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REPORT ON THE INVESTIGATION OF SILTATION IN THE GREEN HOLE, KNYSNA AND TECHNICAL EVALUATION OF REMEDIAL MEASURES

submitted to
The National Parks Board of Trustees
Coastal Areas

January 1989

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EMA - C 8920

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DIVISION OF EARTH, MARINE AND ATMOSPHERIC SCIENCE AND TECHNOLOGY

COASTAL PROCESSES AND MANAGEMENT ADVICE PROGRAMME

REPORT ON THE INVESTIGATION OF SILTATION IN THE GREEN HOLE KNYSNA AND TECHNICAL EVALUATION OF REMEDIAL MEASURES

SCOPE

Much concern has recently arisen due to the apparent increase in siltation in the so-called Green Hole, located in the Knysna lagoon in an area enclosed by the eastern end of Leisure Island, George Rex Drive and the causeway to Leisure Island (Figures 1 and 2).

The need for an investigation and possible remedial action was recognised and the CSIR, Stellenbosch, was commissioned to undertake the investigation.

The objectives of the study were to:

* Identify and quantify the prevailing physical processes influencing sedimentation in and around the Green Hole.

* Identify and technically evaluate alternative remedial measures.

Old maps and photographs were studied. Information on human intervention in and around the Green Hole was evaluated. A bathymetric survey of the study area was carried out and a study of the hydrodynamics was undertaken using water level recordings. Core samples at representative spots in the area were taken and analysed. Based on this information, an assessment was made of the sedimentation and erosion in and around the Green Hole and alternative remedial measures were evaluated.

The study was done and this report was compiled by Messrs P Huizinga and L Barwell of the Coastal Processes and Management Advice Programme (CPMA) of the Division of Earth, Marine, Atmospheric Science and Technology of the CSIR. Mr L van der Merwe carried out the bathymetric survey and Dr D H Swart, Manager of the CPMA, was responsible for the technical editing.

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PROGRAMME MANAGER

Stellenbosch, South Africa

January 1989

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1. INTRODUCTION

Much concern has recently arisen due to the apparent increase in siltation in the so-called Green Hole located in the Knysna lagoon in an area enclosed by the eastern end of Leisure Island, George Rex Drive and the causeway to Leisure Island (Figures 1 and 2).

Sedimentation and erosion are continuously taking place in the Knysna estuary in and around the Green Hole. In the past century these natural processes have been influenced strongly by human intervention. In particular the construction of George Rex Drive and the Leisure Island causeway as well as the channels excavated for material for the construction of this causeway and the construction and various modifications of the culverts in George Rex Drive and in the causeway strongly influenced the natural sedimentation and erosion processes in and around the Green Hole.

Detailed descriptions of all the human interventions that have taken place and accurate hydrographic and topographic survey data of the various stages are not available. However, the historical information that was available, complemented by field data collected for the study, were used to analyse the sedimentation and erosion processes.

Old maps and photographs were studied. Information on human intervention in and around the Green Hole was evaluated. A bathymetric survey of the study area was carried out and a study of the hydrodynamics was undertaken by using water level recordings. Core samples at representative spots in the area were taken and analysed. Based on this information, an assessment was made of the sedimentation and erosion in and around the Green Hole and alternative remedial measures were evaluated.

2. PHYSICAL PROCESSES INFLUENCING SEDIMENTATION AGAINST THE BACKGROUND OF AVAILABLE INFORMATION

In order to assess the reasons why the problem has arisen and to be able to identify possible solutions, an understanding of the physical processes influencing sedimentation in and around the study area is required. Sediment transport can take place in water by waves and currents and on land by wind. The different aspects involved are briefly discussed, in particular against the background of collected field data and other available information.

2.1 Deep-sea Waves and Wind Waves

Deep sea waves entering the Knysna estuary through the entrance at The Heads reach the sand bank and beach in front of the southern side of Leisure Island by refraction (bending) around Fountain Point and diffraction associated with shoaling caused by the shallowing of water as the waves approach the shore. These waves and the nearshore currents that they generate (Section 2.3) move sediment (sand) around within the area.

Under calm conditions associated with relatively low waves, sediment is moved onshore, resulting in beach accretion whereas, during stormy conditions and larger waves, beach erosion can occur.

Waves reflecting off the sea wall along the southern side of Leisure Island move sand offshore, from where longshore currents associated with wind waves caused by prevailing westerly winds could move sediment towards the Green Hole entrance.

Wind waves are caused by prevailing winds blowing across the lagoon and are considered to be a contributing factor to the longshore movement of sediment towards the entrance to the Green Hole and ultimately into the Green Hole under tidal influence.

2.2 Currents Generated by Waves

Waves approaching the shore, in particular when breaking, generate longshore currents that transport sediments (Section 2.1). The waves reaching the beach at the southern side of Leisure Island are considerably smaller than those in the open sea but they could still cause longshore currents, which in turn could transport sediment along this beach.

2.3 Tides

Currents transporting sediments in the channels in and around the Green Hole are mainly driven by tidal forces. To obtain a better understanding of the tidal influences at the Green Hole and surroundings, water level recorders were installed at five positions (Figure 2):

Position 1 (The Heads): The recorder was installed at The Heads in the position where the old Navy recorder (unfortunately destroyed) had previously been.

Position 2 (Leisure Island 1): This recorder was located at the north-western side of the Leisure Island causeway. The data recorded here represent the tidal variation at the north-western entrance to the Green Hole.

Position 3 (Leisure Island 2): The data recorded here, compared with those of position 2, reflected the influence that the culverts through the Leisure Island causeway had on the tidal flow entering the Green Hole.

Position 4 (Woodbourne 1): These data show the tidal variation inside the Green Hole at the Woodbourne culverts in George Rex Drive.

Position 5 (Woodbourne 2): This recorder measured the tidal variation inside the Woodbourne Pan at the other end of the same culverts. From these data the effect of the culverts on the water levels can be established.

The recorders were installed over the period 28 April 1988 to 2 May 1988. Spring tide occurred on 1 May 1988 and the fluctuations under spring tide conditions were thus monitored. The results for the full period are shown in Figure 3.

The spring tide data (1 May 1988) are reflected in Figure 4 and allow for a detailed description of the vertical tidal fluctuations in the area:

i Tidal delays at high tide relative to the reference station at The Heads were 20 min for Leisure Island 1, 35 min for Leisure Island 2, 55 min for Woodbourne 1 and 145 min for Woodbourne 2. An increase of about 0,05 m in the relative high tide level between Leisure Island 1 and The Heads can be observed. This type of increase in water levels is often observed in estuaries and is mostly due to funnel effects influenced by the shape of the channels.

ii At ebb tide the dropping water levels at Leisure Island 1 closely followed those at The Heads until a level of about +0,20 m above mean sea level (MSL) was reached, after which a distinct kink in the graph could be observed. At this stage bottom effects started playing a role, as did the steady water supply from seepage out of areas that were being exposed by the falling tide. The other recordings bottomed out at much higher levels due to the same influences and the threshold effect of the fixed bottom levels of the culverts.

iii About 3 h after low tide at The Heads, the incoming tide started affecting the water levels at Leisure Island 1, which then followed those at The Heads with a delay of about

30 min. About 4,5 after low tide the levels at Leisure Island 2 were influenced by the rising tide. The water levels at the Woodbourne culvert were only slightly affected after about 5,5 h.

A maximum flow velocity of 1,25 m/s was measured through the Leisure Island culverts during flood tide conditions at 15h00 on 30 April 1988. This corresponds with a maximum flow rate of about 5,5 cubic m/s through the four culverts together.

Only very little water flowed into the Green Hole through the southern channel at high water at spring tide, which also is indicative of the severe sedimentation that has taken place in this channel.

2.4 Sand Samples

Sand samples were taken along the beach at the southern entrance to the Green Hole and along the Green Hole western channel (Figure 2). The samples were analysed and the results are shown in Table 1. From these data it can be deduced that the sediment consists mainly of fine sand with a large shell fraction.

2.5 Vibrocore Samples

Vibrocore samples were taken in the study area to determine the long-term sedimentation rate in the Green Hole and the Woodbourne Pan. These samples should be seen as spot readings, which could be strongly influenced by local effects but which are indicative of the overall situation. The cores were analysed and the following was deduced (see Figure 2 for the positions of the cores):

Core 1: Located in the entrance channel at the northern side of the Leisure Island causeway, core 1 reflects the siltation outside the Green Hole down to a depth of -1,8 m (MSL).

The analysis, summarised in Figure 5, shows a predominance of fine sand (FS) over the full length of the core. Surface samples taken at the southern entrance to the Green Hole (Section 2.4 and Table 1) show similar characteristics, which are indicative of a common source.

Four distinct layers of coarse sand (CS) overlain by silt/clay (S/C) and very fine sand (VFS) show up at levels -0,3 m, -0,8 m, -1,6 m and -1,8 m (MSL). These are possibly indicative of periods of scour associated with high flow velocities, probably during river flooding when FS was scoured out, leaving only the coarser fraction. This was followed by the settling out of S/C and FS during post-flood low river flow conditions.

The intermediate periods reflect the continuous influx of FS under normal tidal conditions (Section 2.3).

Core 2: Core 2 was taken at the existing wooden jetty in the channel along the northern side of Leisure Island within the Green Hole. This represents the sedimentology at a point within the channel that is said to have been at least 0,5 m deep as little as 20 years ago (see above).

Three S/C layers can be seen at the surface and at the -0,1 m, -0,4 m and -1,4 m (MSL) levels. These correspond to a reduction in the FS content and an increase in the medium sand (MS) content at the -0,1 m and -0,4 m levels (Figure 6).

Since little changes can be seen to have occurred below the -0,5 m (MSL) level, this level may be indicative of a historic channel bottom level that existed during the period prior to the construction of the Leisure Island causeway and after construction of the causeway using the 4 m box culvert.

The layer seen at level -0,1 m (MSL) could be a reflection of the equilibrium level reached after the installation of the smaller pipe culverts that restricted the flow in the channel.

The S/C, FS and MS influx that occurred in the upper 0,5 m layer is indicative of the siltation after the installation of the present culverts. This sediment originates mostly from the holes scoured out at the ends of the culverts.

Core 3: This core was taken on the Green Hole side of George Rex Drive in the channel going from the old Woodbourne pipe culverts into the Green Hole.

CS occurs intermittently down to a level of - 1,9 m (MSL) and is indicative of scouring associated with high flow velocities. FS predominates over the whole depth, although a significant percentage of MS is present (Figure 7).

Two distinct 0,2 m thick layers of S/C at the surface are separated by a layer of CS at MSL. An increase in FS, together with a decrease in MS over the same depth, could indicate the usual build-up of fine material due to low flow velocity, possibly as a result of the closure of the entrance to the Green Hole and the associated lack of tidal flow into and out of the Woodbourne Pan.

Core 4: Core 4 was taken upstream of the culverts through George Rex Drive within the Woodbourne Pan and represents the sedimentological history at this point (Figure 8).

Below a level of -0,1 m (MSL) down to -1,9 m (MSL), a large percentage of CS and very coarse sand (VCS) is shown. This represents the changes in the old river bed level associated with regular flooding.

The layers of S/C at -0,6 m (MSL) to +0,1 m (MSL) levels could be due to a period of low river run-off but are most probably as a result of the flood damping effect of the small pipe culverts that caused finer material to settle in the Woodbourne Pan instead of being carried out to sea.

A clear layer of coarse material can be identified at a level of -1,0 m (MSL) and could be indicative of the channel bottom level prior to the construction of George Rex Drive. The similarity in the percentage of FS of marine origin that appears below and above this level indicates a common source and similar hydrodynamic sediment transport processes.

This is indicative of the existence of a marine environment prior to human intervention.

The discussion and deductions were based on the interpretation of grain size distributions, together with visual inspection of the core samples.

2.6 Wind and Aeolian Sand Transport

Wind data are not available for Leisure Island but at times winds strong enough to cause aeolian sand transport can occur.

Wind statistics are, however, available from observations by voluntary observing merchant shipping (VOS) taken at regular time intervals while sailing along the coast off Knysna. Based on about 25 000 such observations between 1961 and 1985, seasonal wind roses were drawn and are illustrated in Figure 21.

These indicate a predominance of wind from the north-western, western to south-western sectors throughout the year with opposing easterly winds occurring almost as frequently, but having lower velocities.

Easterly winds predominate during the summer months and westerlies during winter. During autumn and spring the winds are well balanced between the western and eastern sectors.

High velocity gale force winds can occur throughout the year but are most frequent during the winter period.

The local topography plays an important role in modifying the observed VOS wind climate and it is therefore expected that the dominant winds will actually blow "down the valley" from the north-west. The high ridges to the south-east and east of Leisure Island and the Green Hole probably shield the Green Hole area from easterly winds, resulting in a dominant westerly wind regime.

An analysis of the available VOS wind data with due cognisance of the shielding effect of the local topography and the local sand grain size distribution was carried out using a tried-and-tested aeolian sand transport predictive technique (Swart, 1986). Results show that, on average for the whole year, a net movement towards the eastern-north-eastern sector is predicted.

A significant volume of sand has been observed to have blown into the area at the southern entrance to the Green Hole (Mr Hoffacker, pers comm) and the fact that wind-blown sand has accumulated against the south-eastern end of Leisure Island is indicative of the potential input of wind-blown sand into the Green Hole. An increase in the vegetated area at this point is a direct result of wind-blown sand being trapped by pioneer vegetation.

2.7 Old Maps and Charts

Old maps of 1818 and 1864 (Figures 9 and 10) obtained from the Cape Archives give some indication of the original topography before any constructions had taken place. These maps indicate a narrow channel between Leisure Island and the eastern shore. The map of 1864 (Figure 10) shows a note reading "boat channel at high water springs", indicating its shallowness.

2.8 Aerial Photograph Analysis

Aerial photographs for 1936, 1942, 1958, 1968, 1979 and 1987 are available.

Photographs of the study area were prepared to the same approximate scale (1:5 000) (Figures 11 to 16). This enables direct comparisons to be made to determine the changes that have occurred over the past 50 years.

By superimposing the main features, for example the roads, main channels, sand banks, vegetated areas and the high-water mark, it can be concluded that:

i The Green Hole has never been of any significant depth during the past 50 years, although localised deeper areas, such as at the culverts and next to the causeways and Leisure Island, existed.

ii The sand bank at the southern entrance to the Green Hole has undergone significant growth. In particular the growth in vegetation along the entrance is an indication of a higher bottom elevation.

iii There has been an increase in the salt marsh within the Green Hole and a closure of the channel running along the Leisure Island side of the Green Hole.

2.9 Topographic Survey

Since it is very difficult to quantify level changes from aerial photographs (for example the amount of sedimentation taking place in the Green Hole), a comprehensive topographical survey was carried out during May 1988 (Figure 17). A detail of this survey around the Leisure Island culverts is shown in Figure 18, while Figures 19 and 20 show cross-sections and longitudinal sections.

This topographic survey can serve as reference for future monitoring of siltation in the Green Hole.

2.10 Sedimentation and Erosion in the Green Hole

The mechanisms causing sediment transport have been described in the previous sections. In summary, it can be said that sediment is transported into the Green Hole by:

(i) flood tidal currents
(ii) wind-driven currents
(iii) waves and wave-driven currents
(iv) aeolian transport

On the other hand, transport of sediment out of the Green Hole takes place by:

(i) Ebb tidal currents, which normally last longer than the flood tidal currents but which have lower velocities;

(ii) Stormwater discharges, which can for short periods cause a considerable net outflow of sediments.

Besides these general mechanisms the interactions between the different access routes also play an important role. For example improved access through the Leisure Island causeway leads to reduced tidal flows and stormwater discharges in the southern channel, which in turn through the mechanisms mentioned above result in changes in sedimentation and erosion.

On the other hand, if the Leisure Island causeway had not been provided with culverts during its initial construction, all the tidal flow and the stormwater discharges would have gone through the southern channel. Sedimentation of this channel would probably have been much less than it is at the moment.

Under equilibrium circumstances the total inflow of sediment is equal to the total outflow seen over a long period. When this equilibrium is disturbed a net inflow causing sedimentation can occur. In Chapter 3 the historical changes that have occurred are discussed, particularly against the background described here.

3. HISTORICAL CHANGES

3.1 General

According to Reddering and Esterhuysen (1984) Leisure Island is probably part of an emergent flood-tidal delta that was originally deposited during a higher elevation of the sea level. This occurred about 6 000 years ago when the sea level was about 3 m higher than at present.

Chunnett (1965) stated in an unpublished CSIR report that little, if any, sedimentation from external sources is taking place in the Knysna lagoon but that considerable localised sedimentation, in particular near man-made structures, could occur. He deduced that a continual reworking of sediment within the estuary was taking place.

The original situation that existed before the construction of George Rex Drive (before 1903) and the Leisure Island causeway can be estimated from old maps and charts, like the charts of 1818 and 1864, available from the Cape Archives (Cape Town) and other sources (Figures 9 and 10):

i The area between Leisure Island (then Steenbok Island) and the present George Rex Drive along the eastern lagoon shore consisted mainly of salt marsh with drainage channels or creeks. On the old Admiralty map of 1864 (Figure 10) a channel is shown here with the note reading "boat channel at high water springs", indicating the shallowness of the channel and surrounding area.

ii The Bigai River and another small river are shown to have flowed through this area into the lagoon.

iii Although the old Admiralty maps show a narrow channel, without any depth soundings indicated, leading from The Heads to the present Green Hole, it has been said that fishermen at times were moored next to an old building (a fish and bait store, Mr Hoffacker, pers. comm.) about 200 metres south of the present Woodbourne culverts within the Green Hole area.

iv An area in the Green Hole was also previously known as "The Oyster Cove", which could be indicative of greater depths in the past.

v The area of the present Woodbourne Pan was marine dominated and consisted of a large open sand flat.

3.2 George Rex Drive and the Woodbourne Pan

George Rex Drive was constructed between 1901 and 1903. A pontoon bridge at the position of the present Woodbourne culverts (Knysna Town Engineer, pers comm) originally connected Knysna to The Heads. This indicates that at that time the area was considerably deeper than at present. Good tidal interaction between the present Woodbourne Pan area and the Green Hole area was possible and the hydrodynamics were therefore hardly affected.

Core samples taken to a depth of -2,0 m below MSL at positions upstream and downstream of the present Woodbourne culverts (Section 2.6) show a common marine sand layer below a level of -1,0 m (MSL). This is indicative of the situation prior to the construction of George Rex Drive and the Woodbourne culverts.

Sometime before 1936, the pontoon bridge was replaced by four 0,80 m diameter concrete pipe culverts placed at an invert level of 0,0 m (MSL). Without obstructions the total opening of these pipes would be about 2,0 m^2. The bottom level in the Woodbourne Pan is at the moment at about +0,60 m (MSL). Under normal low stormwater flow conditions the opening should have been sufficient to drain the Woodbourne Pan, while tidal influence would have caused in and outflow, weak at neap tides and stronger at spring tides. During periods of high stormwater flow from the

Bigai River and at high spring tides, the pipes would temporarily be obstructions to the flow. These effects could have been further enhanced if the pipes had been partially blocked by stones and sediments.

The flow through the culverts, substantially reduced under extreme conditions, also led under these circumstances to a decrease in the volumes of water flowing through this entrance to the Green Hole at the southern channel, which in turn reduced the scouring potential in the Green Hole. This change in the finely balanced hydrodynamics resulted in an increase in the rate of sedimentation of the Green Hole through this channel.

The reduced influx of salt water to the Woodbourne Pan also resulted in a decrease in salinity within this area, as was observed by local people, a situation to which the ecology of this area adapted itself.

Since the pipe culverts had a damping effect on stormwater run-off from the Bigai catchment, a stilling basin was created within the Woodbourne Pan that allowed silt to settle in this area, resulting in substantial silting-up and a general shallowing of the pan by river-borne sediment. This is the main reason why the bottom of the Woodbourne Pan is very marshy at the moment, while the surface of the salt marsh in the Green Hole is of much harder sandy materials.

During May 1984 two larger box culverts (1,20 x 3,60 m), with the bottoms at a level of +0,48 MSL, were constructed adjacent to the old Woodbourne pipe culverts. This was probably done to alleviate the existing problem of back-flooding of low-lying areas within the Bigai flood plain. At the same time the siltation by finer materials in the pan after stormwater discharges was reduced due to the faster run-off into the Green Hole. It also resulted in an increase in salinities within the Woodbourne Pan due to the improved tidal interaction between the Green Hole and the Woodbourne Pan.

Strong tidal flows through this larger culvert, especially during spring flood tides, caused scouring on the Woodbourne Pan side of the culvert. A large hole (up to 3,0 m deep) has been created and the sand deposited around the perimeter of the hole.

Higher upstream in the Bigai River additional causeways and heavy vegetation are further obstructions to stormwater discharges. Remedial measures here would alleviate flooding problems and further increase flow velocities during stormwater discharges through the Woodbourne Pan and the Green Hole.

3.3 Leisure Island Causeway

The Leisure Island causeway was built around 1930 in order to provide better access to Leisure Island. It connects George Rex Drive with the island at a position, that was convenient at the time of construction. The distance was fairly short and the bottom elevation was relatively high, with one or a few small channels to cross, which probably ran dry at high water. This position was probably also close to the so-called null point of the tides, that is where the tidal currents going around the island normally meet and which position is dependent on the distances and the depths of the channels around the island. The building of causeways at or close to tidal null point positions has been the norm in many countries and good examples are found along the German and Danish North Sea coasts.

Such causeways were often constructed by simply excavating material from both sides of the causeway while the sides were protected from erosion by stony material imported from a nearby quarry. Since the old maps (Figures 9 and 10) indicate that the area consisted of salt marsh prior to development, the existing channels on both sides of the Leisure Island causeway could be remnants of such excavations of material. These channels are already clearly visible on the 1936 aerial photograph (Figure 11).

The same photograph also shows a channel along the bank of Leisure Island inside the Green Hole. It follows the bank so closely that the channel could be either partly or completely artificial, in which case material from the channel could have been used to heighten and formalise the bank.

These channels improved the tidal flow through the Leisure Island causeway into the Green Hole considerably and thereby indirectly reduced the tidal flow through the southern channel. As described earlier (Section 2.10) this disturbed the equilibrium between sedimentation and erosion, leading to increased sedimentation in this channel.

A 4 m wide box culvert was originally provided through the causeway to bridge the channel behind Leisure Island. This channel was at times negotiable by rowing boat (Mr Hoffacker, pers comm).

The old 4 m box culvert was replaced by 12 30-inch diameter concrete pipes in 1954. The pipe inverts were approximately at MSL (CSIR, unpublished report, 1965). The smaller pipe culverts introduced an increased obstruction against the in and outflow of the Green Hole through the Leisure Island causeway and as a result most probably increased the outgoing tidal flow rate in the channel between the island and The Heads. The resulting higher flow velocities during outgoing tides had a large scouring potential that removed a percentage of the total sediment transported into the area during the previous high tide. Thus a deeper channel would have been maintained. An aerial photograph of 1968 (Figure 14) still shows a reasonably deep channel at this position.

The same photograph shows erosion holes opposite the culverts on both sides of the causeway. These were caused by scour as a result of high flow velocities due to concentrated tidal flows. Inside the Green Hole sand scoured from these holes was mostly deposited within a short distance around the holes due to a reduction in current velocity. On the northern side of the culverts outside the Green Hole the eroded sand was mainly transported away by ebb currents through narrow channels.

During 1980 to 1981 the pipes in the Leisure Island causeway were replaced by four box culverts (2,40 m wide and 0,90 m high), with bottom levels at approximately +0,40 m MSL. At high-water levels the flow rate in and out of the Green Hole through these larger culverts was considerably more than that for the smaller pipe culverts.

It is hydrodynamically easier for water draining from an area (such as the Green Hole) during outgoing tides to follow the way of least resistance. Since at the Green Hole the way of least resistance would be via the channels next to Leisure Island and the causeway and through the larger culverts into the greater lagoon area, the tidal flow rate through the channel between The Heads and Leisure Island would be significantly reduced.

Owing to the fact that sand was continuously transported into the Green Hole via the channel at The Heads during each high tide, an increase in sedimentation took place as a result of the reduced scouring potential of the outgoing tidal currents after the larger culverts had been installed.

During 1983 to 1984 sand was removed from the southern channel within the Green Hole and used for construction purposes (Knysna Town Engineer, pers comm). This could have improved the tidal flow through the channel. If such excavations are contemplated in future, precautions should be taken to prevent the blockage of small channels, which play an important role in the hydrodynamics of such a delicate system.

3.4 Green Hole

From historical maps and charts it can be seen that prior to the construction of the road to Leisure Island, unobstructed routes existed for sea water to enter the Green Hole. The routes were via a reasonably deep channel between The Heads and Leisure Island and a shallower channel around the northern side of Leisure Island.

An analysis of aerial photographs taken over a period of about 50 years (Section 2.8) showed that significant sedimentation had taken place within the southern channel at The Heads. In particular the increase in the vegetated area along the shore of Leisure Island is indicative in this respect. The increase in sand build-up in this channel is especially noticeable over the period 1979 to 1987 (Figures 15 and 16).

The aerial photographs also clearly show that no significant increase or decrease in salt marsh area had occurred within the tidal region of the Green Hole. This is indicative of a healthy state of continued tidal flux.

From the photographs it can be deduced that the smaller channels draining the central salt marsh area had remained fairly stable. The only major change was the blocking-off of the channel along the northern side of Leisure Island inside the Green Hole.

As described in Section 2.9 a comprehensive topographical survey was carried out during May 1988 (Figures 17 to 20). This can serve as reference for future monitoring of siltation in the Green Hole.

4. SUMMARY AND CONCLUSIONS

The situation in and around the Green Hole can be summarised as follows:

i The only significant sediment source is the sand bank to the south of Leisure Island at The Heads. From here sediment is being transported into the Green Hole mainly by water and also on a much smaller scale by wind.

ii Very little sediment moves into the Green Hole through the other openings, that is the Leisure Island and Woodbourne culverts.

iii Sand is transported out of the Green Hole by ebb currents and stormwater flow.

iv Sedimentation around and near scouring holes at the culverts is mainly due to material scoured from these holes.

v Sedimentation through the southern channel has been greatly increased in recent years specifically by the reduction in tidal and stormwater flows. The culverts through the Leisure Island causeway, together with the easy access channels into the Green Hole, at present provide the main access route for tidal waters.

vi Old maps and charts (Figures 9 and 10) indicate the existence of a shallow channel that led around Leisure Island through the present Green Hole area and that joined the Bigai River in the Green Hole.

vii An analysis of aerial photographs spanning the period 1936 to 1987 showed little changes to the salt marsh areas and a significant increase in siltation of the existing channels within the Green Hole.

viii Old maps and the results of vibrocore sampling show that the Woodbourne Pan had been tidal prior to the construction of George Rex Drive.

From the above it can be concluded that the natural long-term rate of siltation in the Green Hole area due to the interaction of natural processes was increased by the construction of the Leisure Island causeway and George Rex Drive and was also strongly influenced by related activities such as excavation of channels and construction and modification of culverts.

The present situation on siltation and erosion is therefore the result of all the human activities that have taken place since the beginning of the century.

5. PROPOSED REMEDIAL MEASURES

Various options concerning the siltation in and around the Green Hole were identified and can be evaluated on their technical implications. Remedial action relating to the Green Hole and Woodbourne Pan will be discussed under separate headings.

5.1 Green Hole

Option GH1: No action

If nothing was done, the already far-advanced siltation of the channel between Leisure Island and The Heads will continue probably until the channel has been blocked off completely. Since it will then be impossible for sea water to enter the Green Hole via the blocked-off channel and since little sediment is available on the northern side of Leisure Island, the further influx of water-borne sediment will be minimal and the situation in the Green Hole should stabilise. Since sea water will still reach the Green Hole via the Leisure Island culverts, a new state of ecological and hydrodynamical equilibrium will be reached.

No problems are foreseen with the limiting effect of the present culvert invert levels as this prevents the Green Hole from being completely drained during low tides. A volume of sea water is thereby retained in the Green Hole, which creates a suitable environment for juvenile fish. Very large numbers of small fish were observed during the field exercise in May 1988.

Wind-blown sand could pose a problem in the blocked-off channel and stabilisation by the introduction of suitable vegetation would probably be necessary to prevent sand from being blown into the Green Hole. However, stabilisation should be attempted only if problems with wind-blown sand should arise.

The Leisure Island culverts should be capable of handling stormwater discharging from the Bigai catchment.

Option GH2: Artificial blockage of the entrance channel

By mechanically closing off the channel between The Heads and Leisure Island, the existing rate of siltation of the Green Hole will be immediately reduced and a new state of equilibrium (Option GH1) should be reached sooner.

A new access road to Leisure Island could possibly be constructed at this point and the existing Leisure Island causeway could be removed completely. The open connection between the Green Hole and the adjacent salt marsh areas would thereby be re-established. Leisure Island would, however, become a peninsula and the existing island character might become lost.

It would also mean that the existing infrastructure of the southern part of the island would have to change drastically due to the new access road. Careful planning would thus be necessary. Problems relating to wind-blown sand could arise and could be solved in the same manner as discussed in Option GH1.

Option GH3: Opening of the channel between Leisure Island and The Heads

This option consists of dredging a channel from the main channel in the lagoon at The Heads across the sand bank at the southern entrance to the Green Hole along the existing channel up to the Woodbourne Pan culverts.

A side branch connecting the Leisure Island culverts with the new channel would create a situation similar to that that existed prior to the construction of the Leisure Island causeway. The water circulation within the Green Hole would be improved, although little ecological benefit will be obtained. Tidal variation in the Woodbourne Pan should improve.

Since the existence of an unlimited source of sediment and the flood tidal dominance of the estuary will persist, the siltation of the Green Hole will continue and maintenance dredging will be necessary from time to time.

Option GH4: Widening and deepening of the culverts in the Leisure Island causeway

Without additional action (for example dredging) the only result would be a further draining of the Green Hole at low tide, which could change the existing ecological environment.

Option GH5: Opening of the channel between Leisure Island and The Heads, together with the closure of the culverts in the Leisure Island causeway

As stated earlier (Sections 2.10 and 3.3) the sedimentation in the Green Hole would probably have been much less if the causeway had been closed from the beginning. This would have increased the tidal currents and stormwater discharges through the southern channel, by which sedimentation in this area would probably have been much less.

In addition to the dredging of channels (Option GH3), the closure of the Leisure Island culverts would therefore ensure that the outgoing tidal currents in the channel would increase in velocity because the total volume of water entering the Green Hole during incoming tides (the tidal prism) will be forced to flow back through the entrance. This will create a self-scouring situation whereby part of the volume of sand brought into the Green Hole during the preceding flood tide will be flushed out by the following ebb tide.

Maintenance dredging of these channels could still be necessary from time to time but should be less frequent than would be required for Options GH3 and GH6. Although regular dredging, together with the natural scouring ability of the ebb tide currents, should limit the influx of sediment, the natural net long-term siltation of the Green Hole will continue.

Option GH6: Widening and deepening of the culverts in the Leisure Island causeway, together with the dredging of a channel across the Green Hole

This option is an attempt to re-create the situation that existed prior to human intervention. Reference is made to the old map of 1864 (Figure 10), showing a channel behind the island with the remark "boat channel at high water springs". However, since then a considerable amount of siltation has taken place within the Green Hole area due to natural processes and as a result of human activities.

The removal of the sand, together with the reconstruction of the Leisure Island culverts, would make this option very expensive. Although the situation will be improved, the natural influx of water-borne sediment into the Green Hole via the southern channel will continue due to the mechanisms described earlier (Section 2.10) and an unlimited sand supply. A considerable amount of maintenance dredging will therefore still be necessary from time to time.

Since the provision of a deeper channel across the Green Hole will have little benefit to the existing healthy salt marsh environment, the only actual improvements will be to allow boating and other recreational activities at high tide and the aesthetics of the view of an island surrounded by water.

This option would be very expensive and would therefore probably be justified only if it could be combined with other recreational developments.

5.2 Woodbourne Pan

Option WP1: No action

The situation should stabilise in response to the changes occurring in the Green Hole. Little marine sediment is expected to enter the Woodbourne Pan from the Green Hole as very low velocities are possible in the present situation. Sand scoured from the holes at both sides of the existing culverts will continue to be moved around under the varying tidal conditions but a state close to equilibrium has probably been reached already.

The major cause of the present siltation in the Woodbourne Pan is considered to be river-borne silt washed from the Bigai catchment. The new culverts have considerably improved the stormwater discharge ability of the Woodbourne Pan. As a result the sedimentation during stormwater discharges has probably also been reduced. This situation could be improved only by the scouring out of silt by an above-average flood in the Bigai River. It is, however, important that the larger Woodbourne Pan culverts remain intact to allow for an unrestricted flow of flood waters through the Green Hole into the greater lagoon area.

Higher upstream in the Bigai River stormwater discharge ability could be further improved by cleaning the river bed of rubbish and vegetation and by reassessing the need for the existing causeways upstream of the Woodbourne Pan.

Option WP2: Installation of flap valves in the Woodbourne culvert to prevent the influx of sea water

This option requires the reinstatement of a previously man-made (artificial) situation whereby a primarily salt water environment was changed to a partially fresh water environment.

To do this, it would be necessary to limit the influx of sea water into the pan. This could be done by installing an effective set of flap valves on the Green Hole side of the culverts.

The installation and regular maintenance of flap valves will limit the influx of sea water but still allow for effective relief of flood waters.

A disadvantage would be that the total volume of tidal water (tidal prism) flowing through the Green Hole would again be slightly reduced, leading to a reduction in ebb-tidal scour potential and possibly causing some extra sedimentation in the Green Hole.

6. RECOMMENDATIONS

Since this report describes only the technical aspects of the different options, it is recommended that the various socio-economical implications should also be taken into account before a final decision is reached.

Technically, the most economical alternatives for solving the problem in the Green Hole are Options GH1 or GH2, which are also more in line with recent natural developments.

Option GH3 would maintain the existing island character but would not really be a solution as considerable maintenance dredging would still be required. Option GH4 on its own is totally irrelevant and a waste of money. Option GH5 would preserve the present situation in a better way than before but could still require additional maintenance excavation. Option GH6 is the most idealistic but also by far the most expensive alternative and should be considered only in combination with other developments and would also require considerable maintenance dredging.

Besides the sand deposited around the scoured hole near the culvert in the Woodbourne Pan, little sedimentation is taking place here. In fact siltation during stormwater discharges has probably been reduced due to these new culverts. Option WP2 for the Woodbourne Pan should be considered only if more of a fresh water environment is desired.

Whichever option is selected, it is recommended that regular topographical and biological surveys be undertaken to monitor the effects of the measures taken.

In general it is recommended that any major development should be carried out only with due cognisance of the Knysna Lagoon as a whole.

7. REFERENCES

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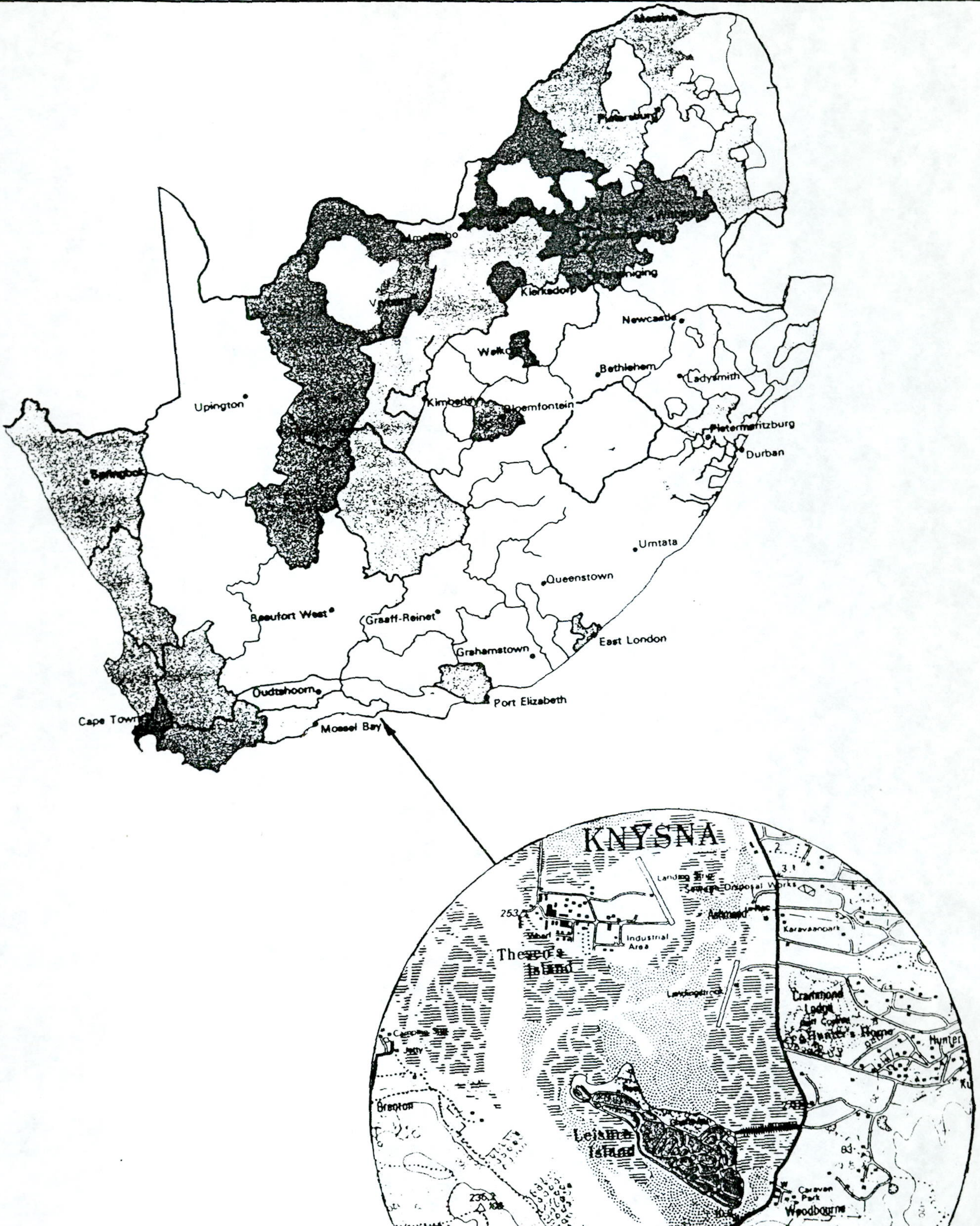

KNYSNA GREEN HOLE

LOCALITY MAP

FIGURE 1

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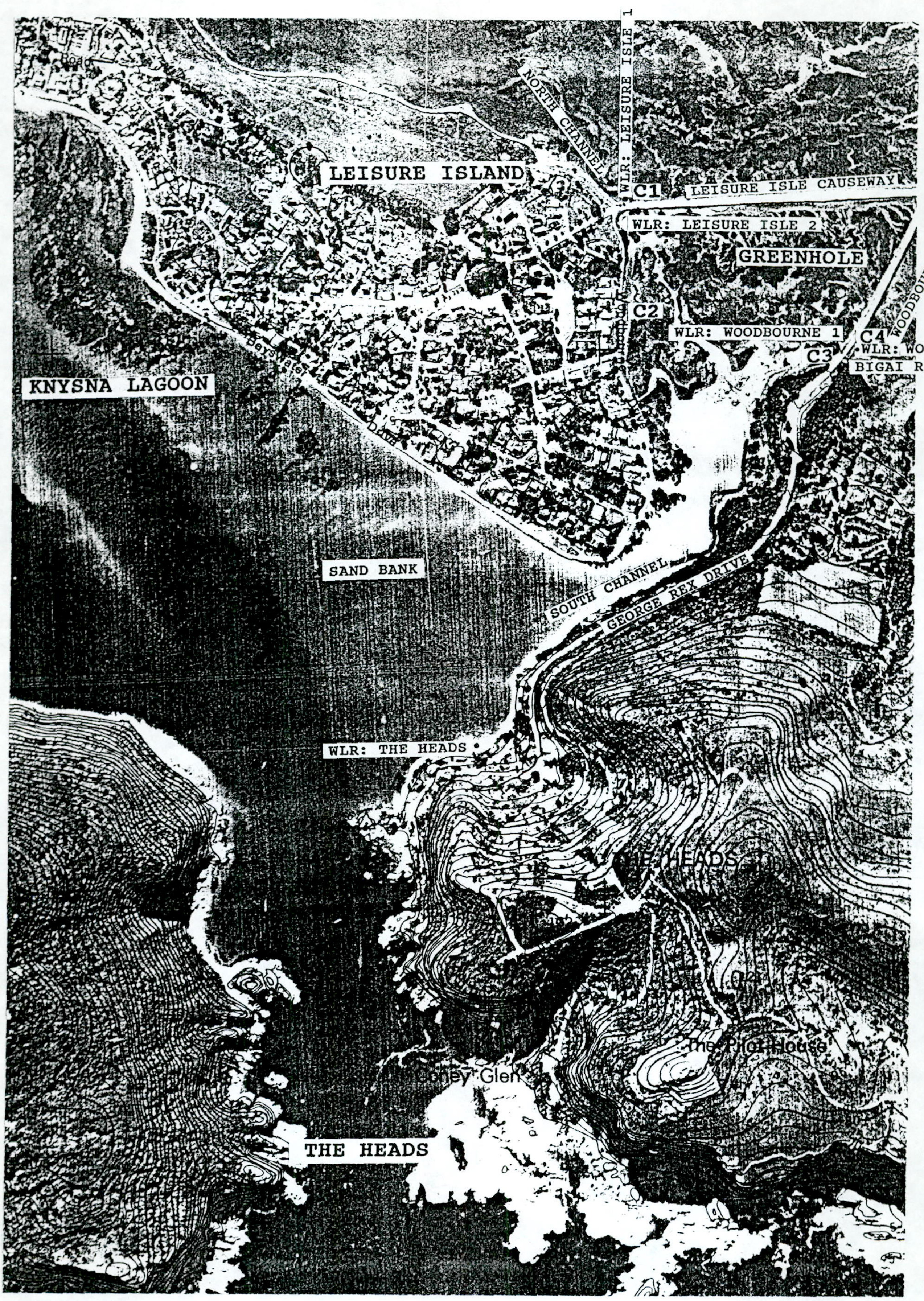
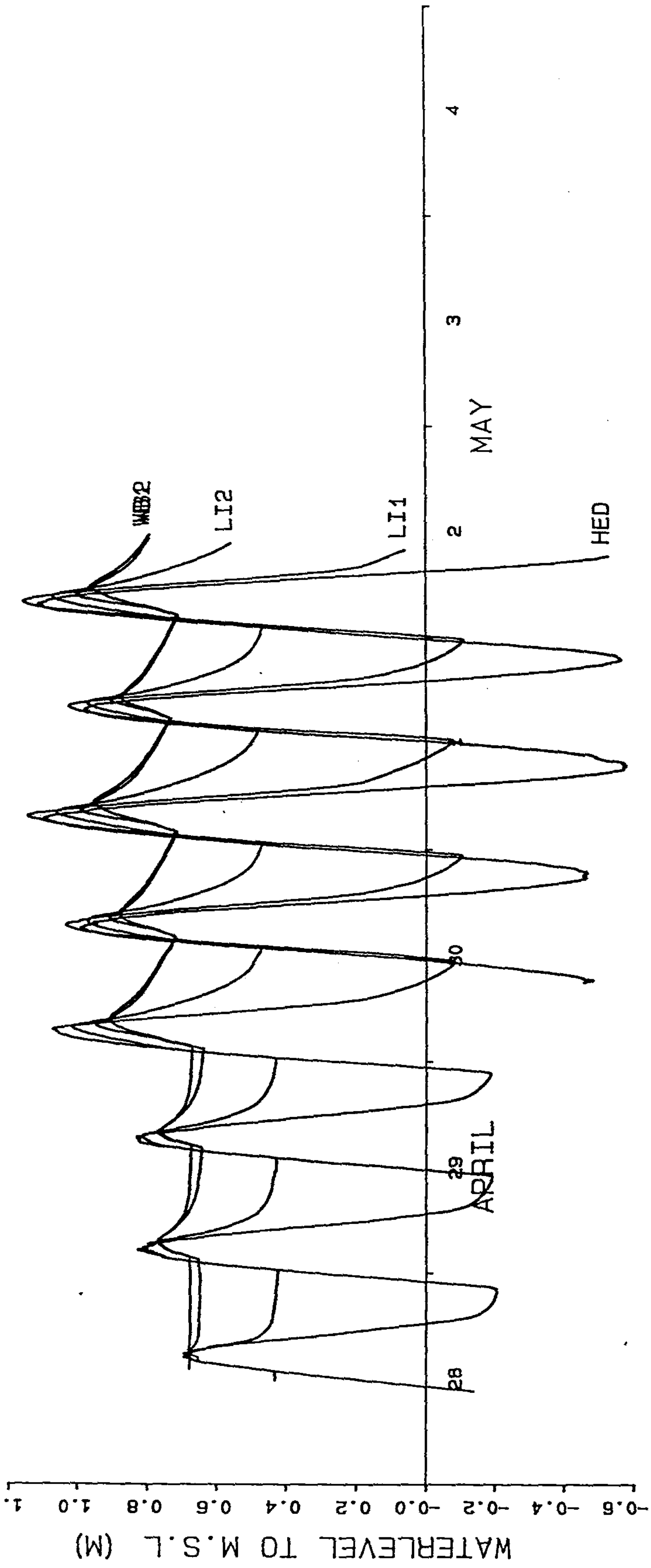


TRACED : CHECKED: L.B DATE : REF. : 730 42228	KNYSNA GREEN HOLE GENERAL DETAIL	FIGURE 2

CSIR-EMA



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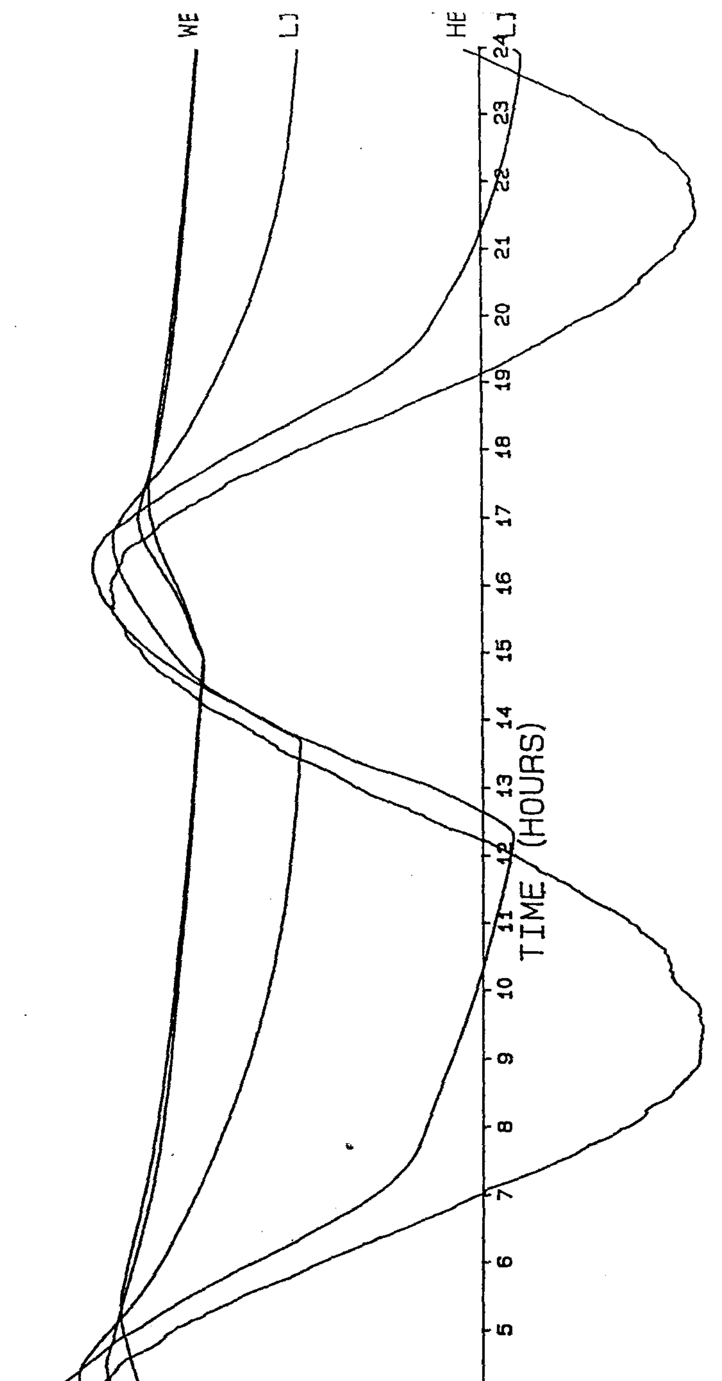

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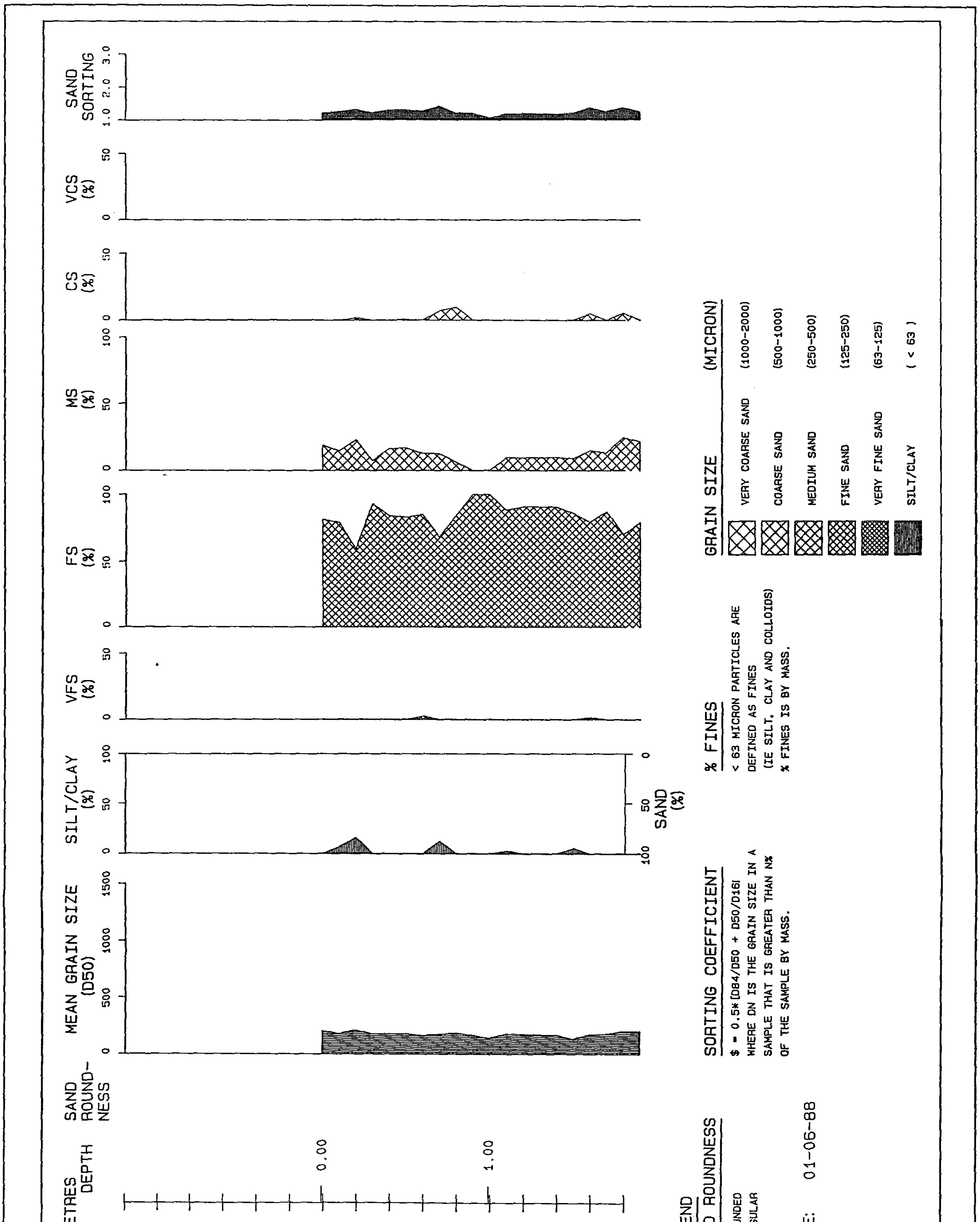
CSIR-EMA



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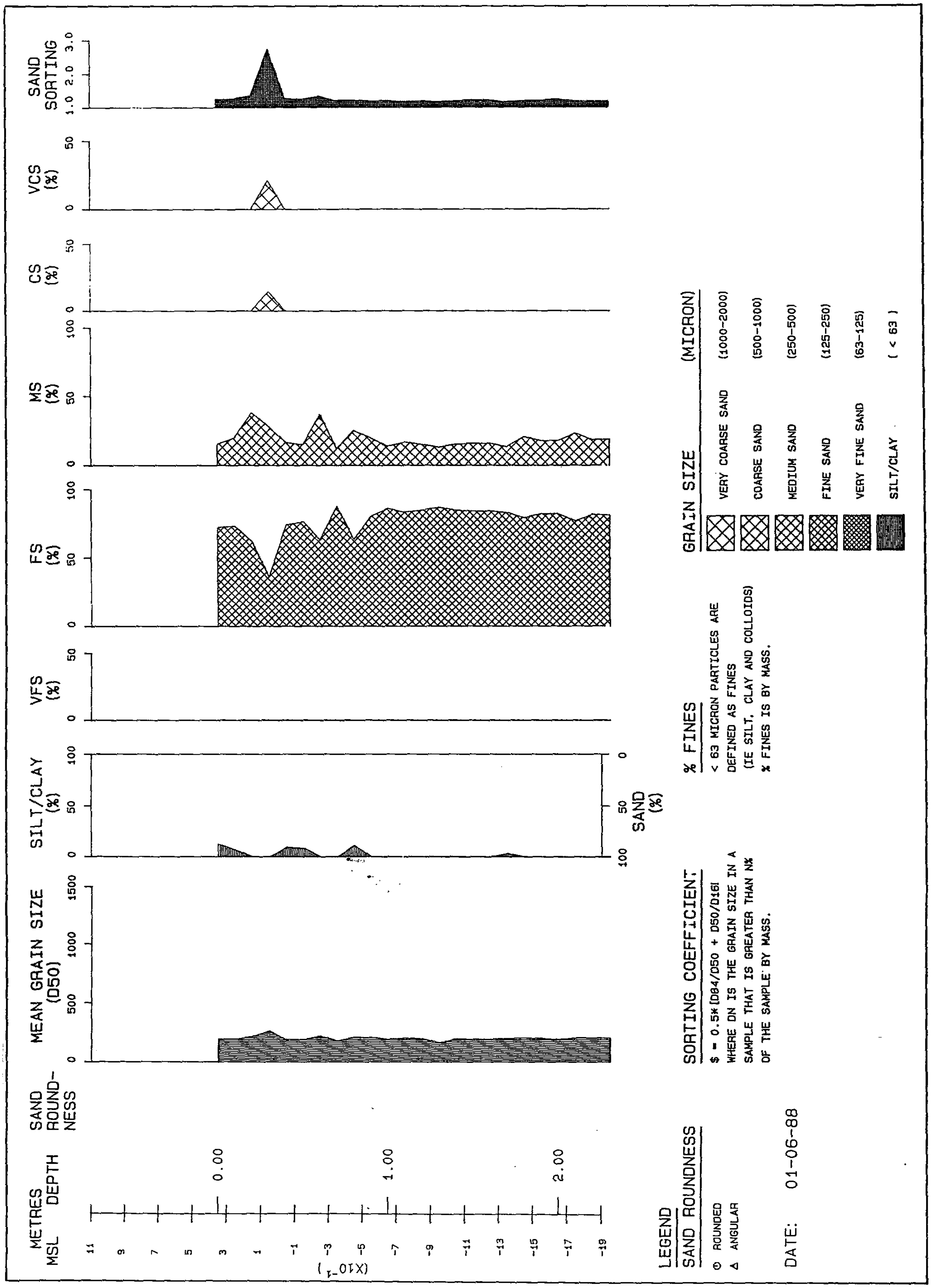
CSIR-EMA



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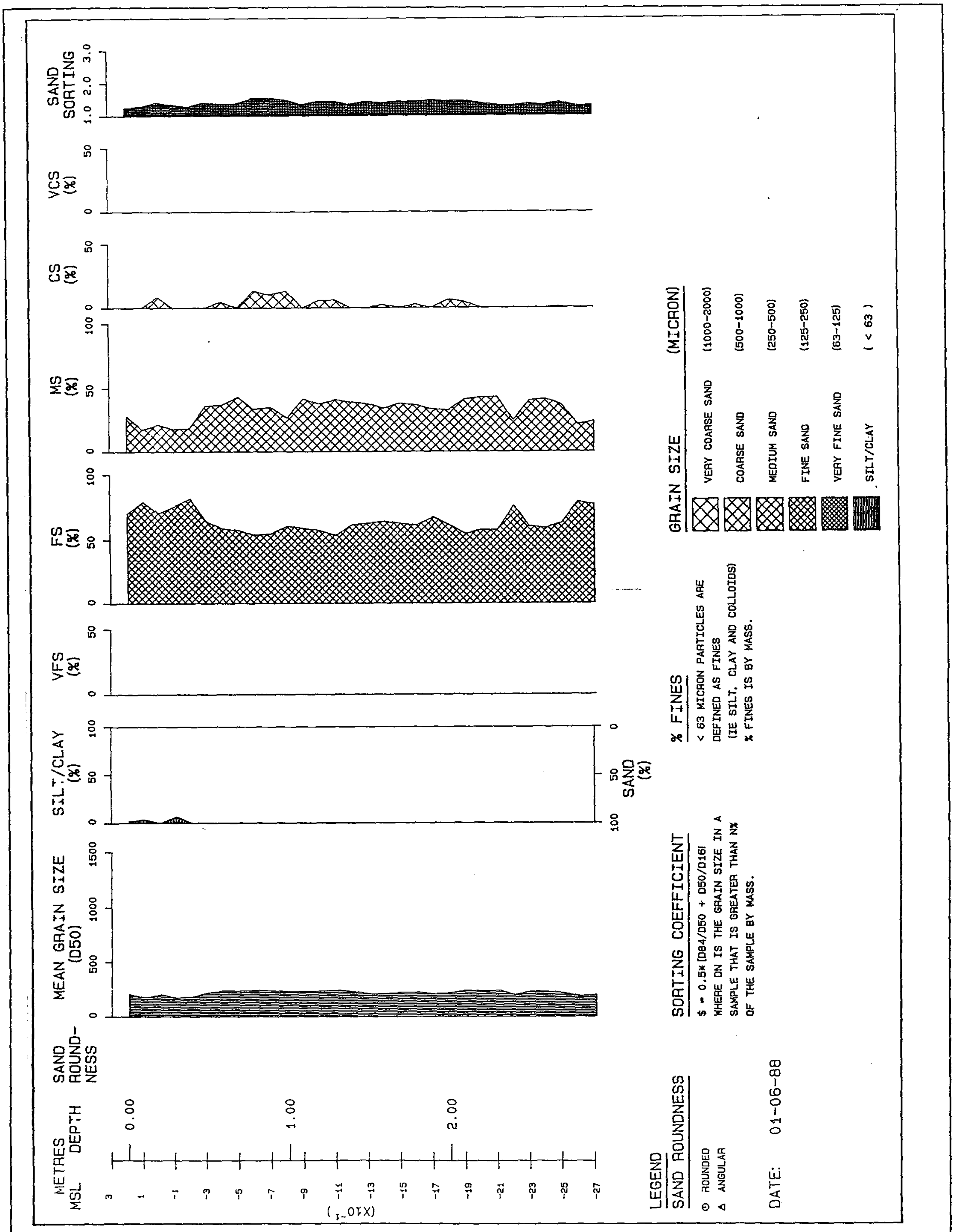
CSIR-EMA



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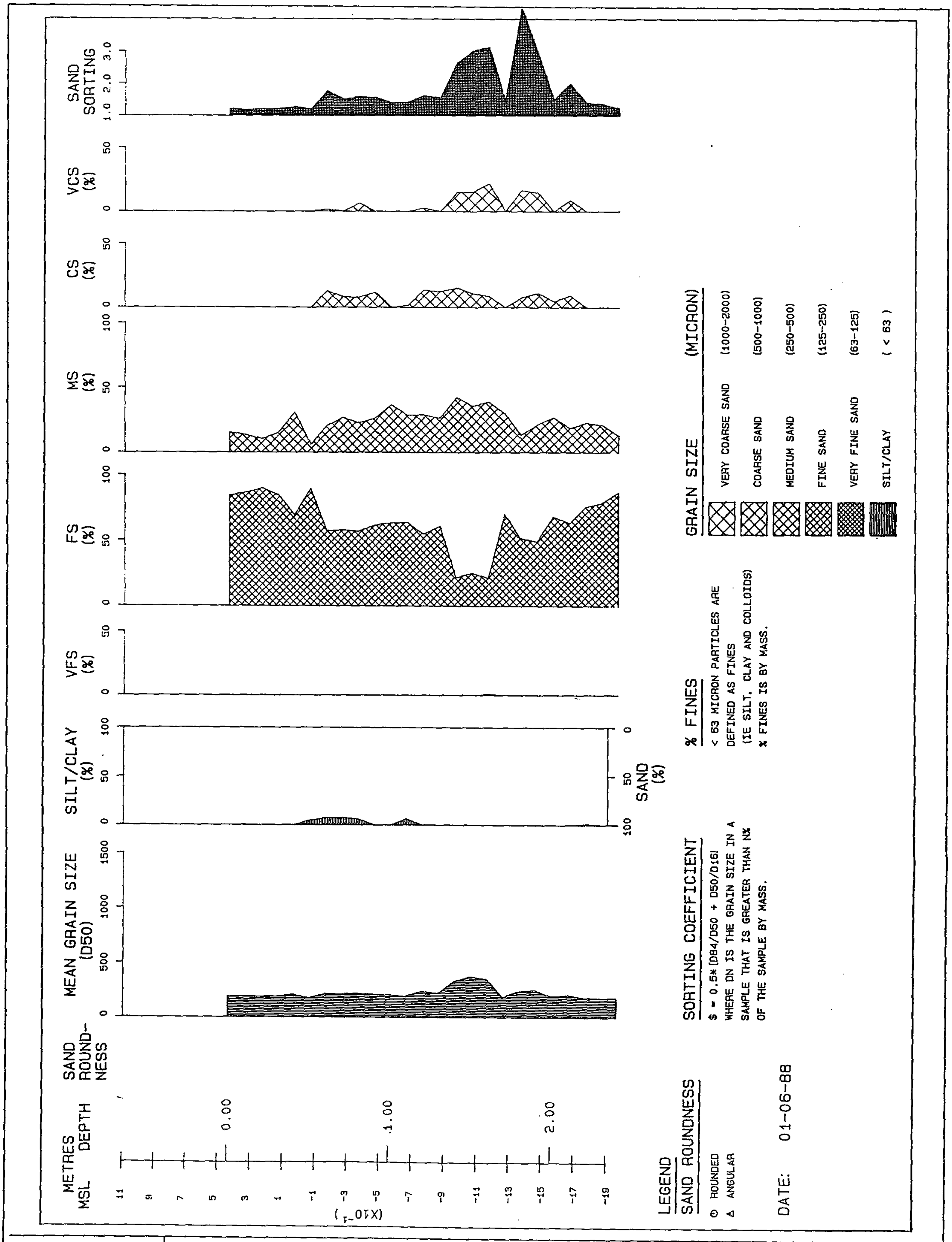

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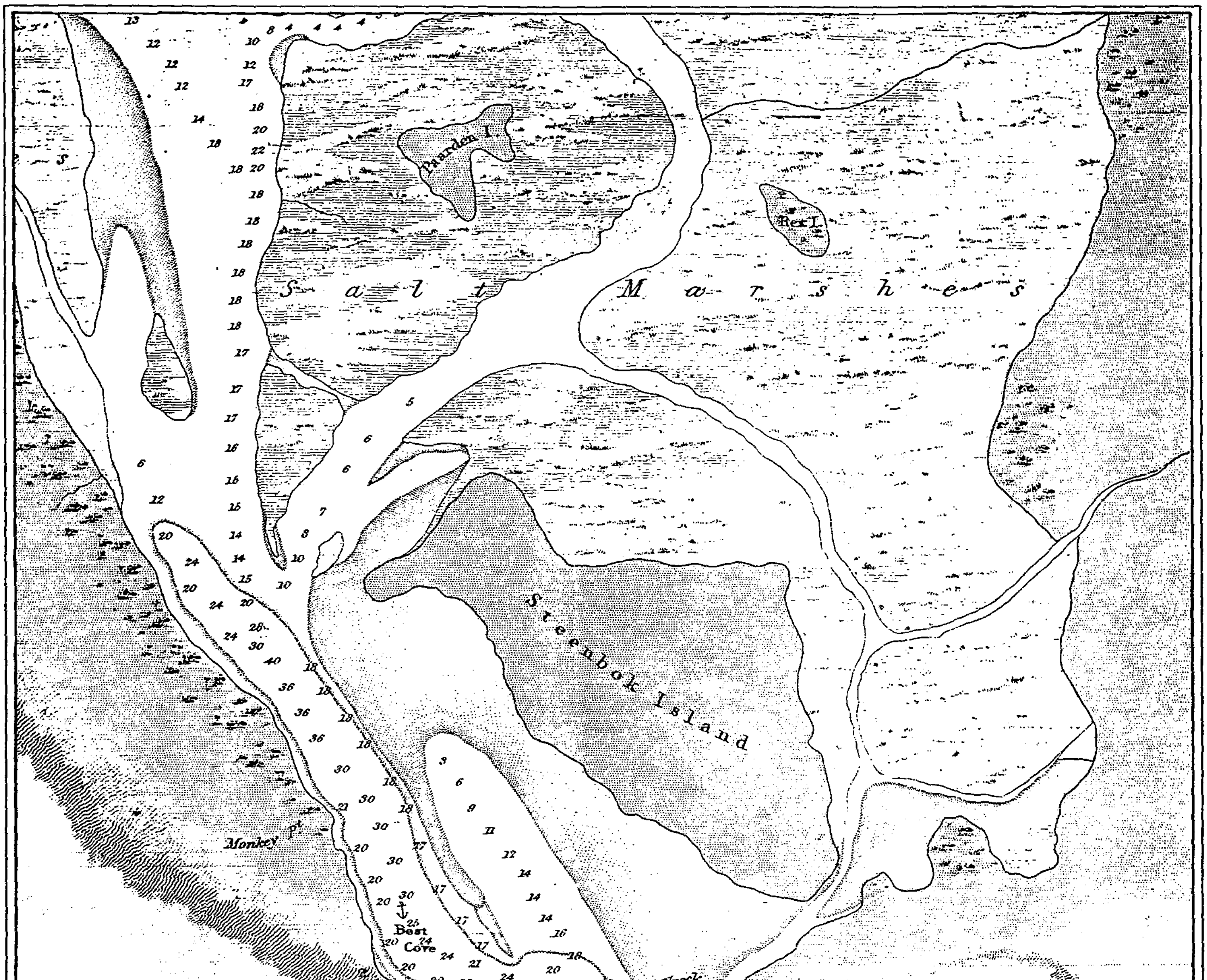

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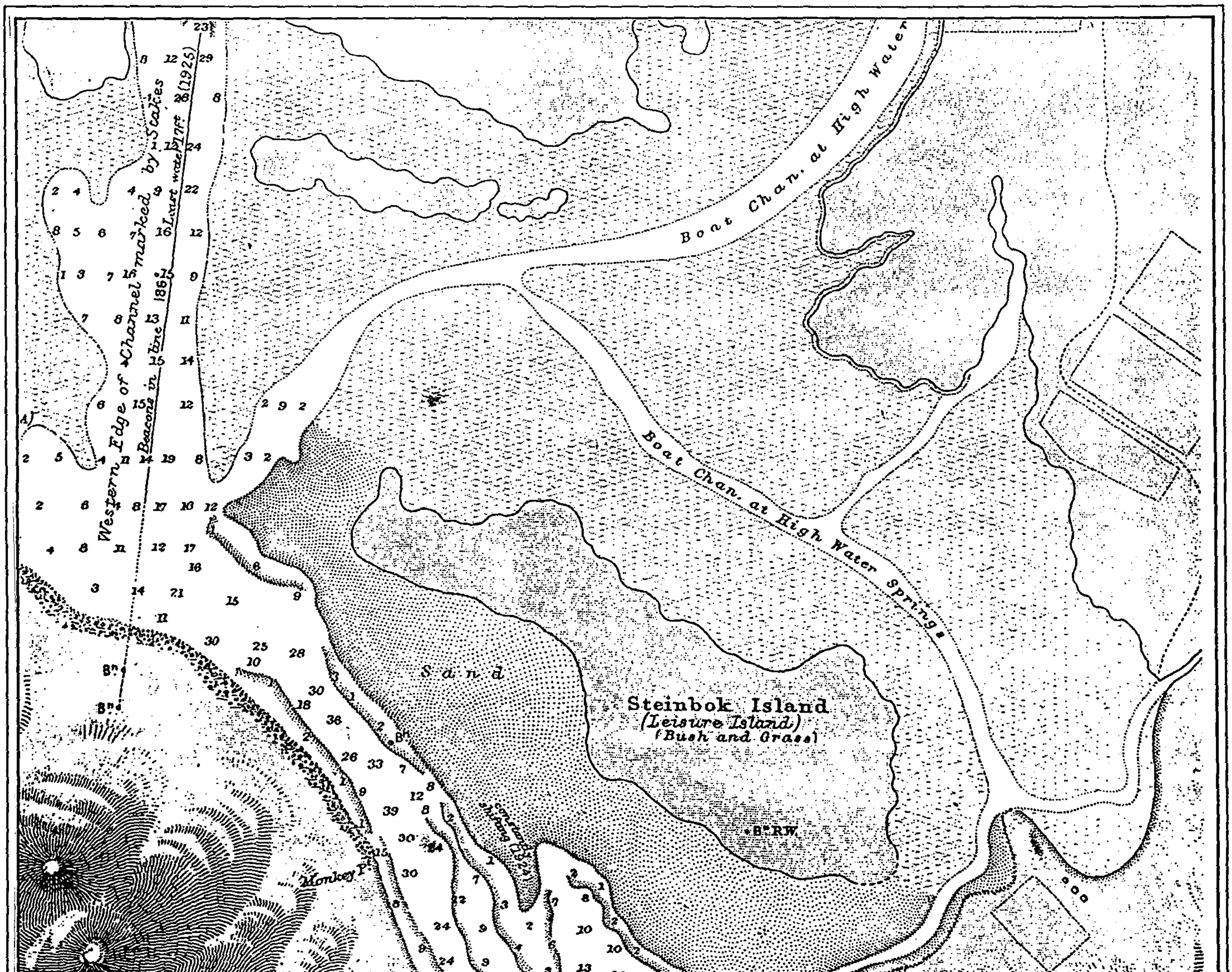

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KNYSNA GREEN HOLE

1864 MAP

FIGURE 10

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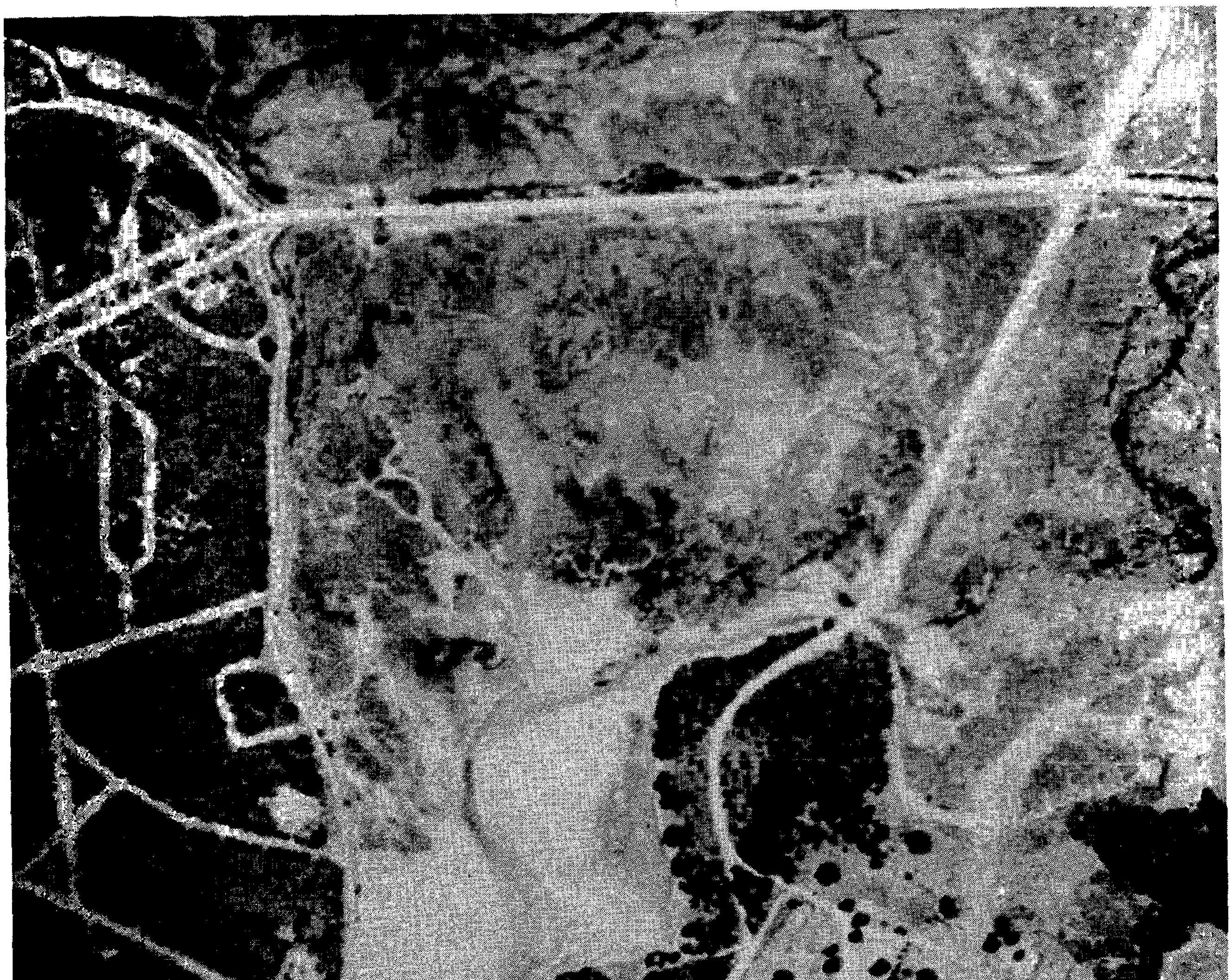

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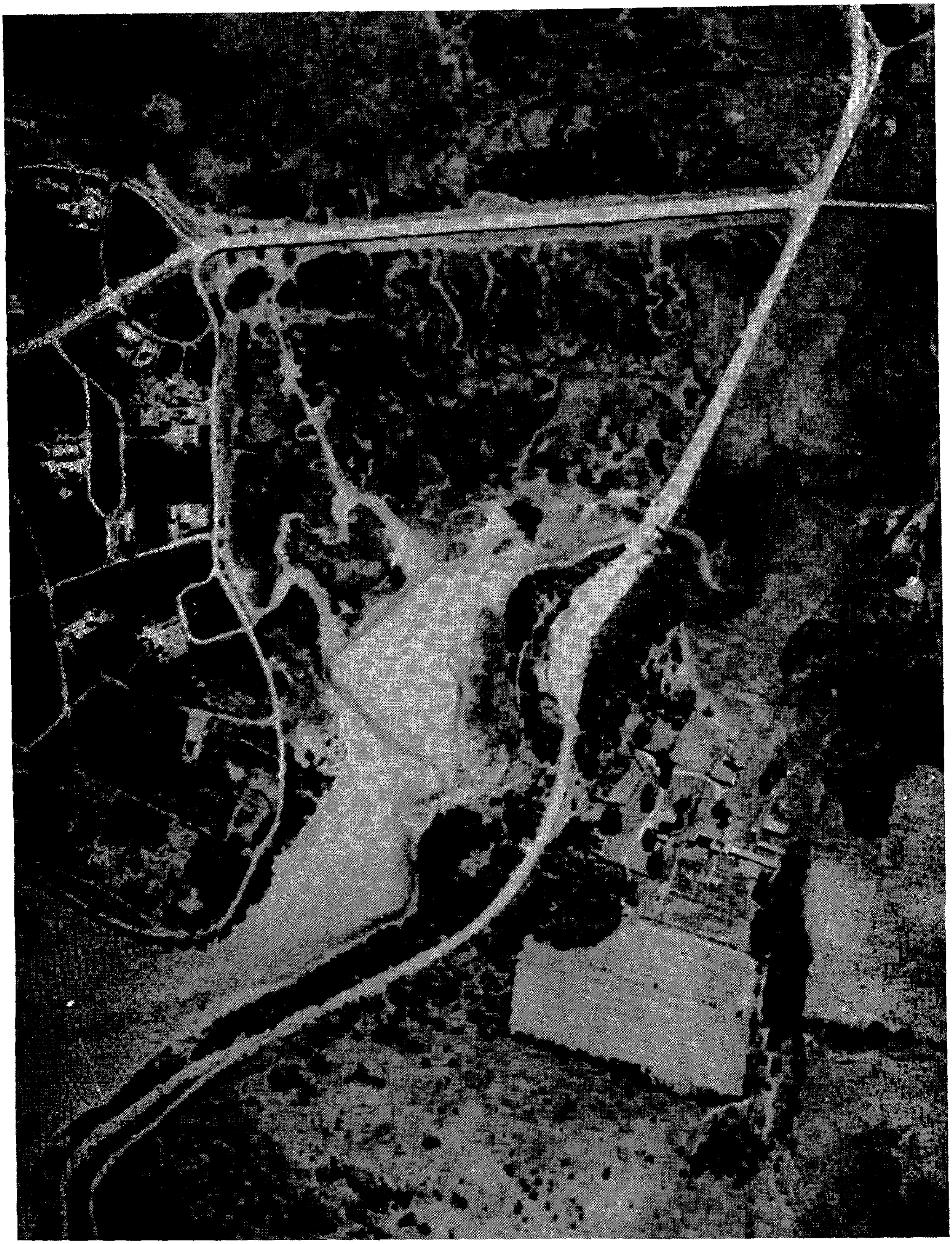
CSIR-EMA



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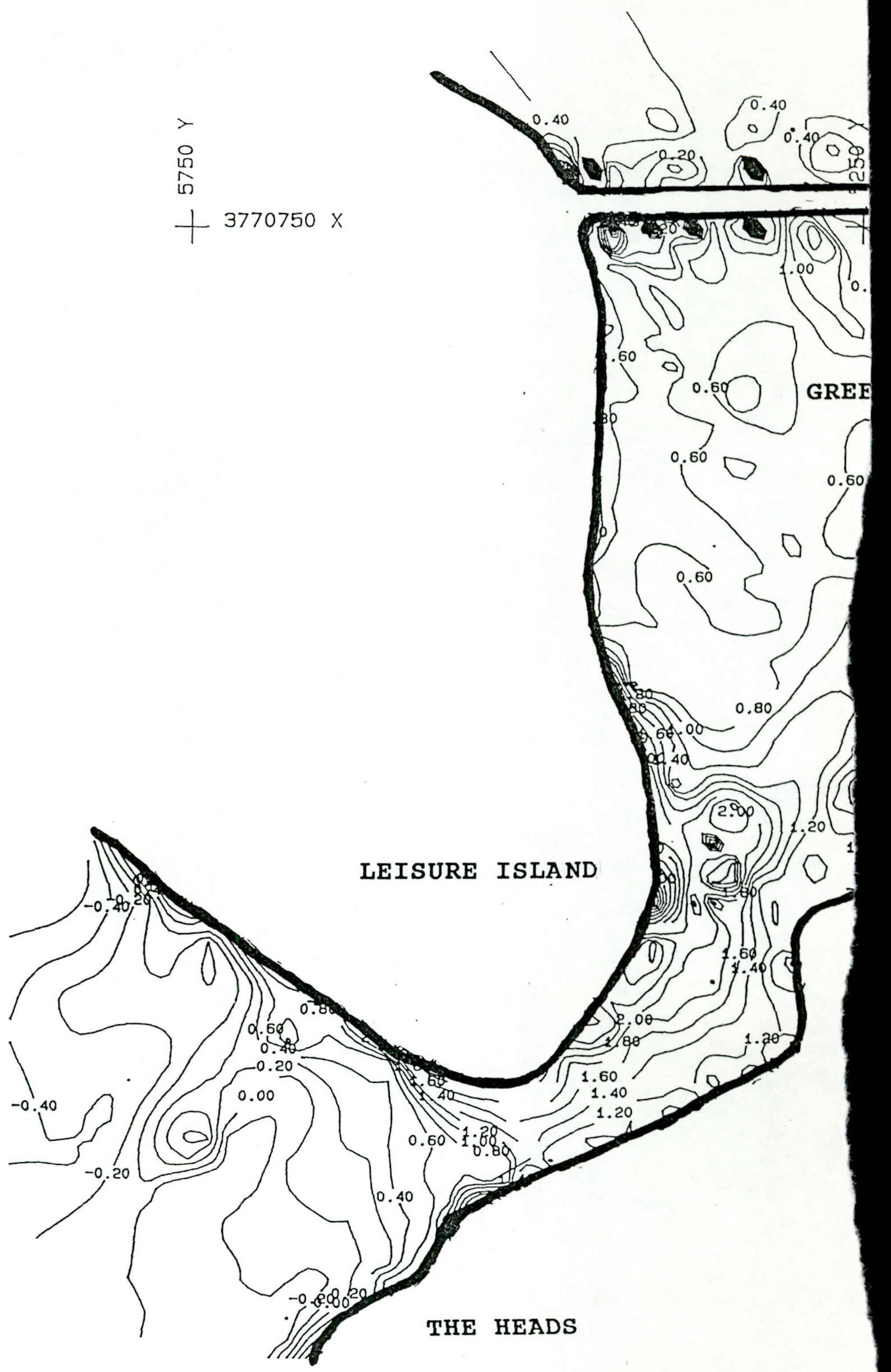

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KNYSNA GREEN HOLE

CONTOUR MAP - MAY 1988

FIGURE 17

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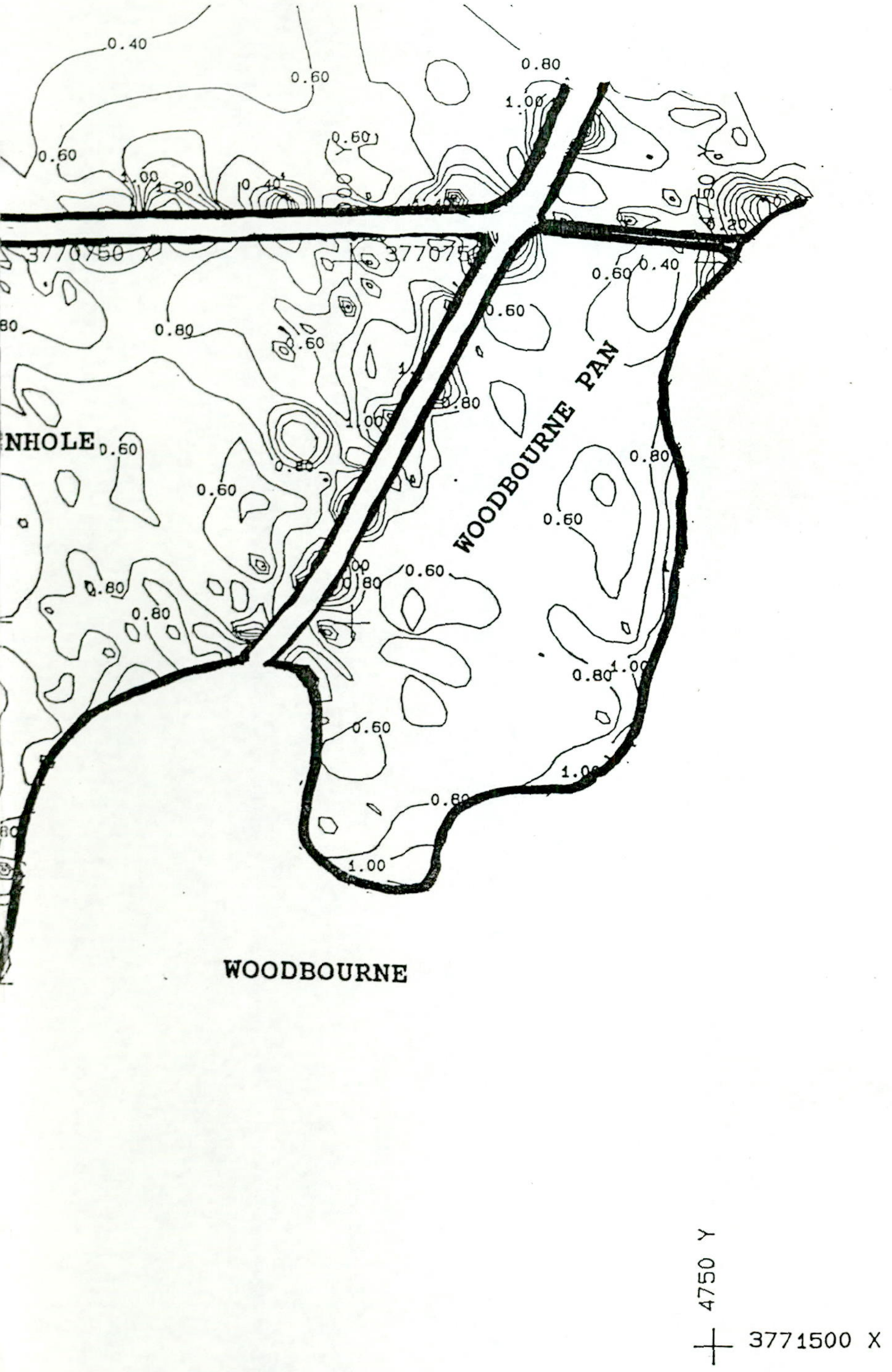

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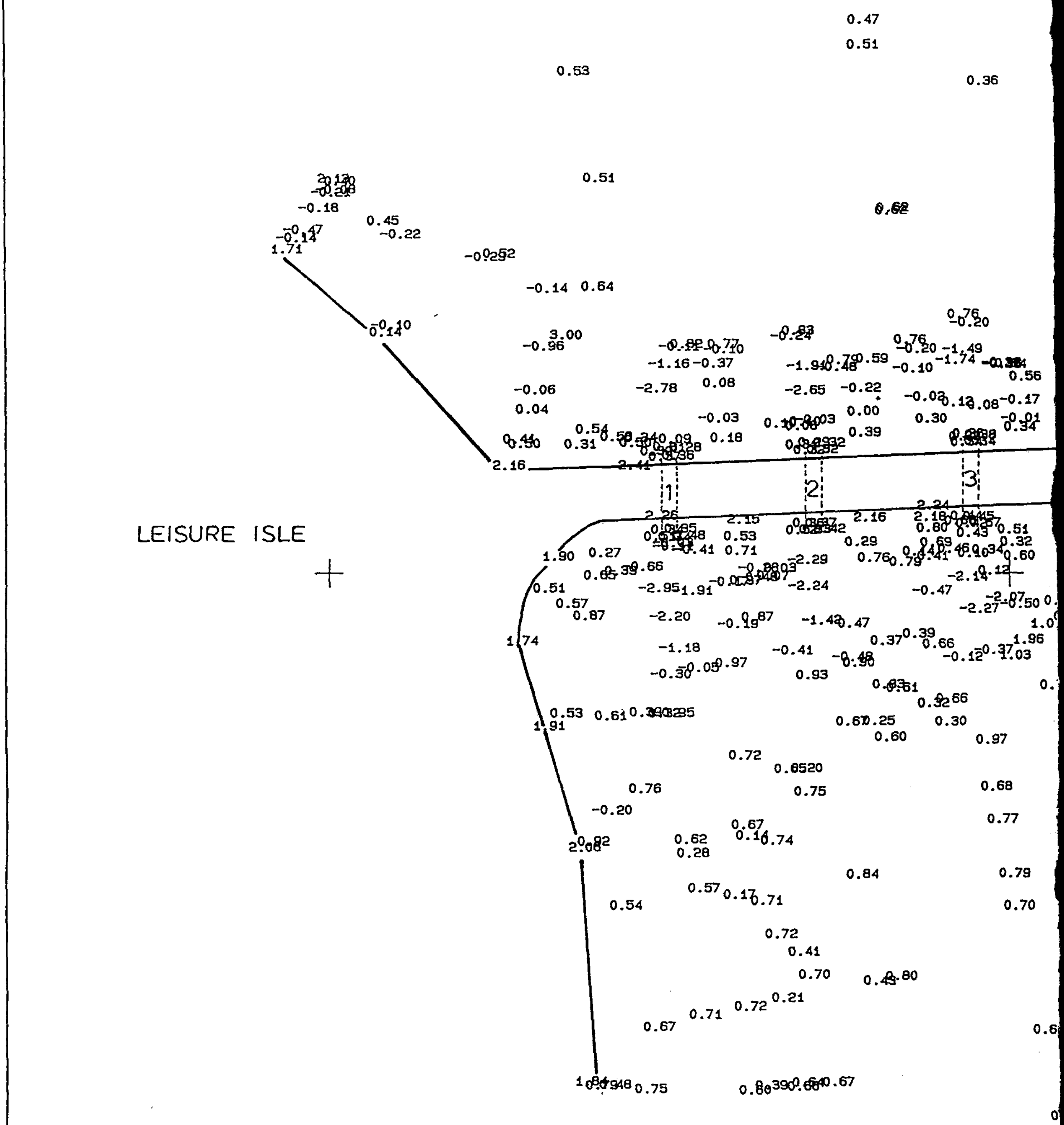

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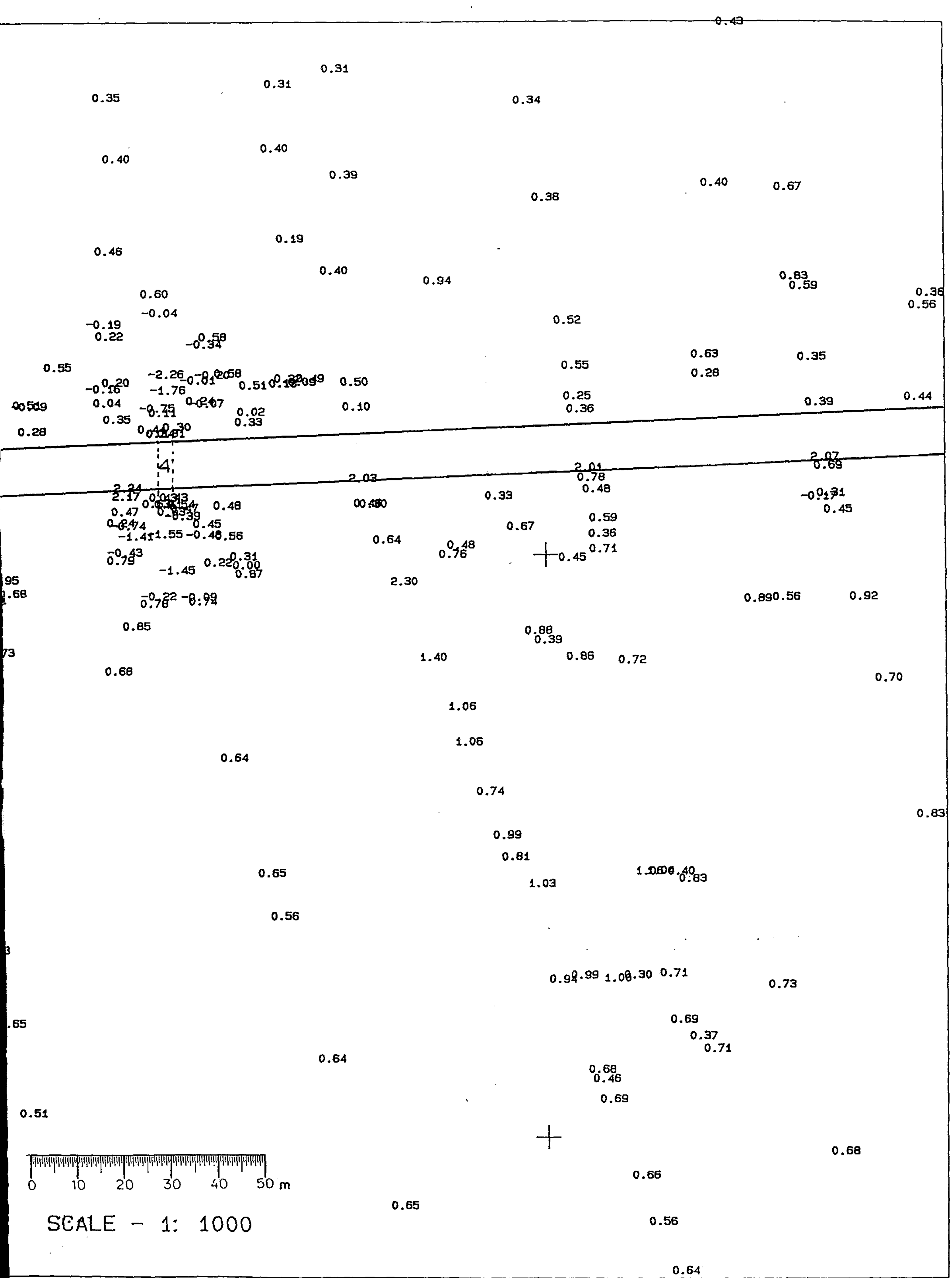
CSIR - DIVISION FOR EARTH, MARINE AND ATMOSPHERIC SCIENCE AND TECHNOLOGY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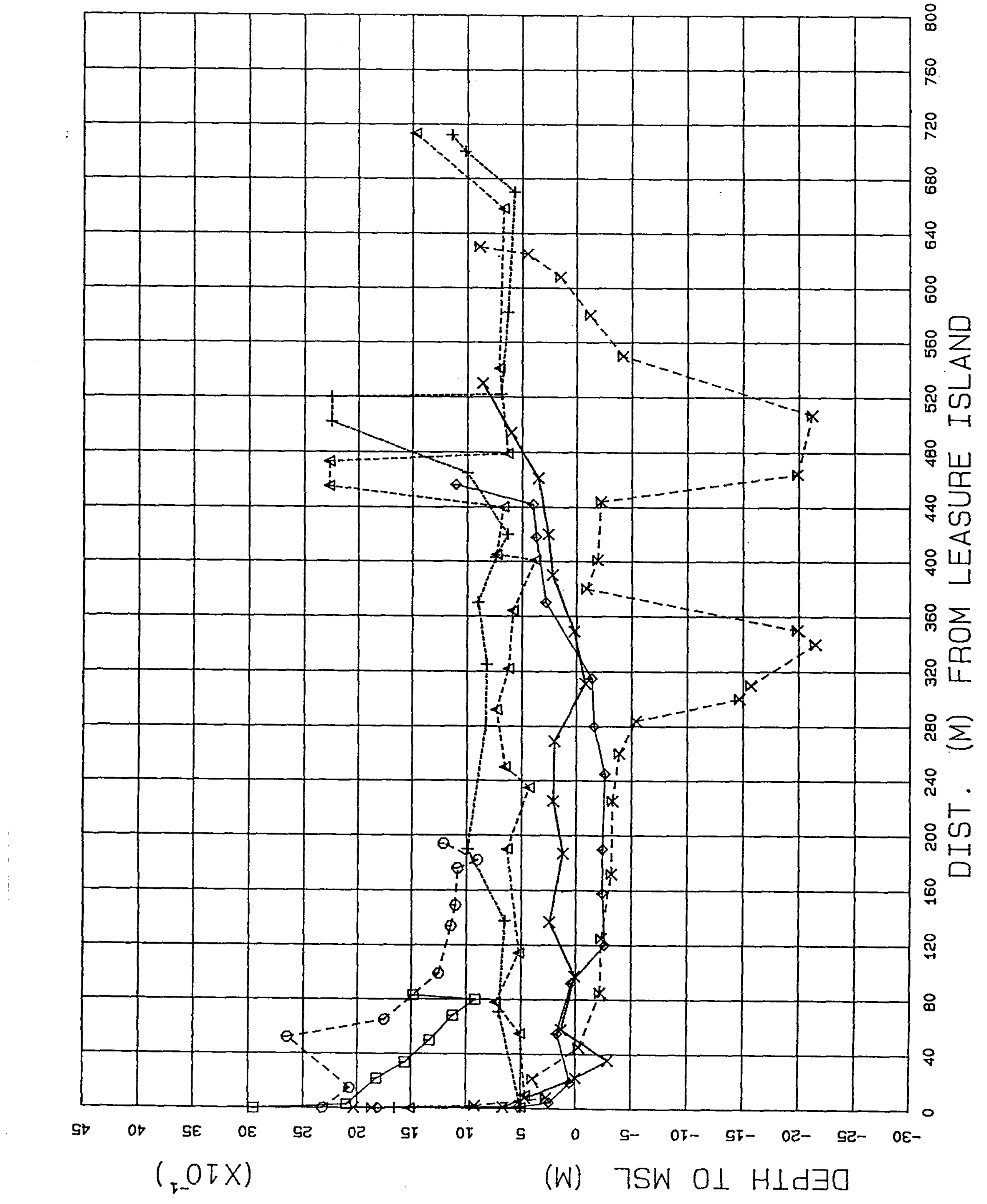

LEGEND : PROFILE 1
PROFILE 2
PROFILE 3
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PROFILE 7

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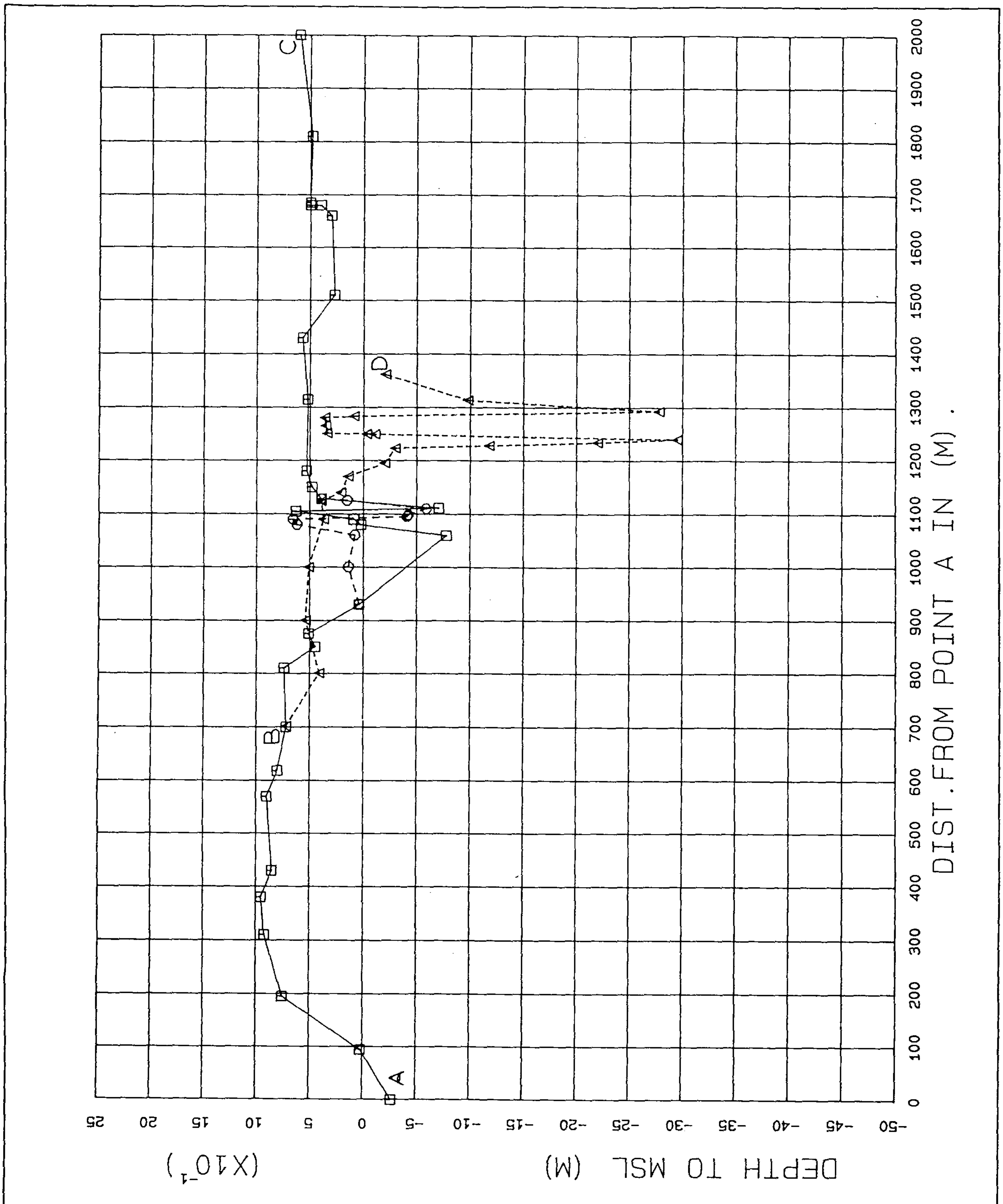

LEGEND : ABC PIPE
ABC CULVERT
BD CULVERT

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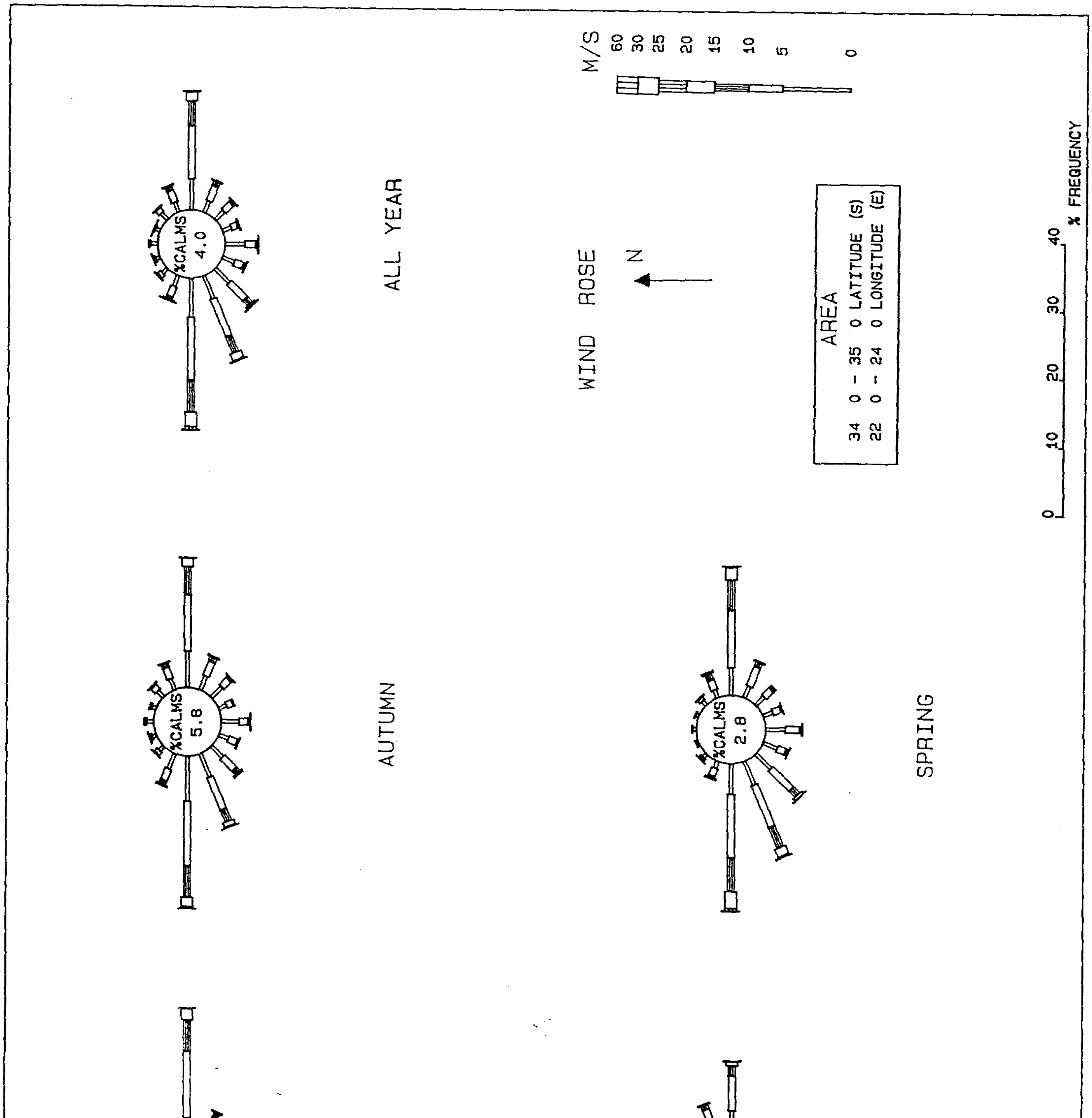

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