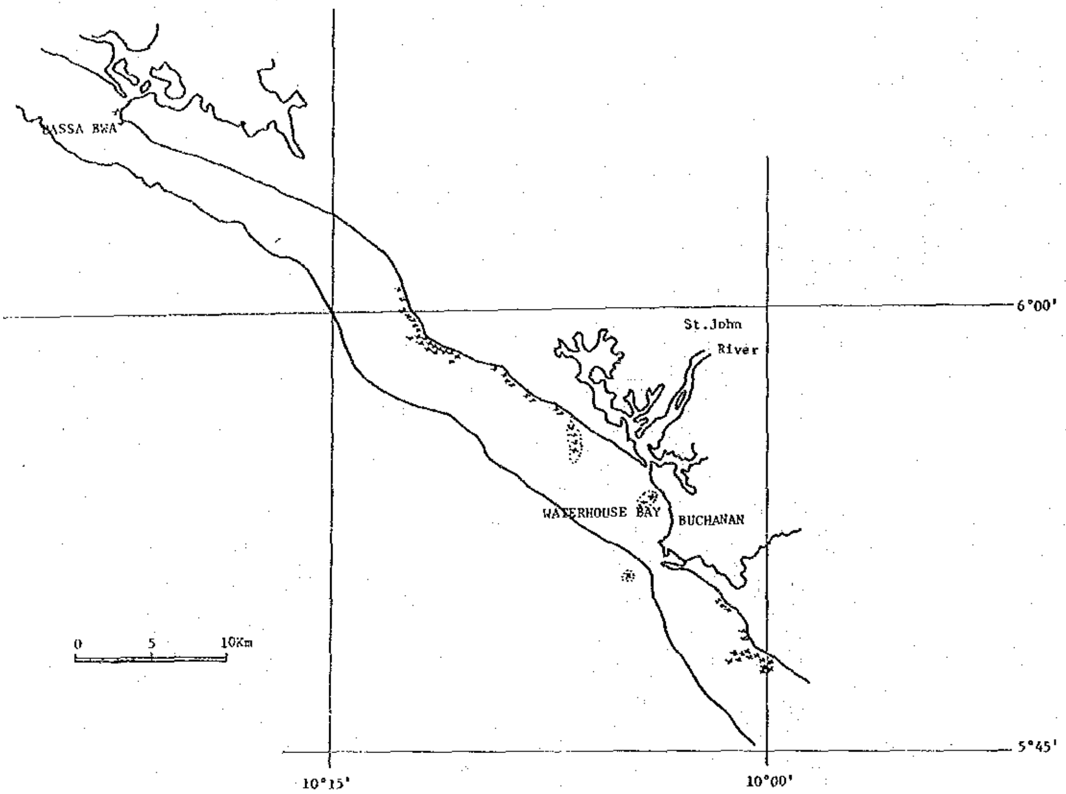


Fig. 3.4 Pattern of Coastline (No. 3)

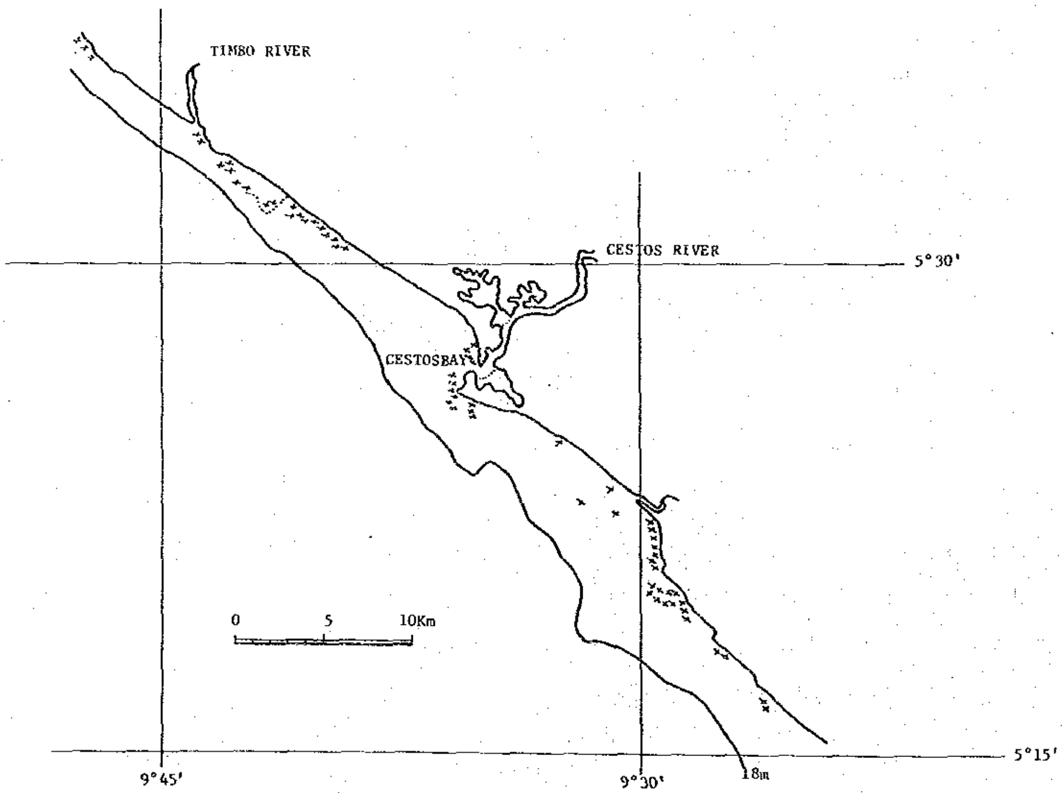


Fig. 3.5 Pattern of Coastline (No. 4)

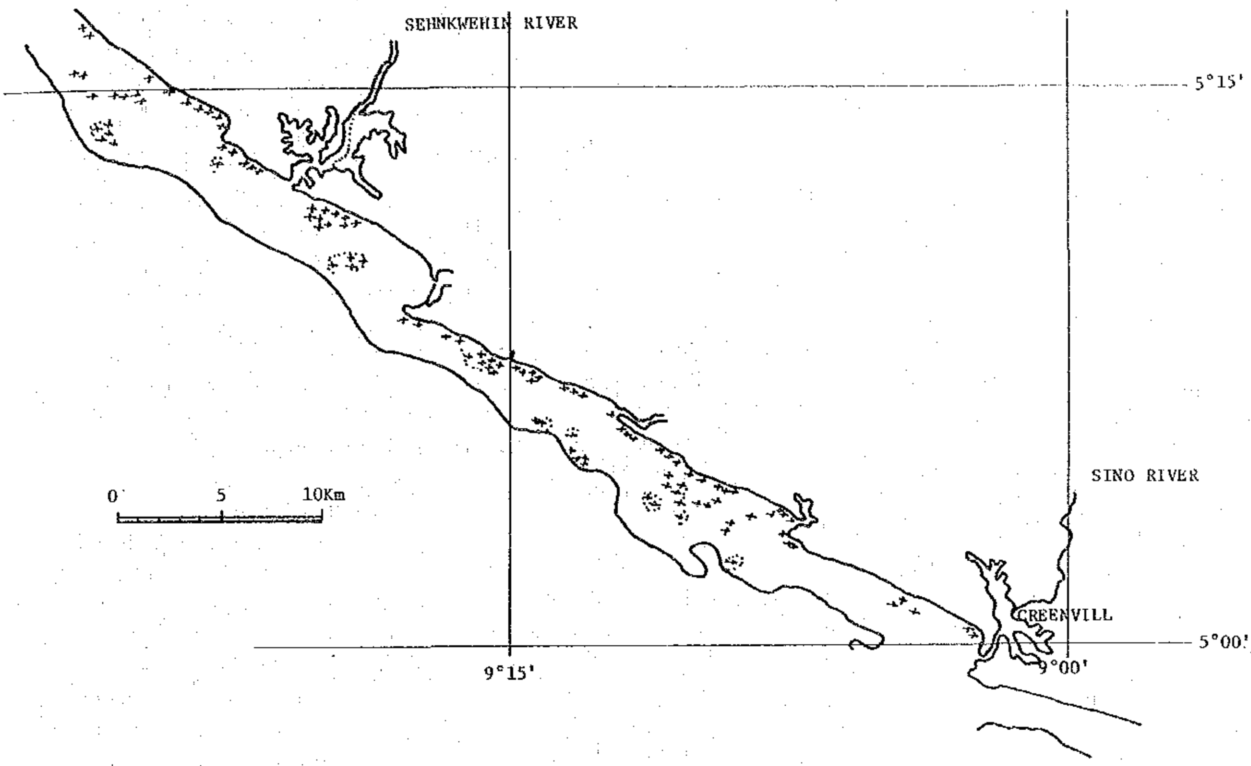


Fig. 3.6 Pattern of Coastline (No. 5)

The Coastline is divided by headlands, rocks, reefs, and river outlets with homogeneous topographical patterns in between. The slope of the bottom profile changes near the headlands. For example, on the east side of Cape Mesurado it is about 2 kilometers from the shoreline to 18 meters contour line while it is about 6 kilometers on the west side near the outlet of St. Paul River. Many river outlets are located on the west side of the headlands or reefs. However, in the case of the Lofa river, which has its outlet at the center of the sandy beach, the eastern part of the coastline advances while the western part retreats. At the same time, the direction of the coastline differs depending on the existence of large rivers. Where there is a large river, the coastline turns clockwise. The above-mentioned topographical characteristics indicate the existance of longshore drift in the direction of southeast to northwest.

The sandy beach is composed of a steep slope of about 1:8 with a width of 10-50 meters with marshes behind it. The slope of the beach is very gentle beyond a depth of 4 meters and the slope is almost constant if no reef is found.

The coast is divided by the headland and reef. However, according to the aerial investigation between Cape Mount and Greenville, it is apparent that even at the headland there exists sand at the offshore and the sand drift is moving continuously. There is nothing such as submarine canyons to prevent the movement of littoral drift on this coast.

3.2 Geological Features

Table 3.1 Geological history in Liberia

Era or Period		Age (millions of years)	Types of Rocks or Deposits	Principal Area of Distribution
Ceno-zoic	Quater-nary	Present	Lagoon and coast sands and river deposits	Lagoons, coast and rivers
	Tertiary	70	Coastal sandstone and lateritic soils	Sandstone: coastal region Lateritic soils: covers of most areas of land
Mesozoic		225	Diabase and peridotite dykes? Wacke and conglomerate	Unmetamorphosed sedimentary rocks: central to northern areas of coastal region
Paleozoic		600	Paynesville sandstone Diabase, norite and peridotite	Igneous rock: scattered dykes in northern mountain lands
Precambrian		4600	Granitic rock gneiss, crystal-line schist and quartzite	Bedrocks of almost entire land area

The geological era concerned is shown in Table 3.1. Liberian land mainly belongs to that of the Precambria and Caivozoic Eras. Most of the land is composed of old Precambrian igneous or metamorphic rocks such as gneiss or granite. The folded-mountains' altitude has been decreased via denudation and erosion and only the residual mountains lie from southwest to northeast almost perpendicular to the coastline.

The main deposits from the Cainzoic Era are Tertiany or Quaternery sandstones and Quaternary non-consolidated sand, clay, and gravel deposits. These deposits form rivers, sand beachs, and sand bars.

The volcanic activity was very brisk between the Precambrian and Cainzoic Era and the sill of diabase was formed then. This interpenetrated the rocks of the former Era and is found lying along the coast or in the inland areas. On the coast, the rocks of diabase form a 50m high platform. The raised beaches are a result of the local uprift of the sand beach which was made by wave erosion after the sea level had gone up in the tertiany or early quaternary Era.

3.3 Meteorological Conditions

According to Keppen's climate classification, most of the Republic belongs in the Tropical Rain Forest Belt and yearly rainfall is tremendous. There are no storms of long duration such as hurricanes or cyclones. However, there are occasionally thunderstorms accompanied by strong winds for short durations.

3.3.1 Wind

The monthly wind direction, average velocity, and maximum velocity measured at Spriggs Payne Airport in Monrovia are shown in Table 3.2.

Table 3.2 Wind direction and Velocity in Monrovia

(Spriggs Payne Airport)

Month	1973			1974			1975			1976			1977		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
January	SW	7.3	-	SW	6.7	-	SW	6.7	20	SW	6.3	-	SW	7.8	-
February	SW	8.5	20	SW	7.0	-	SW	8.0	-	SW	7.8	-	WNW	6.4	-
March	SW	8.4	15	SW	8.3	15	NW	7.4	15	WSW	7.7	-	WSW	7.7	-
April	SW	9.2	30	NW	8.0	14.4	SW	6.9	-	SW	7.3	20	SW	7.3	-
May	SSW	6.7	20	NW	7.7	14	SSW	7.4	20	SW	7.2	15	SSW	6.9	-
June	SSW	9.4	18	SW	8.4	16.7	SSW	8.4	18	SSW	8.2	17	SSW	8.3	17
July	SW	9.4	15	SSW	10.5	17.8	SSW	9.7	18	SSW	8.4	17	SSW	8.7	15
August	SSW	9.7	17	SSW	10.7	17.5	SSW	9.0	15	SSW	8.2	15	SW	8.8	15.5
September	SW	8.6	16	SW	10.0	18	SW	8.4	20	SSW	7.9	20	SW	7.7	15
October	SW	9.0	25	SSW	8.4	21	SW	7.7	25	SSW	8.5	-	SSW	8.2	14.6
November	SSW	7.6	15	SSW	7.8	15	SW	7.0	-	SSW	7.9	20	SSW	7.0	-
December	SW	6.3	10	SSW	6.2	-	SSW	6.9	25	WNW	6.8	-	SSW	6.1	-

1 : Wind direction (Preveiling direction)

2 : Wind velocity (Average, knots)

3 : Wind velocity (Maximum, knots)

The wind is usually blowing from the sea to the land and prevailing wind direction is SW-SSW.

The average wind-velocity during the rainy season is liable to be somewhat higher than that in the dry season.

The maximum wind velocity recorded in Buchanan was 48.1 m.p.h. (21.5m/sec).

The average wind velocity in a year was 19.5 m.p.h. (8.7m/sec). Fig. 3.7 shows the prevailing wind direction[6], and SW and NE denote the sea and the land breezes respectively.

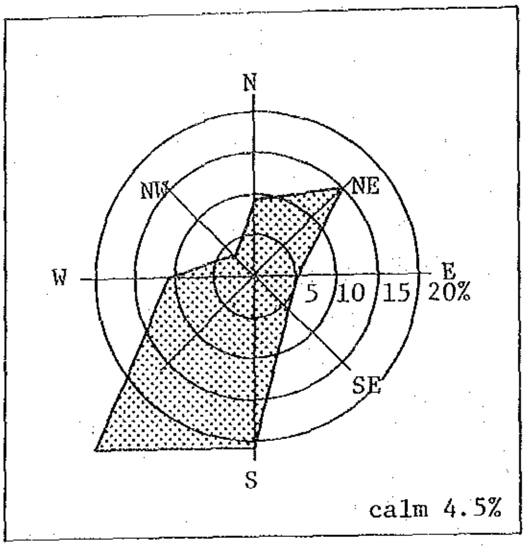


Fig. 3.7 Prevailing wind directions at Buchanan[6]

3.3.2 Rain

Table 3.3 Rainfall in Monrovia

(inches)

YEAR	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1969								14.38	20.34	28.15	6.80	2.86
1970	0.96	0.88	1.20	12.97	22.52	35.56	11.25	14.74	21.44	16.34	5.71	2.45
1971	2.05	3.52	0.95	1.20	8.20	22.85	33.01	25.61	21.50	29.67	6.85	2.42
1972	2.74	1.75	2.67	4.64	24.36	20.37	23.34	29.62	36.65	27.04	4.42	3.45
1973	1.82	2.71	3.23	4.81	12.61	21.32	46.15	30.47	16.85	21.01	4.62	4.12
1974	1.15	1.55	4.00	5.91	11.59	18.80	22.32	33.01	18.43	10.33	6.62	10.91
1975	0	0.05	8.38	10.72	31.48	51.52	45.46	53.04	46.53	37.04	13.86	9.83
1976	2.44	1.95	3.64	4.44	25.86	33.68	12.94	15.75	26.53	19.57	7.98	0.58

(Observed in Spriggs Payne Airport)

Table 3.3 shows the monthly rainfall in Monrovia (1969-1976). It is known that during the rainy season from May to October, the rainfall is heavy while during the dry season of November to April there is little rain.

Table 3.4 Heavyiest rainfall registered in Monrovia for selected periods of time 6

Period	Inches	Millimeters	Date
5 min	0.59	15.0	June 23, 1963
10 min	1.28	32.5	March 15, 1954
15 min	1.67	42.5	March 15, 1954
30 min	2.48	63.0	June 23, 1963
60 min	3.86	98.0	June 23, 1963
24 hrs	14.30	363.2	July 5, 1955

Table 3.4 shows the heaviest rainfall registered in Monrovia. Fig. 3.8 shows the annual rainfall distribution[6].

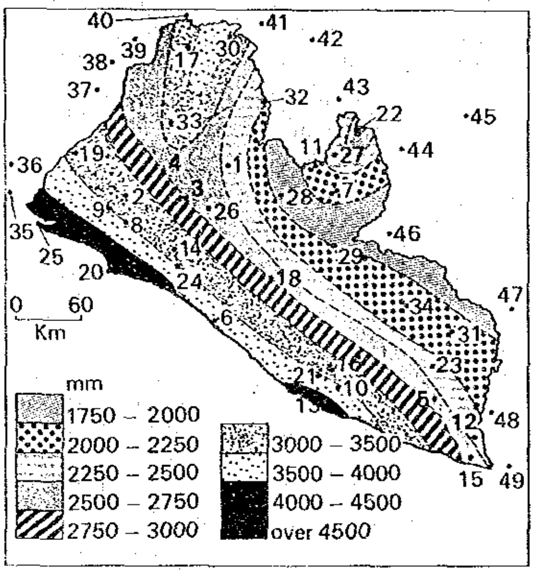


Fig. 3.8 Annual rainfall distribution over Liberia [6]

3.4 Waves and Tides

The wave, tide, and current which are closely related with sand transport are described here. However none of them were measured at this time, and therefore they are assessed by the existing references and data.

3.4.1 Wave

First, the information given by Ocean Wave Statistics[1] is introduced here. This is the statistically processed data of ships and ocean weather stations by the British Meteorological Office. In order to obtain the wave information of the Republic of Liberia, Area 28 in Fig. 3.9 is used.

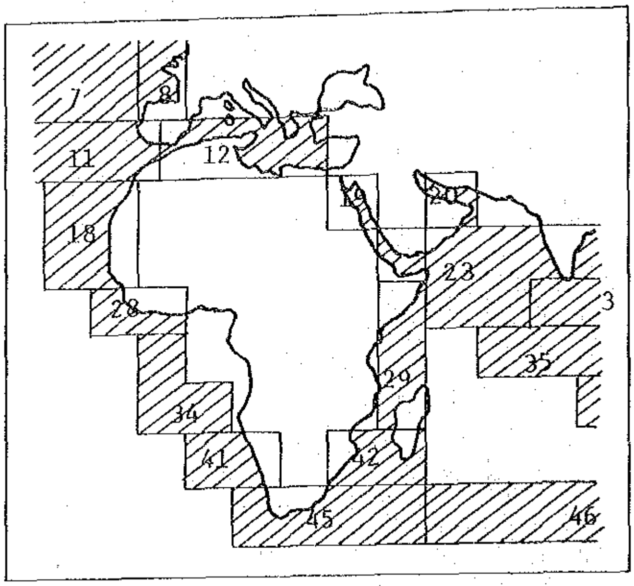


Fig. 3.9 Area for wave statistics

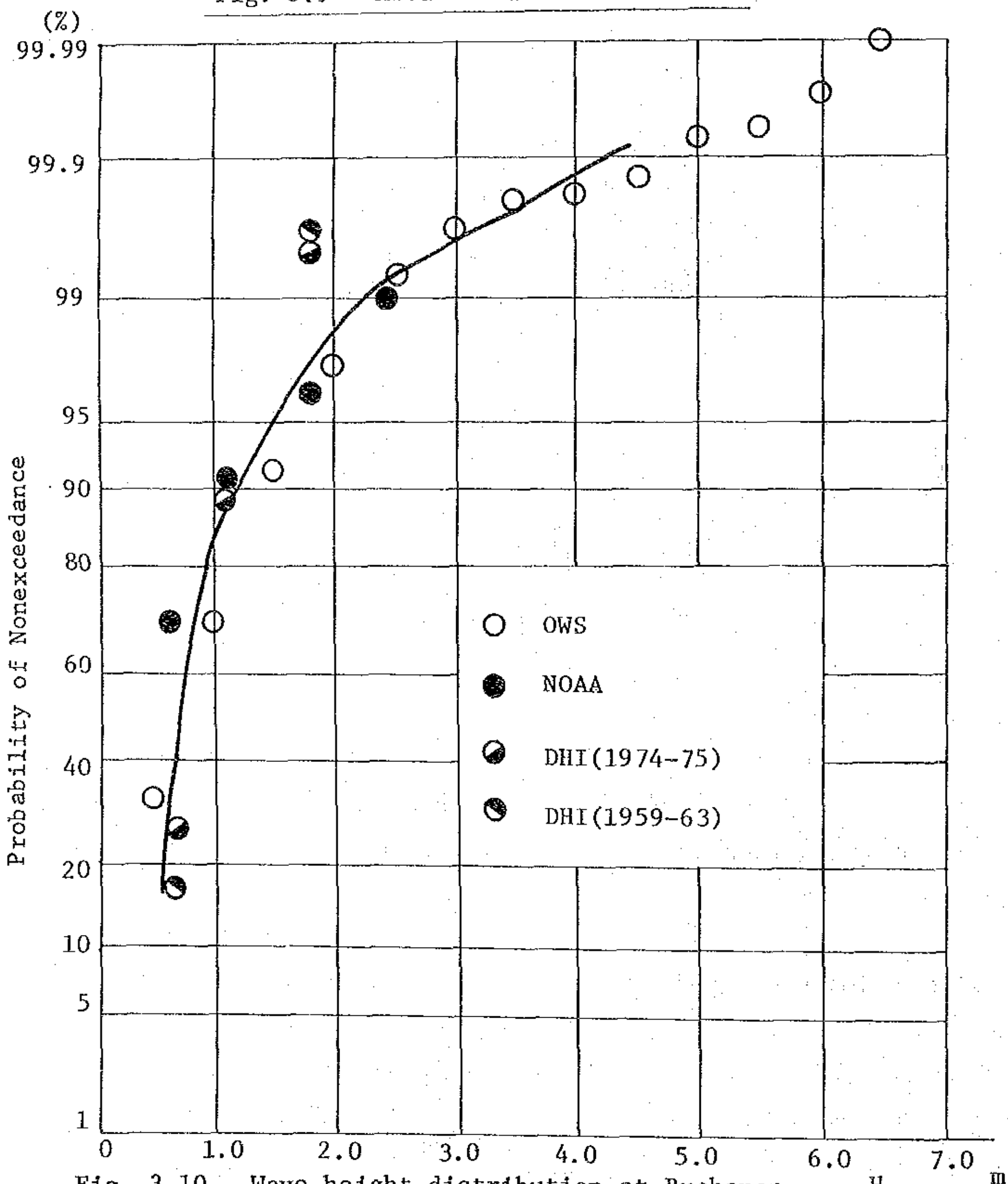


Fig. 3.10 Wave height distribution at Buchanan

Fig. 3.10 shows the probability of non-exceedance of significant wave height $H^1/_3$, and according to the figure, 97% of the wave height is less than 2m. As for the period, 80% of the significant wave period is less than 7 sec and this indicates that the most waves are swell. The significant wave height is defined as the average wave height of the highest third of the waves in series. Long period waves of more than 20sec were also found to be about 2%. As for the wave direction, the most frequent is 140°-160° followed by 110°-130° 170°-190°, and 200°-220°, in that order. It must be noted that area 28 represents a wide range of sea area and is not necessarily suitable for estimating the incident waves which affect Liberian beaches.

Table 3.5 Wave Measurements in Buchanan [4)]

Period	Organization	Location	Water Depth
1958	SOGREAH	———	———
1959 - 1963	DHI	3,500m SSW of the light house	-23m
1974 - 1975	DHI	4,300m SSW of the light house	-27m

Note: DHI: Danish Hydraulic Institute

Next, the incident wave is estimated by the use of internal data obtained at LAMCO[4,5]. Wave measurement off the coast of Buchanan has been done three times so far, as shown in Table 3.5. Due to the short duration of the first one, only the second and third are introduced here. They are as follows.

Observation results (1959-63):

a) Significant wave height $H^1/_3$
   Average 1.0m Rainy Season 1.2m Dry Season 0.9m
   The highest significant wave height 2,4m

b) Significant wave period $T^1/_3$ Average 9 sec

c) Wave directions Range 180°(S) -240°(WSW) Average 202°

Observation results (1974-75):

a) Significant wave height $H^1/_3$
   Average 0.9m Rainy Season 1.1m Dry Season 0.7m
   The highest significant wave height recorded 2.2m

b) Significant period $T^1/_3$
   between 4 and 15 sec Average 8sec
   Most of the waves were swell-type

c) Wave directions range 175°(S)-235°(SW) with the distribution shown in Fig. 3.11. Average 200°

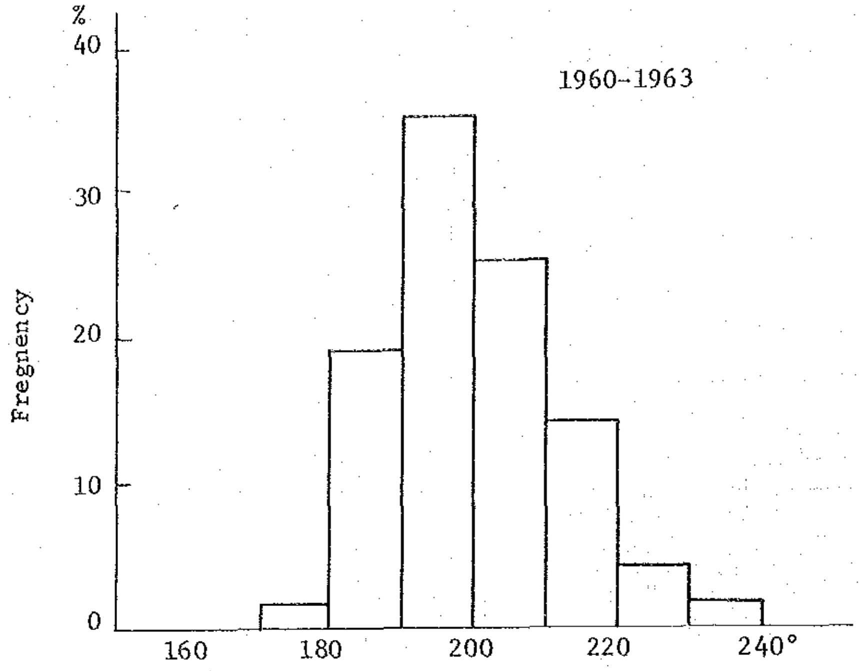


Fig. 3.11 Wave Directions at Buchanan [4)]

With the above documents and the actual site investigation, the incident waves to the beach have been assessed as follows:

In the offshore, at a depth of more than 20m, the swelles with an average significant wave height and period of 1m and 8-9sec are incoming continuously. The waves further advance into shallow water and change into breaking waves approximately 30-40m off the shoreline. The direction of the waves is about 20° to the coastline in the offshore. The angle decreases because of refraction as the waves advance into shallower water.

Table 3.6 Frequency of occurence of wave height [4,5]

Significant wave height ft (m)	Frequency of occurence (%) Port Buchaman NOAA	DHI 1974-75	DHI 1959-63	Vicignity of Fishermans Lake GLENN
0 - 2 (0 - 0.6)	71	23	17	35.6
2 - 4 (0.6 - 1.2)	19	67	72.9	41.6
4 - 6 (1.2 - 1.8)	6.5	9.5	9.7	11.9
6 - 8 (1.8 - 2.4)	2.5	0.5	0.4	6.9
8 - 10 (2.4 - 3.1)	1.0	0	0	2.7
10 - 15 (3.1 - 4.6)	0	0	0	0.9
Over 15 (4.6)	0	0	0	0.4
Total	100	100	100	100

The frequency distribution of the wave height is given in Fig. 3.10. According to the figure, there is little data on waves of large height due to an insufficient measurement period which caused the information to be imprecise. Although the highest wave is important when used in constructing the structure, the medium-range waves are used to know the characteristics of littoral drift. Therefore the data given here is sufficiently useful. Using the various data, it is estimated the height distribution of the waves incoming Liberian coast to be the solid line shown in Fig. 3.10 and in Table 3.6.

Table 3.7 *Estimated Frequency Occurance*

Significant wave heigh (m)	Mean wave height	Frequency of Occurance
0 - 0.5	0.25	17.5
0.5 - 1.0	0.75	64.0
1.0 - 1.5	1.25	13.0
1.5 - 2.0	1.75	3.5
2.0 - 2.5	2.25	1.3
2.5 - 3.0	2.75	0.35
3.0 - 3.5	3.25	0.15
3.5 - 4.0	3.75	0.09
Over 4.0	4.25	0.11
Total		100

3.4.2 Tides

According to the tidal data[4] recorded in 1958 and in 1974 - 75 near Buchanan harbor, the difference between MHW and MLW is about 0.9m. The water level characteristics are shown in Table 3.8.

Table 3.8 Tidal Conditions in Buchanan

Highest recorded high water (1958)	+1.32 m
Mean high water level at spring tide (MHWS)	+1.18
Mean level at high tide (MHW)	+0.95
Mean level	+0.50
Mean level at low tide (MLW)	+0.05
Mean low water level at spring tide (MLWS)	-0.15
Lowest recorded low water (1958)	-0.27

It was about 0.8m according to the tide gauge set at Free Port in Monrovia at the visit of the team.

Generally speaking, the tide of a monotonous coast such as that of Liberia does not vary much with the location. Taking this into account, tides along the Liberian coast are estimated to fall into the 0.8m-0.9m range.

3.4.3 Current

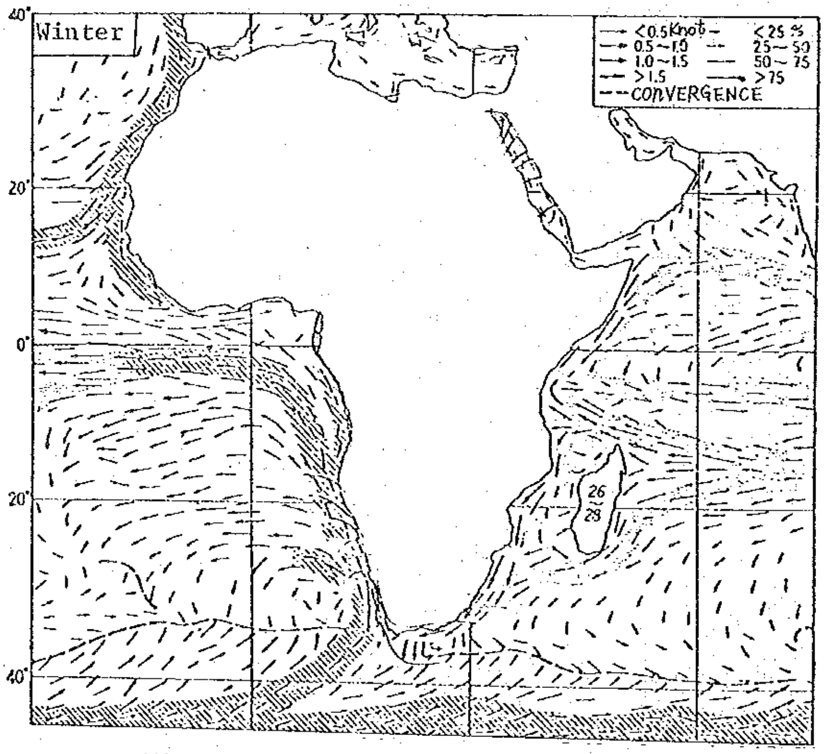


Fig. 3.12 Ocean Current in Africa

As is shown in Fig. 3.12, Guinea Current flows offshore along the Liberian coast from NW to SE in January to September and from SE to NW in October to December. The ocean current flows far off the coast, and it is the coastal current that influences littoral drift. Measurement of the coastal current was done twice in Buchanan[4)]

The first one was conducted in June-October, 1958. The current was measured for about five days at 39 points in Waterhouse Bay. The results are summarized as follows;

a) In Waterhouse Bay, the current direction changes with the tides, and the current velocity varied depending on the measurement points. The maximum velocity recorded was 25cm/sec and the average velocity was between 5 and 10 cm/sec.

b) According to flourescein measurements at Grand Bassa Point, the current was from the open sea to the bay. This might be caused by waves.

c) In the area around the existing port of Buchanan, current direction was parallel to the shoreline (NW-SE) and the direction varied from wave to wave. The current velocity was about 5cm/sec. The dominant current direction was SE 1.5-2.0 km from the shoreline.

The second measurement was done in 1974-75 (3 months) by D.H.I. The results are as follows;

The current direction was parallel to the shoreline (N -SE).

During October and November the northwest currents were dominant.

The current directions in the upper 10m water layers differ from the directions in the deeper layers. Perhaps this is because of the current generated by the wave. With the above data in Buchanan, and with the assumption made about the incoming wave, the characteristics of the current will be as follows;

a) Inside the Breaker Zone

From the shoreline to the breaking point or even beyond the point to the slightly deep area, the current is dominated by the waves, and the dominant current direction is the same as that of the wave, namely, NW.

b) Area further offshore

Depending on the influence of the tide, the current direction changes between NW and SE.

c) At the open-ocean because of the Guinea current, the SE current dominantes.

3.5 Rivers[2)]

There are six main rivers in the Republic of Liberia, namely, Mano, Lofa, St. Paul, St. John, Cestos, and Cavalla. These rivers flow in parallel from NE to SW and empty into the Atlantic Ocean.

The area of river basin[6)] of the main rivers is given in Table 3.9.

Table 3.9 River Basins

River	River Basin in sq. km		Remarks
	Total	in Liberia	
Mano River	8,249	6,320	Border between Sierra Leone
Mafa River	1,321	1,321	Robertstown
Lofa River	10,619	9,194	
St. Paul River	21,911	12,808	Monrovia:New Kru Town
Mesurado River	52	52	Monvovia:West Point
Du River	997	997	
Farmington River	2,914	2,914	
St. John River	17,223	14,763	Buckanan
Timbo River	3,108	3,108	
Cestos River	12,561	10,101	
Sehnkwehn River	4,662	4,662	
Sino River	2,927	2,927	Greenville
Dugbe River	2,227	2,227	
Nuch River	1,994	1,994	
Cavalla River	30,225	13,727	Border between Ivory Coast

Comparisons of specific discharges at representative gaging stations on the major rivers are as indicated in Fig. 3.13 which shows that with the exception of the St. John River, the Mano and other rivers in the west have comparatively high specific discharges, whereas the specific discharge of the Cestos River in the east is low. Accordingly, it can be said that the specific discharges of the major rivers in Liberia have a tendency to become lowerer from west to east. The annual stream flow discharge records are as summarized in Fig. 3.14, from which the return period of rainy and dry years is judged to be approximately 10 years.

The monthly variations in specific discharges of the various rivers are given in Fig. 3.15. According to this, the comparisons between September when discharges are largest and March when they are smallest result in a ratio of 40:1 for the St. John River with the poorest stream regime and approximately 7:1 for the Cestos River which has a comparatively good stream regime, while for the Mano River and the St. Paul River, the ratios are 10:1 and 12:1, respectively. In effect, it may be said that the discharge of a river in Liberia during the dry months is approximately one tenth of that in rainy months.

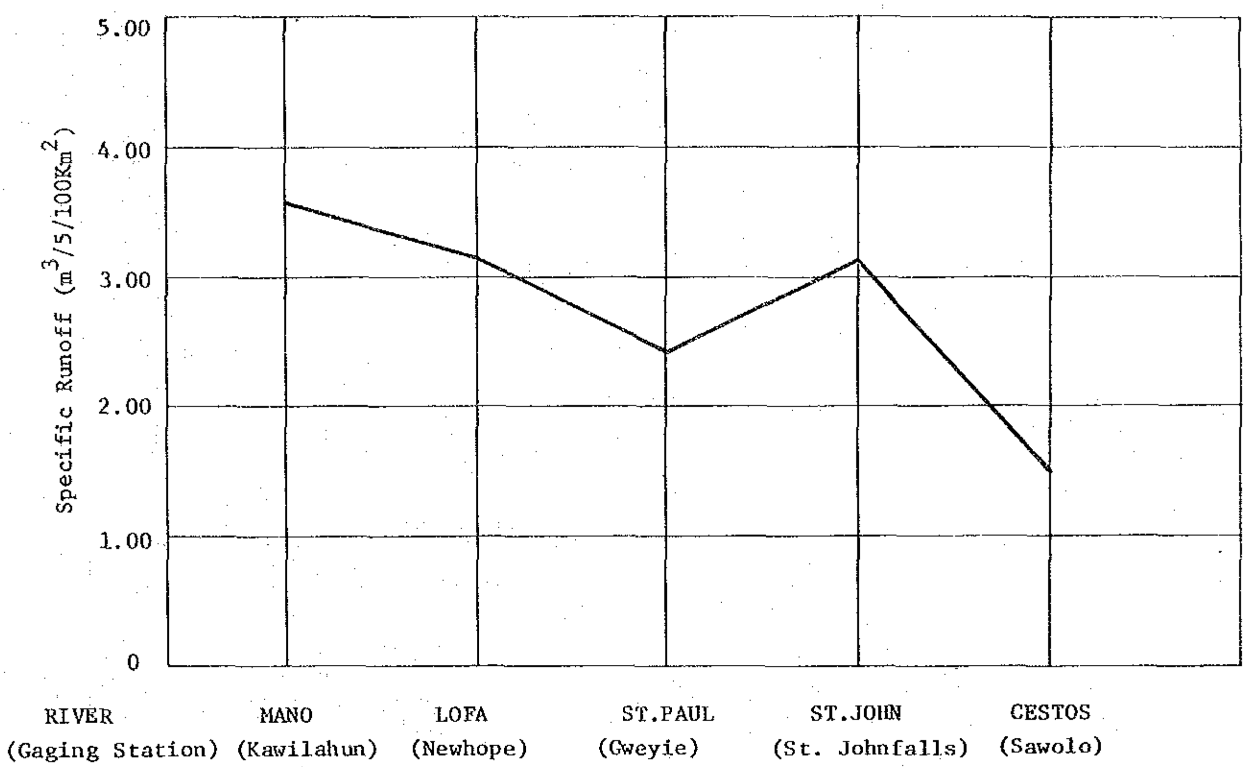


Fig. 3.13 Comparison of River Runoff in 1960[2)]

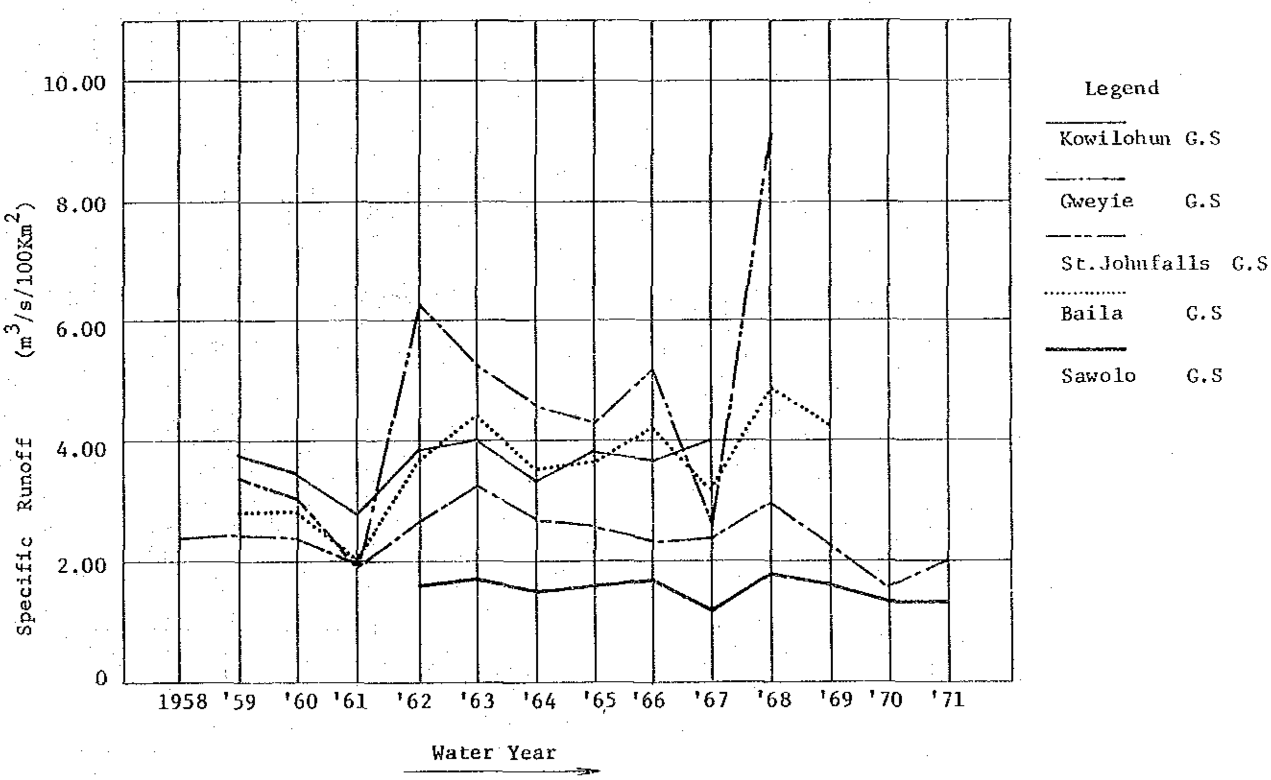


Fig. 3.14 Annual Runoff [2)]

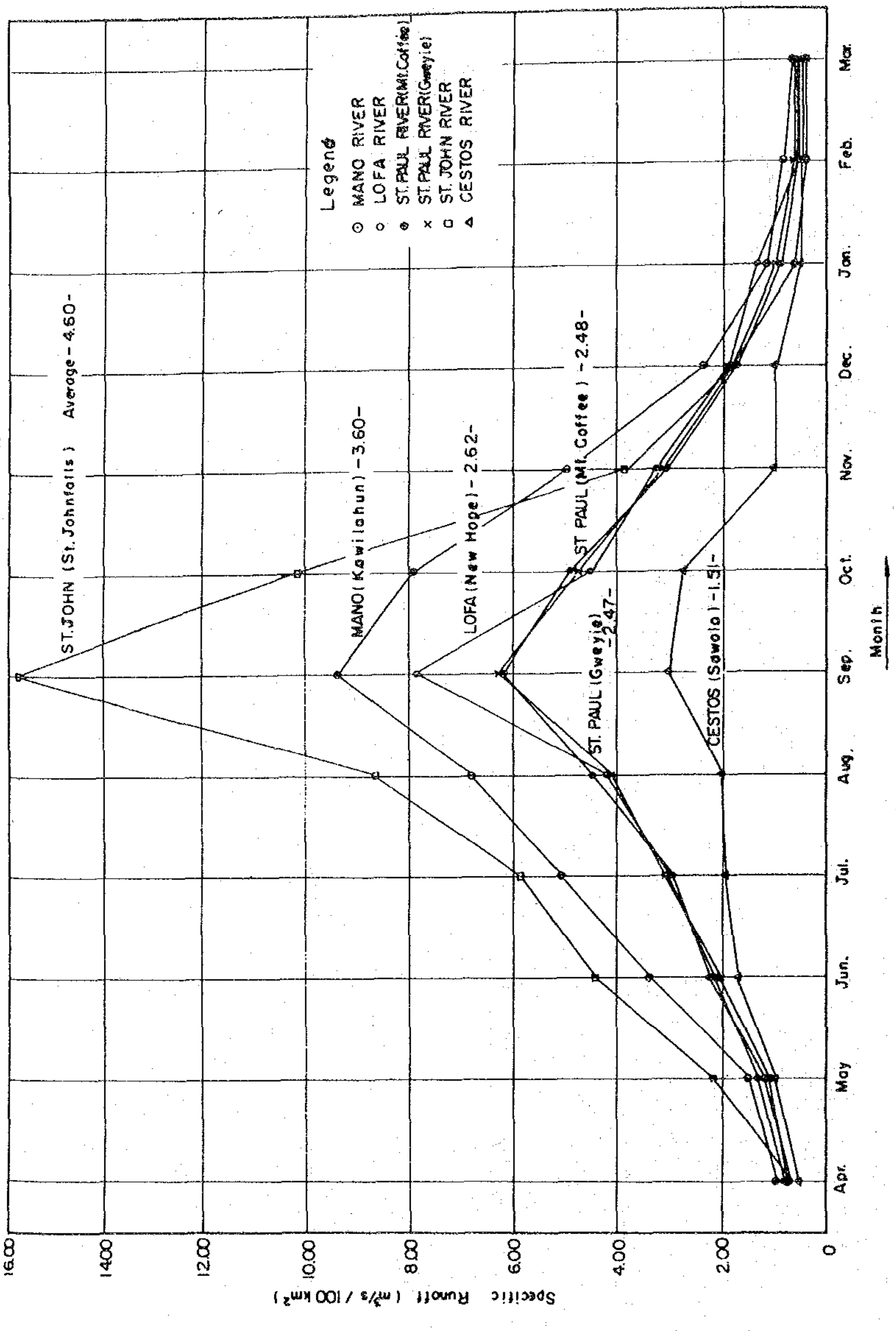


Fig. 3.15 Monthly Runoff 2)

The shift of the outlet of each river is influenced by topography, runoff, river transport, wave direction, littral drift direction, grain size of sand in the river bed and sea bed, and other factors. It also changes according to the year and the season. It can be said that the houses and lands on the sandbanks of West Point in Monrovia or Roberts-town at the mouth of the Lake Piso are in an extremely unstable situation.

River outlets as well as sand beaches are stable if the supply and the loss of sands are in equilibrium. If the sand supply exceeds the loss the sand accumulates and the beach advances. On the other hand if the loss exceeds the supply the result is the erosion and the retreat of the beach. The supply of sand at the river outlet is composed of mainly sand from the upper stream and partly of the sand drift in the littoral current. The rivers in Republic of Liberia flow through thick forests and the mountains are mostly low at less than 1500m above the sea level. The trees which cover the downstream portion of the river prevent rainwater from flowing into the river, and the exposed rocks indicate that there is little amount of sand to be carried into the water.

The rate of sand transport from the river is usually closely related to the runoff of the river. However, since there is no data about sand transport in Liberia, it is hoped that in the future the rate of transport would be investigated to facilitate estimation of the amount of sand brought to the beach. One method is to measure sand accumulation in the reservoir of Mt. Coffee Dem and to use the data to estimate the sand brought to the beach. This also means that a river structure such as a dam can block the transport and reduce the supply of sand to the beach.

There is a graph[3)] to estimate the annual sediment yield per unit drainage area and using this it is estimated that the order of magnitude of the amount of the sand from each river. The results are shown in Table 3.10. Fig. 3.16 shows the unit amount of sand drift in the U.S. and calculation is made on the assumption that the effective precipitation was 200cm and that the discharge is $150m^3/km^2$/year.

Table 3.10 Estimation of river sediment yield

Name of rivers	Drainage area	Annual sediment yield
Mano River	8,249 km^2	6.38 $\times 10^5$ m^3/year
Lofa River	10,619	7.94
St. Paul River	21,911	14.65
St. John River	17,223	11.93
Cestos River	12,561	9.14
Sino River	2,927	2.64
Cavalla River	30,225	19.30
Total		71.98

Note: $Q = 150\ m^3/km^2/year\ (\frac{A}{100})^{-0.15}$

Q: Sediment yield (m^3/year), A: Drainage area (km^2)

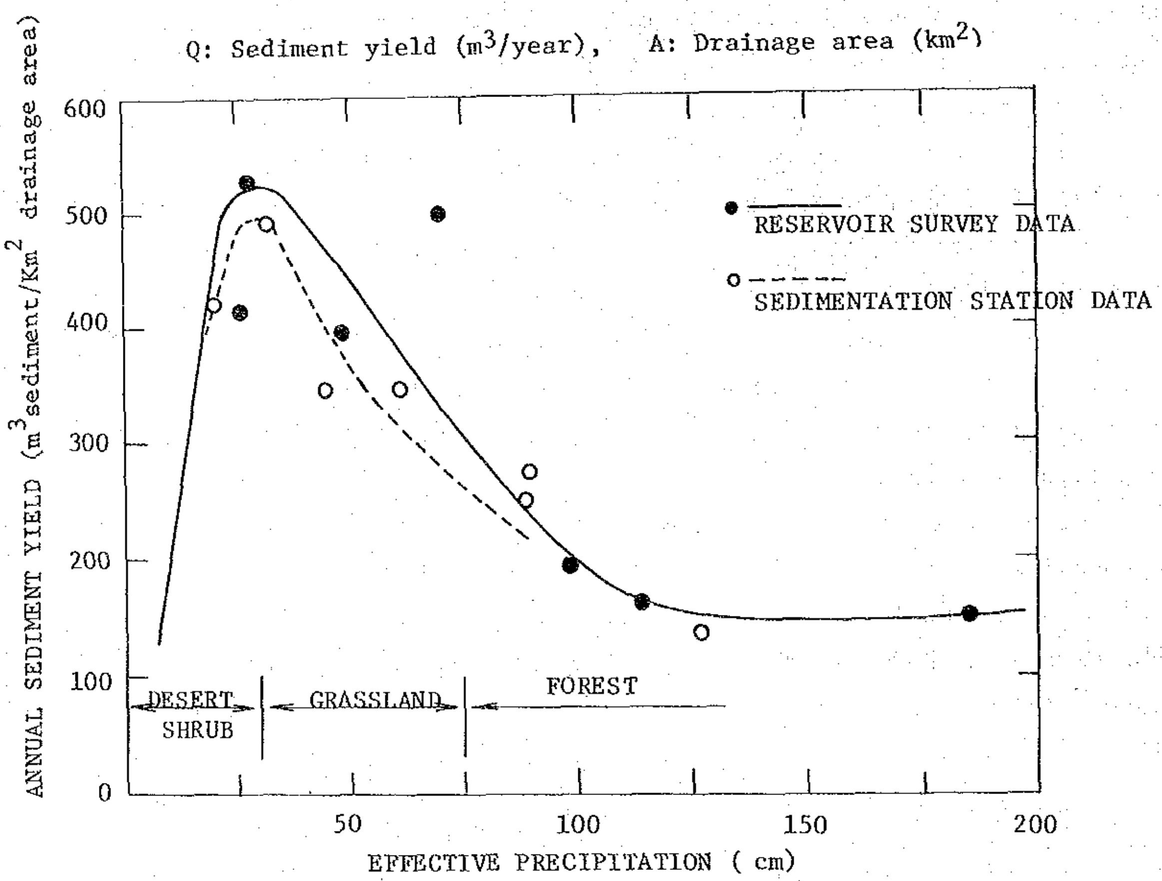


Fig. 3.16 The river sediment yield per unit area of drainage basin as a function of the effective precipitation. The curve is normalized to a drainage area of 100 km^2. For other drainage areas, utilize the rule that the sediment yield is inversely proportional to the 0.15 power of the drainage area. [After Langbein and Schumm (1958)][3)]

3.6 Characteristics of the littoral drift

It is necessary to clarify the influx and outflow of earth and sand in the beach in order to discover the cause of coastal erosion and to find out some countermeasures. The sands of the Liberian coast are thought to move from SE to NW considering the following items.

(1) At the point of headland or reef which would possibly block the littoral drift, the accretion of sand and advanced coastline are seen on the east side, whereas the erosion and the retreated coastline on the west side. This indicates that the direction of littoral drift is from SE to NW, and that the drift is blocked by the headlands, etc.

(2) The break-water has the same effect. There is an accretion on the east side while there is erosion on the west side.

(3) On the east side of the river outlet there is an accretion and on the west, erosion.

(4) The wave direction is tilted against the coastline which contributes to the littoral drift from south east to north west.

With the assumption that the littoral drift moves from SE to NW, the influx and outflow of sand are estimated as follows.

The adjacent beach and river are considered to be the supply source of sand. Not much supply of sand is expected from the Ivory Coast when it is taken into consideration that there are few sand beaches there and that the waves approach almost perpendicularly toward the coastline.

As for the supply from the river at the outlet, the amount was estimated with the data available and is shown in Table 3.10. It is considered that only 1/3-1/5 of the amount thus gained would remain and be supplied to the beach.

The direction of the coastline can be related to the rate of littoral drift provided that the direction of the incident wave is constant. In Buchanan, the average wave direction was about 220° and with the coastline having this direction there would be no littoral sand drift. With the increase in the direction of coastline, the amount of sand drift is expected to increase too. Therefore, in the case of "serial" sand beaches with river outlets, there is a possibility of their directions increasing more than 220° because of the supply. With this inference, Fig. 3.17 shows the relation between the rate of transport from the river and the direction of the coastline of NW edge after dividing the coastline by the headland or reef which blocks the sand drift.

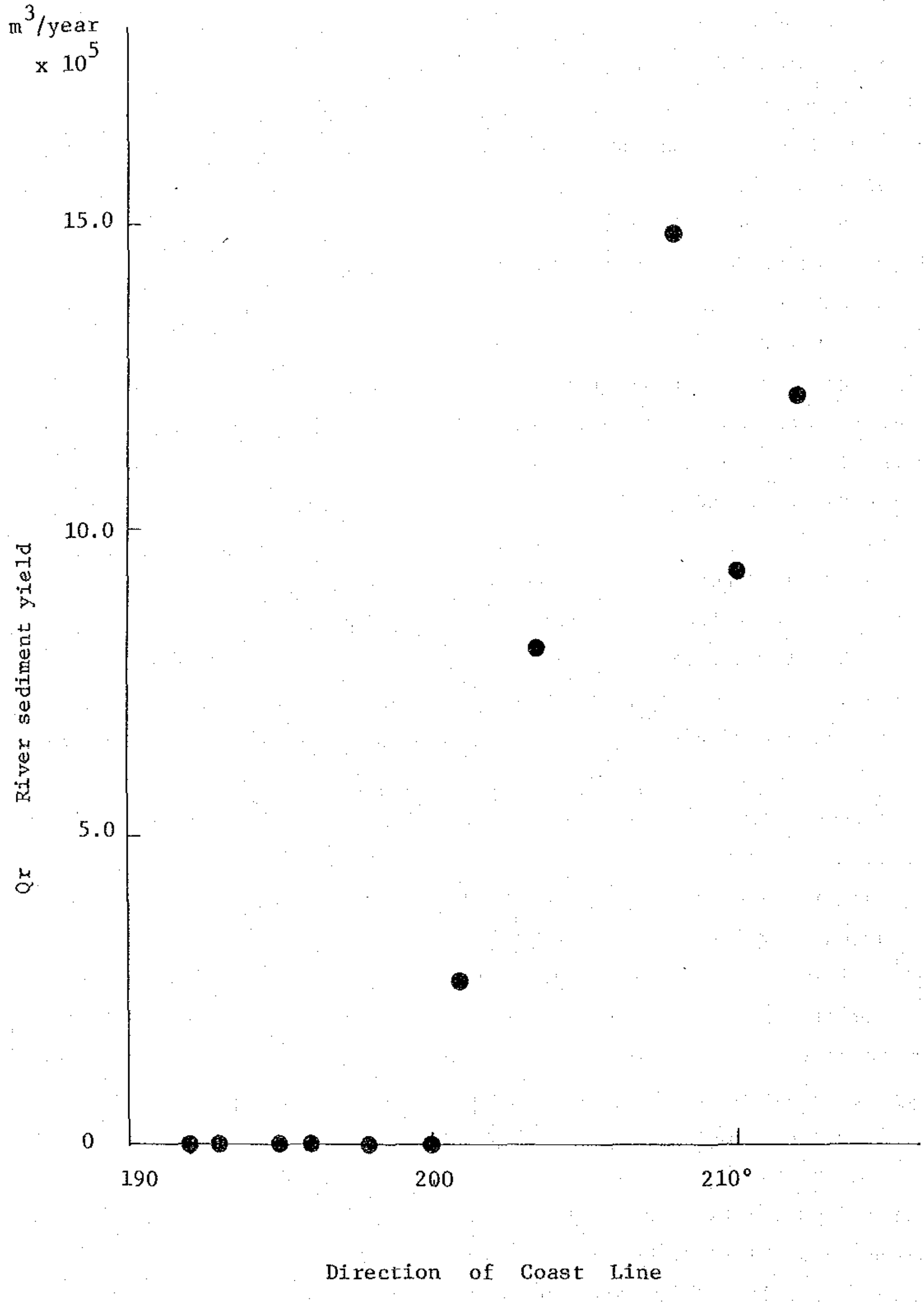


Fig. 3.17 Relation between river sediment yield and the direction of coast line

This clarifies that the direction of the coastline is SW-W, with the coast being supplied with sand from the river, and that the rivers are the sand supply sources.

The rate of littoral drift can be estimated provided that wave conditions such as height, period, direction, etc. are known. According to the generally known formula by Savage

$$q = Ex$$

where, q=rate of littoral drift

α= 0.22 coefficient

Ex=the wave energy flux in the along shore direction

and which is expressed further by the following formula.

$$Ex = \frac{1}{8}\omega Hb^2\ Cb \cdot n\ \sin\alpha b\ \cos\alpha b = \frac{1}{8}\omega Ho^2\ Co \cdot n\ \sin\alpha b\ \cos\alpha b$$

where,

ω : specific weight of sea water

Ho : wave height in deep water

$Co \cdot n = Cg$: group velocity in deep water

α_b : wave incidence angle at the breaking point

The joint distribution of wave height, period, and direction is required to get the value of Ex. Lacking such data, an average period of 9sec was used for the period, and Table 3.7 was used for the frequency distribution of the wave height, with Fig. 3.11 being used for the frequency distribution of wave direction in order to calculate the value of Ex. As for the direction of the coastline 195°, 200°, 205°, 210° were used. The calculated results and the estimated rate of littoral drift are shown in Table 3.11 and Fig. 3.18.

Table 3.11 Relation between Wave Energy and the Rate of Littoral Drift

Direction of Coast	Energy	Rate of littoral drift
190°	-8.6×10^5 ton m/m year	-1.89×10^5 m^3/year
195	−4.2	−0.92
200	+0.26	+0.057
205	+5.9	+1.31
210	+9.0	+1.98

Note: + means north west direction, − means south east direction

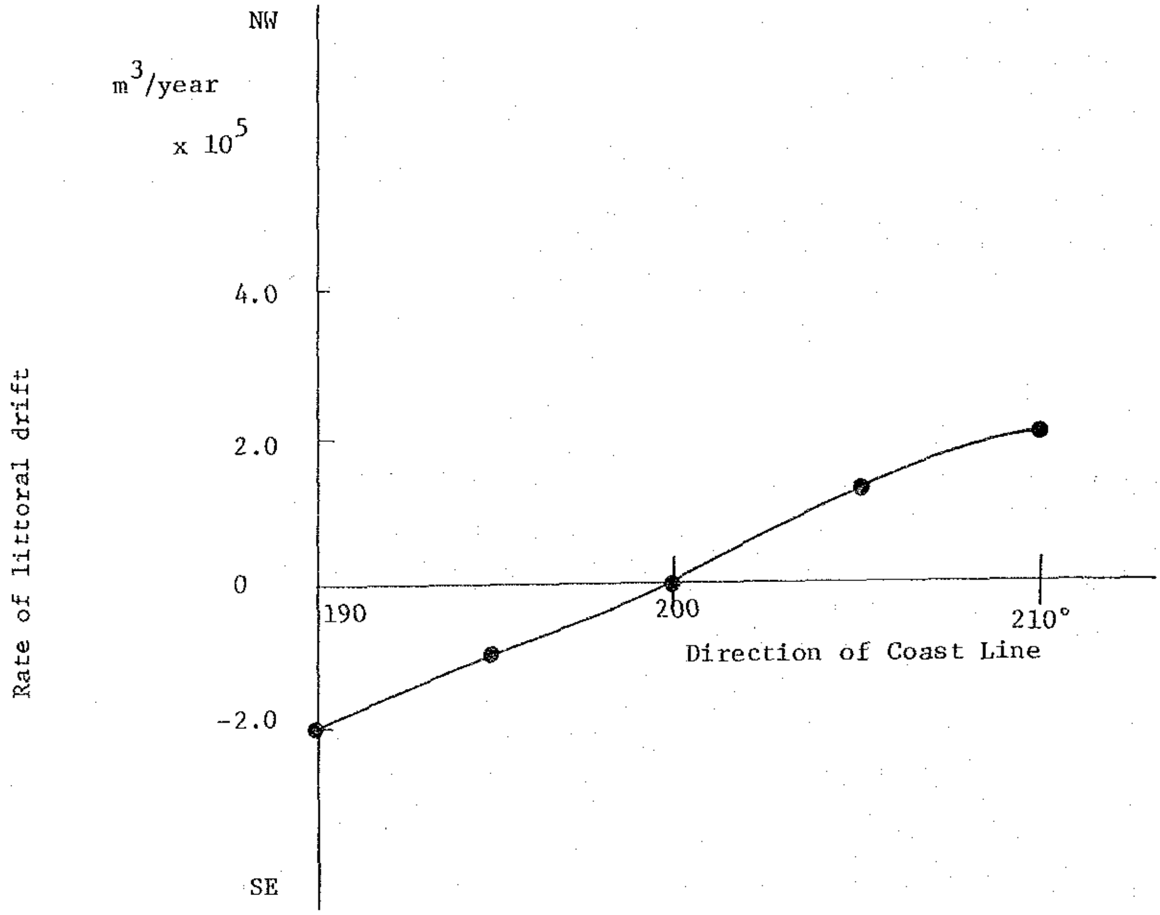


Fig. 3.18 Rate of Littoral Transport

The sand supplied to the beach either remains and accumulates there or, driven by the current out of the beach. Along the coastline, the sand will flow out of the beach to the coast of Sierra Leone. The outflow of sand to offshore will not be significant since the slope of the sea bed offshore is gentle. Therefore, it is expected that most of the sand from the river remain in the beach. Study is made here on the entire balance of inflow and outflow of the sand using the amount of discharge at the river outlet and the littoral drift estimated from various data. First of all, it is necessary to clarify what percentage of the discharge from the river contributes to the littoral drift. It was assumed that there is a balance among the transport from the river, littoral drift, and the sand accreting on the beach in order to estimate the ratio.

Now, assume that the β% of sand from the river contributes to the littoral drift and that most of them move to the NW while some part accumulates on the beach. Assume further that this amount of accumulation does not vary much according to location, but is constant per unit length of the coastline provided that there is no headland, and that there is only monotonous sand beach. This situation is schematically described in Fig. 3.19.

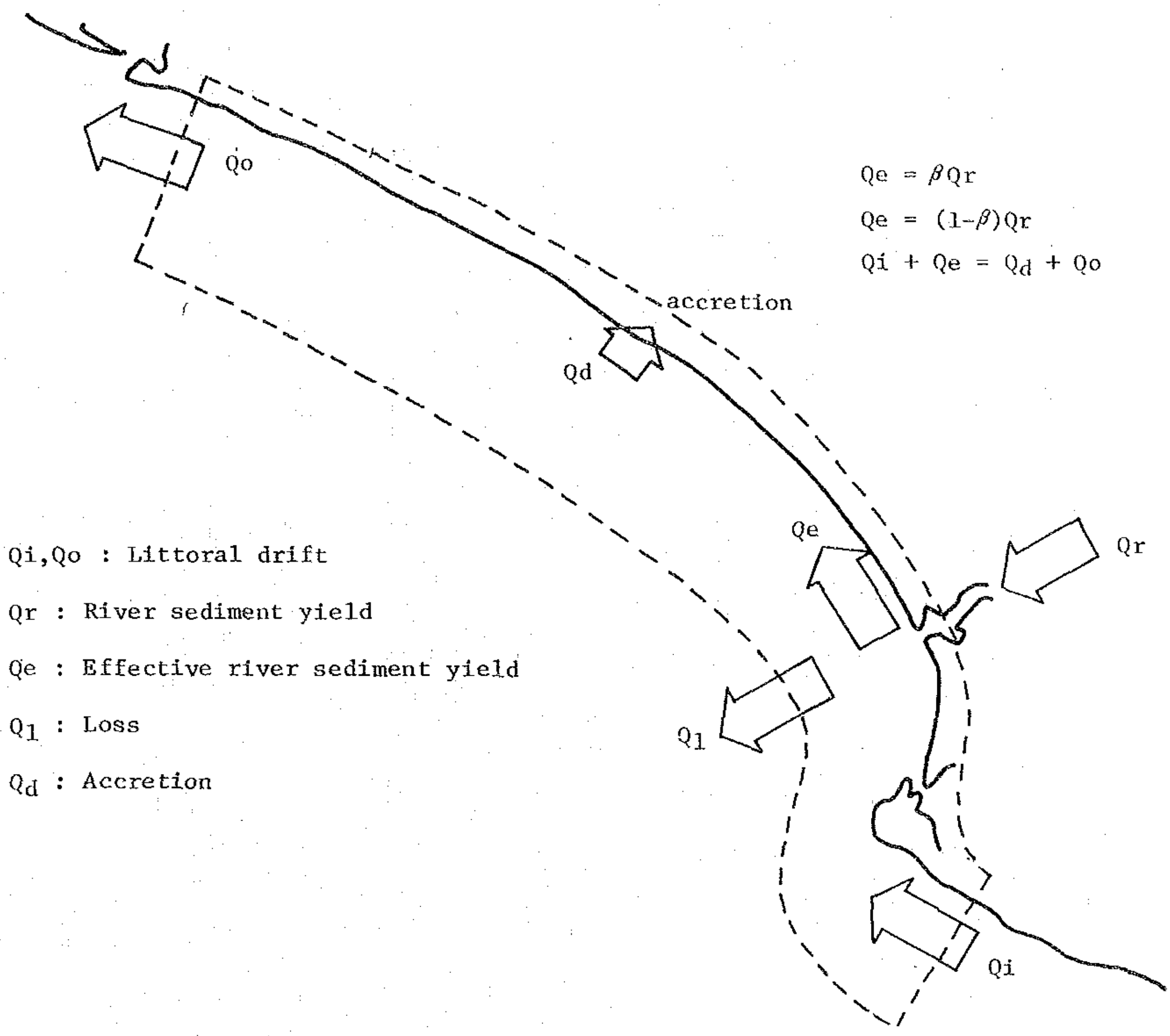


Fig. 3.19 Schematic illustration of budget of sediments

Calculation was made on the amount of accumulation from the balance of inflow and outflow in the unit shoreline assuming that the rate of littoral drift at both ends of coast line is decided by the direction of the coastline as was already shown in Fig. 3.18.

Table 3.12 shows these relations about the beaches at the outlets of Lofa River, St. Paul River, St. John River, Cestos River, and Sino River.

Table 3.12 Balance of Sand

	Zone	Name of River	Sediment Yield ($x10^5 m^3$/year)	Direction of Coastline (o)	Length of Coastline (km)	Outflow of Sand Qo ($x105m^3$/year)	Inflow of Sand Qi ($x105m^3$/year)
1	Cape Mount-Month of Lofa River	Lofa River	7.94	203.5	35	0.9	1.8
2	Month of Lofa River-Cape Mesuhado	St.Paul River	14.65	208	40	1.8	0
3	Kennyon Town - Bassa Bwa	-	0	195	37		
4	Bassa Bwa - Dala Bassa	-	0	200	14		
5	Boda Town - Buchanan	St.John River	11.93	212	11	2.1	0
6	Wamabi - River Cess	Cestos River	9.14	210	7	2.0	0
7	River Cess - Po River Beach	-	0	196	9		
8	Grand Putu Pt.- Greenville	Sino River	2.64	201	9	0.3	0
9	Greenville - Setro	-	0	193	23		
10	Grand Cess - Garawe	-	0	192	28		
11	Garawe - Fishtown	-	0	198	12		

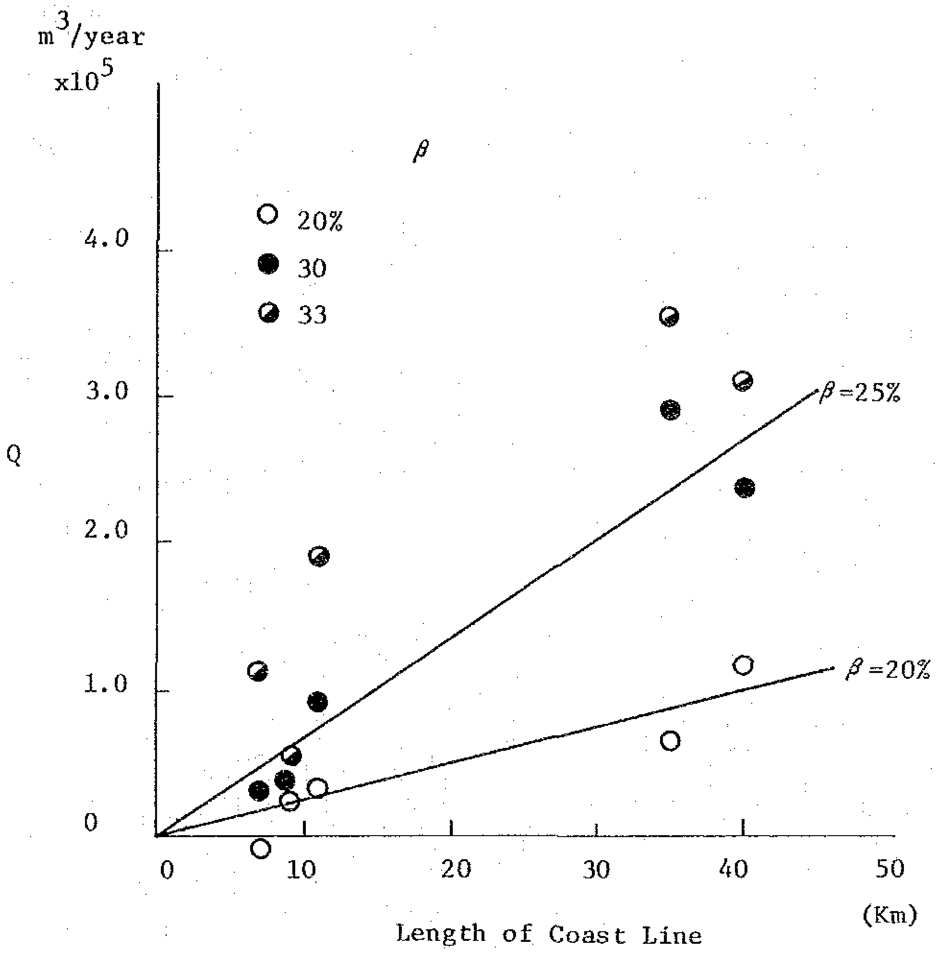


Fig. 3.20

Using these results, Fig. 3.20 shows the relation between the length of coastline and volume of accumulation with the parameter of contribution factor β. On the assumption that the amount of deposit per unit length of coastline is constant, the contribution would be 20-25%. Letting the contribution ratio be 20%, and the height of sands accumulated in the beach be 6m, the amount of advance of the coastline is 0.4m per year.

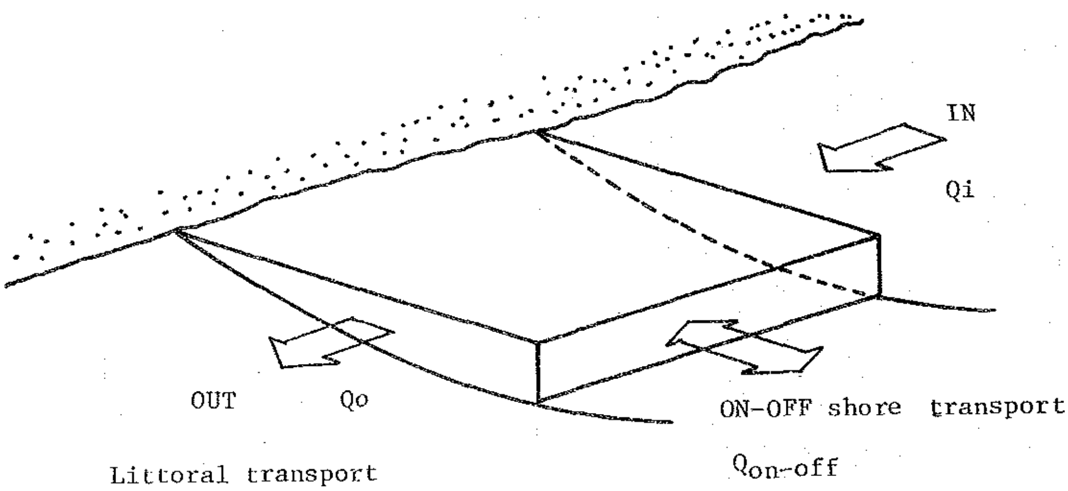
According to Table 3.9 the total transport of sand from the rivers is $7.2\times10^6 m^3$ per year in Liberia, and on the assumption that 20% of this is accumulated on the coast, the total length of coastline is 560 km and that the height is 6m, the amount of advance is 0.4m/year. It is natural to imagine that the rate of accretion is larger given the existance of river outlets. The magnitude of this contribution by the sand from the river would be about $1.4\times10^6 m^3$/year as a whole. The above calculations are derived by the use of various data and information already available, and these results are subject to change with the collection of new data.

4. Causes of Beach Erosion and Countermeasures

4.1 Causes of Beach Erosion

The sand in the beach is stirred up by the wave and transported by the current, and when supply does not balance loss, erosion or accretion occurs.

The movement of the sand is in two directions: either along the coast, or perpendicular to the coast. The movement along the coast is caused by the longshore current which is generated by the obliquely incielent wave. Therefore, the rate of drift is related to the wave height and wave direction in relation to the coastline. As for the movement perpendicular to the coast, the sand near the shoreline shifts offshore by violent storm waves, and the small waves or swells carry sand to the beach.



Deposition or erosion = Qi - Qo + Qon - off

Fig. 4.1 Schematic illustration of balance of transport

The wave condition is not constant but varies from season to season and from year to year, which changes the coastal topography. As is shown in Fig. 4.1 the relation between the amount of moving sand and the change in topography is explained by the balance of inflow and outflow in a given area.

The sources of supply of sand are littoral drift from the adjacent beach, transport from the river, sand made by the erosion of the cliff, sand drift from offshore, sand brought by the wind, and artificial sand nourishment. On the other hand, the outflow is caused by littoral drift to the adjacent beach, wind loss, sand-movement from the coast to offshore, accumulation of sand in the submarine canyon, and removal of sand as mineral resources or construction materials.

Therefore, causes of beach erosion are either the decrease in the supply for some reason or other, or the increase in the amount of sand flowing out of that area. Main causes of decrease in supply are diminution of transport from the river and diminution of littoral drift caused by artificial structures made on the coast. Because the sand brought by the river is the main supply to the beach, the erosion on the coast near the outlet could be caused by the construction of a dam at the upper stream or removal of sand and gravels from the bed for construction materials. The blockage of littoral drift by the coastal structure could be the result of the construction of breakwaters, jetties, groins, detached breakwaters, etc. The blocked amount depends on the scale and location of the structure. However, generally the larger the structure is, the severer the erosion becomes. Some representative examples are shown in Fig. 4.2.

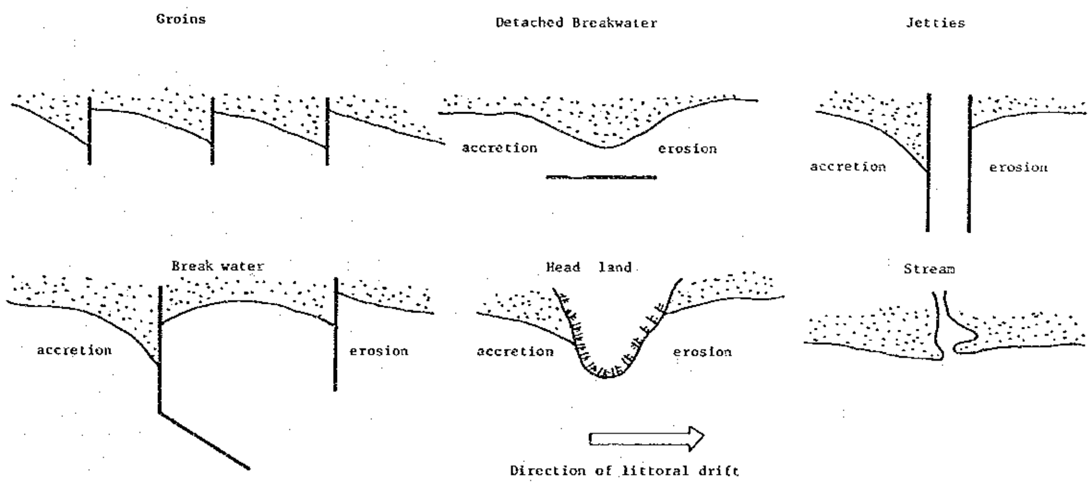


Fig. 4.2 Accretion and erosion around structures

One of the decisive loss of sand from the beach is the consumption of the beach sand for construction purposes.

The cause of beach erosion as a whole from the standpoint of long-term effects has been explained. However there are some cases where seasonal topographical changes are the center of discussion. Generally speaking, wave conditions such as wave height and wave direction are not constant but change according to whether it is summer or winter, or whether it is the dry or rainy season. And this naturally forces the rate of littoral drift and transport from the river to fluctuate. Particularly topographical changes near the artificial structure or near the cape which block the littoral drift are sensitive to change in the rate of littoral drift. On the other hand the outlet of the river changes its location. These are schematically shown in Fig. 4.3.

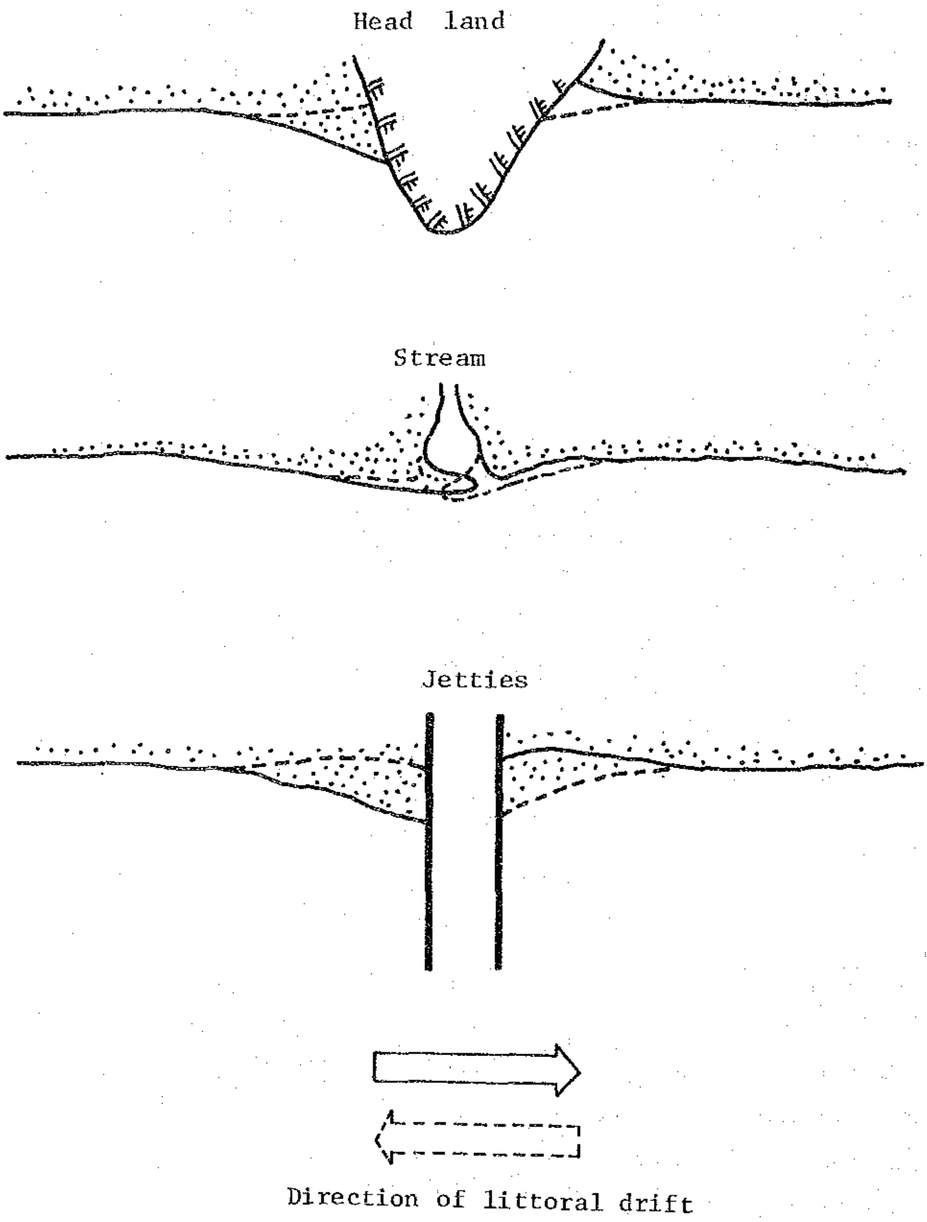


Fig. 4.3 Seasonal changes of coastline

4.2 Countermeasures

Prevention from erosion is attained by balancing the supply and loss of sand in a coast. Therefore, the rate of littoral drift to the beach must be increased or the rate of littoral drift away from the beach must be decreased. One of the means to increase the supply of sand to the beach is the artificial addition of sand, and the sand might be conveyed from some adequate sources. However this method has a flaw in that, without other structures, new sand must be continuously added, and so maintenance cost would be very large.

One of the countermeasures for the situation where the littoral drift is blocked, causing accretion in the updrift side and erosion in the downdrift, is to make an artificial sand by-pass to go through.

Generally, it is difficult to increase the supply of sand, and this method tended to decrease in usage with the development of the coastal area. Most of the countermeasures taken up so far have been to decrease the outflow of sand from the beach.

A groin and detached breakwater are generally used to control littoral drift out of the beach. The groin is a short structure built perpendicular to the coast line which directly blocks the littoral drift, and its effectiveness mainly depends on its length. On the other hand, the detached breakwater is a structure away from and parallel to the shoreline which decreases the movement of sand by the diffraction and dissipation of the wave.

The sea wall or detached breakwater is used to prevent the movement of the sand from the coast to the offshore. The sea wall prevents the sand from flowing out by covering the coast with concrete or asphalt, and it is especially effective when the foot of the cliff is carved by the wave. As for erosion caused by the longshore movement of the sand, the front beach of the sea wall is deeply scoured and its protection is fairly difficult.

The detached breakwater encourages sand accumulation on the shoreline side by maintaining a calm area. In the case of permeable-type detached breakwater, there is an accumulation of sand on the beach brought by the onshore current. When the erosion is caused by annual or seasonal changes in natural conditions (such as wave condition), the width of the sand beach should be widened to make it insensitive to changes in the coast line, and at the same time the groin, jetty, detached breakwater, and others should be built to decrease the change.

4.3 Groins

The groin is an artificial structure built almost perpendicular to the coast line in order to prevent beach erosion, and to protect the port from sand deposit. Its main fuction is to block the longshore drift. As for the flow of the sand offshore, the groin generally aids rather than prevents it. The groin is seldom made as a single structure, and usually several of them are made simultaneously with spacing between them.

When the groin is used, sand is trapped and accretion takes place at the upper stream while erosion is caused at the downstream. Therefore, the rate of littoral drift decreases for the beach as a whole which eliminates the effect of seasonal changes of coastline, and hence makes the beach more stable. When erosion is caused by the imbalance of littoral drift the groin is an effective countermeasure. However, positive sand accumulation cannot be obtained without a sufficient rate of littoral drift. If the rate of drift is insufficient accretion at one place causes new erosion in other parts of the beach.

The alignment of the groin has several variations, namely, perpendicular to the coast line, or a T-type or Z-type with transversed small dikes to prevent flow to offshore.

They can be made of stones, blocks, or concrete, and some of them are permeable while others are not. The permeable groin is made so that the sand can pass through it. However, since the function of the groin is to prevent sand drift the non-permeable type is better and should be used. The permeable groin encourages rather than stabiliges the movement of sand because of the turbulence made by the groin.

The groin can be either perpendicular to the coast line or given a certain angle considering the wave direction. The direction of the incident wave changes according to time, and even if it has some angle, it is generally small.

The longitudinal section of the groin can be divided into three parts, namely, the land-horizontal section, the intermediate section, and the outer section. The height of the horizontal section is so set that the sand can not move over it, and it must at least exceed the level of high-tide plus the average wave-height. This part is attached to a rigid land-structure such as a sea wall in order to prevent erosion by the waves. The slope of the intermediate section is the same as that of the beach. The outer section receives the strongest external force from the wave and must be able to resist it.

The length of the groin and the spacing between two groins depend on the shape of the beach, wave conditions, and the required width of sand beach. The coastline, either inside the groins or outside of them, is perpendicular to the direction of the incident waves. Therefore, immediately after the construction of a group of groins, the coastline between groins changes so that the accretion and erosion are balanced there. This is shown in Fig. 4.4. If there is a long-shore drift, the accretion occurs between the groins, which is depicted in Fig. 4.4. If there is no supply of sand from updrift side, the groin serves to delay erosion, but can not stop it completely.

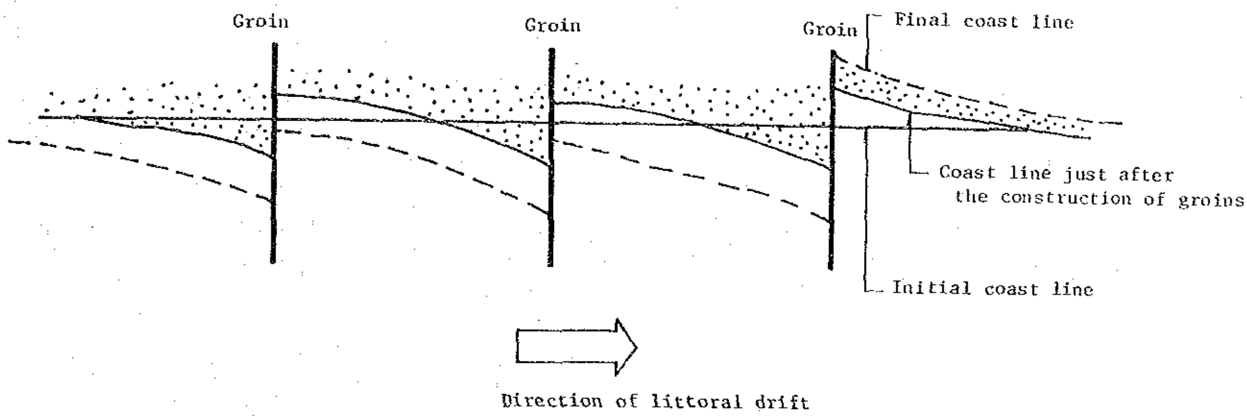


Fig. 4.4 Changes of coast line around groins

When the littoral drift is blocked by groins accumulating sand in the area surrounded by the groins, erosion occurs at the beach downstream. Estimation of this amount is made by assessing the total amount of accretion made by each groin. The erosion of the beach located downstream to the groins can not be evaded and hence, care must be taken beforehand that sand-nourishment is done or the effect of erosion would be of little significance. Several groins in order should be built from the downstream side.

The structure of the groin must be so made that it can block the littoral sand drift, remain stable against the violent wave, and resist scouring and subsidance. Where the wave height is small, the rubble mound are used for inside quarry-run material and armor stones are used to cover the surface. Sometimes, sheet-piles or concrete piles are used.

4.4 Detached Breakwaters

The detached breakwater is a structure built away from the coastline and parallel to it. Some of them are continuous-type and others are not. The function is to eliminate the wave height, to generate a calm area behind it, generate the diffracted waves which advance from both end to the beach, and to form a tombolo by gathering sand from offshore and longshore drift. Therefore, the detached breakwater is built when it is intended to make a calm area, to make a sandy beach by preventing the sand from flowing into the open sea, and to prevent the longshore movement of sand.

If the only objective is to make a calm area behind the detached breakwater, an impermeable continuous detached breakwater should be built as is the case with ordinary breakwaters. In order to prevent beach erosion and to accumulate sands, the permeable noncontinuous type is recommendable. It should be located in the "inside to the breaker-zone" and its length should be 2-3 times the distance from the coastline. It must be high enough to sufficiently dissipate the wave, and it must at least exceed the level of high tide plus one half of the wave height. If the detached breakwater does not reach the mean sea level, its effect suddenly diminishes. The width of its crown is important not for dissipation of the wave but for stability of the structure. If it is made of rubble mound, three or four rows of stones would be enough to give it sufficient strength. The shape of the coastline in the case of noncontinous detached breakwater is shown in Fig. 4.5.

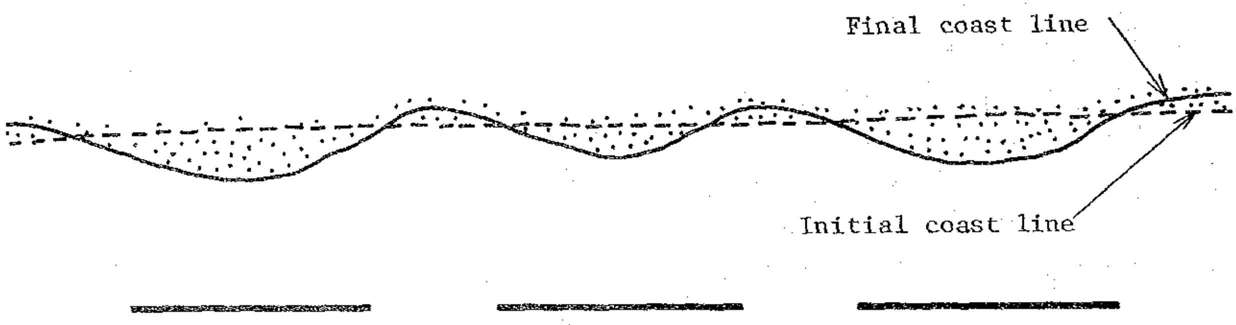


Fig. 4.5 Coastline around detached breakwaters.

With a coast where longshore drift is dominant, the blockage effect of littoral drift is much larger than in the case of groins, and therefore sufficient care must be taken for the inevitable erosion on the downstream side. The amount of erosion in the downstream can be estimated by the same method used in the case of groins. Groins lose their effectiveness if too much sand is accumulated, while a detached breakwater is almost immune to the accumulation of sand and causes no significant change in its effectiveness against littoral drift. The detached breakwater has both large influence and large effect. For the construction of the detached breakwater, stones, asphalt mats, etc. are used to make the base first, and then a structure of armor stones and blocks is formed on top. If a large detached breakwater is made, small blocks are used as inside packing and big ones are used to cover them.

4.5 Artificial Sand Nourishment

Artificial sand nourishment is a countermeasure to prevent beach erosion, or is a method to produce a sand beach by providing sand artificially. In erosion prevention, it is required to keep supplying the exact amount that is taken away by erosion. This countermeasure is often used with others such as groins or detached breakwaters.

The artificial sand by-pass was found to be fairly effective for erosion caused by the stoppage of littoral drift after construction of breakwaters, etc. But various countermeasures must be compared in terms of their cost and their effectiveness. In order to convey sand to the beach, trucks or belt conveyers are used for overland transportation, and baggage boat, barge, or pipeline is used for marine transportation.

4.6 Sea Walls

One countermeasure to prevent coast erosion is to cover the coast with rubble mound or concrete walls. This method is an effective means to protect a cliff made of soft rocks. However, this cannot be used to protect a beach where erosion is caused by the lack of littoral drift. When a wall is constructed to protect the sandy beach the sand in front of the wall moves out, leaving a scouring hole because of the turbulence of the reflected waves. Then the water depth in front of the wall becomes deep enough for nonbreaking waves so that sand movement becomes inactive. Therefore, a large structure is needed for prevention of beach erosion.

4.7 Jetties

The rivers' outlet drifts according to changes in the runoff or in wave conditions of incoming waves. There are two types of change: seasonal changes and longterm change, which takes several years. Serious problems can take place unless there is sufficient space at the river outlet to allow for shifts in the outlet location. One of the ways to cope with this problem is to build a jetty.

A jetty is used to fix the location of a river mouth, and prevent narrowing of the river mouth after formation of a sandbank. Two jetties are made from both ends of the river banks and perpendicular to the coastline. Sometimes only one jetty is built on one bank of the river. If the objective is only to fix the location of the outlet, the jetties can be short. On coasts where longshore drift is especially predominant, jetties must not block this transport.

The jetties should be built perpendicular to the coastline as much as possible. The height of the land part of the jetty must be such that the wave cannot overtop it. It should at least be equal to the level of high tide plus 1~2m. The width must be sufficient to make the structure stable.

The base must be deeply imbedded because the current along it might scour the sand. It must also be able to resist the external force of the waves. Generally, stones or concrete blocks are used to form the structure. Mats are spread at the bottom, and on them are put small stones. If the scale of the jetty is large, the stones are used as a inner packing and heavy stones or concrete blocks are used to cover the structure. The head must especially be protected from the wave pressure by heavy blocks.

5. Beach erosion in Monrovia

Monrovia, the capital city of the country, is densely populated and land in beach area is also intensively utilized for housing. As is shown in Fig. 5.1, beach erosion is taking place in New Kru Town, West point and E.L.W.A..

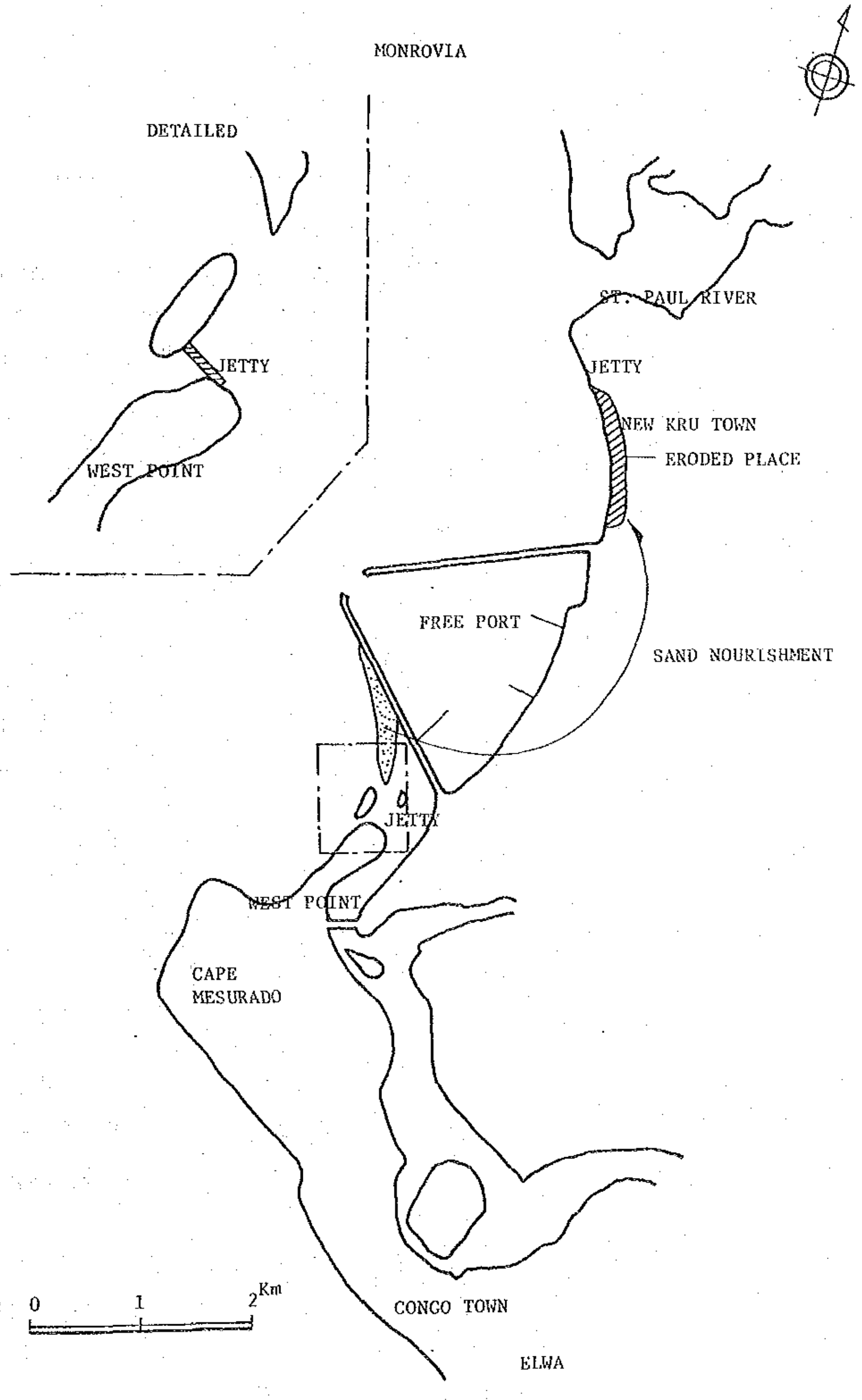


Fig. 5.1 Map of Monrovia

Since the condition of erosion is different from place to place, the change in topography. Causes of erosion and recommended countermeasures in each place are discussed one by one in the following sections.

5.1 New Kru Town

A. Topographical Change

Table 5.1 Shoreline Retreat in New Kru Town

Base Line: Perpendicular to Free Port North Breakwater, Crossing at a Point 2,000m from the Head Point

Distance from North Breakwater (m)	Distance Between the Shoreline and Base Line (m)		Amount of Retreat (m)
	1952 Shoreline (aerial photograph)	1969 Shoreline (Map)	
100	175	240	65
200	190	263	73
300	210	285	75
400	210	300	90
500	235	315	80
600	235	326	91
700	245	338	93
800	250	340	90
900	240	330	90
1000	230	320	90
1100	230	322	92
1200	220	309	89
1300	200	303	103
1400	195	293	98
1500	180	276	96
1600	170	248	78
1700	150	225	75
1800	135	194	59
1900	110	158	48
2000	85	124	39
Sum	3,895	5,509	1,614
Average	194.8	275.5	80.7

Note:

1. Aerial Photograph in 1952, No Revision, Scale 1:20,000, Taken in March, 1952
2. Map Issued by Ministry of Lands and Mines
3. Segregation of Breaker Point and Shoreline was Difficult with the Aerial Photograph

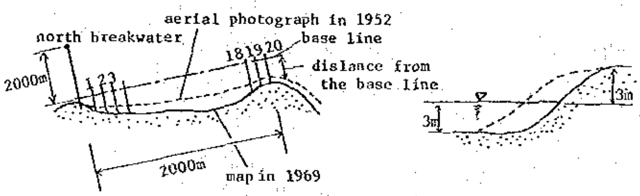


Illustration of the method to estimate the rate of erosion

Comparing the aerial photograph (Scale 1:20,000) taken in 1952 with the map of 1969 (LIBERIA CITY MAPS, Scale 1:7,500), the shoreline has been eroded an average of 80m and a maximum of 100m as is shown in Table 5.1. The average annual retreat of the shoreline is about 5 meters. With this data, the rate of erosion can be estimated. On the assumption that the eroded beach was 3 meters in both the land and sea sides as is shown schematically in the figure, the volume of erosion must have been: 80m x 2,000 m x (3m + 3m) = 960,000m^3
This is the estimated volume of erosion which occurred in the 17 years between 1952 to 1969, and the annual rate of erosion is about 56,000m^3/year as shown in Table 5.1,

As was described already, a large volume of erosion occurred causing shoreline retreat in a 2km stretch. Several houses were washed away.

According to our investigation, the rate of erosion at the outlet of the St. Paul River is fairly small, while that at Free Port North Breakwater is serious. On this beach, there is one wrecked ship offshore and another near the shoreline. The wrecked ship near the shoreline seems to work as a detached breakwater preventing the erosion of the shoreline. The countermeasure taken so far was to damp laterite material of 3,200m^3 with old vehicleframes under the direction of the Ministry of Public Works. However, it was not sufficiently successful to prevent the beach erosion.

B. Causes

There are several causes as described below, but the largest cause and factor for beach erosion may be the north breakwater at Free Port which was built in 1948.

The direction of littoral drift in the Liberian coast is from southeast to northwest, and the construction of the breakwater seemed to have worked as an obstacle to block the transport of sand, thus causing erosion. This assumption is also warranted by the fact that a large amount of sand is accumulated at the south breakwater. The volume of accumulation there is about 1,180,000 m^3 assuming an area of sand bank of 236,500 m^2, and bank height of 5 meters (using the map made in 1969. scale 1:7,500). This accumulation occurred in the 21 years between 1948 and 1969, with annual rate of accretion being about 56,000 m^3/year. This figure shows a close correlation with the rate of erosion at New Kru Town which is 57,000 m^3/year, and leads to the conclusion that the construction of breakwater at Free Port caused both of these, the erosion and the accretion.

It was not considered that the erosion at Free Port might have been caused by the reduction of the discharge from St. Paul River as a result of the construction of Mt. Coffee Dam. It was confirmed by the aerial investigation that there is little possibility of this dam preventing the transport of bed material. The short height of the dam made presumption of the river bed's continuity possible. The rocks were directly exposed in the river bed, and no accumulated sand was found. Therefore, the influence will not be serious enough to have a tangible effect on the beach erosion of New Kru Town.

C. Countermeasures

In order to stop the erosion completely, the ideal method is to make continuous the littoral drift. However this is impossible considering the given conditions at Free Port. Therefore, several other alternatives are proposed.

First recommendation is construction of groins. With the groins, the shoreline at the upper stream (south) stabilizes since the sand drift is blocked by them. But this is done at the sacrifice of the shoreline downstream. Therefore, the groins must be built at the northern side of New Kru Town which is to be protected, namely near the outlet of St. Paul River. Further, there is a choice between many short groins and a few long ones. Unless the groin is long, it cannot function effectively. Even if long ones are projected at New Kru Town, they need not be extraordinarily long because the slope of the beach there is very steep and most of the sand would be trapped with groins of moderate length. With the above reasons, two or three long groins are recommended.

However, it is impossible to regain the land already lost with only groins. The only method to recover the land is sand nourishment. The damage downstream from the groins would not be so serious becauses of the existance of the outlet of St. Paul River which would bring a considerable volume of sand.

At the same time, it is suggested that the dredged sand of Free Port when the extention work project is carried out, or the dredged sand taken from the harbor each year by the National Port Authority, be dumped at the north breakwater as a nourishment. This, combined with the effect of the groins, will serve to prevent erosion considerably.

Another method is related to the projected extention work of Free Port. The method suggests that the development of New Kru Town as a port facility be included in the project. North breakwater would be extended to the mouth of the St. Paul River. The area inside the breakwater would be used as part of the port. This method has a weak point in that many houses in New Kru Town must be moved away.

On the right bank of the St. Paul River outlet, conference hall and other facilities of OAU are now under construction for the conference to be held in 1979. These facilities are being built on the site extremly near the coastline, and although there is no impending danger, erosion problems might occur in the near future. This concern is derived not only from the influence of constructing groins at New Kru Town but also from the possibility in the future that the sand transport from St. Paul River will not be able to countervail the decrease of littoral drift.

5.2 West Point

A. Topographical Change

This coast has received a large amount of sand from south, and the accumulation is conspicuous because of the trapping by the breakwater of Free Port. The total volume of accretion can be estimated (as was described already with New Kru Town) in comparison between the shorelines in 1948 and in 1968. The result was about 1,180,000 m^3. There are woods on the sandbank which shows that the sandbank is already fixed and stable.

The mouth of the Mesurodo River which has a river basin of 50km^2 changes its position each year because of the accumulated sand. The crowded houses of West Point were built on the accumulated sandbank which was formed long ago. The crowded houses on the bank were mainly built by the Kru tribe, and the wreckage of some of them from erosion at the edges of the sandbank was observed.

Comparison between a picture taken several years ago and the present, plus the fact that newer houses are mainly being built near the coastline demonstrate the existance of an accretion process.

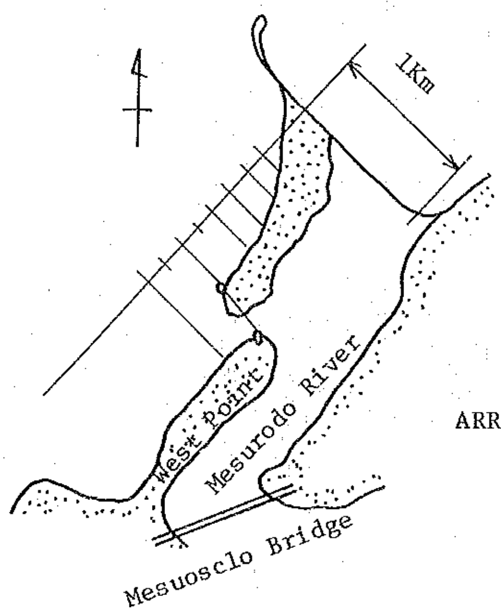
The Ministry of Public Works has been doing protection works with stones to eliminate waves on a small scale. These are not considered to be permanent countermeasures.

With the comparison between the aerial photograph in 1952 and the map of 1969 (Scale 1:7,500), an accretion of the shoreline of about several hundred meters near the south breakwater and several meters near the center of West Point can be ascertained.

Table 5.2 Shoreline change in West Point

Base-Line: Perpendicular to South Breakwater, 1km from the root as shown in the figure

Distance from South Breakwater (m)		Distance Between Shoreline and Base Line (m)		Amount of Advance (m)
		Shoreline in 1952 (Photograph)	Shoreline in 1969 (map)	
Sandbank along the South breakwater	0	560	-405	965
	100	670	-150	820
	200	760	60	700
	300	830	300	530
	400	820	443	377
	500	800	525	275
	600	800	615	185
	700	740	690	50
	Sum	5,980	2,078	3,902
	Average	748	260	488
West Point Sandbank	700	1,060	960	100
	800	1,020	915	105
	900	1,020	922	98
	1,000	990	900	90
	1,100	960	930	30
	1,200	1,020	1,005	15
	1,300	1,070	1,065	5
	1,400	1,120	1,118	2
	1,500	1,150	1,148	2
	1,600	1,190	1,178	12
	1,700	1,200	1,185	15
	1,800	1,220	1,170	50
	Sum	13,020	12,496	524
	Average	1,085	1,041	44



ARRANGEMENT OF BASE LINES

B. Causes

As was discussed already, the shoreline is accreting as a whole. Because of this accretion, the mouth of Mesurado River has shifted southward causing the erosion to take place in the north side of West Point. Mesurado River must have been flowing along the south breakwater without touching West Point. But the outlet has been shifted southward by the influence of the sand deposit along the breakwater. This change of river outlet is causing the erosion at West Point.

At present two outlets are observed, and at ebb-tide the stream can be observed at the West Point side.

C. Countermeasures

The erosion can be terminated by constructing some structure which prevents the stream from flowing through West Point. One countermeasure would be the construction of a jetty in the north of West Point to let the stream flow directly to the ocean. This is shown in Fig. 5.1. In addition, shore protection is needed at the roots of the jetty to prevent erosion there made by the change of the current direction. Without such precautions, the stream might flow through the houses in West Point.

On the other hand, administrative means to control land utilization in places of possible erosion is also a possibility.

5.3 ELWA

A. Topographical Change

This is a monotonous coastline with scattering reefs, and which faces the Atlantic Ocean directly. The distribution of grain size of beach sand is shown in Fig. 5.2. Sand is adequate as the construction material: 60%--0.57mm (diameter), 30%--0.47mm, 10%--0.36mm. The sand removal at various places on the coast are observed.

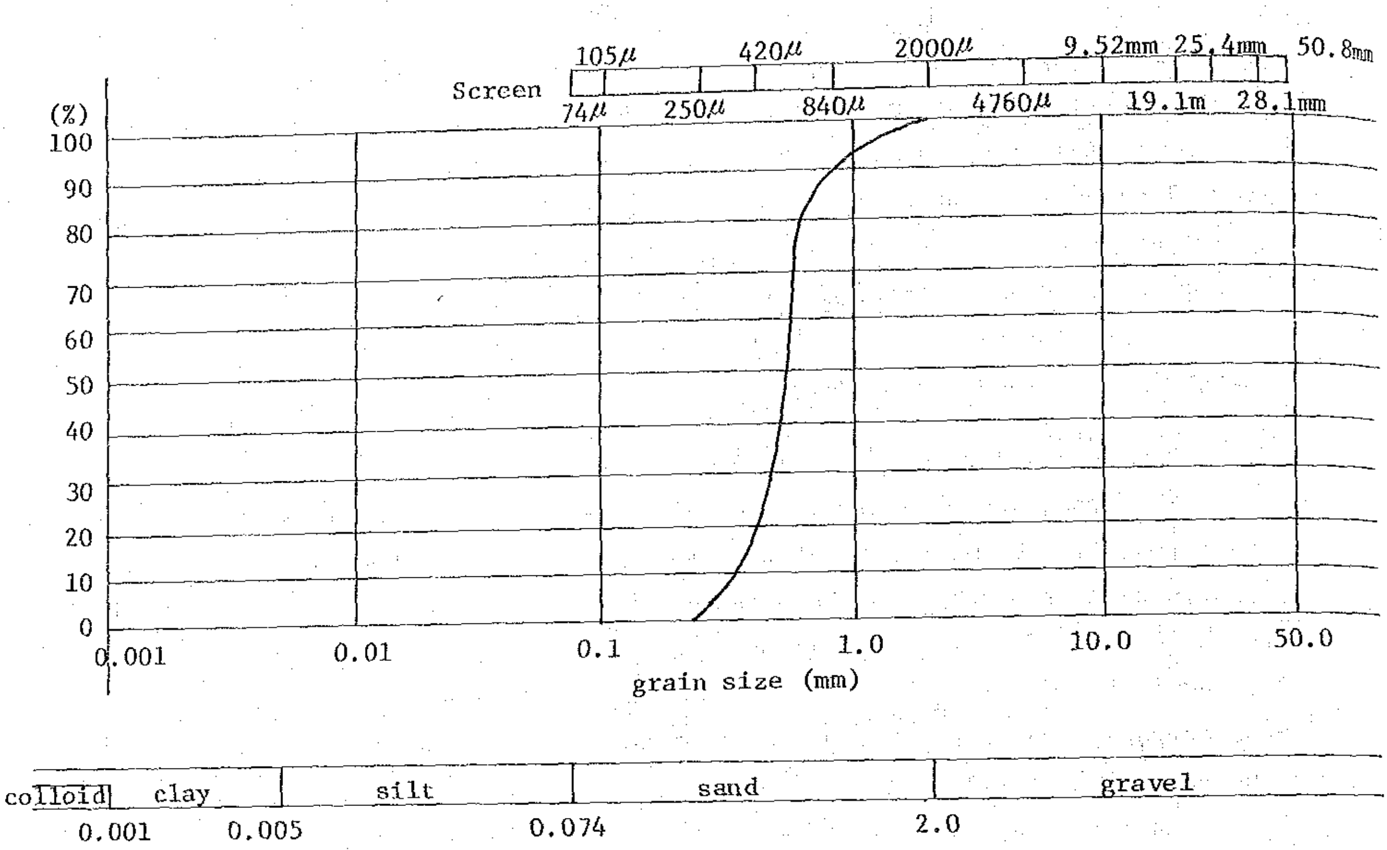
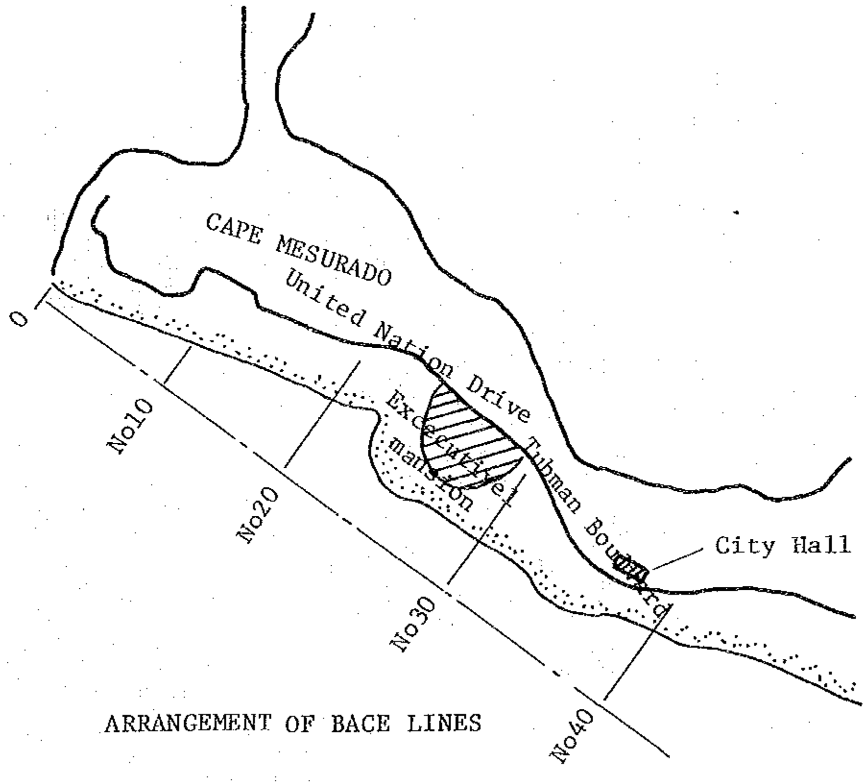


Fig. 5.2 Grain size distribution at, Congo Town Beach

Comparing the aerial photograph taken in 1952 with the map of 1969 (Scale 1:7,500), the shoreline has eroded about 40 meters on an average, which is shown in Table 5.3. Several houses have already been washed away, and the existing houses at the shoreline are facing imminent danger. The Ministry of Public Works seems to be using stones and latelite material to prevent further erosion.

Table 5.3 Shoreline Change Near ELWA

Distance from Cape Mesurado (m)	Distance Between Road and Base Line (m)		Distance Between Shoreline and Base Line (m)		Rate of Erosion
	1952	1969	1952	1969	
200	-	-	0	15	15
400	135	131	20	23	3
600	210	195	35	60	25
800	285	270	70	82	12
1000	-	-	110	128	18
1200	610	555	140	165	25
1400	640	608	170	210	40
1600	670	630	190	240	50
1800	730	700	230	278	48
2000	750	758	230	293	63
2200	740	765	240	285	45
2400	600	622	120	150	30
2600	530	518	15	60	45
2800	470	465	10	-10	-20
3000	390	413	20	17	-3
3200	240	270	20	38	18
3400	240	180	0	23	23
3600	360	240	20	23	3
3800	520	398	70	90	20
4000	660	555	130	150	20
4200	770	690	190	210	20
Sam	-	-	2,030	2,530	500
Average	-	-	97	121	24



ARRANGEMENT OF BACE LINES

Since there is no fixed point on the beach, the comparison between the shorelines of 1952 and of 1969 was made with the use of the baseline derived from United Nation Drive and Tubman Boulevard. The shorelines were compared by measuring the distance from the baseline thus gained.

B. Causes

The causes of erosion were removal of sand from the beach for construction purposes. The removal of sand upstream of the littoral drift caused the decrease in supply downstream. In Monrovia, many houses and public institutions are now under construction, and therefore, the demand of sand is large. The main cause of erosion is the removal of sand at Congo Town and Coopers Beach, etc. to fill the demand described above which influenced the beaches downstream.

C. Countermeasures

The government of the Republic of Liberia just started the control of sand removal from the beach. The cause of the erosion would disappear if the regulation become more stringent or if the removal is decreased under administrative guidance. However, the demand for the sand is still growing fast, and it would be important to shift the locations of removal so that new locations would have little effect on the littoral drift. The south breakwater where the sand is accumulated and NW of St. Paul River (it should be far from OAU conference facilities) would be suitable new places around Monrovia for that purpose.

6. Beach Erosion at Buchanan

6.1 Topographical Change

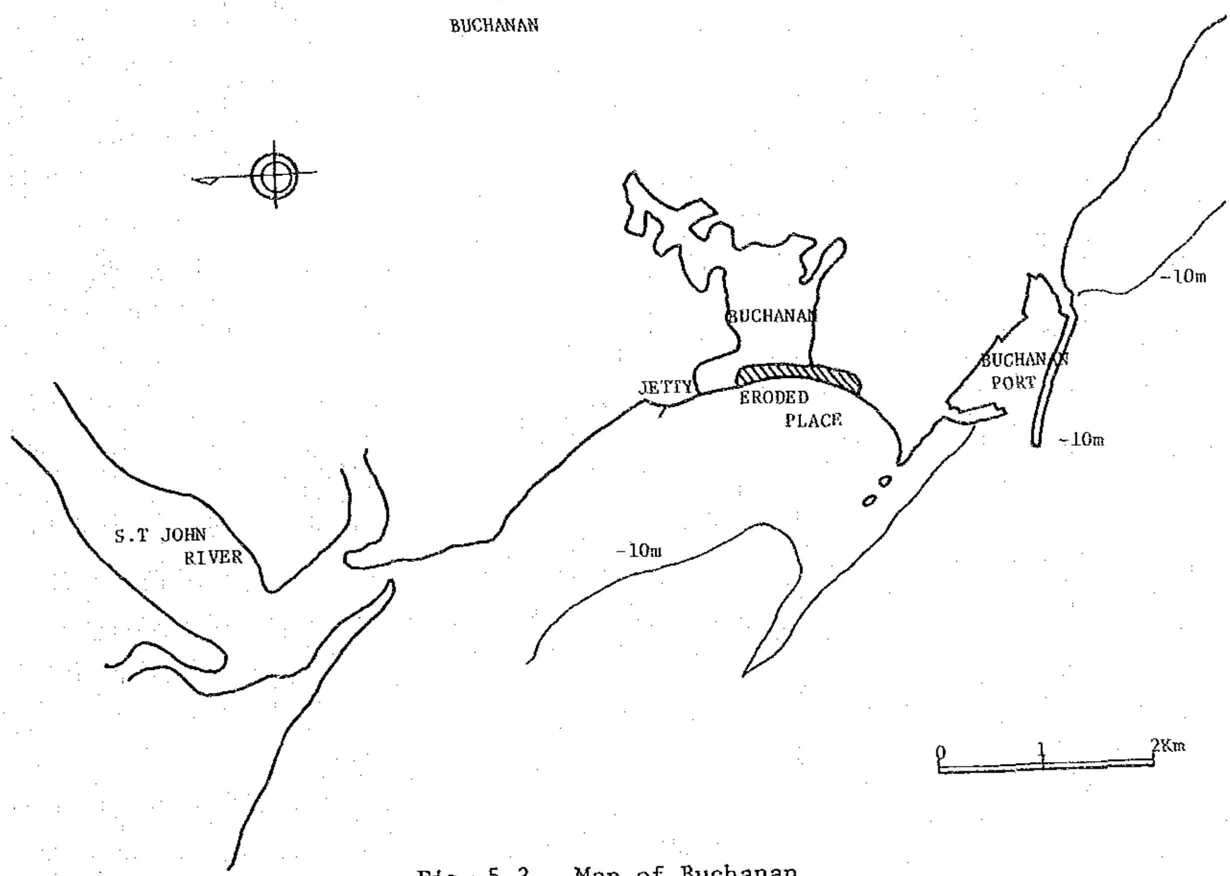


Fig. 5.3 Map of Buchanan

As is shown in Fig. 5.3, there is Buchanan port constructed in 1963 in the south, and the city of Buchanan in the north, and to the far north, there is the outlet of the St. John River.

There was only gradual erosion until the construction of Buchanan port. The construction of the port accelerated the already existing erosion. Table 5.4 was cited from the internal material of LAMCO[4,5].

Table 5.4 Chronology of Erosion in Buchanan

Term	Place	Are of Erosion (m2)	Annual Erosion Rate (m/year)	Note
1954 - 60	Savage R. - Waterhouse Point	15,000	1.5	Before the Construction of Breakwater
	Fanti Town	4,000	1.0	
1960 - 68	Grand Bassa Point - Waterhouse Point	60,000	5.5	
1968 - 71	Waterhouse Point	80,000	20	By Dumping of Tailing Material
1971 - 72	Around Fanti Town	30,000	4.5	
1972 - 75	Waterhouse Point	70,000	11	
	Around Fanti Town	10,000	5	

Although there is erosion on the northern side of Buchanan port, there is a large amount of accumulation of sand on the southern side of the breakwater, and machines can be seen removing the sand for construction purposes. At the end of the south breakwater, we could observe turbidity in the water, which showed that the movement of sand is brisk far into offshore. Extending the coastline to the northwest at Buchanan, there found a reef which keeps the city from the waves of the Atlantic Ocean. Because of this situation, a fairly large amount of sand drift coming from the southeast will evade offshore. So the northern part of Buchanan port might have been eroded mildly even without any artificial structures. The breakwater built in 1963 aggravated the situation, which is clear according to Table 5.4. Against this, tailing materials were dumped heavily (950,000 m^3, diameter: about 0.15 mm) into the outlet of old Savage River in 1968-71 to secure the shoreline. However, the difference of the color of the tailing materials and the natural sand was conspicuous, which caused water contamination. Thus, this trial came to a halt. Aerial investigation revealed this color difference. The color of water around the port was reddish-black and completely different from the othe part.

In addition, even on the left bank of the outlet of St. John River, the houses and telphone lines, etc. are facing danger of erosion and shoreline retreat.

6.2 Causes

Considering the topographical conditions described above, the causes of beach erosion are estimated as follows:

(1) The construction of the breakwater at Buchanan port blocked the

littoral drift, leading to erosion of the beach.

(2) Removal of sand for construction purposes at the south breakwater decreased the amount of sand flow downstream.

(3) The flow of St. John River changed and this caused change in the shape and the depth of the outlet accordingly.

The outlet of Savage River was changed by the construction of Buchanan port. Space for the shift of coastline decreased because the outlet changed. Investigation revealed that the amount of erosion is largest in the south and smallest in the north. This shows how serious the influence of the Buchanan port breakwater is.

The erosion of the left bank of the St. John River is the result of a shift of outlet. Still, this problem is indiginous to the outlet of the river and large damage will not be imminent. Basically, the sand bank at the river outlet is unstable, experiencing erosion and accretion repeatedly.

6.3 Countermeasures

The houses near the coastline are being washed away, and the erosion is expected to aggravate. Effective countermeasures are urgently required. LAMCO built groins near the center of the eroded part, which was considered to be a good decision. The three possible recommendations made in this situation are as follows:

(1) Combine groins with artificial sand nourishment

(2) As is shown in Fig. 5.4, combine the detached breakwater utilizing the reef, with artificial sand nourishment.

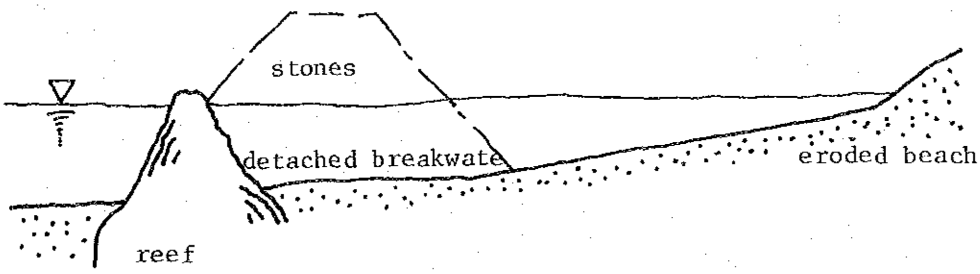


Fig. 5.4. Detached breakwater utilizing a reef

The littoral drift should be blocked with the use of groins or detached breakwater. The entire balance is such that outflow exceeds inflow. Therefore, the only way is to protect the important places where houses or roads etc. exist while discarding the unimportant places. Because the sand is transported from west to east, an artificial structure should be built at the east end of the important places. Care must be taken to ascertain that the erosion on the east side of the structure (such as a groin) is of little significance. If this erosion designated area is near the outlet of St. John River, the erosion would be negligible in front of the larger fluctuation at the outlet. This also means that important facilities at the outlet of St. John River, must be kept away from the shoreline to give some space for erosion.

(3) Use of artificial sand by-pass

This method intends to bring the sand accumulated at the south breakwater to the north breakwater by some artificial means. However, considering the cost-benefit relations, the largest demerit is the huge cost of maintenance.

7. Beach Erosion at Greenville

7.1 Topographical Change

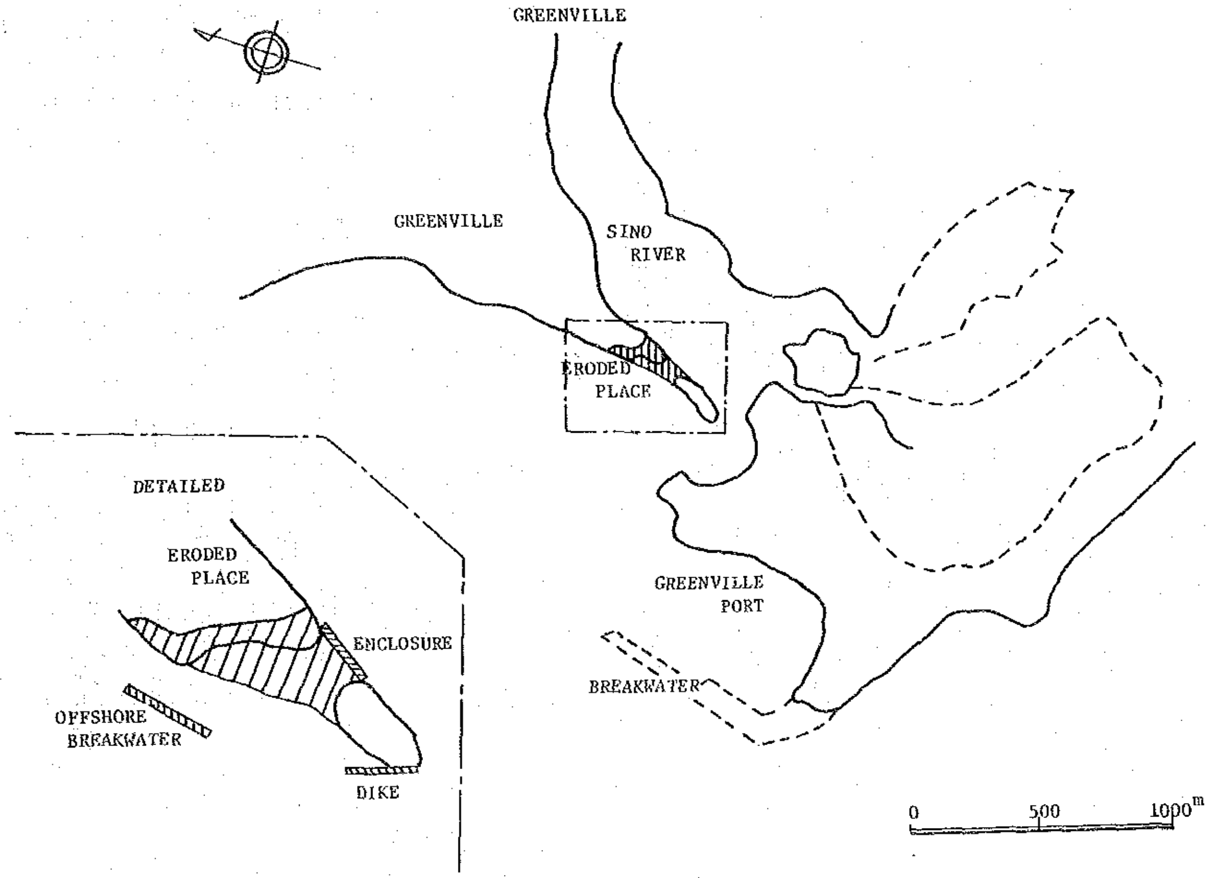


Fig. 5.5 Map of Greenville

As is shown in Fig. 5, 5, the city of Greenville is on the right bank of the mouth of the Sino River. Greenville port was made on the left bank in 1964 in order to bring out timbers, and the port has a breakwater facing the Atlantic Ocean.

The erosion seems to have occurred very recently. The direct cause is thought to be the diversion of the Sino River outlet in April, 1978. According to the aerial photograph in 1952 (Scale 1:20,000) only one outlet is found at the river mouth and this corresponds to the current left-side outlet. On the right-side, a sand deposit can be seen in the photograph while another outlet exists there at present.

The coast erosion is such that about one-fourth of the road width was washed away, several houses were wrecked, and memorial monuments are facing danger. Additionally, dredging work was done twice at Greenville port to keep the required depth in 1972 and in 1977. According to the Port Authority the dredging amount in 1977 was 92,000m^3 (sand 30%, mud 70%).

7.2 Causes

The following are possible causes:

(1) Shift of river outlet location

1) The heavy rain in September, 1977 flooded the Sino River and this became a factor which changed the outlet pattern.

2) The outlet was for some reason divided in two in April, 1978, and the newly-made outlet became the mainstream.

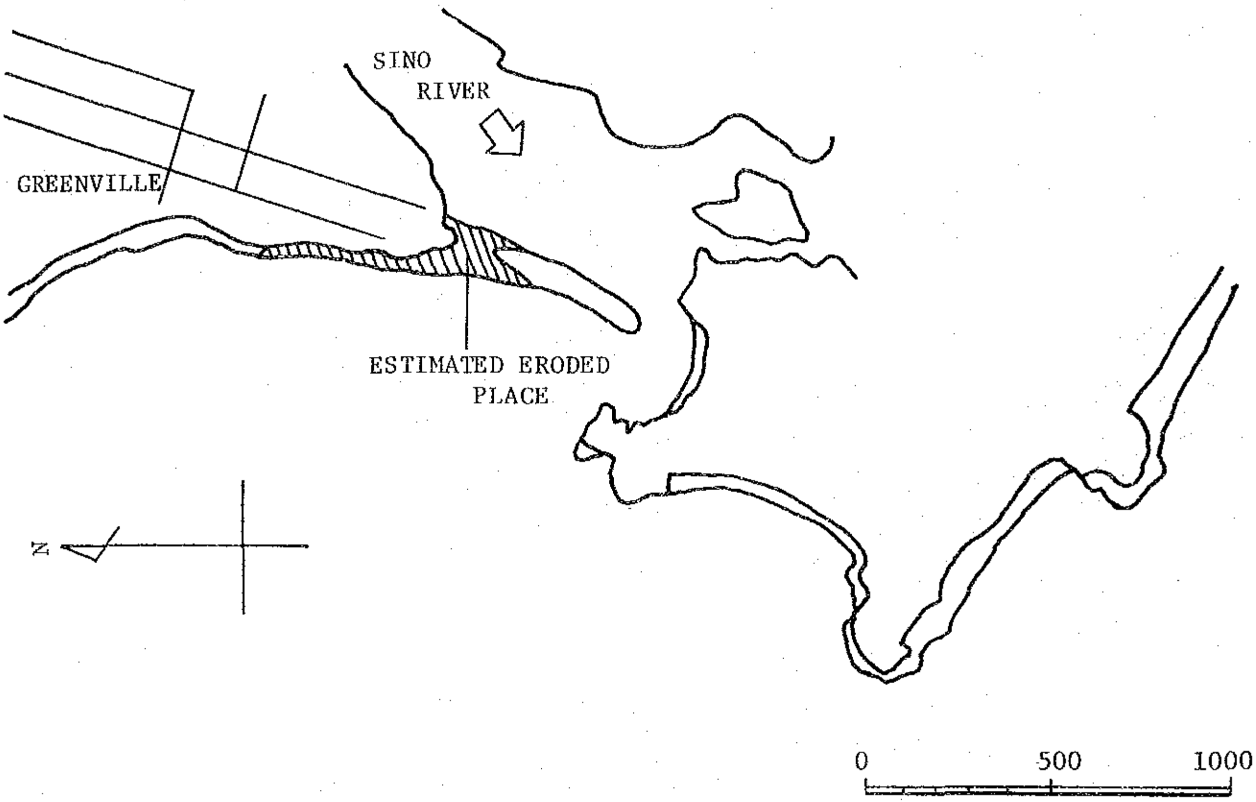


Fig. 5.6 Shifting of the mouth of Sino River

Fg. 5.6 shows the comparison between the aerial photograph taken in 1952 and the actual shape at the time of investigation in May, 1978. According to this, the area of erosion is about 35,000m^2 and the amount of erosion is 175,000m^3 on the assumption of 5 meter depth.

3) The newly made outlet will continue to be dominant and urgent countermeasures must be devised.

(2) Reduction of Littoral Sand Drift

1) The movement of littoral drift was blocked by the Greenville port breakwater, thus changing the shoreline near the outlet of

the Sino River.

2) The dredging work of Greenville port to keep a certain depth decreased the amount of sand drift at the outlet of Sino River.

The beach is protected by the concrete wall to secure the road near the eroded place, and the reflection of waves by the wall increased the turbulence at the bottom causing scouring.

7.3 Countermeasures

The main cause of erosion is the instability of the Sino River outlet. Therefore, countermeasure must be undertaken to stabilize the outlet.

The newly-made outlet might be blocked artificially to increase stability. This could be done by constructing a jetty which can block the ordinary flow, thus reducing the number of outlets to one. Fig. 5.4 shows this schematically. However, care must be taken in the construction not to encourage the shoaling of Greenville port by sand.

As for countermeasures to eliminate the turbulence at the seabed caused by the reflected wave in front of vertical wall protecting the roads, the following items are considered.

1) New roads might be made inland and let the old ones reduce to natural sand beach as shown in Fig. 5.7.

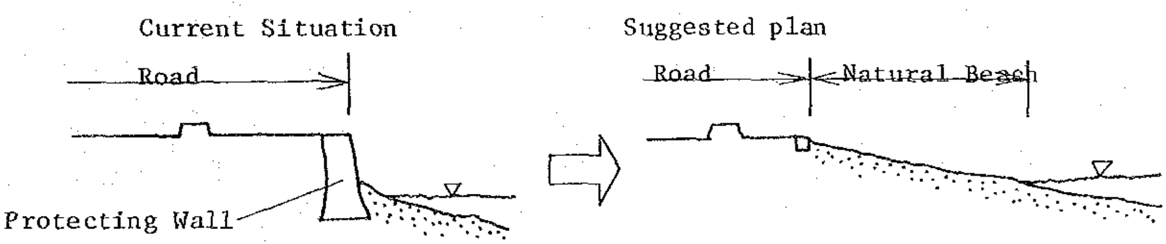


Fig. 5.7 Change of road arrangement

2) A detached breakwater or a groin might be built as shown in Fig. 5.8. After investigating the direction of sand drift, the detached breakwater must be constructed so as to guarantee the shoreline advance while eliminating possible new erosion in other places.

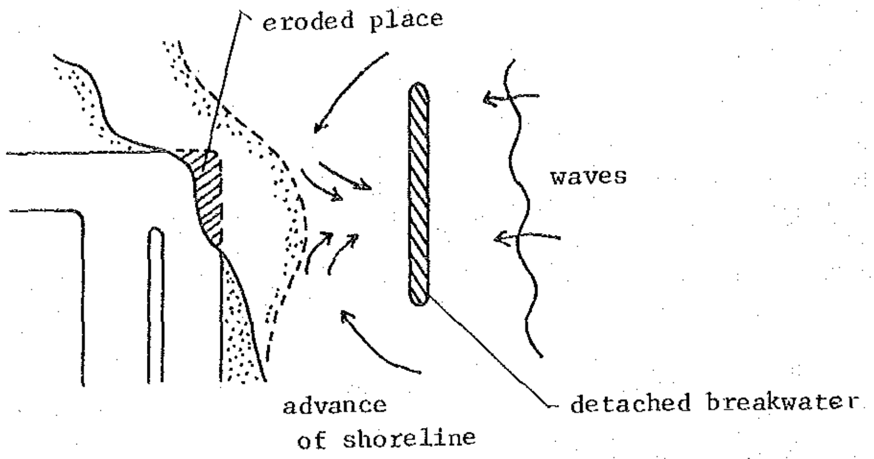


Fig. 5.8 Construction of a detached breakwater

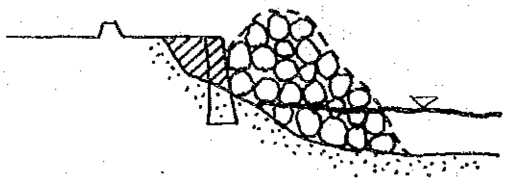


Fig. 5.9 Protection of Scouring

3) A wave dissipation structure might be installed surrounding the concrete wall. As is shown in Fig. 5.9 stones or blocks are used to reduce wave energy. However, this method cannot work permanently. In addition to some possibility of accelerate erosion resulting from increased turbulence at the bottom, maintenance cost will be incurred each year in compensating the stones dispersed, which reduces the height of the structure.

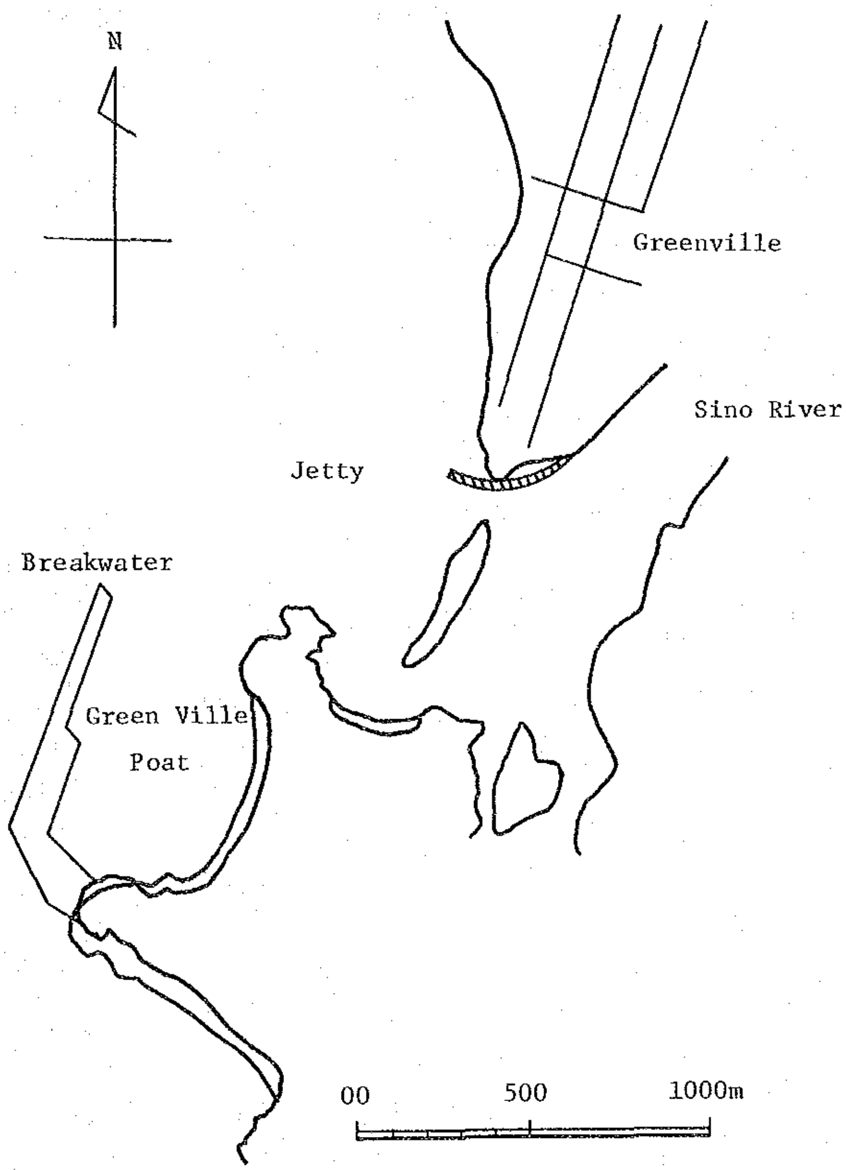


Fig. 5.10 Arrangement of a jetty in Greenville

The countermeasures for each independent cause are described above. Fig. 5.10 shows another aggregate countermeasure to secure the outlet and the shoreline. This method is to build a structure on the west side of the eroded area which works as a jetty and shore pretection at the same time. The structure prevents the eroded area from enlarging eastward, leads the stream to flow into offshore, and gives accretion even on the east side (by making it work as a groin too). Although the dimension of the structure will be large, this method is better than other ones in that the method allows the concentration of work in one place and it does not require the fixed location of the river outlet.

Although several countermeasures are suggested, there is insufficient data to judge them correctly. Hence, it is strongly suggested that the government endeavor to gather data such as the information of shoreline change by aerial photograph, or hydrological data.

8. Coastal management

Because of the dominant littoral drift from southeast to northwest, it is difficult to prevent erosion only by artificial structures. Therefore, some other means must be used to rectify the situation.

There are several forms of beach utilization. Some of them are for port, fishery, removal of sand for construction purposes, or for housing sites. These forms compete potentially. Therefore, administration to take care of the total balance in the utilization of coastal area, rather than a simple concentration on the erosion problems, is important. First of all, the basic policy of utilization must be decided, and then the organizations and the laws necessary to implement the policy can be made.

Most of the current erosion problems were derived from the construction of harbor breakwaters. This is the inevitable result in cases where littoral drift is dominant, and therefore, the influence of breakwaters or dredging work in the port on the neighboring beaches must be clarified beforehand. With such information, the authority can control housing or road construction projects in places facing erosion. In the places where houses or other properties are already in danger, the authority must consider the trade-offs and come up with a balanced utilization project.

Another cause of beach erosion is the removal of sand as construction materials. New houses are being built, and many public works are projected around the cities in addition to land reclamations. The demand of sand will increase drastically. Although it is not known how much sand is used currently, it is estimated to be $1.0\text{-}2.0\times10^5$ m^3 on the assumption that all the cement produced is used as concrete. This value has the same order of magnitude as the rate of littoral drift already calculated. Other than this, the sand is used for land reclamation purposes in Monrovia, and naturally, the actual demand of sand is greater than the value gained above with a simple assumption. It would be difficult to prohibit the removal of the sand from the beach with such an enlarging demand. Therefore, the only means left is to remove sand from an area insensitive to erosion, and such a place must be found beforehand and orderly exploitation must be implemented. Generally, the suitable places for this purpose are the southeast parts of the breakwaters which trap sand or the northeast ends of coastline which is the terminal of the littoral drift.

The construction of a dam is another cause of the decrease in the supply of sand. The stoppage of sand transport in a river causes a reduction in the supply of sand to the beach as well as the reduction in the dam's capacity as a reservoir. In construction of dams, the information about these influences and implications must be collected beforehand so that countermeasures may be devised beforehand.

A basic plan concerning the utilization of coastal zone must be made, and an investigation into the balance between supply and loss influencing erosion directly must be done from the standpoint of coastal management.

In the Republic of Liberia, the littoral drift is dominant and the construction of coastal structures sometimes suffers accordingly. In order to evade this unfavorable influence, the total coast of 560 km must be divided into many sections, and effort must be made to have an equilibrium of supply and loss of sand in each independent section. Even now, there is a natural partition made by the headland and the reef, increasing the stability of the coast. This natural partition should be utilized positively and if the direction of the coastline is made about 200°, considerable stability of the beach will be attained. Therefore, it is important to devise a program of sand supply and consumption taking into account sand supply, blockage of sand drift by the structure, and removal of sand for construction purposes.

9. Items for Future Investigation

There are several items that must be done in the future to establish a project of beach erosion prevention works. However, the following are those which can give results with a short investigation and which are of use in the construction of prevention works.

(1) Analysis of Shoreline Change Via the Aerial Photograph

It is necessary to have information concerning sand balance on the entire coast of the Republic of Liberia in order to prevent erosion, make a project of land utilization, and to arrange the schedule of sand removal. This can be attained by using aerial photographs of the 1950s and 1960s and by obtaining the information about the shoreline change. The scale should be large because with a small scale, it is difficult to locate the shoreline and the breaker point. The shoreline will not move considerably according to the high or low tide, because the slope of the beach at the shoreline is steep (more than 1/10).

With this investigation, stability, erosion, and accretion are assessed in each area, and this clarifies the sand balance and sand movement. The investigation is useful in determining the effects of possible countermeasurers, influence on various parts after the stoppage of littoral drift by certain structures, place and allowable amount of sand removal, and suitable places for coastal utilization.

(2) Mineral Analysis

By the analysis of minerals contained in the sand of river outlets or beaches, the source, transport direction, and range of influence of the littoral drift are known.

The assumptions that the direction of littoral drift is from southeast to northwest, and that the main source of supply is the river is verified by the minaral analysis. If one river transports certain minerals as a "tracer" which cannot be found in other places, it gives information on the range of influence and on the direction of littoral drift by actually tracing the "tracer", namely, by investigating the composition of minerals along the coastline.

Table 9.1 Heavy Minerals

Name of heavy mineral	Depositing places
1. Kynaite	Dwensgrove, Grand Bassa County
2. Columbite	
3. Rutile	Edina, Grand Bassa County
4. Ilumenite	
5. Chromium	Palala, Nimba County
6. Barite	Gibi Range Area
7. Condrundum	Wologisi Area

Generally heavey minerals are used as tracers. In the Republic of Liberia the sources of the following heavy minerals as shown in Table 9.1 are available through geological investigation[6], since they are important for industry. These minerals might be used as a tracer.

Currently, Liveria Beach Sand Exploitation Company is investigating the possibility of recovering rutile, zircon, ilmenite, and monozite from the beach band. These minerals, too, are considered to be suitable as a tracer. When mineral analysis is conducted along the coastline, stress should be laid on the river outlet and places of variation. It is suggested that it be conducted within a spacing of about 1km.

3) Investigation for Construction

Recomendations are made on countermeasures for the erosion problems in Monrovia, Buchanan, and Greenville. In implementing the plans, further investigation is required. First of all, a large-scale map of the place where the new prevention structure is expected to be built must be obtained. This map facilitates the decisions about details concerning the site and dimension of the structure to be built. This site-and-scale information in turn facilitates the forecast of needed expenses for construction. This topographical investigation is also necessary from the standpoint of assessing the effectiveness of the prospective countermeasure.

10. References

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