

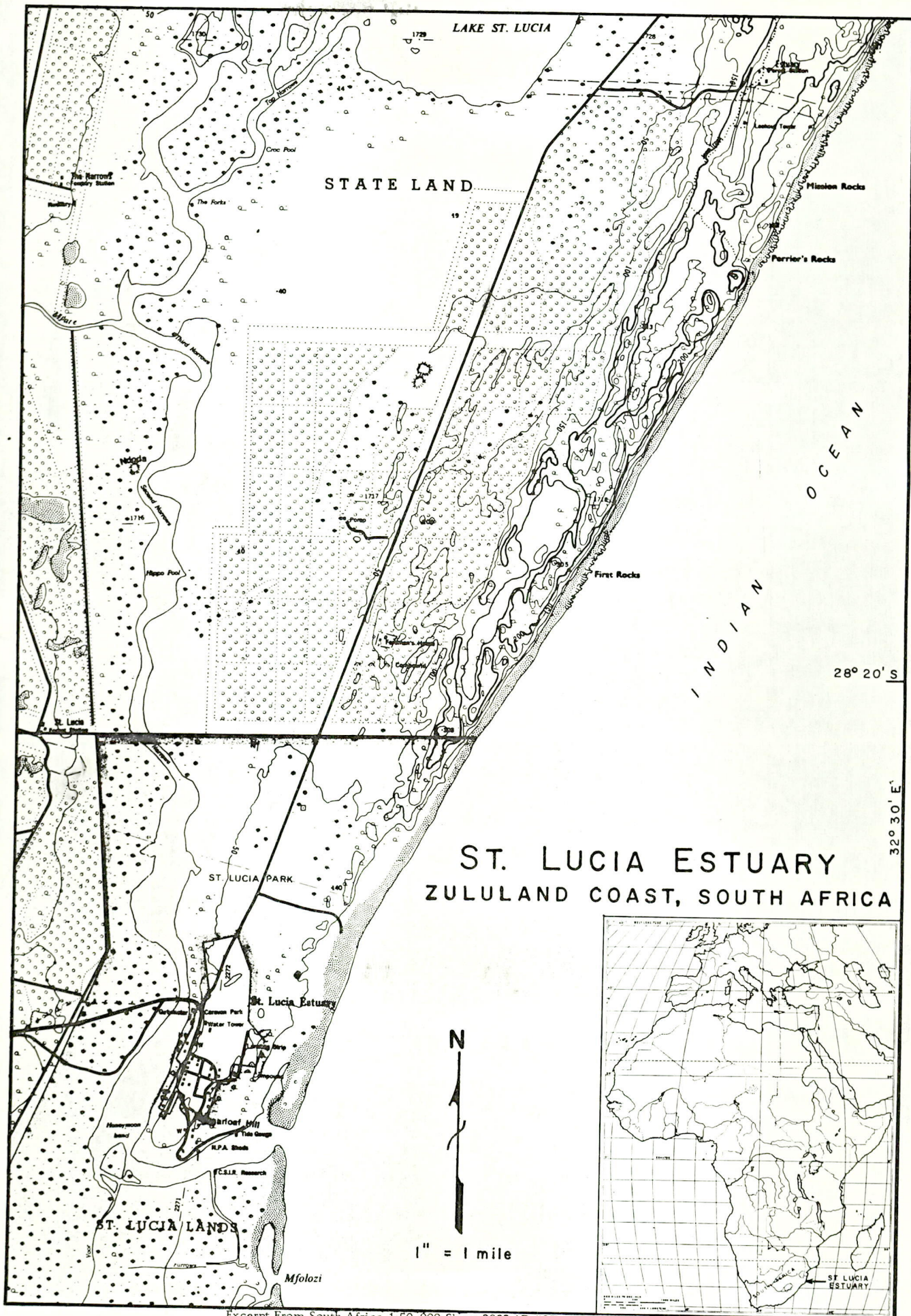
NATAL PROVINCIAL
ADMINISTRATION

DEPARTMENT OF
BUILDING SERVICES

MANAGING THE OCEAN INLET
TO
THE ESTUARY OF ST. LUCIA LAKE, ZULULAND

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Excerpt From South Africa 1:50,000 Sheet 2832 AD "ST. LUCIA ESTUARY"

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MANAGING THE OCEAN INLET
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SYNOPSIS

Recent experience teaches that St. Lucia Lake and its estuary flows will not maintain an open inlet from the sea during drought periods, unless works are built and systematic procedures are carried out to manage the hydraulic dimensions of its channels and basins.

A system of groynes and berms has been devised in an extensive hydraulic model study that was completed and reported upon in September, 1963. The Groyne-Berm Scheme has been proposed for construction at the coast line. Its author has stated it is the most satisfactory of those he considered for "--- ensuring that the mouth of St. Lucia Estuary is kept open even under very adverse conditions of littoral drift." He concluded the scheme should be constructed at an early stage, to create a good, stable estuary mouth, "--- and eliminate dredging.

The strength of the conclusions by the model investigator, Mr. H. B. Sauerman, rest on his obvious thoroughness and the perceptiveness of his observations of the model's behavior. If the

model's predictions should not be fully accepted, it would be primarily because there were so few quantitative sedimentation data available from nature that are needed to verify that the model could reproduce sedimentation changes that had occurred in nature.

It is not clear, from the model study report, that an investment to stabilize the berms that are proposed is financially worthwhile, if other acceptable and reliable means for managing the estuary mouth are available that would cost less. Any scheme that will enable man to manage the mouth of St. Lucia Estuary almost certainly would employ a pair of groynes. To be effective, they must confine tidal flows within prescribed limits, only then can the erosive and sand transporting ability of flowing water be effectively exploited. The groynes also must repel invasion to the channel of heavily sanded water that rushes up the beach faces alongside them with each advancing breaker. To do these things, groynes must have a central core that acts as a barrier. If berms are also employed, their continuing usefulness must be assured by revetting their surface at the prescribed elevations, widths and lengths. This done with layers of quarrystone of appropriate size to withstand wave action and erosive flows would more than quadruple the initial cost of the works; the annual cost of maintenance dredging might be reduced to some extent. Berms constructed with wire baskets filled with smaller stones or cobbles, called gabions, would be as effective

and possibly would save some of the initial cost, perhaps 35 per cent, but would need rebuilding on about five-year intervals.

A concept for a stabilized scour channel mouth for St. Lucia Lake Estuary is offered in this report for consideration. It is devised with groynes but without berms, to achieve a short and erodible channel 150 feet wide, a width identified by Sauerman as typical for the estuary when the mouth is in good condition as observed on many aerial photographs. It proposes a pair of groynes made in their seaward parts of concrete sheets protected from waves by dolosse, the much-admired South African artificial armor piece for breakwaters. The concept includes dredging an off-channel basin near the mouth, to supply a quickly available prism of water to flow through the mouth when ocean tides fall and before the long estuary mass can begin moving. Further, the concept recognizes, and accepts as an economically acceptable cost, that part of the sand that will enter the estuary from the littoral zone will not be returned to the shore by ebb tide flows, but will be deposited where it will need removing periodically by dredging.

INTRODUCTION

In March, 1971, the writer visited St. Lucia Lake and was informed by officials of the status of maintaining the estuary's connection with the sea, and of procedures under way or being considered for improving the situation. Discussions were held at Natal University concerning concepts for mathematical models of the whole lake and estuary system, and the nature of data needed from the site to strengthen the reliability of such models. There also was a meeting at University of the Witwatersrand where the mathematical model authorized by the Natal Provincial Administration is being developed.

Those parts in the Report of the Commission of Inquiry into the Alleged Threat to Animal and Plant Life in St. Lucia Lake (1964-1966) that pertain to the estuary mouth have been reviewed. The parts of the 1963 report by CSIR, the Council for Scientific and Industrial Research, No. C MEG 562, that deal with creating a reliable open mouth for the estuary have been read with great care. All of these efforts have been applied so there may be a considered basis for the writer to respond to the request of the Provincial Building Services Department, "--- to advise the Administration on proposals for the estuary mouth." The report that follows deals with that assignment.

ESTUARY MOUTH MIGRATIONS

The mouth of St. Lucia Estuary is a sedimentological battleground between wave motion and flowing water. The waves move sand along the coast, with the greatest volume normally transported between the breaker depth and the crest of uprush on the beach slope. This longshore transport drops the littoral drift into any opening in the coast, such as an estuary mouth, and builds a beach across it if not counteracted. Flowing water seeks the shortest available path when it moves from a higher level to a lower one. The ability of flowing water to erode and transport sediments relates to the steepness of its flowing surface, which is a measure of its velocity. At those times when estuary out flows are strong enough to counteract the delivery of littoral drift by waves to the estuary mouth, the mouth tends to align itself perpendicular to the beach line and the wave-built bars are diminished or swept away. Conversely, when sand transport power by the waves is too great for estuary flow to counteract, a spit will move across the mouth and deflect the estuary channel along the coast generally in the direction the waves are inclined. Victory for the waves comes when their deposits deflect the estuary channel so far along the coast that the steepness of its flows is too slight to move sand out of its way, and the mouth closes. Typically, estuaries with tortuous, barely open channels, or that are lagoons

that have been closed by littoral drift, break through at their closest proximity to the sea when upland runoff raises the estuary or lagoon level to a great enough height. When that high water level is relieved, by strong flows over the beach bar, the waves will start again to move the mouth downdrift, in the attempt to again close the mouth.

LOCALIZING AND RETAINING AN ESTUARY MOUTH

Man can intervene in the battle between flowing water and wave action at an estuary mouth. For the benefits he would achieve, there are of course costs to be paid. He can:

1. Build works to stop the migrations of the estuary mouth.
If he wants the mouth kept open, he should intervene by building his works where the estuary flows can be most effective in combatting wave-deposited sand.
2. Restrict the width of the mouth, so the erosive force of the tidal flows will be concentrated on an optimum width of bed and thereby can cut a deep and hydraulically efficient cross-section. These same restrictions of width will proportionately reduce the amount of wave energy that can enter the mouth.
3. Plan to remove some beach sand from the estuary periodically that will enter with flood tide flows and deposit where nature cannot return it to the sea.
4. Improve the hydraulic geometry of the whole estuary, so the water in it at high tide can accelerate quickly in flowing to the sea when induced to do so by a falling ocean surface.
5. Provide additional storage capacity for tide water, off channel

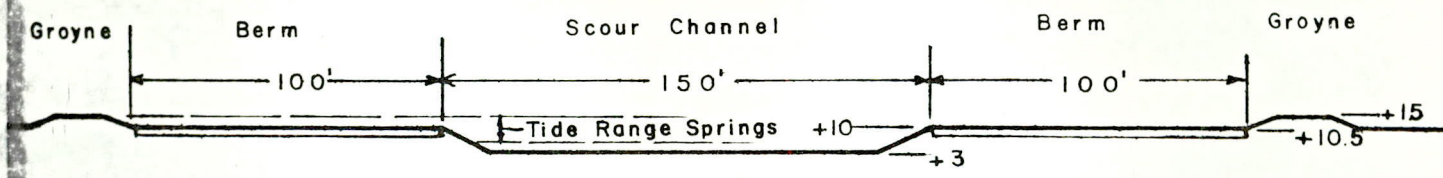
for minimal maintenance, close to the estuary mouth for quick response to sea tides.

6. Augment ebb tide flows by supplementing upland runoff into the estuary system.

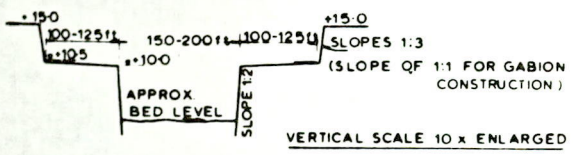
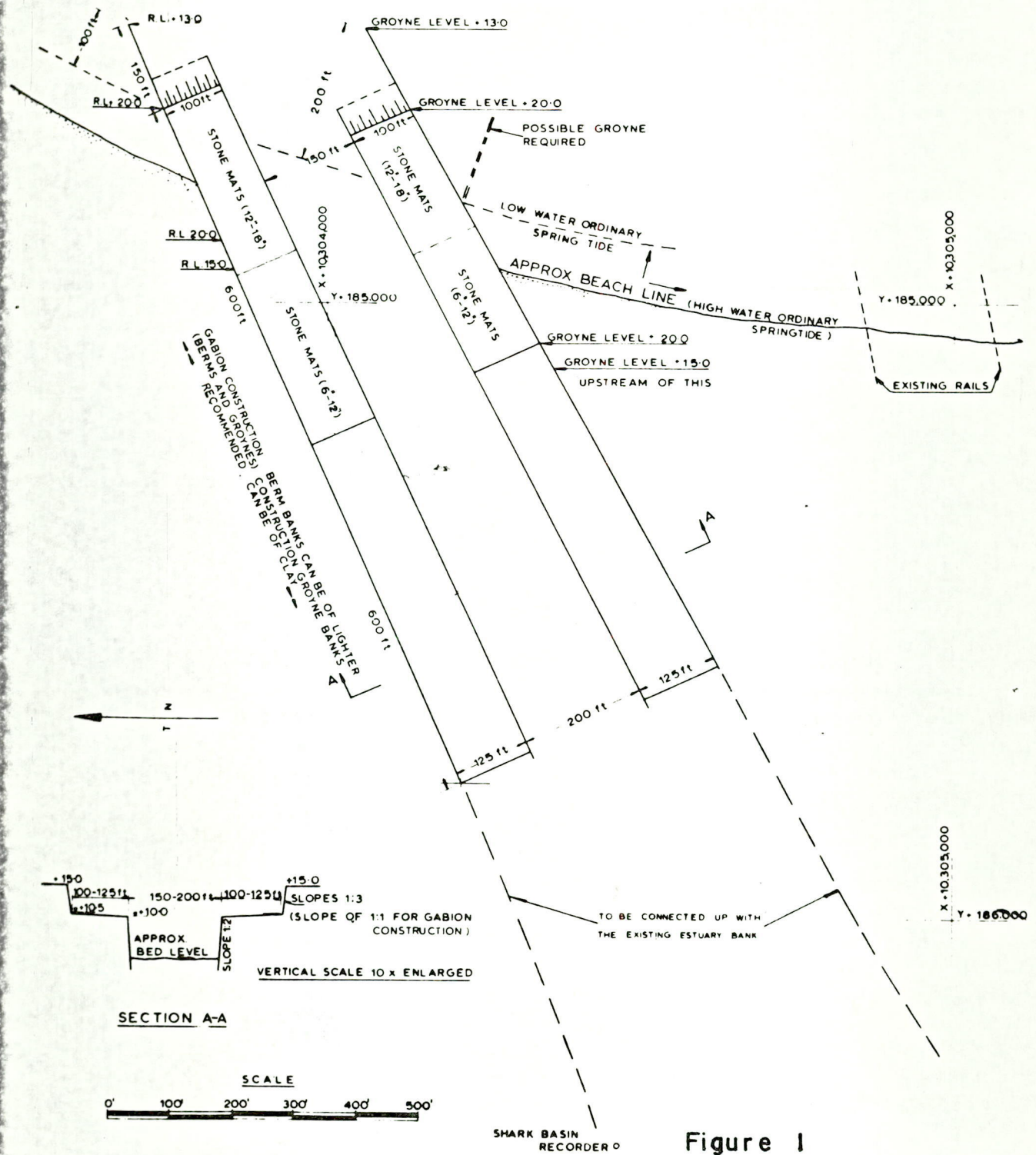
THE GROUYNE-BERM SCHEME: DESCRIPTION AND IMPLEMENTATION

In 1962-63, Mr. H. B. Sauerman, then of the Hydraulics Division of National Mechanical Engineering Research Institute, conducted model studies of the St. Lucia Estuary mouth. To stabilize the mouth and to keep it open, he concluded that a pair of groynes 350 feet apart and inclined by about 45 degrees from a line perpendicular to the coast should be built; that all but the central 150 feet of the width between those groynes should be stabilized with mats of stone-filled wire baskets with their surface at about the mean elevation of the sea. These two stone-covered shelves, each adjoining a groyne and a hundred feet wide, are the berms the scheme name refers to. The central 150 feet between the berms would have only the natural sand for its bottom, and would have a depth that the tidal currents could scour out by ebbing and flooding through the inlet. Figure 1 is a reproduction of Mr. Sauerman's definitive drawing of the Groyne-Berm Scheme, which was Figure 30 of CSIR Contract Report NO. C MEG 562, dated September, 1963. The conceptor recommended that the scheme be built, having concluded from his model study that it ". . . . should comply with the requirements and eliminate dredging."

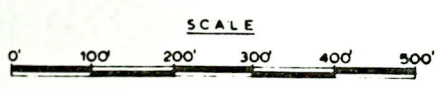
The model study report suggested the adoption of additional measures, as well as recommending the early construction of the Groynes and Berms at the estuary mouth. These were:



Section A-A, Undistorted
Mean Sea Level = +9.6



SECTION A-A



SHARK BASIN RECORDER

Figure 1

1963 GROUYNE-BERM SCHEME

Fig. 30 of CSIR Report C MEG 562
With Undistorted Cross-Section Added

- (a) Construct works to strengthen those already existing to separate Umfolozi River from St. Lucia Estuary.
- (b) Dredge away all silt banks in the 2.5 miles of estuary below the bridges.
- (c) Remove the mid-channel island between the two bridges.
- (d) Collect observations and data to enlarge the understanding of how the estuary and sea coast respond to different natural conditions.

Several steps have been taken that relate to the CSIR recommendations. Two groynes have been built on the alignments and locations proposed by Mr. Sauerman. The south groyne is extended seaward to about the terminal position shown on Figure 1 for the Groyne-Berm Scheme. The north groyne is about 300 feet short of the proposed terminal location for that feature of the Groyne-Berme Scheme. The groynes are built of dolos variants, precast concrete armor pieces weighing about 1500 pounds each, but have no sand-tight core. Thus the groynes are extremely pervious and littoral drift penetrates through them with little hindrance into the area between the groynes. Consistently, ebb flows from the estuary are not confined to any channel limits by the groynes where they extend beyond the shore. Hardened berms have not been built but, as Mr. Sauerman predicted, a natural scour channel about 150 feet wide has evolved between the groynes. Between that

channel and the groynes there are sandy berms onto which littoral drift is delivered by waves and then is moved by the influence of waves and currents into and out of the estuary. Substantial amounts of silt have been dredged out of the estuary, but the results are not yet close to a removal of all silt banks between the sea and the bridges. Apparently very few data have been accumulated since the model study was reported, on ocean shoreline changes, on coastal profile seasonal variations, on wave heights, periods, directions, on ocean tides, on littoral currents, on meanderings, orientation and cross-sectional variations of the estuary mouth, on flow velocities in the mouth, etc.

THE GROUYNE-BERM SCHEME: CRITIQUE

Reliance on Sedimentation Models

Sedimentology has developed a body of knowledge that lets the engineer or mathematician deal more rationally with sediment problems in flowing water than formerly was possible, and to some extent with sediment problems in wave environments. There is little agreement among peers, however, as to how to deal rationally with sedimentation when waves and flowing water together are moving sand and seeking a balanced situation. Therefore, hydraulic modeling of estuary mouth sedimentation would be a powerful device for solving the sedimentological problems that are posed there, if scaling down were not necessary. The mathematical uncertainties of interrelated influences would be moot. These uncertainties can be reduced in importance in a scaled down model if there are good quantitative records of what existed before man altered a sedimentation influence at a location of concern and equally good records have been accumulated to document the sedimentation changes the altered influences caused. The model investigator then, if his art is well developed, can proceed from first approximations through successive modifications of his model until it does the same thing that happened in nature and does it under the same conditions. With that accomplished, his model can be used to forecast future events but the predictions need application of careful engineering judgment. The weight of the model predictions rests on the strength,

applicability, and extent of the data from nature that were available to the model investigator and to his application of them and sense of their significance. One also must consider the consequences, and how they might be dealt with, if extreme influences came to bear in nature that were not effective in averages used or were not anticipated and incorporated in the conditions studied in the model experiments.

As repeatedly pointed out in the Report on St. Lucia Estuary Siltation Model Study, there was a severe deficiency in prototype records. Strenuous and perhaps exceptional efforts were expended in the laboratory in the attempt to compensate for this weakness. The strength of the experimenter's conclusions, as written in the report, imply his confidence that the data weaknesses were overcome. Those who would rely upon the predictions of any model need to keep in mind the effect of any variances from the model conditions that might occur or what extreme conditions that nature might impose could mean to the works.

Verification of the St. Lucia Estuary Model

From reading the model study report, one must conclude the tide recordings made at Shark Basin and at the Bridge were almost the sole quantitative prototype data available and used for calibrating the model. Other than the tide records, and none were taken for the ocean, there were a very few measurements of flow velocity in the estuary

mouth to compare with the model's performance, and some sediment gradation data that also were quantitative and were compared with model measurements. Other information for comparison with nature apparently was all or essentially all qualitative or pictorial. Therefore the reliability of the tide data is critical and the total absence of local measurements of ocean tides is a severe burden on the question of model validity.

Little is said in the model study report about a characteristic of the Shark Basin tide records that is most curious and no explanation is found. Figure 2 illustrates that peculiarity. Tide curves illustrated on Figure 13 of the model study report provided the information for the tables on Figure 2 from which the analysis curves are plotted. As might be expected, one finds high tides at Shark Basin gauge to have the greatest elevations when the ranges of assumed ocean tides are largest. Typically, they become progressively lower as the range of ocean ebb tide becomes smaller. On the other hand, low tide elevations at Shark Basin gauge change hardly at all, regardless of how big or how slight the ocean tide range may be. Further, that seemingly fixed elevation of low tides recorded by Shark Basin Gauge seems to be less than a half foot below Sauerman's estimate of mean sea level in the ocean, which is +9.6 feet on the model study datum of elevations. Diagram (a) of Figure 2 shows the estuary tide data from nature and the assumed ocean tide ranges. Diagram (b) of Figure 2 shows the faithfulness with

ANALYSIS OF TIDAL RESPONSE IN ESTUARY TO FALL OF TIDE IN THE OCEAN

Taken From Fig. 13 Of Sauerman

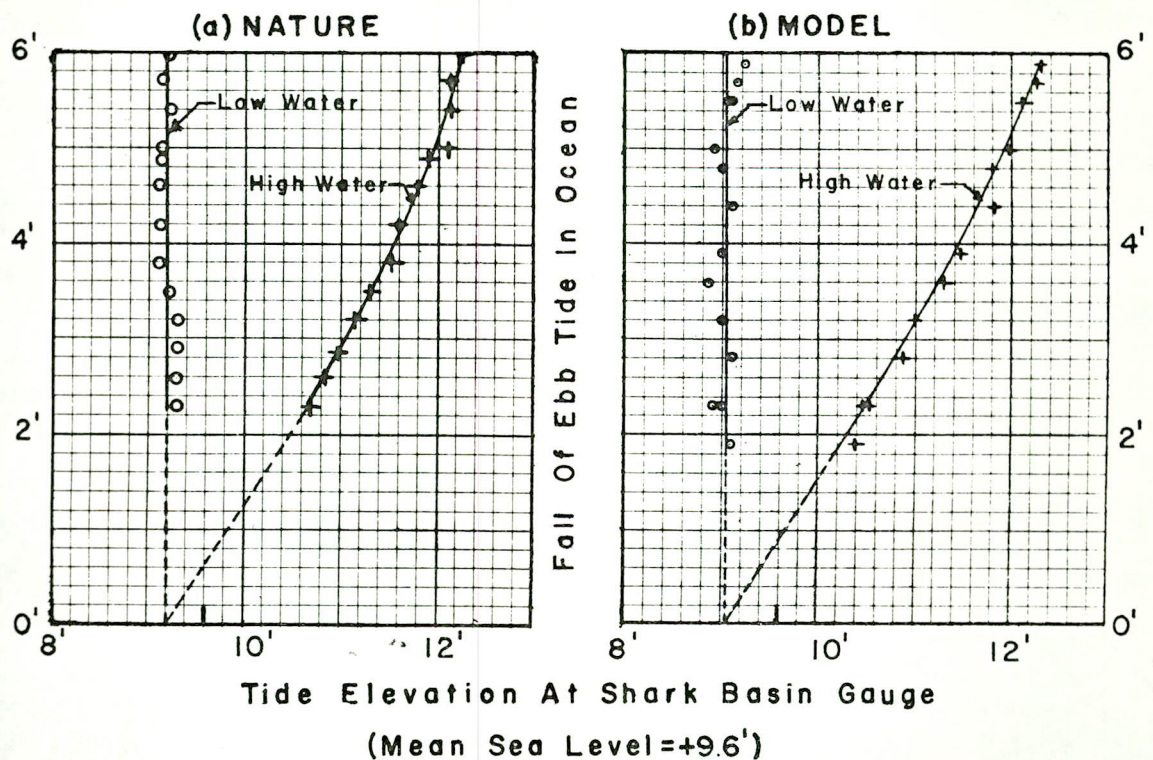


Figure 2

NATURE				MODEL			
Ocean Ebb Range	Shark Basin Gauge			Ocean Ebb Range	Shark Basin Gauge		
	High	Low	Range		High	Low	Range
6.0'	12.28'	9.21'	3.1'	5.9'	12.30'	9.22'	3.1'
5.7'	12.18'	9.17'	3.0'	5.7'	12.25'	9.18'	3.1'
5.4'	12.14'	9.22'	2.9'	5.5'	12.19'	9.11'	3.1'
5.0'	12.09'	9.19'	2.9'	5.5'	12.09'	9.08'	3.0'
4.9'	11.90'	9.18'	2.7'	5.0'	12.00'	8.91'	3.1'
4.4'	11.79'	9.11'	2.7'	4.8'	11.80'	9.00'	2.8'
4.1'	11.60'	9.17'	2.5'	4.4'	11.81'	9.09'	2.7'
3.8'	11.52'	9.13'	2.4'	3.9'	11.43'	9.00'	2.4'
3.5'	11.32'	9.21'	2.1'	3.6'	11.30'	8.84'	2.5'
3.2'	11.15'	9.32'	1.9'	3.2'	11.00'	9.00'	2.0'
2.9'	10.92'	9.33'	1.6'	2.8'	10.84'	9.09'	1.7'
2.6'	10.82'	9.31'	1.5'	2.2'	10.56'	8.92'	1.7'
2.3'	10.69'	9.31'	1.4'	2.2'	10.49'	9.00'	1.5'
				1.9'	10.40'	9.08'	1.3'

which the model was made to reproduce the same phenomena. However, the model study report, at paragraph 6.2.1 on page 37, states that this was accomplished by manually shaping the estuary mouth and freezing its cross-section with a surfacing of large stones (roughly equivalent at 12' diameter in nature), and stabilizing its location with metal sheets. In effect, this procedure changed the model from a sedimentation analog to a model of hydraulic phenomena only. One cannot be confident therefore that the model was a good analog for solving sedimentation problems specifically for St. Lucia Estuary.

Returning to the nearly invariable elevation of low tide at Shark Basin Gauge, one must speculate a bit as to the reason or reasons for this, for the model report provides no clues. One theory might be that a non-erodible threshold exists at the mouth of the estuary, so that ebb flow levels cannot follow the ocean tide lower than about mean sea level. Nothing of this sort has been reported and when one looks at ebb tide flows at the site the water in motion does not appear to be spilling over a hard elevated threshold into the sea. Another possibility for consideration is that the entry way to the tide recorder float well was restricted or plugged, so that water in the float well could not drain out below about +9.4 feet elevation when the water fell lower; or that debris had filled the well to about that height and was not discovered. No reproduction of any tide recorder charts were published, so it is

not known if they have the flat-bottomed character at low tide that would support the ideas of gauge malfunction. A third idea that occurs is that the ocean tide curves that were constructed by reference to Durban tide characteristics might not be representative at all of actual conditions at St. Lucia. That may not be likely but cannot be precluded as a possibility.

Considering the unexplained peculiarities of the tide data employed in the model verification procedures, the near absence of other quantitative prototype data for comparison with quantitative answers provided by the model, and the uncertainty that hardening the sediments in the mouth during calibration raises, and short of any clarifications one might get from Mr. Sauerman that have not been published, one must conclude the model verification was not strong and predictions by the model therefore should be used with some skepticism; the net influence of all factors that bear upon the problems of managing the estuary mouth may not have been discovered.

Benefits Ascribed to Oblique Inlets

The model study report urges the importance of inclining a stabilized channel by 45 degrees from the coast. The argument advanced for the oblique alignment is that the estuary now lines up in that direction, that it is the prevailing direction that waves move past the mouth and thereby a reduction of sand transport relative to the tidal flow is attained. These arguments seem to neglect two factors that could

nullify the advantageous aspects of the oblique direction of flow across the coastal threshold. Clearly, the amount of wave energy that can enter an aperture in the beach is directly proportional to the length of the opening measured along the coast. Thus the wave energy entering a channel of given width that crosses the beach at 45 degrees is more than 40 per cent greater than can enter a channel of the same width that is perpendicular to the shore. Also, during flood tide when sand enters an estuary mouth, the direction of flow that is induced across the surf zone toward the mouth is roughly perpendicular to the alignment of the wave crests when they break. That direction on a reasonably stable coast varies only a few degrees either way from a line normal to the coast, extreme local storms excluded. With a wider threshold for sand-laden breakers to cross, larger volumes of suspended sand in the surf are delivered to the estuary mouth where they can be moved by flood tide flows toward the inner channels. Inclined estuary mouths that are found in nature have usually been deflected in that way by wave sedimentation influences that are superior to the sedimentation capabilities of estuary ebb flows. When man seeks to change the balance of these contesting forces, to help the estuary ebb flow against the sea, he can do so with most effect by shortening the scour channel. Inclining the mouth by 45 degrees has the effect of lengthening the scour channel by more than 40 per cent. Thereby the steepness of the water profile between source level and

delivery point is flattened, which is to say the velocity of the flow is reduced. Reduction in velocity reduces sand scouring capability, as well as cutting down the total volume of water that can be transferred in a given length of time such as a tide change. Clearly a short channel at an estuary mouth has some real virtues which offset to some extent, perhaps entirely, the advantages that may be attained by a longer one.

Benefits Ascribed to Berms

In the report's Summary, 9.3 (f) on page 53, it is stated that outflow velocity, during ebb tide flows, is increased by the berms. Again, on page 55, the berms are said to be the means by which the flattening of the tide curve near the end of an ebb tide is eliminated. It is not clear that the berms, as such, are the means by which erosive flows are made higher and more effective during ebb tides. Rather, it is letting the center 150 feet of the estuary remain erodible, and thereby scouring out a deeper cross-section in which the latter phase of the ebb flows can be contained, that achieves the desired effect on the tide curve. That limitation on the erodible width of the estuary mouth could be done without berms, if groynes were employed alone and situated at the edges of the limited erodible width that is sought. In that arrangement the ebb flow would be confined from its beginning, not just in the last half of its duration, and could move sand from the mouth for a longer effective time.

It is possible that providing the berms between the needed scour channel and the two groynes lets in some flood tide waters that would not be carried through a narrower disciplined width of estuary mouth. Flow across those berms would however not be hydraulically efficient (here meaning quantity passed by a given cross-sectional area of flow), and in fact there might be a shearing of flow between the deeper more efficient central channel and the berms that could produce rotary currents that would further slow the berm velocities and tend to make them stop or reverse. Apparently none of the conditions imposed on the model produced that result, for it was not reported. One must also be skeptical about the statement on page 54, 16.1 (a), that the level recommended for the berms, at about a half foot above mean sea level "will allow relatively clear water to flow over them into the estuary during flood tide -----". Sand that is stirred into suspension by breaking waves is carried forward in high concentration well up on the beach to its characteristic height. Clearly, that height must at all places be above mean sea level except where there is an opening. At an opening in the coast the sand that would rush up the beach slope by breaker transport is still delivered by the waves, but is carried landward by flood tide flows, or is deposited during slack tide periods, or is rejected seaward during ebb flow currents. It must be assumed a supply of littoral drift would be delivered at and above a berm level placed near mean sea level, at all but very low tides and minimal

coincident wave action. Apparently the model did not reproduce this well known phenomenon.

The Cost of the Benefits Ascribed to Berms

The costs that would be incurred to achieve desired benefits need examining before one can say any feature of an effort is worthwhile. Provision of a pair of sand-tight groynes seems a virtually inescapable feature of any system for managing the mouth of St. Lucia Estuary. Their cost would be justified then by the conclusions others have already reached, that a managed access from the sea to Lake St. Lucia is necessary. To weigh the significance of adding the cost of berms to the base cost that would be met for groynes, indexes of relative costs of the features need to be examined. To derive such indexes, some idea of how the works would be built and the materials required has to be defined.

The groynes would need to be sand-tight, lest littoral drift penetrate into the estuary when sand-burdened wave uprush comes obliquely against them. If sand-tight, they also would contain the water flowing through the mouth at ebb tide, when the water profile in the channel mouth must be higher than the mean level of the sea on the far side of each groyne. That would force the sea water entering the estuary on flood tides to make its entrance through only the intended channel width. For maximum hydraulic efficiency, serving as the walls of a

flowing stream, the groynes should be as smooth as practically attainable on their channel sides. In an estuary mouth, however, one must cope with and minimize the adverse effects of waves. Waves impinging on and deflected by a smooth and abrupt boundary have their vertical rise and fall magnified, and pumping away of sand at their base by the quick surges of pressure must be contended with. Deflected, rather than partly absorbed, they could also create unwanted results within the estuary. Therefore it would seem best to absorb as much wave energy as reasonably possible at the groyne faces. The dolos variant that has been used for the existing channel structures can do this admirably well, but the open matrix they create is almost useless as a sand and water barrier unless it covers a dense core. For relative cost purposes therefore, a hypothetical groyne structure composed of a central solid core, and faced all around with dolosse laid over a graded stone bed, can be considered.

At least at their seaward ends, the berms of the Groyne-Berm Scheme would sustain as vigorous attack from waves as would the groynes. Built of gabions, as suggested by Mr. Sauerman, the surface stabilization should not be less than 2.5 feet thick. The wire baskets that are filled with relatively small stones to make a heavy unit called a gabion must be expected to disintegrate from corrosion and from abrasion by water-driven sand. Therefore gabion-stabilized berms would need replacing periodically. If the stones were big enough to

remain in place and be effective against erosion after the wire disintegrates, then the wire would be a wasted investment in the beginning. Reconstructing a gabion-stabilized berm surface would not be an attractive prospect, either physically or financially. Constructing berm surfaces of larger loose quarrystone over a finer filter rock mixture would seem a practical choice, even though that might use nearly twice as much stone.

Based on contract prices for waterfront work at Port Elizabeth that was bid in 1966, it appears construction costs in South Africa may be generally comparable with those in the United States. If that may be assumed, then it appears that for the seaward parts of the Groyne-Berm Scheme the groynes might cost 20 per cent of the whole construction cost and the berms 80 per cent. On the California coast, if similarly situated with regard to stone resources, the Groyne-Berm Scheme of the extent illustrated by Figure 1, and built as described above, might cost on the order of 1.4 million Rand, the berms being R1.1 million of that total and the groynes R300,000. If then the berms would in fact make periodic dredging of the estuary unnecessary, it would be at a capital investment which would have annual equivalent costs, for various economic life and interest rate assumptions, as follows:

<u>Capital Amount</u>	<u>Service Life</u>	<u>Per Annum Value of Public Funds</u>	<u>Equivalent Annual Cost of Capital</u>
R1, 100, 000	Perpetual	4%	R44, 000
		6%	66, 000
		8%	88, 000
	100 years	4%	R44, 890
		6%	66, 200
		8%	88, 040
	50 years	4%	R51, 210
		6%	69, 780
		8%	89, 910
	25 years	4%	R70, 410
		6%	86, 050
		8%	103, 050

The "Value" of public funds is construed to be the rate at which the taxpayer could earn with prudent investment of his funds, were they not paid to the State for public works. That may not be the same as the rate at which the State can borrow funds.

The equivalent annual cost of capital for building berms, selected from the appropriate combinations above of desired service life and value of money, is a crude measure of how much could be spent each year on dredging shoals of beach sand from the estuary if the berms were not built. It is called a crude measure for a number of reasons. For example: it assumes the berms would be entirely effective in preventing dredging needs; it assumes there would be no periodic maintenance expenditure on the berms; it assumes that the volume of tide water delivered to the estuary from the sea would be the same with

the Groyne-Berm Scheme as with another workable scheme. It is also true that the tabulated figures are based on dimensions of the berms and costs for materials that are certainly subject to scrutiny and revision. However, it is not likely the costs after refinement would be half as much, but if they were, the economic justification for the berms might still be dubious.

Additional Recommendations of 1963

The additional measures suggested in the model study report for adoption and implementation had varying degrees of pertinence to the question of managing the estuary mouth. The first related to the question of excluding Umfolozi River from the estuary, in order to prevent silt burdens in that river's waters from depositing in the estuary channels. The writer of the report concluded that St. Lucia Lake could better endure losing the Umfolozi's fresh water than it could tolerate receiving that river's silt. That conclusion might be justified or not. At some cost, such silts could be removed by dredging. It is not clear that the cost of dredging away Umfolozi's silts was estimated and submitted to qualified ecologists to compare with benefits they might foresee if that supply of fresh water were attained for the ecosystem.

The present critique assumes no expertise in life sciences, so it rests on the above comment. There would be benefit toward assisting ebb flows to maintain the estuary mouth if the river flows were added to

the tidal flows from the estuary. It would seem appropriate to investigate the feasibility of building an adjustable weir at the river bank and excavating a transfer channel to deliver river water under selected conditions from such a weir to the estuary. Assuming the weir would be designed so silty water would not compromise its reliability, it could be operated to keep a threshold at selected heights for various flow conditions, to deliver only acceptably turbid river water to the estuary. The "Fabridam", a water-inflatable and collapsible river control barrage invented some years ago by Norman M. Imbertson, might be investigated to determine if it could serve this purpose reliably and with economic logic.

Anything that is done to improve the hydraulic efficiency of the estuary will add to the effective prism of tide water that moves through the mouth with each ebb and flood of the tide. Therefore, to the extent that it makes economic sense, the suggestions of the model study report concerning removal of silt banks and mid-channel islands is strongly endorsed. Further, it is apparent the solid causeway approaches to the bridge abutments, where the road crosses the estuary toward St. Lucia, are a hydraulic impediment that could be removed with benefit.

Data on wave heights, periods, directions, durations; on shoreline variations and beach profiles; on estuary mouth migrations, velocities, cross-sections, and coincident water levels in the estuary and the sea; on ocean and estuary tide characteristics; on littoral currents and sand

transport have not been accumulated on any systematic basis since the model study report suggested a comprehensive program of data accumulation should be carried out. That is regrettable. However, such data taking programs need constant evaluation by those to whom responsibilities for engineering decisions will be given, lest the data be merely elegant but not of practical use to the decision maker.

Critique Summary

(A) Models of sediment erosion and deposition are useful and valuable in varying degrees as tools for formulating engineering judgments. They can be a principal basis for estimating the way nature will respond to new influences imposed by man if they have been able faithfully and repeatedly to reproduce sedimentological changes that have already been measured in nature. They can be used with care as a qualitative indicator of future conditions if only qualitative information as to past conditions is available, but the model has been able repeatedly to reproduce those qualitative observations. If either quantitative or qualitative data from a problem site have been repeatedly reproduced by a model, but sediments have been restricted from moving in the model, then the model cannot be said to have been verified as a device for predicting sedimentological change. In that case, it should not be relied upon for such purposes.

(B) The St. Lucia Estuary model study had no quantitative data from nature concerning sediment deposition and erosion that could be used

for model calibration. It was calibrated to reproduce tide records in the estuary that are strange, and the calibration was achieved by restraining sediment movement at the mouth. Therefore no sedimentological calibration was documented by the report.

(C) It is not evident from the model study report that the cost of constructing berms alongside a central scour channel of a managed estuary mouth is justified by the supposed benefits.

(D) It is questionable the berms would function in nature as they did in the model, and the extra width of channel between groynes that is necessary because of the berms is viewed as a distinct disadvantage; it enlarges the aperture into which waves can drive their energy and deliver their sand burden.

(E) Inclining the estuary mouth by any oblique angle with the coast is not logical if one would augment the ability of tide flows to scour and maintain an open mouth. The oblique alignments result in wider thresholds to the sea, with consequent advantages for waves against ebb currents. They also flatten hydraulic gradients between estuary and sea which causes flow velocities and quantities of water exchange to be reduced and impairs the erosive power of the water through the inlet channel.

(F) If the prism of water passing through the estuary mouth with each change of tide were enlarged, the problems of maintaining the mouth

would be lessened. Therefore, within economic limits, introducing Umfolozi River water to the estuary and hydraulic efficiencies that would be derived by dredging away silt banks, islands and bridge approaches that constrict the channels of the estuary would all be beneficial.

(G) Useful numerical and descriptive records of phenomena affecting hydraulics and sedimentation should be accumulated. They should be subjected to continuing review as to their value by those on whom responsibility will be laid for technical advice concerning management of the estuary mouth.

AN ALTERNATIVE

Objectives

If the concepts of the Groyne-Berm Scheme are not accepted, an alternative needs description. Any means for stabilizing the migrations of an estuary mouth, and managing its condition to pass tidal flows, is likely to employ groynes. A scheme should try to minimize the amount of sand that will enter an estuary mouth at flood tides and yet admit as large a prism of water as possible. Effective return to sea of sand that has entered the estuary on the flood tide, or has deposited in the inlet at high slack water, depends on the quick acceleration and sustained seaward flow of that tidal prism at high velocity when the ocean tide begins falling. Therefore the estuary basins and channels need to be deep, short and close to the mouth and to be of efficient cross-section. It must be assumed that part of the sand that enters on flood tides will not be returned to the seacoast on subsequent ebb tides, and there should be provisions in the relationship of features of the alternative so the deposits can be removed periodically by dredging while there is adequate freedom meanwhile for the estuary to receive and discharge tide flows. Provisions need to be made so that floods from upland that exceed the cross-sectional capacity of the confined estuary mouth will pass elsewhere to the sea, without creating a new mouth remote from the desired location and its works. Concept Drawing Figure 4 , bound at the end of this report, shows a concept for a scour channel mouth for St. Lucia Lake

Estuary that may incorporate the best of the insights which evolved from the 1963 model studies and also meet the requirements just enumerated. Elevations shown on the concept drawing refer to mean sea level.

Scour Channel

A scour channel 150 feet wide, essentially the same width as adopted for the Groyne-Berm Scheme, is shown. It is bounded immediately by a pair of sand-tight groynes which are aligned perpendicular to the sea coast. Recent aerial photographs that have been examined show scour channels between the present dolos and sand bag dikes that approximate 150 feet width. With some wave conditions they tend to cross from alongside the north dike, diagonally toward the south dike's tip. Many photos, taken before the present works were installed also show the estuary mouth aligned perpendicular to the coast and usually south of the present mouth. Placing the mouth south of the present works provides opportunity to build groynes for a new entrance before diverting the tide flows to pass between. That placement also gives opportunity for the thread of ebb currents from the upper estuary to align with the axis of the mouth channel without being abruptly deflected. The impervious lengths of the groynes extend to the contour at 5 feet below mean sea level in the surf zone. For that length there are crawler cranes available that can stand at the upper end of the wave swash at low tide and reach far enough to erect the sand barrier and the protective armor,

as well as place stone bedding for the armor.

Sand Trap Area

Experience will demonstrate if the area shown southwest from the disciplined mouth correctly anticipates where trapped sediments from the surf zone will be dropped and need periodical removal.

Relief of Upland Floods

When major upland storms send flows to the sea through Lake St. Lucia and its estuary, the 150 foot width of scour channel probably would be engulfed. That berms would help pass such floods is a valid point. Without them, there needs to be a relief plug to pass the excess flows without a new mouth being created. Schematically, therefore, the scour channel concept of Figure 4 indicates a sill should be extended south from the south groyne that would be overtopped by flood flows but would limit the depth of channel those exceptional discharges would cut through to the sea. The overflow sill could be of treated timber sheeting braced by impregnated piles, or stone fill, or sacked concrete or any other functionally and economically suitable material. Its crest elevation and length would be related to flood profile estimates which need to be calculated. North of the estuary a fill should be placed, high enough to provide adequate freeboard above design flood profiles.

Augmented Tidal Prism

It is well known that the cross-section for passing tidal flows that can be maintained in nature at an estuary mouth is related to the total quantity of water that passes through that mouth in a tide range. The tidal prism held by a deep harbor or bay, with a relatively narrow but free entrance, very closely approximates the volume between parallel horizontal planes at the elevation of high tide and the elevation of low tide. If however the land-locked body of tide water is shallow or elongated or both, the tidal prism may be more like a wedge in form, and estimating its extent is not simple. St. Lucia Estuary is of the second type and Mr. Sauerman has estimated its volume at 2,000 acre feet, which would extend its edge up the estuary about 9 miles to a point slightly short of St. Lucia Lake itself.

Water in the ocean is readily accelerated to flow through any estuary mouth when the tide rises above the estuary water level. Conversely, the wedge type prism of water in St. Lucia estuary is not readily accelerated into motion, to flow seaward when the ocean tide falls below the estuary's stage; the frictional resistance to motion of still water in the estuary channels consumes too much, for too long, of the head that must be shared for accelerating the mass and for sustaining the motion once it has been achieved.

Both the model study report and this one have urged that the hydraulic

geometry of the estuary be made more efficient, by dredging away silt banks and islands and by removing channel boundary constrictions at the road bridges. Appropriately planned and carried out, that could effectively increase the tidal prism and thereby make easier the task of keeping the inlet open to the sea. Because the estuary is also a channel to relieve upland inflows to St. Lucia Lake, the dredging of silts will need repeating from time to time and that should certainly be attended to.

The scour channel concept of Figure 4 seeks to augment the tidal prism by additional dredging off the estuary channels. Topographic information is indistinct, but it appears that about 40 acres of water area could be added away from the estuary channels just north of the Shark Basin Gauge Location. Dredged to 8 feet or more below mean sea level, that area could provide a more quickly available and readily moveable addition to the tidal prism. It should function somewhat as a surge chamber does when a hydro-electric station below a long penstock is put on line, responding quickly to a differential head while the remaining mass of water upstream is getting into motion. Being off the estuary channels, the problems of maintaining its depth should be slight, except possibly at its portal.

Construction

If the alternate Scour Channel Mouth for St. Lucia Estuary is

constructed, the groynes will require a central core that will deny passage of sand through the structure and that will contain water flowing at a different level in the mouth than it stands in the sea on the opposite side of each groyne. Figure 4 illustrates one method by which such a dense core could be achieved. The wood king piles and walers that are shown are provided to guide the placement of the concrete sheet piles and to hold them until the wave protection base rock and armor are in position and have settled in. Subsequent deterioration of the wood parts should be expected, and would be no matter for concern if the rock and armor are stable. Construction should proceed from the break of the beach into the surf zone, working seaward. Pot-holing at the advancing edge of the sheet pile wall is to be expected where the seas will eddy and swirl the sand floor. Therefore it will be important to advance the stone bedding right with the sheet piles, and to lay the armor on the stone soon after, if not immediately. The 1,500-pound dolos variants that have been cast and used in the existing mouth structures should be adequate for armoring the sides of the groynes. They may not be massive enough on the flanks of the seaward terminals. It is known that a large number of 6,000-pound dolosse were cast and placed recently in Cape Province, at Port Elizabeth. That size would be appropriate for the sides of the end thirty feet of the groynes for St. Lucia Estuary. Over three thousand extra castings were made and stored for future use for maintaining the Port Elizabeth project. If the few

needed at St. Lucia could be purchased from that lot a convenience might be achieved, if not a saving. Perhaps more practical, because of the haul distance involved, would be an arrangement to rent the moulds used at Port Elizabeth so that casting could be done on site.

If the picture of groyne lengths shown on Figure 4 has reasonably related to the actual position of the 5 foot depth curve and the crest of the beach, then neat quantities would approximate the following:

Quarry waste filter layer	6,000 tons
Bedding stone	8,000 "
Concrete sheet piles	11,000 sq. ft.
Timbers and blocking	8,000 fbm
Bolts, washers, hardware	1,500 lbs.
Wood piles	100 units
3/4 - ton dolosse	9,300 units
3 - ton dolosse	250 units

The above figures do not include allowances for breakage or subsidence nor are they extended to derive an estimate of cost. These should all be developed with consideration of local experience.

No information is available on which to estimate the amount of material to be dredged in the original capital work from the shaded areas shown on Figure 4, nor where it would be most advantageous to dispose of it.

Disposal of Trapped Sand by Dredging

When periodic dredging is performed in the future, to remove that

fraction of littoral material that will enter the estuary and not otherwise be returned to the sea, disposal should be made on the sea coast. To do otherwise would be contrary to good beach conservation practice. Partly for insights to choose a favorable location for a perpendicular inlet for the estuary, but also trying to discover a most favorable point to return maintenance dredgings to the sea coast, new wave refraction diagrams were calculated and drawn for seven different conditions of direction, and periodicity. From those wave computations, and the three presented in the Groyne-Berme Scheme report as Figure 7, 8, and 9, ten sheets identified as Figure 3 (a) through 3 (j) were prepared. As pointed out by Mr. Sauerman in his report, the unit energy of the waves is increased or decreased as orthogonals to their crests converge or diverge. Further, the amount of energy flux affecting a unit length of shoreline must be reduced from the flux per unit length of wave crest if the wave approaches the shore obliquely. The upper parts of Figure 3 show how the onshore energy flux varies along the Zululand coast from near Lake Nhlabane to Cape Vidal for the specific wave periods and directions before refraction. That is not enough, however, to imply how the longshore sand transporting influence of those waves may vary in magnitude and even in direction. The lower diagram on each sheet of Figure 3 helps with that concern. However, one cannot take the data on which these diagrams are based and calculate a quantity of littoral transport, partly because these beaches are not straight and partly because

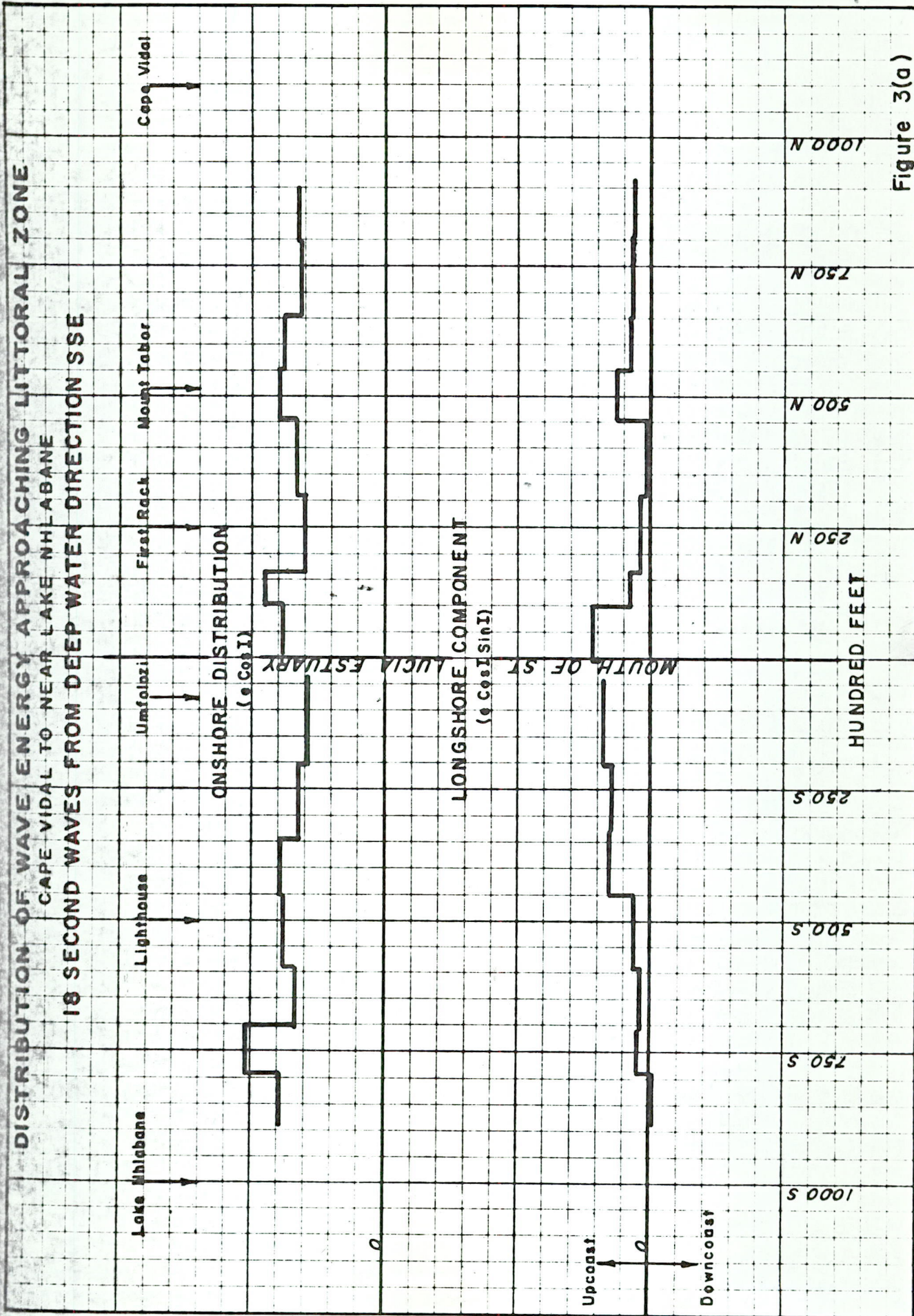


Figure 3(a)

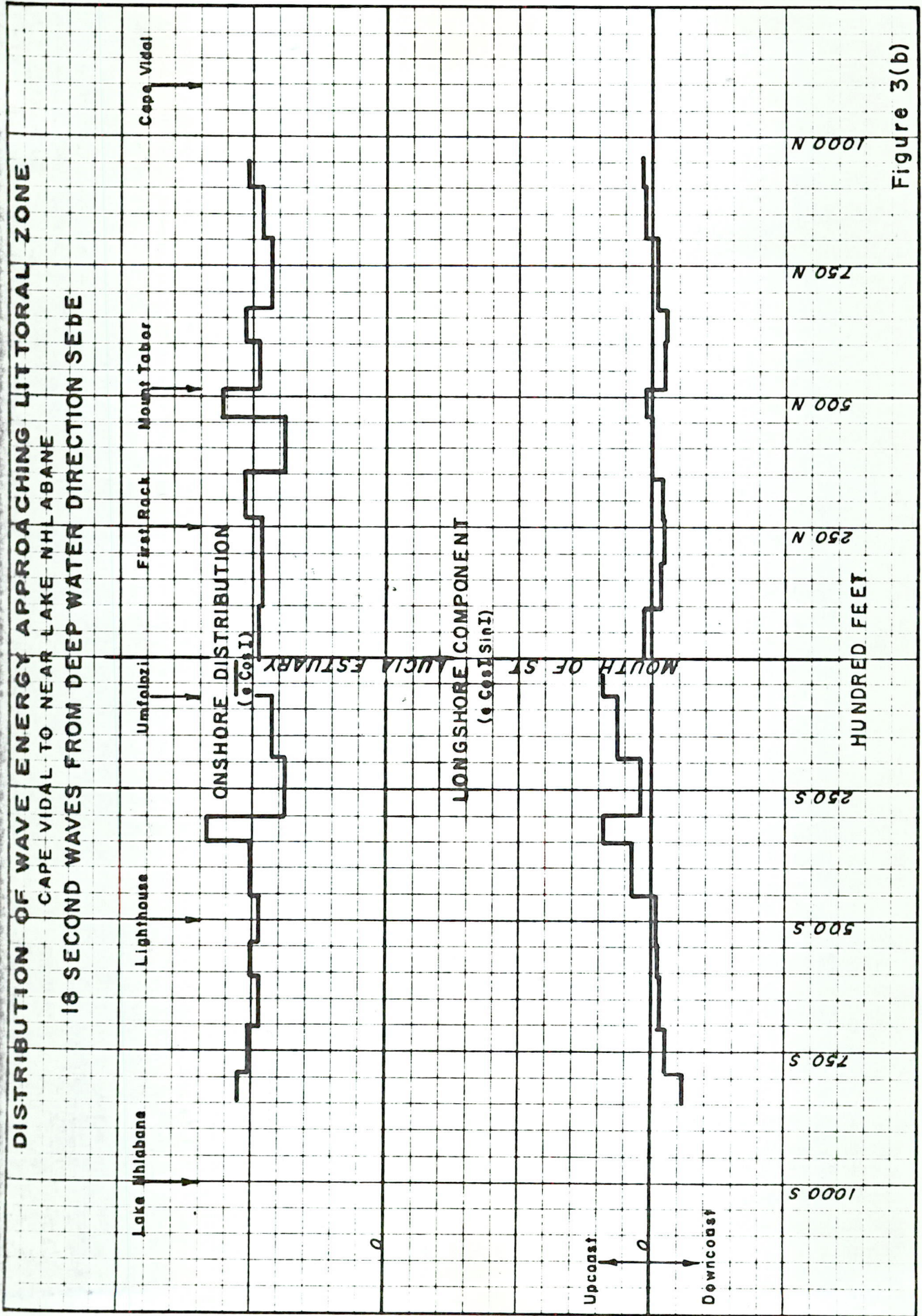


Figure 3(b)

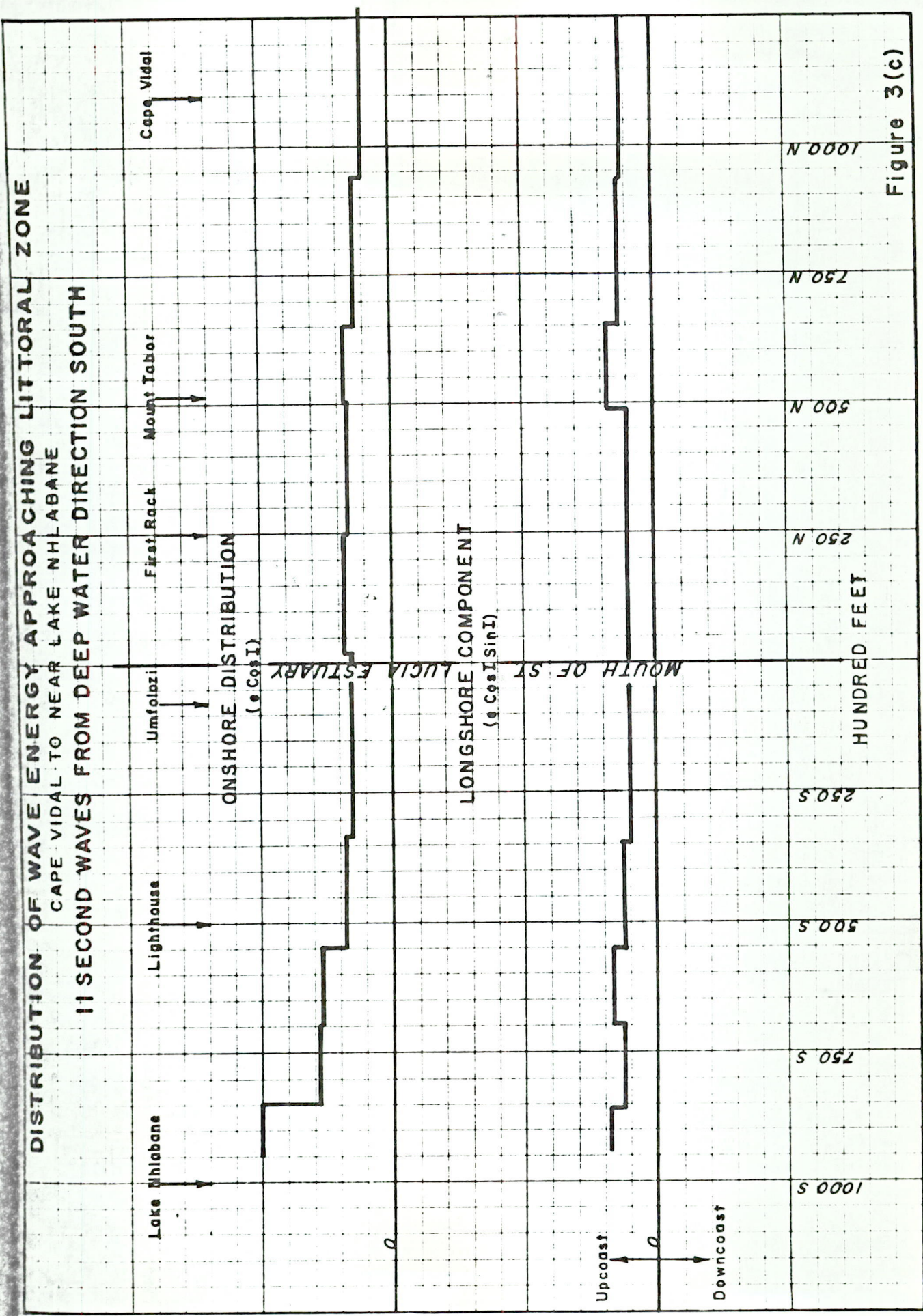


Figure 3(c)

**DISTRIBUTION OF WAVE ENERGY APPROACHING LITTORAL ZONE
CAPE VIDAL TO NEAR LAKE NHLABANE
II SECOND WAVES FROM DEEP WATER DIRECTION SE_bs**

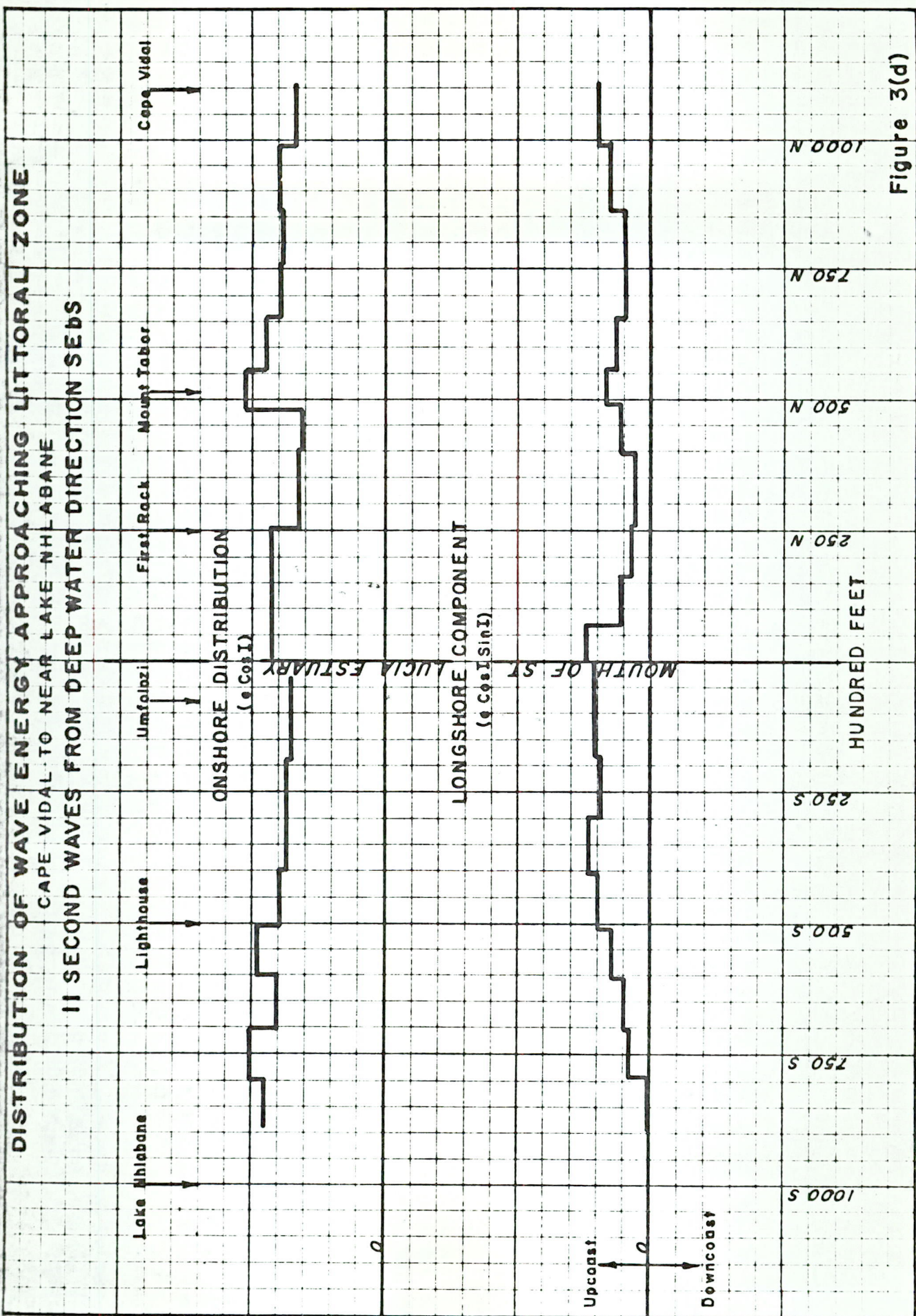


Figure 3(d)

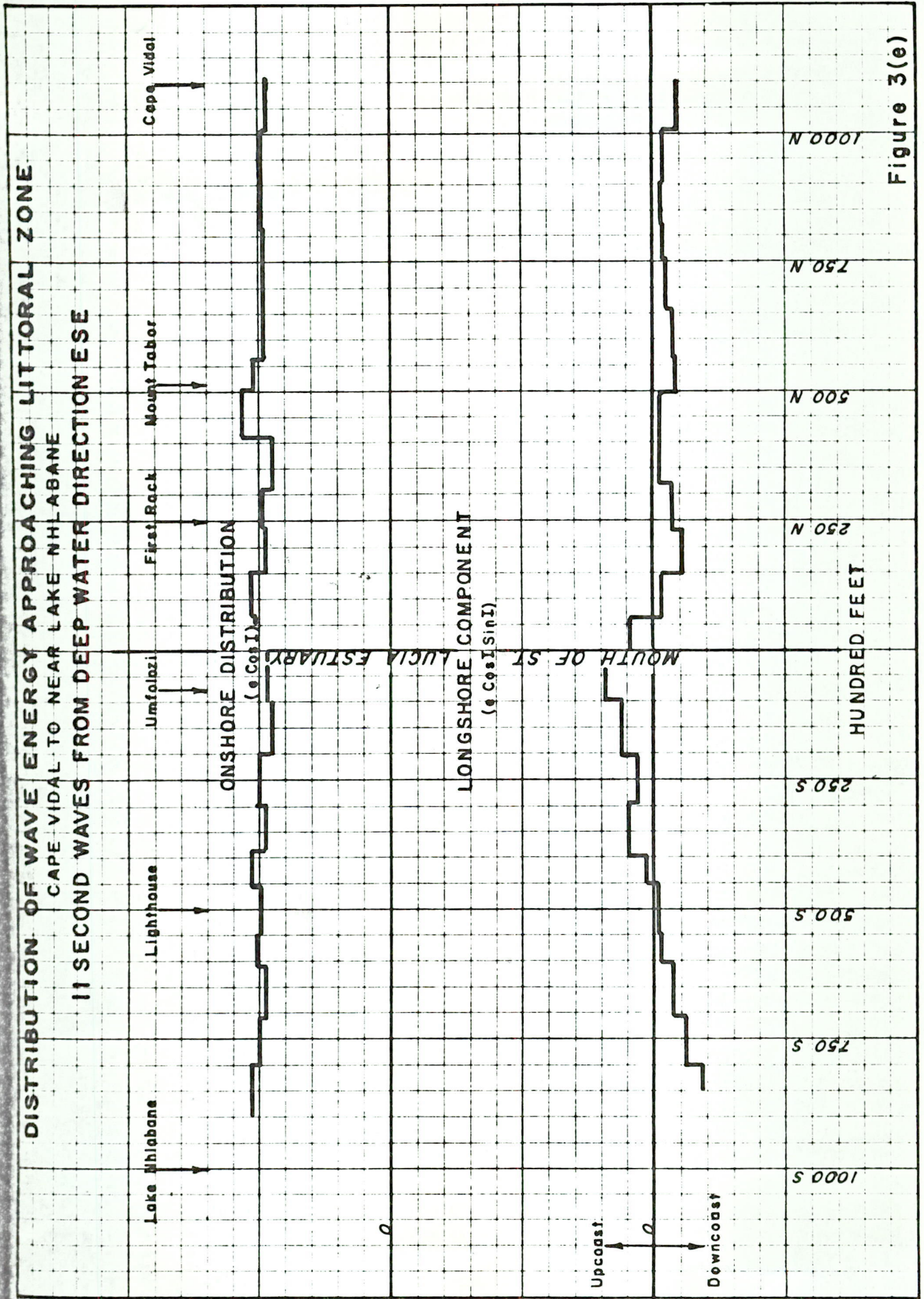


Figure 3(e)

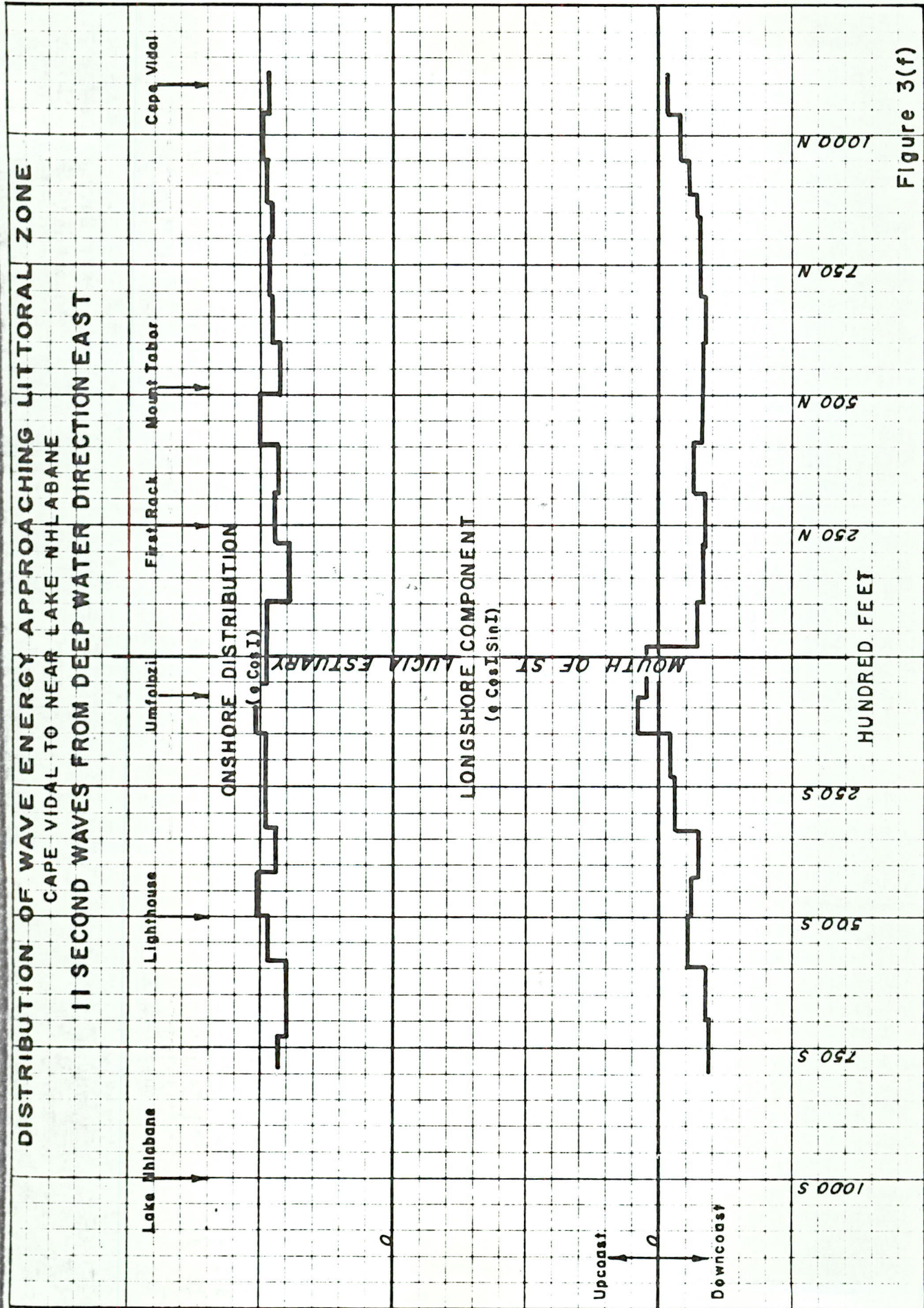


Figure 3(f)

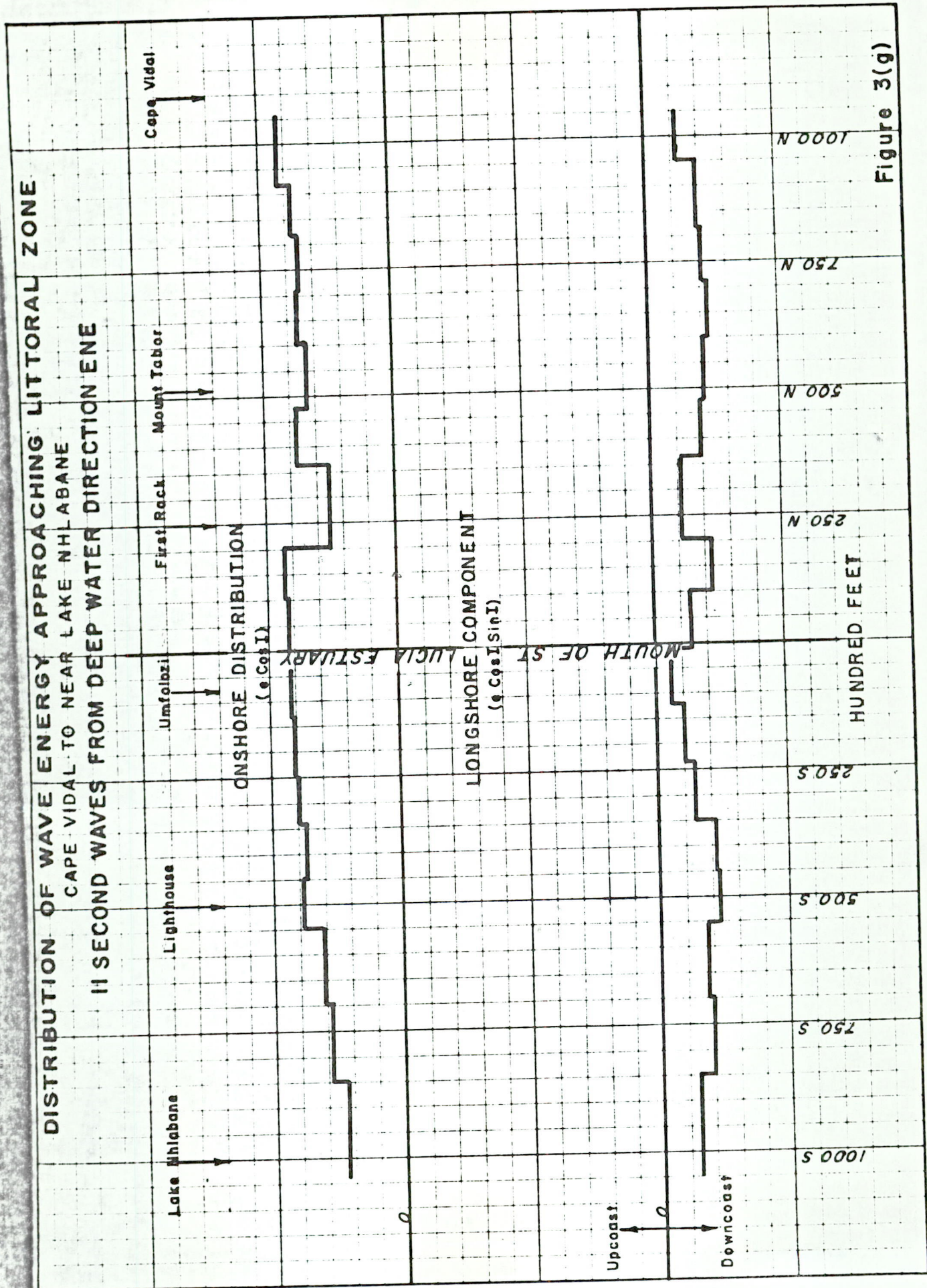


Figure 3(g)

**DISTRIBUTION OF WAVE ENERGY APPROACHING LITTORAL ZONE
CAPE VIDAL TO NEAR LAKE NHLABANE
10 SECOND WAVES FROM DEEP WATER DIRECTION SE**

(Based On Refraction Diagrams By CSIR)

Lake Nhlabane Lighthouse Umfolozi First Rack Mount Tabor Cape Vidal

ONSHORE DISTRIBUTION
($\cos^2 I$)

LONGSHORE COMPONENT
($\cos^2 I \sin^2 I$)

MOUTH OF ST. LUCIA ESTUARY

Upcoast

Downcoast

1000 S 750 S 500 S 250 S 250 N 500 N 750 N 1000 N

HUNDRED FEET

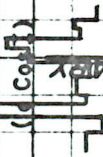
Figure 3(h)

**DISTRIBUTION OF WAVE ENERGY APPROACHING LITTORAL ZONE
CAPE VIDAL TO NEAR LAKE NHLABANE
9 SECOND WAVES FROM DEEP WATER DIRECTION EAST**

(Based On Refraction Diagrams By CSIR)

Lake Nhlabane Lighthouse Umfolozi First Rack Mount Tabor Cape Vidal

ONSHORE DISTRIBUTION
(100 ft)



LONGSHORE COMPONENT
(4 Cos² Sin²)

MOUTH OF ST

Upcoast
0
Downcoast

1000 S 750 S 500 S 250 S 250 N 500 N 750 N 1000 N

HUNDRED FEET

Figure 3(i)

**DISTRIBUTION OF WAVE ENERGY APPROACHING LITTORAL ZONE
 CAPE VIDAL TO NEAR LAKE NHLABANE
 9 SECOND WAVES FROM DEEP WATER DIRECTION ENE**
 (Based On Refraction Diagrams By CSIR)

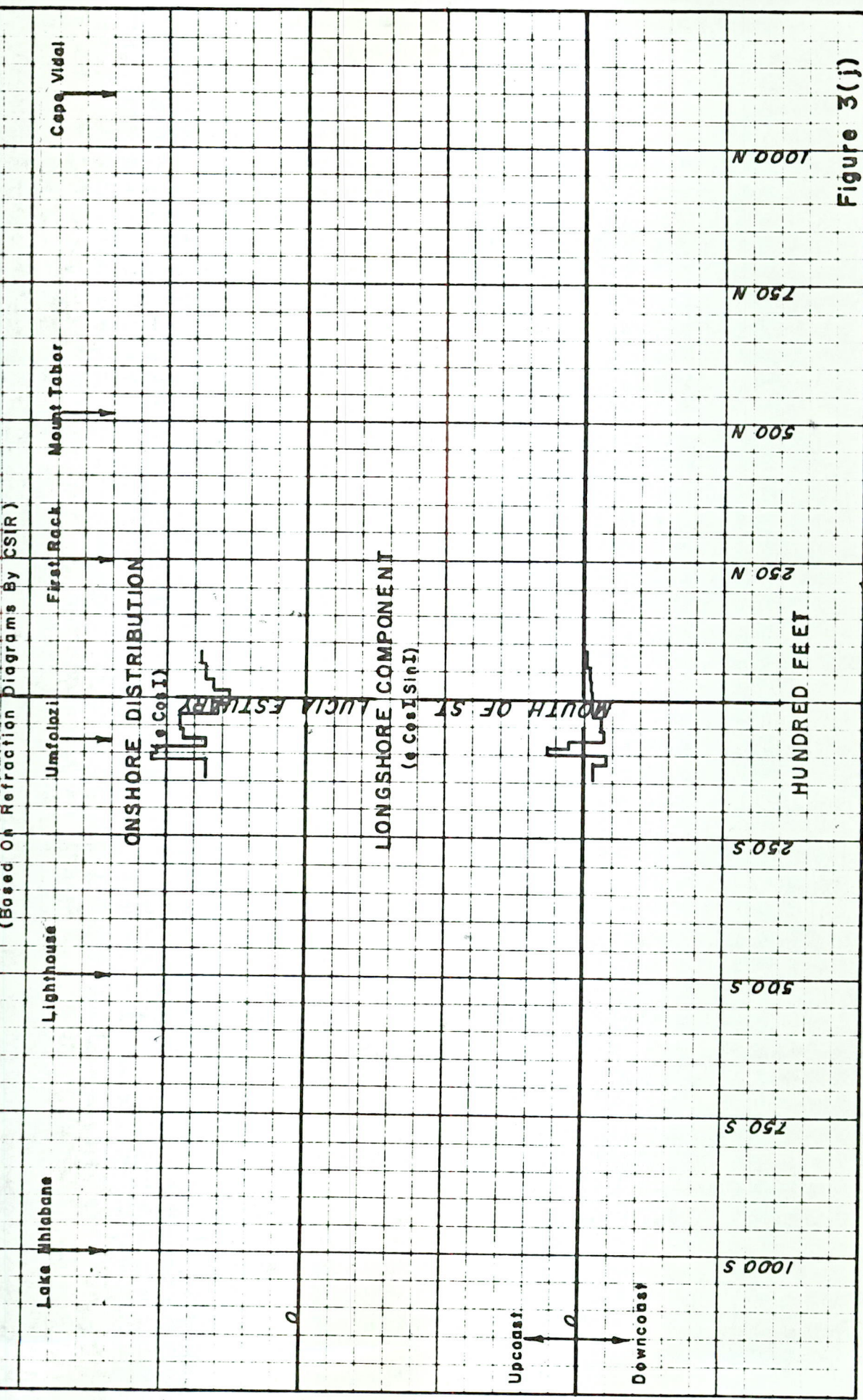


Figure 3(j)

not enough is known of occurrences of wave heights and periods, or of their durations and seasonal nature.

The amount of work performed by waves is a function of their height, their period and the length of time each height-period combination persists. The amount of energy expended by waves at a point of interest in any length of time is the summation of energy expended by the several wave conditions that occurred during that selected length of time. Therefore the information of Figure 3 is only a beginning on what must be known, if accretion-erosion influences at a point or a reach of coast need to be examined. Refraction diagrams for more period-direction conditions are necessary to be sure and could be plotted now, but the critical need is knowing the breakdown of height-duration for each period-direction condition that has been calculated with the diagrams. For future decisions on maintenance techniques that will make the dredging program most effective for the money it costs, there needs to be immediate implementation of systematic observations of wave directions at breaking, the coincident period, height and duration of the waves, the set and approximate speed of the littoral current, the tide stage, the nature of the local weather, and comment on special conditions prevailing. For purposes of discovering the best location for disposing of dredgings on the beach, the data taking need not be sophisticated but should be rigorously systematic and uniform. If adequate refraction diagrams were calculated,

the inshore observations of wave directions at any one carefully selected station on the coast could be recorded as a deep water azimuth. From that common denominator, conditions at any station or extent of shoreline that is of interest can be estimated, again by employing the refraction diagrams.

EROSIONAL CHARACTERISTICS AT THE INLET - EFFECT ON
MATHEMATICAL MODELLING

The need for learning the tide characteristics of the ocean at St. Lucia Estuary has frequently been urged and an installation may now be in service that can bring light on that matter. It should be possible to reduce the uncertainties regarding effect of various practices that may be employed in managing the estuary mouth and regarding the relationship to these questions of hydraulic phenomena. There need to be coincident recording of tides in the estuary and the sea; a program of estuary mouth cross-section surveys at high and again at low tide during various phases of the tide-producing forces, during various conditions of upland inflow to the estuary and during various conditions of the sea. With such information the mathematical modelling of the estuary and lake system can be more usefully and reliably employed to answer questions regarding the appropriate places to dredge and the possible effectiveness or optimum dimensions of dredged channels and surge basins such as are incorporated in the concept here of the Scour Channel Inlet. It is important to keep in mind that the mathematical model may be at a greater disadvantage at the mouth of the estuary than the hydraulic model was, with no information as to how the tides and erosive flows through the mouth altered the cross-section within each tide change and under different ocean conditions. If the mathematical model can be programmed to impose some typical measured transient conditions at

the mouth, where the conflict of sedimentary influences of waves and flows is not well enough understood today to be expressed by mathematical statements, the reliability of its predictions of what will take place in the estuary and lake will be improved. It is not possible to overemphasize the importance of continuing collaboration between those who take data and those who are expected to use them for studies, recommendations and decisions relating to both construction and operating questions.

CONCLUSION

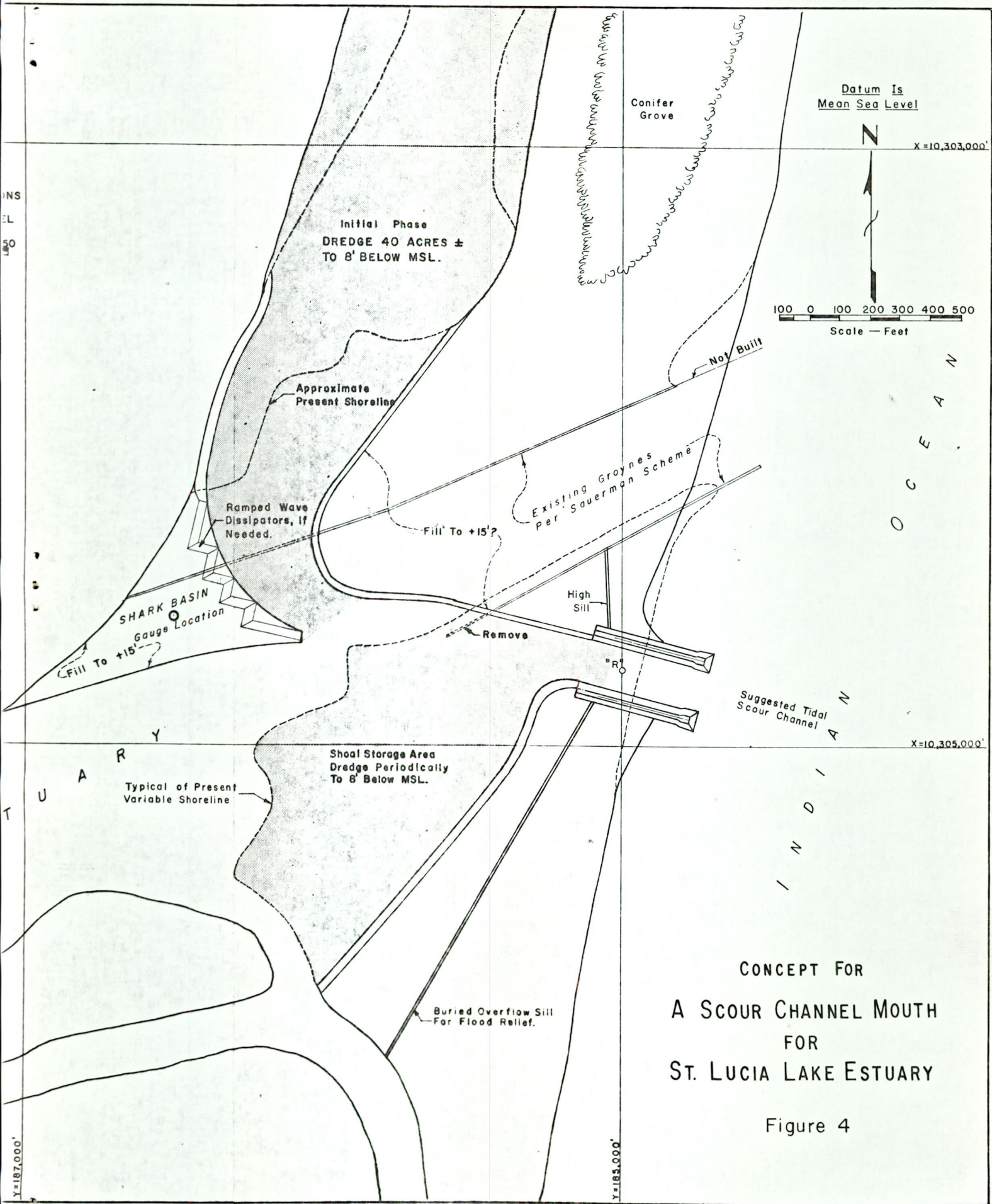
1. Managing the mouth of St. Lucia Estuary requires that works and procedures be reliable, economically appropriate, and flexible under unusual or unrecorded conditions that might be imposed by nature and by the works of man.

2. The Groyne-Berm Scheme would involve expenditures for the berms that are not clearly justified. The sand that stabilized berms would exclude from the estuary, if they were as effective as their conceptor believes they would be, could be allowed to enter and be dredged away periodically at an expense that would be less than the cost of building the berms.

3. An alternative concept for means to manage the mouth of St. Lucia Estuary is available for consideration. It involves a short channel of restricted width, erodible and hydraulically efficient, and includes provisions for enhancing the effectiveness of tidal prism flow through the mouth to scour out sand. Conceptual aspects are described and illustrated in the present report. Detailed dimensions and procedures need developing, from data on natural phenomena that needs to be acquired and with the possible assistance of the mathematical model of the lake and estuary now in development at Johannesburg.

Los Angeles, California
July 30, 1971





CONCEPT FOR
 A SCOUR CHANNEL MOUTH
 FOR
 ST. LUCIA LAKE ESTUARY

Figure 4

