ENGLISH NATURE

Northey Island managed retreat

Report 4: Overview to February 1994

No. 103 - English Nature Research Reports

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No 103

Northey Island Managed Retreat
Report 4
Overview to February 1994

Institute of Estuarine and Coastal Studies
University of Hull
March 1994

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1. INTRODUCTION

In the summer of 1991 a small-scale managed retreat experiment was initiated on Northey Island in the upper reaches of the Blackwater Estuary in Essex. The primary aim of the work was to provide a relatively long term solution to a sea defence problem on the south side of the island where the saltings had eroded to a narrow strip. The resulting destabilisation of the sea defence embankment meant that the viability of continued maintenance was questioned. It was therefore decided by the National Rivers Authority in conjunction with English Nature and the landowners, the National Trust, to carry out a trial managed retreat scheme in this area.

The Institute of Estuarine and Coastal Studies (IECS) was commissioned by English Nature to carry out a baseline study of the site and produce recommendations for the techniques required to produce a viable saltmarsh. After the work was implemented in July 1991 IECS continued to monitor the geomorphological development of the site while English Nature have been monitoring changes in the vegetation. Three reports have been produced to cover the geomorphological monitoring to date. At this point, two and a half years after implementation of the scheme, it was decided to draw together the results so far in an attempt to identify trends. Details of the rationale behind the scheme and the methodology of data collection are given in the first report and are not repeated here.

2. OVERVIEW OF WORK TO FEBRUARY 1994

2.1 Baseline survey

A baseline geomorphological survey of the proposed site, fronting mudflats and adjacent terrestrial land was carried out in June 1991. The results of this survey, together with predictions of the expected results of the scheme, were used to produce a recommended plan for implementation. The baseline survey consisted of the following work:

- Installation of a tide gauge in a creek within the saltings to the north of the central part of the island. This gauge remained in place for 2 weeks recording tidal data for 30 seconds every 5 minutes. The resulting data was calibrated against data from the nearest Primary Port to produce a tidal curve for Northey.

- A preliminary topographic survey of the surface of the proposed site together with the sloping terrestrial land behind. Standard land survey techniques were adopted for this and all subsequent surveys, with a large number of randomly located points distributed across the area to enable contour maps to be generated and statistical analysis of change over time to be carried out.

- Analyses of sediment characteristics were undertaken, including sediment grain size, clay mineralogy, organic content and presence of trace metals.

In addition to these surveys a number of predictions were carried out in order to assess the expected effects of the work, these included:

- prediction of the number of tides per year which would inundate the different parts of the marsh surface;

- prediction of flow rates through proposed designs of sluice and weir;

- theoretical prediction of accretion rates which may be expected given the amount of suspended sediment in the Blackwater estuary.

2.2 Implemented managed retreat works

The managed retreat scheme as designed on the basis of the baseline survey results was implemented in July 1991. The following works were carried out:

- An open spillway 20m wide was constructed in the eastern corner of the site, the base of which was at 2.6mOD to be equivalent to the lowest part of the new marsh surface. The width was designed to allow all water to drain from the site within 2 hours of high water, and the position of the spillway was intended to coincide with the location of the relic creek system.

- The crest level of the outer wall was lowered to a height of 3.3mOD, to allow approximately 100 tides onto the site per year, whilst stilling the water within the set-back area to maximise the potential for sediment deposition. The material from the top of the old wall was used to infill the original borrow dyke behind the wall.

- The inner sea wall was modified to a line slightly further inland and raised to a height of 4.3mOD. The line of the wall was extended to include an additional area in front of the decoy pond and thus reduce the total length of wall requiring maintenance.

Following later repeat surveys of the site additional maintenance works were carried out which included the following elements:

- An additional lower channel was dug around the side of the spillway to allow output of water from adjacent field drain. This was subsequently re-filled and replaced by a pipe beneath the surface which exits adjacent to the spillway.

- The old borrow pits within the site were disrupting the flow of water and were therefore infilled more completely in the summer of 1992 using material gained by widening the new borrow pit behind the inner sea wall. The infill material was compacted using bulldozers.

- The wall at the eastern end of the site was suffering signficant erosion, possibly through a combination of high current velocities and internally generated wind waves, with seepage occurring through the wall to the brackish ditch behind. The wall was therefore strengthened using geofabric material.

2.3 Geomorphological monitoring following implementation

Geomorphological surveys of the site have been continued annually following implementation of the scheme. To date the surveys have been carried out in:

- August 1991, immediately following the managed retreat works,
- January 1992, six months after the work,
- August 1992 and February 1993, to comprise the 92/93 monitoring campaign,
- July 1993 and February 1994, to comprise the 93/94 monitoring campaign.

During the first repeat survey in August 1991 a series of permanent re-locatable benchmarks were installed to standardise the topographic surveys. At this time also a series of 17 accretion plates were installed at a distance of 10m apart along a transect from the foot of the inner embankment across the site through the spillway and extending to the low water channel.

For each monitoring campaign the following work is carried out:

- Topographic survey using the standard methodology
- Analysis of sediment characteristics, to determine temporal change along the transect line, and spatial change using random samples distributed across the managed retreat area.
- Analysis of accretion rates from measurements of the accretion plates, commencing in August 1992 after allowing sufficient time for the plates to settle. In February 1994 a further 10 accretion plates were installed in a random distribution across the site.
- Analysis of development of the drainage topography from both the topographic survey data and observations of the water flow and creek form.
- General observations of the site condition including patterns of vegetation colonisation, although full vegetation monitoring is not included in the IECS remit; condition of the enclosing walls, particularly that at the eastern end of the site; patterns of water flow through the spillway and across the site; and condition of the spillway to determine whether erosion of the underlying clay is occurring.

Following each of the monitoring campaigns outlined above a report of the results was produced for English Nature, the present report being the latest of these. These reports also included more details of the survey methodology than have been described here.

3. RESULTS OF GEOMORPHOLOGICAL MONITORING

3.1 Topographic development

The baseline survey confirmed visual observations that the proposed set-back site was at a relatively high elevation, with a general slope down from west to east across the site and a steeper slope upwards into the terrestrial land behind. The average ground level at the western end was found to be between 3.0mOD and 3.2mOD, sloping down to 2.6m OD at the eastern end. Visual observations also suggested the presence of a relic creek through the centre of the site draining towards the eastern corner. This was similarly confirmed by the topographic survey, and, together with the direction of the general slope, resulted in the spillway being located in this corner.

The tidal measurements and predictions, combined with the elevation measurements, suggested that the lowest parts of the new marsh would be covered by approximately 100 tides per year. The number of inundations would be reduced with distance up the marsh, with only about 10 tides per year predicted to reach the western corner of the site. This overall height and low number of predicted inundations suggested that saltmarsh plants representative of high marsh would be most likely to develop on the site. This provided an opportunity to create communities which are rare in the Essex context, although the opportunity to create a transitional habitat sloping into the adjacent high land was lost by the construction of the new inner sea wall.

The height of the spillway was designed to correspond with the lowest point of the marsh, and was cut into the consoliodated material of the original embankment, thus reducing the potential for erosion. Although this has proved an advantage in not causing erosion of the spillway edges or fronting mudflat the development of a renewed creek system may have been slowed by the lack of headward erosion into the marsh.

The contour maps produced from this and the previous topographic surveys are included in Appendix 1. As stated in the previous reports it is important to bear in mind that slight variation in the interpolated contours will be observed. In view of this, the method of change analysis between surveys involves statistical comparison using a t-test.

The normal processes on a saltmarsh involve raising of the marsh surface through sediment accretion while the creek lines develop as the marsh surface rises differentially around them. At this high elevation, however, the creeks must develop by erosion of the marsh surface, although the difference in the topography is enhanced as the marsh surface still continues to rise. The two sets of measurements for marsh surface and creeks have therefore been separated out for the analysis to determine any negative changes in the creek area and positive changes over the remaining surface. The mean elevations of the marsh surface for each survey are shown in table 1.

Table 1. Mean elevations of marsh surface (excluding creeks) for each survey date

Survey date	Mean elevation (mOD)	Variance	Standard deviation
Aug 1991	2.927	.052	.229
Jan 1992	2.880	.073	.271
Aug 1992	2.959	.069	.262
Feb 1993	2.964	.065	.255
Jul 1993	2.969	.067	.260
Feb 1994	2.943	.063	.251

The mean elevation of the marsh surface decreased by 4.7cm between the first survey in August 1991 and the second in January 1992. Subsequently the mean elevation experienced a gradual increase, reaching a level approximately 4cm higher than the original surface in

July 1993, although the latest set of results show a further lowering of 2cm over the winter of 1993/94. However, the variability of the elevations over the whole surface results in standard deviations which are consistently of the order of 25cm. The results of the t-test comparison therefore indicate that none of the survey results are statistically different, with the exception of the January 1992 data which is significantly different from all other surveys. It is assumed that this first set of data represents the original period of surface lowering as the terrestrial grasses were either stripped off or compacted through decay. Subsequent increases, although small, may have resulted from sediment deposition. Particularly large accumulations would be expected over the summer period, compared with the winter when either very little sediment is deposited, or the summer depositions are removed by winter erosion. However, on this basis it would have been expected that the February 1994 results would show a more significant increase than previously since this was the first winter when a more or less complete vegetation cover was present to prevent re-erosion of the sediment.

The general pattern of change in the marsh surface is matched by corresponding but inverse patterns of change in the creek bed elevations. The standard deviations of the creek measurements are smaller than those of the marsh surface, but the results are nevertheless not significant in the t-test comparison.

The contour maps in Appendix 1 show the gradual deepening of the relic creek which experienced an increase in depth from 20cm to 30cm following the July 1992 survey. The headward extension of the creek line along the former inner borrow ditch is clearly visible in the February 1994 survey. A general lowering of the spillway surface may also be seen from the change in contour height from 2.6m in January 1992 to 2.4m thereafter. However, this now appears to be stable without any further lowering of the contour height.

3.1.1 LONG TERM IMPLICATIONS OF PRESENT ELEVATION

A recent study carried out by IECS on behalf of English Nature looked at a number of areas in Essex where sea defences had failed naturally in historic times with differing responses in terms of the type of saltings which resulted. The results of this study showed that elevation within the tidal frame is the primary factor which determines the fate of the new saltings over a long timescale. Interpretation of the data indicated that sites with an elevation higher than 2.1mOD at the time of the breach are less likely to suffer significant amounts of erosion than lower areas. The elevation of the Northey Island site ranged from 2.6mOD to 3.2mOD across the surface at the time the scheme was implemented, with all the subsequent mean elevations being around 2.9mOD. This is considerably higher than any of the sites in the historical study, the highest of which had an average elevation of 2.366mOD. However, the vegetation types on the historical sites were extremely uniform, with very little gradient across the site, although even this degree of slope was found to have an influence on the type of vegetation which resulted. It is to be hoped, therefore, that the greater height and slope across the Northey Island area will allow the eventual development of a more diverse habitat type, although the height may have implications in terms of the development of the creek system, as described in section 3.4.

In terms of the present development of the marsh habitat *Salicornia* has colonised the site prolifically over the past year, although the current elevation of the Northey Island marsh is relatively high for this species which is generally found in pioneer situations. *Salicornia* has been found in studies elsewhere to be a highly opportunistic coloniser of bare substrates. It is therefore expected that the presence of abundant *Salicornia* will provide shelter for other species to become established, which will then have a competitive advantage at this elevation, and a more representative vegetation type will be promoted. This site therefore represents a unique opportunity to examine the temporal patterns of vegetation establishment and relate these to development of the measured physical processes.

3.2 Accretion

The measurement of changes in the marsh surface by a large number of random topographic survey points distributed across the whole site is complemented by measurement of actual accretion along a transect line at the eastern end of the site. This line of 17 accretion plates was installed on the first repeat survey visit in August 1991, and extended across both marsh and mudflat, with six plates on the marsh and 11 across the mudflat to the low water channel. The primary aim of these plates was to assess the accretion rates on the mudflat surface in order to complement the elevation surveys which provide information about change in the surface of the new marsh site. In February 1994 a further 10 accretion plates were installed in random locations across the site to allow assessment of the spatial patterns of marsh accretion. The depth of the accretion plates is determined at each survey visit, with the increasing depth of the plates representing the accreted sediment as shown in Appendix 3. The first set of changes between August 1991 and January 1992 represent a period of the plates settling into position and are therefore not taken to represent accretionary changes.

The changes in the depths of each plate over the five subsequent survey periods are shown in figure 1. This shows the August 1991 accretion plates at a single depth, representing the average depth of all plates on this date. The plate numbers 1-11 are located in the mudflat and show marked accretion over all plates. Plates 1, 2 and 3 located at the lower end of the mudflat, i.e. adjacent to the low water channel, are more variable with the lowest plate actually experiencing erosion over the latest survey period. At the upper end of the mudflat plates 10 and 11 have experienced slow rates of accretion over the whole timescale. At these locations the substrate generally consists of the hard underlying clays in contrast to the soft estuarine sediments which predominate over the other mudflat plates. The significant accretion observed on the mudflat is slightly unexpected along this otherwise stable channel, and may be a combination of continued adjustment of this area to the presence of the causeway, and the altered tidal flows resulting from the new marsh of the set-back area.

In contrast, plates 12 to 17 are located within the marsh and have experienced considerably less accretion over the timescale of the work. Plate 17, located at the landward end of the transect towards the inner sea wall, originally experienced nearly 2cm of erosion, and although a slow rate of accretion has followed the plate is still located nearer the surface than its original depth. Two distinct patterns are visible in the other 5 plates in the marsh. Plates 16 and 12 have experienced a low but steady rate of accretion over the monitoring timescale, whereas plates 13 and 14 have been more variable, subject to both erosion and accretion over the study period.

Over the 2.5 years of the monitoring to date an average of 6.2cm of accretion has occurred across the whole transect. However, as would be expected from the above observations there is a marked difference in the marsh and mudflat averages, with a total accretion of 8.6cm on the mudflat compared with only 1.8cm on the marsh surface. There is also a significant difference in the annual rates of accretion on the marsh and mudflat. These are shown in table 2.

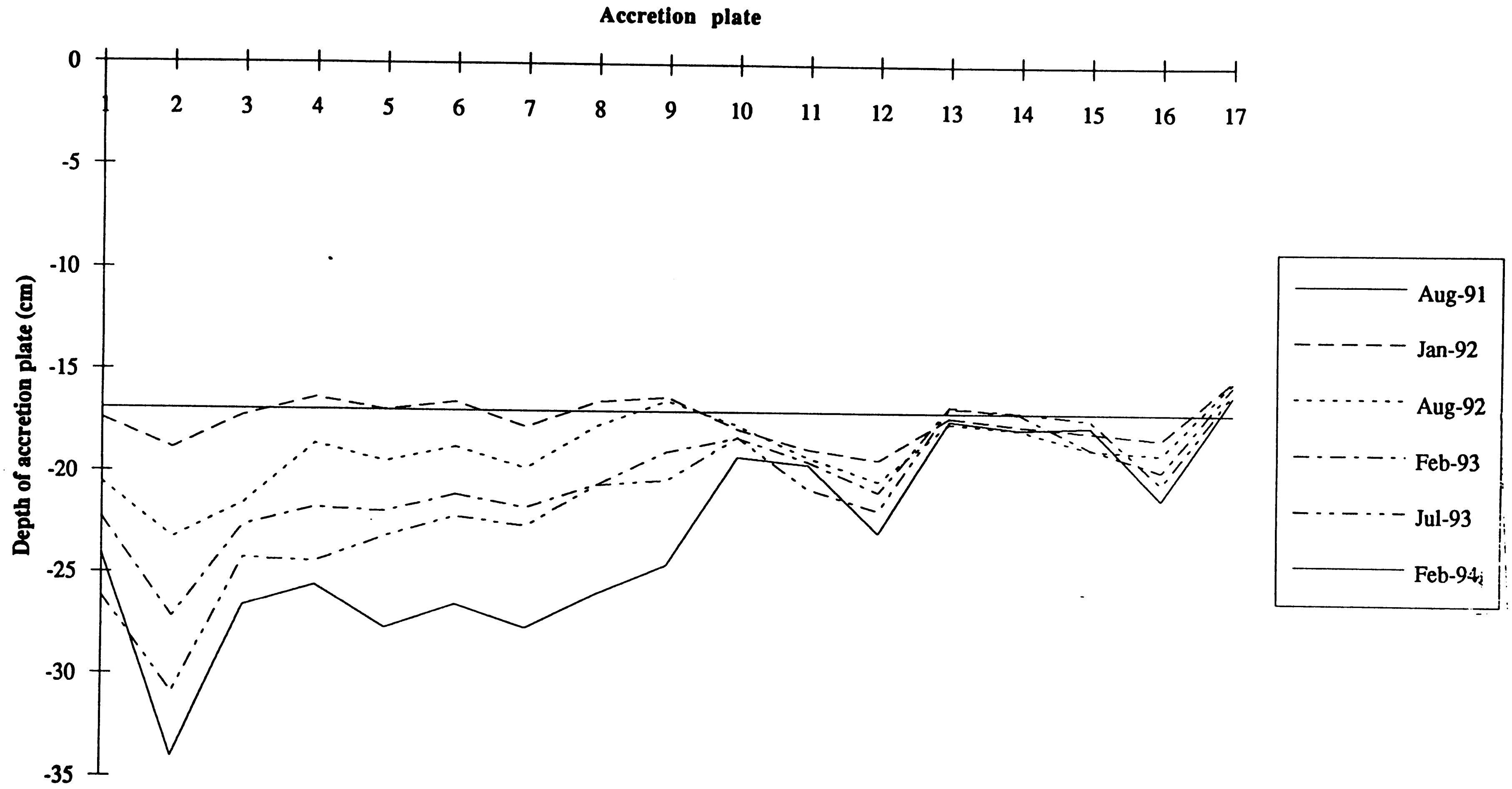

Figure	Institute of Estuarine and Coastal Studies
Changes in the depth of accretion plates over the full survey period	University of Hull

Table 2. Annual accretion on the mudflat compared with the marsh surface

	January 1992 - February 1993	February 1993 - February 1994
Mudflat	4.125 cm	4.125 cm
Marsh	0.552 cm	0.071 cm

Although only two years are available to allow annual accretion rates to be calculated the data so far show that the relatively high rate of accretion on the mudflat has remained very stable over the project timescale. This high rate of accretion is important in modifying the wave environment which reaches the edge of the marsh, both on and diffracting through the spillway, and on the remaining outer wall. The rapid rates of accretion immediately outside the spillway are also important in showing that the enhanced current flows of water entering and leaving the new marsh area are not increasing erosive processes on the mudflat.

It was predicted that the relative height of the marsh surface in the tidal frame would result in low accretion rates here. It was originally predicted on the basis of 75% of the sediment load being deposited during the 100 inundations per year that an accretion rate not exceeding 0.1mm per year would result. The actual accretion over the first year was therefore observed to be significantly greater than the predicted rate, although reducing in the second year to a level which is more consistent with the prediction.

3.3 Sedimentological changes

From the original baseline survey the average sediment grain size of sub-surface samples was found to 12.7μm, i.e. medium silt. The relative proximity of all samples meant that there was little variation between them, although the landward sample was found to be slightly coarser with a smaller percentage of clay/silt. The presence of a high proportion of fine grains suggested that the site had originally been located in an accretionary environment.

The clay mineralogy of these samples was similar to that of the London Clays underlying most of the Blackwater and may have been derived from slope run-off or from a source elsewhere within the Blackwater area. The presence of a large proportion of illite in the samples was identified as a potential problem, since this acts as a swelling component which could make the substrate unstable by slaking and scouring with current movements. The effect of this was tested during one of the later surveys using a vane shear strength method, but was found not to have a significant impact. The composition and amount of trace elements within the samples was within the limits for farmland, although the effect of these on saltmarsh plants could not be predicted since the tolerance limits of these plants is largely unknown.

During subsequent surveys repeat samples of surface sediments were taken along the transect line to determine changes in sediment composition across the site. Additional random surface sediments were also sampled to determine changes within the site. The sediment grain size data and analyses of organic content for both the transect and the random samples are given in Appendices 4 to 7.

With this frequency of sampling, i.e. biannually in summer and winter, no systematic or statistically significant changes were found, with the exception of the final sample taken in February 1994 as shown in table 3.

Table 3. Mean values of sediment grain size (μm), skew and standard deviation for all samples from each survey date

Survey date	Mean grain sizes (μm)	Skew	Standard deviation
August 1991	(no samples)	-	-
January 1992	17.03	0.087	1.858
August 1992	10.7	0.102	1.369
February 1993	10.62	0.108	1.382
July 1993	28.19	0.285	1.529
February 1994	6.59	0.002	1.702

No consistent trends can be identified after the first 30 months of tidal inundation. A gradual fining and increase in sorting of the surficial sediment layer may be expected over time as marine deposits replace terrestrial sediments, with a spatial fining of the deposits towards the north-west corner as tidal velocities diminish. In addition, previous studies in other areas (Husain, 1991) have identified that a higher proportion of fine sediments is generally deposited in the summer months when the waters are warmer and viscosity is reduced.

Examination of the spatial distribution of mean grain size across the site shows no clear trend of fining towards the upper corner. The density of the samples may not be sufficient to show conclusive patterns, particularly as the distributions are complicated by the introduction of sediments from the flow of water along the creek and borrow ditch. There is also no evidence of summer fining, indeed a marked coarsening of sediments occurred in the summer of 1993 and a uniformly fine layer was present the following winter, both of which are contrary to the expected seasonal patterns.

The analysis of sediment samples can provide misleading results when taken over relatively short timescales as in this case. The findings obtained on each survey occasion generally represent short term changes in sediment type resulting from meteorological conditions prevailing immediately prior to the sampling time. The sample sizes obtained in the first 20 months are consistent with the medium silts of the surrounding London Clays. However, the coarse samples observed in July 1993 may be the result of onshore winds generating large waves which entrain coarser sediments from elsewhere in the estuary and transport these into the set-back site. The subsequent fine samples of February 1994 are more likely to result from local wind conditions redistributing the internal sediments. Once deposited these would be less likely to be re-eroded than in previous years because the significant increase in vegetation cover which occurred in the 1993 growing season provides enhanced protection, and a larger proportion of fine sediments is therefore retained.

3.4 Development of drainage topography

This is an important aspect of the site development, influencing the transport of sediments across the marsh. For much of the history of the site so far the flows have been disrupted by the presence of the original borrow pits. These have largely been filled in with material obtained from the borrow pit behind the new sea wall and compacted by bulldozer. This procedure has served to produce an extremely hard surface which is not readily colonised by saltmarsh species. The compacted areas are only now starting to be colonised eighteen months after the borrow pits were filled, and show a considerably less dense vegetation cover than the rest of the marsh (Plates 3 and 4).

Observations and elevation measurements showed that a relic creek was present through the centre of the site, draining towards the eastern corner. This, together with the general slope from west to east, resulted in the spillway being positioned in the eastern corner of the site. Subsequent topographic surveys have shown that the creek is indeed deepening along the expected line. However, Plates 15 and 16 show that significant areas of standing water remain permanently behind the original fronting sea wall. A narrow channel is becoming incised into the surface of the spillway. It is to be expected that continued headward erosion of this channel may eventually result in more complete ebb drainage of the standing water.

The original inner sea wall was moved landward as part of the managed retreat scheme, and the borrow pit associated with this wall was never completely filled. There is no link between this line and the central creek since it is in an entirely artificial location, and now remains as a permanent channel of standing water which has become successively deeper over time. In addition, a further area of standing water remains at the front of the site to the west of this line, also with no link to the main creek. The borrow pit line runs along the back of the new inner sea wall towards the head of the relic creek, with a distance of approximately six feet between the two channels. This remaining area is low and soft but has not yet broken through, as shown in Plates 5 and 6. Although development of a linking channel may be expected at some stage the relative depths of the two channels may result in enhanced water movement into the site but not necessarily more efficient ebb drainage.

These artificial configurations in the surface topography - the compacted areas, channels and standing water pools - are affecting the overall development of the site, both in terms of the topography and the patterns of vegetation colonisation. However, it is not recommended that futher modifications are carried out at this stage since the engineering works to date have only served to disturb rather than improve the situation.

A large amount of research into the design of artificial drainage systems has been carried out in the United States where re-creation of wetlands has been a major issue for many years. Haltiner & Williams (1987) noted that although tidal flows could be allowed to establish a new system by natural processes of deposition and erosion, this tended to take a long time. This is particularly the case where consolidation of the surface has occurred, resulting in minimal erosion rates and causing poor circulation, and potentially delayed vegetation colonisation, although this latter does not appear to be a problem on Northey Island. The created wetlands in the US tend to be substantially larger than the Northey Island site, and therefore the slow creation of a drainage system is less of a problem in Northey as the water is able to reach all but the highest western part of the site as a sheet flow on the rising tide. The overall coverage may therefore allow an adequate water circulation on this site but may be a more important consideration in larger areas.

A further point which may be relevant in this situation regards the development of a drainage system on wetlands created on dredge fill material. Weckman & Sales (1993) reported that dredge sites which were filled too high never developed an adequate drainage system, and eventually lacked habitat diversity. By contrast, those sites which were filled at or lower than the recommended level, although requiring longer to reach suitable elevations, developed a complex system of branching channels and a variety of natural habitats. Although the

Northey Island managed retreat was not created on dredge material the elevation is relatively high and may therefore provide an analagous situation.

4. GENERAL OBSERVATIONS

A number of general observations regarding the condition of the site are made on each survey visit. These are accompanied by a series of photographs obtained from similar viewpoints to enable direct comparisons to be made over the project timescale.

The condition of the wall at the eastern end of the site was originally causing significant problems with erosion along much of its length, possibly through the action of internally generated wind waves. This necessitated maintenance work to strengthen the wall with geo-fabric although the continued erosion resulted in the geo-fabric being exposed again as shown in Plate 2. After this time, however, the general increase in vegetation cover over the entire site and the sea walls in the next growing season resulted in the eastern wall becoming much better stabilised as shown in Plates 3 and 4. These plates show that this wall is now well-vegetated in both summer and winter, increasing the overall levels of protection.

The dramatic increase in vegetation cover which occurred in the single growing season of the spring and summer of 1993 indicates that up to two years may be required for conditions to become optimum for plant colonisation. Examples of wetland re-creation in the United States have also found that a surface layer of freshly deposited sediment is the most ideal substrate for vegetation establishment (Krone, 1993). Once vegetation colonisation has started the rate of establishment generally increases rapidly as new growths are sheltered by the surrounding vegetation (Knutson & Woodhouse, 1983). The enhanced colonisation rates on Northey may also be due to stabilisation of the sediment following eventual removal or compaction of the terrestrial grasses.

Although the vegetation cover currently on the site consists largely of annual species such as *Salicornia* and *Suaeda* the dead stems of these plants remain and provide a degree of continued protection for the accumulated sediment throughout the winter (Plates 5 and 6). The presence of standing water along both the creek and the inner borrow pit prevents vegetation establishment along these lines and creates a more distinct edge. The differential vegetation colonisation along the compacted borrow pits may also have implications for the long term development of the site. However, the evidence to date is that colonisation is occurring although at a slower rate than elsewhere on the site.

Plates 7 and 8 show the changes which have followed since the maintenance work to infill the borrow pits which took place in June 1992. This work has been successful from the point of view of stabilising the sea walls along the front and the eastern edge of the site, although incomplete in not filling the inner borrow pit. In addition, the tracks of the machinery to the outer wall remain visible 18 months after completion of the work, as shown in Plate 8 to the right of the standing water area.

The degree of success achieved through infilling the front borrow pit may be seen in Plates 9 and 10. The first of these shows the rapid flows of water into the borrow pit, with the water reaching the far end of the site before the near end is flooded. After infilling the flow spreads more evenly across the site. The reduction in relative height of the outer wall produces a more even grading into both the back marsh and the spillway. This has allowed colonisation by stabilising marsh plant species which helps to reduce the problems of scour from extreme flows down the rear of this wall. However, close observation of this wall has identified that the surface of the front of the wall is being removed in layers, resulting in an overall lowering of the surface elevation, particularly noticeable relative to the remnants of fronting blockwork (Plates 13 and 14).

A further area of erosion has also been observed along the inner wall as shown in Plates 11 and 12. The erosion, which is located at the head of the central creek, is still relatively minimal, and is possibly caused by current flows up the creek impacting on the wall. Continued observation of this potential problem is recommended to ensure that the integrity of the wall is not compromised.

5. CONCLUSIONS

Two and a half years after the Northey Island managed retreat was carried out the general conclusion is that the site is developing satisfactorily. Accretion of estuarine sediments has been occurring on both the new marsh and the fronting mudflats, although at a vastly different rate in the two locations. The relatively low rate of accretion on the marsh means that changes in the surface elevation have been extremely small, and overall trends cannot yet be distinguished from the background variation over the whole site. This low accretion rate is expected in such a high site and is not predicted to increase over time. However, the presence of a layer freshly deposited sediment, possibly combined with enhanced surface stability resulting from compaction or decay of the underlying terrestrial grasses, has allowed a good halophytic vegetation cover to be achieved after two years of tidal flooding.

The drainage system of the site is developing less satisfactorily, although the relic creek through the centre of the site is becoming well defined by the increase of vegetation on either side. However, this is not yet connected with the spillway to provide efficient ebb drainage, and large areas of standing water remain permanently along the predicted line of the creek. In addition the inner borrow ditch is also permanently filled with standing water, as is a large area to the west of the borrow ditch. Despite the possibility that eventual development of a more effective creek system may take some time it is not recommended that further maintenance work should be carried out to alter the creek pattern at this stage.

The early problems with erosion of the eastern wall have been alleviated by the development of a good vegetation cover. However, further minor problems are being experienced by the back wall at the head of the relic creek, possibly from rapid current flows along the creek impacting on the wall. It is recommended therefore that observation of this wall is continued.

5.1 Recommendations for future monitoring

It is recommended that monitoring of the site development should be continued using the same methodology to allow comparable results to be collected. However, the slow rates of geomorphological change on the site may allow the monitoring frequency to be reduced to one survey per year. In addition it is strongly recommended at this stage that stereo aerial photographs covering the site and adjacent estuary should be obtained soon as possible. These should be at an appropriate scale to allow accurate measurements, preferably no smaller than 1:5000. The aerial photograph survey should be repeated at regular intervals over the coming years to provide a permanent record of changes. These are particularly valuable in recording elements which may not have been observed during the actual survey visits.

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7. APPENDICES

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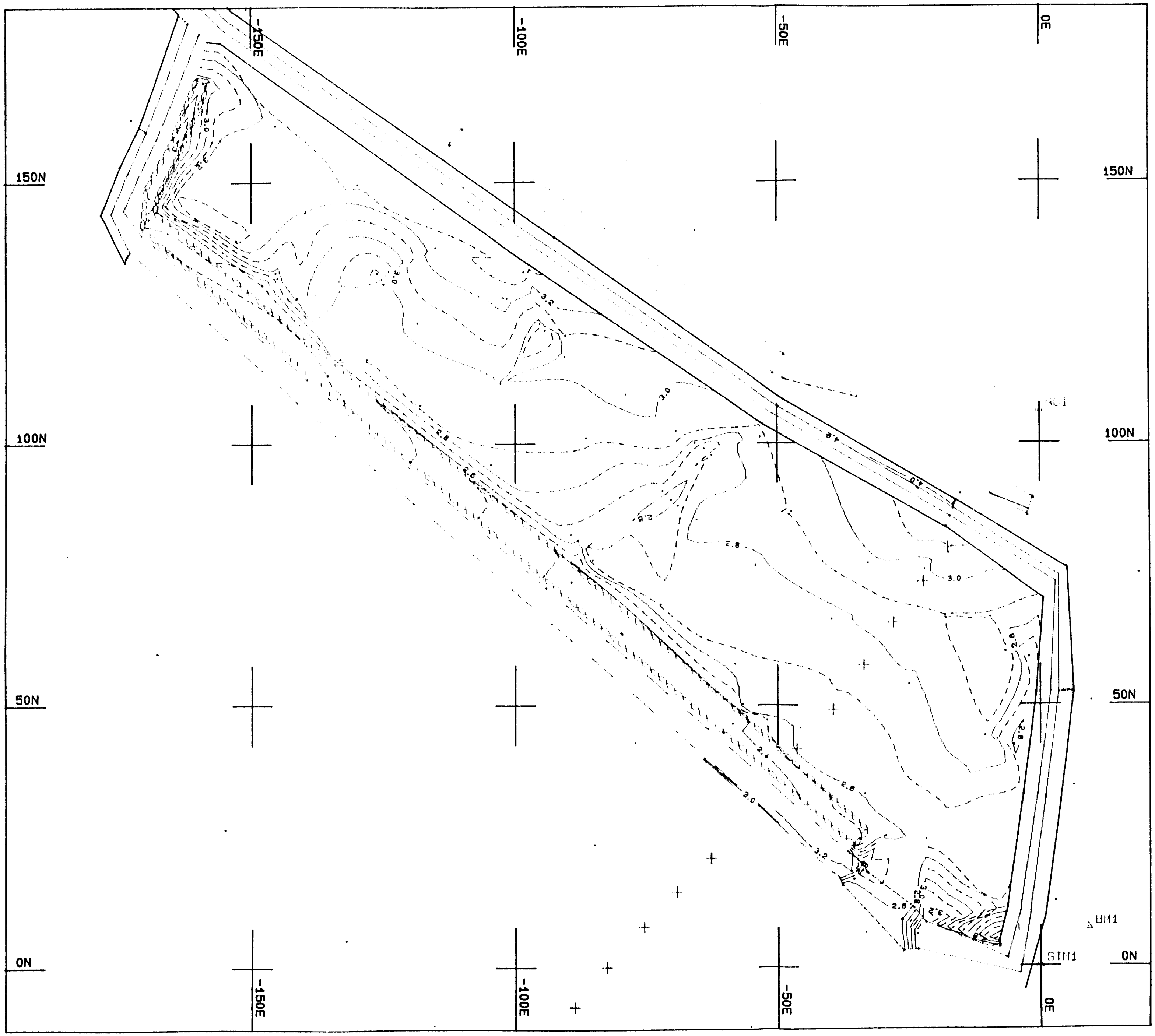
Appendix 1.

Topographic survey maps obtained from each survey



LEGEND

- Sea Wall Base
- Sea Wall Top
- Former Sea Wall
- Former Borrow Ditch
- New Borrow Ditch
- Accretion Plate
- Survey Point

MTP LAND SURVEY SYSTEM

Northey Island Survey 20.8.91

SCALE 1 : 750

CONTOUR INTERVAL : 0.1m

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HULL HU6 7RX
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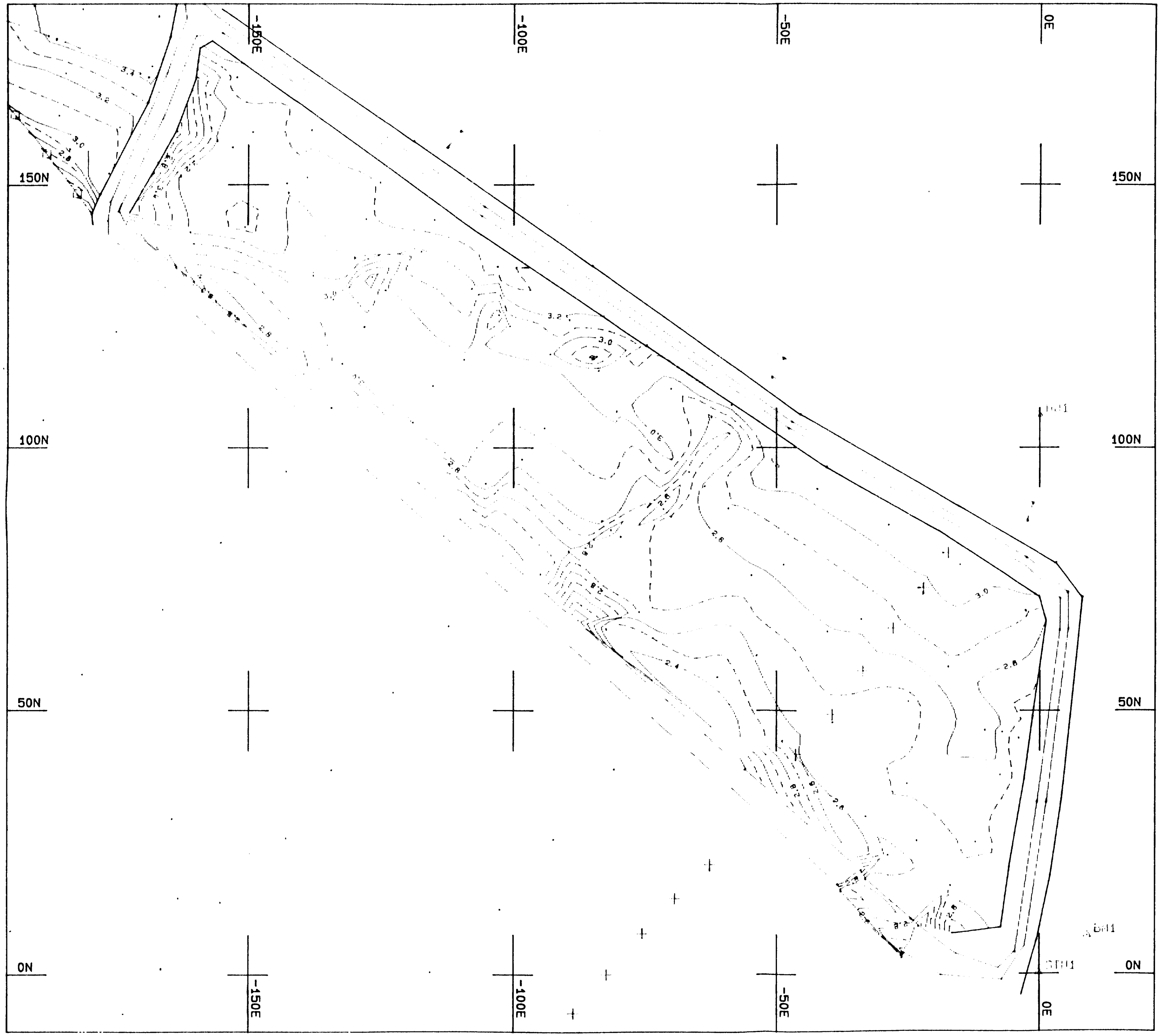
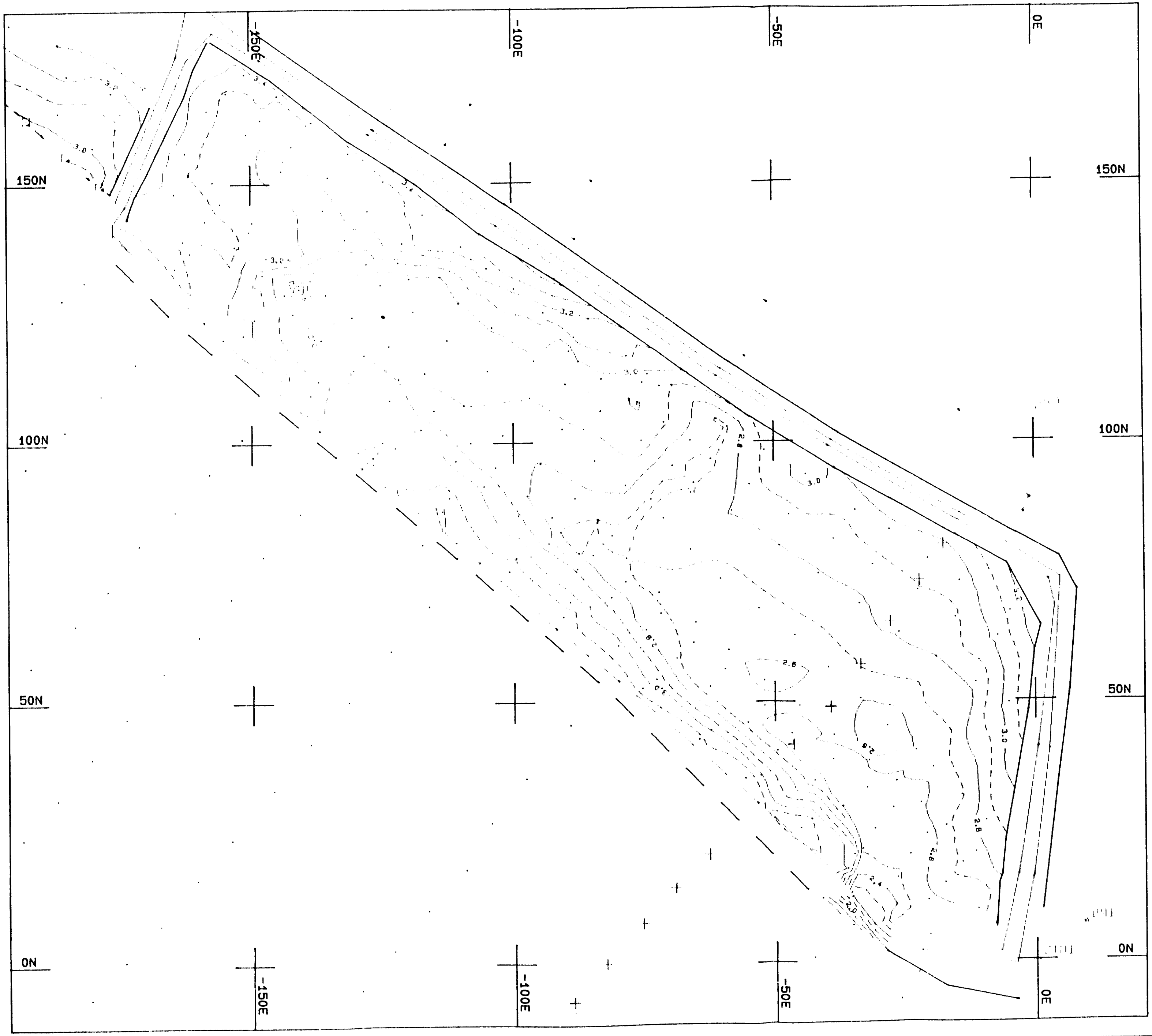


LEGEND

- Sea Wall Base
- Sea Wall Top
- Sluice Cutting
- New Borrow Ditch
- Former Sea Wall
- Marsh Edge
- Accretion Plate
- Survey Point

MTP LAND SURVEY SYSTEM
Northey Island Survey 21.1.92
SCALE 1 : 750
CONTOUR INTERVAL : 0.1m
Institute of Estuarine & Coastal Studies University of Hull HULL HU6 7RX Tel: (0482) 465667



LEGEND

- Present Sea Wall Base
- Present Sea Wall Top
- New Borrow Ditch
- Former Sea Wall Top
- Former Sea Wall Base
- Marsh Edge
- Accretion Plate
- Survey Point

All measurements to OD

MTP LAND SURVEY SYSTEM

Northey Island Survey 24.7.92

SCALE 1 : 750

CONTOUR INTERVAL : 0.1m

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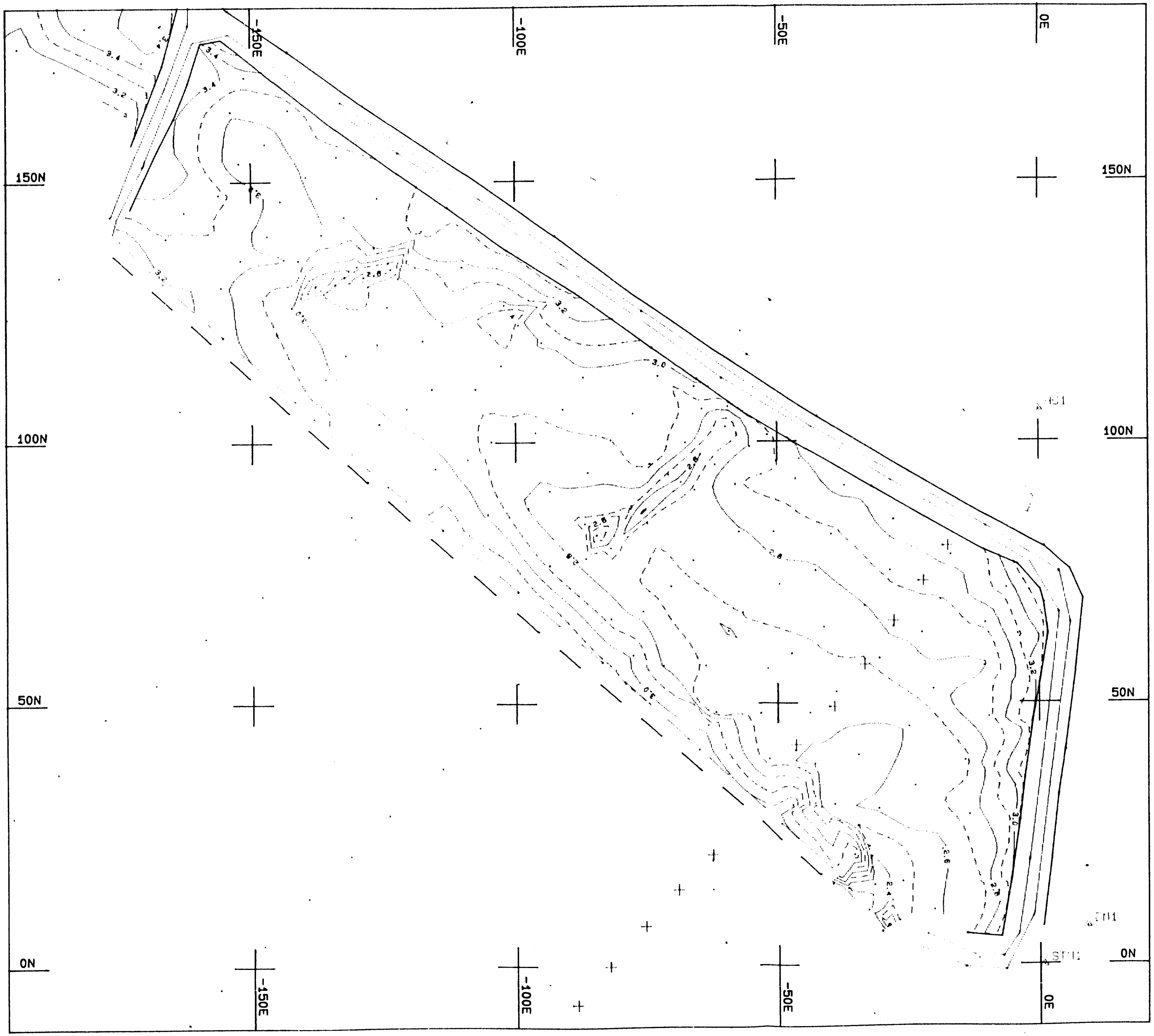

LEGEND

- Present Sea Wall Base
- Present Sea Wall Top
- New Borrow Ditch
- Former Sea Wall Top
- Former Sea Wall Base
- Accretion Plate
- Survey Point

All measurements to OD

MTP LAND SURVEY SYSTEM

Northey Island Survey 9.2.93

SCALE 1 : 750

CONTOUR INTERVAL : 0.1m

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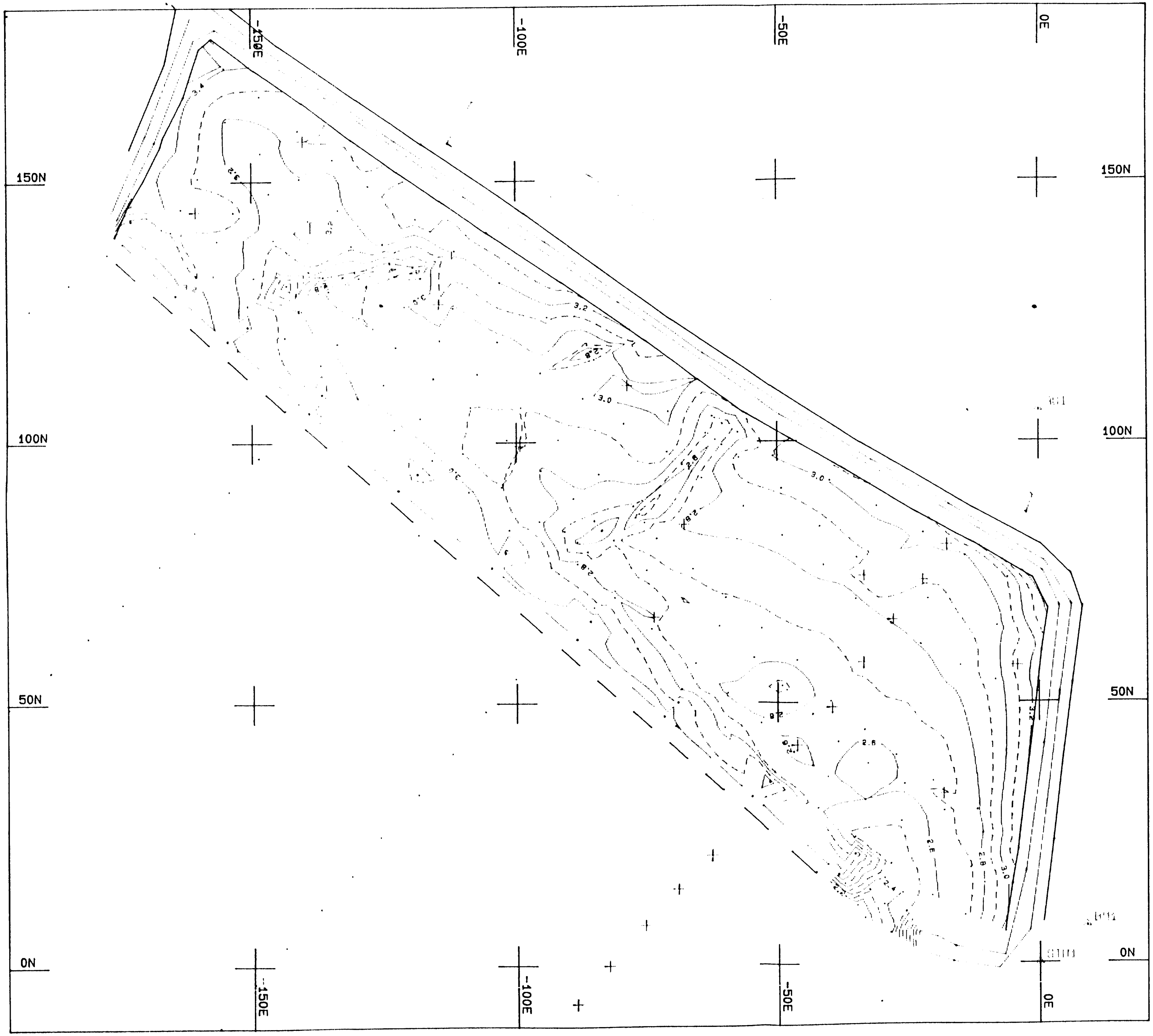

LEGEND

- Present Sea Wall Base
- Present Sea Wall Top
- New Borrow Ditch
- Former Sea Wall Top
- Former Sea Wall Base
- Accretion Plate
- Survey Point

All measurements to OD

MTP LAND SURVEY SYSTEM

Northey Island Survey 6.7.93

SCALE 1 : 750

CONTOUR INTERVAL : 0.1m

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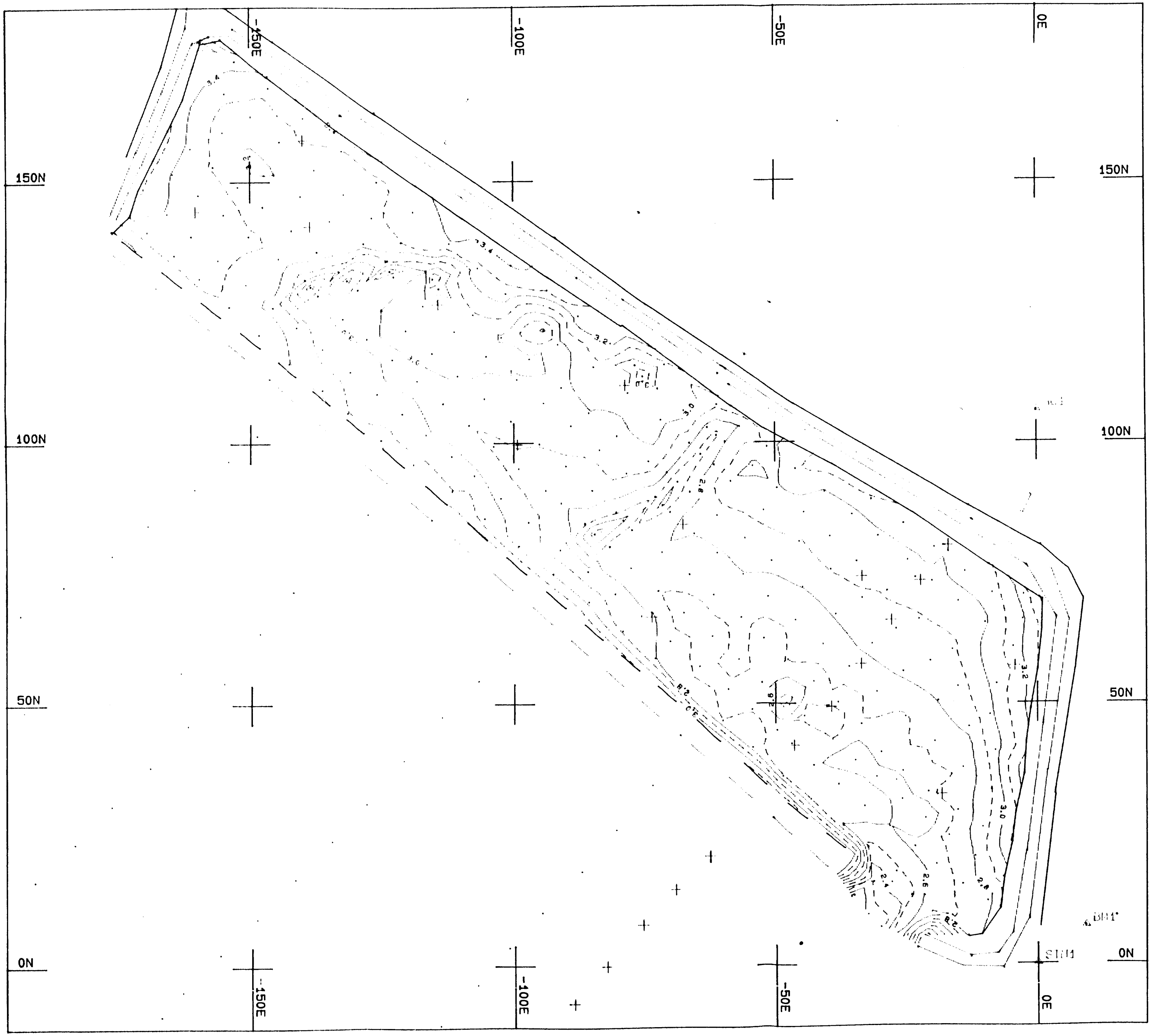

LEGEND

———	Present Sea Wall Base
- - -	Present Sea Wall Top
·	New Borrow Ditch
· · ·	Former Sea Wall Top
— —	Former Sea Wall Base
+	Accretion Plate
·	Survey Point

All measurements to OD

MTP LAND SURVEY SYSTEM

Northey Island Survey 21.2.94

SCALE 1 : 750

CONTOUR INTERVAL : 0.1m

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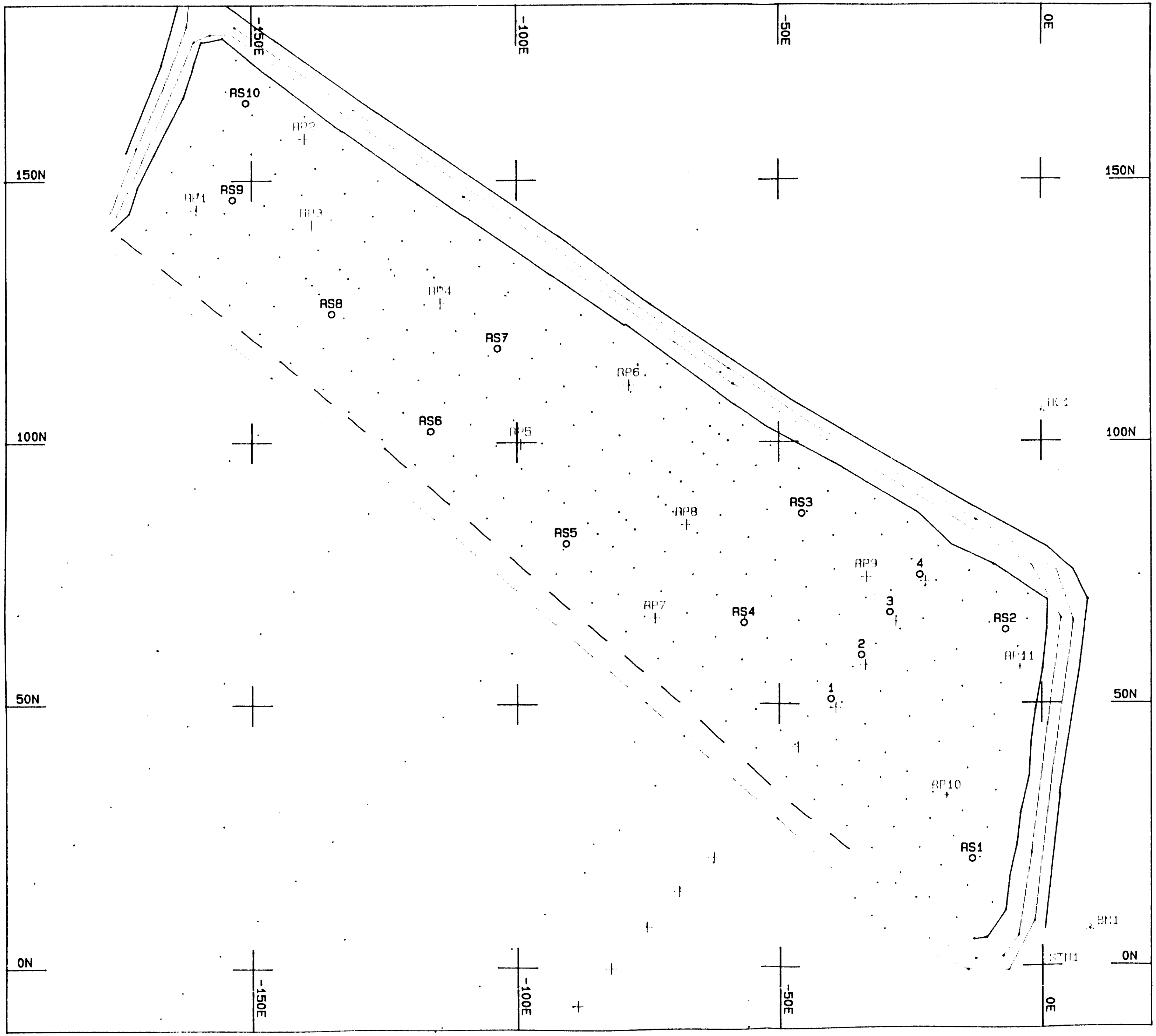
Appendix 2.

Location of accretion plates and sediment samples



LEGEND

——	Present Sea Wall Base
- · -	Present Sea Wall Top
·	New Borrow Ditch
····	Former Sea Wall Top
— —	Former Sea Wall Base
+	Accretion Plate
RP1 +	Random Accretion Plate
2 o	Sediment Sample
RS1 o	Random Sediment Sample

MTP LAND SURVEY SYSTEM

Northey Island Surveys

Accretion/sediment sample points

SCALE 1 : 750

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Appendix 3. Depth (cm) of accretion plates for each survey

Accretion Plate	Distance from low water (m)	Aug. 91	Jan. 92	Aug. 92	Feb. 93	Jul. 93	Feb. 94
1	0.00	-19.08	-19.56	-22.71	-24.46	-28.32	-26.22
2	8.81	-18.14	-20.06	-24.50	-28.40	-32.16	-35.24
3	17.77	-16.86	-17.16	-21.50	-22.60	-24.21	-26.51
4	26.87	-18.44	-17.86	-20.11	-23.26	-25.92	-27.06
5	34.85	-16.60	-16.56	-19.11	-21.60	-22.80	-27.32
6	44.09	-18.50	-18.08	-20.28	-22.62	-23.70	-28.02
7	52.80	-18.08	-18.84	-20.88	-22.84	-23.74	-28.74
8	62.40	-17.84	-17.40	-18.54	-21.42	-21.46	-26.78
9	72.77	-17.56	-16.84	-17.02	-19.52	-20.92	-25.08
10	82.03	-11.68	-12.50	-12.32	-12.92	-12.90	-13.88
11	91.15	-8.36	-10.16	-10.54	-10.76	-12.12	-10.92
12	117.56	-16.86	-19.16	-20.20	-20.75	-21.64	-22.74
13	127.76	-15.94	-16.14	-16.45	-15.62	-15.68	-16.30
14	137.95	-21.78	-22.38	-22.57	-21.80	-21.72	-22.54
15	147.77	-17.46	-18.36	-19.21	-19.14	-17.74	-18.08
16	157.39	-16.04	-17.24	-17.98	-18.82	-19.45	-20.21
17	165.41	-17.90	-16.26	-16.34	-16.52	-16.84	-17.02

Appendix 4. Sediment grain size characteristics of transect samples

Sample	Mean µm	Median µm	% clay/silt	Mean ø	SD ø	Skew
August 1991						
1	11.2	11.7	96.6	6.5	1.54	0.27
2	12.9	14.7	96.0	6.3	1.55	0.43
3	11.9	13.1	97.0	6.4	1.56	0.39
4	14.9	18.4	93.3	6.1	1.60	0.50
January 1992						
1	13.1	13.5	90.8	6.3	1.77	0.01
2	14.1	14.6	88.3	6.1	1.81	0.03
3	16.9	20.4	89.4	5.9	1.72	0.42
4	15.4	18.4	89.6	6.0	1.74	0.31
R1	20.0	23.0	82.2	5.6	1.87	0.36
R2	14.2	17.1	92.6	6.1	1.65	0.48
August 1992						
1	13.8	13.6	90.2	6.1	1.62	0.15
2	14.2	15.3	92.8	6.0	1.53	0.29
3	11.3	10.0	90.2	6.2	1.49	-0.09
4	8.9	9.0	100.0	6.8	1.20	0.02
February 1993						
1	14.7	14.7	88.5	6.1	1.64	0.12
2	14.6	15.7	93.2	6.1	1.50	0.27
3	13.6	12.8	90.7	6.2	1.51	-0.12
4	9.1	9.1	99.8	6.8	1.23	0.00
July 1993						
1	15.5	16.6	91.6	6.0	1.47	0.11
2	13.6	13.3	92.7	6.2	1.43	-0.09
3	14.4	15.7	98.1	6.1	1.30	0.26
4	14.4	14.2	89.7	6.1	1.52	-0.06
February 1994						
1	5.9	6.05	98.67	7.4	1.55	-0.06
2	6.18	6.36	100	7.34	1.58	0.03
3	6.34	6.66	98.46	7.3	1.61	-0.01
4	7.12	7.07	97.03	7.13	1.70	-0.05

Appendix 5. Sediment grain size characteristics of random samples

Sample	Mean µm	Median µm	% clay/silt	Mean ø	SD ø	Skew
January 1992						
VEG	22.8	22.1	75.6	5.5	1.85	0.0
1	11.1	11.6	92.6	6.5	1.76	0.16
3	21.2	22.0	74.2	5.6	1.98	0.18
4	13.0	12.4	87.0	6.3	1.84	0.01
August 1992						
1	13.2	13.4	96.1	6.2	1.51	0.32
2	8.4	8.4	100.0	6.8	1.30	0.20
3	10.4	10.0	97.2	6.6	1.27	0.06
4	11.0	11.2	96.4	6.7	1.34	0.07
5	18.2	18.7	82.2	5.6	1.58	0.01
6	8.7	8.6	100.0	6.8	1.32	0.15
7	8.5	8.7	100.0	6.8	1.16	0.10
8	10.0	10.1	99.7	6.7	1.30	0.19
9	8.9	8.6	100.0	6.8	1.50	-0.22
10	9.7	9.7	98.2	6.8	1.41	0.14
February 1993						
1	12.3	12.7	97.9	6.3	1.49	0.30
2	9.7	9.7	99.7	6.7	1.32	0.13
3	9.8	9.7	99.6	6.7	1.32	0.13
4	10.7	10.4	97.6	6.6	1.37	0.11
5	17.6	17.7	84.4	5.8	1.59	0.06
6	8.9	8.9	99.6	6.8	1.38	0.11
7	8.1	8.5	100.0	6.9	1.14	0.14
8	9.5	9.5	99.9	6.7	1.33	0.13
9	9.4	8.8	95.4	6.7	1.46	-0.15
10	10.2	10.1	97.9	6.6	1.42	0.12
July 1993						
1	23.0	27.7	85.9	5.4	1.38	0.51
2	27.0	28.5	71.3	5.2	1.64	0.13
3	33.2	36.7	64.8	4.9	1.65	0.27
4	28.9	31.4	71.3	5.1	1.56	0.18
5	22.8	23.0	79.3	5.5	1.51	0.08
6	33.0	36.9	66.7	4.9	1.57	0.29

7	37.5	43.9	62.1	4.7	1.52	0.45
8	29.9	33.9	70.4	5.1	1.54	0.27
9	20.3	22.8	85.0	5.6	1.47	0.30
10	26.4	30.3	77.2	5.2	1.45	0.37

February 1994

1	9.87	9.6	90.99	6.66	1.87	-0.06
2	5.12	5.16	100	7.61	1.46	-0.05
3	6.85	6.94	98.65	7.19	1.61	0.01
4	5.82	5.85	99.60	7.42	1.56	-0.03
5	5.28	5.47	99.84	7.56	1.52	-0.04
6	6.27	6.45	99.69	7.32	1.65	0.03
7	6.37	5.79	92.92	7.29	1.77	-0.49
8	5.45	5.48	98.77	7.52	1.52	-0.12
9	6.54	5.85	94.64	7.26	1.90	-0.25
10	12.34	12.05	80.88	6.34	2.16	0.04

Appendix 6. Analysis of organic content of transect samples

Sample	Organic content (%) [see note A]	Loss on ignition at 400°C (%) [see note B]	Loss on ignition at 480°C (%) [see note B]
January 1992			
1	4.24	7.75	11.35
2	10.48	16.4	20.55
3	2.47	3.85	6.35
4	4.24	7.6	10.5
R1	3.31	5.1	7.35
R2	4.16	6.25	9.45
August 1992			
1	12.2	9.4	4.78
2	8.5	6.4	4.24
3	16.4	11.52	6.45
4	22.1	15.21	4.52
February 1993			
1	13.9	8.25	5.75
2	9.4	8.0	6.15
3	15.8	13.25	5.65
4	19.5	13.2	2.55
July 1993			
1	4.71	12	4
2	4.23	8	2
3	5.83	13	4
4	4.71	12	3
February 1994			
1	6.40	9.74	5.09
2	6.12	10.45	5.46
3	6.82	16.87	5.26
4	8.38	16.40	5.33

Notes:

A The organic content is expressed as percent carbon by weight

B LOI included as an independent estimate of organic carbon content to determine coal content c.f. particulate organic matter. The difference between LOI at 400°C and LOI at 480°C represents the coal fraction present in the sample.

Appendix 7. Analysis of organic content of random samples

Sample	Organic content (%) [see note A above]	Loss on ignition at 400°C (%) [see note B above]	Loss on ignition at 480°C (%) [see note B above]
August 1992			
1	4.7	4.1	3.41
2	5.2	12.1	8.79
3	28.5	24.57	5.42
4	16.2	11.52	4.52
5	13.5	8.9	7.09
6	1.8	2.4	2.19
7	22.1	13.58	6.87
8	17.8	12.64	4.87
9	22.9	24.3	6.91
10	13.6	6.54	5.24
February 1993			
1	7.5	3.75	4.4
2	7.5	13.5	7.45
3	27.3	22.8	6.7
4	15.9	10.8	6.55
5	12.2	10.0	6.0
6	2.8	1.85	3.85
7	18.4	12.65	5.7
8	19.0	12.45	5.35
9	23.1	20.25	5.15
10	10.8	7.15	4.8
July 1993			
1	3.75	6	4
2	9.18	18	10
3	10.53	21	5
4	10.69	26	7
5	8.46	27	7
6	4.95	26	3
7	11.01	23	6
8	10.37	22	6
9	3.19	8	3
10	6.06	15	4

February 1994

1	5.64	6.56	3.87
2	8.43	10.79	5.41
3	8.38	17.08	5.02
4	6.10	10.07	5.45
5	4.88	9.35	4.84
6	4.52	8.68	4.67
7	10.14	16.58	4.10
8	8.55	13.69	4.42
9	3.38	5.80	2.56
10	5.88	21.22	4.94

Appendix 8.

Photograph plates

Plate 3: **July 1993**
Eastern end of the site 2 years after implementation. Note significant increase in vegetation cover on the wall, and consequent reduction in wall erosion problems

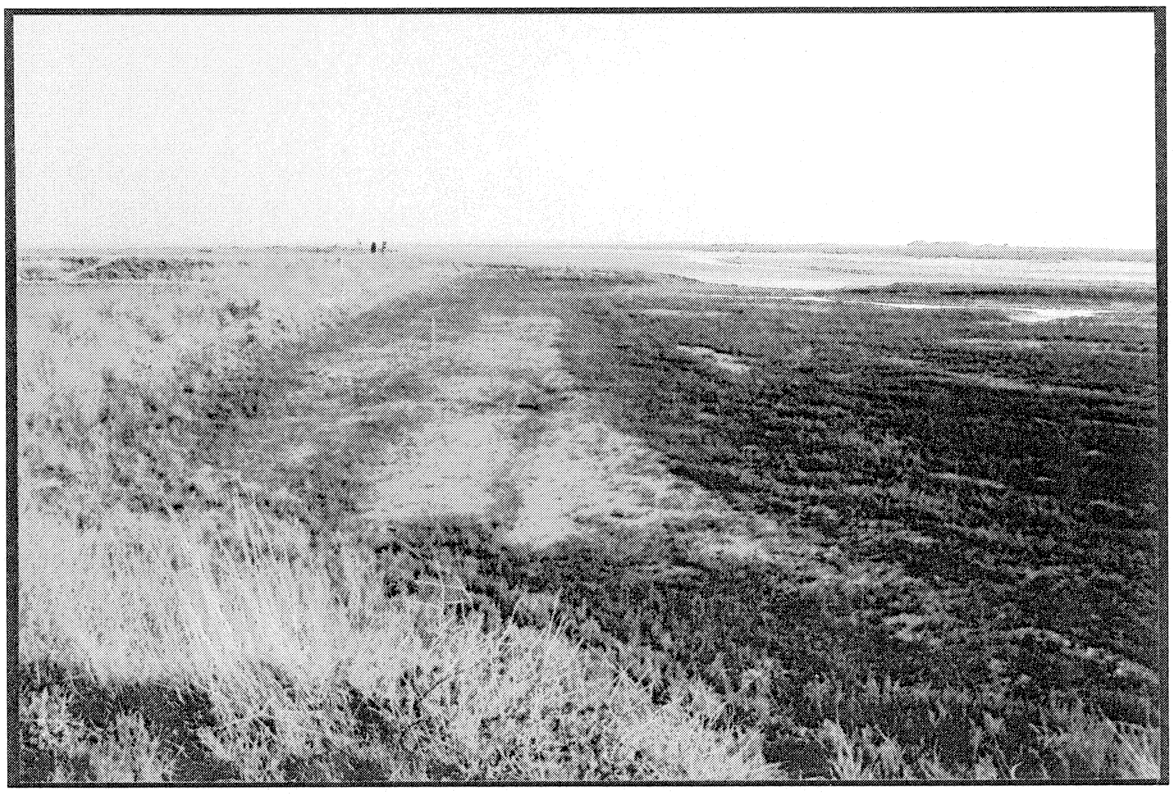

Plate 4: **February 1994**
Eastern end of the site 2.5 years after implementation. Note sparse vegetation on compacted borrow pit compared with the rest of the marsh surface

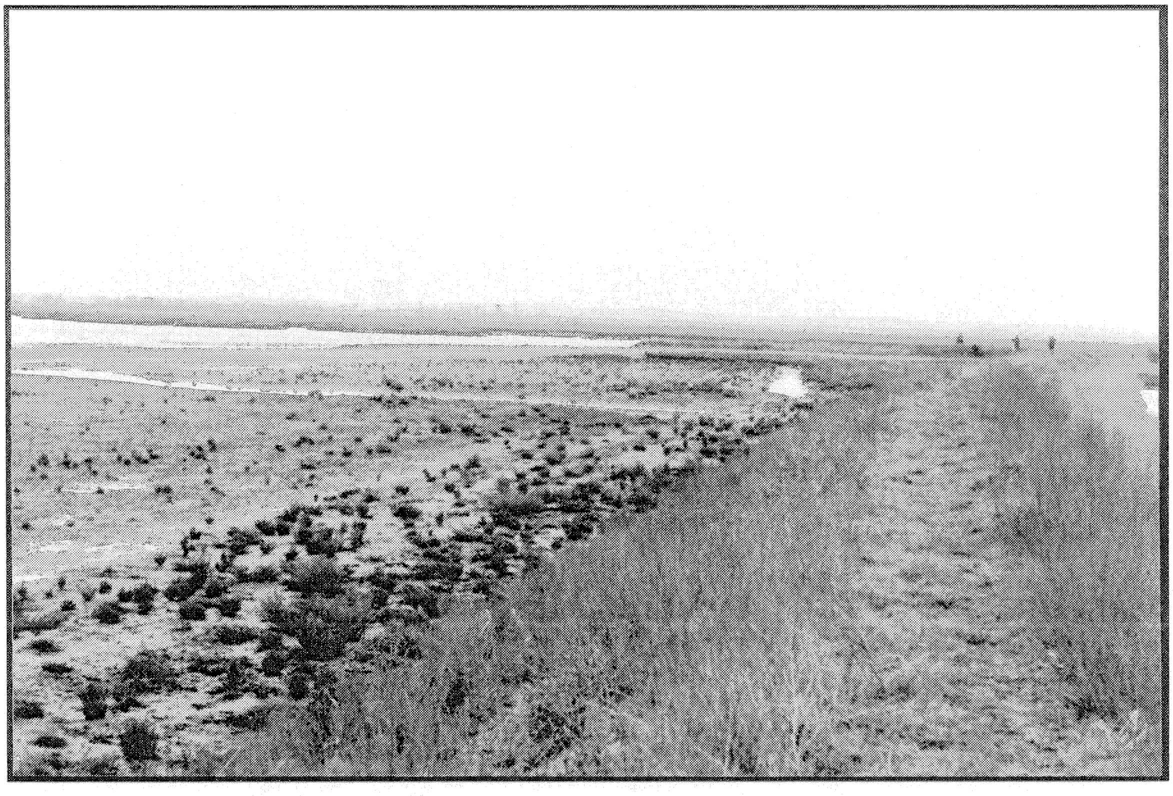

Plate 5: **Feb 1993**

Plate 6: **Feb 1994**
Views looking west across site showing dramatic increase in vegetation cover. Note distinct line of creek running from right to left, and old borrow pit running into distance

Plate 7: **June 1992**
View looking east across site during maintenance work to infill the borrow pits

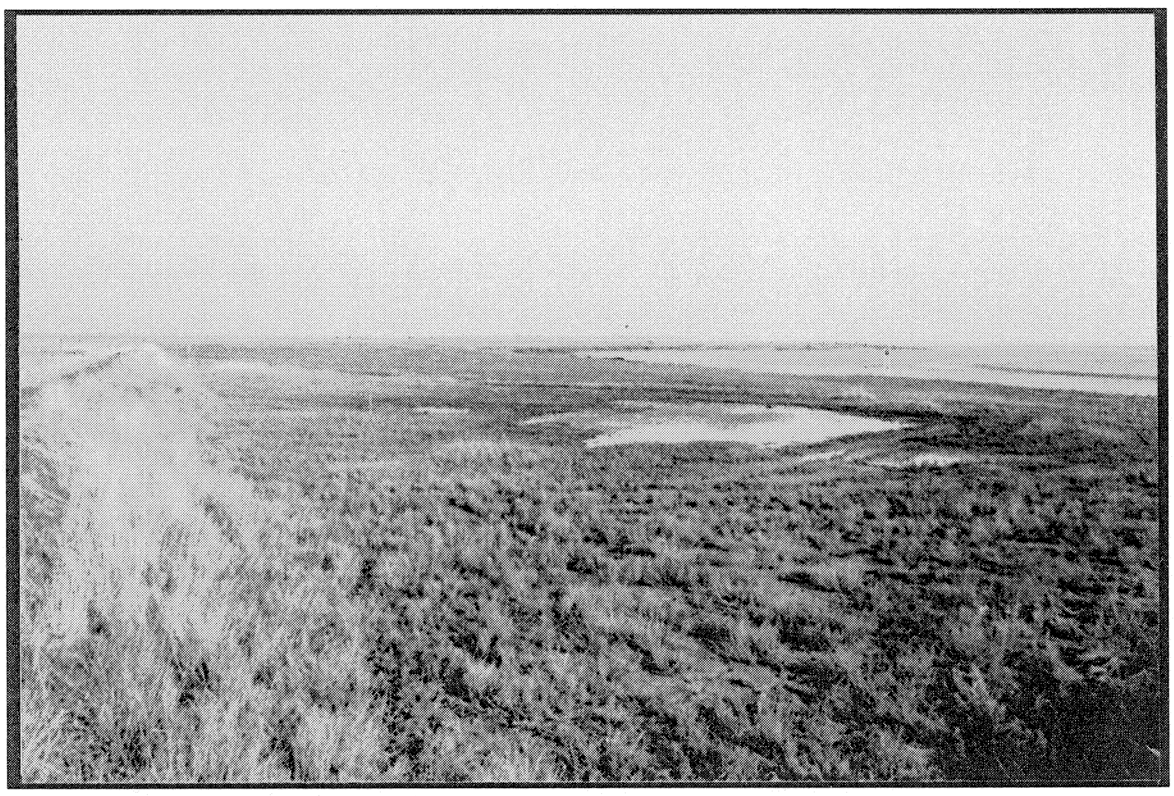

Plate 8: **February 1994**
View looking east across the site. Note raised vegetated line alongside old borrow pit, and large area of standing water unconnected to drainage network

Plate 9: **January 1992**
View across the spillway showing wave diffraction patterns and current flows into the front borrow pit before this was filled

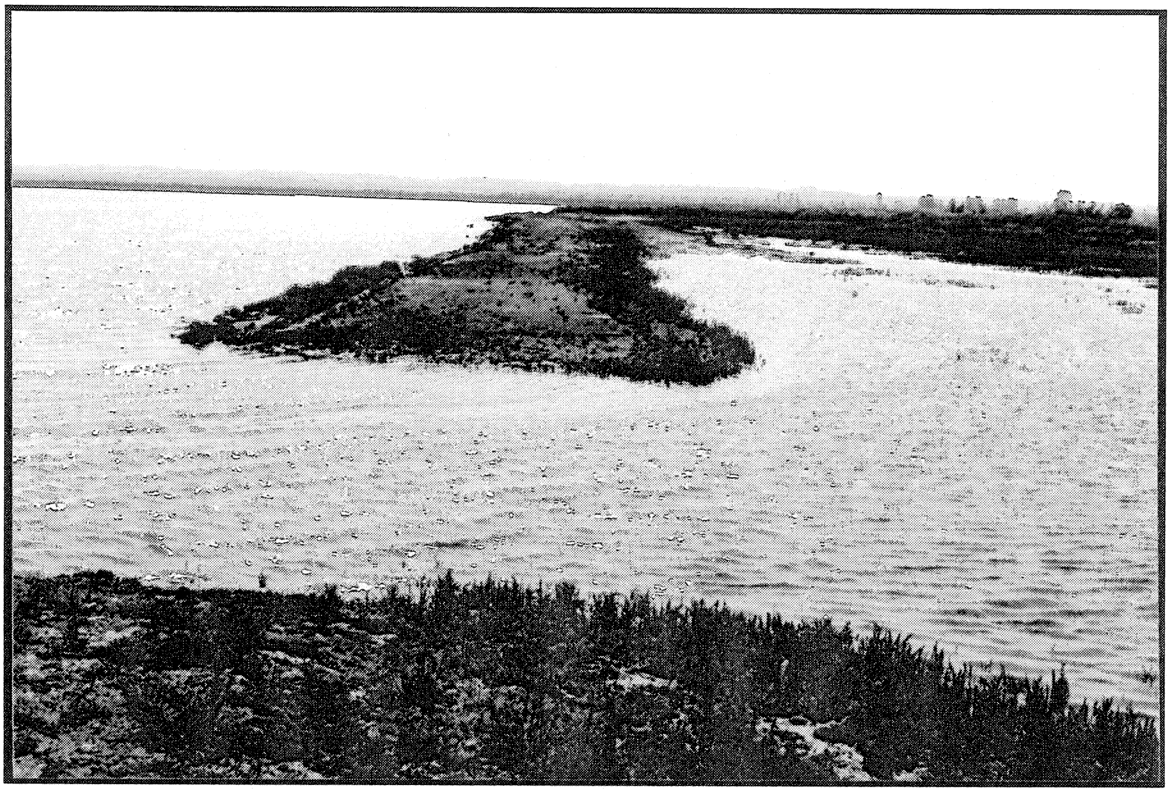

Plate 10: **July 1993**
Same view at similar state of the tide showing difference in patterns of water flow across the site. Note also the difference in profile of the front wall

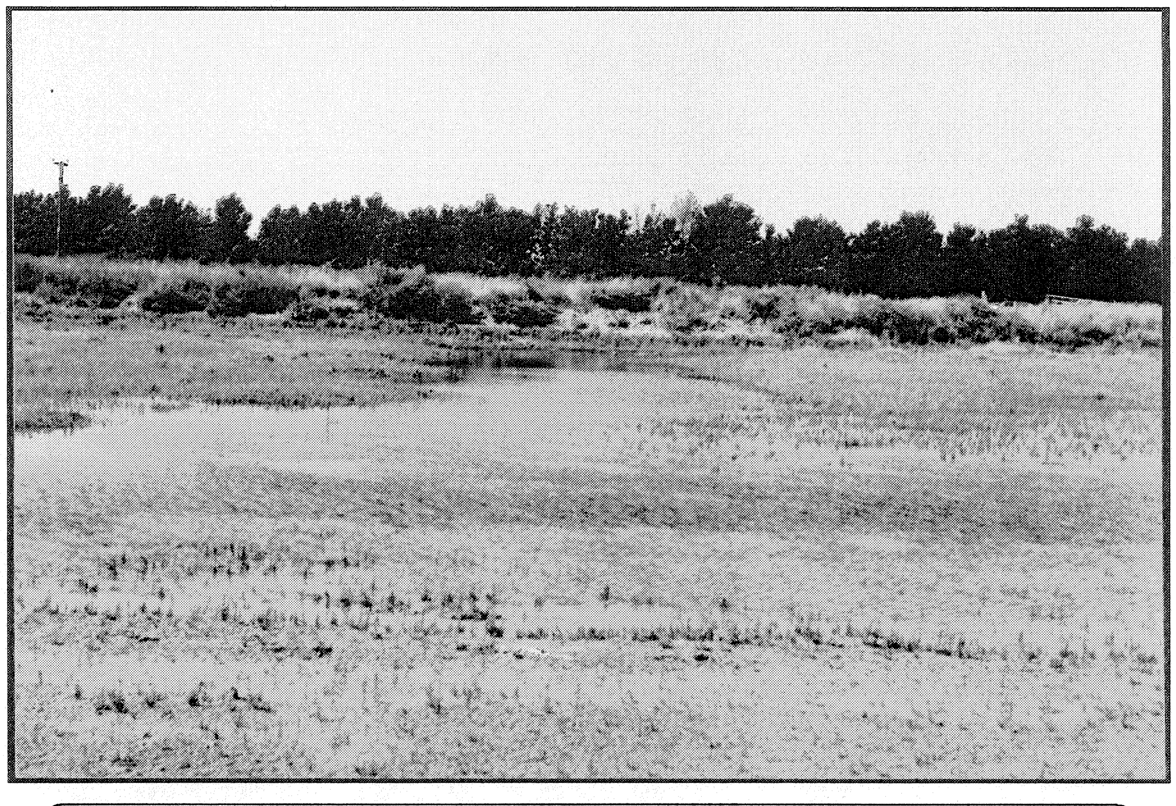

Plate 11: **July 1993**
View along the centre creek showing erosion of the inner sea wall at the creek head

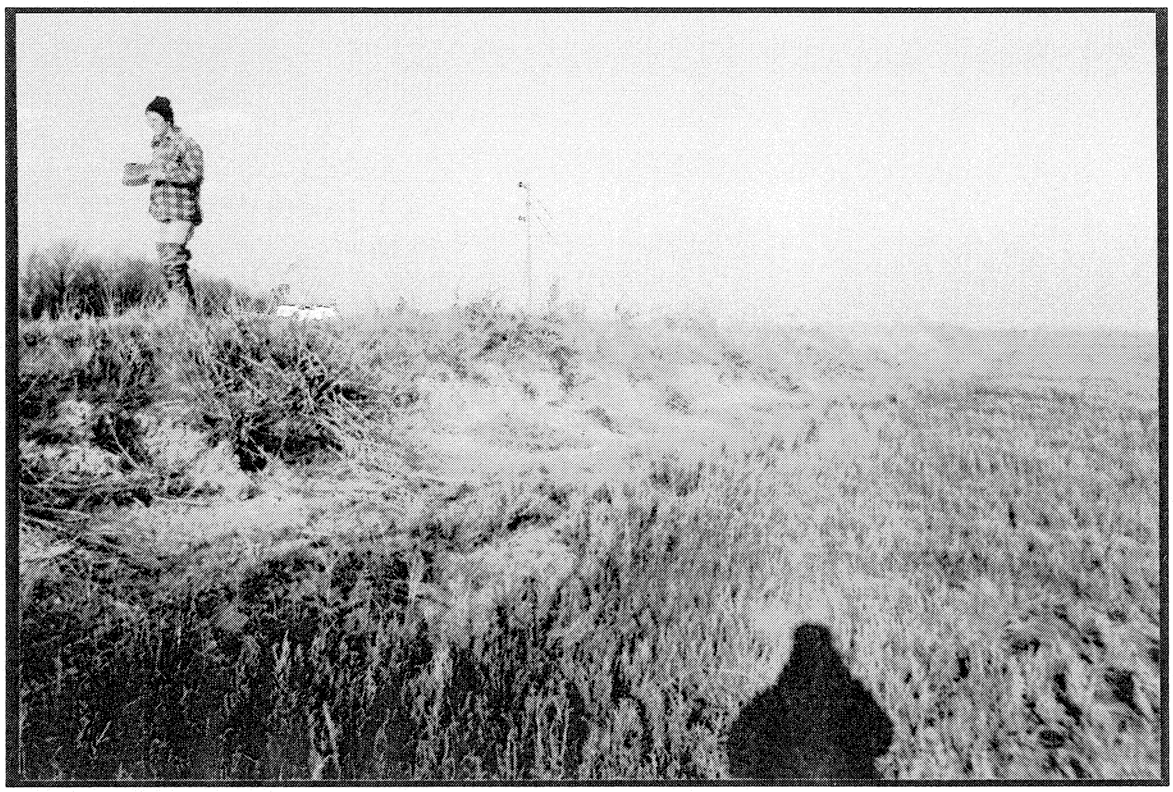

Plate 12: **February 1994**
Closer view of erosion of the inner sea wall

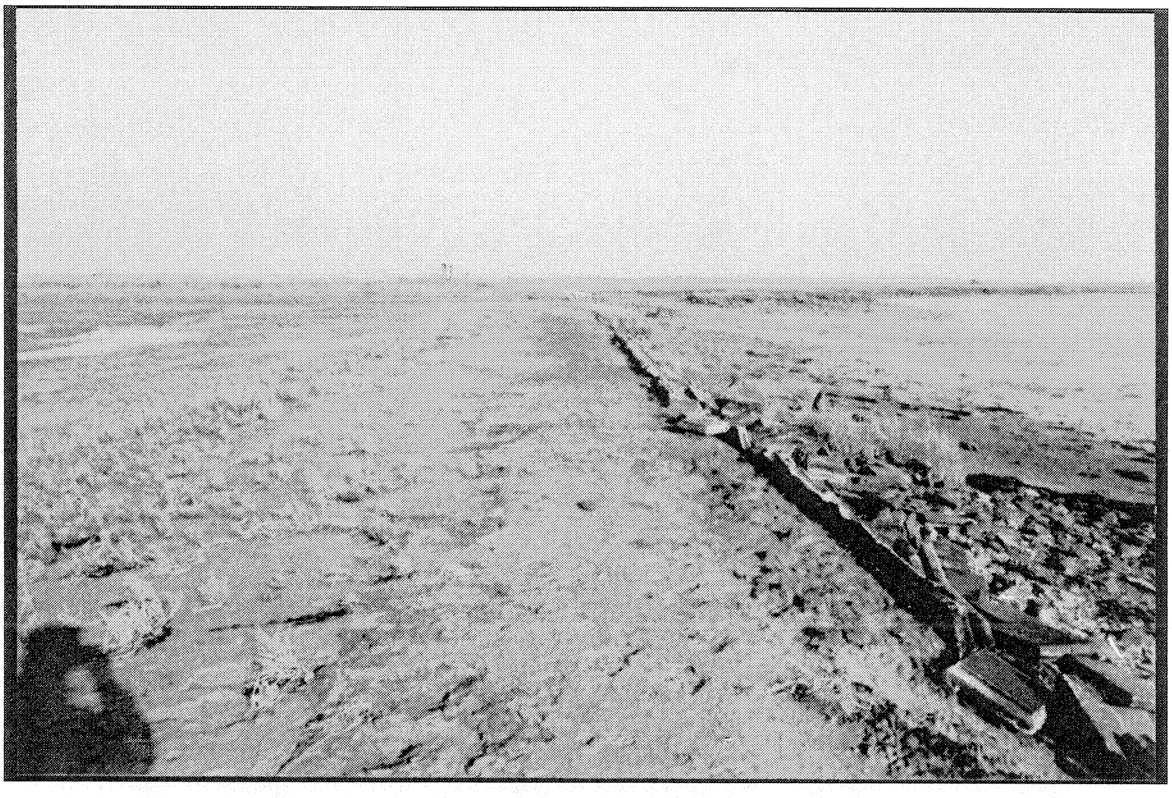

Plate 13: **February 1994**
Looking along the front wall from west to east showing overall lowering of surface level relative to the fronting blockwork

Plate 14: **February 1994**
Looking along the front wall from east to west showing flaking of surface sediment layers

Plate 15: **February 1993**
General view across the whole site looking west from the spillway corner

Plate 16: **July 1993**
Similar general view across the whole site. Note the difference in vegetation cover after only one growing season and the identical patterns of standing water