Journal of Coastal Research	16	3	724–734	West Palm Beach, Florida	Summer 2000

The Impacts of Fish-Tail Groynes on Sediment Deposition at Morecambe, North-West England

Peter W. French and John S. Livesey

Wetland Ecosystems Research Group
Department of Geography
Royal Holloway
University of London
Egham, Surrey, TW20 0EX, U.K.

ABSTRACT

FRENCH, P.W. and LIVESEY, J.S., 2000. The impacts of fish-tail groynes on sediment deposition at Morecambe, north-west England. *Journal of Coastal Research,* 16(3), 724–734. West Palm Beach (Florida), ISSN 0749-0208.

The development of an elaborate system of fish-tail groynes at Morecambe, north-west England is discussed in relation to its impact on sediment deposition and beach formation. The comparison of beach surveys from 1992 and 1996 has shown that in all cases, sediment build-up has occurred around each groyne, although with a distinct spatial pattern, concluded to be caused by the influence of a large jetty built as part of the scheme and designed to regulate the position of the primary ebb tide channel. In addition, qualitative observations indicate that the pattern of sediment accretion has shown a shift from coarser to finer grade sediments concluded to be a result of the energy reduction and resulting inability of the tidal and wave currents to transport coarser sediments into the beach environment. As a result, the beach area has become largely silt and mud dominated, resulting in the need of beach feeding to provide suitable amenity beaches for the tourist industry.

ADDITIONAL INDEX WORDS: *Fish-tail groynes, coastal defence, sediment regime, channel stability, accretion patterns.*

INTRODUCTION

Morecambe Bay (Figure 1) is a large, macrotidal coastal embayment covering ca. 38,000 hectares, and located on the west coast of northern England. Historically, it can be viewed as a large sediment sink, receiving material predominantly from the Irish Sea, but also from the feeder estuaries of the Leven, Kent, Lune and Wyre entering the bay around its margins (COMBER and HANSOM, 1994) (Figure 1). This sediment is transported and deposited in relation to wave and tidal currents, and in particular, the slight tidal asymmetry which occurs within the Bay (ALDRIDGE, 1997).

The Bay experiences a mean spring tidal range of 10.5m (+6.0 to −4.5m O.D.) and mean neap tide range of 3.4m (+2.0 to −1.4m O.D.). This means that during spring tides at Morecambe, high water mark is represented by the sea wall, with water covering the whole of the intertidal area under study in this paper. At low water, because of the large tidal range and low intertidal gradient, the tide may recede for up to several kilometres from the shoreline, exposing extensive areas of intertidal sand and mud flats (Figure 1), interspersed with flood and ebb channels. With a neap tide height of only +2.0m O.D, however, much of the shoreline under study remains exposed during neap phases. The tides are slightly asymmetrical with flood tides lasting for approximately one hour less than the ebb (KESTNER, 1972). This results in current flood velocities of between 0.1 to 0.2 $m.s^{-1}$ greater than ebb (PRINGLE, 1987). As a result of this flood-dominance, sediment transport is strongly influenced by flood tides which, in the case of the Morecambe frontage, leads to a strong south-west to north-east transport (ROSTRON and MCCLAREN, 1989).

The wave patterns within the Bay are very complex because of the refraction caused by the constantly changing areas of deep and shallow waters caused by channel movements. Although Morecambe Bay represents a tidal embayment, the maximum fetch is in the order of 225 km from west-south-west and, given a suitable wind, this can result in waves with up to 8 second periodicities in ca. 100m water depth (PRINGLE, 1987). With respect to the study area, Figure 2 shows the general wave climate along the Morecambe frontage, as presented by SHORELINE MANAGEMENT PARTNERSHIP (1990). The direction and focus of wave fronts (Figure 2) closely match channel position (Figure 3), due to the strong influence of areas of deeper water. With respect to our study, it is possible to identify three main areas where wave exposure may be a primary controlling factor over sediments. Firstly, the area to the south-west of the Stone Jetty is an area where waves are focussed (Figure 2, Figure 3), with the jetty acting as a barrier to prevent any further north-easterly procession of the wave front. Secondly, the area to the north-east of the jetty (Figure 2, Figure 3) is in a wave shadow under normal conditions, although north-easterly winds will produce waves, albeit with minimal fetch; and thirdly, waves are again focussed on the coast further to the north-east in the region of the Bare pool groyne (Figure 2, Figure 3). This

97125 received 30 September 1997; accepted in revision 18 October 1999.

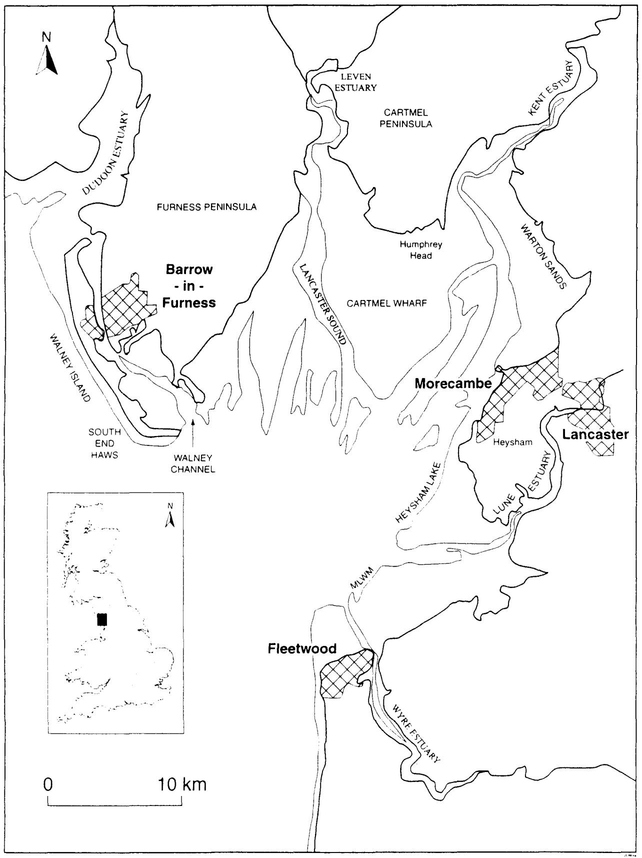

Figure 1. Location map of the Morecambe Bay area, showing mean low water mark and channel positions. Inset, Morecambe Bay in the context of the U.K. (Added to, and modified from COMBER and HANSOM, 1994).

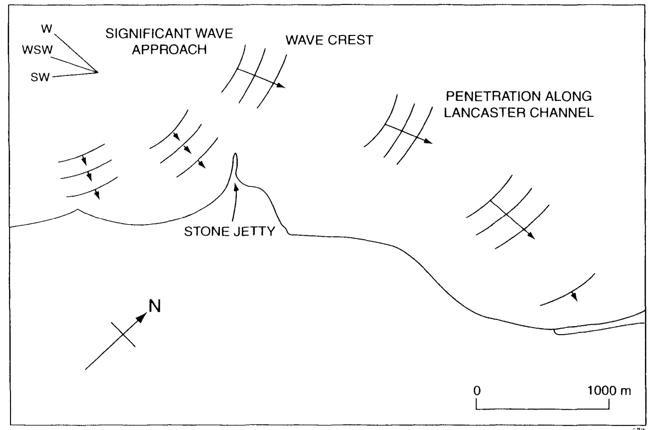

Figure 2. General wave climate along the Morecambe Frontage. (Modified from SMP 1990).

association will be discussed further in the light of our field results.

Because of the large tidal range, and with currents in excess of 1.3m s^{-1} (ALDRIDGE, 1997), the Bay is well mixed and typified by rapid sediment movement and corresponding changes in channel position. Such channel dynamics are clearly shown by COMBER and HANSOM (1994), and also, more recently, by MASON *et al.* (1999), who have mapped channel position and movement using digital elevation models.

Within the context of this paper, the Lancaster Channel (Figure 3) is of primary importance because it runs close to the Morecambe shoreline, and its position relative to the shoreline can alter the coast's vulnerability to storm activity. Over the past few decades, the Lancaster Channel has been migrating towards the south-east and this, combined with variation in local intertidal levels has allowed greater tidal and wave penetration inshore towards Bare Pool and Scalestone Point (Figure 3, Figure 4). This situation became of critical importance in November 1977 when severe storm activity produced waves which entered the nearshore region along the Lancaster Channel, causing significant wave heights close inshore. This produced storm breaches in the sea wall at Morecambe and destroyed the Victorian West End Pier (the location of which is currently marked by the West End groyne, Figure 3), and as a result, necessitated defence improvement schemes, part of which included a new wave reflection wall along the promenade. The severity of this storm was put as a 1:100 year magnitude event. By the mid 1980's, the reflection wall was completed but had produced a significant drop in sediment levels on the fronting beach areas, further increasing the area's susceptibility to storm attack. In January 1983, a second 1:100 year magnitude storm breached the coastal defences between Central Pier and Lord Street, now the site of the Green Street and Town Hall groynes (Figure 3). It was clear that the new wave reflection wall was unable to retain sediment, and this problem was manifest in the further landward migration of channels, further compounding the problems of wave attack and tidal activity via the Lancaster Channel. Having experienced the second 1:100 year storm in 1983, the area received its third 1: 100 magnitude event in 1990 causing breaching of the defences at Scalestone Point (Figure 3) (WRIGLEY, 1991).

Having received three magnitude 1:100 year storms which caused major structural damage over the space of 13 years, a thorough review of coastal defences by the local defence authority found that the new wave reflection wall was producing unacceptable loss of beach material and undermining of older defences. The basic conclusion of this review was that the defences were at the end of their useful life, and that a major new defence initiative was needed. It was vital that this addressed the fundamental problems of the area:

(1) The instability of the Lancaster Channel and its tendency to migrate inshore, thus leaving the defences vulnerable to wave attack.
(2) Loss of beach sediment and subsequent foreshore lowering due to storm waves and defence-associated scouring.
(3) The problem of strong shore-parallel currents in association with flood and ebb tides.

The use of simple offshore (shore detached) breakwaters was considered to provide suitable protection against storm

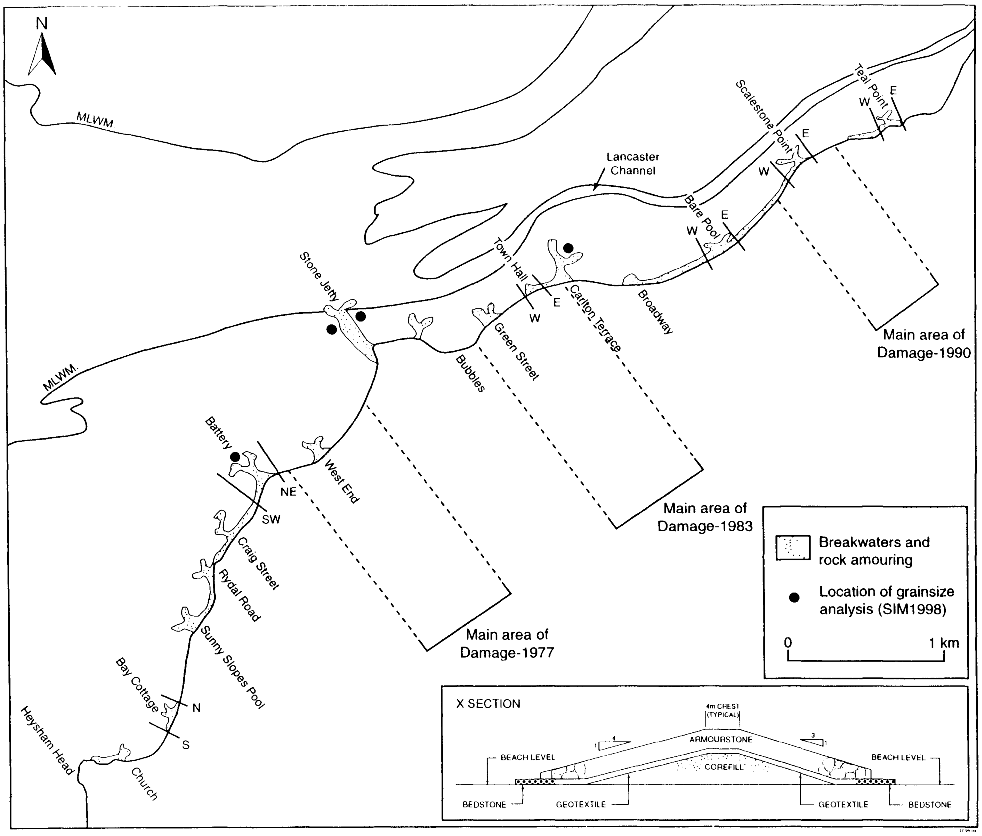

Figure 3. The Fish-tail groyne scheme along the Morecambe frontage showing areas of storm damage in 1977, 1983, and 1990 and approximate position of low water channels. For each of the six groynes studied, transects are marked and labelled according to their description in the text. Locations of sediment grain-size analysis are marked with '●'.

waves, and also serve to reduce the impact of shore-normal currents. Previous studies (MAGOON, 1976; POPE and ROWEN, 1983; TANIMOTO and GODA, 1992; WONG, 1981) have demonstrated that these structures can effectively reduce wave impact on the shoreline and promote sediment accumulation in their lee. However, with such an approach, the problem of strong shore-parallel currents due to ebb and flood flow in association with the Lancaster Channel remained and, according to hydrographic modelling, this problem was predicted to increase due to confinement of flow between the shore and breakwater. The linking of the offshore breakwaters to the shore and their orientation to the predominant wave direction to protect the coast against surge and wave activity removed long-shore current effects and resulted in the final fish-tail groyne design (Figure 4). The intention of these structures was the trapping of sediment and build-up of beaches leading to the provision of natural attenuation of storm waves along the Morecambe frontage. Furthermore, the expected crescent-shaped beach areas between the structures would provide an amenity beach area to boost the area's tourism potential.

Whilst the use of traditional groyne systems (*i.e.* linear structures perpendicular to the coast) to intercept long-shore sediment movement is common in many areas, the use of fish-tail structures as a means of also reducing wave exposure is a more recent trend. BULL *et al.* (1998) describe a similar system to that studied here, at Llandudno, North Wales. Whilst also studying the impacts on sediment characteristics and net temporal changes in beach profile, they focus mainly on grain-size trends and spatial variation around the groynes. Despite this slight difference in approach, the findings of the Llandudno project provide a good comparison to this study and will be discussed further in the context of our results. The Llandudno study identified three main conclusions:

(1) Erosion rates were significantly reduced by the groynes.
(2) A change to a finer sediment depositional regime occurred.
(3) The project had little success in increasing beach levels.

METHODOLOGY

In order to quantify the impact of fish-tail groynes (subsequently to be referred to as 'groynes'), sediment deposition in association with six groynes (Bay Cottage, The Battery, Town Hall, Bare Pool, Scalestone Point, Teal Bay—see Figures 3 and 4) were investigated along the Morecambe Shoreline. An initial beach profile survey, carried out in 1992

Figure 4. Scalestone Point groyne from the Promenade, Morecambe.

(WARBURTON, 1993) shortly after many of the groynes had been put in place, provided a baseline to which the current survey, carried out in 1996 (LIVESEY, 1997) could be compared. Surveying was done along the same transect lines (Figure 3) so that comparisons with regard to changes in sediment surface elevation could be made. Transect lines were surveyed along either side of each of the breakwaters to investigate variations in beach profile between 1992 and 1996, and also to allow an investigation of differential sediment accretion on either side of each structure. In order to ensure a valid comparison, both the 1992 and 1996 surveys were carried out in July and August to remove possible influences of seasonality. Each transect was linked to Ordnance Datum (O.D.) by using levelled spot heights on the promenade, established by Lancaster City Council.

The survey data provide an insight into how the foreshore has changed in response to groyne construction over the intervening four year period. In addition, information gathered as part of annual foreshore surveys (SHORELINE MANAGEMENT PARTNERSHIP, 1991 *et.seq.*) provides a useful overview of yearly changes in sedimentation patterns. Although not on a quantitative basis, these surveys do provide a valuable source of information regarding short-term changes, and, in particular, the pattern of sediment infill which may have occurred. This is of particular importance when considering that the complete groyne construction project is phased, and as such, the adjustment of the natural system will be punctuated by new phases of construction. At the present time, phases 1–4 are complete, with phase 5 ongoing at the time of writing. Phase 6 is planned for the future along the southern section of the frontage (Figure 3), in an area where the existing sea wall is in a poor condition (SHORELINE MANAGEMENT PARTNERSHIP, 1996).

There is clear evidence from WARBURTON's study to indicate a long-shore variation in sediment build-up along this coast. This would indicate some long-shore current or wave control over sediment accumulation on a spatial scale. To investigate this issue, a recent survey of sediment grain-size properties (SIM, 1997) has been used to provide data relating to how sediment grain-size varies in association with groynes at different parts of the coast. Although not as detailed as the survey by BULL *et al.*, it does allow us to develop a greater understanding of long-shore changes and system dynamics.

RESULTS

Observations from Annual Monitoring

It is clear that significant sediment accretion has occurred since groyne construction. The Stone Jetty (Figure 3) has had the greatest impact on sediment levels and channel position, due to it being the one structure built right out into the Lancaster Channel. This was a design feature of this structure with the intention of pushing the channel further offshore and stabilising its position. This has been achieved following the extension, in 1995, of the original structure, with the channel now being stabilised between the end of the jetty and an offshore skear[1]. In addition to channel stabilisation, the jetty has facilitated significant accretion in the region of the

[1] A skear is an area of consolidated material, gravel grade and coarser, representing the site of a former drumlin, now planed off by marine erosion.

Table 1. *Mean grain size values for surface sediment samples from the Morecambe groyne scheme. (Data from SIM, 1998).*

Location	Mean Grain Size (μm)	Range (μm)
Battery groyne	86.1	76.9–90.9
Stone Jetty (south–west)	91.5	87.3–95.5
Stone Jetty (north–east)	42.7	36.2–57.1
Carlton Terrace	52.1	41.9–61.9

West End groyne (Figure 3) to the south west. In addition, it may also have an influence to the north-east due to its sheltering effect and the protection of this area from waves. BULL *et al.*, 1998 make similar observations in their study at Llandudno.

A common, although unquantified, observation from the annual foreshore surveys (SHORELINE MANAGEMENT PARTNERSHIP, 1991 *et.seq.*), and now quantified by our study, is that sediment accretion has occurred in association with all groynes, although the sediment regime has shifted towards finer sediment. Areas originally receiving coarse sand and shingle now receive finer sands, whilst those originally receiving fine sand now receive silts and clays. It is argued that this shift in depositional environmental has arisen because of the reduction in energy levels caused by the groynes, a point also indicated in the groynes at Llandudno (BULL *et al.*, 1998). Although unquantified at the present time, nearshore currents are weaker than those pre-construction, and with the groynes effectively compartmentalising the foreshore into small 'cells', currents are very much reduced and finer sediment can settle. Investigations by the local Sea Fisheries Committee have indicated that sand-grade sediment is being deposited further seaward to produce deposits in the low beach and offshore areas. In addition, it is likely that this increased build up of sediment into an offshore berm is reducing wave base and producing further energy attenuation. As such, the formation of natural sand-dominated beaches between the groynes has not fully materialised, but instead, potential amenity beach areas have developed into areas of silts and muds. It has been argued, by Lancaster City Council, however, that a single, high-energy event will be sufficient to drive the stored low-beach sediment into the nearshore beach environment, where it should stay to produce sandy amenity beaches. Whilst this may occur, the post-storm low energy conditions will again favour muddy sediment deposition. Further to this, the local authority plans a programme of beach renourishment over the next few years.

A Summary of Grain-Size Variation

The work of SIM (1998) highlights the long-shore changes in mean sediment grain size. From his study covering three groynes (Battery, Stone Jetty, Carlton Terrace—see Figure 3) SIM (1998) demonstrated a distinct spatial gradient with respect to grain-size. These data can subsequently be employed to help support the conclusions made here, and also the comparison with the Llandudno project (BULL *et al.*, 1998). Table 1 shows the mean grain-size and range for each groyne. The results clearly demonstrate a major change either side of the Stone Jetty. To the south-west, where exposure to incoming waves is greater (Figure 2), sediment is coarser than to the north-east, which is sheltered from waves by the Jetty. In addition, there appears to be a net coarsening towards the structure from the south-west, and away from it to the north-east. This latter observation, however, is based purely on the three groynes used by SIM, and so whilst it is suggestive of systematic spatial change, further data would be needed to support any firm conclusions. Details of grain-size trends will be incorporated into subsequent discussions.

Returning to this work, there are two main areas of discussion regarding the survey results. Firstly, how sediment has accreted over the study period, and secondly, how this accretion varies in association with each groyne.

Observations from Surveying

Levelling of beach profiles in both 1992 and 1996 has provided data with which to make a direct comparison of sediment accretion along the Morecambe frontage. Figure 5 demonstrates the differences which have occurred during the intervening four years along both sides of each groyne. In all cases, levelling indicates net sediment accretion between 1992 and 1996, although the thickness varies between locality. Figure 5 indicates that the Battery has experienced significant accretion along both sides, whilst Bare Pool has experienced relatively little. Care needs to be exercised here, however, because the sediments in question are silts and clays. As such, they experience de-watering and compaction, the amount of which will depend on factors including grain-size and period of deposition. It is inadvisable, therefore, without additional investigation, to attempt any quantification of sediment accumulation or rates. It is clear, however, that in all cases, sedimentation has occurred over the intervening four year period, and given that sediment compaction would have occurred to some extent in all cases, the visual thicknesses depicted in Figure 5 can be regarded as minimum sediment accumulations.

Impacts of Groynes on Sediment Accretion—1992 to 1996

Looking at each groyne in turn, starting in the south-west and moving towards the north-east (see Figure 3) the impact of each will be described. The results for this survey are shown for each structure in Figure 5. The Bay Cottage groyne (Figure 3) was the first to be constructed following the loss of Bay Cottage during a storm in 1983. The survey indicated a marked increase in beach levels since 1992 with a gentle seawards gradient (Figure 5). Some of this material may be derived from some artificial renourishment which has occurred in the main 'neck' on the structure.

Further up the coast, the Battery groyne (Figure 3), completed in 1991, has shown significant sediment accretion since 1992 (Figure 5). On the south-western side, the beach profile has increased in height to produce a flattening of the intertidal zone, but with a much steeper seawards slope. The north-eastern side, however, is lower in elevation than the south-west, although the 1996 survey does indicate significant sediment accretion on this side since 1992, with an el-

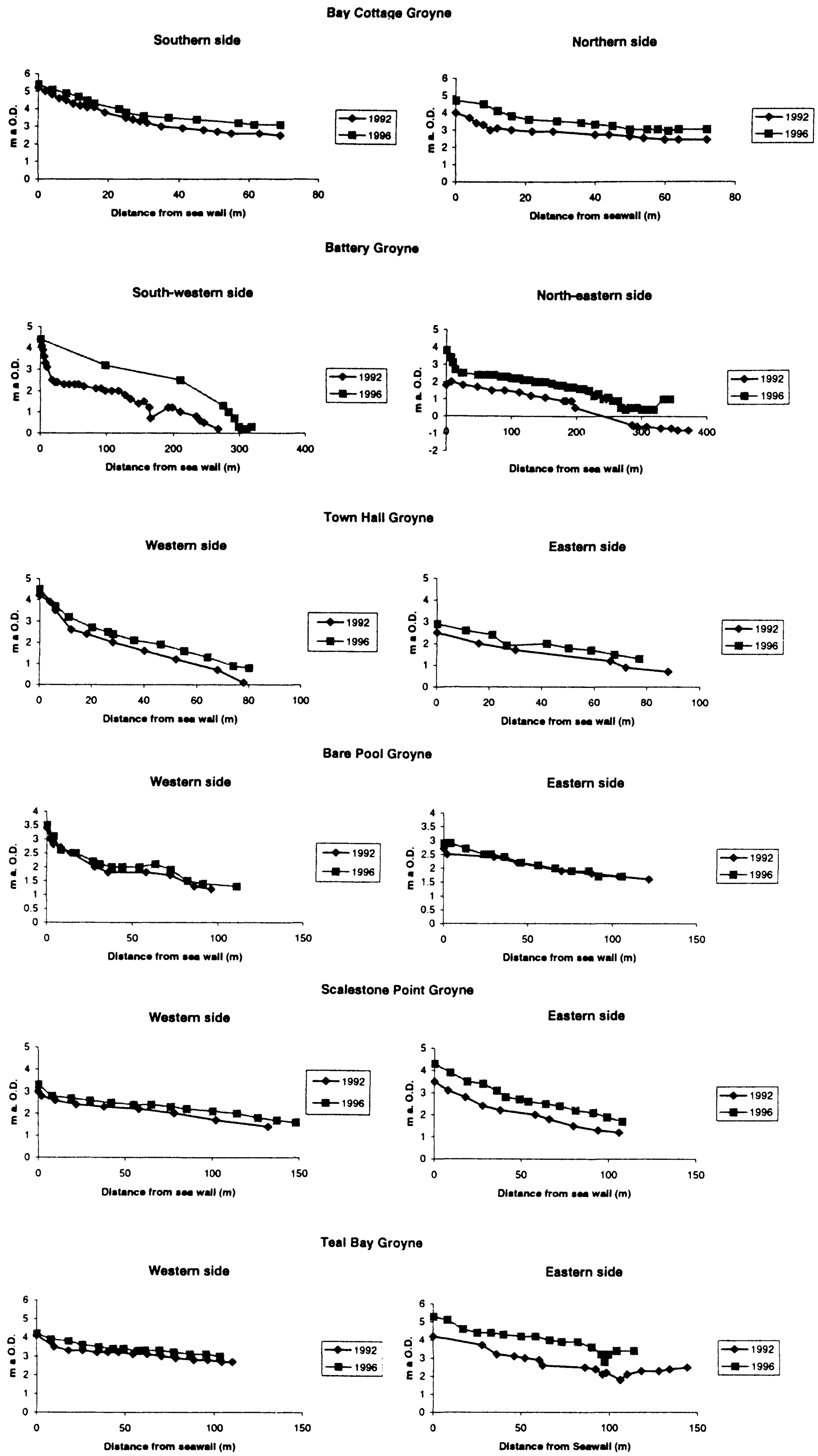

Figure 5. Sediment accretion between 1992 and 1996 for each of the six groynes studied.

evation increase from below to above ordnance datum beyond 240m (Figure 5). The analysis of sediment grain-size (SIM, 1998) was carried out from sediment located in the seawards facing portion of the 'Y' shape (Figure 3). Sediment shows a mean grain-size of 86.1 μm (range = 76.9–90.9μm) (Table 1). The next site used by SIM (1998) for grain-size analysis, the Stone Jetty, lies between the Battery groyne and Town Hall groyne, which is the next used in our study (Figure 3). Grain-size analysis for sediments around the Stone Jetty (Table 1) occurs from two sites either side of the structure, and shows an interesting variation. Given that the Jetty represents a major barrier to waves (Figure 2), it protects the coast to the north-east from the prevailing wave direction and as such, energy levels are expected to vary accordingly. The differences observed by SIM (1998) tend to support this. To the south-west, where wave exposure is greater, sediments had a mean grain-size of 91.5μm (range = 87.3–95.5μm), whilst to the north-east, this becomes finer, with a mean of 42.7μm (range = 36.2–57.1μm) (Table 1). Clearly this represents a major contrast in conditions either side of the Jetty, and will be discussed in the context of our results later.

The Town Hall groyne is relatively sheltered by both the Carlton Terrace groyne and the Stone Jetty (Figure 3), and is typified by the accumulation of silts and clays. Sediment accretion has been fairly uniform on both sides of the structure, producing a slight shallowing of the foreshore (Figure 5). This shallowing is also marked by a seaward progradation of the intertidal flat. Just to the north-east is the Carlton Terrace groyne (Figure 3), which was used by SIM (1998) in his grain-size investigations. As with the Battery, samples were taken within the seaward-facing part of the 'Y' (Figure 3) and the resulting analysis reflects the fining of sediment first seen at the Stone Jetty (Table 1). Mean grain-size is 52.1μm (range = 41.9–61.9μm) and, although slightly coarser than immediately north-east of the Jetty (Table 1), sediments remain considerably finer than to the wave-exposed south-east.

The Bare Pool groyne (Figure 3) is typified by coarser sediment than in the Town Hall groyne area, indicating a higher energy regime. This observation would suggest that the sheltering effect of the Jetty is becoming less, and is supported by the wave patterns indicated by the SHORELINE MANAGEMENT PARTNERSHIP (1990). Despite some sand nourishment having occurred since the 1992 survey, the changes in elevation were only small, although both sides of the structure show an increase in surface height since 1992 (Figure 5). Although this increase in surface elevation has been small, there is an important and significant change regarding sediment accretion patterns. The elevation of the sediment surface either side of the groyne changes from being greater on the western side to the eastern. In all previous cases, sediment build up has been greater on the western side of each structure. If we regard the primary sediment movement as being associated with long shore movement, then it appears that sediment is derived from a different direction here, and in subsequent structures eastwards along the coast. However, the presence of the Stone Jetty must also be considered due to its wave sheltering effects. This issue will be discussed in more detail in the next section.

At Scalestone Point (Figure 3, figure 4), the beach profiles have remained similar with regards to gradient, but with an increased surface elevation and seawards pro-gradation (Figure 5). This location represents the site of the most serious storm damage in 1990 and some low, pre-1992 beach levels. The final structure is located at Teal Bay (Figure 3), and represents the limit of the groyne construction to date. Again, in 1996, sediment levels are higher on the eastern side, following the change in trend first noticed at Bare Pool. Both sides of the groyne have experienced an increase in sediment since the 1992 survey, but this has been significantly greater on the eastern side (Figure 3). Eastwards from here, coastal defences are typified by salt marshes and low earth embankments.

To summarise the above detail, all profiles indicate net sediment accretion since 1992. As this has continued, there has been a corresponding decrease in wave base, and an increasing reduction in wave energy. This factor would explain the predominant fine sediment regime which exists in association with many of the groynes studied, and has also been observed in other studies (BULL *et al.*, 1998). The amount of accretion varies between groynes, although as has been previously mentioned, this would also include possible differential de-watering and compaction.

The highest surface elevations occur by groynes located at each end of the defence scheme, with the Bay Cottage, The Battery, and Teal Bay groynes having the highest sediment surface elevations, and Bare Pool and the Town Hall groynes, the lowest. This situation is the case in both 1992 and 1996. Further evidence for this can be obtained from surveys of other structures done in 1996 but not 1992 (Carlton Terrace and Broadway groynes (Figure 2)), and hence not included here as part of the primary analysis which demonstrate lower beach elevations, akin to those at Bare Pool and the Town Hall.

It appears, therefore, that different sedimentation rates are occurring in association with structures along the Morecambe frontage, with sedimentation greater in the eastern and southern areas, but low in the central portion. However, without data relating to sediment compaction and de-watering, this must remain purely as an observation. It is likely, however, that this observation is real, with the prime cause being the association of the Lancaster Channel with the Stone Jetty (Figure 3) with secondary impacts caused by the presence of the groynes and their impact on long-shore sediment movement. Firstly, by forcing the Lancaster Channel offshore, the decrease in sedimentation which has occurred, coupled with the reduction of energy associated with the offshore shift of the main channel, has caused sediment starvation from this area. Secondly, the groynes have interrupted long-shore sediment movement with cumulative impacts downdrift for successive groyne compartments.

Sedimentation Patterns on Each Side of the Breakwaters

The second observation to be drawn from the data relates to how the accretion of sediment varies either side of each groyne. Figure 3 indicates the location of the transects and

Figure 6 details the sediment surface elevation on each side of each groyne for both 1992 and 1996. Transgressing from Bay Cottage in the south to Teal Bay at the north-eastern end of the frontage, sedimentation accumulation changes from being greater on the southern (western) side to the eastern. The use of south and west here could appear confusing, occurring due to a change in orientation of the coastline. The change could be looked at in another way. By defining left and right sides of the groyne as those of the onlooker standing on the promenade looking out to sea, then this same trend shifts from being greatest on the left side at Bay Cottage, to greatest on the right side at Teal Bay, the change being first observed at Bare Pool (Figure 3) as discussed in the previous section. This observation may be explained in one of two ways. Firstly, that the derivation of sediment changes along the coast. It is generally accepted that shore normal structures interrupt the long-shore movement of sediment, and produce sediment build-up on their up-drift side. In this case, this would imply that sediment derivation is primarily from the south in the Bay Cottage region, and from the east in the Teal Bay region. Furthermore, if this trend is correct, then sediment starvation in the mid-part of the scheme would result from a loss of sediment from either direction. A second possibility is that sediment deposition is linked primarily to the Lancaster Channel, and its relation with the Stone Jetty. With predominant sediment movement from the south-west to north-east (ROSTRON and MCCLAREN, 1989) this movement would be interrupted by the Stone Jetty, meaning that updrift (*i.e.* to the north-east) would be an area of sediment starvation. The grain-size data would indicate that this area is one in which coarse sediments are not deposited and may further implicate the Stone Jetty as an influence over sediment depositional patterns. This issue represents an aspect of the area which requires further study.

DISCUSSION

It is clear that the primary objectives of the Morecambe coastal defence scheme have been achieved, in that sediment accumulation has been significant and considerable foreshore protection has been achieved by a combination of both hard defence structures and sediment accumulation. This immediately provides a contradiction with the analysis of BULL *et al.* (1998) who indicate that in their study, no significant sediment accretion had occurred. However, if considered in relation to controls over coastal processes, then an explanation for this becomes clearer. BULL *et al.* (1998) highlight the Gogarth Breakwater as the primary cause of this problem. In our study, we do notice apparent sediment starvation up-drift of the Stone Jetty, and so it may be concluded that in both studies, the presence of a structure of such size will influence the effectiveness of the scheme due to interference with primary sediment transport pathways. Given the larger area covered by the Morecambe scheme, the impact of the structure can be seen to reduce with distance away from it. The smaller area at Llandudno makes the impacts of the Gogarth Breakwater more ubiquitous.

Whilst significant favourable changes in beach levels have occurred at Morecambe, it should also be said that the area has not received a similar magnitude storm to those experienced during the 1970's, 1980's and early 1990's and so the response of the defences and sediment build-up to storm activity has not been fully tested. Perhaps the statisticians would argue that with three 1:100 magnitude events in the space of 13 years, this is predictable. In February 1997, however, a storm surge forced high water levels to those experienced in 1977 when the West End pier was destroyed. Winds reached storm force 10 and, although not as strong as in 1977, the defences worked well with no overtopping or structural damage reported.

Given that from a coastal defence aspect the scheme appears to be working well, and that subsequent phases could be predicted to have a similar successful outcome, it could be suggested that the scheme is a good example of coastal management in operation. BULL *et al.* (1998) concluded that their study revealed a major reduction in erosion rates. Although our work did not investigate erosion *per se.,* we did investigate sediment accretion and showed how net accretion between 1992 and 1996 has occurred across the scheme. As such, we too can conclude that the use of fish-tail groynes have successfully reduced this aspect of the problem.

In many respects, the success of groynes is clear, but there are several implications from both this study, and that of BULL *et al.* (1998) that tend to indicate that fish-tail groynes may have negative aspects which need to be considered by coastal planners. The issue of linking the development of such structures to larger breakwaters or jetties has already been discussed, but perhaps the key issue which arises is the relation to the sediments which accumulate following construction. The fining of sediments means that the function of the area as an amenity resource is reduced. In both our study and that at Llandudno, the predominance of silt and very fine sands has been a characteristic of the use of fish-tail groynes. This, in effect, has been a result of the scheme's success, in that because the energy reduction obtained has been so great, this has meant that coarser sediments, such as sands, cannot be transported into the nearshore environment. It is possible that a storm would serve this purpose but this would only be followed by renewed fine-grained sediment deposition once the low energy conditions return. Equally, artificial beach nourishment would add sand and, given that the energy regime is low, it can be argued that the probability of sand retention after such a scheme would be high, although the issue of renewed fine sediment deposition would remain.

The prime aim of the scheme has been to develop a sheltered environment to allow the natural accretion of sediments. The groynes play a major part in this although other factors, such as forcing the Lancaster Channel offshore to increase the width of the foreshore would also facilitate the formation of wide, shallow intertidal profiles. Given that the series of storms through the 1970's and 80's caused major foreshore lowering in this area, the development of the groyne system has permitted large-scale sediment build-up, to levels which are approaching mean spring high water in some places.

At the current time, sediment is continuing to build-up, although some change is occurring with respect to sediment elevation and tidal range. The mean high water spring tide

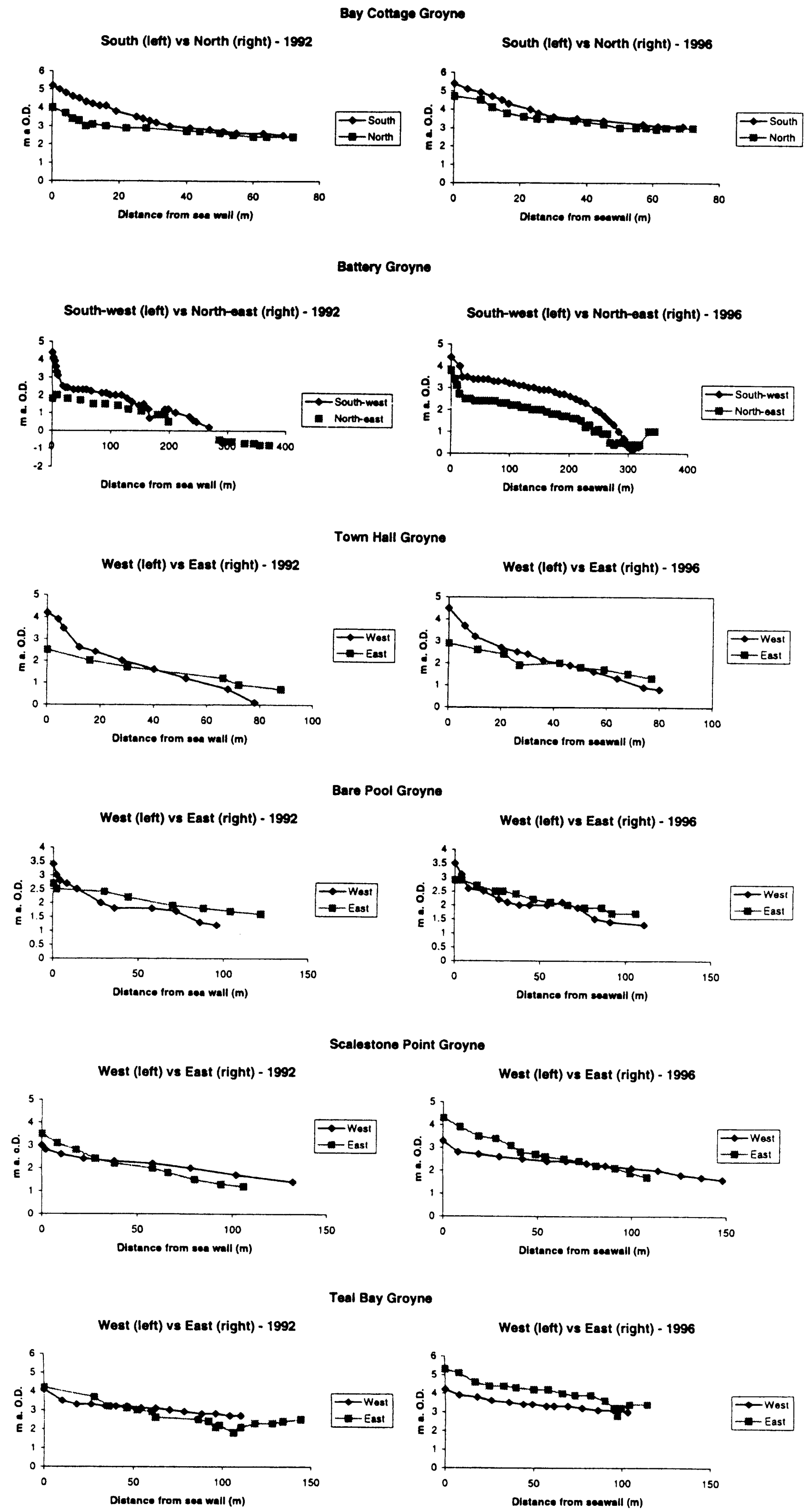

Figure 6. A comparison of beach levels either side (left and right transects) of each groyne.

height at Morecambe is ca. +6.0m O.D. and as the level of the tidal flats increases, so the frequency and duration of inundation by sediment laden water will reduce. As a result, the vertical accretion of these areas slows down and more sediment remains in the system for deposition elsewhere on the lower fats. Such ideas as indicated here are well established, particularly with respect to salt marsh dynamics (ALLEN, 1990). Profiles at Bay Cottage and Teal Bay are approaching the 6.0m O.D. mark and as such, would experience a slowing down of accretion due to reduction in sediment supply.

The influence of the Lancaster Channel cannot be underestimated in this study. By operating as the main flood tide channel, it can bring in not only large volumes of sediment but large waves close inshore (SHORELINE MANAGEMENT PARTNERSHIP, 1990). BULL *et al.* (1998), however, highlight the presence of the North Channel in their study as contributing to accretion failure. Due to this discrepancy between the two studies, the presence of a channel does not, in itself, appear to govern the success of sediment accretion. This suggests that we need to look for additional reasons which may act independently of, or in association with channel processes. When considering the two studies, both have a low energy environment dominated by a tidal channel, although the channel in the Llandudno study is further offshore than at Morecambe. This distance offshore may, in itself be a factor which, in accordance with the wave and tide regime of the two localities, affects sediment supply to the groyne area. Clearly, on the data available here, more detailed investigation of this issue is not possible.

The use of a breakwater or jetty to provide a wave shadow is, in principal, a sound idea. However, in both this and the Llandudno study, such structures appear to be operating in conflict with the natural system by not only removing wave energy, but also deflecting sediment away from the desired areas. Again, this comes back to the presence of a channel because whilst the breakwater may deflect currents. It is also deflecting sediment into the channel which is effectively removing it from the local area.

Returning to issues relating to our study, the problem of fine sediment build-up and beach quality is perhaps one which is quite easily addressed given adequate capital funding and suitable sediment sources, both factors which have already been determined. Of greater difficulty, however, is the impact which the Stone Jetty is having on other aspects of the defence scheme. The results of this work have indicated how this structure was designed to control and regulate the position of the Lancaster Channel. As far as the central portion of the Morecambe frontage is concerned, *i.e.*, the area from the Stone Jetty to Carlton Terrace (Figure 3), the Jetty appears to be causing sediment starvation due to the forcing seawards of the channel. It is well known, however, that channels respond to artificial forcing, often by the initiation of meanders and channel reactivation elsewhere along its course. Such channel movements have occurred in both directions along the coast and does explain the presence of coarser sediments being deposited in the Bay Cottage/Battery and Scalestone Point/Teal Point regions, *i.e.* those furthest from the breakwater, which indicate higher energy regimes (see Figure 2). Whilst this is certainly not a problem at the present time, and could perhaps be argued to be of an advantage, given the coarser sediment deposition, it may mean that in future, this may initiate marsh erosion beyond Teal Bay, and possible scouring of the foreshore.

The discussion so far has concentrated on the scheme directly. Other aspects could also be highlighted in the context of the defence impacts. COOK (1996) discusses the problems which the new defences have caused in relation to the loss of mussel beds in the central part of the scheme. After extension of the Stone Jetty, the increase in sediment levels, and the corresponding shifting seawards of the low water mark have resulted in the silting over of one of the area's prime mussel beds, causing an area reduction of 3.6 Ha in 1988, to 1.7 Ha in 1993, to 0.0 Ha by 1995 (COOK, 1996). In recompense, however, the local authority is undertaking schemes of new mussel bed construction.

Although coastal defence was the prime driving force behind the scheme, the potential of beach formation also provides the advantage of increasing the area's appeal to tourists. As part of this, provision of an amenity beach was an aim of the project. As has been mentioned previously, much of the dramatic increase in sedimentation has been with silts and clays. This can, and will be rectified with sediment renourishment, but other problems remain. Such significant defence structures do provide obstacles to beach access, and where access does occur, this is often into soft sediment. Again, beach feeding will allow this access to be to sandy beaches in the future. It is also true, however, that the local authority has deliberately made some areas inaccessible, primarily for nature conservation reasons.

CONCLUSIONS

When the Morecambe coastal defence scheme was at the planning stages, it was envisaged that it would provide a series of fish-tail groynes which would promote the natural accretion of sand-grade sediment, and provide the means by which to retain it on beaches. This would increase the level of protection afforded the town from storm surges. Loss of sediment due to long-shore movement, and potentially, natural sea level rise.

The results from this study demonstrate that at least in part, the project has achieved its objectives with a general increase in beach levels along the whole Morecambe frontage from Bay Cottage to Teal Bay. It is clear that groynes in the shadow of the Stone Jetty have lower beach levels than those elsewhere, whilst sites along the coast, such as Scalestone Point and Teal Bay have thicker accumulations of coarser grade sediment due to the closer proximity of channels. This indicates that the groynes themselves, in order to be effective, are reliant on the tide/wave regime to deliver sediment, and that any obstacle to this movement will prevent the scheme from achieving its full potential. This is not a unique observation to our study, but has also been shown in similar locations elsewhere.

Accretion around each of the groynes is a good indication that change is occurring within the Morecambe coastal system, a change which has been initiated by phased defence construction. Following each phase, the system adjusts to its new regime by rapid sediment deposition, followed by smaller scale erosion/accretion episodes as environmental controls, such as storms, rather than construction-induced system instability, reinstate themselves as primary environmental controls. It is clear, however, that whilst sediment accretion has been achieved, such fish-tail groynes may cause a switch to a finer sediment regime. Clearly, an observation based on two examples (Morecambe and Llandudno) needs further quantification before any general statements can be supported. Such issues are being addressed by ongoing research.

When considering the problems raised in the discussion, it should, perhaps, be remembered exactly what the scheme was set up to do. Following three 1:100 magnitude storms which resulted in considerable financial and structural losses for the town's residents, it is this group of people for whom the scheme was set up to protect. Foreshore accretion has occurred and subsequent storms have not proved a threat to coastal residents. As such, these people can now live with the (relative) security that goes with such an elaborate engineering achievement. The provision of amenity facilities is a secondary aspect of the scheme.

ACKNOWLEDGEMENTS

Discussions with Mr. Ron Eckersley, coastal engineer, Lancaster City Council, are gratefully acknowledged, as is the permission to view coastal survey reports. In addition, JSL acknowledges the help and advice given by PWF in the aspects of this work which comprised his undergraduate dissertation. The Cartography Unit, Geography Department, Royal Holloway, University of London is thanked for the preparation of Figures 1, 2 and 3.

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