



CONFIDENTIAL

CSIR REPORT C/SEA 74/6

**PROPOSED  
BRAAMEKRAAL MARINA, KNYSNA  
MODEL STUDIES**

Submitted to

**THE DEPARTMENT OF AGRICULTURAL CREDIT AND  
LAND TENURE**

**COASTAL ENGINEERING AND HYDRAULICS DIVISION  
NATIONAL RESEARCH INSTITUTE FOR OCEANOLOGY  
COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH**

CSIR REPORT C/SEA 74/6

Stellenbosch, South Africa  
June, 1974

Series No.

OK 184

Reference No.

MEW/4869

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## S U M M A R Y

The Department of Agricultural Credit and Land Tenure was approached by a private firm in connection with the establishment of a marina in the Knysna lagoon. Before deciding on this matter, the Department approached CSIR to undertake a model study to determine the possible detrimental effects of a marina development on the existing hydraulic conditions in the lagoon.

A fixed bed model of the area, covering the entire lagoon from the sea to the limit of the tidal reach, was constructed to a horizontal scale of 1 in 400 and a vertical scale of 1 in 40.

No decision on a particular marina layout had been taken other than that the development should take place on the tidal flats between Leisure and Thesen's Islands. It was therefore decided to test three hypothetical layouts including the maximum and minimum anticipated development in the area concerned.

Apart from the maximum area layout, consisting of a large closed marina which had a considerable reducing effect on the tidal prism, the general effects on the hydraulic regime were found to be insignificant. Slight repositioning of sand banks due to changes in flow directions and velocities can be expected. Scour at the south bank opposite the tip of Leisure Island may occur and shore protection could become necessary in this area. Some deposition of silt may occur near the tip of Leisure Island, but this is considered of little importance.

From the results of the investigation it is concluded that a marina development with no or little effect on the magnitude of the existing tidal prism, will have no adverse effect on the hydraulic conditions in the lagoon. It is, however, suggested that once a definite marina layout has been decided upon, this layout be tested in the model as a final check. These tests should also include a check on possible pollution problems in the marina itself.

NATIONAL RESEARCH INSTITUTE FOR OCEANOLOGY  
COASTAL ENGINEERING AND HYDRAULICS DIVISION

PROPOSED BRAAMEKRAAL MARINA, KNYSNA  
MODEL STUDIES

S C O P E

This report presents the results of field and model studies into the effects on the existing regime of the Knysna Lagoon of a marina constructed on the tidal flats between Leisure and Thesen's Islands.

The model study was undertaken on behalf of the Department of Agricultural Credit and Land Tenure. The purpose of the study was to provide the Department with the necessary information to establish whether the proposed marina development would not be hydraulically detrimental to the Knysna Lagoon.

The field work, model construction and calibration of the model were carried out by various personnel under the project leadership of Mr J.W. Kluger. The final tests with and without the various marina layouts were done by Mr D.J.P. Scholtz of this Institute's Coastal Engineering and Hydraulics Division under the guidance of the Head of the Division, Mr J.A. Zwamborn. Mr Scholtz was mainly responsible for the compilation of this report.



F.P. ANDERSON  
ACTING DIRECTOR : NATIONAL RESEARCH INSTITUTE  
FOR OCEANOLOGY

STELLENBOSCH  
May, 1974.

C O N T E N T S

	<u>PAGE NO.</u>
1. INTRODUCTION	1
1.1 Terms of reference	1
1.2 General approach	2
2. FIELD DATA COLLECTION	4
2.1 Aerial survey	4
2.2 Hydrographic survey	4
2.3 Tide level recording	4
2.4 Current measurements	4
3. MODEL CONSTRUCTION	6
4. CALIBRATION OF MODEL	7
5. TEST PROCEDURE	10
6. INFLUENCE OF MARINAS ON WATER LEVELS	11
6.1 Existing layout	11
6.2 Scheme I - Large closed marina	11
6.3 Scheme II - Small closed marina	12
6.4 Scheme III - Open marina	12
6.5 Various marina layouts with different river discharges	13
7. INFLUENCE OF MARINAS ON FLOW CONDITIONS	15
7.1 Existing layout	15
7.2 Scheme I - Large closed marina	15
7.3 Scheme II - Small closed marina	17
7.4 Scheme III - Open marina	17
8. ACCURACY OF RESULTS	19
8.1 Levels	19
8.2 Velocities	19
8.3 Flow rates and tidal prisms	19
9. CONCLUSIONS AND RECOMMENDATIONS	21
REFERENCES	
LIST OF TABLES	
FIGURES	
APPENDIX	

LIST OF TABLES

TABLE I	High- and low tidal levels and time of occurrence for different marina layouts
II	Tidal levels at "The Heads" for different marina layouts
III	Tidal levels with different marina layouts and various river discharges
IV	Shear stress at Section A opposite Leisure Island
V	Mean hourly current velocities measured at "The Heads" for different marina layouts (m/s)
VI	Maximum current velocities at "The Heads" for different marina layouts (m/s)
VII	Tidal prisms for various marina layouts.

LIST OF FIGURES

FIGURE 1	Knysna Lagoon
2	Knysna model layout
3	Photograph of Knysna model
4	Marina schemes tested
5	Maximum and minimum values of recorded tide levels, July to October, 1971
6	Current measurements at 'The Heads'
7	Current measurements at the railway bridge
8	Current measurements at the national road bridge
9	Model construction and tide equipment
10	Propeller current meter and artificial roughness
11	Prototype tides based on recordings from the 20th to 22nd October, 1971
12	Amended prototype tidal curves used for calibration
13.a	Mean and extreme model tidal levels at Thesen's Island and 'The Heads' for existing layout
13.b	Mean and extreme model tidal levels at the channel behind Thesen's Island and Red Bridge for existing layout
14	Mean and extreme model tidal levels at Thesen's Island and 'The Heads' for Scheme I
15.a	Mean and extreme model tidal levels at Thesen's Island and 'The Heads' for Scheme II
15.b	Mean and extreme model tidal levels at the channel behind Thesen's Island and Red Bridge for Scheme II
16.a	Mean and extreme model tidal levels at Thesen's Island and 'The Heads' for Scheme III
16.b	Mean and extreme model tidal levels at the channel behind Thesen's Island and Red Bridge for Scheme III

LIST OF FIGURES (continued)

- FIGURE 17 Mean tidal levels for existing layout  
18 Mean tidal levels for Scheme I  
19 Mean tidal levels for Scheme II  
20 Mean tidal levels for Scheme III  
21 Contour plan of area covered by detailed flow measurements  
22 Flow line photographs for existing layout  
23 Flow line photographs for Scheme I  
24 Flow line photographs for Scheme II  
25 Flow line photographs for Scheme III  
26 Flow patterns and velocities for existing layout  
27 Flow patterns and velocities for Scheme I  
28 Flow patterns and velocities for Scheme II  
29 Flow patterns and velocities for Scheme III  
30 Flow past 'The Heads' for existing situation and various marina layouts

PROPOSED BRAAMEKRAAL MARINA, KNYSNA MODEL STUDIES1. INTRODUCTION1.1 Terms of reference

The Knysna Lagoon is an important and well-known holiday resort and tourist attraction. The local authorities, responsible for the improvement and development of the Knysna- and surrounding lagoons, therefore feel rightly concerned about the detrimental effect that man-made structures and activities may have on the existing conditions in the Knysna Lagoon.

During 1964 representations were made through the local Member of Parliament to the CSIR, for an investigation to be carried out on the siltation problems in the lagoon. A report, "Siltation Problems in the Knysna Lagoon" (CSIR Report MEG/353, April 1965) was submitted and the following is quoted from this report:

"Examination of the physical conditions in the Knysna Lagoon and a detailed comparison of surveys made in the past 150 years have revealed with considerable certainty that there is little if any increase in the real extent of sandbanks within the lagoon. It can thus be said that siltation from external sources is negligible.

On the other hand, it was determined that the sandbanks are subject to quite considerable fluctuations in location and sometimes in form. In the majority of cases this fluctuation takes place about some mean position and there is no trend with time. In a few cases, however, there has been a tendency for sediment to accumulate in special areas and these situations are invariably associated with *man-made structures* in the lagoon."

During 1970 the Hydraulics Research Unit of the National Mechanical Engineering Research Institute was commissioned by the Department

of Agricultural Credit and Land Tenure, at the request of the Department of Planning to investigate the hydraulic effects of possible *marina developments* in the Knysna Lagoon.

The object of the study was to determine whether the construction of a marina on the tidal flats between Leisure and Thesen's Islands would have any detrimental effect on the existing stability of the lagoon and what the effect would be on the tide levels, flow patterns and current velocities with respect to possible scour and/or siltation.

As no specific marina layout could be made available by the Department for testing, it was suggested in a letter MEW/4869 dated 30th April, 1971, that some arbitrary layouts be tested. This suggestion was approved of by the Department of Agricultural Credit and Land Tenure in their letter G.D.064-00082 dated 25th May, 1971.

## 1.2 General approach

To be able to carry out the necessary studies, a model covering the lagoon area between "The Heads" and the "Charlesford Rapids" had to be constructed (see Figures 1, 2 and 3). For the construction of the model and the calibration thereof, field data comprising detailed topographic surveys of the lagoon, tide level recordings and current velocity measurements at various points in the lagoon, had to be collected.

After the completion of the collection of field data and the model construction the model was calibrated by reproducing the prototype tides and flow conditions in the model.

After satisfactory calibration, *three* arbitrary marina layouts, as shown in Figure 4, were installed and tested in the model, viz:-

- (a) Scheme I, representing a large area (extreme case) closed marina with constant water level, connected to the lagoon by a small boat shipping lock.

- (b) Scheme II, representing a more realistic, smaller area, closed marina also connected to the lagoon by a shipping lock.
  
- (c) Scheme III representing a completely open marina with the necessary approach channels to enable boats to enter or leave at any stage of the tide. Since no details were available of the proposed channel system, recessed areas or basins representing the water areas of the channel system were constructed in the model. The shapes of these basins were completely arbitrary, although the connecting channels were located in the most probable positions (see Figure 4.c).

The effects of these schemes on the tide levels, current velocities and flow patterns were recorded. The effects on the tide levels for different marina schemes were also determined for floods with a recurrence period of 50 and 100 years.

In this report all values given, refer to the prototype and not to the model, unless otherwise stated. All levels refer to geodetic mean sea level (GMSL).

## 2. FIELD DATA COLLECTION

### 2.1 Aerial survey

An aerial survey of the Lagoon was made in July, 1970 by Map Studio Productions Ltd. of Johannesburg, who also produced a 1:5000 scale photo-mosaic of the entire area. A contour map with 0,5 m vertical interval contours from low water (- 0,5 GMSL) to +5,0 m GMSL was also made.

### 2.2 Hydrographic survey

Depth soundings in the Lagoon were carried out in February, 1971 by the Hydraulics Research Unit's fields group and the data obtained were combined with the aerial survey mentioned above to provide the basic contour map for the construction of the model (see Figure 2).

### 2.3 Tide level recording

Tide recorders were established on:

- (a) Thesen's jetty
- (b) a specially constructed tripod in the area of The Point,  
and
- (c) on Red Bridge

The data obtained from these recorders, together with the data obtained from the S.A. Navy tide recorder situated at The Heads, were used for the assessment of tidal propagation in the Lagoon. Tide recordings in the Lagoon extended over a period of about 9 months, during the final analysis of results, however, only the records which could be correlated simultaneously at all four measuring positions were selected for use in the model.

Maximum and minimum values of the tide level recordings are given in Figure 5.

### 2.4 Current measurements

Current measurements were made at three cross-sections in the Lagoon:

- (a) across the entrance channel at The Heads,
- (b) at the Railway Bridge, and
- (c) at the National Road Bridge

The measurements were done using an Amsler propeller type current meter at depths of between 1 m to 5,4 m (below water surface) depending on the cross-section and the depth of the measuring section. The meter was moved at approximately 5 minute intervals between the selected positions on each cross-section, throughout a full tidal cycle. The direction of the current could not be measured and was assumed to be either "in" or "out" of the lagoon depending on the state of the tide.

It was not possible to carry out the current measurements simultaneously at the three cross-sections and the measurements were done on three consecutive days, viz 20 to 22nd October, 1971.

The results of the current measurements are given in Figures 6, 7 and 8.

### 3. MODEL CONSTRUCTION

A model, covering the entire Knysna Lagoon, was constructed to a horizontal scale of 1 in 400 and a vertical scale of 1 in 40. Such distortion of scales is acceptable and necessary on a model where large areas of shallow tidal flats are present and thus the naturally scaled down depth of flow in the model would be excessively influenced by model bottom roughness and surface tension effects.

Other scales derived for the model were as follows <sup>1)</sup> (prototype/model ratios):

velocity scale	6,32
time scale	63,25
discharge scale	101 193

The model was built with cement mortar, with the contour lines and depths based on the topographic and hydrographic surveys mentioned in Section 2 of this report. The surface was moulded to steel pegs put in along the contours to the required levels (see Figure 9.a). A general view of the model is shown in Figure 3 and the plan of the model in Figure 2.

The model was provided with an automatic tidal generating system whereby once a tidal curve was properly established it could then be automatically repeated for as many cycles as was required (see Figure 9.b).

Water levels were recorded with vibrating needle level recorders installed at the positions shown in Figure 1. Current measurements were done using 15 mm diameter propeller current meters and by photographing confetti floating on the water surface (see Figure 10.a).

#### 4. CALIBRATION OF MODEL

Before a hydraulic model can be used it must first be proved or calibrated against a known recorded prototype phenomenon. In this instance the tidal propagation as recorded in the lagoon during the field studies was used as the basis for calibrating the model.

A number of tide recordings were examined and many rejected on the grounds of anomalies which could not be accounted for e.g. wind effects and river flow. It was also found that the tide records in the area of The Point could not be correlated reasonably with the remaining tide recording stations and consequently The Point records were not used in the calibration.

The reason for the non-correlation is thought to be the fact that The Point recorder was mounted on a tripod which could have settled, possibly at an angle, into the muddy bottom of the lagoon, thus effecting the tide datum on the recorder and general recording accuracy.

The tidal cycle finally selected for calibration and subsequent tests is shown in Figure 11. Because the tidal generating system on the model was capable of producing a symmetrical tide curve only, the field records had to be amended slightly, on the ebb side of the curve only (see Figure 12), to allow compatibility with the model generated tides.

The tidal levels could not be reproduced exactly the same for repetition tests in the model as the automatic tidal generating apparatus produced a slightly fluctuating tide as can be seen in Figures 13.a and 13.b. These fluctuations had to be accepted at the time and the means of the tides recorded during subsequent tests were therefore used to compare the effects of the various marina layouts.

To ensure that the flow conditions, as they appear in nature, are correctly reproduced in the model the roughness in the model was adjusted until the prototype tide levels and currents were satisfactorily simulated. Stones, wire netting and narrow upright steel strips were used to reproduce the correct roughness (see Figure 3 and 10.b).

Comparing the model results with the prototype recordings (see Sepia Figure 17 and Figure 12) it was noticed that at 'The Heads' the mean high tide level reproduced in the model was about 30 mm lower and occurred approximately

10 minutes later than the amended prototype high tide level. The mean low tide level recorded in the model, at the end of the tidal cycle, was approximately 15 mm higher than the prototype low tide level. This means that a total discrepancy of 45 mm occurred over the full tidal range (1,61m), which gives an error of about 2,8 per cent. The mean tidal cycle recorded in the model had a period of 12 hours and 20 minutes, while the prototype tidal cycle took 12 hours and 30 minutes, giving a difference of approximately 1,3 per cent.

At Thesen's Island, considering the variation in the model recordings, the agreement between model and prototype tide levels was considered as extremely good (compare Figure 12 and Sepia Figure 17). The mean model high tide level was 10 mm lower than the prototype level and they occurred at approximately the same time. The low tide levels in the model and prototype corresponded exactly, therefore the tide level difference over the full tidal range was approximately 0,6 per cent. The duration of the tidal cycles also corresponded.

The prototype tide levels at Red Bridge could not be reproduced in the model as well as the tides at 'The Heads' and Thesen's Island. The mean high tide level recorded in the model was 110 mm higher, and the mean low tide level, at the beginning of the tidal cycle, 90 mm higher than the prototype tide levels. These two discrepancies cancel one another and give a model produced tidal range of 1,36 m compared to the prototype tidal range of 1,34 m or an error of about 1,5 per cent in the tidal range. The duration of the tidal cycles agreed.

Unfortunately no river flow measurements were carried out during the period the prototype tides were recorded, therefore the river flow had to be varied during the calibration tests to find by trial and error the most likely flow that occurred at the time of the tide records (20th to 22nd October, 1971) used for the calibration of the model. The river flow resulting in the most correct reproduction of tidal levels was found to be  $50 \text{ m}^3/\text{s}$ .

An attempt to reproduce in the model the tidal current velocities recorded in the prototype at 'The Heads' and the National Road Bridge (see Section 2.4) was not very successful although at the Railway bridge (the most important area) the agreement was acceptable (see Figures 6, 7 and 8). The

reason for the lack of agreement is most likely the fact that in the prototype the velocity measurements were done over three days, therefore over totally different tides, while the model recordings were done during one tide (except for the slight fluctuation in the levels) which was repeated until all the measurements were taken. It may also be mentioned that the propeller of the current meter (130 mm) used in prototype could not be scaled down to the model scales as a propeller only 1 mm in diameter would have been required. A current meter with 15 mm diameter propeller was used in the model which is equivalent to a propeller 2 m in diameter in prototype. A current measurement in the model therefore represented the mean velocities over a much greater area in the prototype than was actually recorded.

In the prototype the current meter was held for five minutes at each measuring position which is equivalent to 5 seconds in the model. This period, both in prototype and model, is considered as being too short to obtain a good average velocity in a turbulent flow and the measuring period therefore should have been longer in the prototype to ensure better results.

## 5. TEST PROCEDURE

Tests with the various marina layouts were done using the same tide (1,61 m range) and river flow  $50 \text{ m}^3/\text{s}$  used during calibration (see Section 4). The different marina schemes were built into the model and tested one after the other. The tide levels were measured with water level followers and recorders at the different positions shown in Figure 1. An additional water level follower was later installed in the channel behind Thesen's Island to record the variation in tide levels there as well.

Similar to what was found during calibration the various tide level, current velocity and flow pattern tests gave tide levels which fluctuated slightly for the same marina layout because the tidal generating system could not always repeat the same tide exactly. Both the highest and lowest tides recorded, as well as the calculated mean tide levels for each marina layout are therefore given in the test results.

Current velocities were recorded at the same positions as during the calibration tests (see Section 2.4 and Figures 6, 7 and 8) except that additional recordings were made at sections A and B as shown in Figure 1.

All the water level and current velocity recorders were manually synchronized and the time always fixed in relation to that at 'The Heads'.

Flow patterns were photographically recorded. Confetti was sprinkled over the water in the area being investigated (see Figure 1). The sprinkling of confetti was timed so that by the time the photograph was taken, the pieces of confetti were following the flow lines and gave a good indication of the flow pattern and surface velocities on the photographs. The photographs were taken vertically downward from an overhead bridge above the model. An exposure time of one second was used for the photographs. From this exposure time and the co-ordinate grids in the model, the surface velocities could be determined by measuring the distances travelled by the confetti, shown up as small stripes on the photographs. Two photographs were made per tidal cycle, three and nine hours after low water at 'The Heads'. At these times the inflow and outflow velocities reached a maximum and were fairly constant.

## 6. INFLUENCE OF MARINAS ON WATER LEVELS

### 6.1 Existing layout

The recorded extreme water levels for the existing layout are shown in Figures 13.a and 13.b. The mean levels for all recording stations are combined in Figure 17. To make it easier to compare the results of the existing layout with those of the different marina schemes, a sepia copy of Figure 17 is inserted in the back of this report. By laying this sepia over the tidal curves recorded with the different marina schemes, the effects of the various schemes on the tides are easily noticeable.

The main results are also tabulated in Table I.

### 6.2 Scheme I - Large closed marina

The recorded extreme water levels for Scheme I are shown in Figure 14. During the tests with Scheme I; the tide recorder at Red Bridge was out of order except for one test, - therefore Red Bridge has no figure showing recorded extreme water levels.

The area cut off by the walls\* (see Figure 4A) is not effected by any tidal variations in the lagoon, as access to the lagoon is only provided via a small boat shipping lock.

To determine the influence of the marina on the tide levels the tide curves of the existing layout (sepia copy of Figure 17) should be compared with the tide curves of Scheme I (Figure 18).

The difference in tide levels at 'The Heads' is seen to be negligible (see Table I). At 'Thesen's Island' the high water level is increased by 0,06 m and occurs 15 minutes earlier, while the change in low water level is negligible. Because the tide level recorder in the channel behind "Thesen's Island" is located in the "dead" area behind the wall, no tide levels were recorded there. The high water tide at Red Bridge varied by a negligible 0,02 m and occurred 10 minutes earlier, while the low water level dropped by 0,05 m and appeared 15 minutes earlier.

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\*These could represent any type of water proof construction, e.g. sand dyke or rubble mound breakwater.

At all three measuring points, the time of high water was slightly earlier. This is because the area of the lagoon, affected by the tide, is decreased by the marina area and less time is thus required to fill the remaining area. For the same reason the water level in the lagoon drops more rapidly.

The mean tidal level measured at 'The Heads' dropped by 0,04 m (see Table II).

The tide period at 'The Heads' is, however, governed by the tide in the sea (12 hours, 30 minutes) therefore it should not be affected by any scheme.

### 6.3 Scheme II - Small closed marina

The recorded extreme water levels for Scheme II are shown in Figures 15.a and 15.b. In this case the area behind the wall is again completely isolated from the tidal variations in the lagoon (see Figure 4B).

The effect on the tide at both "The Heads" and "Thesen's Islands" is also negligible for this scheme (see Figure 19). In the channel behind "Thesen's Island" the high tide level occurs 10 minutes earlier and is increased by 0,08 m, while the low water level rises by 0,04 m and is 7 minutes earlier (see Table I). The area subjected to the tidal range between Leisure- and Thesen's Islands, is reduced, therefore the maximum water level in the unrestricted area between these two islands is reached sooner and, while the flow to the channel behind Thesen's Island remains unrestricted, it is possible for more water to flow up this channel resulting in a higher water level.

At Red Bridge both the high- and low water levels dropped by 0,05 m and 0,07 m respectively. The change in time of occurrence is negligible.

The high tides at all the measuring points occurred slightly earlier.

### 6.4 Scheme III - Open marina

The recorded extreme water levels for Scheme III are shown in Figures

16.a and 16.b. This scheme also has a negligible effect on the tides at "The Heads" and "Thesen's Island" (see Sepia Figure 17 and Figure 20).

The high water level in the channel behind "Thesen's Island" is raised by 0,04 m and advanced by 20 minutes. The low tide level remains fairly constant, although it is advanced by 15 minutes (see Table I). This effect is most probably due to the new enlarged approach channel.

The effect on the high tide at Red Bridge is negligible. The level of the low tide is, however, reduced by 0,06 m.

#### 6.5 Various marina layouts with different river discharges

To ascertain the effect of the marinas on the water levels in the lagoon with various river flows, two different river discharges were tested apart from the basic discharge of  $50 \text{ m}^3/\text{s}$  used for the calibration tests and test described in sections 6.2 to 6.4. The floods used were a discharge of  $640 \text{ m}^3/\text{s}$ , representing a flood occurring once every 50 years and a discharge of  $850 \text{ m}^3/\text{s}$  representing a once in 100 year flood. These floods are based on a catchment area of the river of  $362 \text{ km}^2$  (140 square miles) using the flood prediction method described by Midgley, Pullen and Pitman<sup>2)</sup>.

The results of these tests using these floods together with the basic tide (Figure 12) are compiled in Table III.

As can be expected the greatest difference in levels due to the different floods are encountered at Red Bridge, where  $640 \text{ m}^3/\text{s}$  and  $850 \text{ m}^3/\text{s}$  floods effect increases of 0,38 m and 0,50 m respectively in the high water levels and increases of 1,50 m and 1,78 m in the low water levels under existing conditions.

The smallest effects on tidal levels were recorded at 'The Heads'. Increases of 0,15 m and 0,17 m in the high water levels and 0,05 m for both floods in the low water levels were measured here.

The various marina layouts are seen to have very little influence on the tide levels for both river discharges of  $640 \text{ m}^3/\text{s}$  and  $850 \text{ m}^3/\text{s}$

The only noticeable effects occur with Scheme III during the low tides at 'The Heads' and Thesen's Island. The  $640 \text{ m}^3/\text{s}$  and  $850 \text{ m}^3/\text{s}$  floods effect increases of the low tide levels at 'The Heads' of 0,12 m and 0,15 m and at Thesen's Island of 0,05 and 0,10 m respectively.

For comparison it should be mentioned that the average tidal flow through 'The Heads' is approximately  $1000 \text{ m}^3/\text{s}$  and the maximum tidal flow about  $2000 \text{ m}^3/\text{s}$ .

## 7. INFLUENCE OF MARINAS ON FLOW CONDITIONS

### 7.1 Existing layout

Detailed flow measurements were made in the model in the "area covered by photographs", marked in Figure 1. A contour plan of this area, showing the two sections A and B where sub-surface velocity measurements were made, is given in Figure 21. A sepia copy of Figure 21 is included at the back of the report, which can be used as an overlay for the flow diagrams (Figures 26 to 29).

The flow conditions occurring in this area for the existing layout, are shown on Figure 22.

The flow lines were traced from the photographs (Figures 22 to 25) and surface velocities were determined, as shown in Figure 26. Figure 26 also shows the sub-surface velocity measurements made in the model along lines A and B (velocity measurements were made 1,5m below GMSL at the positions shown in Figure 21. At position 6 only, measurements were made 1 m below GMSL because of the restricted depth). A sepia copy of Figure 26 is enclosed at the back of this report for easier comparison of the flow conditions for the various marina layouts.

This particular area for detailed comparison of flow conditions was selected on the basis that the influence of the marina layouts considered in this report would be *greatest* in this area.

### 7.2 Scheme I - Large closed marina

The area behind the walls is separated from the lagoon proper by a shipping lock, therefore, no flow occurs in this area and the water is stagnant. Also very little or no flows occurs in the area in front of the wall and between "Leisure- and 'Thesen's Islands' (see Figure 4A).

Apart from these areas, the marina has little effect on the flow patterns and velocities (Figures 23 and 27). Both during tidal inflow and outflow, the main flow shifts slightly towards the deeper section of the main channel at section A. Compare sepia Figures 26 and 21 and Figure 27.

The stability of the channels is mainly determined by the shear stresses caused by the tidal flow and acting on the channel sides and bottom. The shear stresses were, therefore, determined for the *measured* velocities in section A (see Figure 21 and Table IV). The method used to determine the shear stress is explained in the Appendix.

The shear stress for Scheme I was found to be  $1,02 \text{ N/m}^2$ , i.e. an increase of  $0,29 \text{ N/m}^2$  or some 40 per cent compared with the existing maximum shear stress of  $0,73 \text{ N/m}^2$  in section A (see Table IV). The critical shear stress for the sediment mean grain size (200 micron) in the lagoon, is  $0,17 \text{ N/m}^2$  as calculated from Shields curve <sup>3)</sup>.

It must be mentioned that the sand samples, on which the 200 micron characteristic mean grain size is based, were taken from above the low water line. The grain size below the low water will be greater, as the tidal flow would have washed the smaller particles out and deposited them in the shallow parts or tidal flats. The critical shear stress for the sand below low water will therefore probably be considerably higher than the  $0,17 \text{ N/m}^2$  mentioned above. Furthermore, the recommended permissible unit tractive force for canal design in non cohesive material is  $1,3 \text{ N/m}^2$ .<sup>5)</sup>

The maximum shear stress ( $1,02 \text{ N/m}^2$ ) is still well below this recommended value, which means that although under the existing conditions some movement of sediment is taking place, this movement will be small and the increase in shear stress caused by Scheme I, and thus the resulting increase in sediment movement, will be unimportant.

At 'The Heads' the mean inflow and outflow velocities were both reduced from 0,9 to 0,7 m/s or by about 22 per cent (see Table V) and the maximum, deep, inflow and outflow current velocities decreased by 0,5 m/s or 36 per cent and 0,6 m/s or 35 per cent respectively (see Table VI).

The flow rates past 'The Heads' were also determined from the velocity measurements and the cross-sectioned area. It was found to be greatly reduced over virtually the complete tidal cycle compared with the existing situation, as may be seen from Figure 30A and B. As a result

the tidal prism also diminished from  $29 \times 10^6 \text{ m}^3$  to  $21,8 \times 10^6 \text{ m}^3$  or by 24,9 per cent. (see also Table VII).

### 7.3 Scheme II - Small closed marina

As with Scheme I, the water in the area cut off by the wall becomes stagnant.

Scheme II, also has no significant effect on the flow patterns and velocities in the area between Leisure Island and the mainland (see Figure 24, sepia Figure 26 and Figure 28), although in section A slightly greater sub-surface velocities were observed near the mainland.

An increase of  $0,08 \text{ N/m}^2$  or 11 per cent was effected in the existing maximum shear stress at section A opposite "Leisure Island" (see Table IV) which would only cause a very slight increase in the existing sediment movement.

No difference in the mean inflow and outflow velocities at 'The Heads' was observed (see Table V) while the greatest effect on the maximum current velocities there, appeared in the deep outflow velocities and amounted to a decrease of  $0,3 \text{ m/s}$  or about 18 per cent (see Table VI).

The flow rate past 'The Heads' is reduced over the complete tidal cycle except during the first two hours and during the 7th and 8th hour after the time of low water at 'The Heads' when it is slightly increased (see Figure 30).

The tidal prism is reduced to  $25,9 \times 10^6 \text{ m}^3$  or by 10,7 per cent compared with the existing situation (see Table VII).

### 7.4 Scheme III - Open marina

In this case, the flow in the main channel opposite "Leisure Island" is also moved slightly towards the main land at section A (see Figure 25, sepia Figure 26 and Figure 29). At the tip of "Leisure Island" a fairly "dead" area marked X on Figure 25 is created. This is due to the main flow between the two islands being more concentrated along the western side of the channel marked Y on Figure 25 and along the new enlarged channel (see Figure 4C).

The mean current velocities at 'The Heads' are not affected (Table V) and the maximum velocities there are only reduced by about 13 per cent (Table VI).

The maximum shear stress at Section A opposite "Leisure Island" is increased with Scheme III by  $0,17 \text{ N/m}^2$  or about 23 per cent (see Table IV). This means slightly more sediment can be expected to move about.

The outflow velocities at 'The Heads' for Scheme III are considered to be incorrect because, for all the other layouts, the mean inflow velocities were equal to the mean outflow velocities. The test results for Scheme III however, gave values for the outflow velocities which were smaller than the inflow velocities (see Tables V and VI). The effect of these incorrect outflow velocities is also noticed in Figure 30B, where the curve presenting the accumulative water volume flowing past 'The Heads' does not return to below the zero volume line as with the other schemes.

The error in these velocities is probably caused by an obstacle, such as a small hair, which got stuck in the propeller of the current meter in such a way that it only interfered with the propeller when the current flowed in one direction. Unfortunately, due to deterioration of the model tidal mechanism at the time this was discovered, it was impractical to repeat these measurements.

The flow rate past 'The Heads' is slightly reduced over the complete tidal cycle, except for the first two hours, after time of low water at 'The Heads' when it is slightly increased (see Figure 30A).

The mean inflow velocity can be accepted to be correct as the first half of the accumulative curve in Figure 30B has the correct shape, judged by the three other curves. The tidal prism therefore, is also correct since it was calculated from the inflow velocities. The tidal prism was found to be  $27,4 \times 10^6 \text{ m}^3$ , which is only 5,5 per cent smaller than the existing one (Table VII).

## 8. ACCURACY OF RESULTS

### 8.1 Levels

The dimensions which had to be worked with in the model were very small. One millimeter difference in water level in the model represented 40 millimeter in prototype. The tide controlling apparatus did not function 100 per cent, therefore the tide fluctuated somewhat. The mean of all the maximum tide level fluctuations (see Figures 13.a to 16.b) was 0,08 m or 2 mm in the model while the mean of all the average tide fluctuations came to 0,05 m or 1,3 mm in the model.

In the test results the means of the recorded levels (see Figures 17 to 20), for a series of tests were always used when comparing the effects of one layout with that of another, therefore the error due to the fluctuating tides was fairly well eliminated.

### 8.2 Velocities

The current velocities were usually recorded with one, or, when possible, with two current meters simultaneously. The current measurements at each position was recorded over a full tidal cycle. Currents at different positions were thus recorded during different tidal cycles, therefore the tidal levels during current measurements at one position could have been different from the tide levels while current measurements were recorded at the next position because of the fluctuating tide.

The effect, that the fluctuations in tide levels had, on the current velocities is considered as completely negligible as the fluctuation is so small (0,05 m average) in comparison with the flow depth (approximately 2 m minimum) at the measuring positions that a noticeable variation in current velocities is most unlikely.

### 8.3 Flow rates and tidal prisms

Both the results from the water level and current velocity recordings, at 'The Heads' were used to determine the flow rates at different stages of the tide as well as the tidal prisms.

As the velocities remain roughly constant during the tide level fluctuations encountered in the model (Section 8.2) the flow rate as well as the tidal prism will only be affected by the difference in the cross-

sectional flow area due to the errors caused by the fluctuating tide.

It is expected that, with the existing layout, the effect of the fluctuating tide on the flow rate will be greatest, at about 9 hours after low water at 'The Heads' when the mean flow velocity is high, viz.

Tide level at 'The Heads' (9 hours after L W)  
= +0,31 m above GMSL

Cross sectional flow area (9 hours after L W)  
= 1374 m<sup>2</sup>

Difference in cross sectional flow area due to maximum tide fluctuation of 0,04 m from the mean  
= 9 m<sup>2</sup>

∴ Difference in flow rate (assuming the velocity remains constant)  
= 0,7 per cent.

The effect of the fluctuating tide on the tidal prism will also be proportional to the effect on cross sectional flow area. With the existing layout the following applies at 'The Heads':-

Mean low tide cross sectional flow area	= 1178 m <sup>2</sup>
Difference in cross sectional flow area due to maximum tide fluctuation of 0,04 m from the mean	= 9 m <sup>2</sup> or 0,8 per cent
Mean high tide cross sectional flow area	= 1537 m <sup>2</sup>
Difference in cross sectional flow area due to tide fluctuation of 0,04 m from the mean	= 9 m <sup>2</sup> or 0,6 per cent

The maximum possible effect on the tidal prism will therefore be about 0,7 per cent.

From the above it can be seen that the effect of the fluctuating tide on the flow rate and tidal prism is negligible.

## 9. CONCLUSIONS AND RECOMMENDATIONS

The three 'arbitrary' marina layouts tested in the model, were found to have little effect on the *water levels* in the Knysna lagoon, except for the areas directly affected by the walls. The effect of the different marinas on the tide levels during river floods are also negligible.

All three marina layouts have some effect on the *flow* in the main channel opposite "Leisure Island". These effects are, however, small except for the considerable increase in shear stress (40 per cent) at position 3 Section A with Scheme I (see Table IV). As this increase in shear stress only occurs at position 3 along Section A (see Figure 21), only some local scour is expected here which is not considered serious and will only cause slight re-positioning of the sand banks in that area until a new stable condition is reached.

Scheme I will cause some *silting-up* of the area between the walls and the main channel in Figure 4A, as no or very little flow occurs there. This siltation may later on lead to navigation problems in that area.

In both Schemes I and II no flow occurs in the areas behind the walls and the water will thus be stagnant and special precautions will have to be taken against *pollution*.

Due to the higher flow rate and more concentrated flow in the new approach channel to the marina in Scheme III, *scour* along the western bank of the approach channel, marked Y, and along the main channel bank, marked Z, on Figures 21 and 25, is expected to occur. Scour at point Y would merely cause a local change in the channel configuration, which would not be serious, but scour at point Z should be watched and *shore protection* may have to be considered here.

With Scheme III *siltation* is expected to occur in the area marked X in Figures 21 and 25 eventually resulting in an increase in size of "Leisure Island". From a hydraulic point of view, there is seen to be no disadvantage in this siltation. Inside the basins it was noticed that the replacement of water with fresh water is very poor which will most probably result in very badly *polluted* conditions. However, it must be remembered that these basins have an arbitrary shape and with a real marina layout the channels would be interconnected to allow a through-flow of water which

would improve the flushing ability of the tidal flow.

Probably the most important change caused by the different schemes, is the reduction in the *tidal prism* which is as high as 24,9 per cent with Scheme I. This reduction in the tidal prism generally results in a reduction of the same order of the mean flow velocities in the main channel between "The Heads" and Section A in Figure 1 as virtually the total tidal flow passes through this channel. The reduction in flow velocities will cause the sand banks to shift until a new stable condition is again reached.

At "The Heads" however, even with Scheme I, the mean flow velocities will still be rather high (0,7 m/s) and siltation there by the sediment from the lagoon which has a characteristic mean grain size of 200 micron, is not expected. Coarser material in the order of 1 000 micron and larger, from the sea, may however enter the channel at "The Heads" and the current velocities may be too small to clear it out. If this happens, the flow at "The Heads" will become restricted to a certain extent, causing further changes in water levels, flow velocities, flow patterns and sand bank configurations, finally resulting in a new equilibrium to be reached.

The 10,7 per cent reduction in the tidal prism of Scheme II is significant but it is not considered to be high enough to cause problems with siltation, while the 5,5 per cent reduction of Scheme III is considered insignificant.

*From the above it is concluded that a marina development along the lines of Schemes II and III will have no detrimental effect on the hydraulic conditions in the Knysna Lagoon. However, a large area scheme along the lines of Scheme I should not be considered until a detailed study is made of the expected changes in the channel regimes (sediment movement study).*

It is therefore *recommended* that if a marina is to be built in the Knysna Lagoon, the layout be so designed that the existing tidal prism is reduced as little as possible. Furthermore, once a definite marina scheme has been decided upon, this layout should be tested in the model as a final check. Depending on the accepted marina layout, further attention will have to be given to scour protection and possible siltation in the connecting channels, as well as to pollution problems in the marina area.

## REFERENCES

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TABLE I

HIGH- AND LOW TIDAL LEVELS AND TIME OF OCCURRENCE FOR DIFFERENT MARINA LAYOUTS

Layout	The Heads			Thesen's Island			Channel behind Thesen's Island			Red Bridge						
	H.W.	Time	L.W.	Time	H.W.	Time	L.W.	Time	H.W.	Time	L.W.	Time				
Existing	+1,03	6-15	-0,56	0	+1,04	6-30	-0,56	0	+1,05	6-50	-0,28	1,55	+1,18	6-40	-0,18	1-30
Scheme I	+1,03	6-10	-0,57	0	+1,10	6-15	-0,57	0	-	-	-	-	+1,20	6-30	-0,23	1-15
Scheme II	+1,04	6-00	-0,55	0	+1,03	6-25	-0,56	0	+1,13	6,40	-0,24	1,48	+1,13	6-35	-0,25	1-30
Scheme III	+1,04	6-20	-0,56	0	+1,04	6-30	-0,54	0	+1,09	6,30	-0,30	1,40	+1,16	6-35	-0,24	1-30

H.W. - Tide level during high water in metres to geodetic Mean sea level. (GMST.)

L.W. - Tide level during low water in metres to geodetic Mean sea level.

Time - Time in hours and minutes after low water occurred at "The Heads"

TABLE II  
TIDAL LEVELS AT "THE HEADS" FOR DIFFERENT MARINA LAYOUTS

Layout	Time after Low water at "The Heads" (Hours)												Mean Tidal Level		
	0	1	2	3	4	5	6	7	8	9	10	11		12	12,5
Existing	-0,56	-0,45	-0,15	+0,20	+0,52	+0,83	+1,01	+0,96	+0,70	+0,31	-0,11	-0,41	-0,54	-0,55	+0,13
Scheme I	-0,57	-0,46	-0,14	+0,21	+0,55	+0,87	+1,03	+0,92	+0,57	+0,16	-0,23	-0,50	-0,57	-0,57	+0,09
Scheme II	-0,55	-0,40	-0,09	+0,26	+0,58	+0,88	+1,04	+0,96	+0,66	+0,26	-0,14	-0,44	-0,55	-0,56	+0,14
Scheme III	-0,56	-0,43	-0,12	+0,23	+0,57	+0,87	+1,04	+0,97	+0,69	+0,29	-0,11	-0,42	-0,54	-0,56	+0,14

Levels in metres to GMSL

TABLE III

## TIDAL LEVELS WITH DIFFERENT MARINA LAYOUTS AND VARIOUS RIVER DISCHARGES

Layout	River Discharge (m <sup>3</sup> /s)	The Heads		Theron's Island		Channel behind Theron's Island		Red Bridge	
		H.W.	L.W.	H.W.	L.W.	H.W.	L.W.	H.W.	L.W.
Existing	50	+1,03	-0,56	+1,04	-0,56	+1,05	-0,28	+1,18	-0,18
	640	+1,18	-0,51	+1,24	-0,46	+1,24	-0,16	+1,56	+1,32
	850	+1,20	-0,51	+1,24	-0,44	+1,24	-0,16	+1,68	+1,60
Scheme I	50	+1,03	-0,57	+1,10	-0,57	-	-	+1,20	-0,23
	640	+1,18	-0,53	+1,24	-0,53	-	-	+1,60	+1,36
	850	+1,20	-0,47	+1,24	-0,46	-	-	+1,68	+1,60
Scheme II	50	+1,04	-0,55	+1,03	-0,56	+1,13	-0,24	+1,13	-0,25
	640	+1,14	-0,50	+1,21	-0,52	+1,20	-0,16	+1,56	+1,36
	850	+1,24	-0,48	+1,28	-0,45	+1,29	-0,14	+1,72	+1,64
Scheme III	50	+1,05	-0,56	+1,04	-0,54	+1,09	-0,30	+1,16	-0,24
	640	+1,17	-0,39	+1,21	-0,41	+1,22	-0,13	+1,56	+1,36
	850	+1,23	-0,36	+1,29	-0,34	+1,24	-0,14	+1,68	+1,56

H.W. Max. Tidal level during high water

L.W. Min. Tidal level during low water

All levels in metres to GMSL

TABLE IV

SHEAR STRESS AT SECTION 'A' OPPOSITE LEISURE ISLAND

Layout	Time after Low water at 'The Heads' (Hour)	Shear Stress (N/m <sup>2</sup> )				Maximum shear stress and position where it occurs
		Position 1	Position 2	Position 3	Position 4	
Existing	3	0,32	0,53	0,58	0,40	0,73 N/m <sup>2</sup> at positions 2 and 3
	9	0,29	0,73	0,73	0,26	
Scheme I	3	0,36	0,53	0,58	0,26	1,02 N/m <sup>2</sup> at position 3
	9	0,26	0,73	1,02	0,44	
Scheme II	3	0,48	0,53	0,68	0,32	0,81 N/m <sup>2</sup> at position 3
	9	0,32	0,63	0,81	0,26	
Scheme III	3	0,36	0,63	0,53	0,40	0,90 N/m <sup>2</sup> at position 3
	9	0,36	0,78	0,90	0,29	

Average sand size in Section A : 200 $\mu$

Critical shear stress (start of sand movement) 0,17 N/m<sup>2</sup>

Refer to Figure 18 for location of Section A and measuring positions

TABLE V.

MEAN HOURLY CURRENT VELOCITIES MEASURED AT "THE HEADS"  
FOR DIFFERENT MARINA LAYOUTS (m/s)

TIME after L. W. at The Heads	Existing Layout		Scheme I		Scheme II		Scheme III	
	Near Surface	Deep <sup>+</sup>	Near Surface	Deep <sup>+</sup>	Near Surface	Deep <sup>+</sup>	Near Surface	Deep <sup>+</sup>
0 hour	-0,2	-0,1	-0,3	-0,3	-0,2	-0,3	-0,3*	-0,2*
1	+0,3	+0,1	+0,3	+0,3	+0,6	+0,5	+0,5	+0,5
2	+1,0	+1,0	+0,8	+0,7	+1,0	+1,0	+1,0	+1,0
3	+1,2	+1,2	+0,9	+0,8	+1,1	+1,1	+1,2	+1,1
4	+1,2	+1,2	+1,0	+0,9	+1,1	+1,1	+1,2	+1,1
5	+1,2	+1,3	+0,9	+0,9	+1,0	+1,0	+1,1	+1,1
6	+0,6	+0,7	+0,5	+0,6	+0,3	+0,4	+0,6	+0,6
7	-0,6	-0,5	-0,6	-0,6	-0,8	-0,7	-0,6*	-0,5*
8	-1,4	-1,3	-1,1	-1,0	-1,3	-1,2	-1,1*	-0,9*
9	-1,6	-1,6	-1,2	-1,1	-1,4	-1,3	-1,1*	-1,0*
10	-1,5	-1,5	-1,2	-0,9	-1,2	-1,2	-1,1*	-1,0*
11	-1,0	-1,1	-0,9	-0,8	-0,9	-0,9	-0,9*	-0,7*
12	-0,3	-0,4	-0,5	-0,5	-0,3	-0,4	-0,4*	-0,4*
Mean Inflow velocity (+)	+0,9	+0,9	+0,7	+0,7	+0,9	+0,9	+0,9	+0,9
Mean Outflow velocity (-)	-0,9	-0,9	-0,8	-0,7	-0,9	-0,9	-0,8*	-0,7*

+ 3 m to 5,5 m below water surface  
\* Results to be considered as incorrect

TABLE VI

MAXIMUM CURRENT VELOCITIES AT "THE HEADS" FOR DIFFERENT  
MARINA LAYOUTS (m/s)

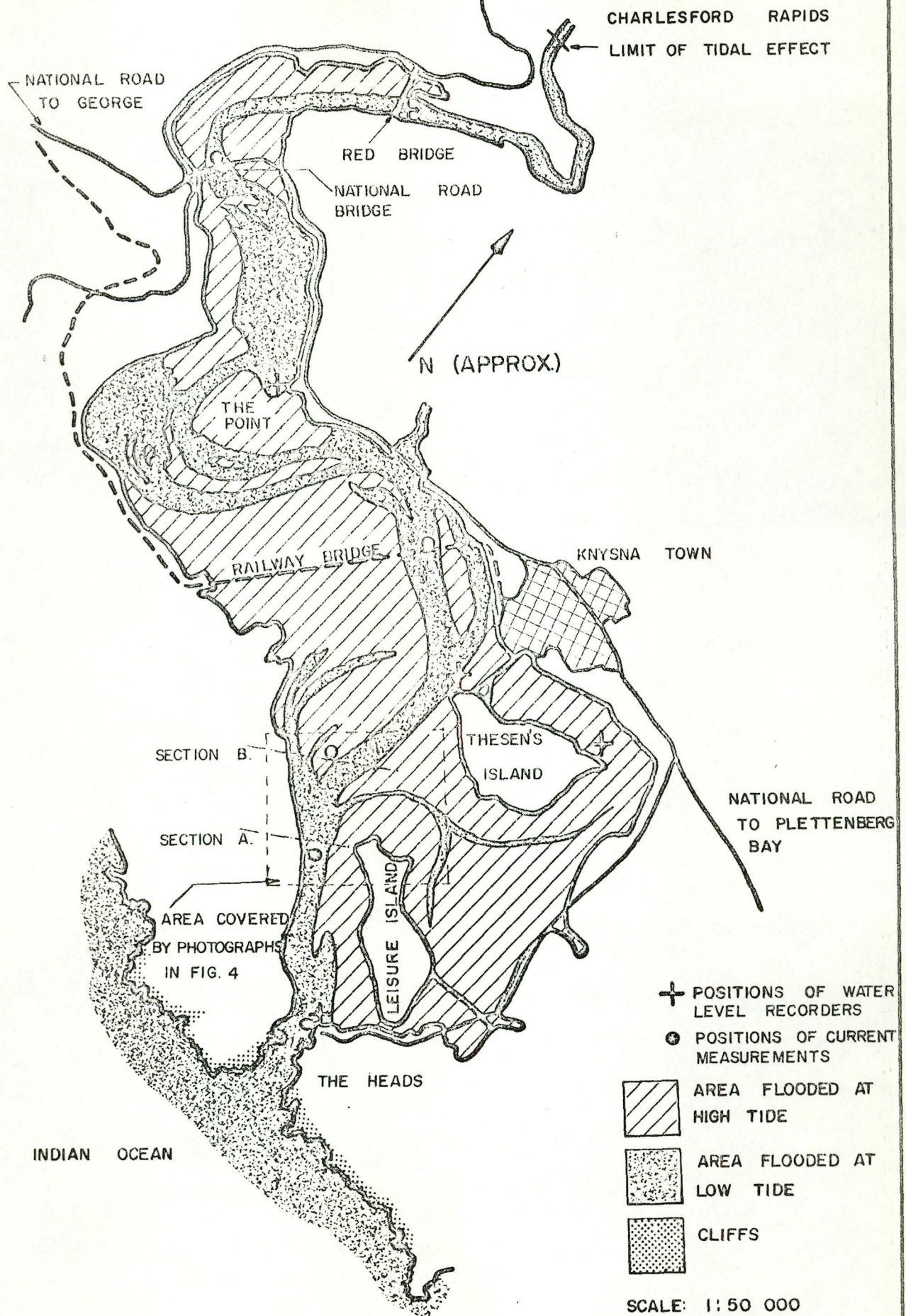
Layout	Inflow Velocities		Outflow velocities	
	Near surface	Deep	Near surface	Deep
Existing	1,5	1,4	1,7	1,7
Scheme I	1,1	0,9	1,3	1,1
Scheme II	1,3	1,2	1,5	1,4
Scheme III	1,3	1,3	1,3*	1,2*

\* Results to be considered as incorrect.

TABLE VII.

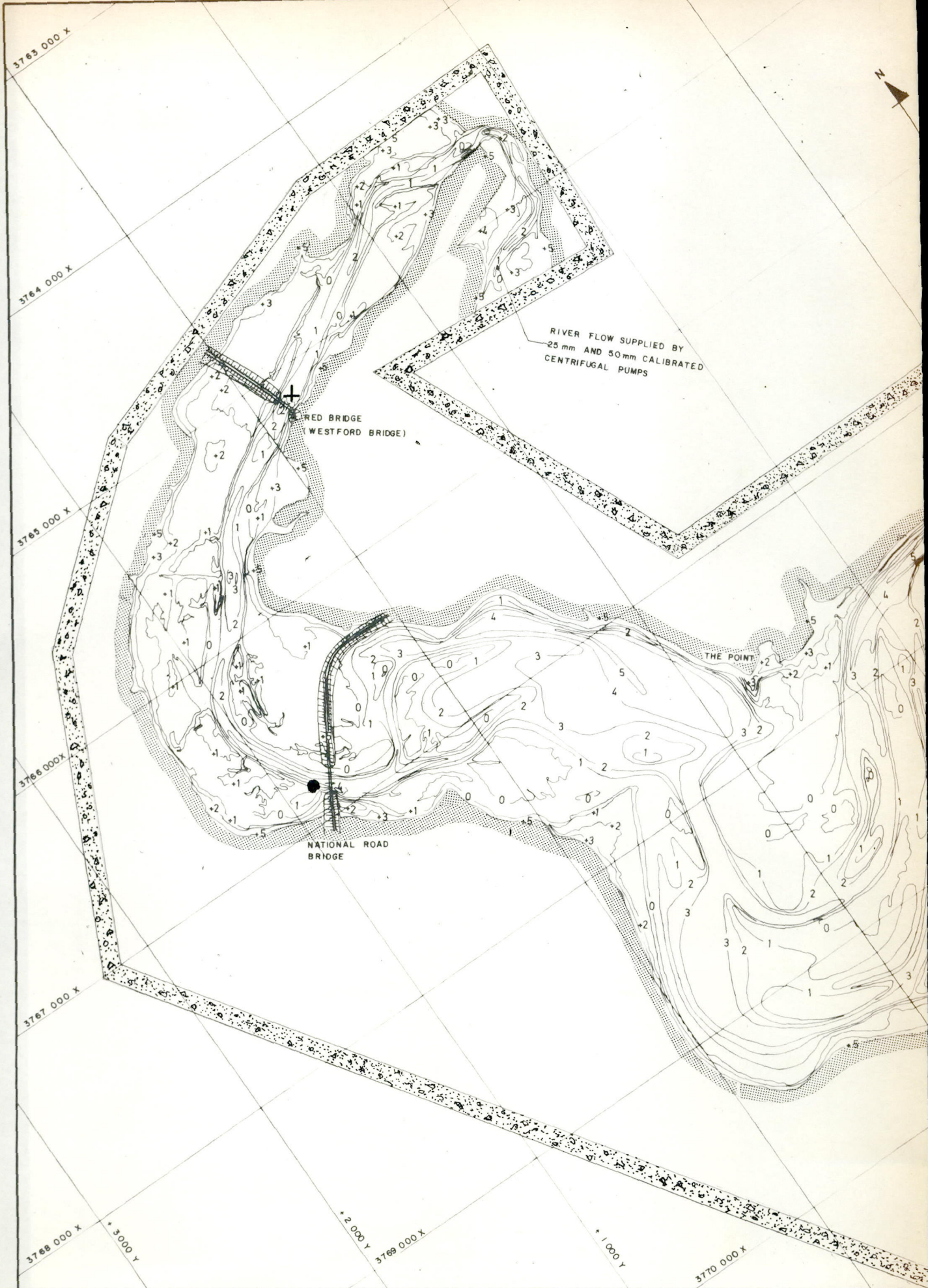
TIDAL PRISMS FOR VARIOUS MARINA LAYOUTS

Layout	Tidal Prism ( $10^6 m^3$ )	Percentage change to existing conditions (%)
Existing	29,0	-
Scheme I	21,8	-24,9
Scheme II	25,9	-10,7
Scheme III	27,4	- 5,5



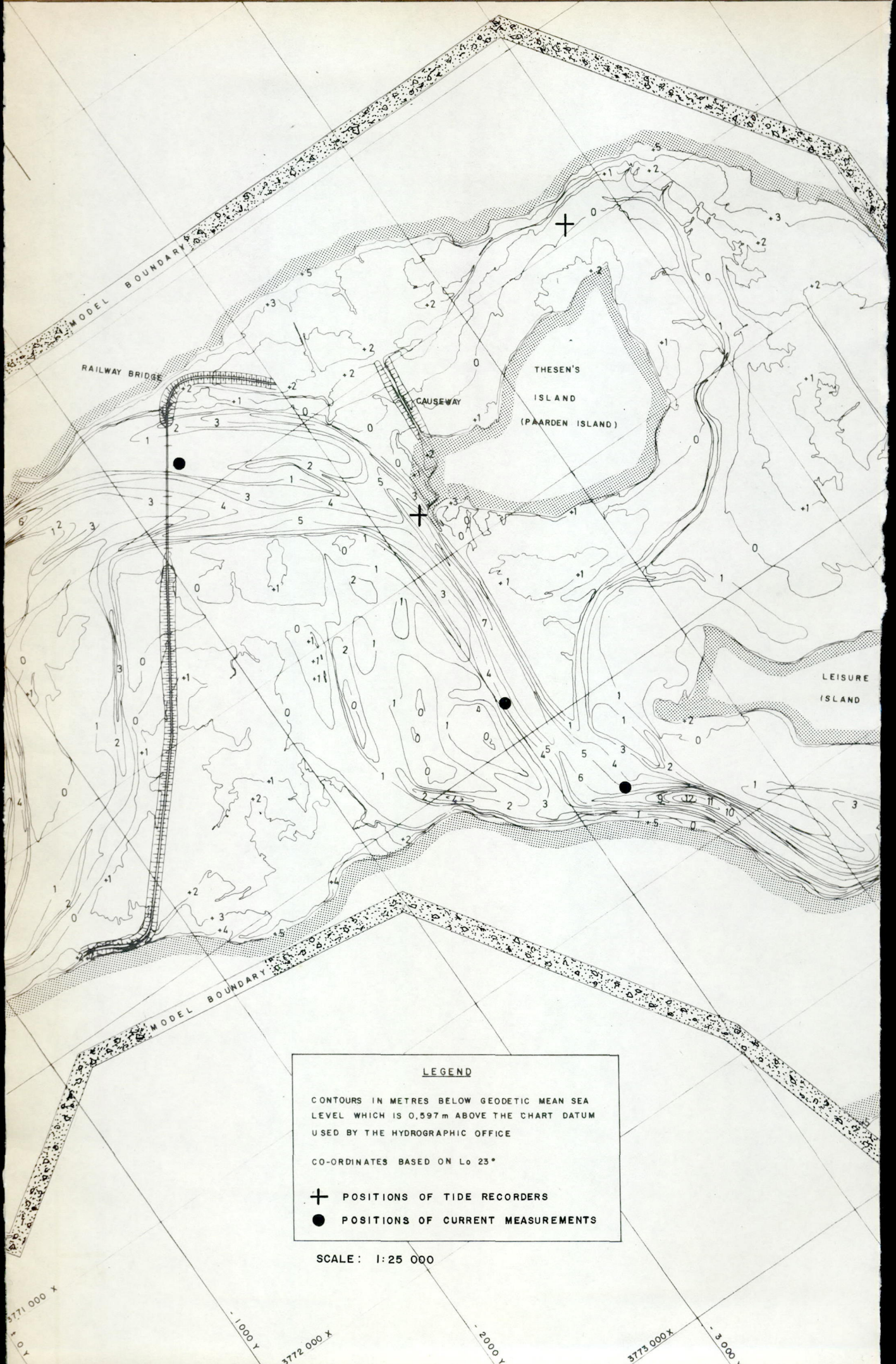
KNYSNA LAGOON

FIGURE



KNYSNA MODEL LAYOUT

FIGURE



**LEGEND**

CONTOURS IN METRES BELOW GEODETIC MEAN SEA LEVEL WHICH IS 0.597 m ABOVE THE CHART DATUM USED BY THE HYDROGRAPHIC OFFICE

CO-ORDINATES BASED ON  $L_0 23^\circ$

✚ POSITIONS OF TIDE RECORDERS

● POSITIONS OF CURRENT MEASUREMENTS

SCALE: 1:25 000

3771 000 X

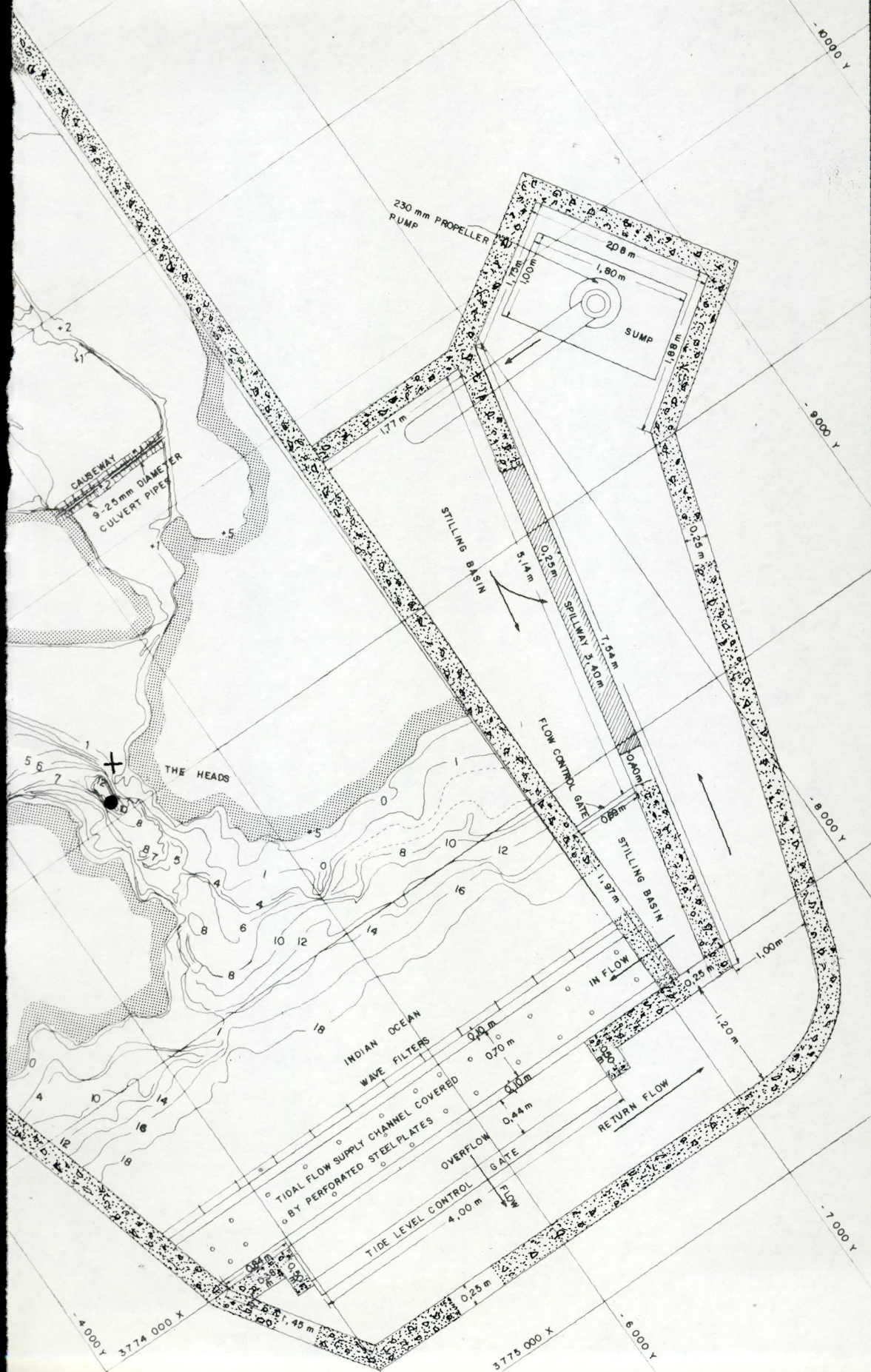
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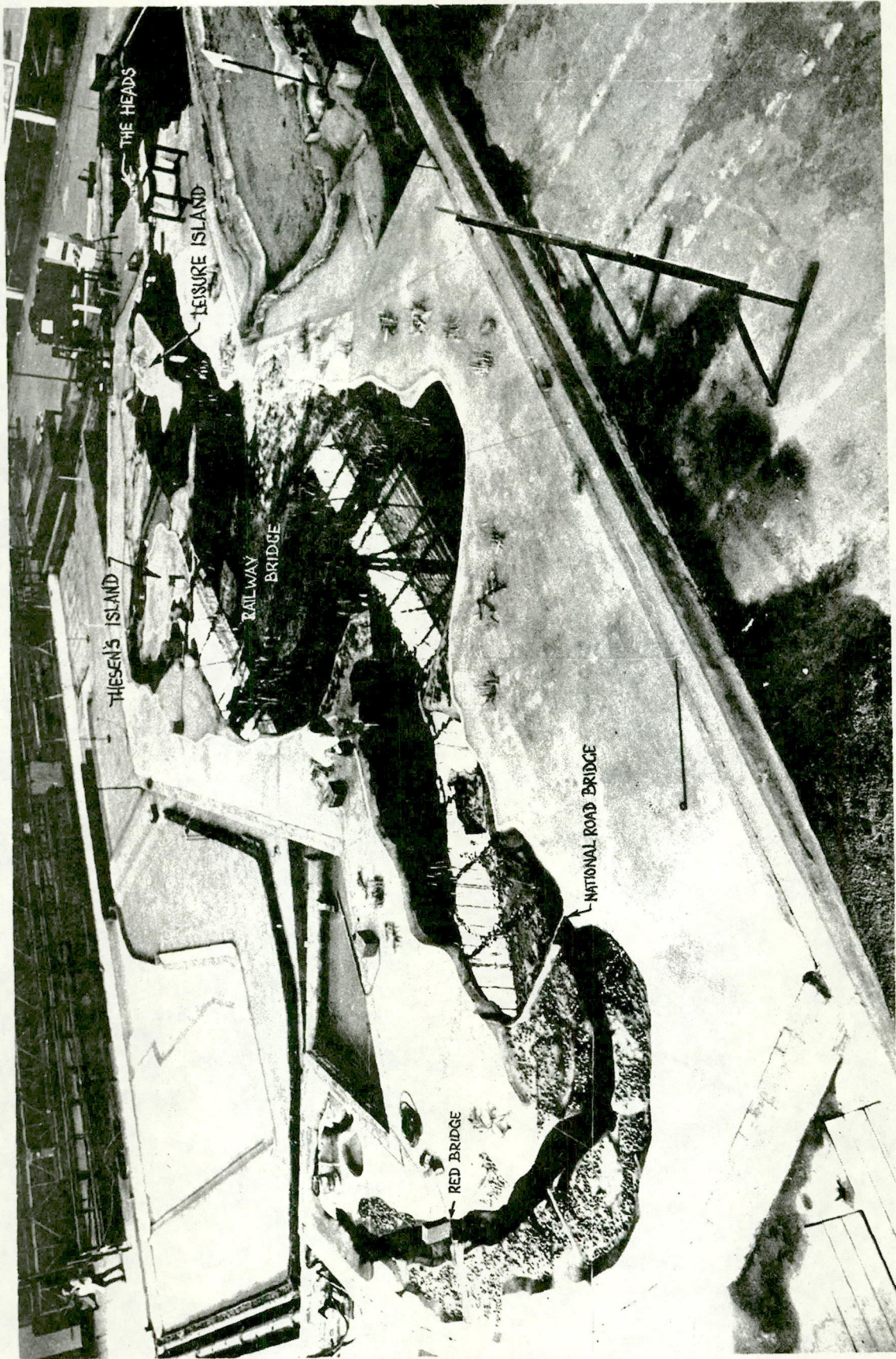
3772 000 X

- 2000 Y

3773 000 X

- 3000 Y

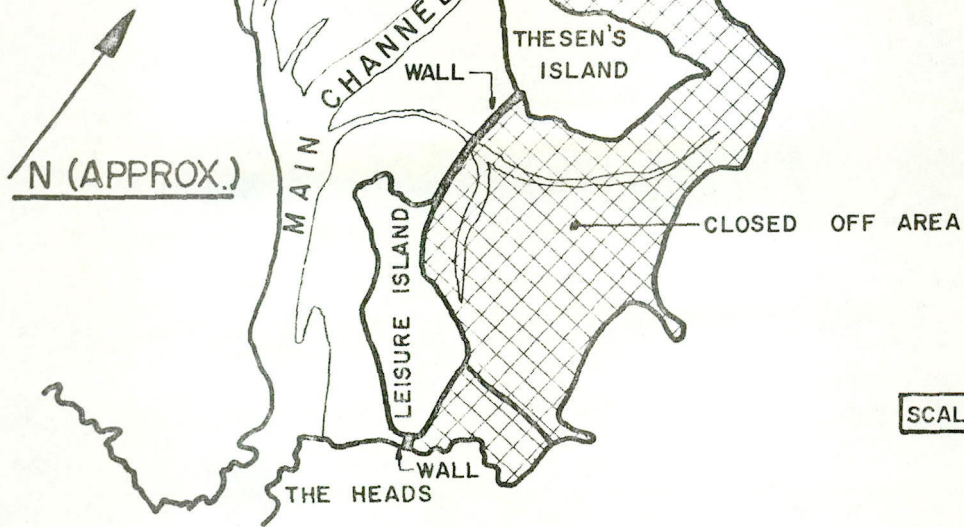




PHOTOGRAPH OF KNYSNA MODEL

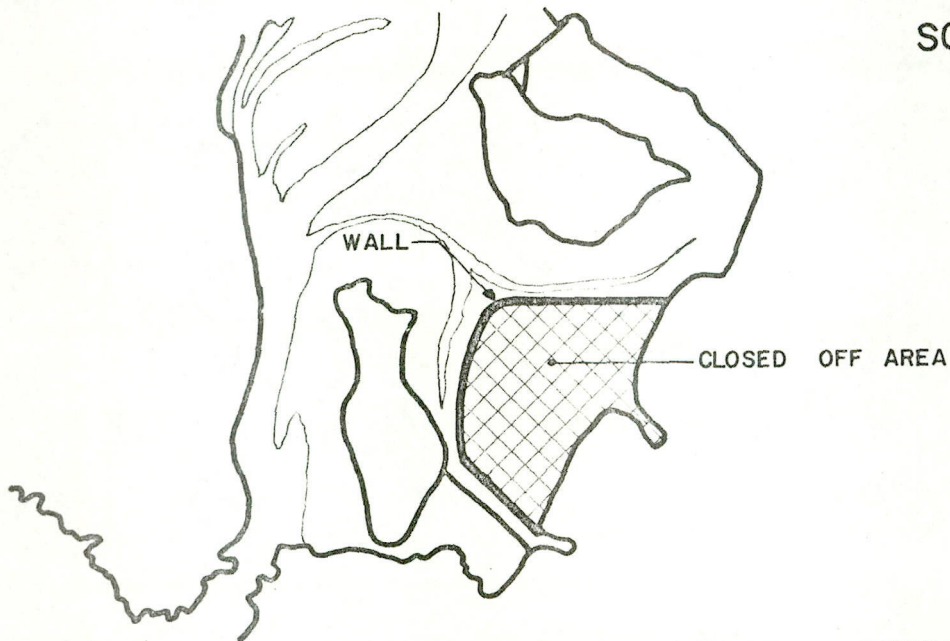
FIGURE

**SCHEME I**



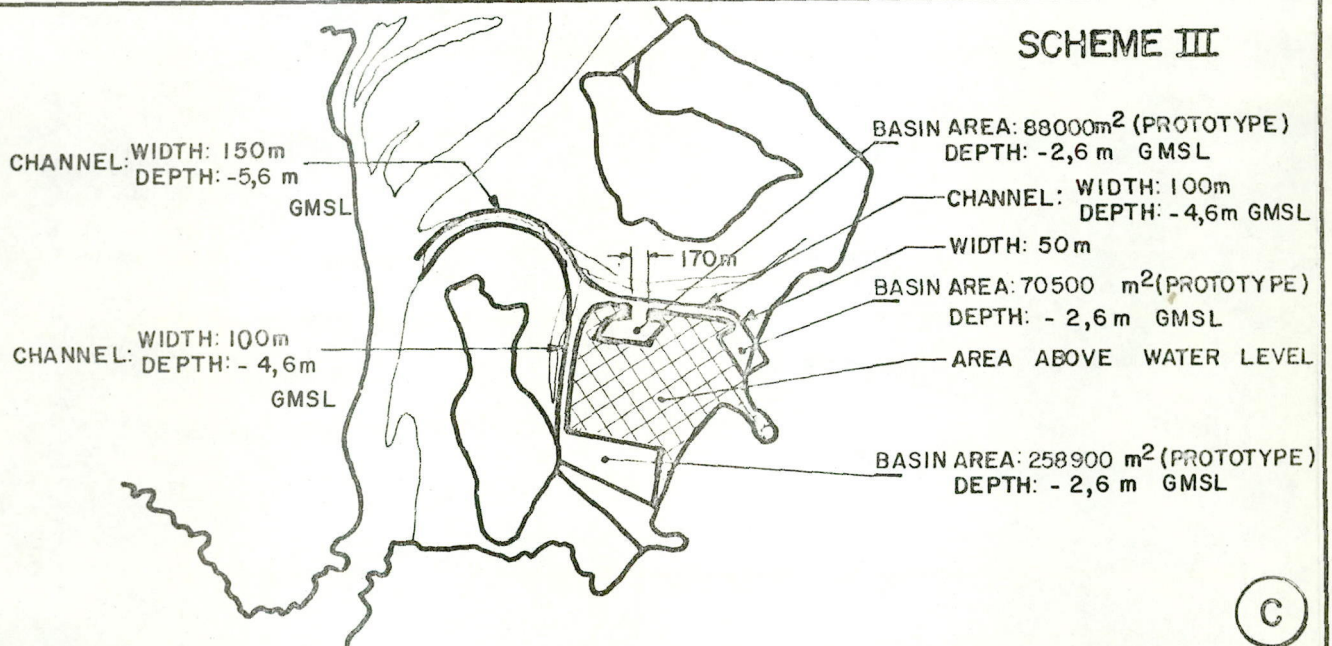
(A)

**SCHEME II**

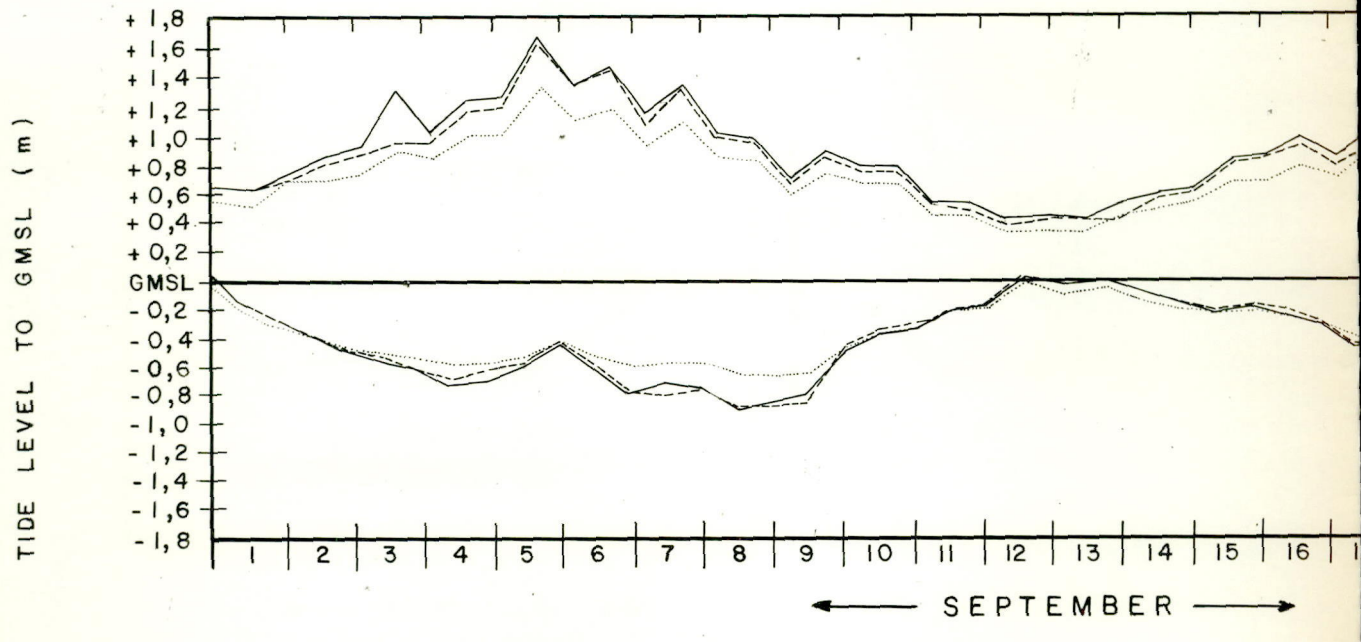
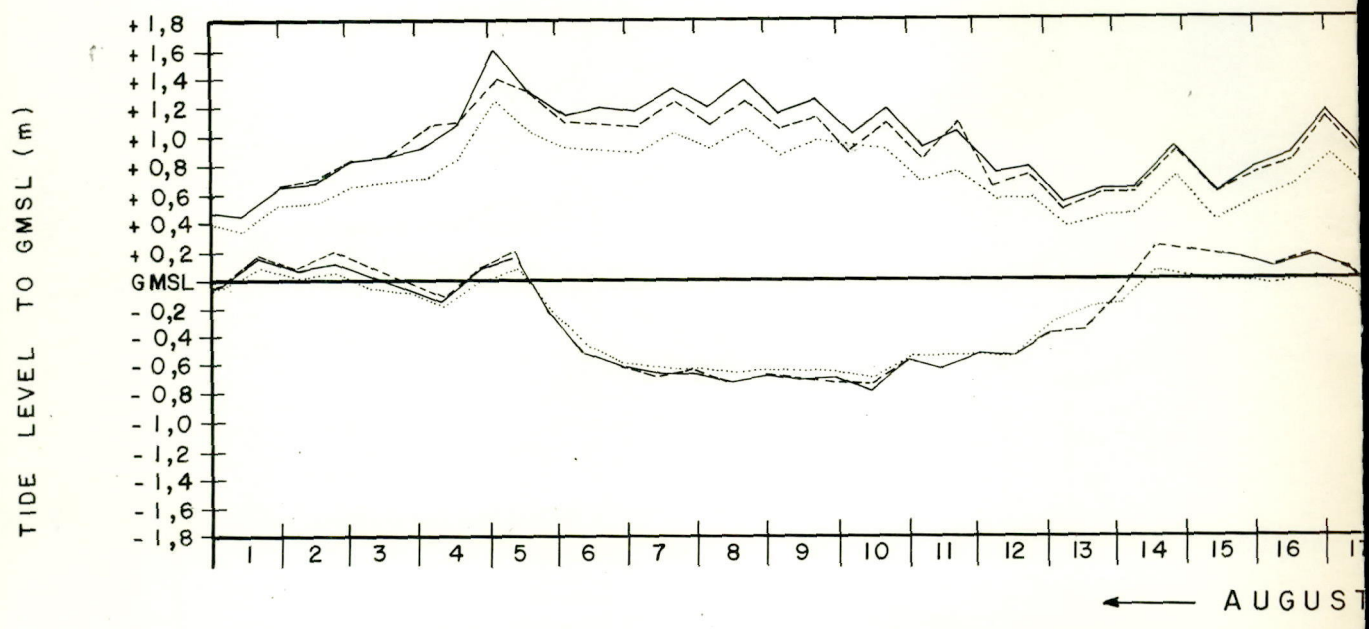
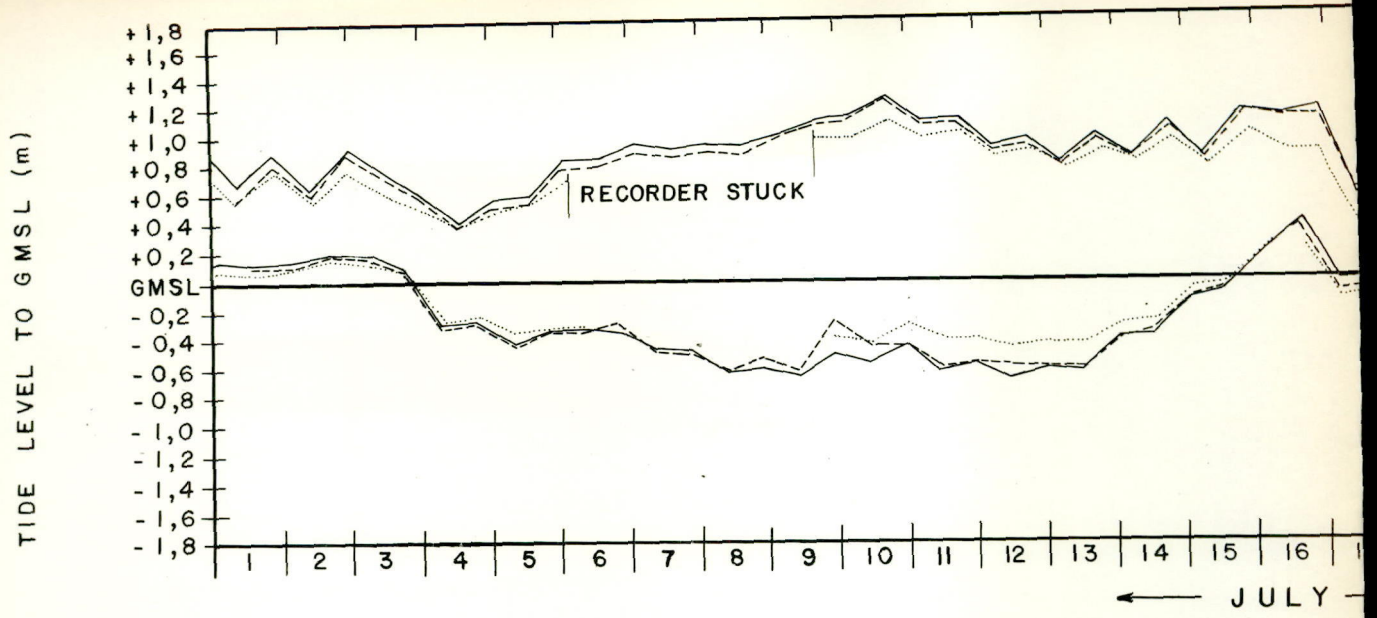


(B)

**SCHEME III**

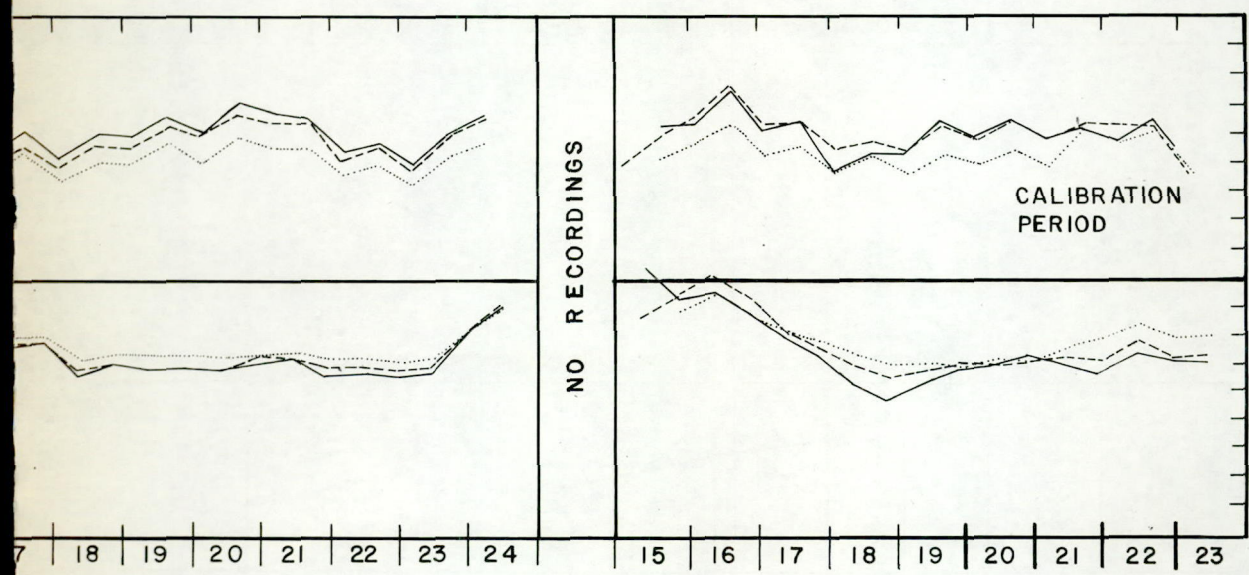
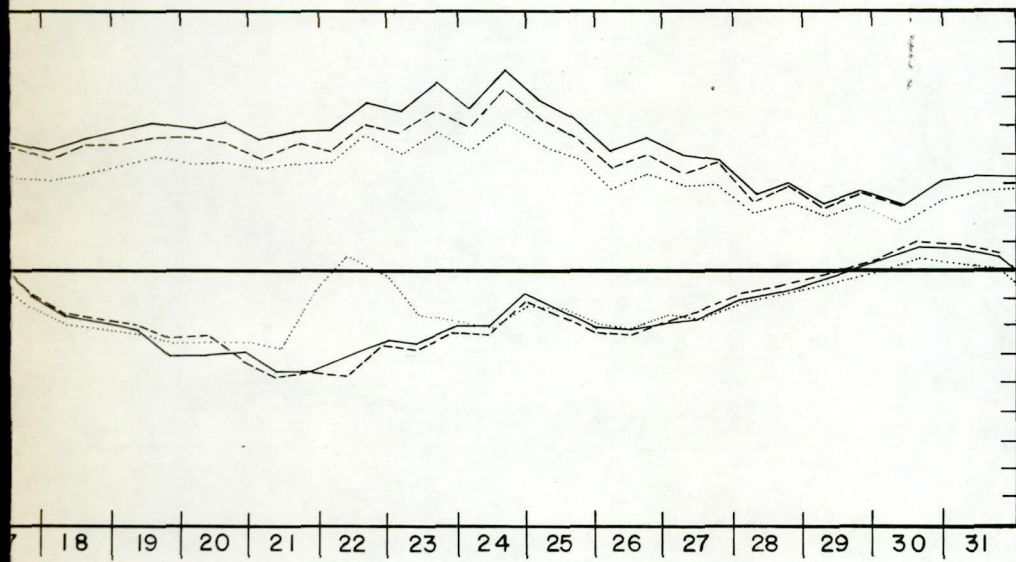
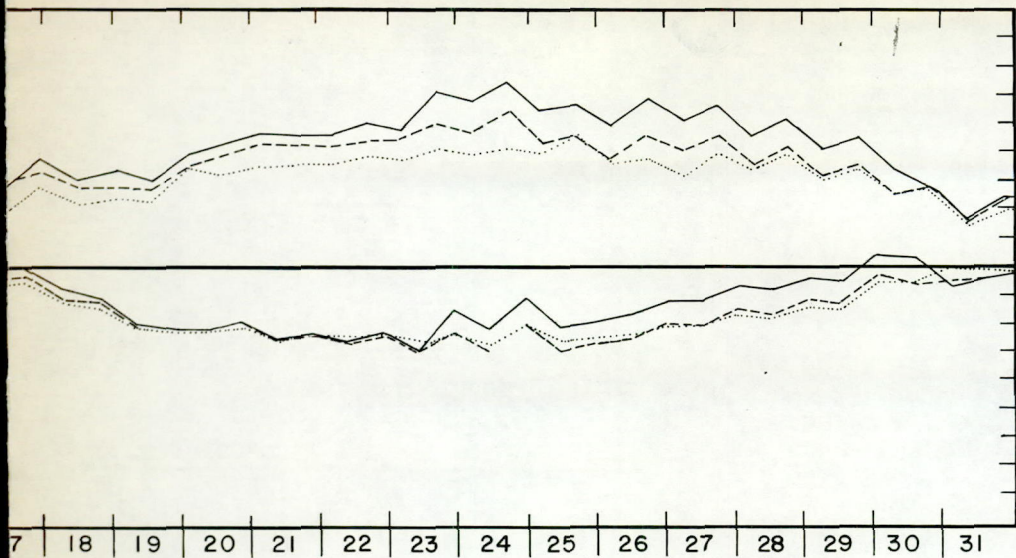


(C)



MAXIMUM AND MINIMUM VALUES OF  
RECORDED TIDE LEVELS, JULY to OCTOBER, 1971

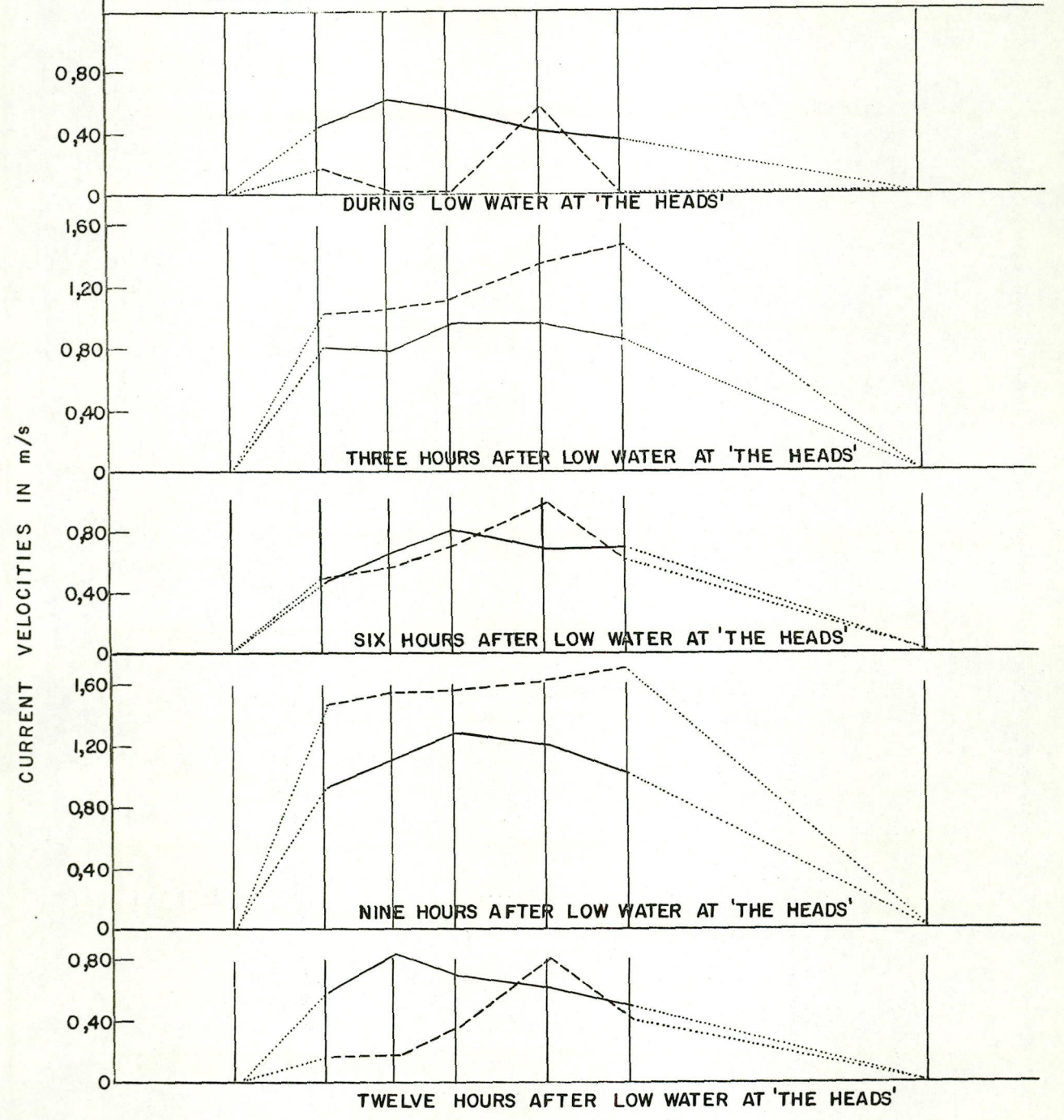
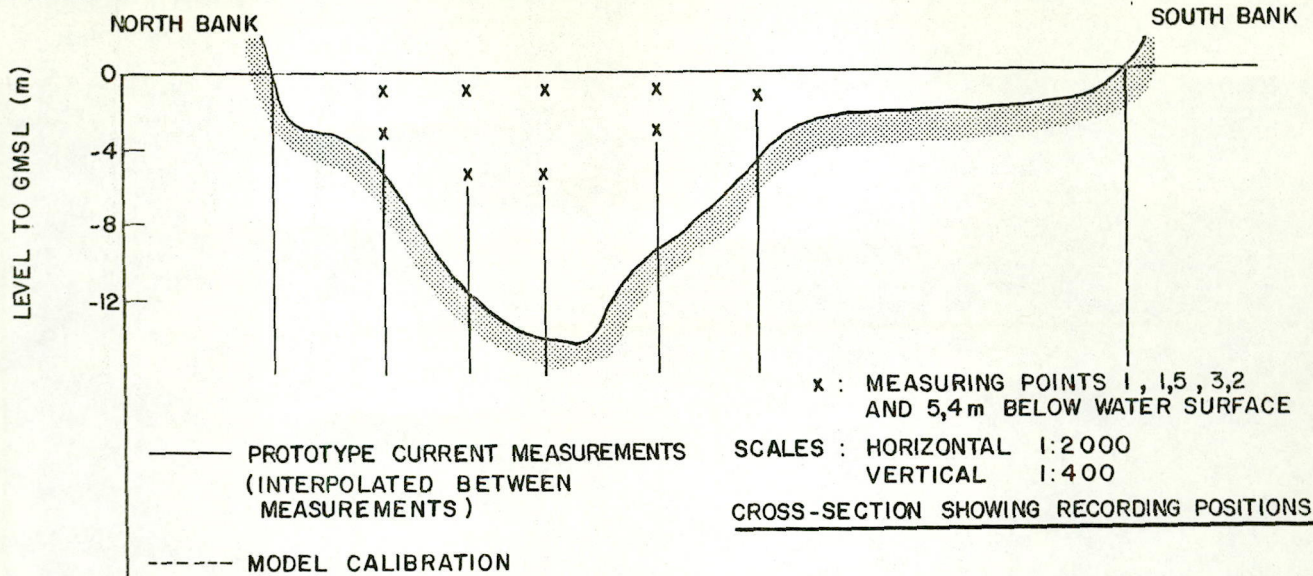
FIGURE  
5



← OCTOBER →

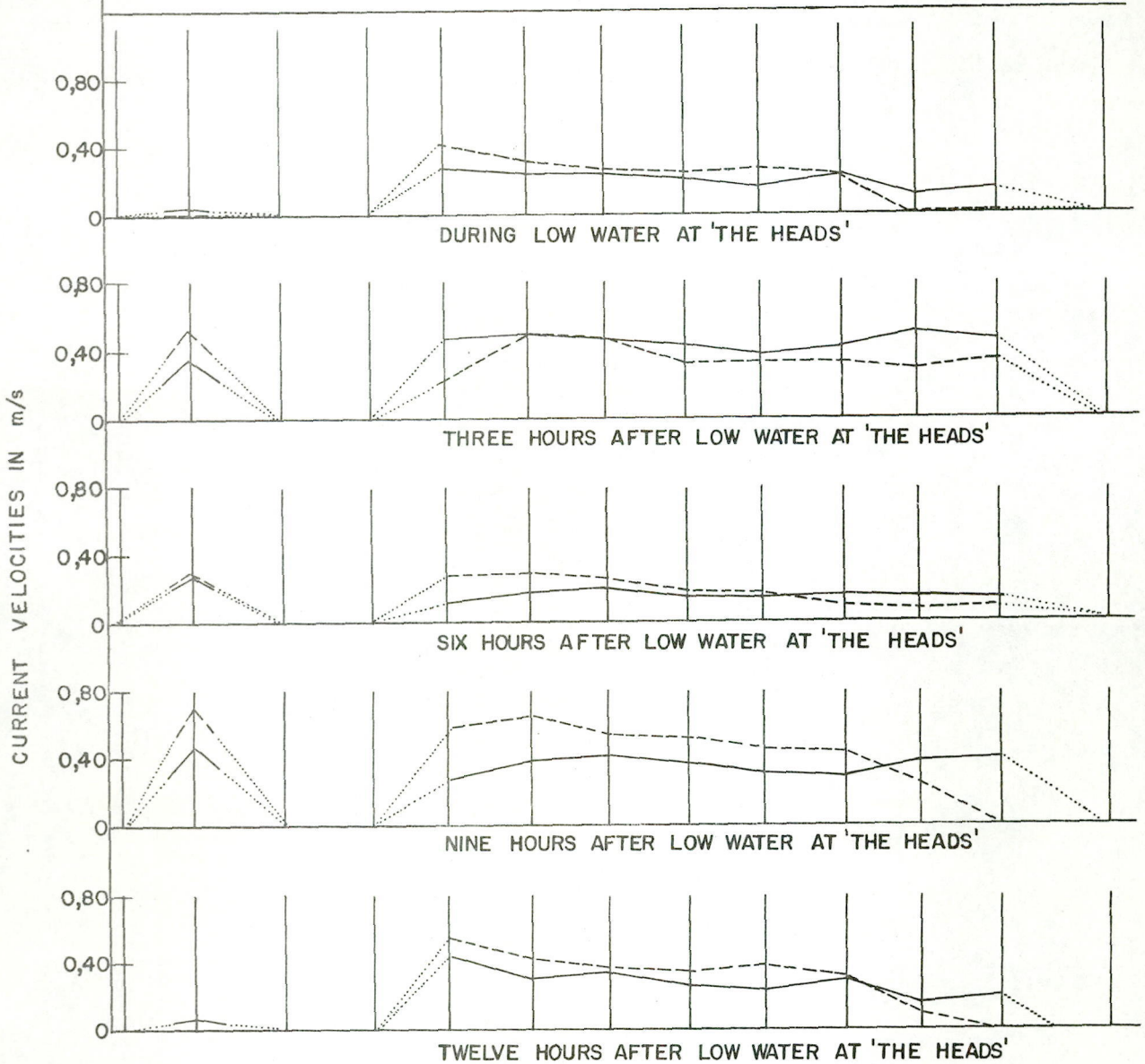
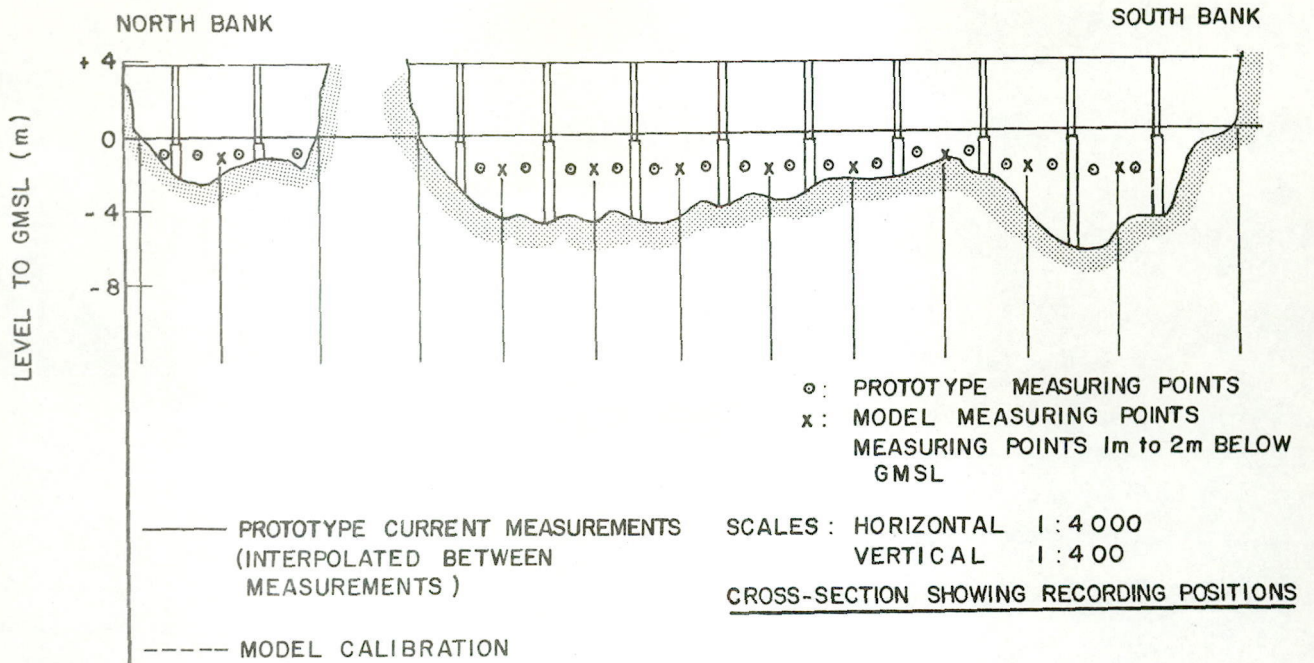
**LEGEND**

- TIDES AT THESEN'S ISLAND
- ..... TIDES AT RED BRIDGE
- - - TIDES AT 'THE HEADS'



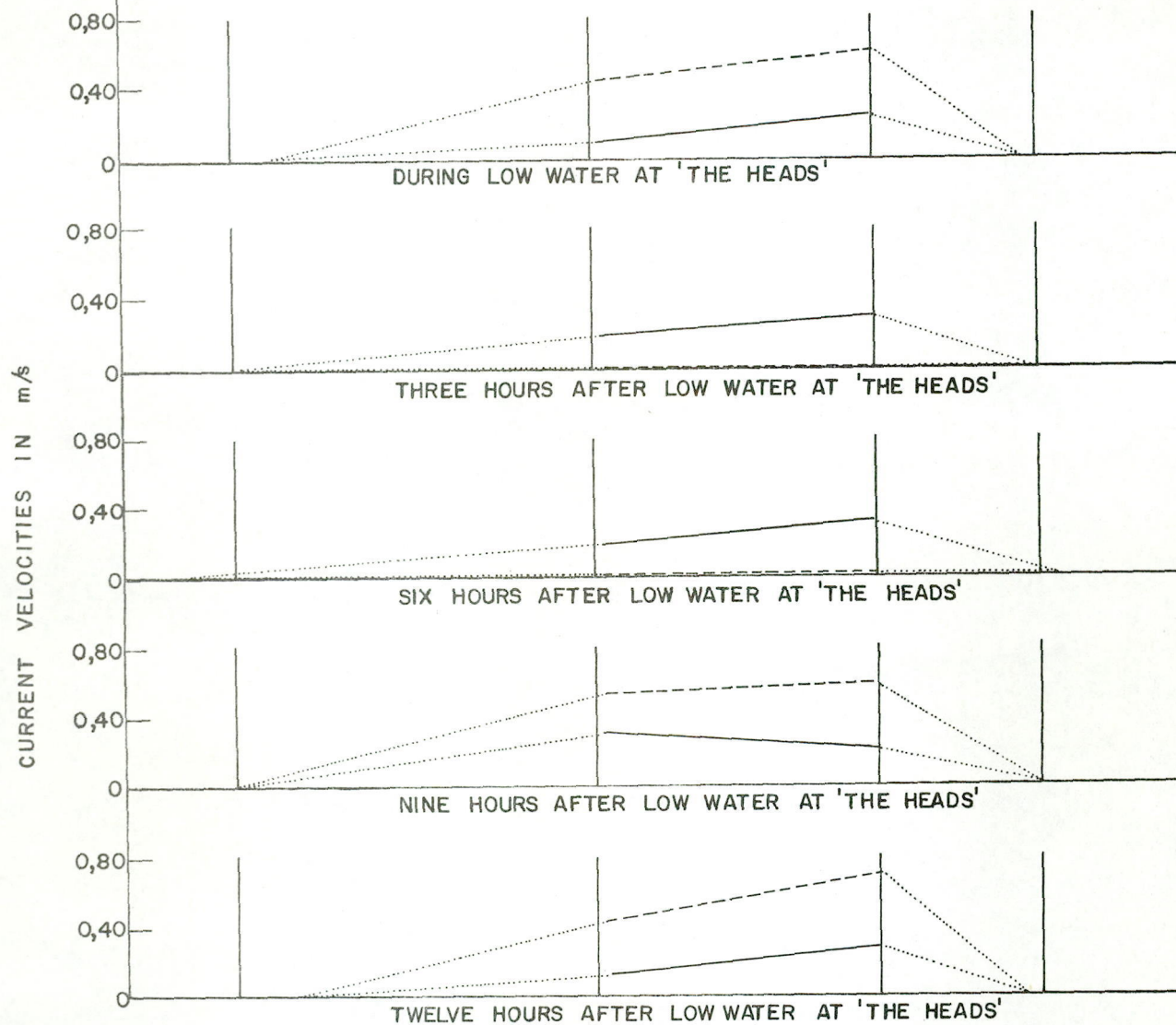
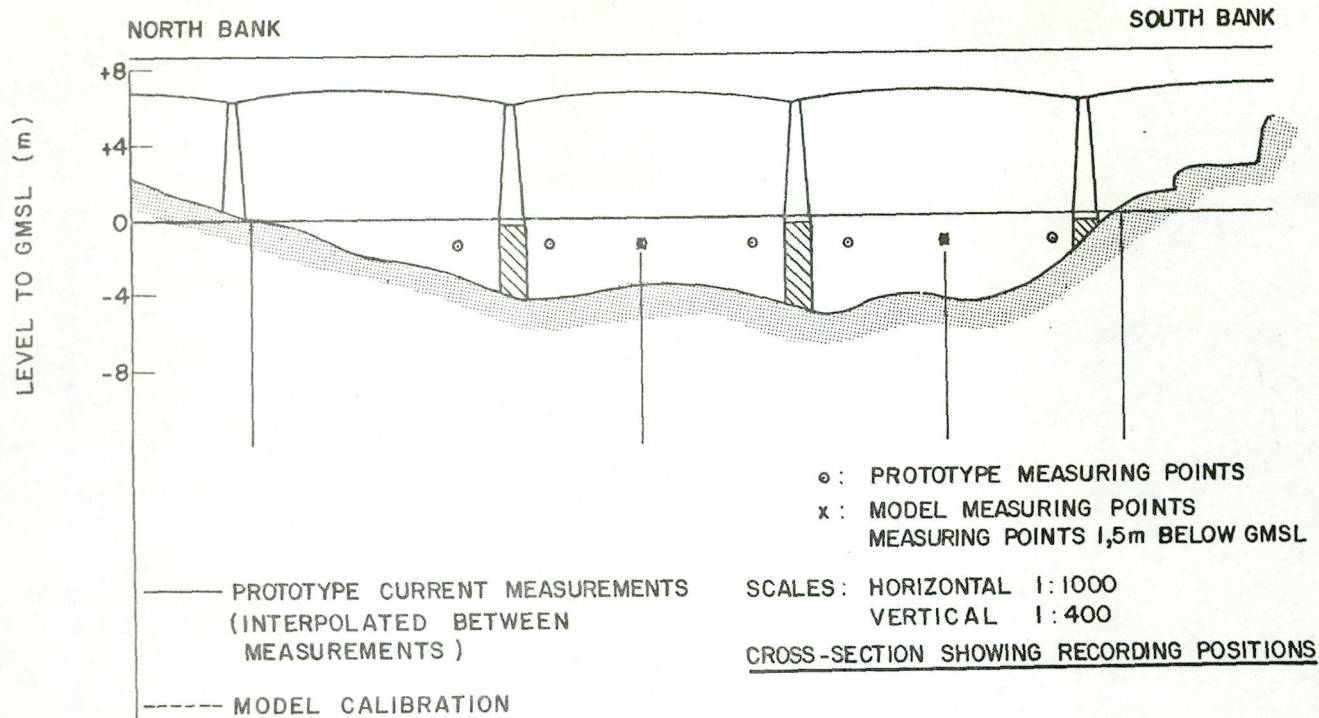
CURRENT MEASUREMENTS AT 'THE HEADS'

FIGURE



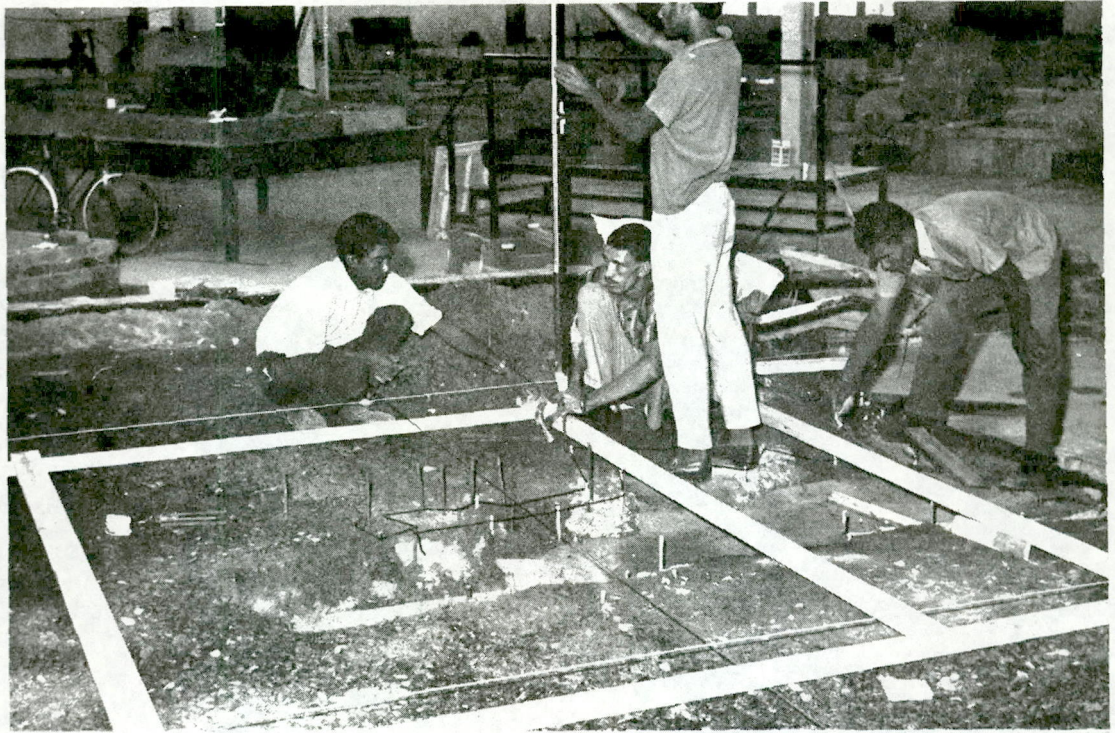
CURRENT MEASUREMENTS AT THE RAILWAY BRIDGE

FIGURE

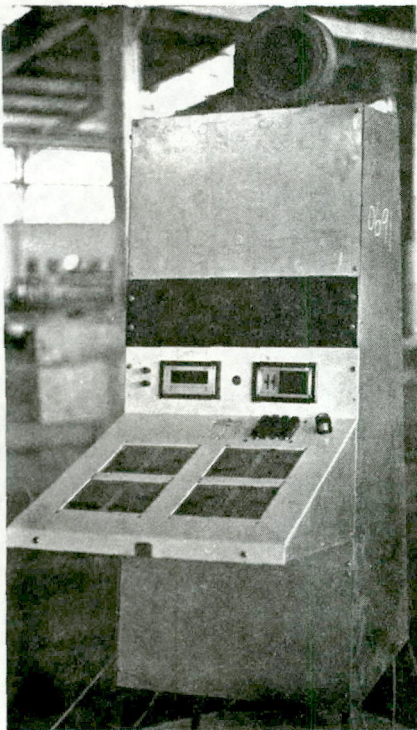


CURRENT MEASUREMENTS AT THE NATIONAL ROAD BRIDGE

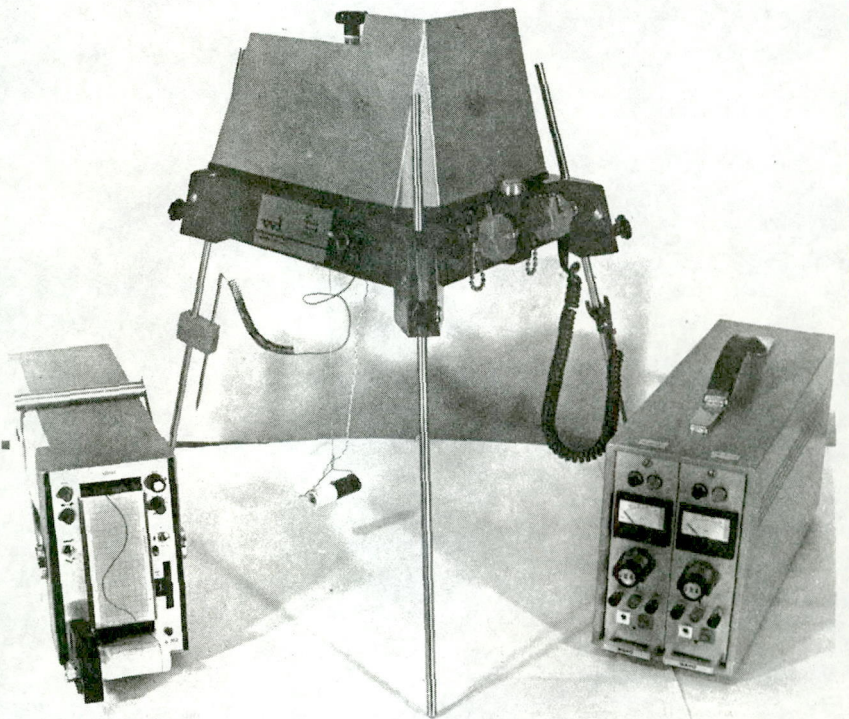
FIGURE



a CONSTRUCTION OF THE MODEL TOPOGRAPHY



b TIDAL GENERATING EQUIPMENT

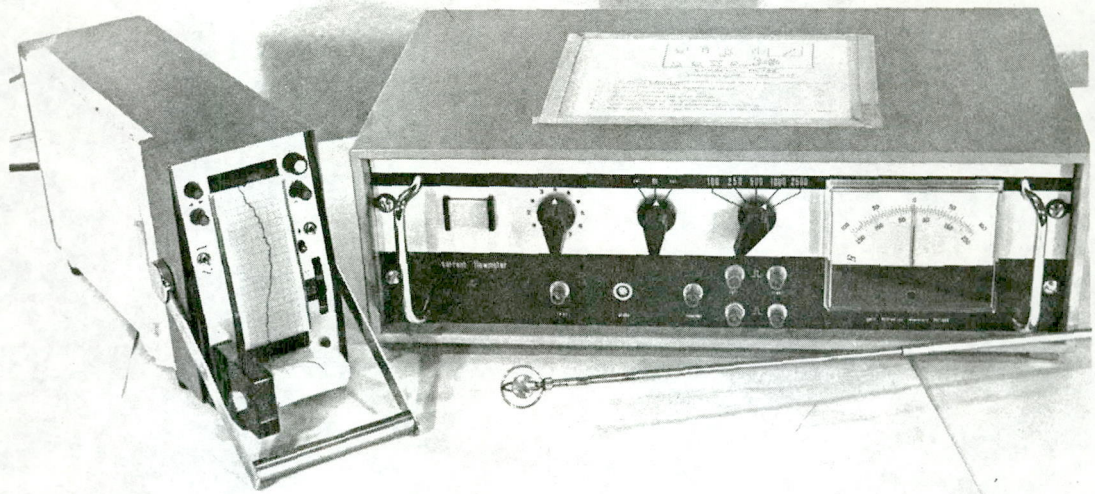


c WATER LEVEL FOLLOWER AND RECORDER

MODEL CONSTRUCTION AND TIDE EQUIPMENT

FIGURE

9



a PROPELLER CURRENT METER AND RECORDER



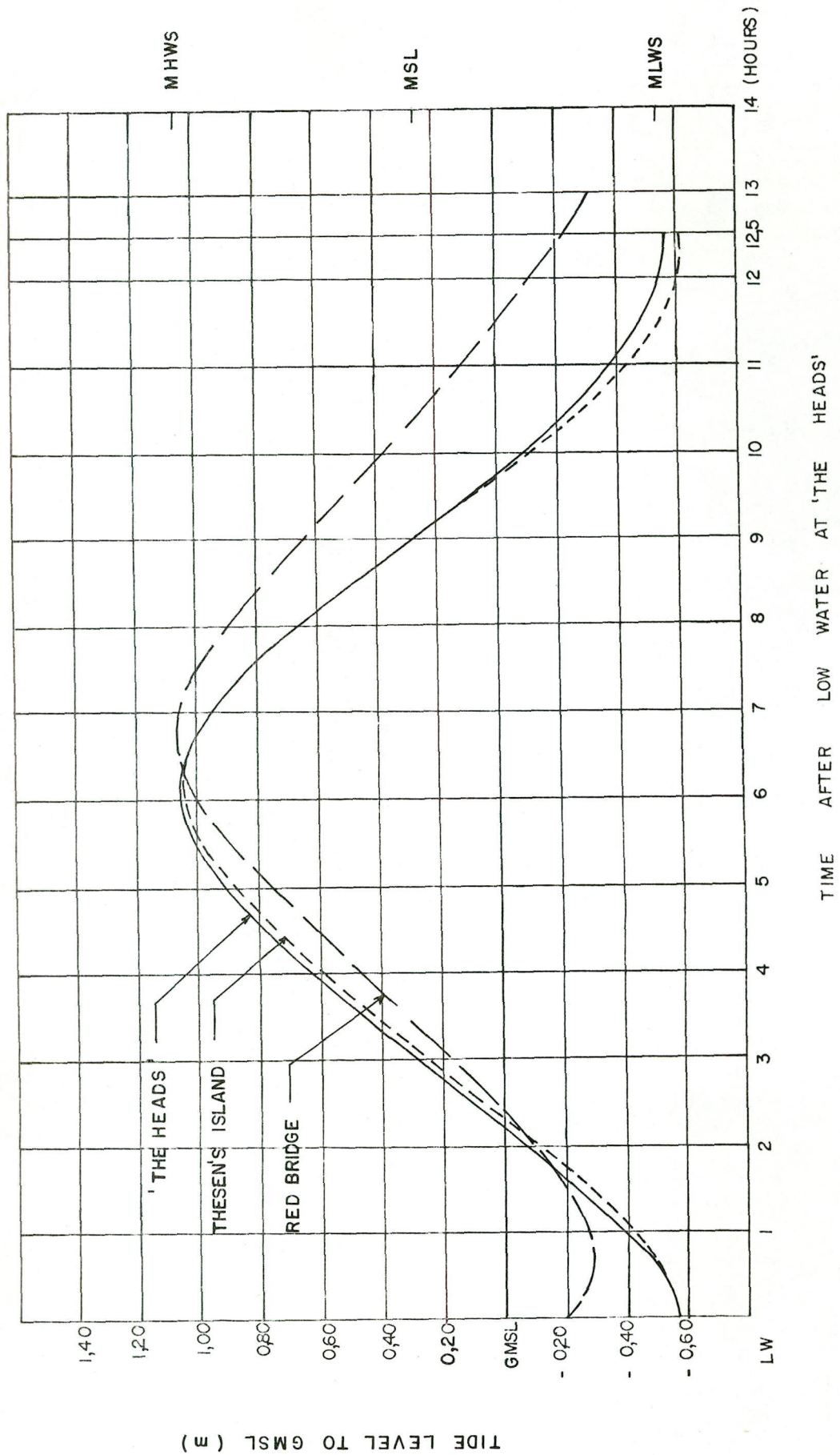
b ARTIFICIAL ROUGHNESS ELEMENTS IN THE MODEL

PROPELLER CURRENT METER AND ARTIFICIAL  
ROUGHNESS

FIGURE

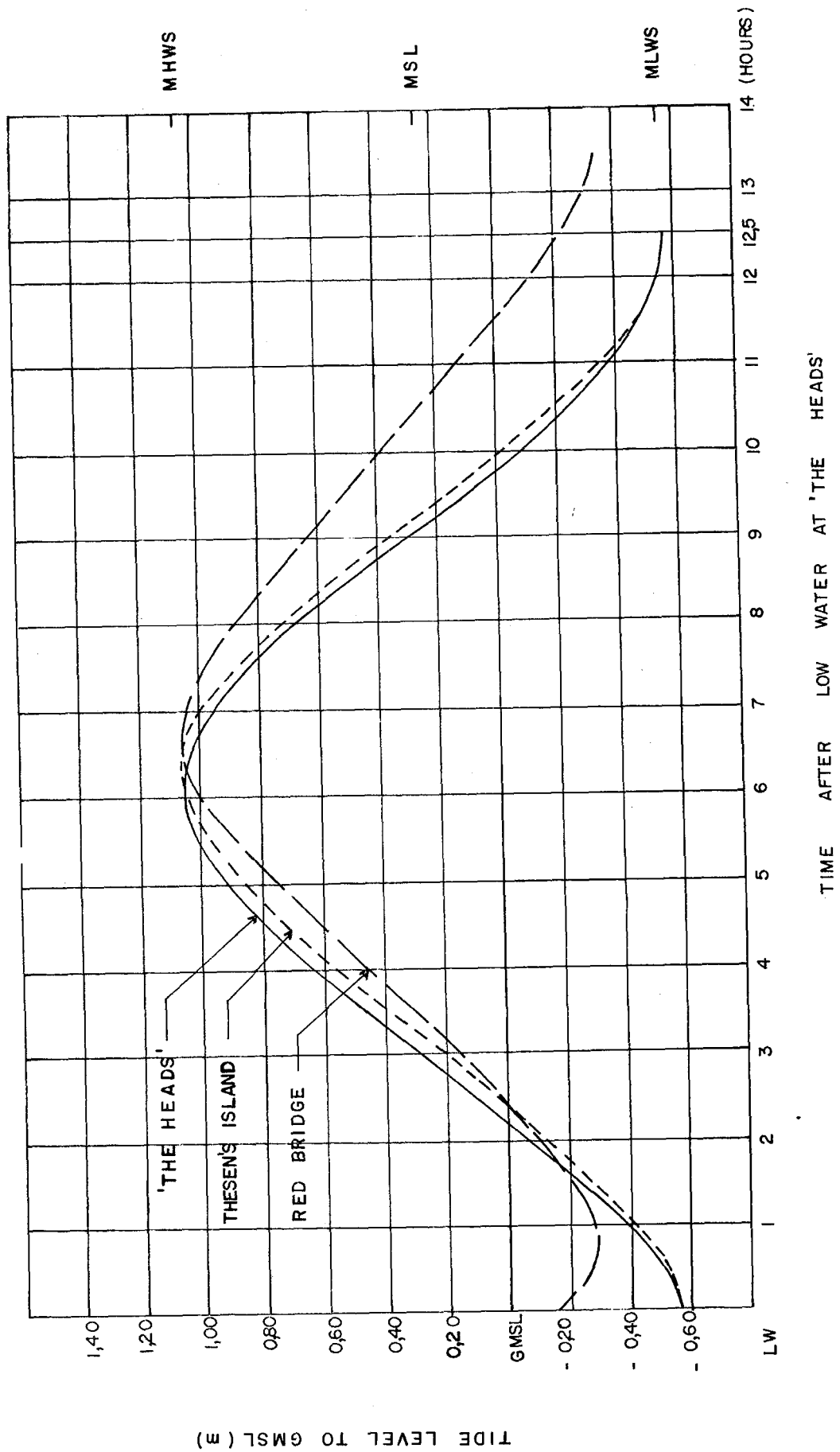
10

NOTE: GEODETIC MEAN SEA LEVEL (GMSL) IS 0,257m BELOW  
MEAN SEA LEVEL (MSL - 1966/73) AT KNYSNA



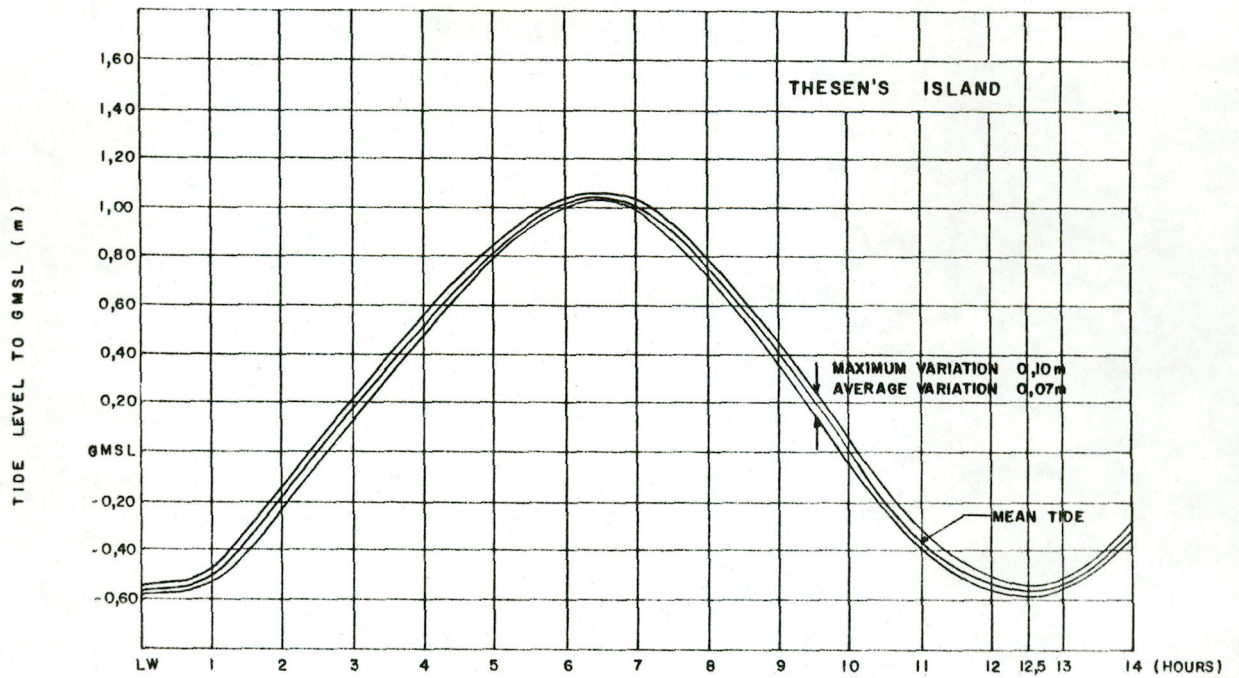
PROTOTYPE TIDES BASED ON RECORDINGS FROM  
THE 20<sup>th</sup> TO 22<sup>nd</sup> OCTOBER, 1971

FIGURE

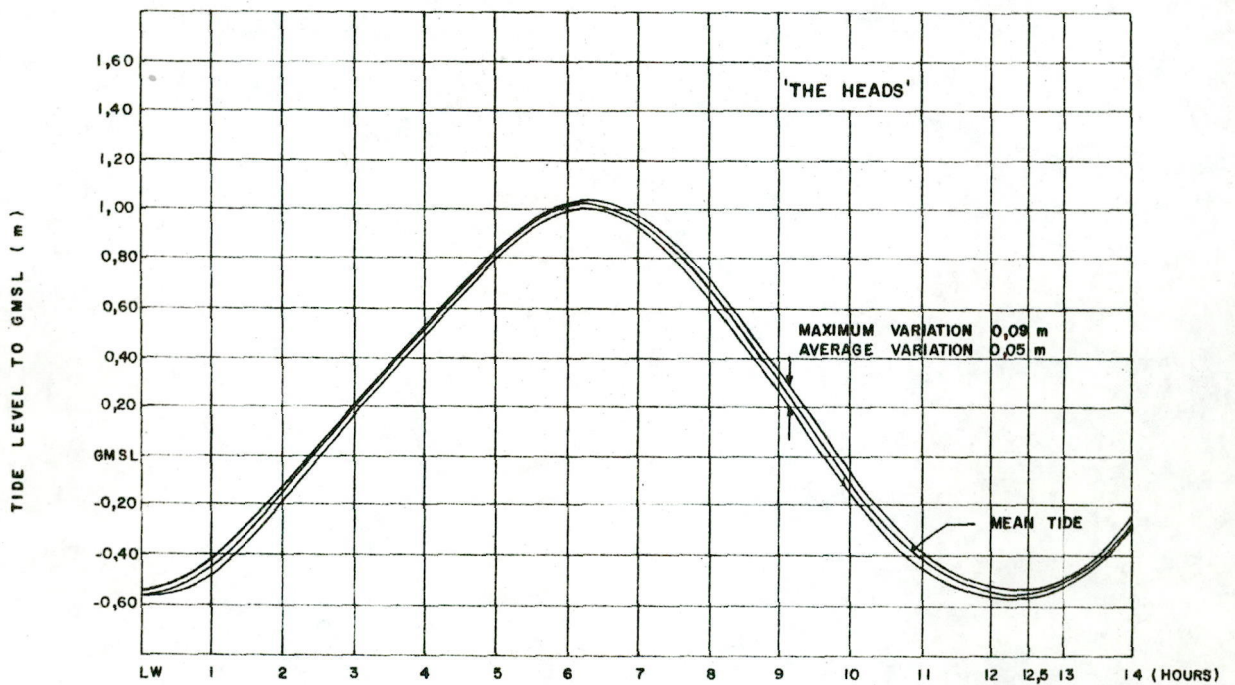


AMENDED PROTOTYPE TIDAL CURVES  
USED FOR CALIBRATION

FIGURE  
12



TIME AFTER LOW WATER AT 'THE HEADS'

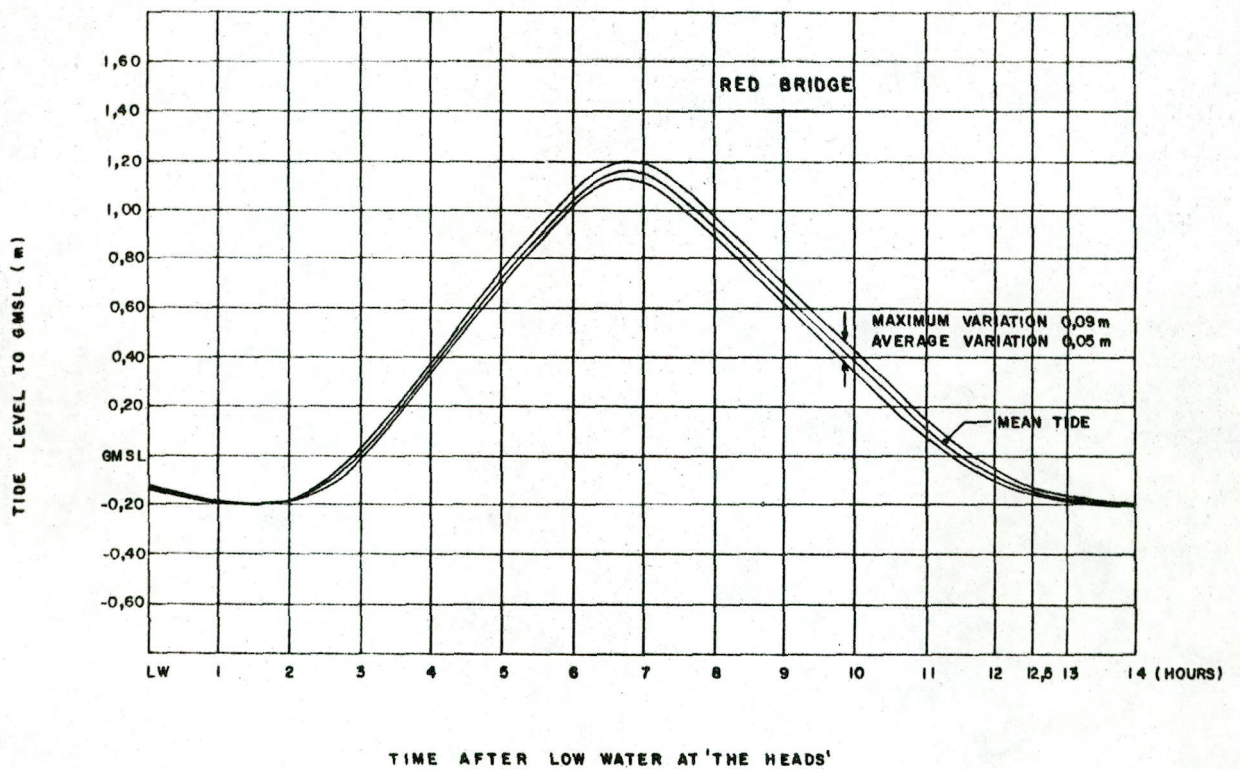
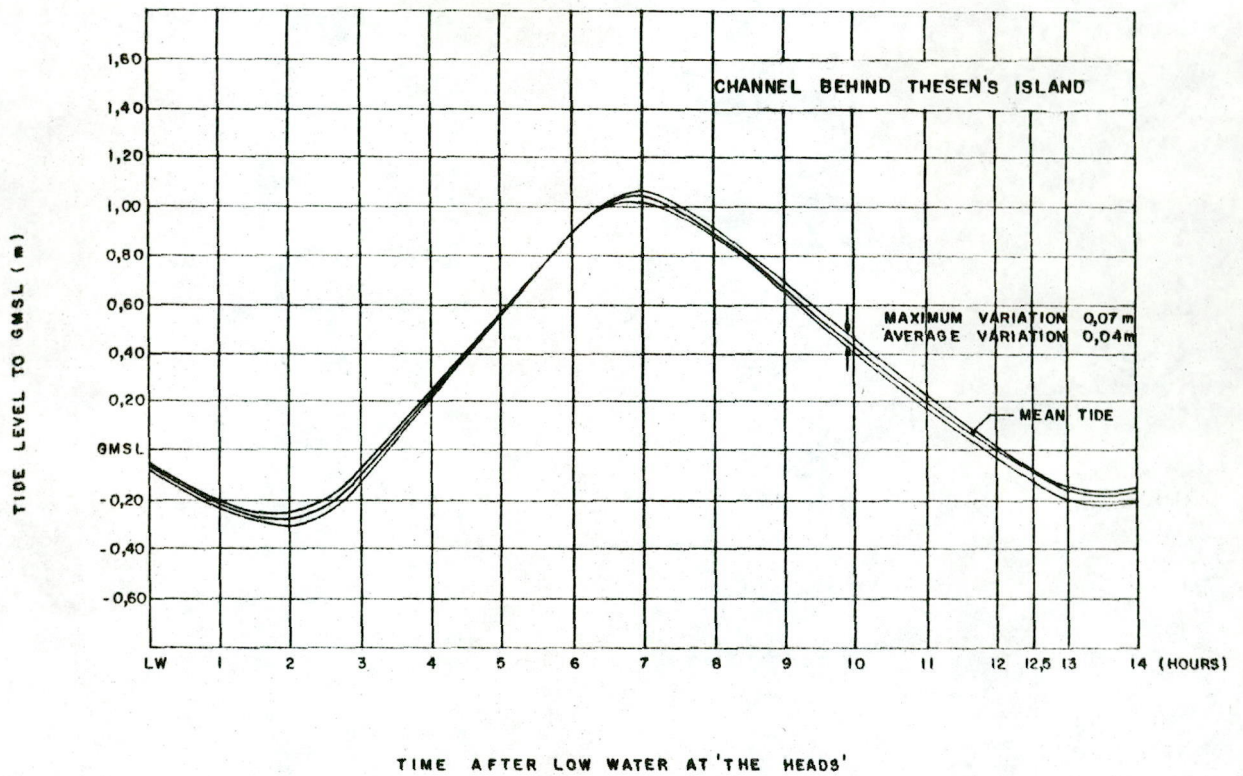


TIME AFTER LOW WATER AT 'THE HEADS'

MEAN AND EXTREME MODEL TIDAL LEVELS AT THESEEN'S ISLAND AND 'THE HEADS' FOR EXISTING LAYOUT

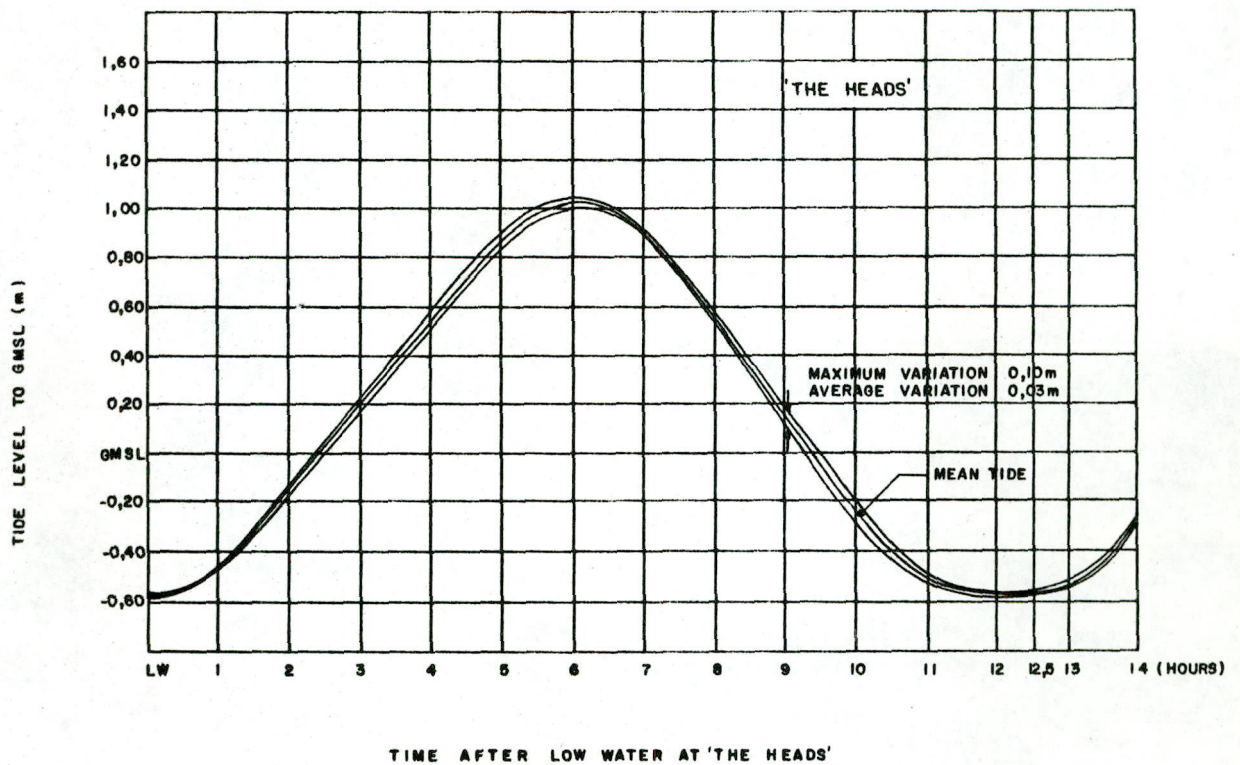
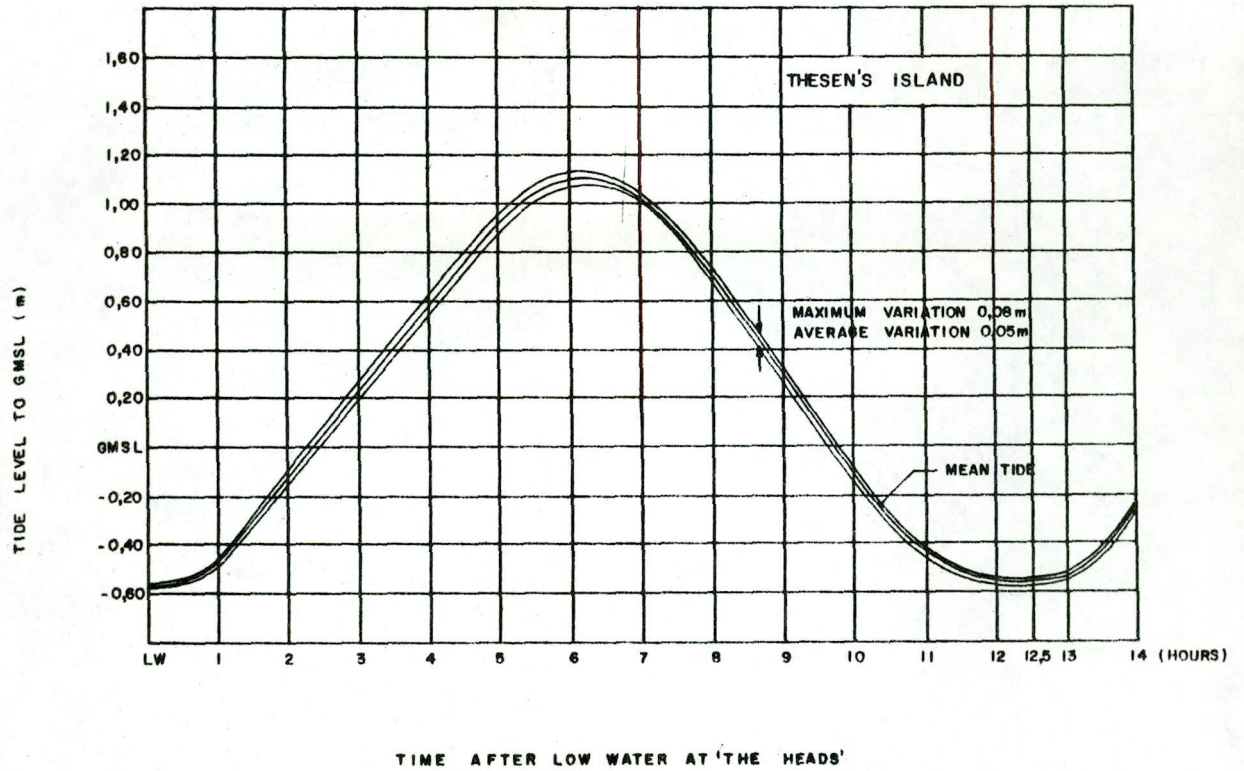
FIGURE

13.a



MEAN AND EXTREME MODEL TIDAL LEVELS AT THE CHANNEL BEHIND THESEN'S ISLAND AND RED BRIDGE FOR EXISTING LAYOUT

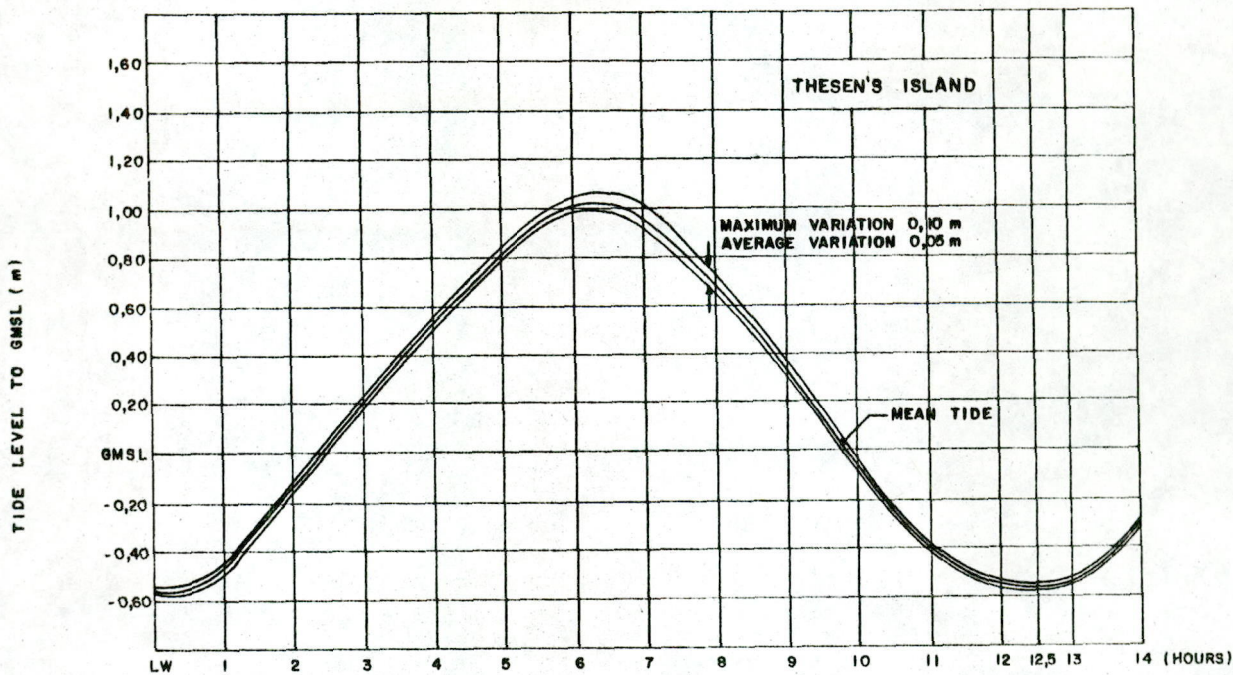
FIGURE 13.b



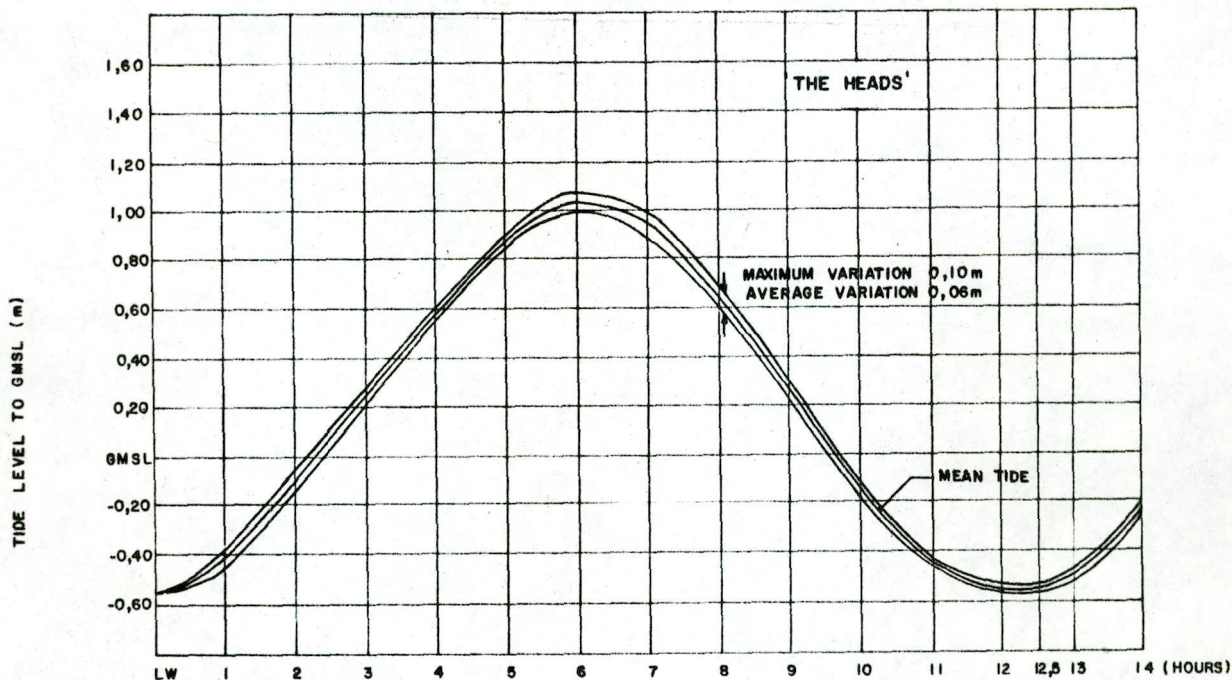
MEAN AND EXTREME MODEL TIDAL LEVELS AT THESEEN'S ISLAND AND 'THE HEADS' FOR SCHEME I

FIGURE

14



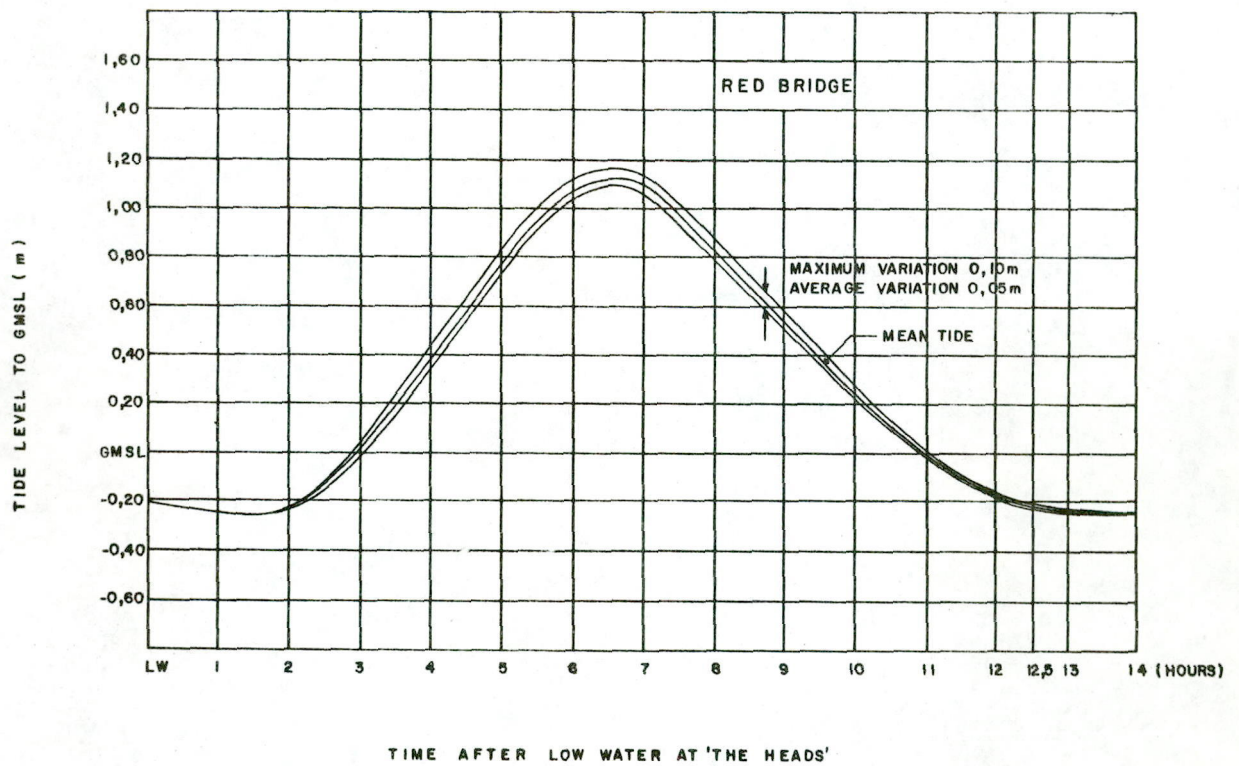
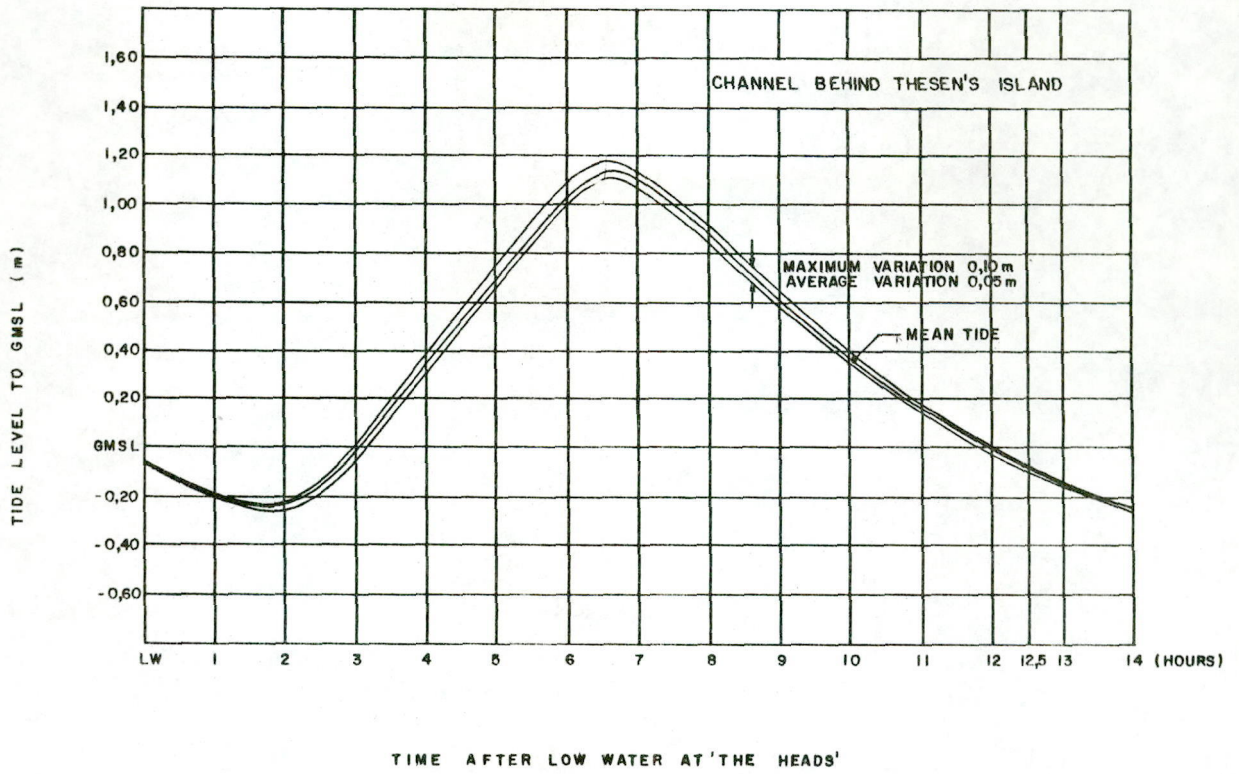
TIME AFTER LOW WATER AT 'THE HEADS'



TIME AFTER LOW WATER AT 'THE HEADS'

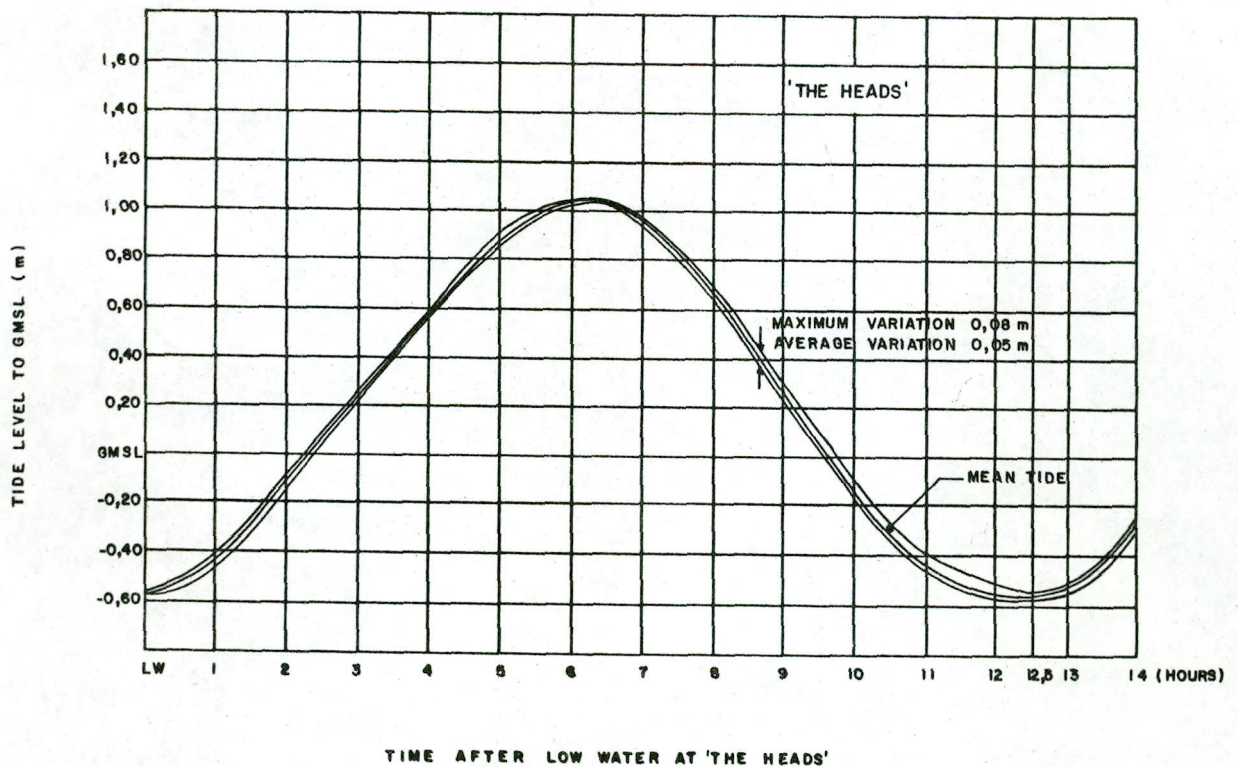
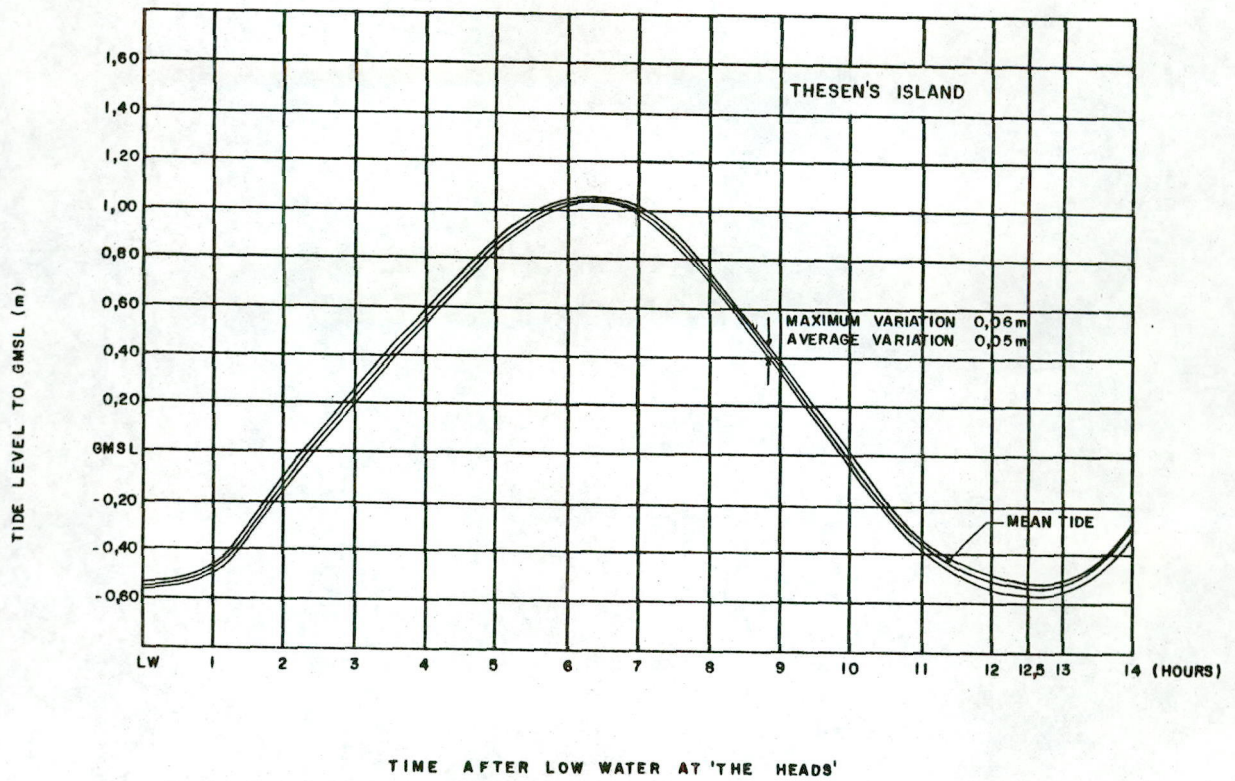
MEAN AND EXTREME MODEL TIDAL LEVELS AT THESEN'S ISLAND AND 'THE HEADS' FOR SCHEME II

FIGURE  
15.a



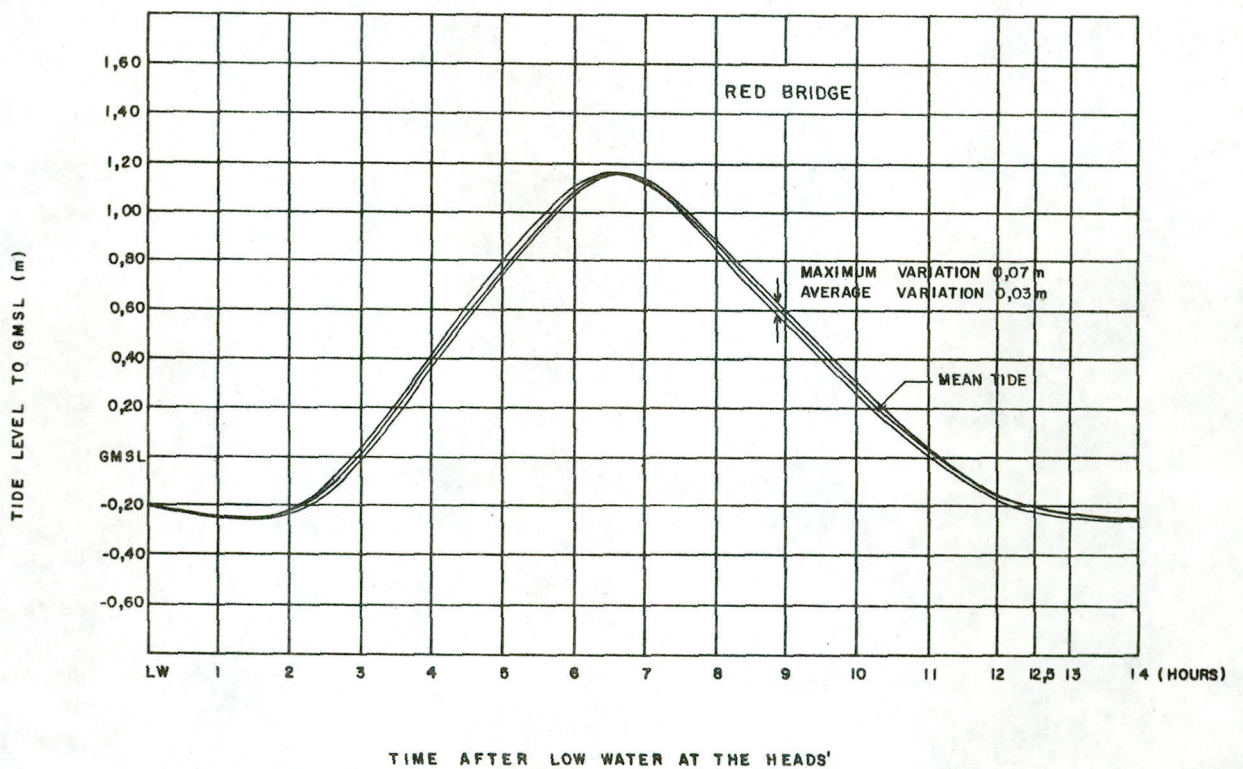
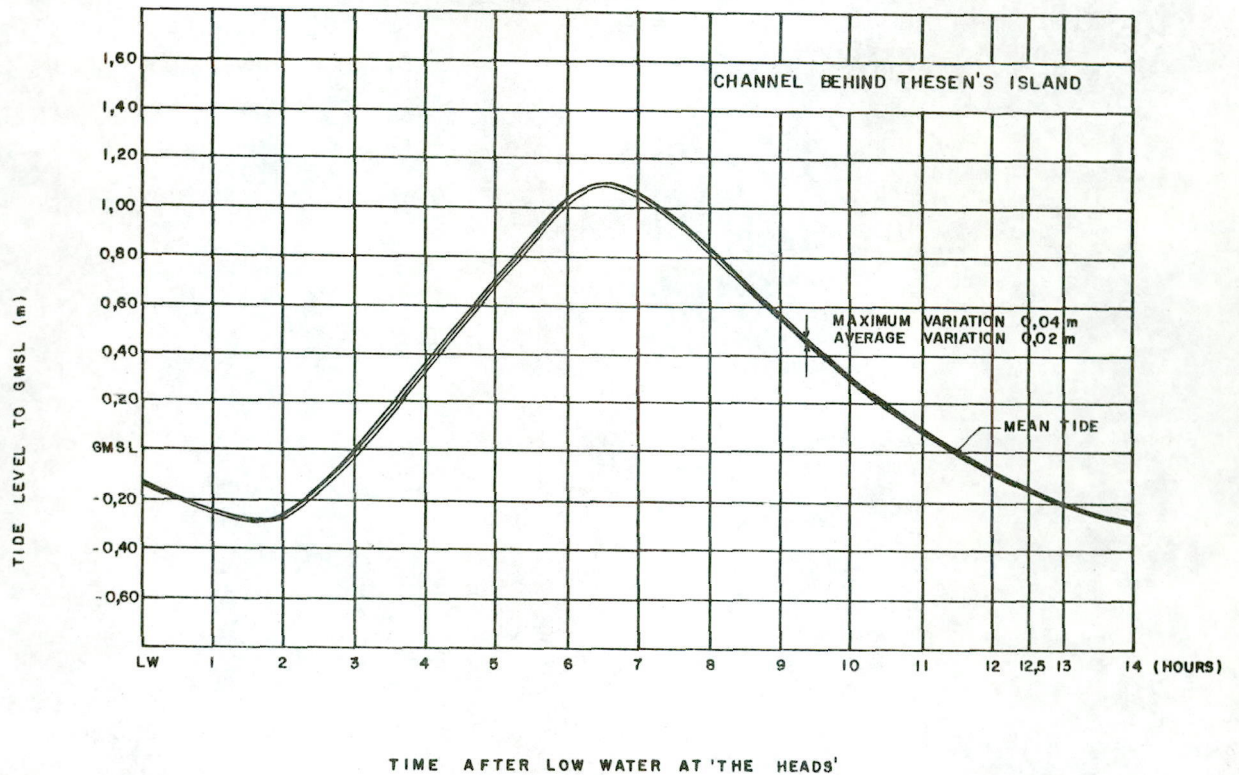
MEAN AND EXTREME MODEL TIDAL LEVELS AT THE CHANNEL BEHIND THESEN'S ISLAND AND RED BRIDGE FOR SCHEME II

FIGURE 15.b



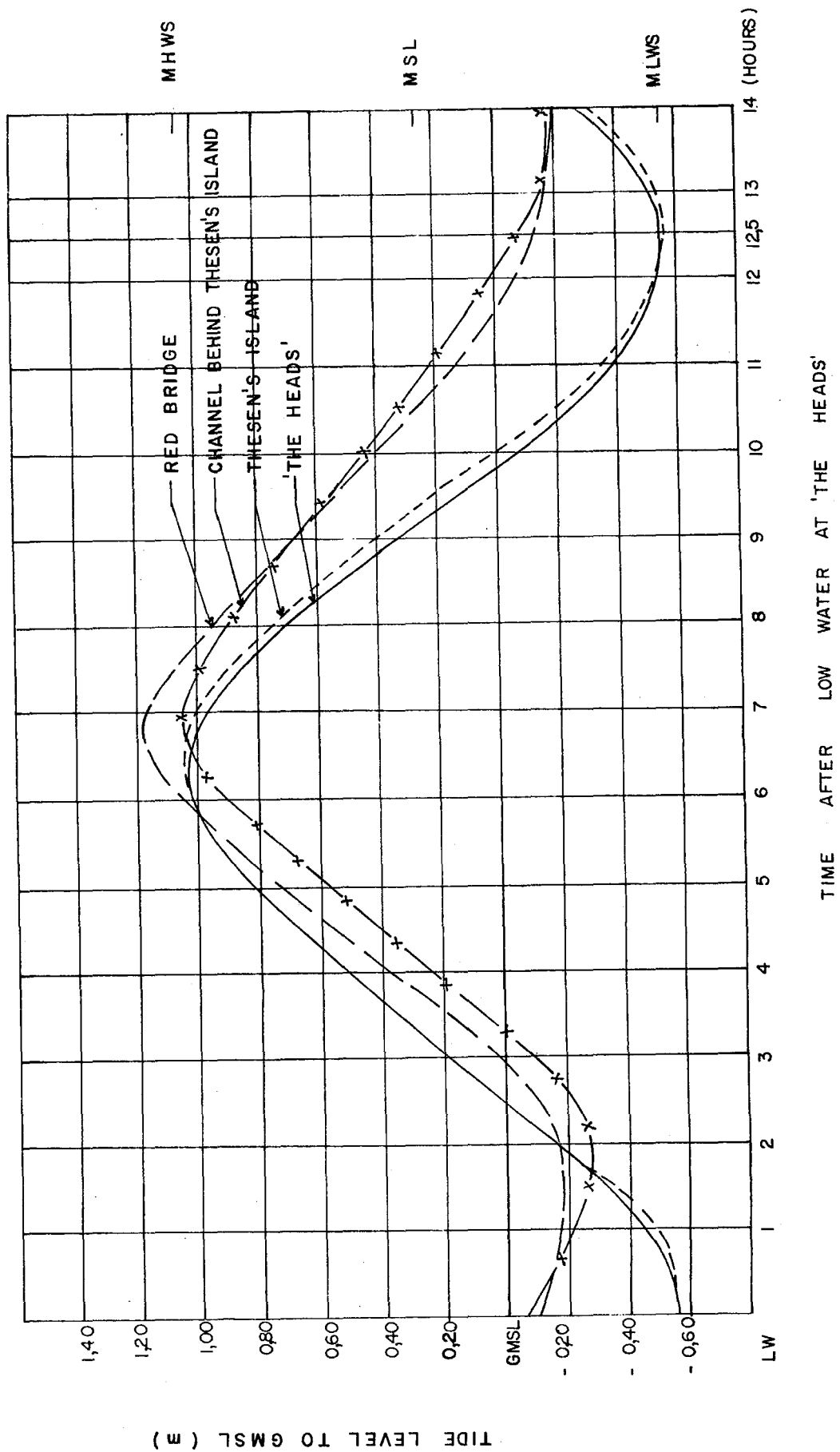
MEAN AND EXTREME MODEL TIDAL LEVELS AT THESEEN'S ISLAND AND 'THE HEADS' FOR SCHEME III

FIGURE  
16.a



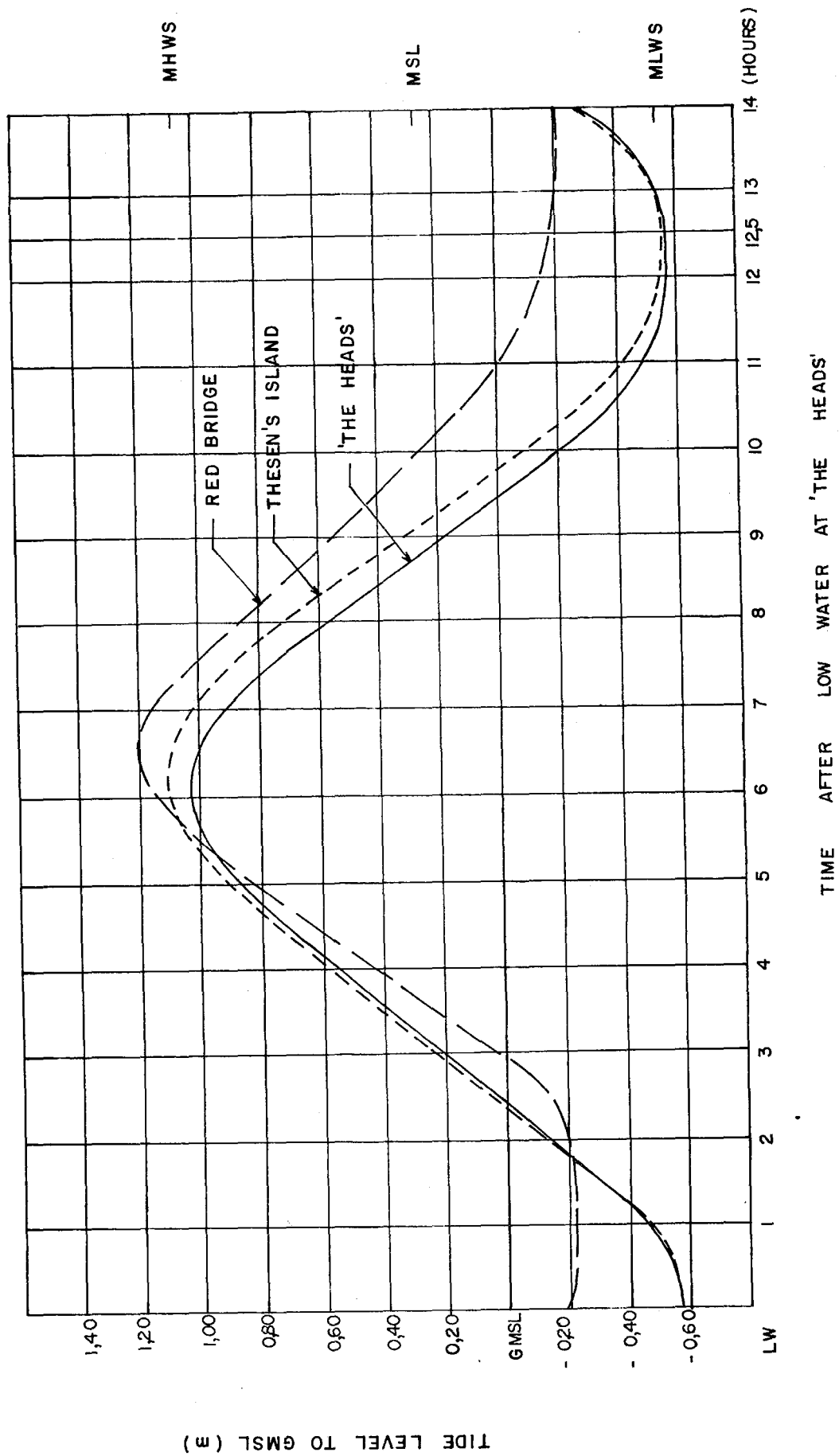
MEAN AND EXTREME MODEL TIDAL LEVELS AT THE CHANNEL BEHIND THESEEN'S ISLAND AND RED BRIDGE FOR SCHEME III

FIGURE  
16.b



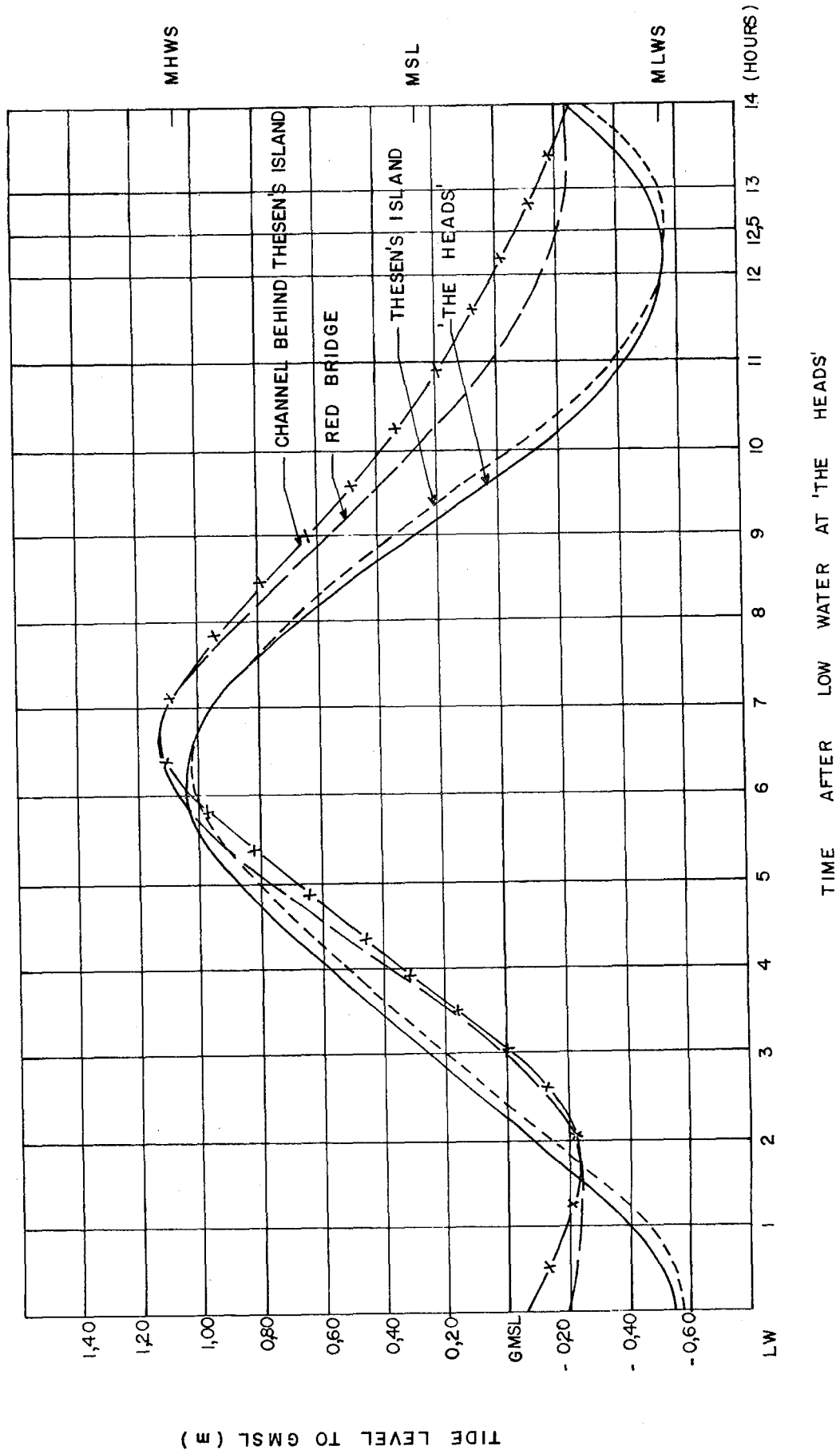
MEAN TIDAL LEVELS FOR EXISTING LAYOUT

FIGURE



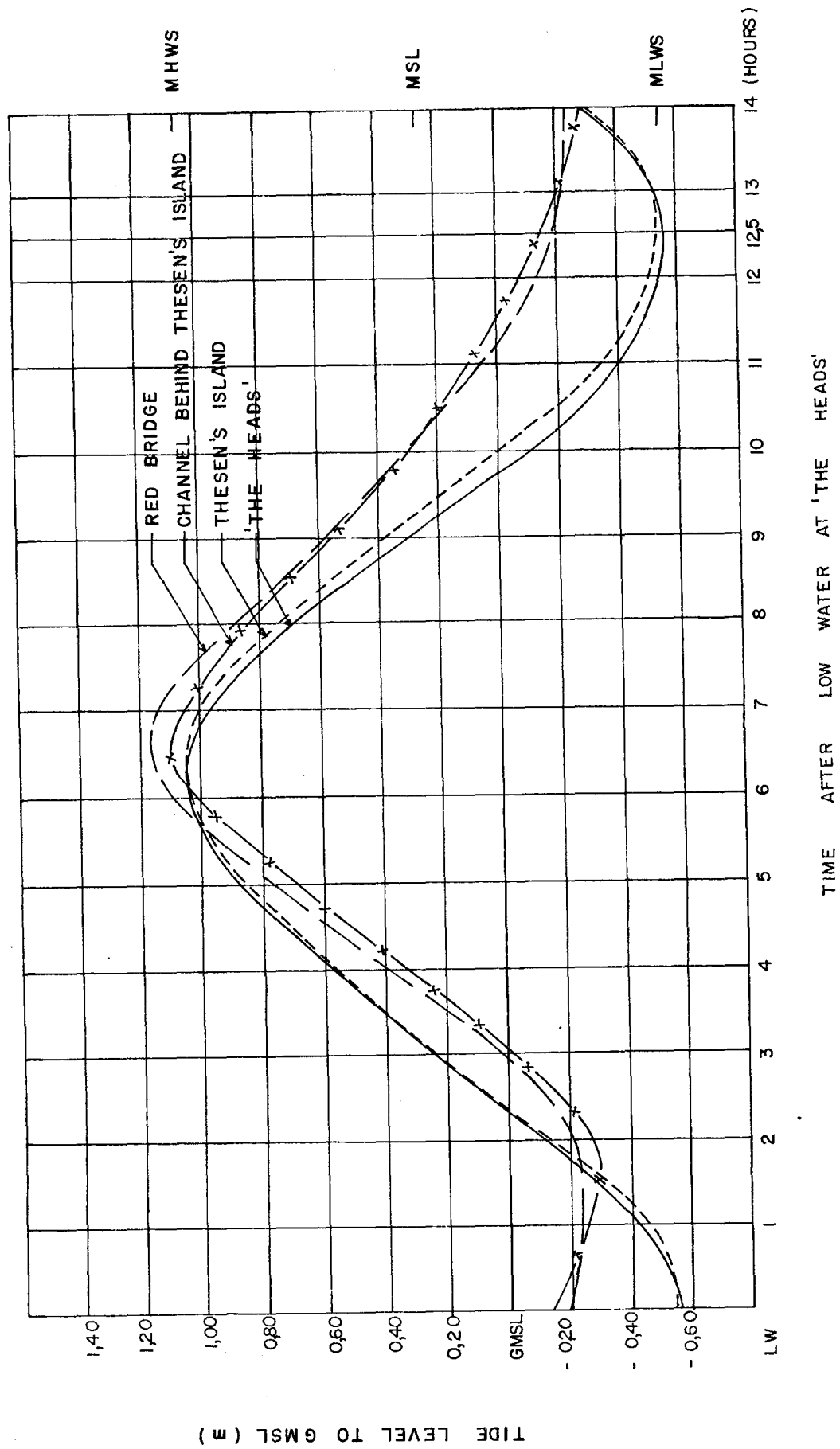
MEAN TIDAL LEVELS FOR SCHEME I

FIGURE



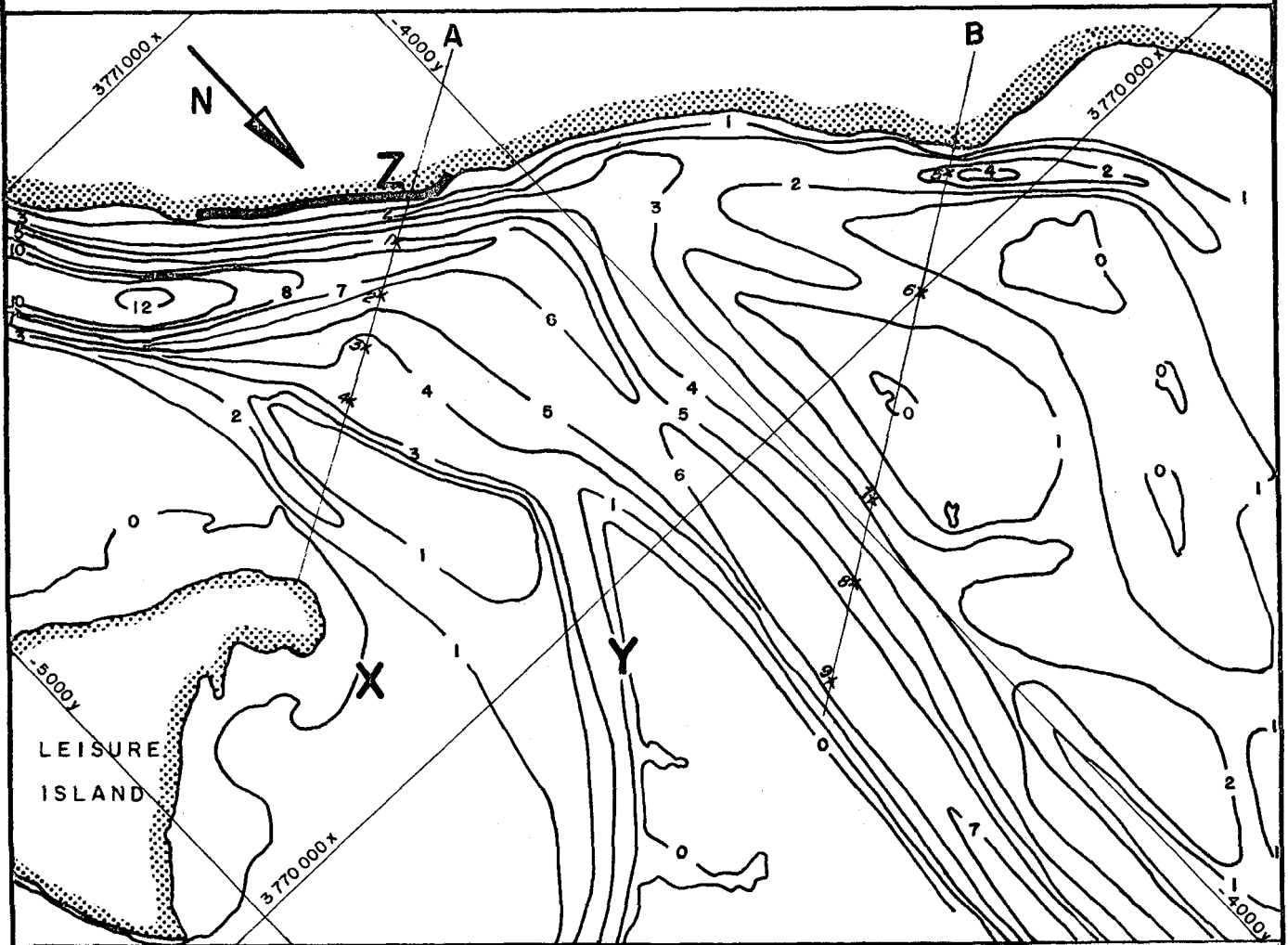
MEAN TIDAL LEVELS FOR SCHEME II

FIGURE



MEAN TIDAL LEVELS FOR SCHEME III

FIGURE



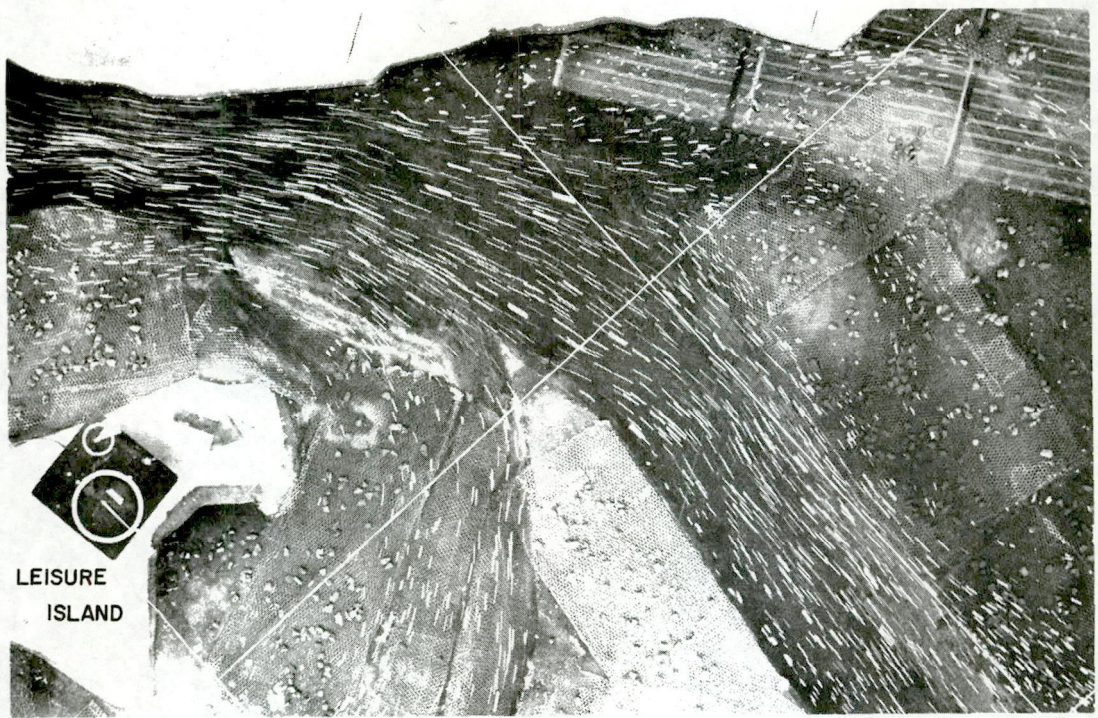
Lo 23° CO-ORDINATE SYSTEM  
 CONTOURS IN METRES BELOW GMSL

SCALE: 1:10000

CONTOUR PLAN OF AREA COVERED BY DETAILED FLOW MEASUREMENTS

FIGURE

21

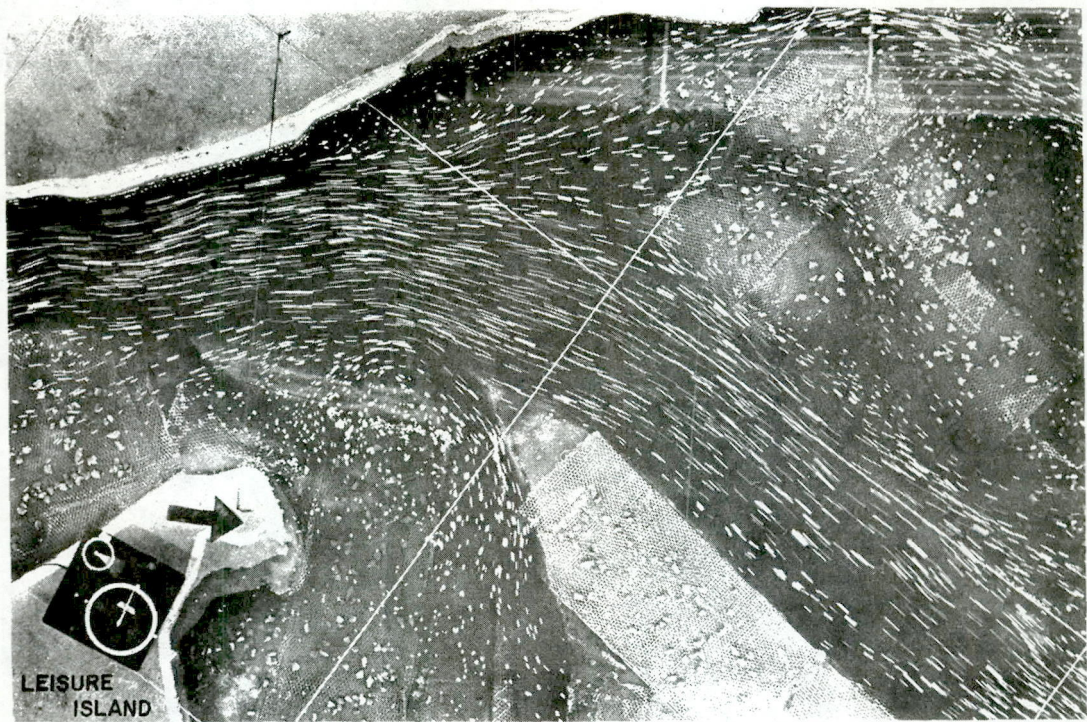


THREE HOURS AFTER LOW WATER AT 'THE HEADS'

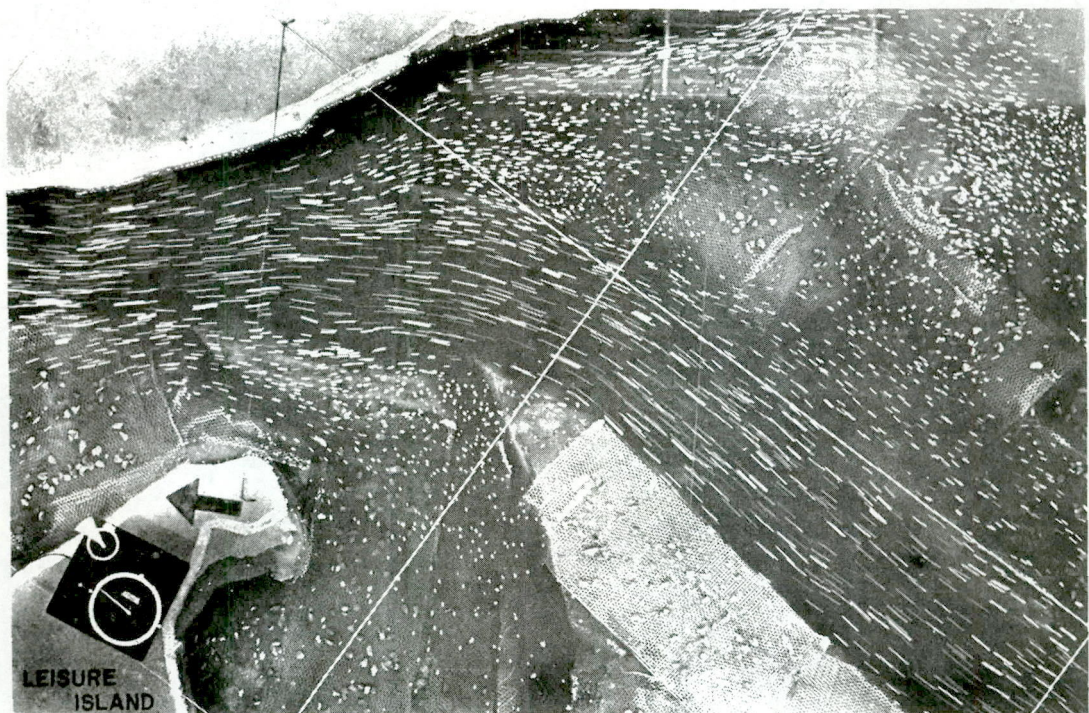


NINE HOURS AFTER LOW WATER AT 'THE HEADS'

Scale 1 : 12 500  
 Velocity Scale 1 mm = 0,2 m/s



THREE HOURS AFTER LOW WATER AT 'THE HEADS'



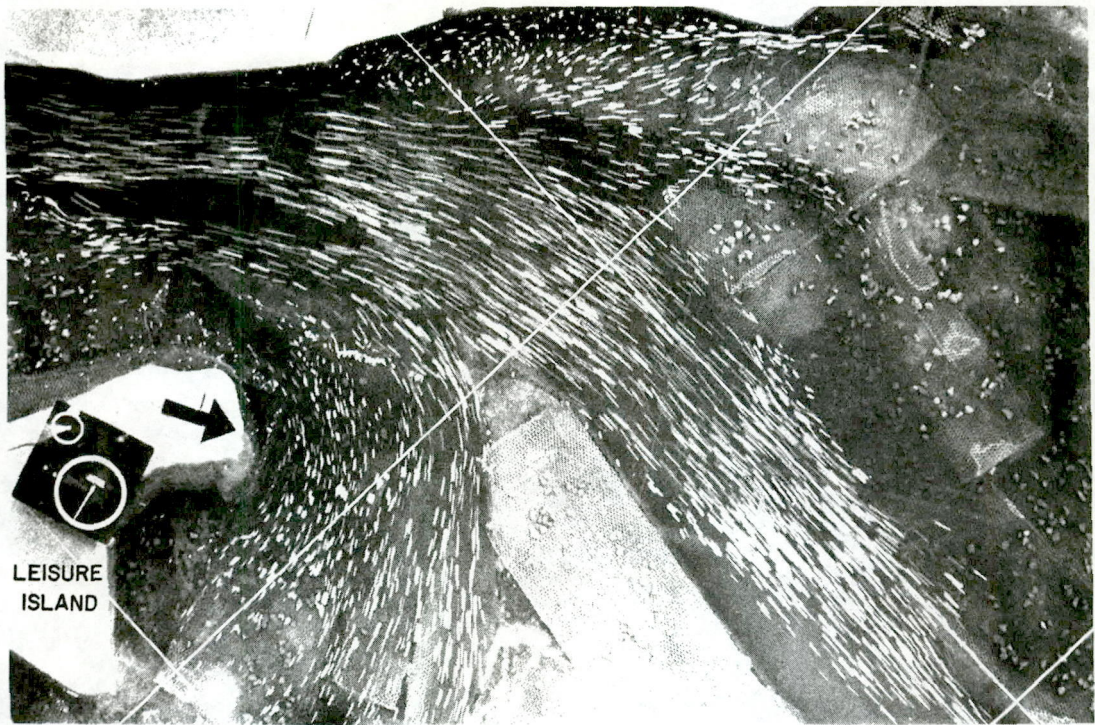
NINE HOURS AFTER LOW WATER AT 'THE HEADS'

Scale 1 : 12 500  
Velocity Scale 1 mm = 0,2 m/s

LINE PHOTOGRAPHS FOR SCHEME I

FIGURE

23

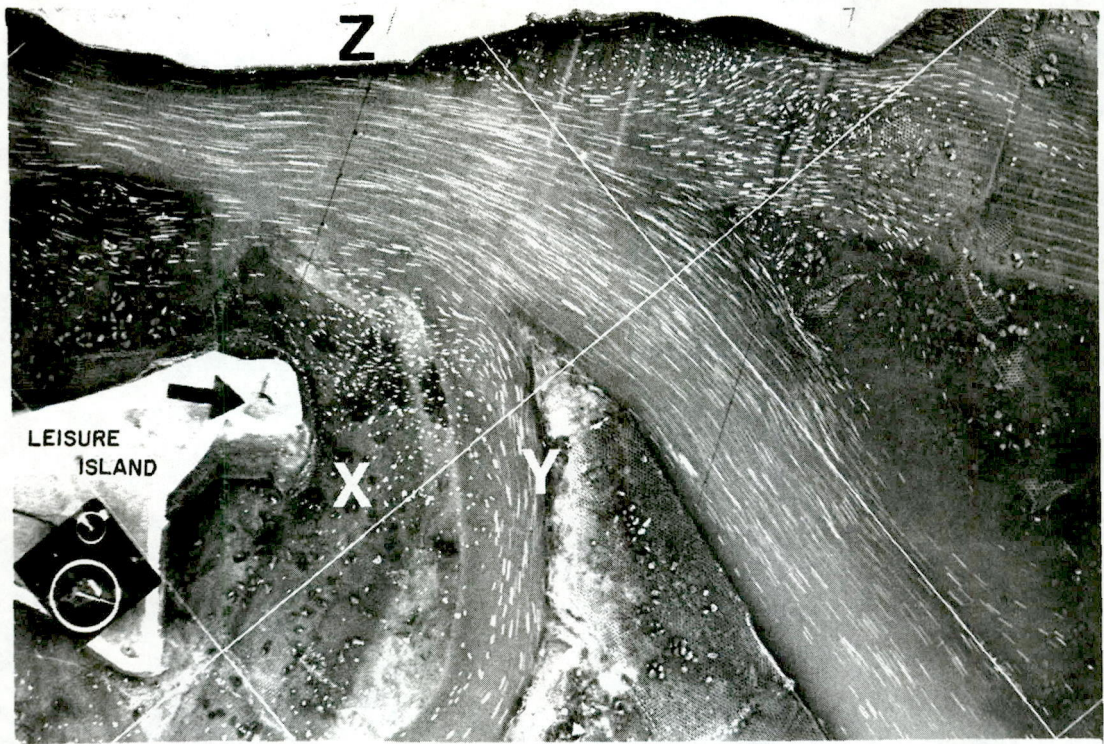


THREE HOURS AFTER LOW WATER AT 'THE HEADS'

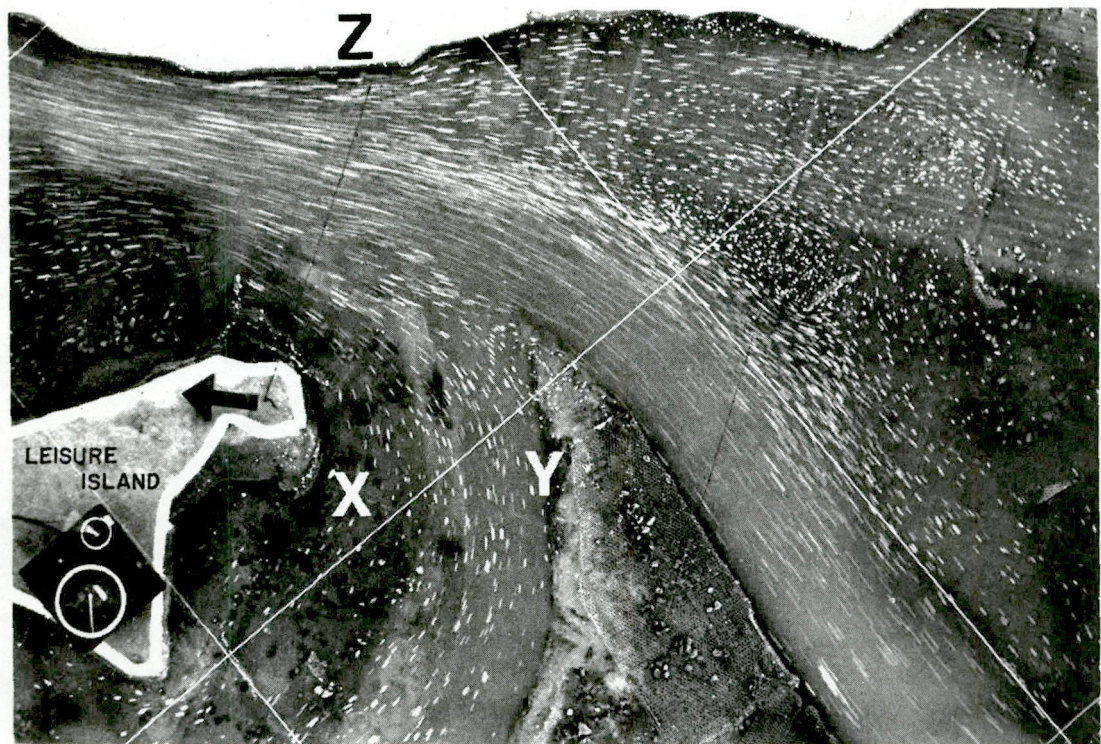


NINE HOURS AFTER LOW WATER AT 'THE HEADS'

Scale 1 : 12 500  
Velocity Scale 1 mm = 0,2 m/s

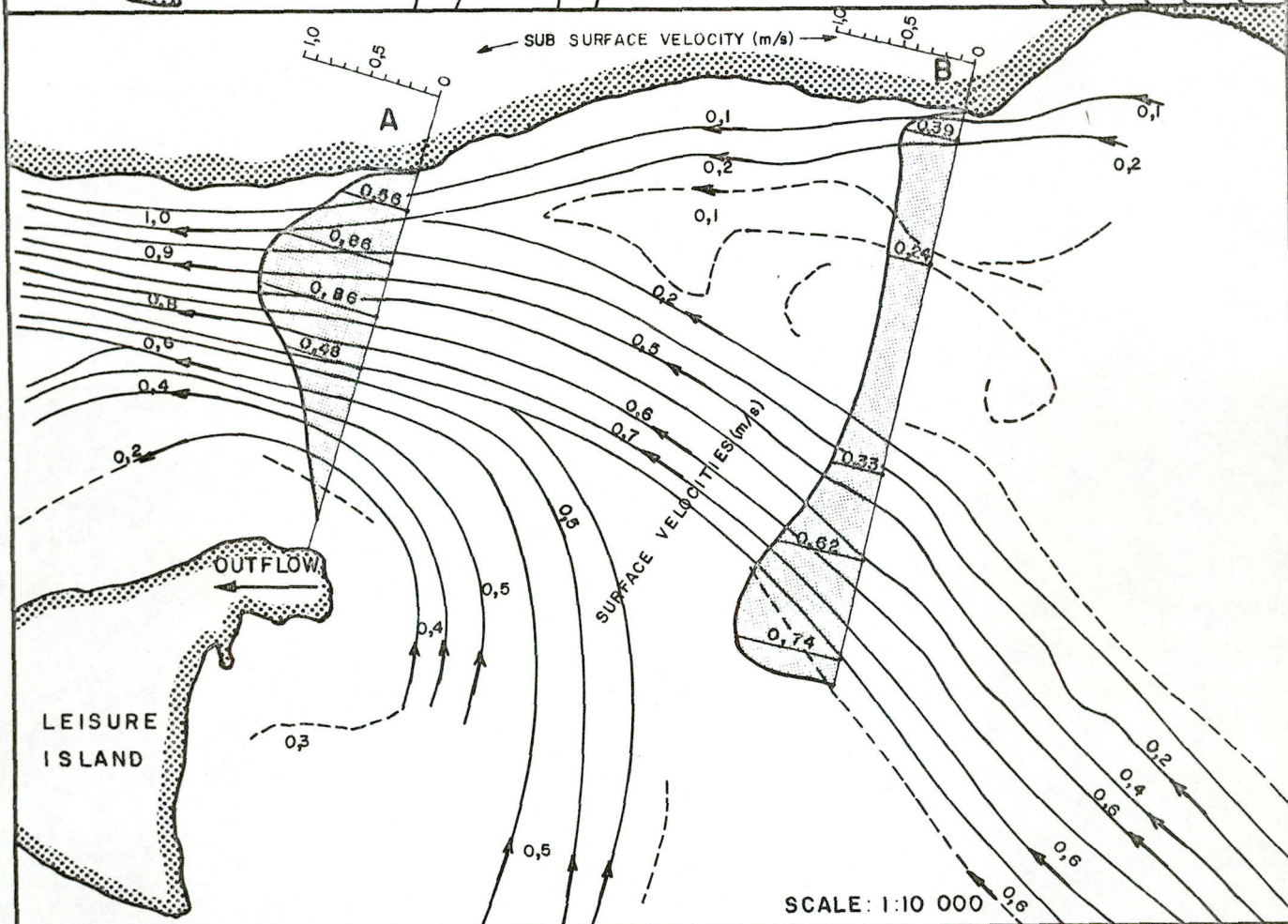
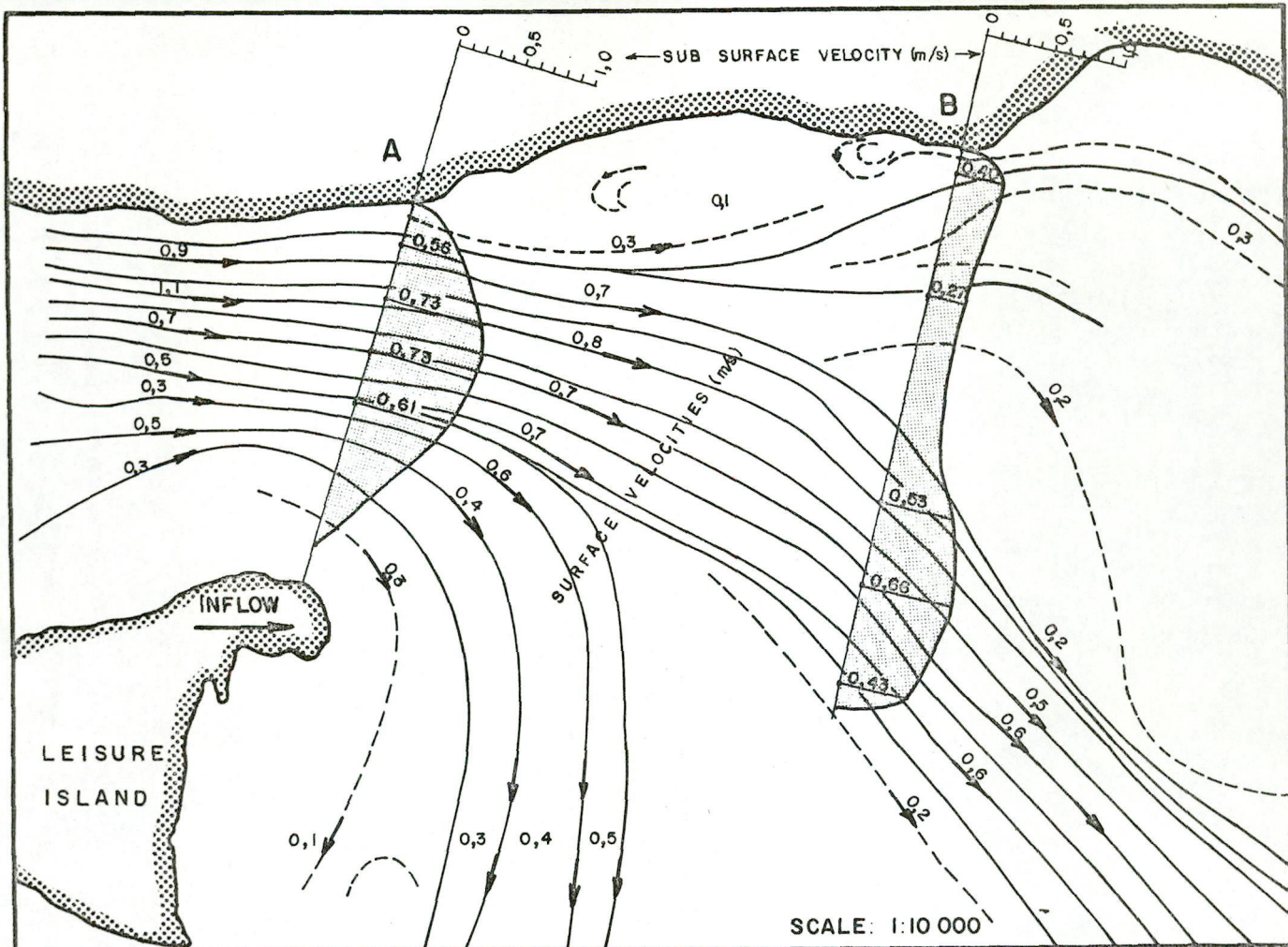


THREE HOURS AFTER LOW WATER AT 'THE HEADS'



NINE HOURS AFTER LOW WATER AT 'THE HEADS'

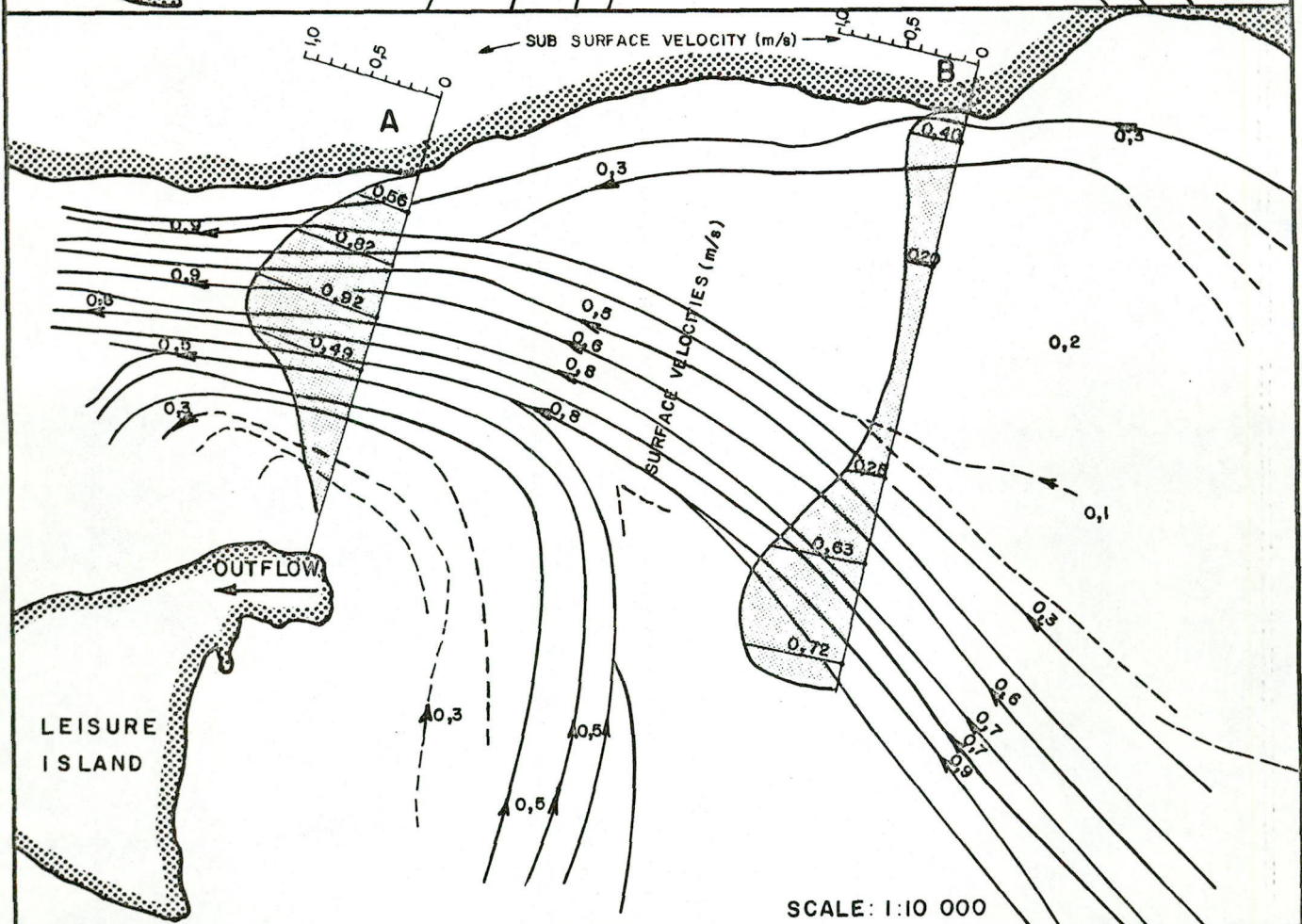
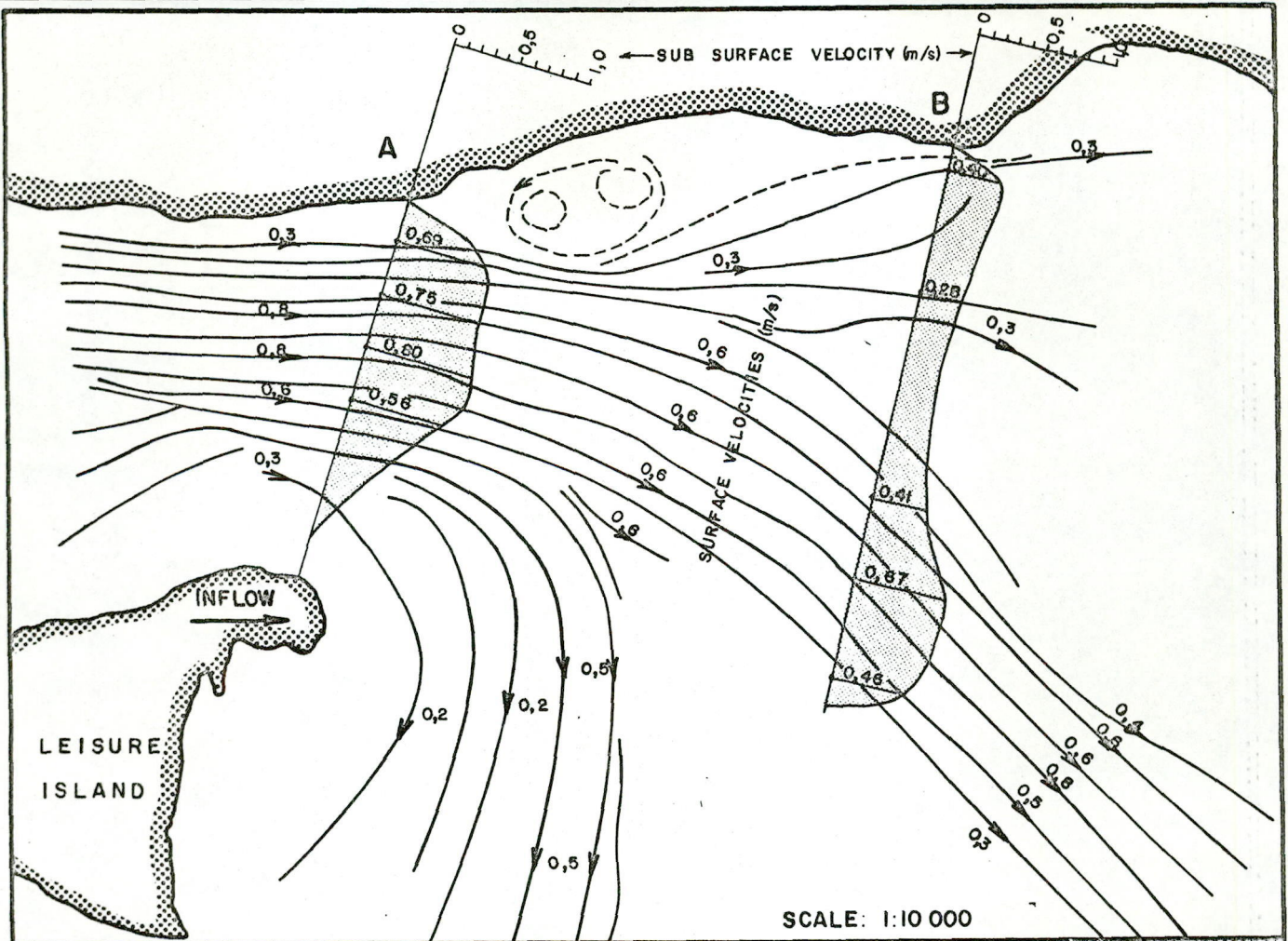
Scale 1 : 12 500  
 Velocity Scale 1 mm = 0,2 m/s



FLOW PATTERNS AND VELOCITIES FOR  
 EXISTING LAYOUT

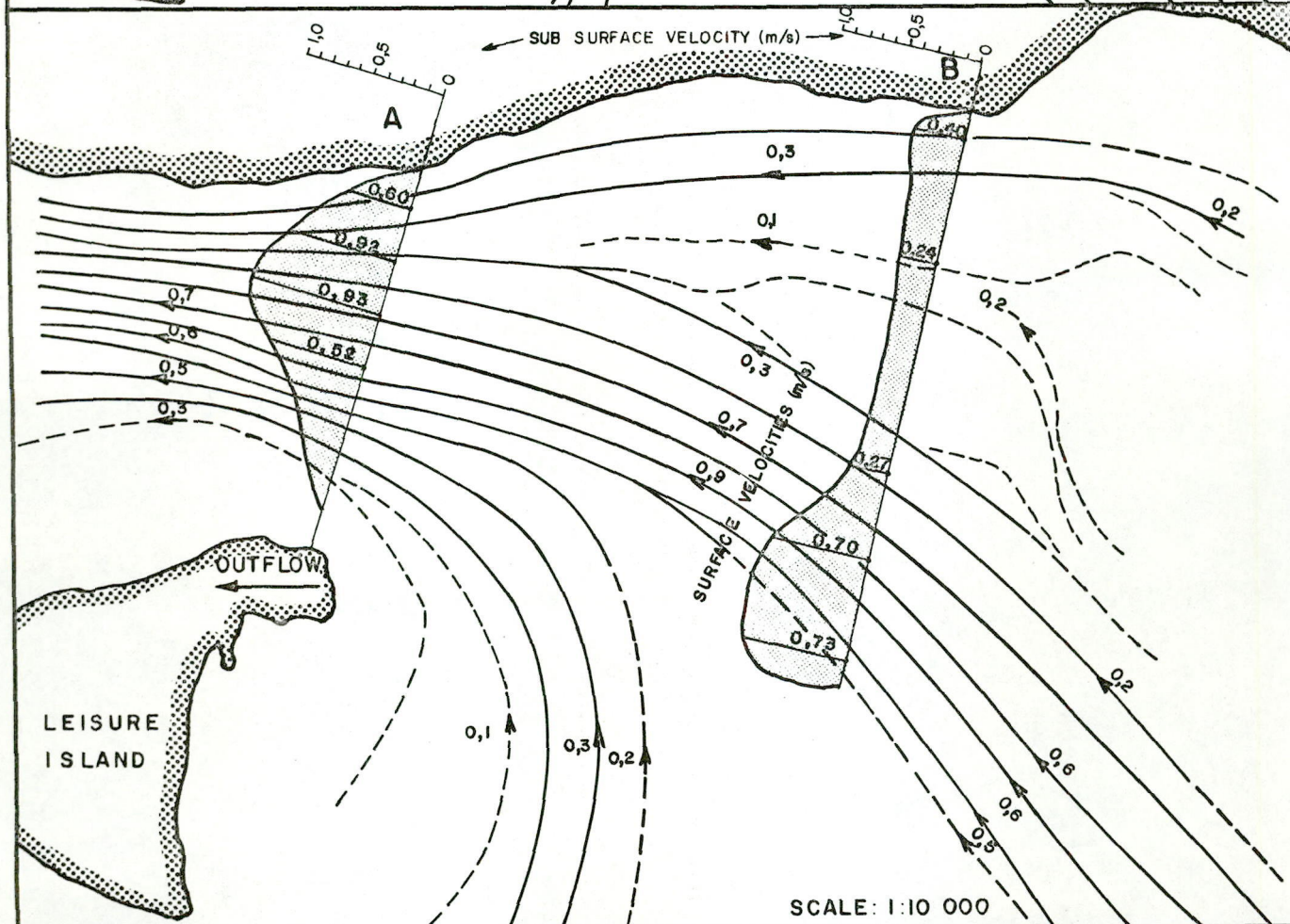
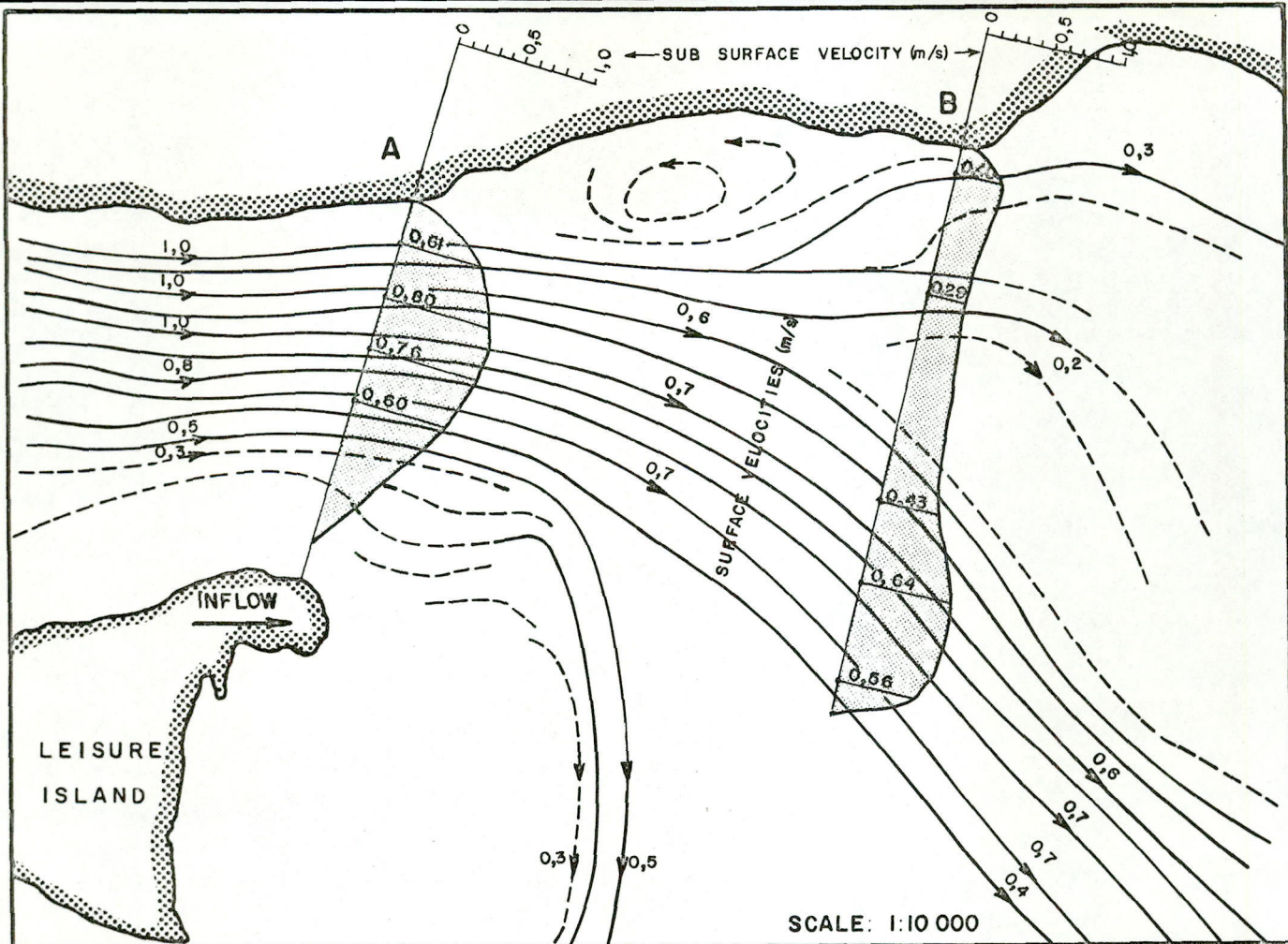
FIGURE  
 26





FLOW PATTERNS AND VELOCITIES FOR  
 SCHEME II

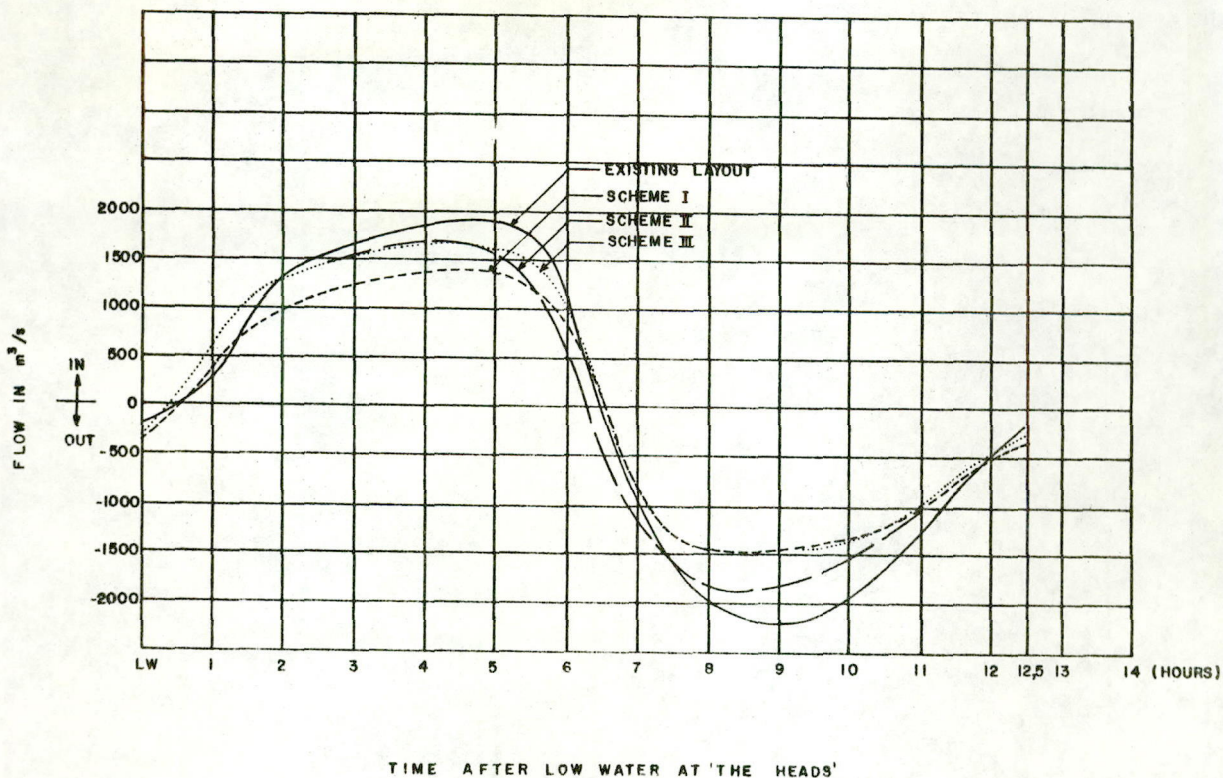
FIGURE  
 28



FLOW PATTERNS AND VELOCITIES FOR SCHEME III

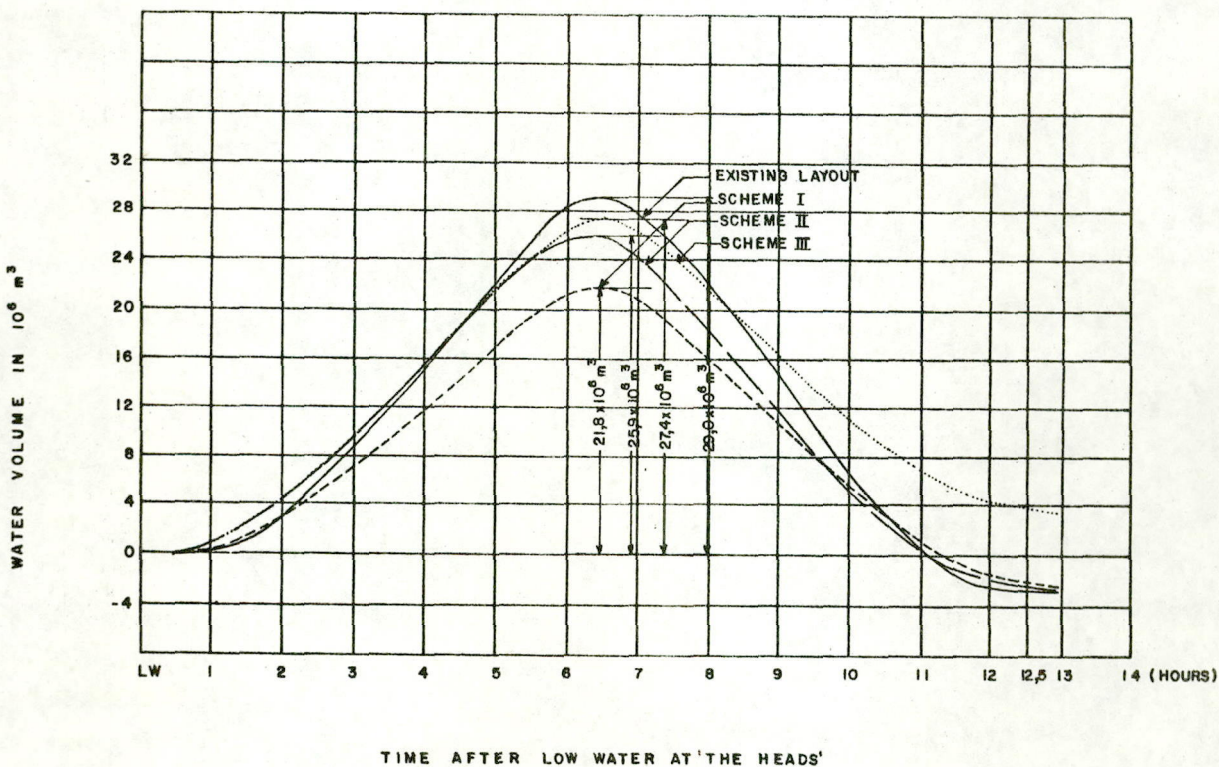
FIGURE 29

FLOW RATE PAST 'THE HEADS'



A

CUMULATIVE WATER VOLUME FLOWING PAST 'THE HEADS'  
DURING AVERAGE TIDAL CYCLE



B

FLOW PAST 'THE HEADS' FOR EXISTING SITUATION AND VARIOUS MARINA LAYOUTS

APPENDIX

METHOD USED FOR CALCULATION OF THE SHEAR STRESS

The shear stress, which is the pull of the water on the wetted area per unit area, was determined by the equation<sup>3)</sup>.

$$\tau = \rho V_*^2 \dots \dots \dots (1)$$

where  $\tau$  = shear stress in  $N/m^2$   
 $\rho$  = mass density in  $kg/m^3$   
 $V_*$  = shear velocity in  $m/s$

The shear velocity is unknown, but the relationship between  $V_*$  and  $V$  (mean velocity) is given by the equation<sup>4)</sup>

$$V = V_* \left( 2,5 \ln \frac{y}{k_s} + B - 2,5 \right) \dots \dots \dots (2)$$

where  $y$  = water depth in  $m$   
 $k_s$  = grain size in  $m$   
 $B$  = roughness function

The mean grain size ( $k_s$ ) in the lagoon is known (200 micron) and  $V$  is known from the current measurements. To obtain  $y$ , the water level at Section A (see Figures 1 and 19) was assumed to be equal to the average between the water levels at 'The Heads' and 'Thesen's Island'.  $V_*$  and  $B$  were therefore the only unknowns in equation (2).  $B$  is a function of  $V_*$ ,  $k_s$  and  $\nu$  (kinematic viscosity =  $10^{-6} m^2/s$  for water). This equation therefore had to be solved by the trial and error method.

A value for  $V_*$  was assumed and  $B$  found from a graph<sup>4)</sup> giving  $B$  in terms of  $\frac{V_* k_s}{\nu}$ .  $V$  was then calculated and if it did not correspond with the known  $V$ , another value for  $V_*$  was assumed and the procedure repeated until the calculated  $V$  was equal to the known  $V$ .  $V_*$  was now known and the shear stress could be determined using equation (1).

The critical shear stress, or the shear stress at which the sediment will start moving, was determined from Shield's curve<sup>3)</sup>.