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CSIR REPORT
EMA-C 8899

AN EVALUATION OF THE EFFECTS OF THE CONSTRUCTION OF A VIADUCT ACROSS THE TIDAL FLATS IN THE VICINITY OF THE WHITE BRIDGE, KNYSNA

submitted to
SCOTT AND DE WAAL INCORPORATED

October 1988

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CSIR

DIVISION FOR EARTH, MARINE, ATMOSPHERIC SCIENCES AND TECHNOLOGY

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DIVISION OF EARTH, MARINE AND ATMOSPHERIC SCIENCE AND TECHNOLOGY

COASTAL PROCESSES AND MANAGEMENT ADVICE PROGRAMME

AN EVALUATION OF THE EFFECTS OF THE CONSTRUCTION OF A VIADUCT ACROSS THE TIDAL FLATS IN THE VICINITY OF THE WHITE BRIDGE, KNYSNA

SCOPE

The CSIR was requested by the consulting firm, Scott and De Waal, to investigate the environmental implications of using a viaduct rather than the present road embankment to traverse the salt marshes in the vicinity of the *White Bridge* across the Knysna lagoon. Aspects which are addressed in this report include an assessment of relevant hydrodynamic, topographic and ecological parameters which could influence the choice of construction design.

The physical environment of the estuary and the area affected by the road embankment is discussed in Section 2 and this is followed by a statement of the alternatives, constraints and impacts in Section 3. The ecological implications of the alternatives are discussed in Sections 4 and 6 and a number of recommendations are provided in Section 7. A brief analysis of the possible road failure mode under extreme tidal and flood conditions is provided in Section 5.

The report was compiled by M Burns and A Heydorn of the Coastal Processes and Management Advice Programme, with contributions from P Huizinga, L van der Merwe and A de Wet of the same Programme. The flood hydrograph was compiled by the Hydrological Research Unit of Rhodes University.

D H SWART
PROGRAMME MANAGER

Stellenbosch, South Africa
October 1988.

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SUMMARY

* The report assesses some of the environmental impacts of the proposals for constructing a viaduct across the salt marshes in the upper reaches of the Knysna lagoon. The ecological and hydrodynamic implications of retaining or removing part of the existing road embankment are addressed.

* In addition to its importance as a natural feature landmark, the estuary supports a rich and diverse biota which require that the system is managed according to sound conservation principles.

* Sedimentation processes play an insignificant role in the functioning of the Knysna lagoon system as a whole due to the geological characteristics of the catchment and the lack of a large input of sediment from the sea. The distribution of mud is confined to areas where local run-off drains adjacent Mesozoic deposits and where artificial structures such as the N2 road embankment retard flow velocities and cause suspended material to settle out.

* An historical airphoto study shows that, apart from blocking the original channels which drained the marsh immediately upstream of the N2 road, the embankment has had little influence on the basic configuration of the mudflats, salt marshes and main river channel in the nearby vicinity. A vertical accretion of approximately 0,3 m has, however, occurred within the marshes since construction of the embankment.

* The survey that was made of the affected marshes and a control area a short distance downstream of the embankment shows the stepped topography that has resulted due to the sediment accretion. The contour elevations show, however, that adequate lateral flow can still occur within the affected marshes during normal tidal exchange.

* The hydrodynamic model test results show that the maximum predicted water levels during a 1:100 year flood will be considerably lower than the minimum levels of the embankment, even if a flood co-incides with a spring high tide. The structure should therefore be able to easily withstand such extreme conditions. The significance of the proposed option to remove part of the embankment beneath the planned viaduct will be the increased flow velocities that will occur through the breached area under extreme conditions. Without bottom protection measures, this flow is likely to cause considerable erosion scour at the downstream opening and cause the development of a channel through the salt marsh.

* The aim of the ecological survey was to test whether the presence of the embankment has induced a response within the marsh which is reflected in obvious physical and biotic differences between affected and unaffected areas of marshland.

- No differentiation could be made between the three study sites on the basis of the present phytosociology of the salt marshes and the dominant and sub-dominant macrophyte species were shown to occur throughout. It is likely that some change may have occurred to the relative dominance of the various species but in the absence of detailed historical data, this cannot be quantified.

- The results of the macrofaunal study suggest that the affected marsh may be slightly impoverished relative to the control area but it is not possible to state whether this is significant or not. The diversity and abundance of the dominant species were not markedly different between the sites.

- Differentiation can be made between the studied areas of marshland on the basis of gradients in the physical environment. Major factors responsible for this include higher clay and organic contents, increased elevation and increased salinity of the affected marsh substratum.

- On the basis of the biotic response to the modified environment it can be inferred that an equilibrium now exists which does not differ *significantly* from the situation that prevailed prior to the construction of the embankment. The status of the area is therefore ecologically sound.

* Of the four management options that have been presented, only two are ecologically acceptable.

- The "least management" option implies retaining the embankment in more or less its present state, which will maintain the present acceptable ecological equilibrium within the affected area. The complete removal of the embankment will initiate a restoration process towards the natural situation, which existed before the embankment was built and which can be stated as an ideal conservation objective.

- Some doubt exists as to whether the two other proposed management alternatives will represent a significant improvement to the present situation. The removal of a part of the embankment will not restore the natural ecological equilibrium and if only a narrow opening is created, significant disruption could occur, particularly during a flood event. The conservation objective would not be achieved.

* It is inevitable that the final management decision will have to be largely based upon the cost and aesthetic implications of the proposed management alternatives. Should the option to retain the embankment in its present state be chosen, however, this should not be regarded as mitigation for the future construction of such structures across other estuaries. Rather, it will illustrate how difficult it can be to reverse past management actions due to the severe cost implications involved.

* Detailed recommendations with regard to procedures to be followed during construction can be provided once a decision has been taken with respect to the most cost-effective management or construction alternative. Aspects that will have to be addressed in due course include: The provision of guidelines that will ensure the least ecological disruption during construction; the establishment of precise excavation levels if the embankment is to be removed; where necessary, careful re-instatement of the natural drainage channels through the marsh; the prescription of optimal rehabilitation measures, including the possible artificial re-establishment of seriously impacted salt marsh; and the initiation of a monitoring programme to measure the effects of the chosen management option in order to assist in future management decisions of a similar nature; in the event of the present embankment being retained, treatment of its slopes to make it more acceptable in the aesthetic sense.

1. INTRODUCTION

1.1 Background and Brief

The routing of the road system through and around Knysna, as part of an ongoing programme of upgrading of the N2 between Port Elizabeth and Cape Town, has been a controversial topic for a long time. On the one hand a major road artery through Knysna was seen as a barrier between the town and its greatest asset - the lagoon. On the other hand it was realized that road widening and bridge construction would be impossible without at least some impingement upon the ecologically important saltmarshes and floodplains of the lagoon system. Every effort would have to be made to limit such negative impacts to a minimum.

The region where the Knysna River enters the lagoon system is a case in point. The so-called "White Bridge" crosses the main channel of the river at the western edge of an extensive saltmarsh which also serves as floodplain. The bridge is about 200 m in length and it is connected with the higher ground to the east via a solid embankment with an elevation of 4,20 m to MSL and 650 m long (Figures 1 and 2). This eastern approach to the bridge is curved and receives traffic from the town via a road hugging the edge of the lagoon. The eastern approach was constructed in the early 1940's and no provision was made for culverts to facilitate tidal exchange between the two sides of the floodplain divided by the embankment.

The National Parks Board (NPB) is now responsible for the ecological management of Knysna Lagoon. Consequently considerable discussion took place between representatives of the NPB, the National Transport Commission (NTC), the NTC's road-building consultants Scott and de Waal Incorporated (S & de W) and the landscape architectural firm Dennis Moss and Associates (DM),as to how negative environmental impacts of the upgrading of the road through Knysna, could be reduced to a minimum.

The present report deals with the section of the road crossing the Knysna River and its floodplain over a distance of some 850 metres. The brief given to the Division of Earth Marine and Atmospheric Sciences and Technology (DEMAST) of the CSIR by S & de W, was to investigate the environmental implications of using a viaduct rather than the present embankment to carry road traffic from the White Bridge eastwards. Although following the approximate alignment of the embankment, the viaduct would be elevated above it. Instead of connecting with the road along the lagoons edge, it would carry straight on into a ravine to give access to a higher road which would join the existing road into Knysna near the railway line across the lagoon. In this manner the negative ecological impacts of widening the road hugging the lagoon's edge could be reduced to a minimum. Specific aspects to be addressed by DEMAST were:

i) If, subsequent to construction of the viaduct, the embankment were to be removed partically or completely, would the hydrodynamic characteristics of the Knysna River in its region of entry into the lagoon be altered significantly?

ii) If so, could the present bridge or the piers of the new viaduct be endangered by altered flow patterns, especially during extreme events such as a 1:100 year river flood, especially if this were to co-incide with an unusually high tide?

iii) Has the eastern approach embankment, which is now more than 40 years old, led to a change in levels of the floodplain on either side of the embankment?

iv) If so, would partial or complete removal of the embankment lead to a change in the present physcial and ecological equilibrium of the floodplain? Could changes in the equilibrium be ecologically harmful?

1.2 Study site and *modus operandi*

The study site therefore encompasses the region where the Knysna River enters the lagoon. It consists of the main flow channel of the river spanned by the White Bridge and the floodplain on either side of the eastern approach embankment. The floodplain consists of saltmarshes which are inundated at high tides and during floods. These marshes offer a range of habitats because of the presence of a number of plant and animal communities which have adapted to localized conditions such as higher or lower ground, channels, type of substratum and degree of inundation.

Following discussions with Mr R Hales of Scott and de Waal on 7 September 1988, the following *modus operandi* was adopted by DEMAST:

i) An analysis of historical aerial photographs taken between 1942 and the present time was undertaken to determine whether the extent and shape of the floodplain had changed with time or under the influence of the embankment. This included tracing of the major channels discernible in the saltmarshes.

ii) The hydrodynamic characteristics of the study site were determined using the CSIR's existing mathematical model for the Knysna estuarine system. Two scenarios were tested by these means:

- a simulation under springtide conditions without any river inflow;

- a simulation for the same springtide but with a 1:100 year riverflood occuring simultaneously.

iii) With this background a field investigation was undertaken on 27 and 28 September 1988 during which the following was done:

- the levels on either side of the embankment were surveyed for purposes of obtaining accurately plotted transects and a contour map of the marsh. Furthermore an area further south in the lagoon, i.e. beyond the immediate influence of the bridge and its embankment, was surveyed for comparative purposes;

- as complete a range of saltmarsh habitats as possible were investigated in terms of the composition of plant and animal communities, on either side of the embankment and in the comparative area further south.

These various facets of investigation gave a comprehensive picture of the study site and the natural processes operative within it. On this foundation, it is possible to assess the environmental implications of the various options which could be followed during the construction of the viaduct.

2. THE PHYSICAL ENVIRONMENT

2.1 Estuary Characteristics

The Knysna estuary is one of the largest estuaries in South Africa and represents an ecosystem with many unique characteristics. It is very well known as a natural feature landmark and much concern has been shown for its preservation and future management.

The general ecology of the Knysna estuary or lagoon has been described *inter alia* by Day (1967, 1981), Grindley (1976, 1985), Grindley and Eagle (1978) and Grindley and Snow (1983). Various physical aspects of the system are also described by Chunnett (1965), NRIO and VISKOR (1980), Huizinga (1985) and Reddering and Esterhuysen (1984). The review which is provided below has been extracted from these sources.

Although the catchment of the estuary is relatively small, the annual rainfall and run-off are high. The water quality entering the estuary is good and in spite of the relatively steep catchment gradient, is relatively silt-free and has a low mud content. Factors responsible for this include the catchment geology, which is predominantly quartzite of the Table Mountain Group, and the well preserved state of the catchment which is either under indigenous forest, fynbos or plantations.

The mouth of the system at the heads remains permanently open and the tidal limit extends some 17km up to the Charlesford rapid. Above the *White Bridge* and the National Road crossing, the system has true estuarine features due to the fresh water influx from the Knysna River. Further downstream, it forms a lagoon or marine embayment which, however, supports a predominantly estuarine biota.

Sedimentation processes play an insignificant role in the functioning of the Knysna estuary. The rocky headlands at the mouth and the deep offshore coastal water prevent the longshore transport of sediment and there is thus at present a negligible input of sediment from the sea. Reference has already been made to the catchment geology which limits the input of terrestrial sediments.

The estuary substratum or floor is predominantly sandy, with the coarser material occurring within the subtidal channels and the finer fractions distributed over the intertidal and supratidal flats. The distribution of mud is confined to areas where local run-off drains adjacent Mesozoic deposits and where artificial embankments, such as the National Road crossing, retard flow velocities and cause suspended material to settle out. Reddering and Esterhuysen (1984) consider the mudflats at the road embankment to be recent deposits and have found that they overly well compacted sand at a depth of less than 0,5 m.

Zostera capensis and *Halophila ovalis* are the dominant aquatic macrophytes, while several semi-aquatic species comprise the saltmarshes which occur either as a fringe around the estuary or in larger expanses on the intertidal flats. *Spartina maritima* occurs extensively at the lower and mid tidal levels and species of *Sarcocornia*, *Triglochin*, *Chenolea*, *Limonium* and *Plantago* predominate at the upper saltmarsh limits. With the low phytoplankton levels evident within the estuary, *Spartina* and *Zostera* are considered to be the most important primary producers.

The benthic macrofauna is extremely rich and diverse, with *Upogebia africana*, *Arenicola loveni*, *Solen corneus* and *Altrina squamifera* and various gastropods plentiful throughout. *Sesarma catenata*, *Cleistostoma spp.* and other crabs occur commonly within the saltmarshes and the benthic communities reflect the high levels of primary production within the system.

2.2 Hydrodynamic Aspects

Two tests were carried out using the CSIR mathematical model of the Knysna lagoon to illustrate the hydrodynamics at the *White Bridge* (Huizinga, 1985). A simulation was made of a springtide tidal condition with no river inflow and the test was repeated for the same tidal conditions but with a 1:100 year river flood. The flood hydrograph, with a maximum flow of 822 m^3/s, was roughly estimated by the Hydrological Research Unit at Rhodes University and the results of the tests are shown in Figure 3.

For the test under normal conditions, the water level difference on either side of the bridge is at all times less than 0,03 m and the maximum flow rate under the bridge is about 120 m^3/s. Under the flood conditions, the maximum water levels up- and downstream of the bridge are + 1,80 and + 1,26 m relative to MSL respectively. The maximum drop in water level across the bridge is 0,65 m and the maximum flow rate is 840 m^3/s (Figure 3). The model was not calibrated for flood conditions but these results are nevertheless indicative of what can be expected.

Under normal tidal conditions, the flow is concentrated in the main channel and the *White Bridge* does not really cause any extra obstruction to this flow. The salt marshes on either side of the embankment are elevated at a level of approximately + 0,70 m above MSL and are periodically flooded at high tide.

Under the 1:100 year flood conditions, the embankment becomes a considerable obstacle to the river flow but the maximum water levels at the bridge are still considerably less than the level of the embankment of the eastern approach road, which at its lowest is at + 4,20 m above MSL (*Scott and De Waal*, Plan 8011/R66 and confirmed during this study).

2.3 Historical Changes

In order to assess part of the physical impact of the *White Bridge* and road embankment on the adjacent marshland and on the position of the main channels of the estuary, a photographic analysis was carried out of the historical changes that have occurred since construction. The situation that existed during 1942, 1958, 1973 and 1987 is reflected in Figures 4(a)-(d), which have been traced to similar scale from the respective aerial photographs using a transferscope. Due to the different tidal states when the photographs were taken, it is difficult to use such tracings to establish absolute changes that may have occurred but they can nevertheless reflect any major trends and changes. A brief description of each tracing is provided below:

1942: The construction of the *White Bridge* and road embankment has been started, with minimal impact to the marsh Figure 4(a). The marshland which the embankment will traverse is still comprised of a single unit and appears to be similar in nature to the marsh along the right bank of the estuary. A narrow apron of sediment is evident along the left bank of the estuary between the marsh and main water channel.

1958: The position of the *White Bridge* and road embankment is shown and any associated impacts since 1942 should be evident. Most conspicuous, is the marshland on the left bank which has been split into two units (Figure 4(b)). The low state of the tide has exposed a sediment or mud deposit downstream and adjacent to the eastern section of marsh while the apron of mud is also evident along the left bank of the channel adjacent to the western section of marsh. Due to the tidal difference between the two photographs used, it is not possible to state whether any extension to the natural mudbanks has taken place since 1942.

1973: This reflects the state at a higher tide than 1958 and little can be inferred from Figure 4(c). The apparent decrease in area of exposed mudflats along the left bank is considered to be an effect of the tide and not of the embankment.

1987: Due to the tide, much of the saltmarsh on either side of the road embankment was inundated with water and little can be deduced on the extent of the mudbanks (Figure 4(d)). The apron of mud adjacent to the eastern marsh on the left bank, shown in Figure 4(b) was not exposed above the water.

In spite of the difficulties in interpreting the photographs, due to the tidal effects, it can be stated that apart from the division of the saltmarsh on the left bank of the estuary by the road embankment, there has been no major apparent change to the configuration of the estuary channel, mudbanks and marshes.

2.4 Topographical Survey

The survey that was carried out is based on the co-ordinate system Lo 23° of the South African Grid Degree Square 3422 (Gauss conform projection). The heights of the survey are relative to mean sea level and the instruments which were used are a Kern DKM2 Single Second Theodilite and a Pulsar Electronic Distancemeter. The observations that were made were taken from the survey bench mark CH48600 (9ML) (+ 550,08 y + 3 766 513,58 x Level 5,024), as determined by *Scott and De Waal*, who are the consultant engineers.

Three transects, used during the ecological study, were surveyed initially and are indicated in Figure 5. Transect A is located to the north-west of the National Road (N2), while Transects B and C are located to the south-east. Transect C covers a *control area* some 350 metres downstream of the embankment, while Transects A and B cover the marshland that has been directly affected by the road construction.

The greater part of the survey covered the marshland immediately adjacent to the road and the density of the observations that were made is shown in Figure 7. A contour map was compiled from the data points (Figure 8) and a series of 3-dimensional images were produced for the marsh surface, where the vertical scale has been exaggerated to emphasize the measured topographical features (Figures 8(a)-(d)). The embankment contours have been excluded from Figures 7 and 8 in order to establish images of the marshland without the presence of the road.

The implications of the topography on the existing and future ecological equilibrium within the marsh is referred to briefly in Section 2.5 below and is discussed later in Sections 5 and 6, where its relevance to the management options is evaluated.

2.5 Ecological Survey

In order to establish a basis for evaluating the ecological significance of the proposed alternatives, it was considered necessary to carry out a field survey of the affected area. The aim of this was firstly, to assess the present situation with respect to the marsh topography (Section 2.4) and key biotic components, and secondly, to compare this with a similar marsh environment which has been unaffected by the embankment. An objective evaluation was then made of the survey data to test the following hypothesis:

"Construction of the road embankment has induced a significant ecological response within the marsh environment, which is reflected in obvious physical and biotic differences between affected and unaffected areas of marshland."

It was assumed that a negative result would indicate that a satisfactory ecological equilibrium now exists which does not differ significantly from the likely situation that prevailed prior to the construction of the embankment. The implications of removing part or all of the embankment can thus also be evaluated objectively on this basis and this aspect is discussed in Sections 5 and 6.

Methods

Three study sites were defined during the survey and they are indicated in Figure 10. The first comprises the marshland upstream, or west, of the road embankment; the second is the smaller area of marsh to the east of the embankment and the third represents a control area a short distance downstream, which is considered to have been relatively unaffected by the road construction.

Three transects, which were considered to accommodate the apparent variation represented within each area, were laid out across the study sites (Figure 5).

A systematic random sampling method was employed during the survey and most of the data was collected at pre-set 30 metre intervals along the transects. A 1 x 1 metre quadrat size was used to estimate vegetation cover of the aquatic and semi-aquatic macrophytes and standard Braun-Blanquet cover values were allocated to each species. Spot elevations were measured at the sampling points and representative surface (top 50 mm) sediment samples were taken. The samples were analyzed for salinity, organic content, percentage clay and the percentage sand fraction within various grain size classes. A limited number of sediment cores were also extracted at a few of the points.

The macrophyte data were arranged in a phytosociological table and the other physical environmental parameters were processed using *Principal Component Analysis* (PCA), which is a compatible multivariate analysis technique. One of the uses of PCA is the graphic illustration it gives of the existence of a possible environmental gradient, should such a gradient exist, since any strong directions of variation in the data matrix are likely to be reflected by the analysis. The information comprising the PCA two-way data matrix of *samples x associated physical characteristics* is presented in Table 1.

Following the phytosociological survey, during which the major macrophyte associations were identified, a quantitative assessment was made of the dominant benthic macrofauna within the study area. This was carried out using a 0,1 m^2 quadrat size to make burrow counts at eight random points within each marsh type and on the mud-flats and channels occurring in the three areas. *Upogebia africana* and *Cleistostoma edwardsii* burrows could not easily be differentiated from one another and were grouped together, while species such as *Sesarma catenata*, *Scylla serrata* and *Callianassa kraussii* were recorded as sampled.

Results

Vegetation Survey

A total of nine macrophyte species were recorded during the survey, some of which were exclusive to certain recognizable zones within the marshland while others occurred in species associations. Four major differentiating species can be identified in Table 2 and include *Juncus kraussii*, *Spartina maritima*, *Cotula coronopifolia* and *Zostera capensis*.

The arrangement of the releves in Table 2 does not show any significant differentiation between the three study sites and the dominant species are shown to occur throughout. *Juncus kraussii* is clearly the most ubiquitous element and of the total number of releves, has a constancy value of 59 percent (Plate 1). *Cotula coronopifolia* is the next most common species, followed by *Spartina* and *Zostera*, with constancy values of 9, 6 and 5 percent respectively (Plates 2 and 3). The releves are, however, grouped in Table 2 according to elevation, indicating that this physical parameter is of greater phytosociological significance than the position of the marshland relative to the road embankment. For example, the releves comprising the group *Juncus marshland* have a mean elevation of + 0,67 m (SD = 0,18) above mean sea level, while the *Cotula-*, *Spartina-* and *Zostera* groups shown in Table 2 are established at mean elevations of + 0,63 m (SD = 0,18), + 0,21 m (SD = 0,16) and + 0,22 m (SD = 0,05) respectively.

The distribution of the basic macrophyte communities is shown in Figure 10, which comprises part of a larger map compiled of the Knysna lagoon by Barker (1986). The scale of this map does not indicate the precise boundaries of the marshland types identified during the survey but it does provide a reflection of the relative dominance of each within the three study sites. *Juncus* marshland is shown to be most prevalent above the embankment, while *Spartina* appears to predominate elsewhere.

Principal Component Analysis

The percentage of the total variance accounted for by the first seven principal components is given in descending order in Table 3. The first, second and third components account for 43, 19 and 12 percent of the data variance respectively and with a cumulative total of 74 percent, were considered to be the most suitable for gradient interpretation.

The component scores for 41 of the sampling sites were used to plot the points about the first and second and first and third Principal Component axes (Figures 11 and 12). A number of trends are clearly evident on the ordination diagrams, which reflect environmental gradients differentiating the three areas of marshland which were sampled.

Two groups can be identified in Figure 11. *Group A* is comprised of the sample points within the *control* marsh, downstream of the embankment, while *Group B* is comprised of those points sampled within the impacted marshland. The differentiation is made along the first Principal component axis and the scoring coefficients of the environmental variables which are responsible for the gradient include: *percentage clay*, *percentage organic content*, *percentage medium sand content* and *salinity* (Table 4).

It can be seen from the data matrix table (Table 1) that the points within the impacted marsh areas had high mean clay contents (74,5 and 61,3 percent), high mean total organic contents (8,7 and 9,3 percent), low medium sand contents (11,4 and 21,4 percent) and high mean soil salinities (27,3 and 39,5 °/00). In contrast, the points within the control marsh had a low mean clay content (30,6 percent), a low mean organic content (3,8 percent), a high medium sand content (31,6 percent) and a low mean soil salinity (17,1 °/00).

Two groups can also be identified in Figure 12, where the differentiation is made along the third Principal Component axis. *Group C* is comprised of points sampled predominantly within the marsh upstream of the embankment, while *Group D* is comprised of points sampled predominantly within the marsh immediately adjacent to the embankment but downstream of it. The points sampled within the *control* area are differentiated from these two groups but the gradient along Axis I, which is responsible for this has been discussed above. The scoring coefficients responsible for the gradient include: *salinity, very fine sand content* and *elevation* (Table 4).

From the data matrix provided in Table 1, it can be seen that the western, or upstream, marshland recorded a lower mean soil salinity (27,3 percent), a higher mean percentage very fine sand content (0,15 percent) and a higher mean elevation (+ 0,71 m above MSL). In contrast, the marshland downstream of the embankment recorded a higher mean soil salinity (39,5 °/00), a lower mean percentage very fine sand content (0,08 percent) and a lower mean elevation (+ 0,49 m above MSL).

Macrofauna Survey

The results of the macrofauna survey are presented as histograms in Figures 13(a)-(d), where the burrow density of the various species occurring within the different marsh or environment types are plotted for the three surveyed areas. Where one or two of the areas do not appear on a specific histogram, this indicates that a particular marsh type was either not represented on the site or was not sampled.

Of the nine habitats that were sampled, complete sets of densities plus approximate elevations, where the eastern, western and control areas could be compared, were obtained for four habitat types only. These were:

Zostera beds
Juncus marshes
Cotula marshes
Mud Banks

For each of the above four habitats, the comparitive densities were obtained for two burrow types - *Upogebia africana/ Cleistostoma edwardsii* and *Sesarma catenata*. The results of the sampling exercise showed a number of *trends* from which interpretations can be made. These trends rather than the actual recorded densities, are of significance.

In all cases, with the exception of *Sesarma catenata* within the mud bank habitat, burrow densities on the eastern, or downstream, side of the embankment were greater than on the western side. These results could be attributed to elevation differences between equivalent eastern and western habitats, where, for example, sampled eastern habitats were at a slightly higher elevation than western habitats or may reflect some other differentiating environmental parameter.

The similarity in densities of *S. catenata* within the mud banks of the eastern and western areas could reflect a similar environment for the two areas. This species is, however, generally more abundant towards the high water neap tide mark and thus, densities within the sampled western habitat, which was somewhat lower than the equivalent eastern site, may have been higher. The results therefore indicate that a healthy environment exists within the impacted marsh.

Burrow densities for the species within the control area were either less than at the eastern site but greater than the western site or greater than both of the latter counts for *Zostera* beds, *Juncus* marshes, *Cotula* marshes and mud banks. This trend did not appear to be related to elevation differences, suggesting that the western habitats may be somewhat impoverished.

Burrow densities recorded in the *Sarcocornia/Chenolea*, *Triglochin/Limonium* saltmarshes and sandy channels and on vertical mud banks cannot be compared directly for the three sites. They do, however, provide some indication of the presence of the recorded species within the habitats that were sampled.

Discussion

The objective of the ecological survey was to test the hypothesis: "*that the construction of the road embankment has induced a significant ecological response within the marsh environment, which is reflected in obvious physical and biotic differences between affected and unaffected areas of marshland.*"

The results of the study show that differentiation *can* be made between the studied areas of marshland on the basis of variation or gradients in the physical environment. The Principal Component Analysis indicates, for example, that the sediment of the affected marshland has a higher clay and organic content than the unaffected area due to the siltation that has been caused by the embankment. Also, an increase in mean elevation of the affected marsh and an associated increase in soil salinity through evaporation and salt accumulation is another significant environmental modification that has become established.

It is certain that these changes in environment have induced some biotic response within the marsh communities and this aspect is discussed briefly in Section 5 below. However, neither the phytosociological- nor the macrofaunal surveys show a significant differentiation between the affected and unaffected areas of marshland. The results indicate, for example, that the dominant and sub-dominant macrophyte species occur throughout and that although some variation between the dominant macrofauna of the three marsh areas was observed, these differences are not conclusively significant. The general trend shown by the results of the faunal survey suggests that the marshes to the west, or upstream, of the road embankment may be *slightly* impoverished relative to both the eastern marsh and the control area. An improved sampling technique and a statistical analysis of the data would, however, be required to test whether or not the observed differences are significant and whether, in fact, they are due to the presence of the embankment.

From a biotic aspect, it can therefore be inferred that an equilibrium now exists which does not differ *significantly* from the likely situation that prevailed prior to the construction of the embankment. The tolerance ranges of both the plant and faunal communities have allowed them to persist in spite of the environmental changes that have occurred and the proposed hypothesis does not therefore appear to be true. It can therefore be assumed that an ecologically acceptable situation now prevails within the affected marshland.

3. STATEMENT OF ALTERNATIVES CONSTRAINTS AND IMPACTS

It was stated in the Introduction that various options need to be considered in the planning of the viaduct across the Knysna River Floodplain. Referring to Figures 1 and 2, these can be outlined as follows:

Option 1: BUILD THE VIADUCT BETWEEN CHAINAGES 48760 AND 49300 AND LEAVE THE ENTIRE EXISTING EMBANKMENT IN PLACE

This would be the cheapest option and would imply that the existing hydrodynamic regime and ecological equilibrium of the saltmarshes on either side of the embankment would remain unchanged. Ecologically this option is perfectly acceptable and as will be shown in Section 4 it will not lead to the danger of failure of the embankment, the viaduct or the White Bridge under extreme conditions. A debateable constraint would be an aesthetic one, but the appearance of the embankment could be softened considerably by suitable treatment of its sloping sides.

Option 2: BUILD THE VIADUCT BETWEEN CHAINAGES 48760 AND 49300 BUT REMOVE THE EXISTING EMBANKMENT BETWEEN CHAINAGES 48760 AND 48940

This option would be more expensive than Option 1 but would create a situation in which increased tidal exchange across the floodplain would be possible at times of high water levels.

Constraints would be:

- the debateable questions of the aesthetics of "an embankment with a gap in it";
- the question of whether water flow through the gap could lead to scour and damage of the viaduct pier foundations;
- disturbance of the present ecological equilibrium of the saltmarshes on either side of the embankment.

Option 3: EXTEND THE VIADUCT TO SPAN THE FLOODPLAIN BETWEEN CHAINAGES 48510 AND 49300 AND REMOVE THE EMBANKMENT BETWEEN CHAINAGES 48510 AND 48940

This option extends that of Option 2 and would obviously cost considerably more. The advantages and constraints would be similar to those stated for Option 2 but the scale of the effects would be different.

Option 4: EXTEND THE VIADUCT TO THE WHITE BRIDGE, i.e. TO SPAN THE ENTIRE FLOODPLAIN BETWEEN CHAINAGES 48300 AND 48940 AND EXTEND TO CHAINAGE 49300. REMOVE THE ENTIRE EMBANKMENT BETWEEN 48300 AND 48940

This option would ensure that the floodplain is restored to its original condition before the embankment was built in the early 1940's. Aesthetically this would be by far the most pleasing option. The present equilibrium between the portions of the floodplain on either side of the embankment would be disturbed and initially siltation of the salmarshes and channels downstream of the embankment can be expected. However this impact would be temporary in nature and with time an equilibruim closer to that of the original will be re-established. The major constraint would obviously be that this is by far the most expensive option.

4. ROAD FAILURE MODE ANALYSIS

The test results using the mathematical model (Section 2.2) show that the maximum predicted water levels (+ 1,80 m above MSL) during the 1:100 year flood conditions are still considerably lower than the minimum levels of the embankment of the eastern approach road (+ 4,20 m above MSL). The embankment should therefore easily withstand such flood conditions.

The proposed option to remove part of the embankment beneath the planned viaduct will alter the situation considerably during flood conditions and of greatest significance will be the increased flow velocities that will occur through the breached area over the predicted fall of 0,65 m. Without special bottom protection measures, this flow is likely to cause considerable erosion scour at the downstream opening and cause the development of a channel through the narrow fringe of saltmarsh adjacent to the embankment. Flow velocities will be governed by the width of the breaching and the anticipated impacts will be reduced proportionately to an increase in width of the opening.

An aspect which has not been addressed in this study, as it falls beyond the contract brief, is the effect of erosion at the *White Bridge* under extreme river flood conditions.

5. ECOLOGICAL IMPLICATIONS

5.1 Introduction

It is difficult to relate, ecologically, the present situation within the study area to that which existed prior to the construction of the *White Bridge* without specific baseline data on the exact bio-physical nature of the mudflats and saltmarsh. An attempt has been made in Section 2 to review, as accurately as possible, the present status of the area but in the absence of detailed historical data, it is not possible to have the same insight into the situation before 1940. The interpretation of the likely impact that the embankment may have had on the marsh environment and what the ecological benefit will be if it is removed, must therefore be based largely upon speculation and assumptions.

5.2 Marsh Hydrology

The macro-scale hydrological consequences of the road embankment have been addressed briefly in Section 2.2. At a smaller scale, however, it can be assumed that the embankment will have modified the general hydrology within the marsh environment and possibly have caused an associated ecological response.

From the aerial photograph interpretation that was carried out, it was evident that a number of shallow channels, which typically occur in salt marshes, penetrated into the mudflats and marshland. The orientation of these channels followed the general trend of the estuary, with the mouths opening downstream into open water and their upper limits situated some distance into the mud (or sandy) deposits and marsh. Some of the channels appear to have traversed the entire area between the up- and downstream reaches of open water. Water would have moved freely up and down these channels under flood- and ebb-tides and would have encroached into and drained out of the adjacent marshland at higher and falling tidal levels.

The road embankment has effectively blocked off all of the natural channels which fed into the greater marsh area from downstream and a new hydrological equilibrium has become established. Water moving towards the marsh under flood tides now backs up downstream of the embankment and flows laterally across the small marsh area towards the main channel of the estuary at the bridge. Upstream of the embankment, the marsh is supplied with water via lateral flow from the main channel in much the same manner as in the past but without the downstream input from some of the original channels. The latter do still operate above the embankment as a supply and drainage mechanism but in a somewhat modified manner (Plates 4 and 5).

The ecological significance of the modified marsh hydrology is related *inter alia* to the following: The role of tidal movement in the transport of nutrients and organic carbon into and out of the area; possible changes in water and substratum salinity within the marshes; increased water clarity due to the longer residence period; and changes in the physical nature of the marsh substratum through the accelerated deposition of suspended sediments. Some of these environmental criteria have been reviewed in Section 2.5 and are discussed below. However, it is considered that the hydrology within the marsh has not become modified to the extent that severe negative impacts have resulted, such as a reduced flux of nutrients through the system.

5.3 Marsh Topography

Theoretically, the general flow rate of water moving upstream into the marsh will have become retarded due to the backing up effect below the embankment. A similar situation should also exist above the embankment under ebb conditions when the water can no longer drain as freely downstream over the marsh as it did in the original state. A decrease in flow rates, enhanced by the boundary layer effect above the marsh, will have lead to a longer water residence period of the marsh water, particularly above the embankment, and caused (*inter alia*) an increase in the deposition of suspended silt and particulate organic matter and detritus (Plate 6).

Reddering and Esterhuysen (1984) refer to the above process and the presence of the road embankment as being responsible for the development of the adjacent mudbanks. Chunnett (1965) considers the embankment to have had no modifying influence on the lateral configuration of the adjacent marsh and mudbanks and this opinion is supported by the aerial photograph analysis carried out during this study (Section 2.3). It is almost certain, however, that a *vertical* accretion of mud has taken place, as suggested by Reddering and Esterhuysen (1984) and that this is reflected in some physical change to the marsh. Without information on the unaffected topography before the construction of the embankment, it is difficult to quantify this.

From the survey that has been carried out, it would appear as if there may have been greater vertical accretion of the mudbanks and marsh above the embankment relative to the marsh downstream. The slight stepped topography between the latter two areas is evident in Figures 9(a)-(d), in which the profile of the road has been excluded from the survey data (See Section 2.4). A more even gradient could have been expected between the two areas of marshland before the construction of the road embankment.

The ecological implications of the possible elevation of the marsh relative to the situation prior to the construction of the embankment are related largely to the hydrology and could include a change in the phytosociology, macrofaunal composition and chemical and nutrient status within the marshland. That an ecologically acceptable situation now prevails is, however, evident from the field survey that has been carried out (Section 2.5).

5.4 Biotic and Environmental Factors

Phytosociology

The data presented in Table 2 indicate that neither of the two marshes adjacent to the embankment differ significantly from the *control* area with respect to overall species composition. There may, however, have been changes to the relative areas covered by the different species or species associations but this cannot be confirmed.

It is likely that the vertical accretion of the mudbanks adjacent to the embankment, which has occurred since 1940, has been accompanied by an associated compositional change within the marshland. If, for example, there has been an accretion of some 0,3 m, as suggested by Reddering and Esterhuysen (1984) and confirmed during the survey, the plant communities would previously have been established at lower tidal elevations.

The area upstream of the embankment, which is now covered by *Juncus* marshland (Plate 7), may previously have existed at a level of approximately + 0,3 m above MSL and may therefore have been colonized by *Cotula*-dominated saltmarsh. Similarly, the present areas of *Cotula* marshland may previously have been dominated by *Spartina* or even *Zostera* (See Table 2).

The levels of productivity within the marsh may also have been influenced by any shift in species composition and if either *Spartina* or *Zostera* were more abundant in the past, within the affected area, the present level of organic carbon production may have become reduced. Grindley (1976, 1978) considers the latter two species to contribute most of the organic input to the lagoon system but does not refer to the significance of *Juncus kraussii* in this respect. During the field survey, however, a large amount of litter was observed within the marsh to the west of the road embankment which had been derived from the *Juncus* stands (Plate 8) and it is quite possible therefore that the present level of organic input from the affected marshland is not significantly less than previously.

The ecological implications of the present embankment on the phytosociology of the affected marshland does not appear to have been too severe. All species represented in the control area also occur within the marsh, although it is possible that the relative areas occupied by each may have become altered. Levels of productivity have in all likelihood been maintained or at least have not become reduced significantly.

Macrofauna

Most of the benthic macrofauna can tolerate a range of environmental conditions and for the species occurring within the affected marsh, which were recorded during the survey, the tolerance limits have not been exceeded. The species have accommodated the slight vertical accretion that has taken place upstream of the embankment and have adjusted to the physical changes that have occurred to the intertidal marsh substratum, such as increased clay and organic contents and higher salinity values.

It is possible to speculate that the ongoing accretion process could eventually reduce the population densities of the dominant species as the optimum tidal habitat ranges, which are given below, are exceeded. *Upogebia africana* and *Scylla serrata* would be the first species to be affected, followed by *Callianassa kraussii* and *Cleistostoma edwardsii*. *Sesarma catenata*, which prefers supratidal mudflats, would be most tolerant of the anticipated environmental changes. It is very unlikely, however, that any of the dominant species would ever be totally eliminated, since the many drainage channels within the marsh will continue to provide the necessary habitat ranges for the forseeable future.

SPECIES	TIDAL HABITAT RANGE
Upogebia africana	Mid - Subtidal
Scylla serrata	Mid - Subtidal
Callianassa kraussii	HWST - Subtidal
Cleistostoma edwardsii	HWST - LWNT
Sesarma catenata	HWST - Midtide

Environmental Factors

The analysis of some of the the major edaphic characteristics of the marsh has shown that the presence of the embankment has definitely had a modifying influence on them. The changes can all be related to the modified hydrological regime within the affected marsh and the altered topography of the area.

The processes that have induced the changes to the marsh environment are likely to persist in future in much the same fashion as they have over the past forty years but at a progressively slower rate. Vertical accretion will continue to take place within the marshes until the possible upper sedimentation limits are eventually achieved.

The soil salinity values, which could be expected to increase through evaporation and the accumulation of salt, will stabilize eventually and a salt marsh community, which is more tolerant of high salinities and dominated by a species such as *Sarcocornia pillansiae*, for example, is likely to become established. The general status of the sediment characteristics is likely to remain unchanged.

6. EVALUATION OF ALTERNATIVES AND IMPACT PREDICTION

The four options that have been presented in Section 3 can be evaluated in terms of the review which has been provided above.

OPTION 1: Build the viaduct between chainages 48760 and 49300 and leave the entire existing embankment in place.

The changes that have occurred within the physical environment of the marshland on either side of the road embankment have established an ecological equilibrium that will be more or less maintained if this management option is chosen. It is likely that the present equilibrium differs somewhat to the situation prior to the construction of the road but considering the status of the surveyed biotic components, it is nevertheless an ecologically acceptable option (Plate 9).

The general marsh environment is healthy due largely to the good tidal flushing that has persisted in spite of the modification to the natural hydrology. Changes to the topography have in all likelihood shifted the dominance hierarchy of the saltmarsh elements towards a situation where a species such as *Juncus kraussii*, which occurs at higher marsh elevations, has been favoured at the expense of lower elevation species but the latter have not, however, been eliminated. The benthic macrofauna are well established within the affected area and this further supports the evaluation on the good apparent state of the marshland.

OPTION 2: Build the viaduct between chainages 48760 and 49300 but remove the existing embankment between chainages 48760 and 48940.

This option will allow for the removal of some 180 m of the existing road embankment and is the design that has been accommodated in the initial planning of the proposed viaduct.

One of the most apparent effects that this option will have upon the marsh environment will be the modification of the present tidal hydrological regime within the area. Removal of the embankment down to the mean elevation on either side of the road reserve of between + 0,80 and + 1,00 m above MSL (See

Figure 8) will permit the unhindered movement of water through the opening during both high water springs and high water neaps. The mean levels of the latter two tidal states for Knysna are estimated at + 1,96 m and + 1,43 m above MSL respectively (South African Tide Tables, 1988).

How this will exactly influence the functioning of the marsh is uncertain but it is probable that flushing rates within the marsh, upstream of the embankment, will be accelerated and siltation will correspondingly become somewhat reduced. Under normal tidal flow, it is likely that some form of channel development will take place along the direction of flow and that the marshland within the immediately affected area will be impacted. It is not anticipated that this option will have any major impact on the remainder of the marsh biota.

The greatest negative aspect of this proposal will be the likely impact that a flood could have on the marshland due to erosion scour under high flow velocities through the opening, which would be in the order of 3 - 3,5 m/s. The greatest impact would occur within the downstream marsh area and the associated channel development following such an event would create a very unnatural situation which would be ecologically less acceptable than the present equilibrium.

OPTION 3: Extend the viaduct to span the floodplain between chainages 48510 and 49300 and remove the embankment between chainages 48510 and 48940

Removal of the embankment would create an opening some 430 m wide and as with *Option 2*, the greatest significance of this would be the modification to the marsh hydrology during tidal exchange. At least two of the channels which previously serviced the western marsh during normal tidal flow would be reinstated, provided that the embankment was removed to the correct level. From the contour diagram presented in Figure 8, it would appear that the base level would have to be established at an elevation of + 1,00 m above MSL at the northern limit of the opening with a slight fall to + 0,20 m above MSL at the southern limit.

The flushing rates through the marsh would become accelerated and the unnatural rate of sedimentation that has occurred over the past 40 years would become reduced due to shorter water residence periods. It is unlikely, however, that the composition or structure of the established saltmarshes would be influenced significantly by this process as the improved channel flow through the marsh would not necessarily cause the fixed mudbanks to erode to their previous natural levels. Only during flood events, where mass water flow would pass over the marshes at relatively high velocities, would erosion take place.

The scour effect of flood waters passing through the opening in the embankment would be less marked than in the case of *Option 2* and no serious negative impacts are likely to be associated with such an occurrence.

OPTION 4: Extend the viaduct to the White Bridge, i.e. to span the entire floodplain between chainages 48300 and 48940 and extend to chainage 49300. Remove the entire embankment between 48300 and 48940.

This option would reinstate the situation prior to the construction of the embankment, particularly with respect to restoring normal tidal exchange between the western area of marshland and the estuary.

As with *Option 3*, however, the effect of this is unlikely to be reflected immediately by the marsh biota that have become established at raised tidal elevations due to sedimentation. Erosion of the fixed mudbanks is only likely to occur during extreme flood events and the natural equilibrium would take a considerable time to become re-established. An intermediate phase in the re-establishment process may be increased sedimentation downstream of the embankment as accumulated mud and silt is released from the western marsh.

No negative impacts are likely to be associated with this option.

7. RECOMMENDATIONS

From the evaluation that has been carried out it is clear that the two extreme management alternatives are both ecologically acceptable. The retention of the entire road embankment in its present state will, for example, ensure that the established ecological equilibrium within the affected areas of marshland will be maintained, while the complete removal of the embankment will initiate the restoration process towards a more natural situation.

Some doubt exists as to whether the two other proposed management alternatives will represent any significant improvement to the current situation. The removal of a part of the embankment will not restore the natural ecological equilibrium and if only a narrow opening is created, significant disruption could in fact occur, particularly during a flood event. The expressed conservation objective - *to restore the impacted marshland to its former state* - would not be achieved.

Although the brief in this report is not to address either the cost implications or the aesthetic aspects related to the proposed management alternatives, it is inevitable that the final management decision will have to be largely based upon these considerations.

- The option to retain the embankment intact would the cheapest and would be acceptable from an aesthetic point of view, while the complete removal of the embankment would be extremely costly but would be aesthetically more desirable. Both of the latter are ecologically acceptable, as stated above. In the event of retention of the entire embankment, attention should, however, be given to the rehabilitation of its slopes.

- The option to remove a small part of the embankment would have relatively low cost implications but would have little aesthetic advantage, while the removal of a wider section would be costly but would be aesthetically more desirable. The ecological benefits of these two management options would not be very significant in terms of achieving the conservation objective.

It would appear that the alternative to remove only a small portion of the embankment can be rejected both on ecological and aesthetic grounds. However, in order to establish which of the remaining alternatives should be considered, the following questions must be posed:

* What are the likely cost implications of the proposed alternatives?

* Are the costs justified in terms of the aesthetic and ecological benefits that each represent?

Should the most desirable alternative prove too costly, it is recommended that the "least management" alternative should be adopted. This implies retaining the affected marshland in its present state and accepting that although it has been modified by the presence of the embankment it is nevertheless a productive and ecologically viable unit. Considerable improvements can be made to the appearance of the portion of the embankment that will not be incorporated into the design of the viaduct in order to satisfy some of the aesthetic requirements and a grass, shrub or even tree cover, for example, would be easy to establish.

It is important to recognize that the option to leave the embankment intact should not be regarded as mitigation for the future construction of such structures across other estuaries. Rather, it illustrates how difficult it can be to reverse past management actions due to the severe cost implications involved. The physical nature of the Knysna estuary and the minor role of sedimentation within the system in particular, are the major aspects which differentiate it from other estuaries where the impacts of road embankments have been more significant.

A matter of considerable concern is the extent of additional infilling of the flood plain on either side of the existing embankment, as indicated on Figure 2. At chainage 48760 this appears to be approximately 32 m wide from the edge of the reconstructed road into the floodplain on either side. This narrows to about 20 m on either side at chainage 48500. In addition, the temporary infill for the road deviation during construction must be noted.

From Sections 2.4, 2.5 and 5.2 of this report it will be evident that this is highly functional and sensitive salt marsh. Furthermore, the channels running paralell with and immediately adjacent to the existing embankment are important in terms of the lateral flows which are part of the tidal exchange mechanism operative in these salt marshes.

While it is appreciated that there must be sound engineering reasons for this extensive amount of infilling on either side of the widened road or viaduct, it is nevertheless recommended that this infilling should be reduced to a minimum as far as possible. Thought should therefore be given to the possibility of avoiding the substantial additional infill shown on Figure 2, between chainages 48720 and 48760. This recommendation is made on the assumption that the existing embankment is retained over its full length.

Detailed management recommendations cannot be provided until a decision has been taken with respect to the most cost-effective management alternative. Aspects that will have to be addressed in due course include (*inter alia*): The provision of guidelines that will ensure the least ecological disruption during construction; the establishment of precise excavation levels if the embankment is to be removed; the assisted re-instatement of the natural drainage channels through the marsh; the prescription of optimal rehabilitation measures, including the possible artificial re-establishment of seriously impacted salt marsh; and the initiation of a monitoring programme to measure the effects of the chosen management option in order to assist in future management decisions of a similar nature.

REFERENCES

BARKER, J (1986). The Knysna estuary: saltmarsh plant zonation. *Vegetation Map*. SANCOR, CSIR.

CHUNNET, E P (1965). Siltation problems in the Knysna Estuary. *CSIR Report* No. MEG 353.

DAY, J H (1967). The biology of the Knysna Estuary, South Africa. *In: Estuaries*. Lauff, G H (ed). Washington, D C. American Association for the Advancement of Science. Publ. No. 83: 397-407.

DAY, J H (ed) (1981). *Estuarine ecology with particular reference to southern Africa*. Cape Town, Balkema.

GRINDLEY, J R (1976). *Report on the ecology of the Knysna Estuary and proposed Braamekraal Marina*. Univ. of Cape Town, School of environmental Studies.

GRINDLEY, J R (1985). Estuaries of the Cape. Part II: Synopses of available information on individual systems. Report No. 30: Knysna (CMS 13). Heydorn A E F and Grindley J R (eds.). *CSIR Report* No. 429.

GRINDLEY, J R and EAGLE, G A (1978). Environmental effects of the discharge of sewage effluent into Knysna estuary. Univ. of Cape Town, School of Environmental Studies.

GRINDLEY, J R and SNOW, C S (1983). Environmental effects of the discharge of sewage effluent into Knysna lagoon. Univ. of Cape Town, School of Environmental Studies.

HUIZINGA, P (1985). Mathematical model study of the Knysna Estuary. The effect of river flow on salinity distributions. *CSIR Report* T/SEA 8506.

NRIO and VISKOR, (1980). Knysna plesierboothawe uitvoerbaarheidsondersoek. Deel I en Deel II. Stellenbosch.

REDDERING, J S V and ESTERHUYSEN, K (1984). Sedimentation in the Knysna Estuary. *ROSIE Report No. 9*. Univ. of Port Elizabeth.

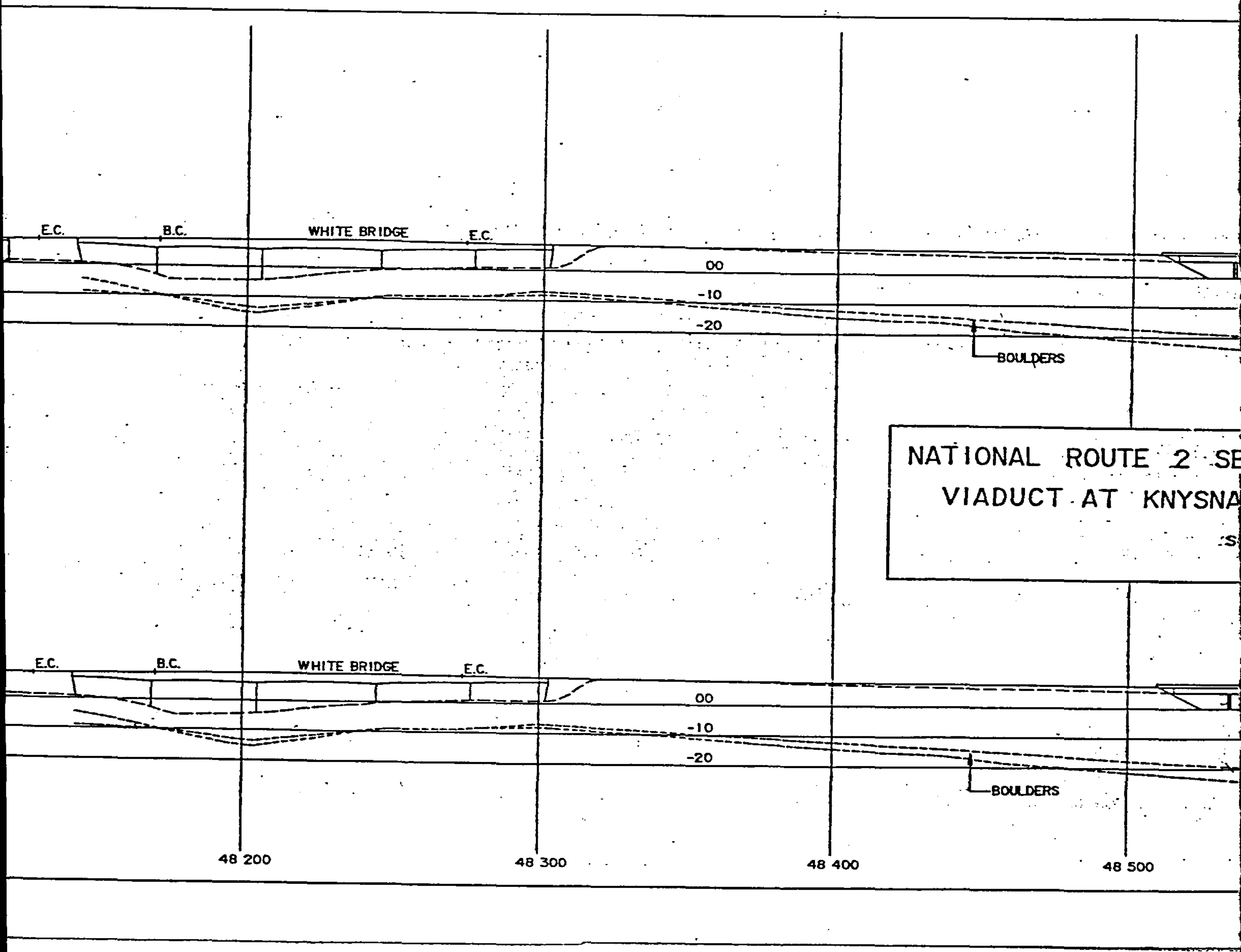
SOUTH AFRICAN TIDE TABLES, (1988).

TABLE 1: DATA MATRIX USED DURING THE PRINCIPAL COMPONENT ANALYSIS

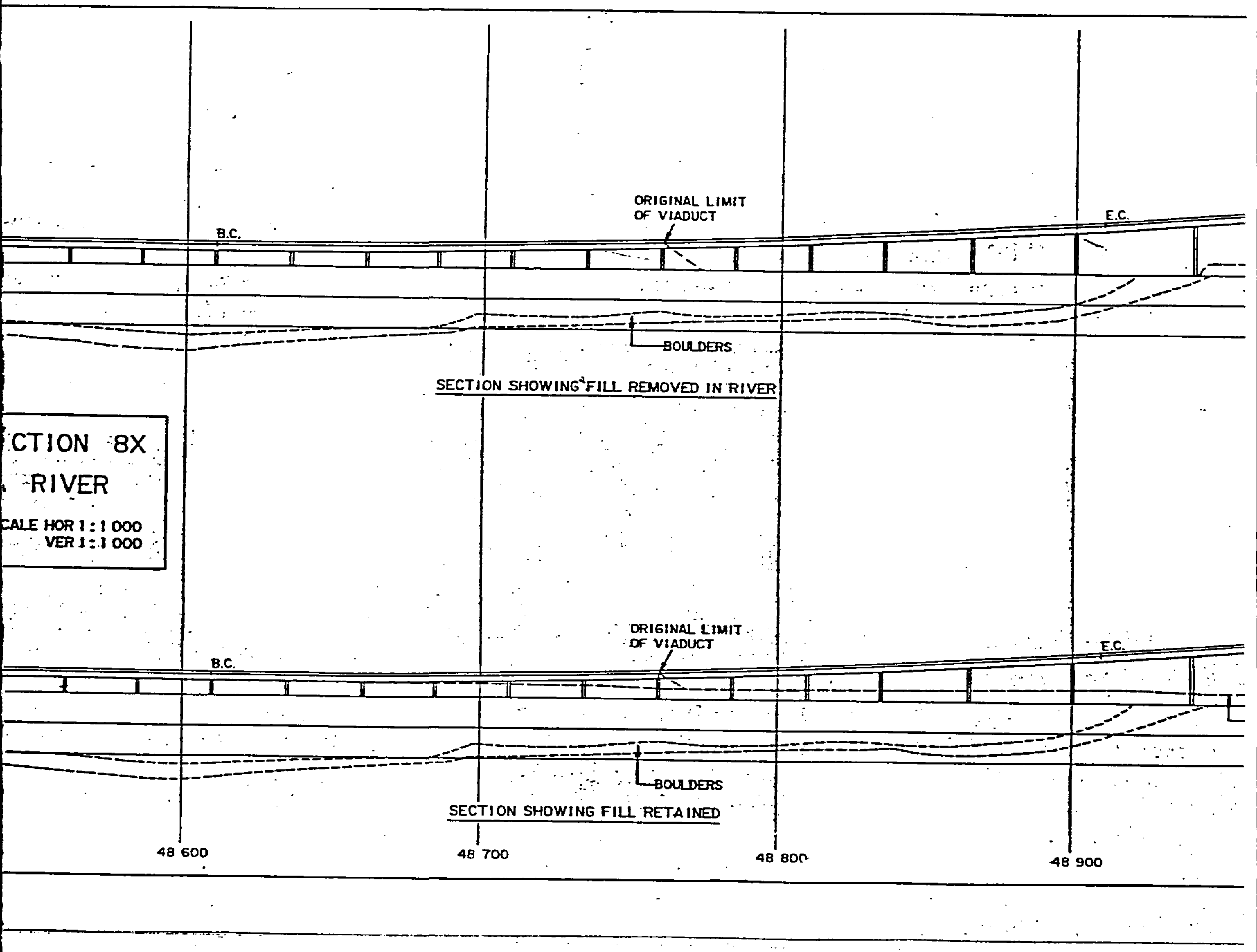
SAMPLE NO.	VEGETATION	ELEVATION (m)	ORGANIC CONTENT(%)	SALINITY (°/00)	CLAY CONTENT(%)	VFS (%)	FS (%)	MS (%)	CS (%)	VCS (%)
A2	SPA/COT	0.43	6.24	24.23	43.95	0	7.51	26.12	21.62	0.8
A3	JUN	0.7	14.78	34.38	77.41	0.36	11.52	5.94	4.76	0
A4	JUN	0.71	9.86	25.57	76.34	0.54	19.77	3.35	0	0
A5	JUN	0.48	8.56	29.18	80.77	0.77	8.59	7.62	2.25	0
A6	JUN	0.7	8.27	31.09	61.61	0	6.14	23.44	8.81	0
A7	JUN	0.84	8.11	22.28	53.15	0	6.54	22.74	17.57	0
A8	*	0.29	4.28	26.71	36.74	0	11.42	28.8	23.04	0
A9	JUN	0.67	9.35	44.66	78.59	0.14	6.66	11.04	3.57	0
A12	JUN	0.81	8	27.56	94.66	0	2.78	1.83	0.74	0
A13	JUN	0.94	11.22	23.38	86.79	0	11.39	1.82	0	0
A14	JUN	0.96	11.86	25.67	96.76	0.32	1.98	0.94	0	0
A15	JUN	0.94	0	22.27	95.67	0	4.33	0	0	0
A16	JUN	0.99	14.76	33.45	96.56	0	3.3	0.14	0	0
A17	JUN/SAM	1	17.51	38.01	95.15	0.48	4.36	0	0	0
A18	*	0.53	3.92	16.87	48.92	0	17.24	29.95	3.89	0
A19	JUN 1%	0.53	7.56	24.54	52.64	0	18.84	28.52	0	0
A21	COT	0.57	7.23	22.77	93.17	0	4.15	2.68	0	0
A22	COT	0.68	5.29	18.61	72.57	0	13.63	9.8	4.00	0
Mean		0.71	8.71	27.29	74.53	0.15	8.9	11.37	5.01	0.04
SD		0.20	4.15	6.73	19.65	0.23	5.42	11.29	7.47	0.18
B1	COT/ZOS	0.66	11.87	55.39	71.92	0	13.48	14.6	0	0
B2	ZOS	0.57	15.82	74.15	91.66	0	4.24	3.45	0.65	0
B3	ZOS	0.97	13.7	54.14	89.45	0	4.61	4.34	1.58	0
B4	*	0.89	5.36	20.92	39.56	0	17.07	34.38	9.00	0
B6	JUN	0.29	7.4	34.78	63.46	0	17.23	17.01	2.30	0
B7	ZOS	0.27	4.38	35.86	42.96	0	34.22	22.82	0	0
B8	ZOS/COT	0.63	10.21	43.85	58.22	0	15.43	24.01	2.35	0
B9	JUN	0.6	3.47	17.37	40.25	0	13.09	40.62	6.05	0
B10	SAR	0.31	9.91	30.97	79.43	0.78	7.79	9.35	2.65	0
B11	TRI/LIM	0.22	15.53	50.85	58.06	0	6.71	32.46	2.77	0
B12	JUN	0.21	12.13	47	72.73	0.14	16.81	10.32	0	0
B13	SPA	0.2	2.23	8.29	27.85	0	28.46	43.69	0	0
Mean		0.49	9.33	39.46	61.3	0.08	14.93	21.42	2.28	0
SD		0.26	4.51	17.77	19.75	0.22	8.73	13.27	2.64	0
C1	CHE/COT	0.94	0.74	6	2.51	0	31.34	66.15	0	0
C2	JUN	0.79	1.16	12.32	5.78	0	29.05	60.29	4.88	0
C3	JUN	0.5	5.93	12.71	30.76	0.35	40.88	28.01	0	0
C4	JUN	-0.04	2.28	17.67	12.98	0	41.77	45.25	0	0
C5	SPA	-0.08	3.04	13.79	34.49	0	41.93	23.58	0	0
C6	JUN	0.44	3.36	18.05	35.07	0	52.35	12.58	0	0
C7	ZOS	0.15	2.46	13.47	12.65	0	29.87	55.73	1.75	0
C8	ZOS	0.25	2.88	23.02	16.13	0	40.45	43.42	0	0
C9	JUN	0.83	6.17	20.02	51.43	0	38.39	10.18	0	0
C10	JUN	0.82	5.78	24.93	56.79	0.86	41.27	1.08	0	0
C11	JUN/SPA	0.94	8.38	25.79	78.49	0.6	19.35	1.56	0	0
Mean		0.50	3.83	17.07	30.64	0.16	36.97	31.62	0.60	0
SD		0.37	2.28	5.81	22.75	0.29	8.46	22.68	1.44	0

TABLE 2: Phytosociological Table - White Bridge Marsh, Knysna

MARSH TYPE AND ELEVATION ABOVE MSL					Juncus Marshland (0,66 m)																											Spartina Marshland (0,21 m)					Cotula Marshland (0,63 m)							Zostera Beds (0,22 m)		
QUADRAT:	A8	A10	A18	B4	A3	A4	A5	A6	A7	A9	A11	A12	A13	A14	A15	A16	A19	B2	B3	B9	B5	B6	B12	C3	C10	C4	C9	C6	C11	C2	A17	B13	A1	A2	C5	B11	A20	A21	A22	B1	B8	B10	C1	B7	C7	C8
SPECIES																																														
Juncus kraussii					5	5	4	4	5	3	4	4	5	5	5	5	1	4	5	4	3	3	3	5	5	3	3	2	3	3	4															
Spartina maritima																													1			4	3	2	3	3										
Cotula coronopifolia																														1				1			5	3	2	3	1	1	2			
Samolus porosus																															2															
Triglochin spp.																																				3						1				
Sarcocornia sp.																																				2						3				
Zostera capensis																																								1	4			4	5	3
Limonium scabrum																																				3										
Chenolea diffusa																																										3				

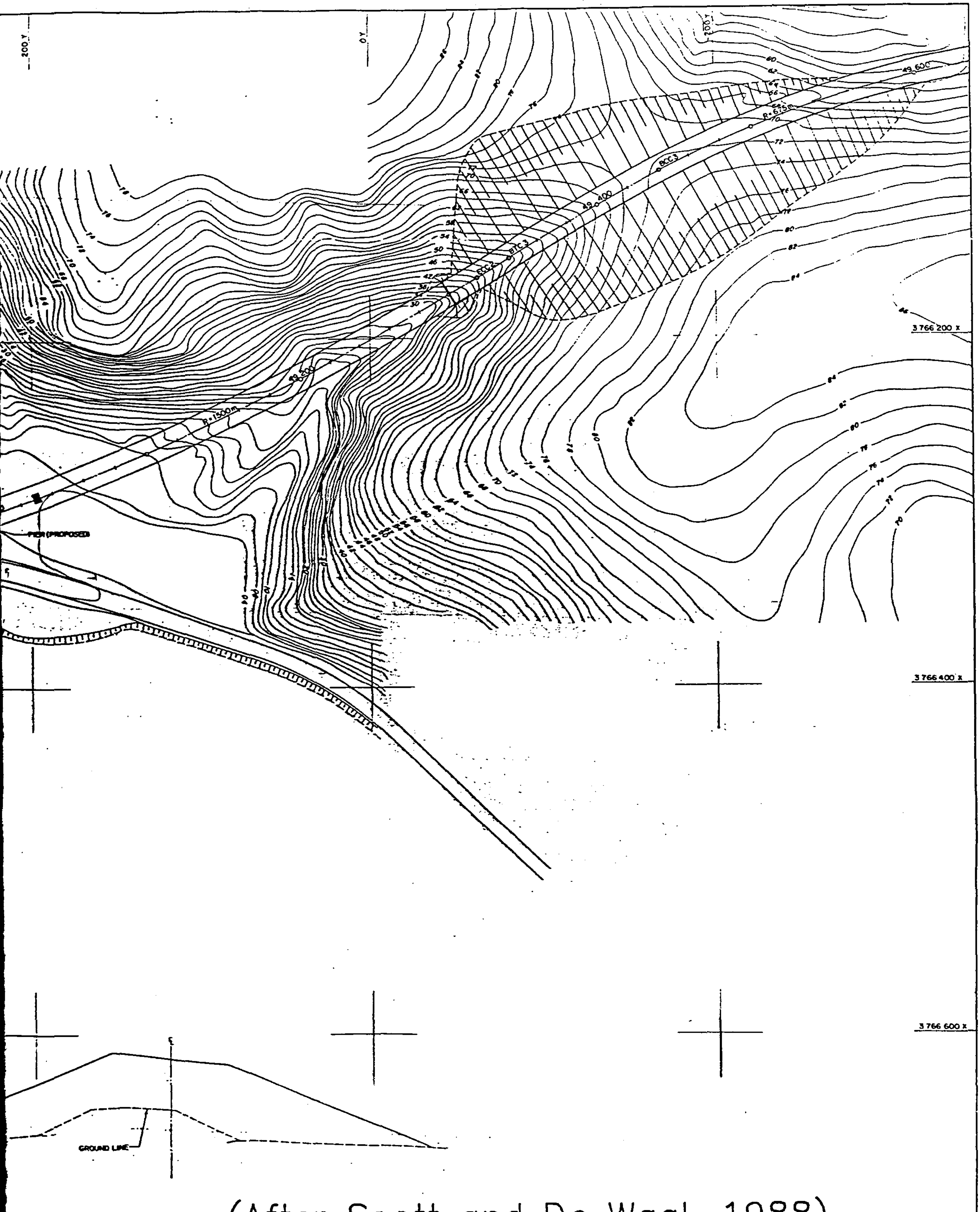


E.C.
B.C.
WHITE BRIDGE
E.C.
00
-10
-20
BOULDERS
NATIONAL ROUTE 2 SE
VIADUCT AT KNYSNA
E.C.
B.C.
WHITE BRIDGE
E.C.
00
-10
-20
BOULDERS
48 200
48 300
48 400
48 500



(After Scott and De Waal, 1988)

VIADUCT AT KNYSNA RIVER – LONGITUDINAL SECTION	FIGURE 1
CSIR – EMA	



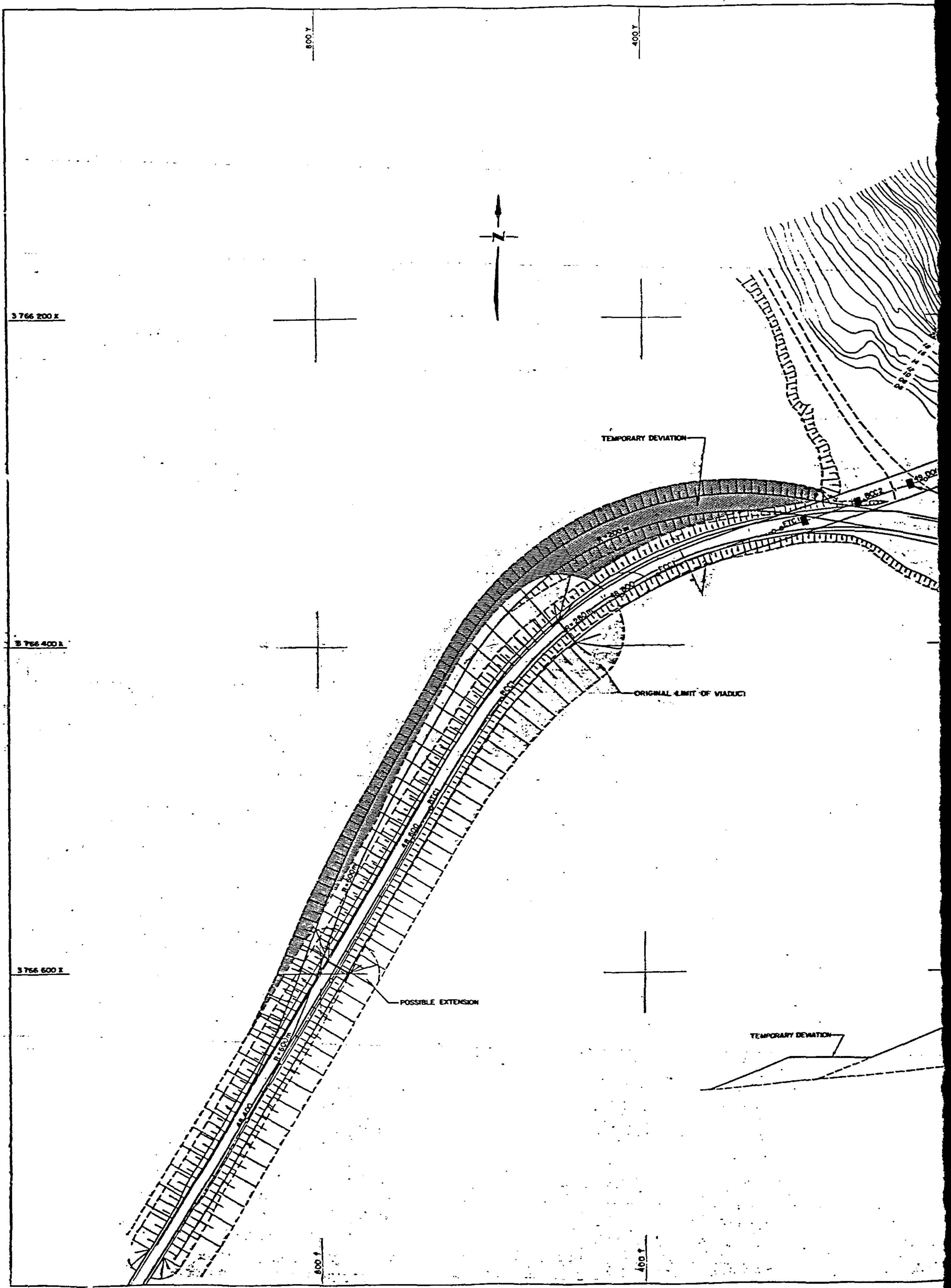
TYPICAL CROSS SECTION
(DIST. 48700)
SCALE 1:200

(After Scott and De Waal, 1988)

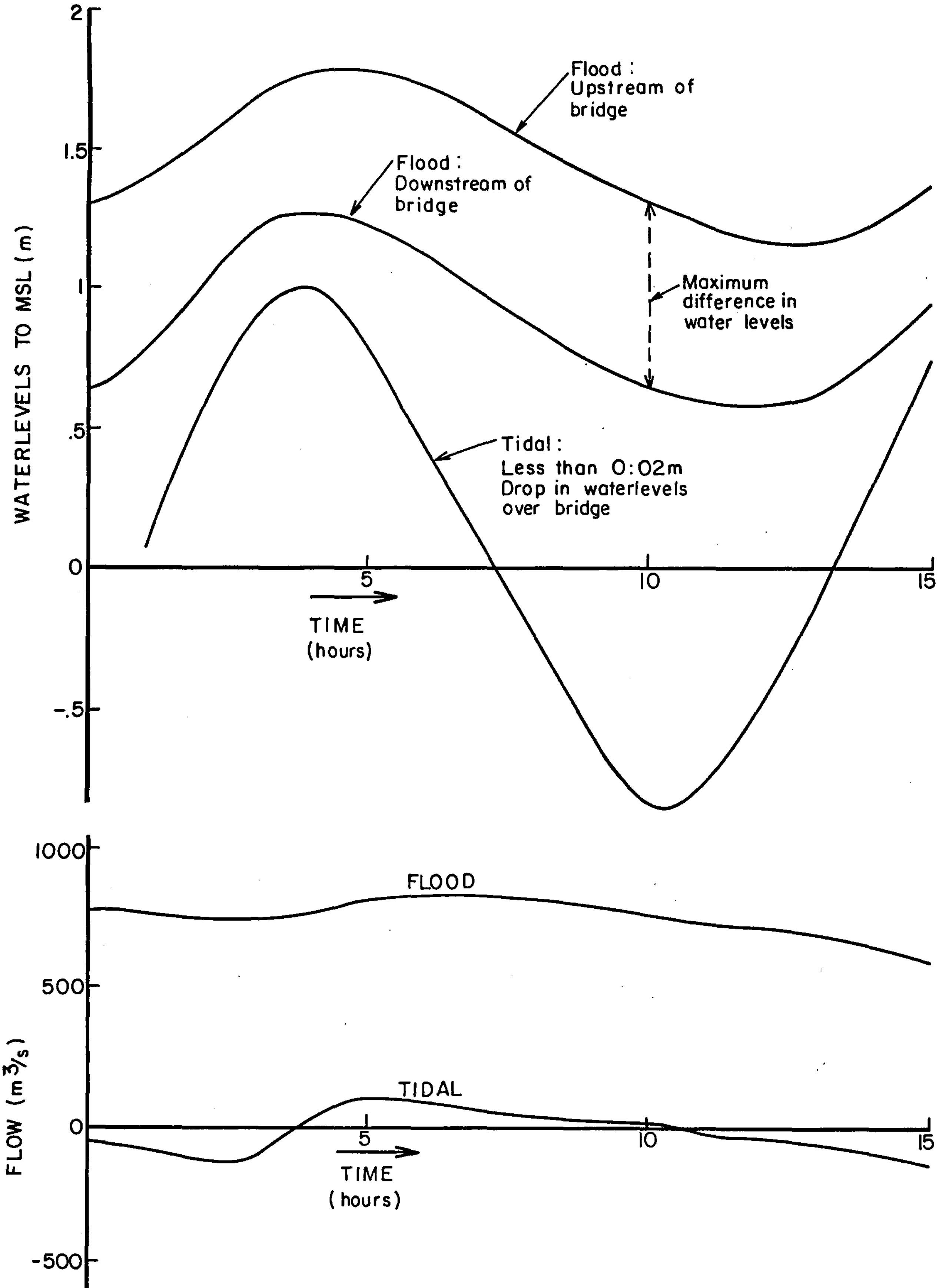
VIADUCT AT KNYSNA RIVER

FIGURE 2

CSIR — EMA



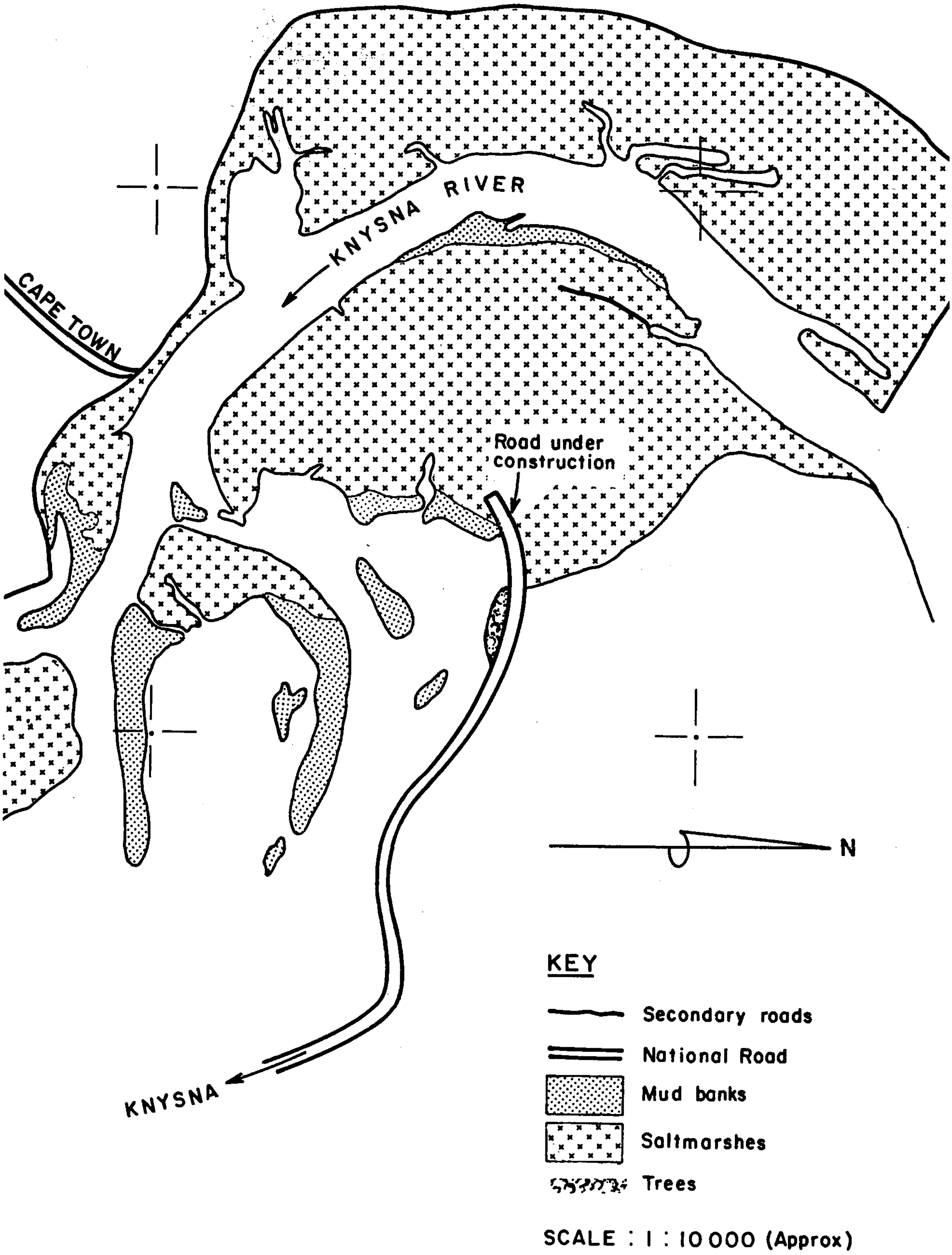
800 Y
400 Y
3 766 200 X
3 766 400 X
3 766 600 X
TEMPORARY DEVIATION
ORIGINAL LIMIT OF VIADUCT
POSSIBLE EXTENSION
TEMPORARY DEVIATION
800 Y
400 Y



WATER LEVELS AND FLOODS AT WHITE BRIDGE UNDER SPRING TIDE AND 1:100 YEAR FLOOD CONDITIONS

FIGURE 3

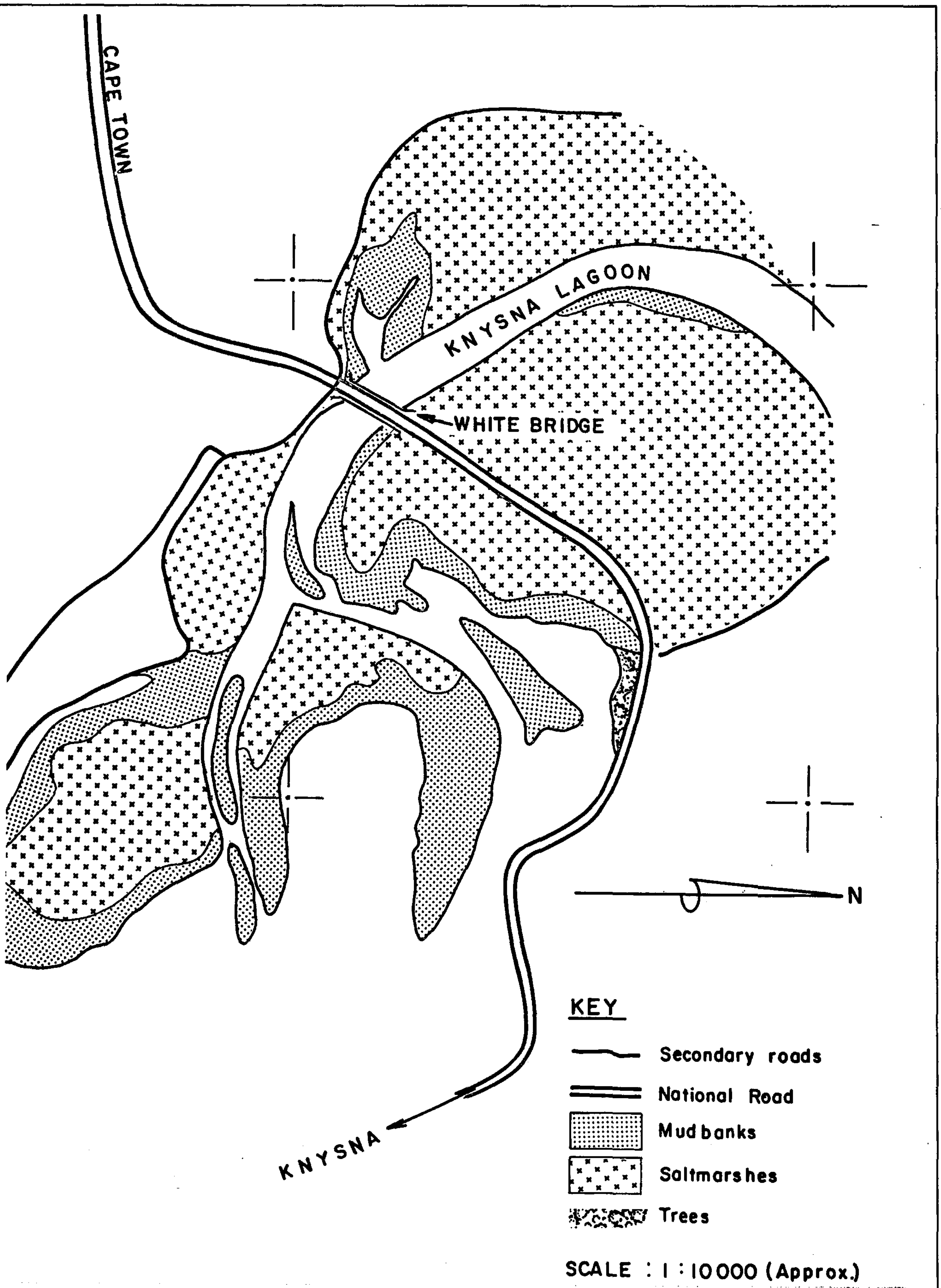
CSIR – EMA



1942: HISTORICAL CHANGES TO THE WHITE BRIDGE MARSH

FIGURE 4(a)

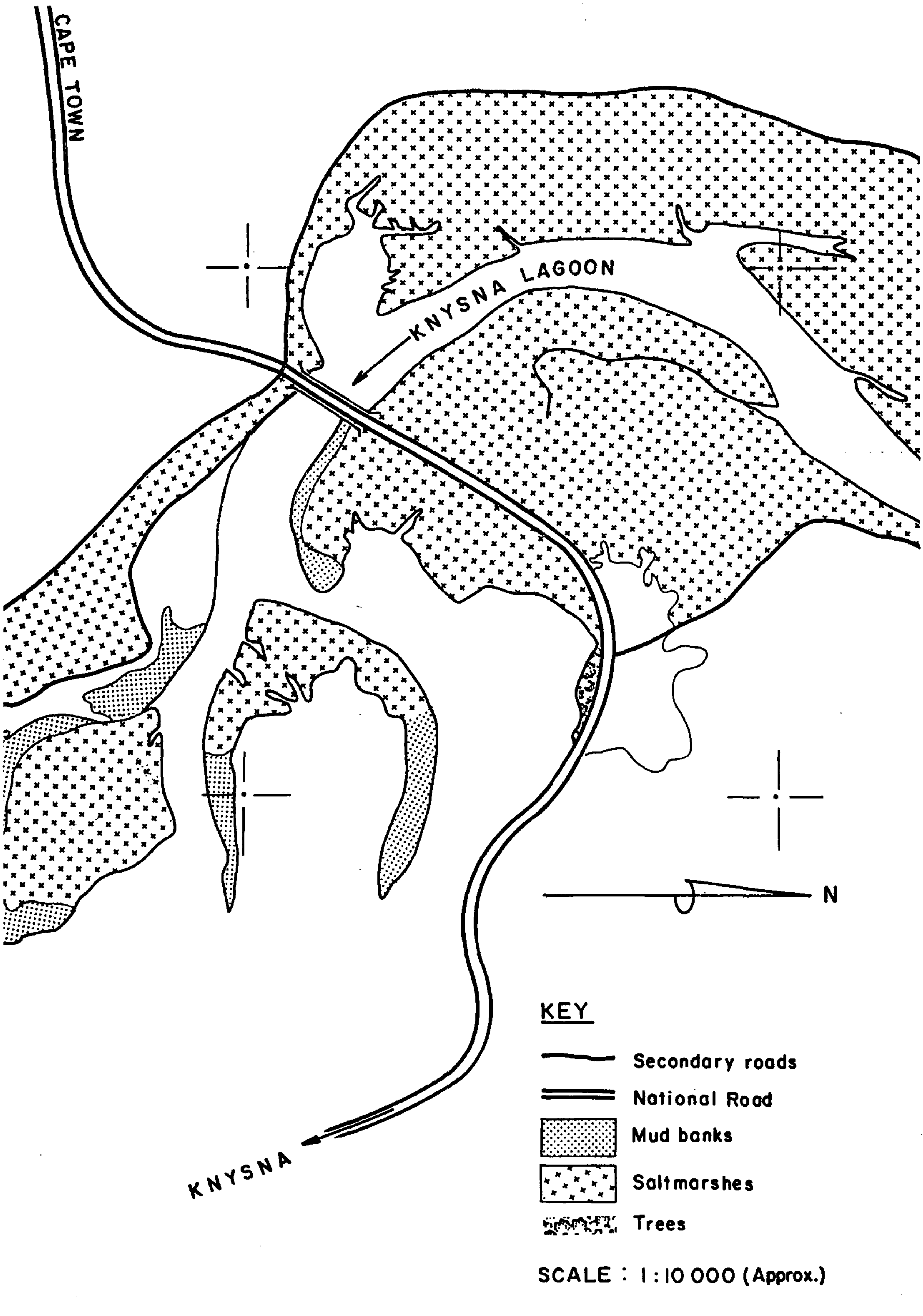
CSIR – EMA



1958: HISTORICAL CHANGES TO THE WHITE BRIDGE MARSH

FIGURE 4(b)

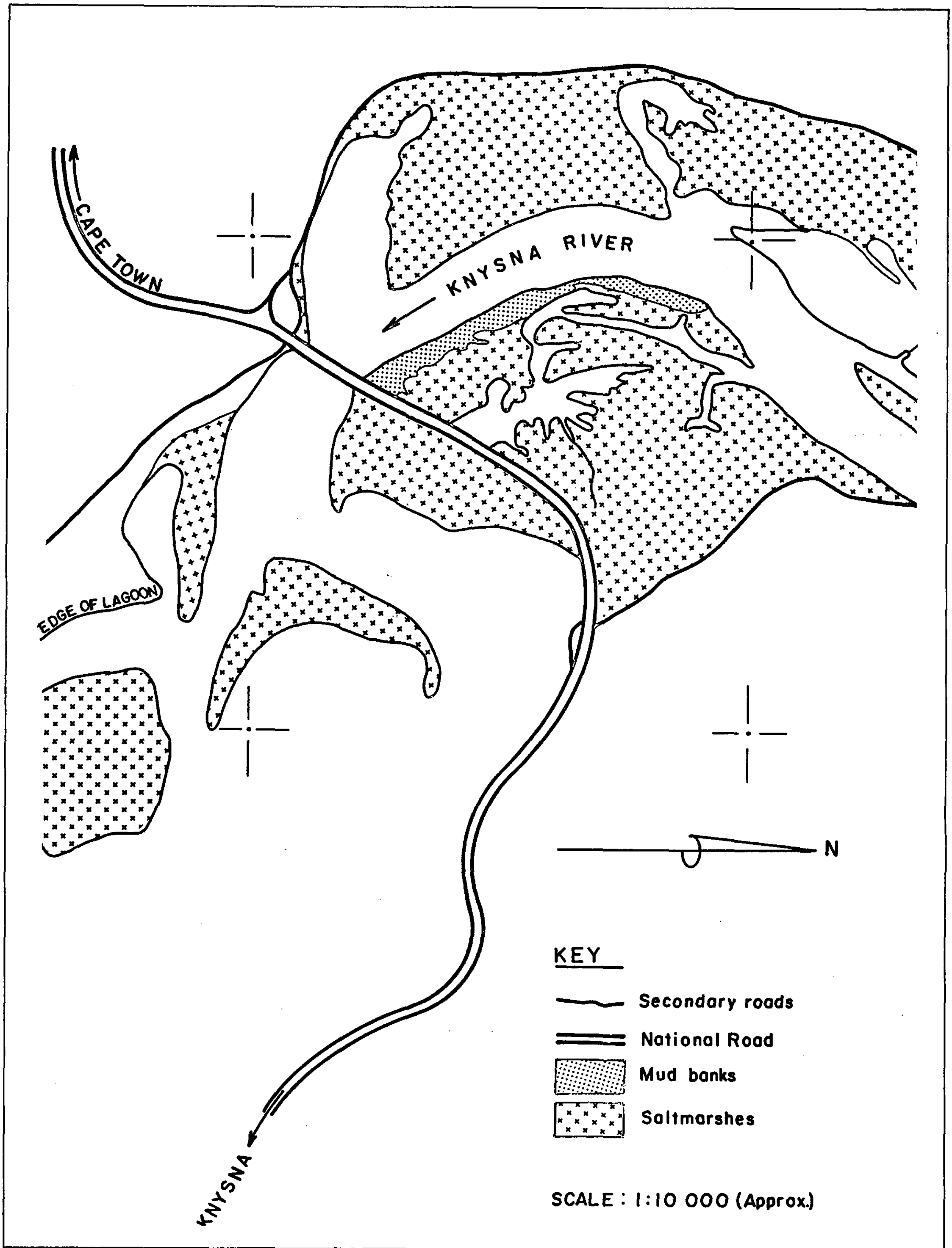
CSIR – EMA



1973: HISTORICAL CHANGES TO THE WHITE BRIDGE MARSH

FIGURE 4(c)

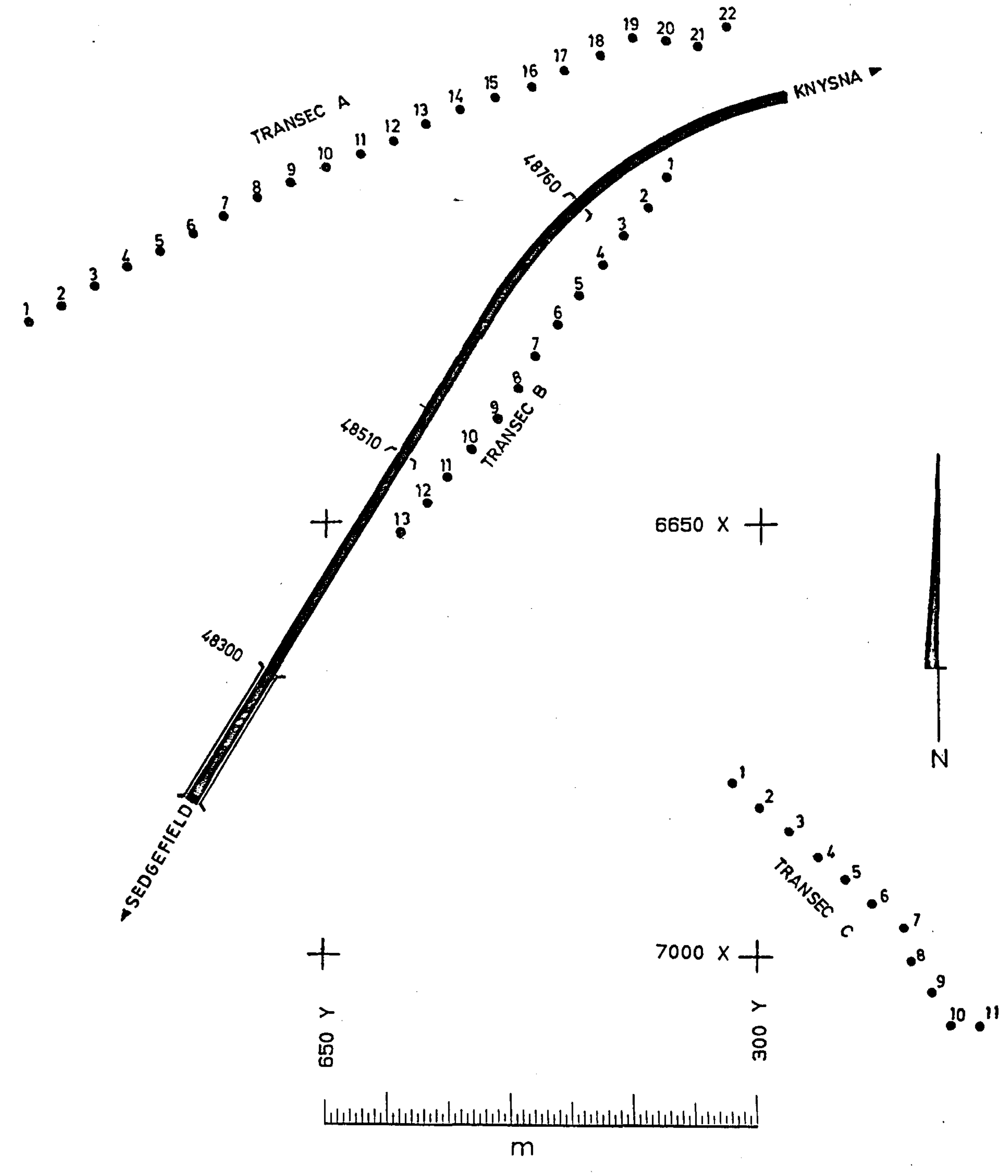
CSIR – EMA



1987: HISTORICAL CHANGES TO THE WHITE BRIDGE MARSH

FIGURE 4(d)

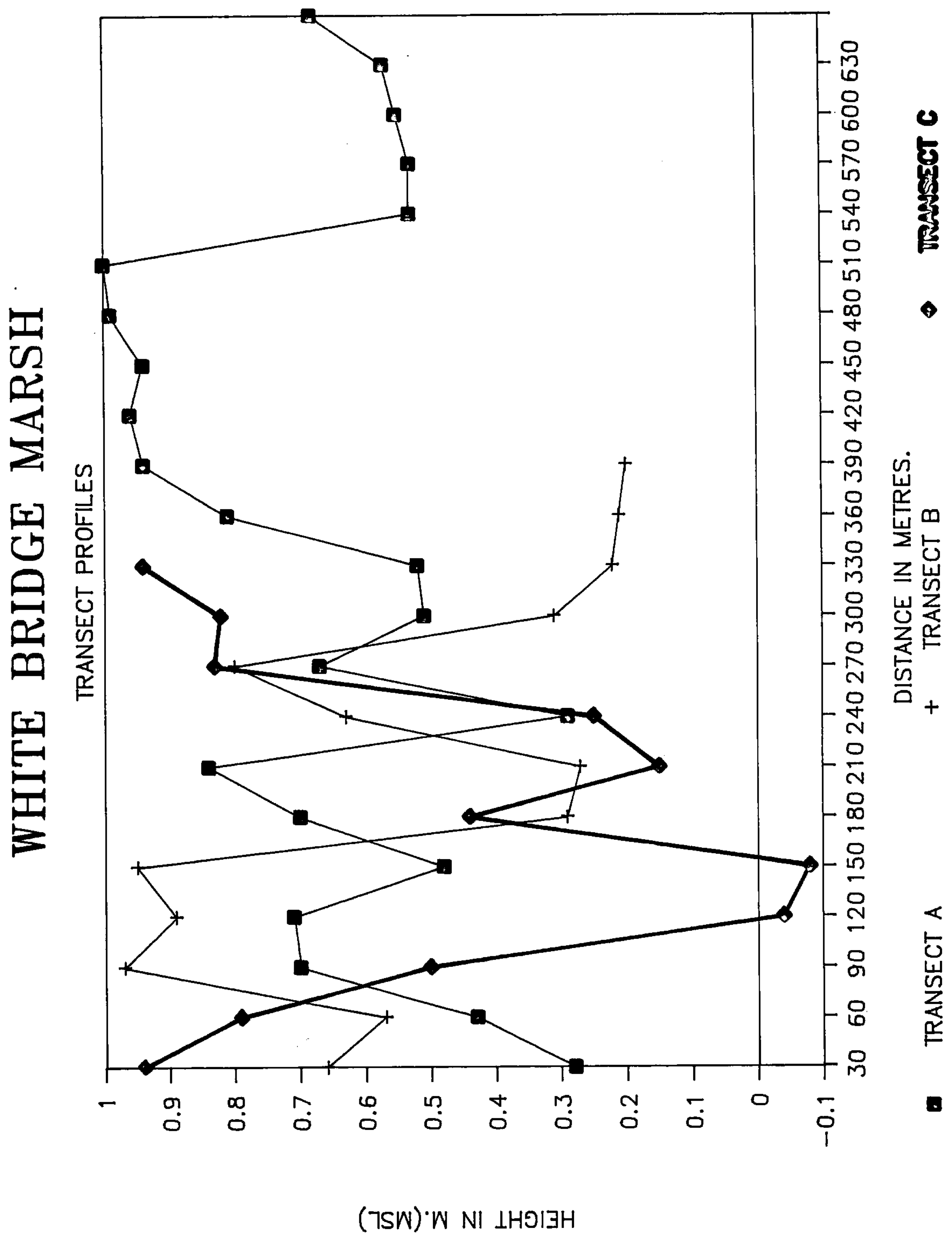
CSIR — EMA



LOCATION OF THE SURVEYED TRANSECTS USED DURING THE ECOLOGICAL STUDY

FIGURE 5

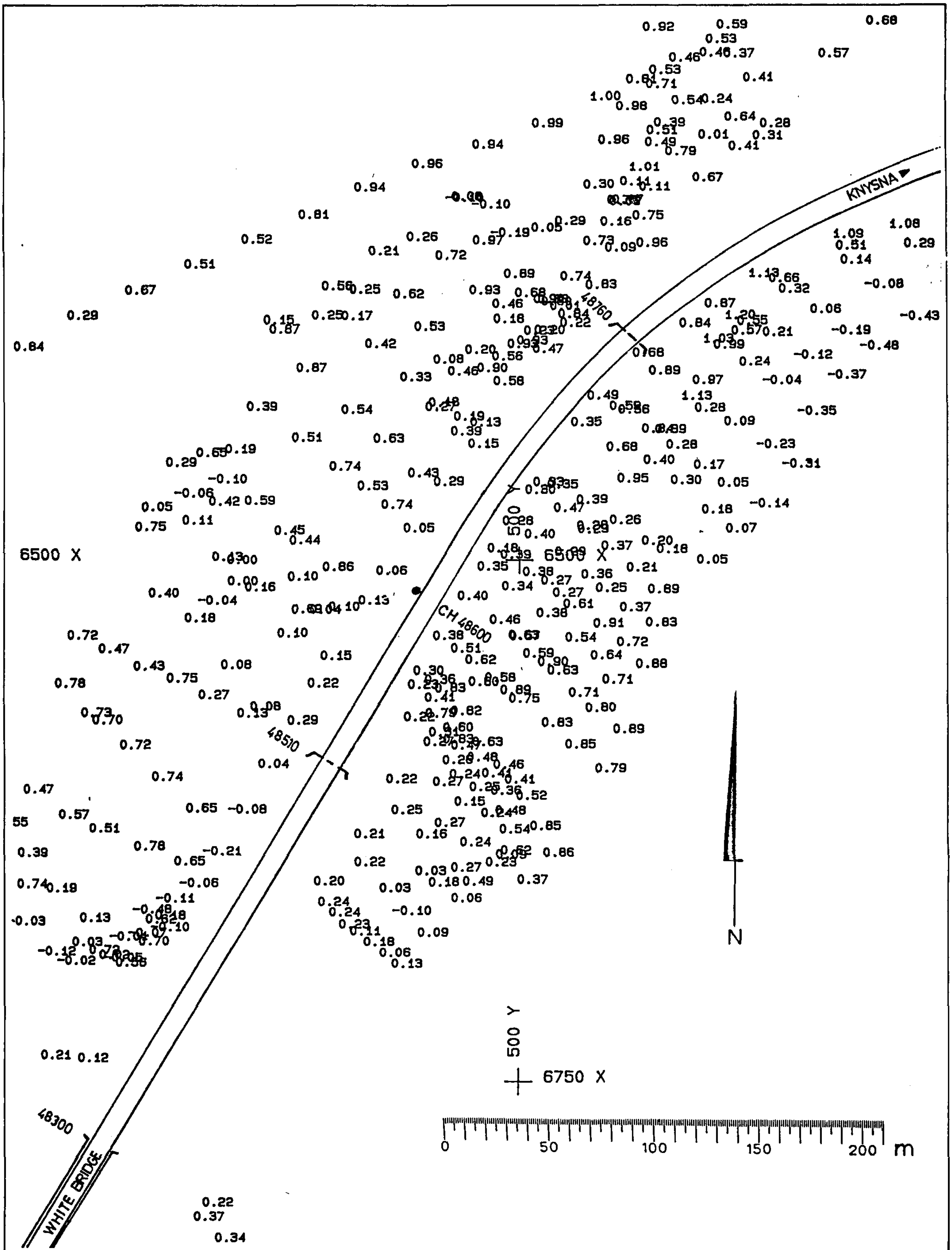
CSIR – EMA



TRANSECT PROFILES

FIGURE 6

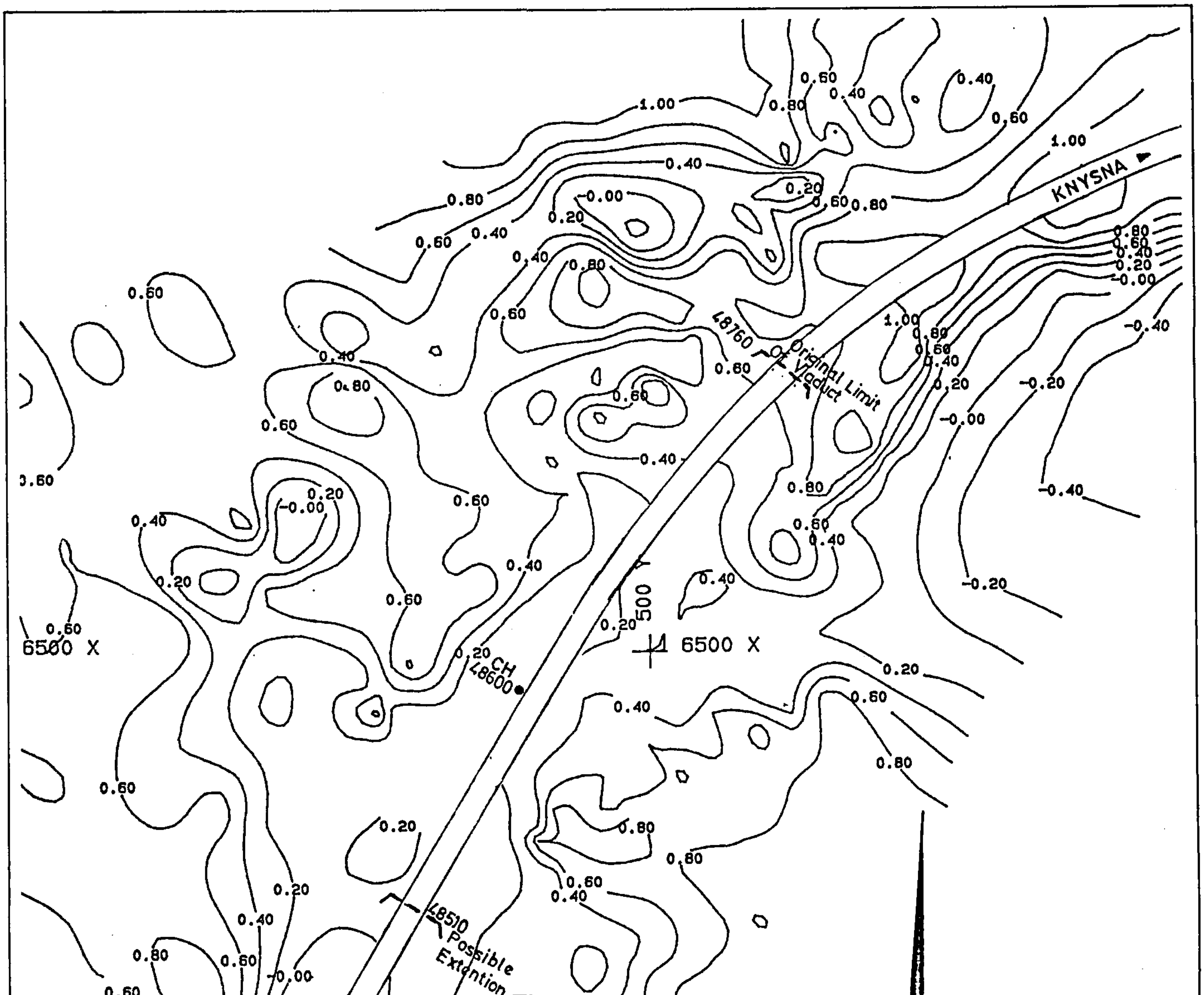
CSIR - EMA



SURVEY FAIR CHART OF THE WHITE BRIDGE MARSH

FIGURE 7

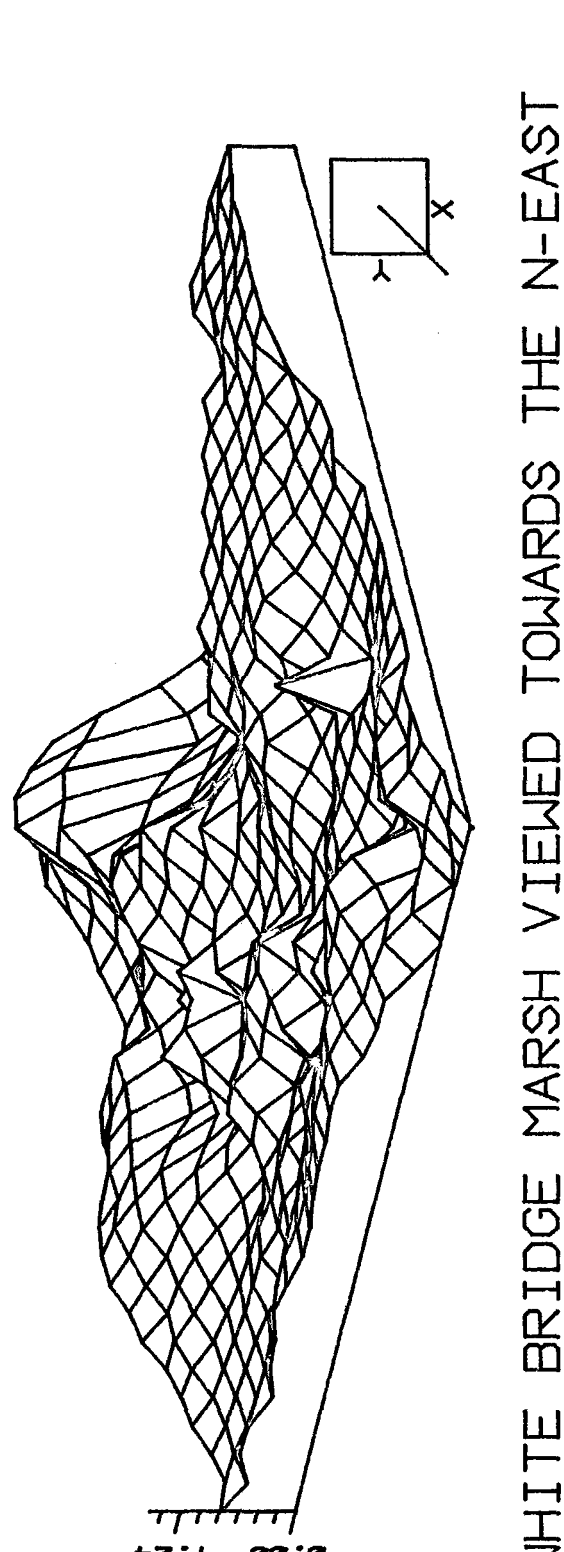
CSIR — EMA



CONTOUR PLAN OF THE WHITE BRIDGE MARSH

FIGURE 8

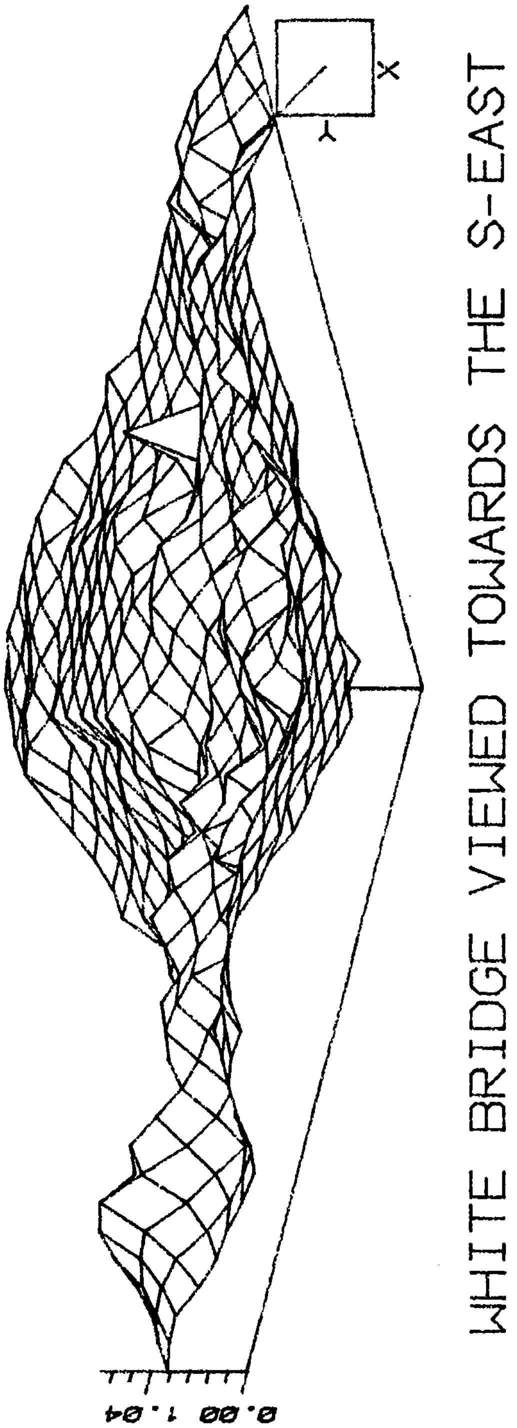
CSIR — EMA



THREE-D IMAGE OF THE WHITE BRIDGE MARSH VIEWED TOWARDS THE NORTH-EAST

FIGURE 9(a)

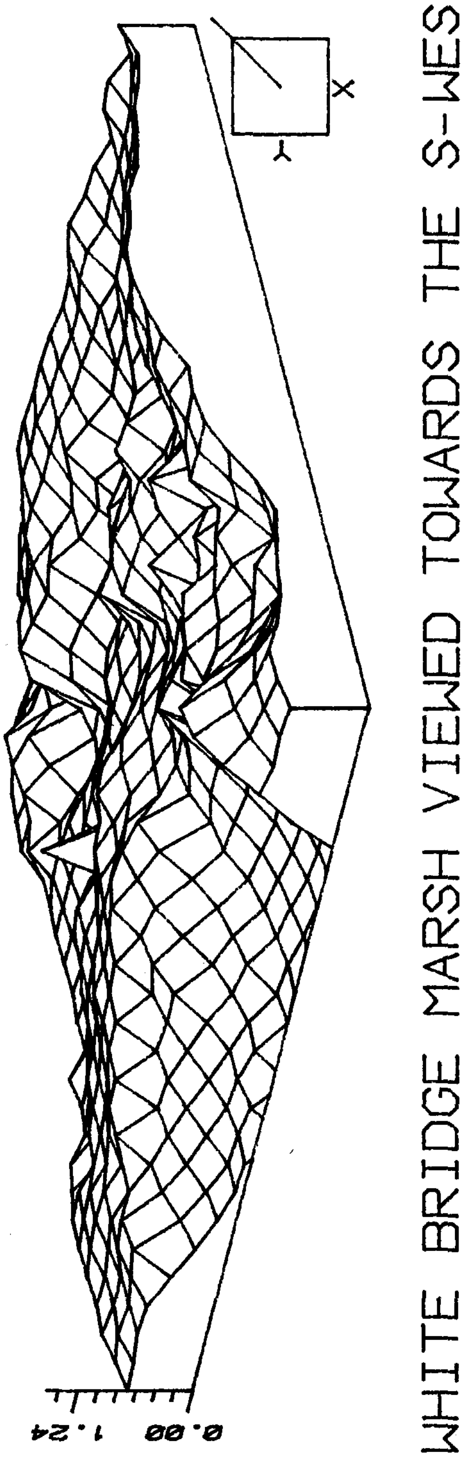
CSIR – EMA



THREE–D IMAGE OF THE WHITE BRIDGE MARSH VIEWED TOWARDS THE SOUTH–EAST

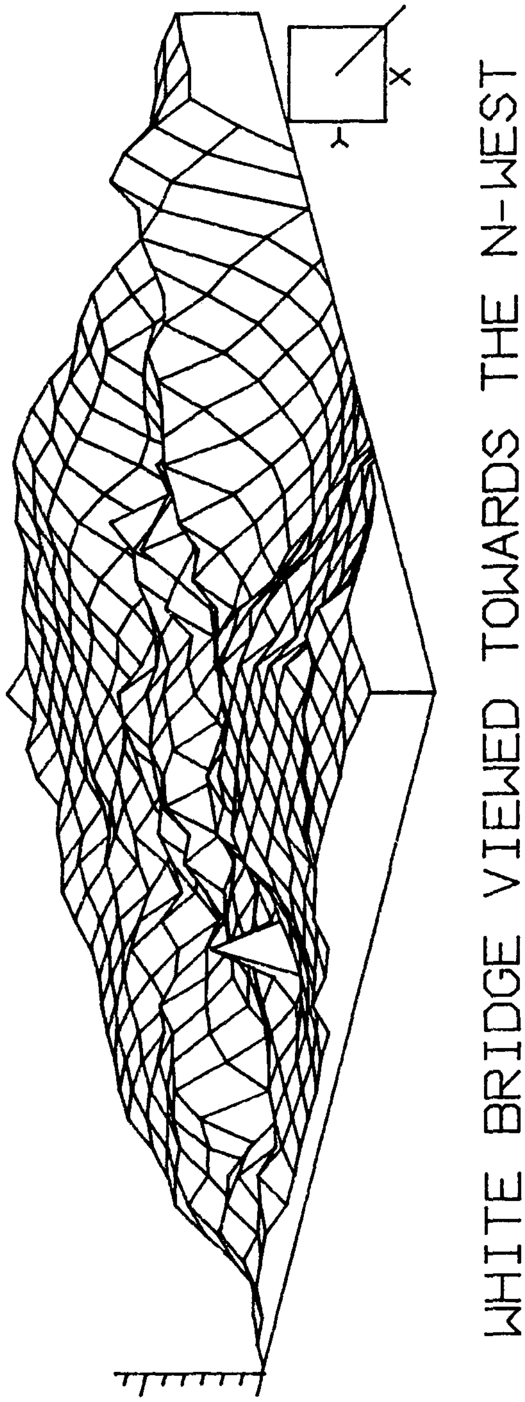
FIGURE 9(b)

CSIR – EMA



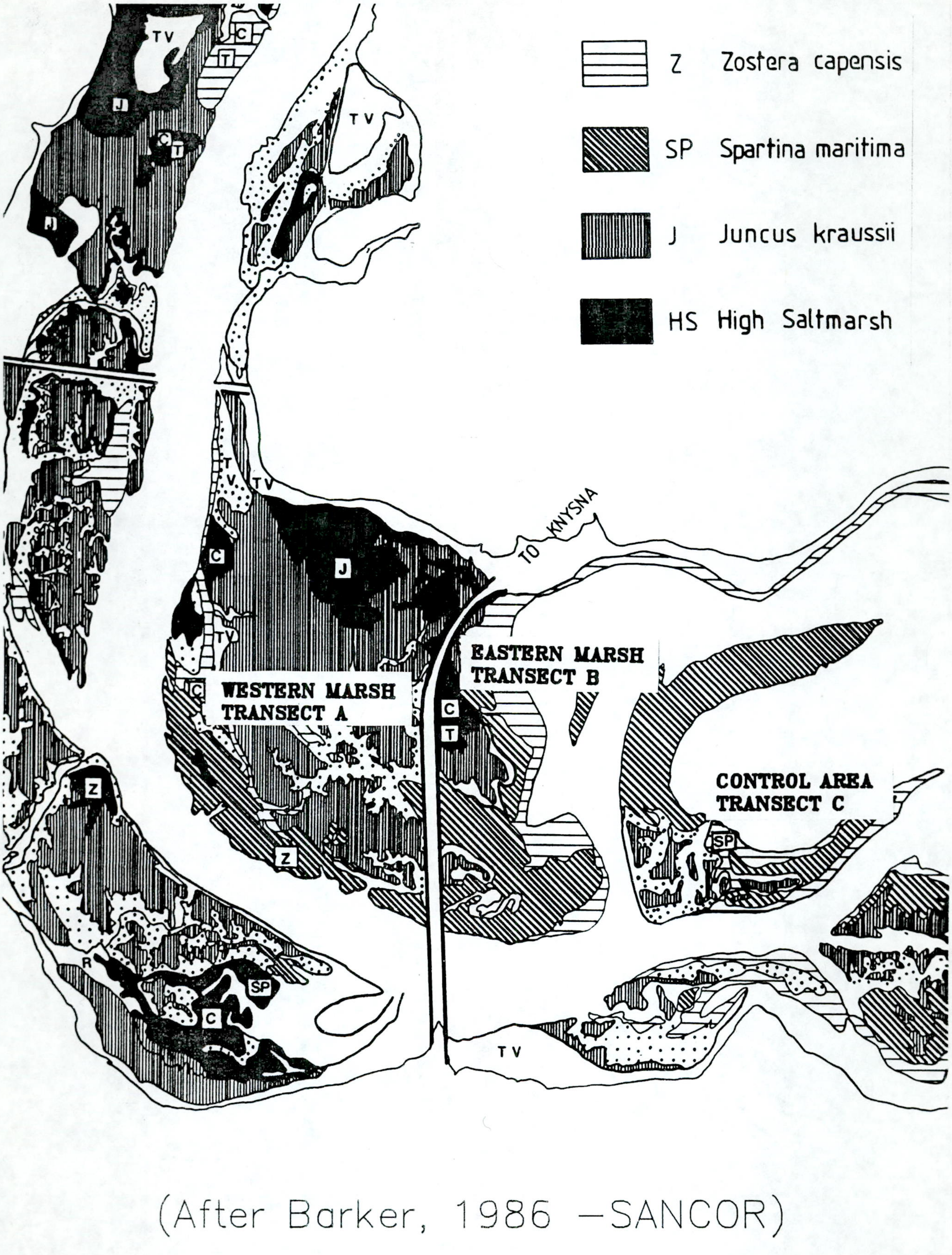
THREE-D IMAGE OF THE WHITE BRIDGE MARSH VIEWED TOWARDS THE SOUTH-WEST

FIGURE 9(c)



THREE-D IMAGE OF THE WHITE BRIDGE MARSH VIEWED TOWARDS THE NORTH-WEST

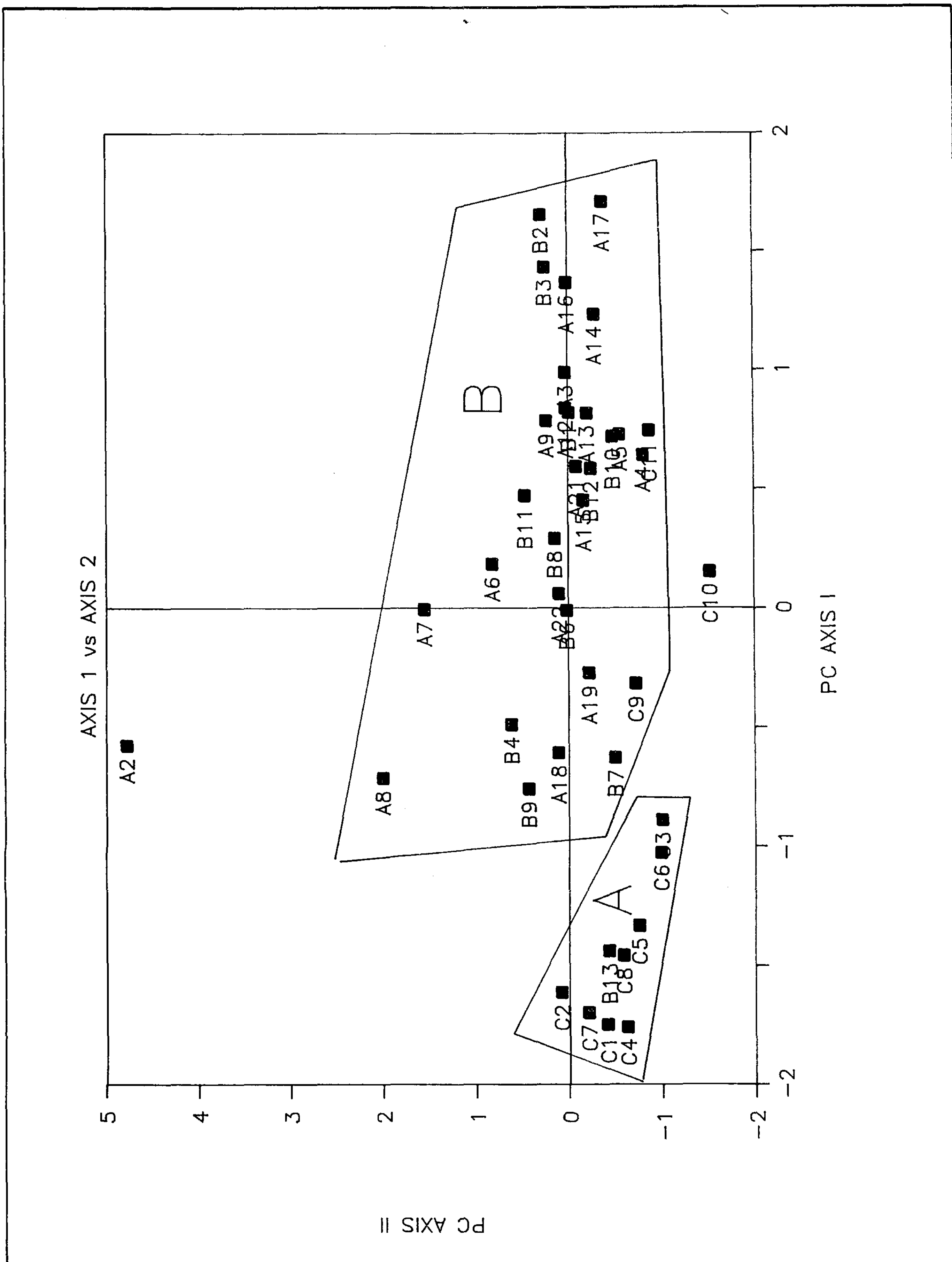
FIGURE 9(d)



VEGETATION MAP SHOWING THE THREE STUDY SITES

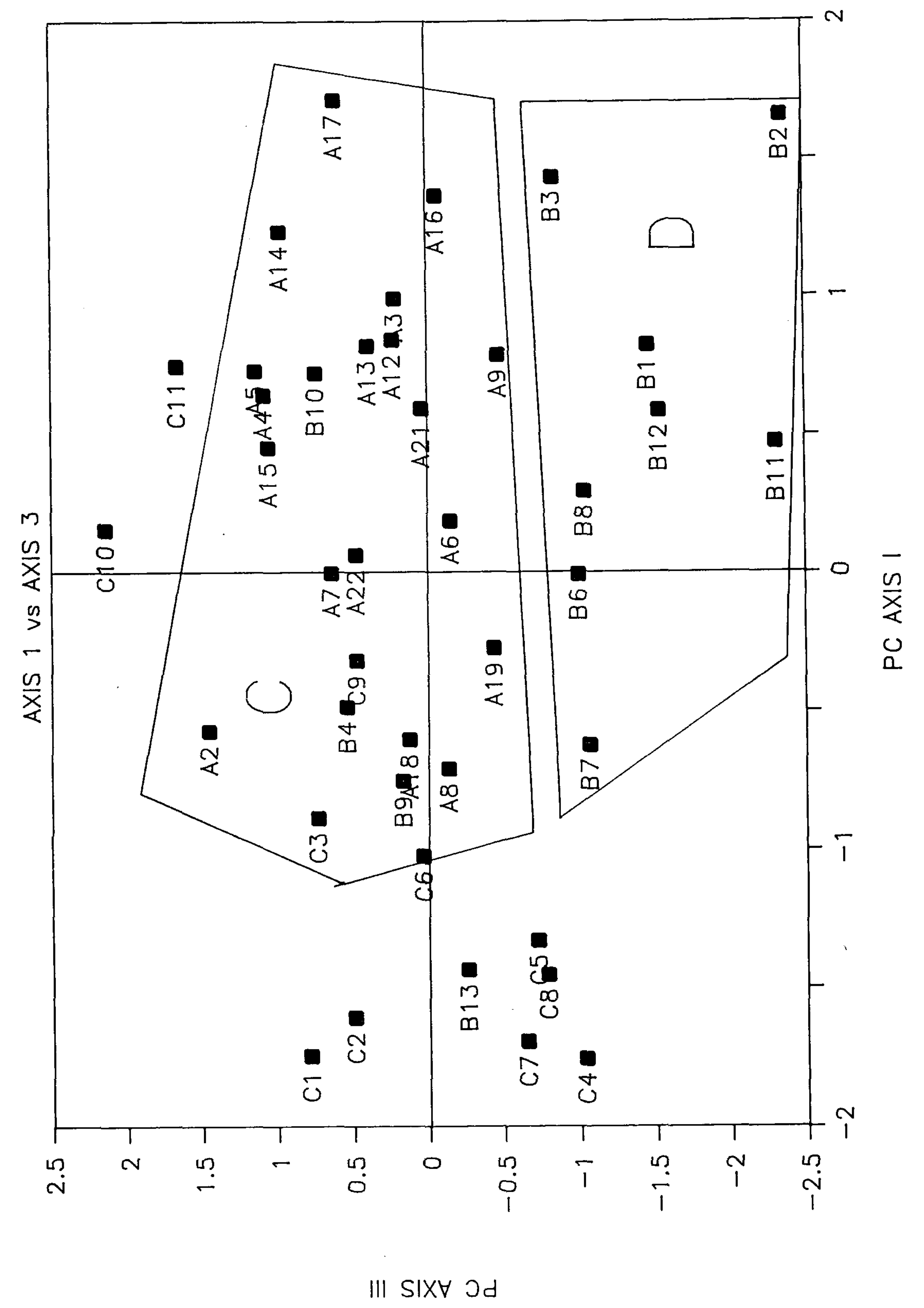
FIGURE 10

CSIR – EMA



	P C A ORDINATION OF THE ENVIRONMENTAL DATA OF THE WHITE BRIDGE MARSH – AXIS I vs AXIS II	FIGURE 11

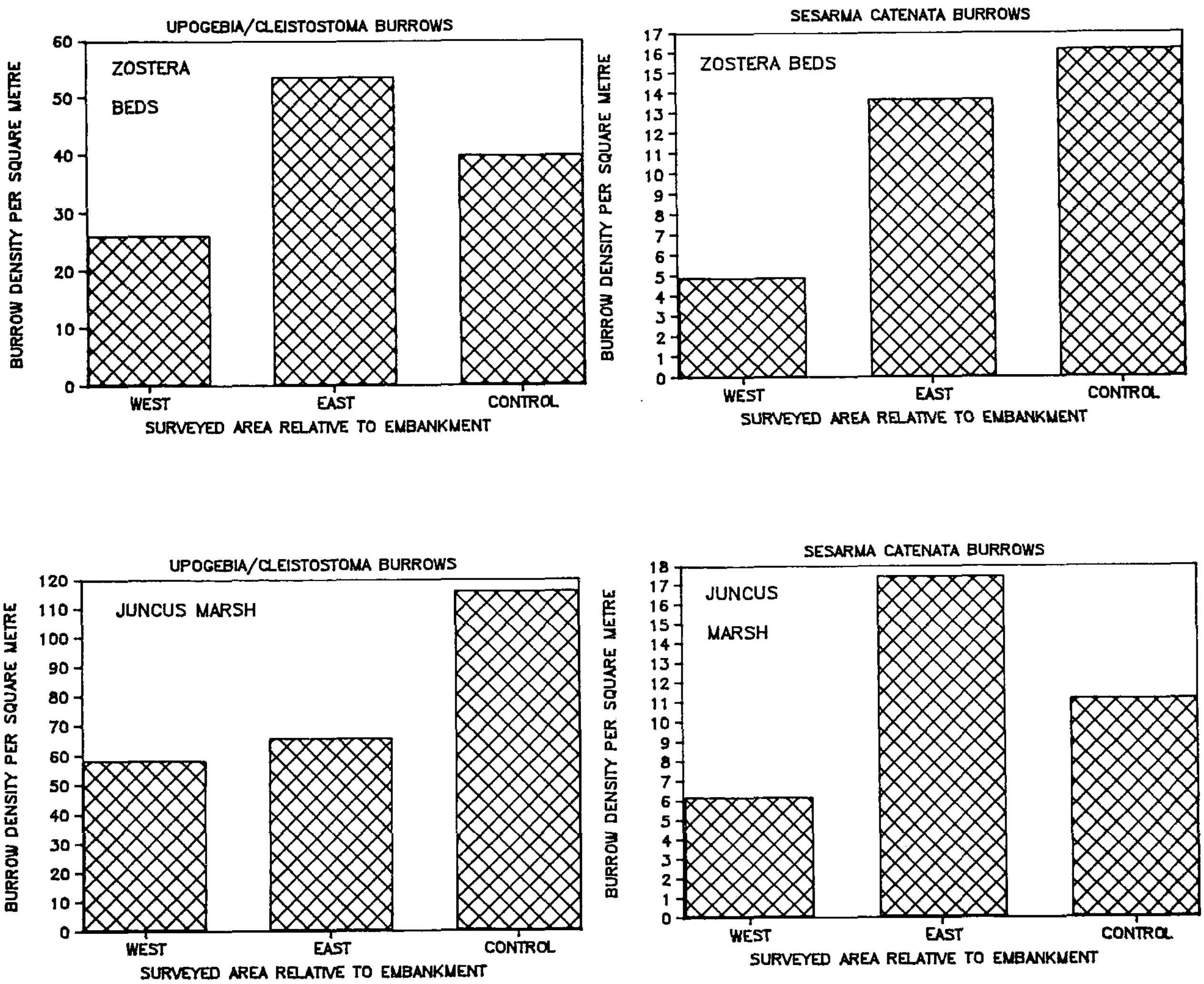
CSIR – EMA



P C A ORDINATION OF THE ENVIRONMENTAL DATA OF THE WHITE BRIDGE MARSH – AXIS I vs AXIS III

FIGURE 12

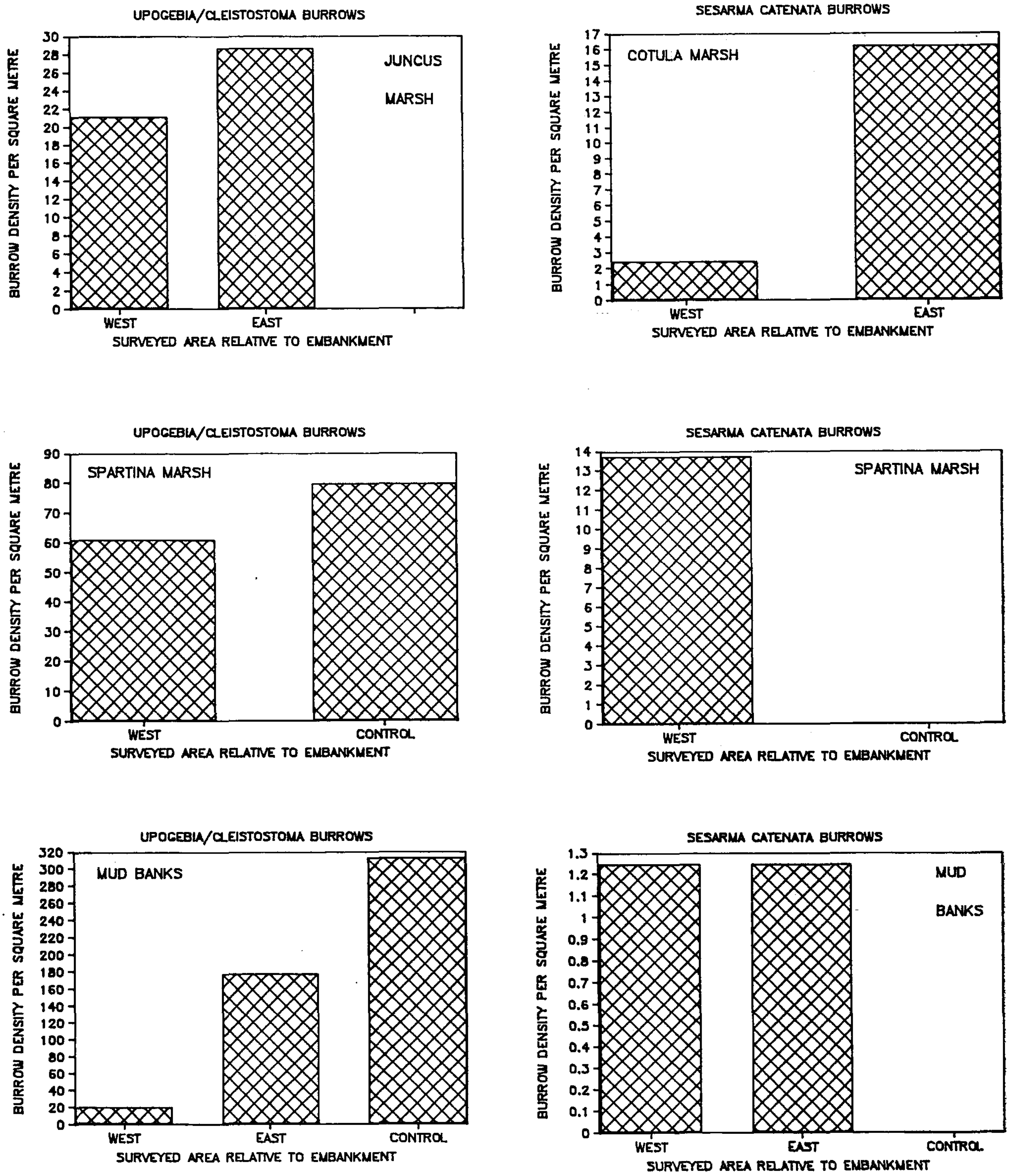
CSIR – EMA



DENSITY HISTOGRAMS OF THE DOMINANT MACROFAUNA OF THE WHITE BRIDGE MARSH

FIGURE 13(a)

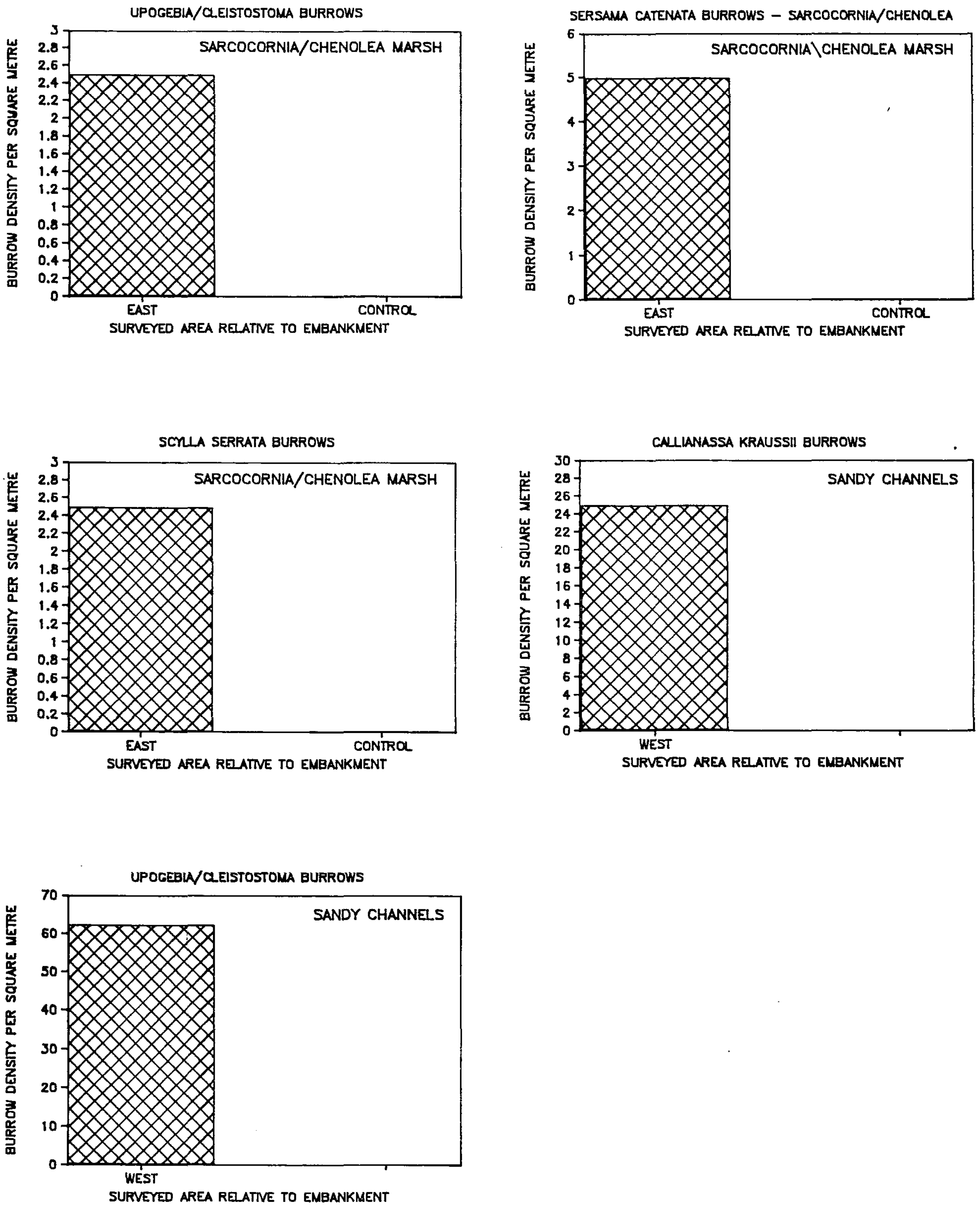
CSIR — EMA



DENSITY HISTOGRAMS OF THE DOMINANT MACROFAUNA OF THE WHITE BRIDGE MARSH

FIGURE 13(b)

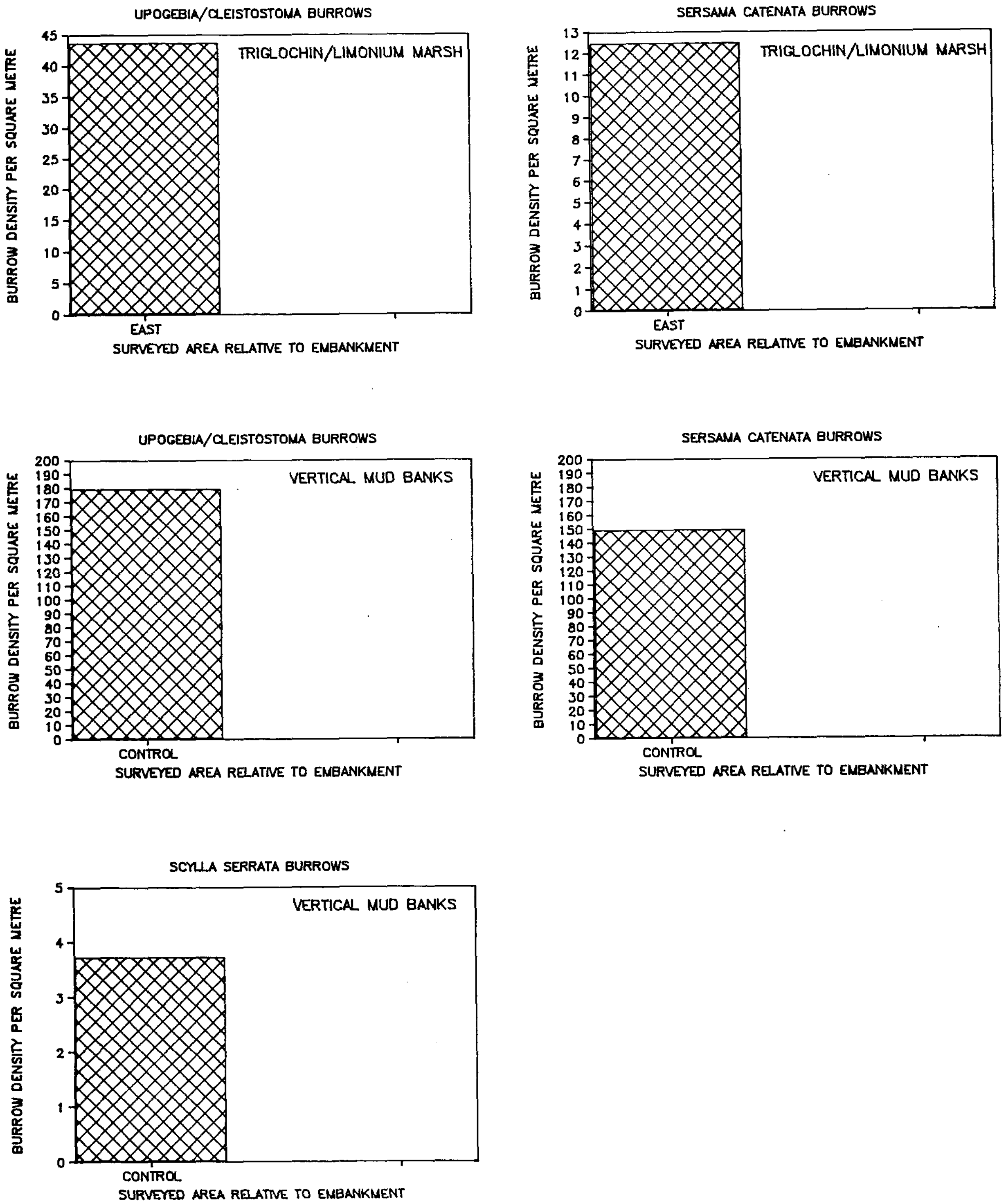
CSIR — EMA



DENSITY HISTOGRAMS OF THE DOMINANT MACROFAUNA OF THE WHITE BRIDGE MARSH

FIGURE 13(c)

CSIR – EMA



BURROW DENSITY HISTOGRAMS OF THE DOMINANT MACROFAUNA OF THE WHITE BRIDGE MARSH

FIGURE 13(d)

CSIR – EMA

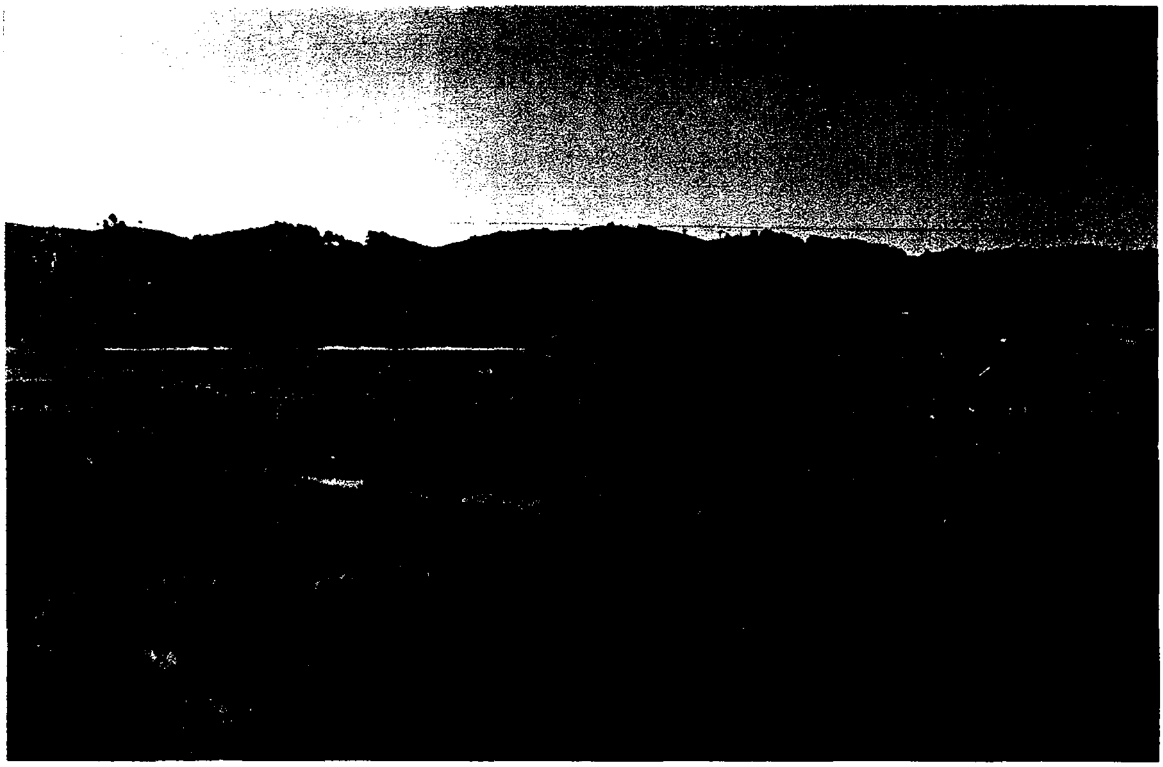


PLATE 1: *Juncus kraussii* marshland above the N2 road embankment.

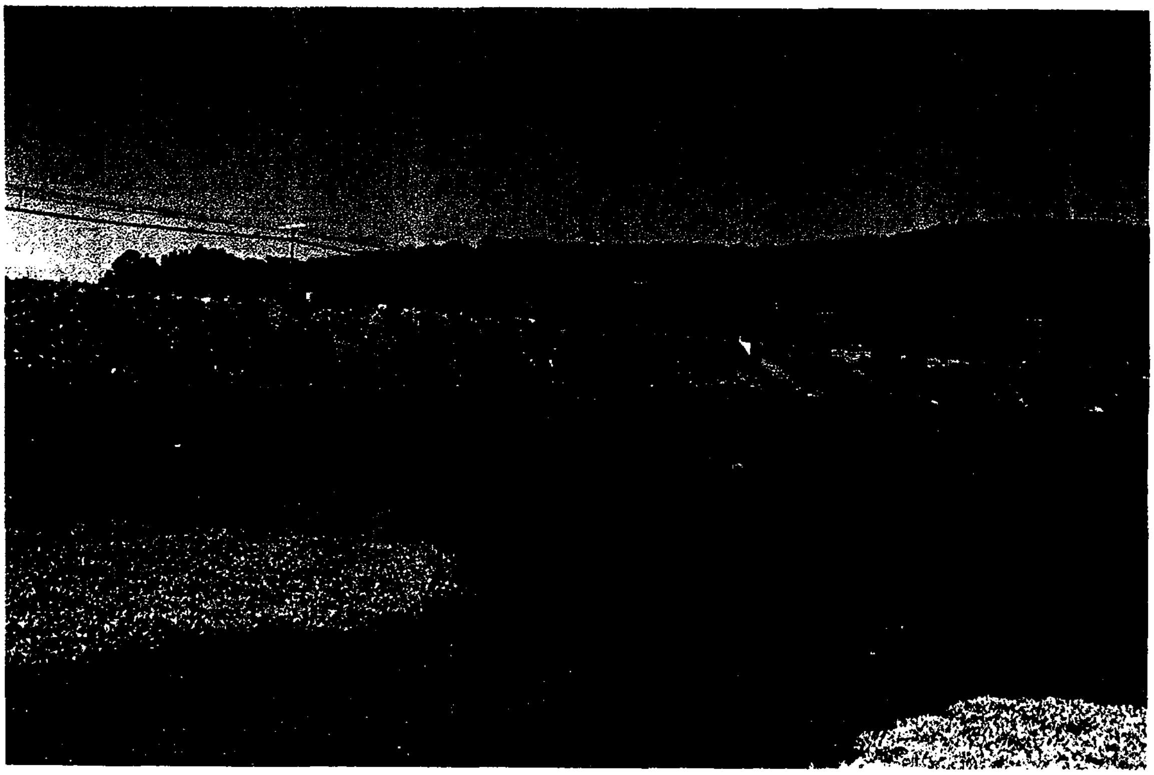


PLATE 2: *Cotula*, *Spartina* and *Zostera* marsh communities above the road embankment.

PLATE 3: *Cotula, Zostera* and *Juncus* marsh communities below the road embankment.

PLATE 4: Channel providing lateral flow into the marsh above the road embankment.

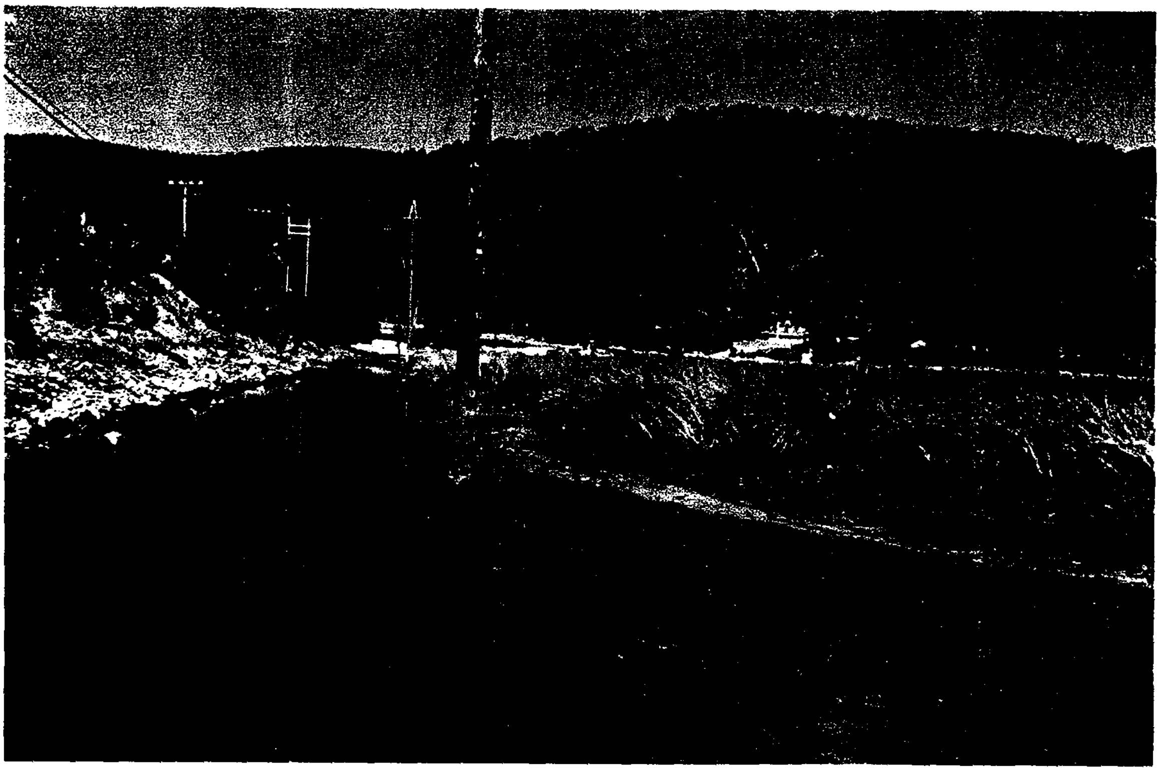


PLATE 5: Modified drainage channel above the road embankment.

PLATE 6: Silt and clay deposit on top of sandy layer above the road embankment.

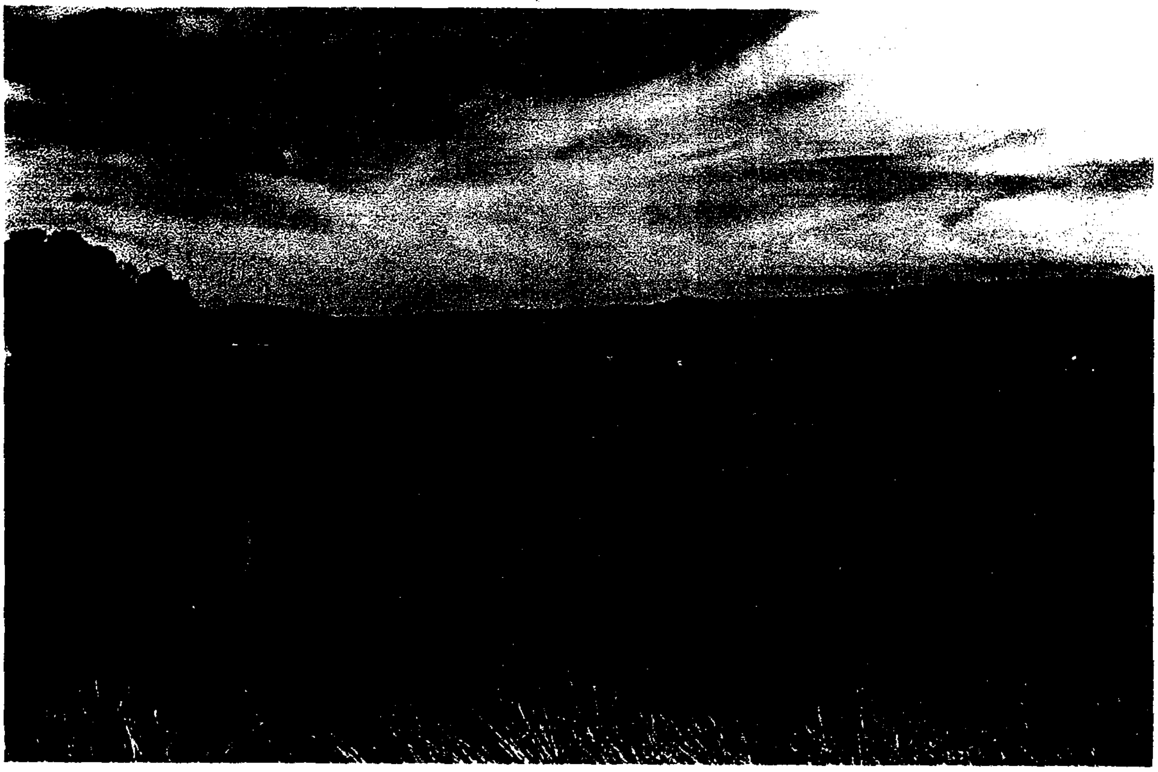


PLATE 7: *Juncus kraussii* marshland established at higher elevations on top of deposited silt/clay layer.

PLATE 8: *Juncus kraussii* litter which provides an organic input to the White Bridge marsh.

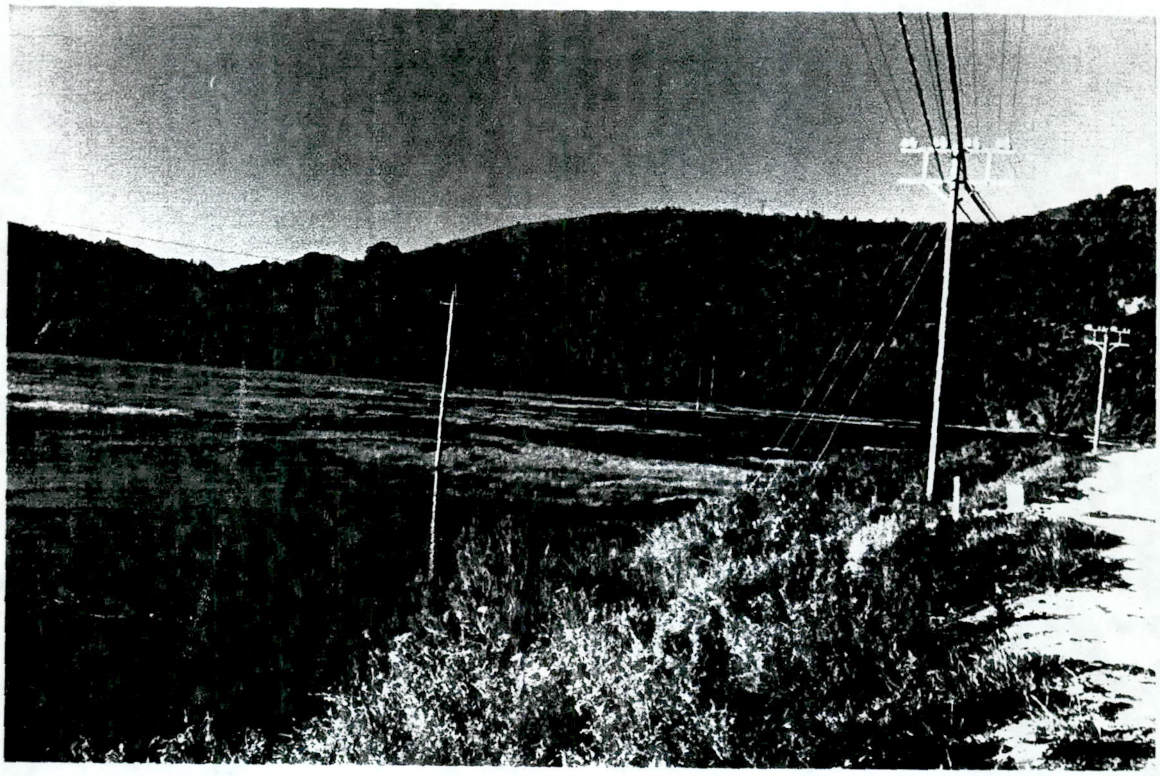


PLATE 9: A functional and healthy salt marsh system above the road embankment.