52. Morant P.D. (1984). In *Estuaries of the Cape, Part II: Synopses of Available Information on Individual Systems*, eds. A.E.F. Heydorn and J.R. Grindley, rep. no. 26 Olifants (CW 10), Stellenbosch, CSIR Research Report 425.

53. Parkington J. (1981). The effects of environmental change on the scheduling of visits to the Eland's Bay Cave, Cape Province. In *Patterns of the Past*, eds. I. Hodder, G. Isaac and N. Hammond, chap. 12, pp. 341–359. Cambridge University Press.

54. Parkington J. (1987). Changing views of prehistoric settlement in the western Cape. In *Papers in the Prehistory of the Western Cape, South Africa*, eds. J. Parkington and M. Hall, pp. 4–23. BAR International Series 332 (i), Oxford.

55. Horwitz L. (1979). *From materialism to middens: a case study at Eland's Bay, western Cape, South Africa*. B.A. (Hons.) thesis, Department of Archaeology, University of Cape Town.

56. Deacon J. (1987). Holocene and Pleistocene palaeoclimates in the western Cape. In *Papers in the Prehistory of the Western Cape, South Africa*, eds. J.

Parkington and M. Hall, pp. 24–34. BAR International Series 332 (i), Oxford.

57. Deacon J. and Lancaster N. (1988). *Late Quaternary Palaeoenvironments of Southern Africa*, pp. 1–225. Oxford University Press.

58. Deith M.R. (1988). A molluscan perspective on the role of foraging in Neolithic farming economies. In *The Archaeology of Prehistoric Coastlines*, eds. G. Bailey and J. Parkington, chap. 10, pp. 116-124. Cambridge University Press.

59. Swadling P. (1976). Central Province shellfish resources and their utilization in the prehistoric past of Papua New Guinea. *Veliger* 19, 293–302.

60. Jerardino A., Castilla J.C., Ramírez J.M. and Hermosilla N. (1992). Early coastal subsistence patterns in central Chile: a systematic study of the marine invertebrate fauna from the site of Curaumilla-1. *Lat. Am. Antiq* 3, 43–62.

61. Straus L.G., Altuna J., Clark G.A., Gonzalez Morales M., Laville H., Leroi-Gourhan A., Menéndez de la Hoz M. and Ortea J.A. (1981). Palaeoecology at La Riera (Asturias, Spain). *Curr. Anthrop.* 22, 655–682.

62. Heller J. (1990). Longevity in molluscs. *Malacologia* 31, 259–295.

The possible impacts of sea-level rise on the Diep River/Rietvlei system, Cape Town

P. Hughes, G.B. Brundrit, D.H. Swart[1] and A. Bartels[1]

Department of Oceanography, University of Cape Town, Private Bag, Rondebosch, 7700 South Africa; and
[1]EMA, CSIR, P.O. Box 320, Stellenbosch, 7600.

Many of the Cape Province's estuaries and tidal inlets have sandy connections to the sea and are often intensively developed for industrial or residential purposes. The possible impacts of sea-level rise are of considerable interest to these developments. One such setting is the Diep River/Rietvlei system at Milnerton, north-east of Cape Town. This paper presents the likely geomorphological changes to accompany a 1-m rise in sea-level. It demonstrates the vulnerability of an inlet's channel banks and mouth area to sea-level rise and shows how the internal tidal range may be affected by increased coastal erosion. In essence, it highlights the complexity of the impacts of sea-level rise in these environments and the need for effective management strategies.

One of the more widely publicized problems facing this and future generations is that of the greenhouse effect and the resulting global warming. As a result of a warmer atmosphere, global sea-level is expected to rise and appears to have already done so at a rate of between 10 cm and 15 cm over the last century.[1-4] It has been suggested that this is in response to an apparent warming trend in global air temperatures over the same period. With further 'greenhouse' warming, global sea-levels have been predicted to rise between 30 cm and 150 cm within the next century.[5] Such a rise will affect many of the world's low-lying coastlines, so that coastal management will be required to ameliorate the consequences.

South African tide-gauge records are short in comparison with similar records elsewhere but, of the four longest South African records, three show a positive secular trend over the last few decades. The Port Nolloth tide-gauge record shows a rise in sea-level of 1.23 cm per decade over the period 1960–1988,[6] significant at the 95% confidence level. This rise is in keeping with the global estimates and it is reasonable to expect that the predictions for future globally modelled sea-level rise are applicable to South Africa. It is prudent therefore to consider the impacts of a future rise in sea-level on the South African coastline.

This paper examines the impacts of a 1-m rise in sea-level on the Diep River/Rietvlei system at Milnerton near Cape Town and presents a likely scenario for the geomorphology after the rise. This study area was chosen as it is typical of many locations in South Africa where development has taken place on or near a dune barrier that is backed by an extensive vlei and wetland system. The analysis is not intended as a definitive prediction of geomorphological changes, but rather as a likely scenario for changes resulting from a 1-m rise in sea-level. The present wave, current and wind conditions are used in the calculations, although it is likely that they also will alter with further global climate change. The prediction of future design waves, currents and winds is not yet possible with existing climate models. Coastal erosion effects on the open coast are modelled using the Bruun Rule[7] and Swart technique[8] and their appropriate applications are discussed.

Site description

The study site is the coast and low-lying area immediately adjacent to the mouth of the Diep River approximately 5 km to the north-east of Cape Town (Fig. 1). The main features are a tidal inlet (Milnerton Lagoon) and wetland system (Rietvlei) which open onto an essentially unconsolidated sandy coastline. The periphery of the vlei system is an increasingly developed residential extension of the Municipality of Milnerton. The mouth of the river is generally closed in the summer months by the development of a sand bar. A portion of the spit on the northern side of the river mouth, known as Woodbridge Island, is an intensively developed residential area with houses within 2-m elevation of the current mean high water spring level.[7] To the north of Woodbridge Island the primary dunes are moderately well vegetated and backed by a golf course. The toe of these dunes and the hummocky dunes fronting the southern end of Woodbridge Island are often scarped, indicative of erosion during storms. Occasionally, during severe winter storms, the sea washes over onto the golf course, through a low gap in the dunes approximately 100 m to the north of the lighthouse.

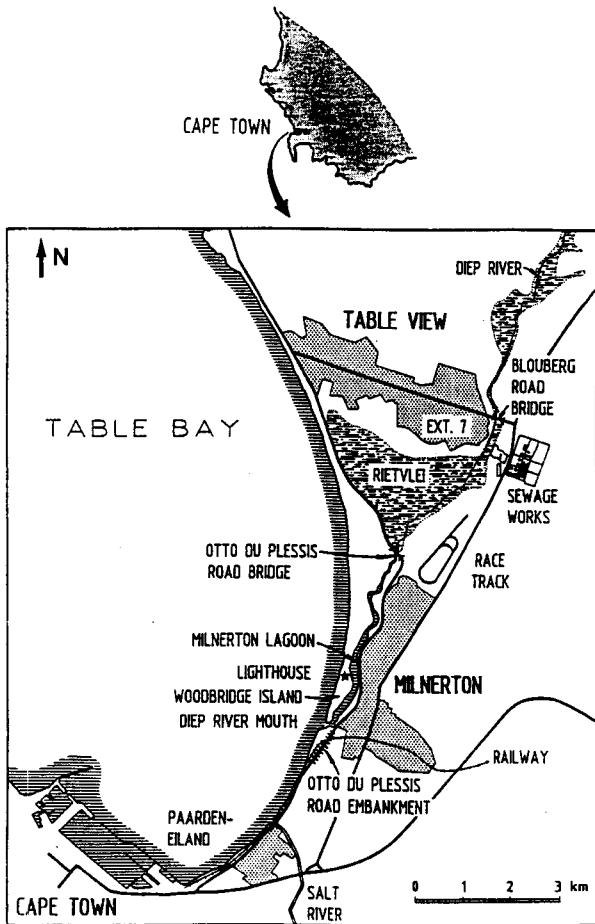The nearshore surface sediment along this stretch of coast-

Fig. 1. Location map of study area.

line is fine sand[10] with occasional coarse shelly patches and some small pebbles. Sediment thickness is about 10–20 m,[10,11] increasing to more than 25 m within 1 km landward of the shoreline.

Coastal hydraulics

Surface and nearshore currents (to 18 m depth) are dominated by the wind direction in Table Bay with significant sediment-transporting currents in the surf and nearshore zone as a result of combined wind and wave action.[11] Prevailing winds are north-westerly in winter and south-easterly in summer. Sediment distribution off the Diep River mouth suggests bimodal transport, north and south along the coast, in concert with the wind direction.[11] However, there appears to be net sediment transport towards the north at a rate estimated[11] to be of the order of 100 000 m³ yr⁻¹ at Woodbridge Island. Sediment starvation to the south of the river mouth is apparent and can be expected to aggravate future coastal erosion around the Woodbridge Island area with a rise in sea-level.

Historical aspects

Historically, the mouth of the Diep River has been highly mobile,[12] which emphasizes the area's vulnerability to change. At the time of van Riebeeck's arrival in the Cape in 1652, the Diep River entered the sea via two mouths, one a little south of the present opening and another further south at the present Salt/Black River mouth.[12] The channel linking the two cut off Paarden Eiland from the mainland. Barbier's map of 1786 shows the Diep River mouth about 3 km south of its current position.[12] It appears that both vlei and river were considerably deeper than today and unsubstantiated reports[12] claim that the river was navigable by small ships up to 13 km from the

mouth. Marked siltation was noted by 1860 and parts of the lagoon were first dredged in 1905 to provide facilities for water sports.[12] In 1928 a weir was built across the river mouth to increase the water depth in the lagoon to counter the effects of siltation. The weir was demolished after two particularly severe floods, in 1941 and 1942, and its remains have served as a sediment trap, apparently causing the tip of the spit to grow in length and elevation.[9]

Maps, charts and photographs have shown that the Milnerton coastline has been in a state of accretion between at least 1780 and 1900. In about 1900 the situation reversed and, since then, approximately 80 m of progressive erosion has taken place on Woodbridge Island.[9,12] This change in tendency has been attributed to wave reflection from large-scale extensions to Cape Town harbour.[9] Figure 2 shows the trend of shoreline changes at Woodbridge Island compared with harbour developments.[9] The construction of the Ben Schoeman Dock has been shown to correlate with erosion of about 30 m by the CSIR,[9] who have indicated that the rate of erosion is slowing and the shoreline is returning to a new equilibrium. This report states that less than 10 m of erosion resulting from construction of the dock is still expected.[9]

It is clear from historical evidence that this shoreline is highly mobile.

Analysis of effects of sea-level rise

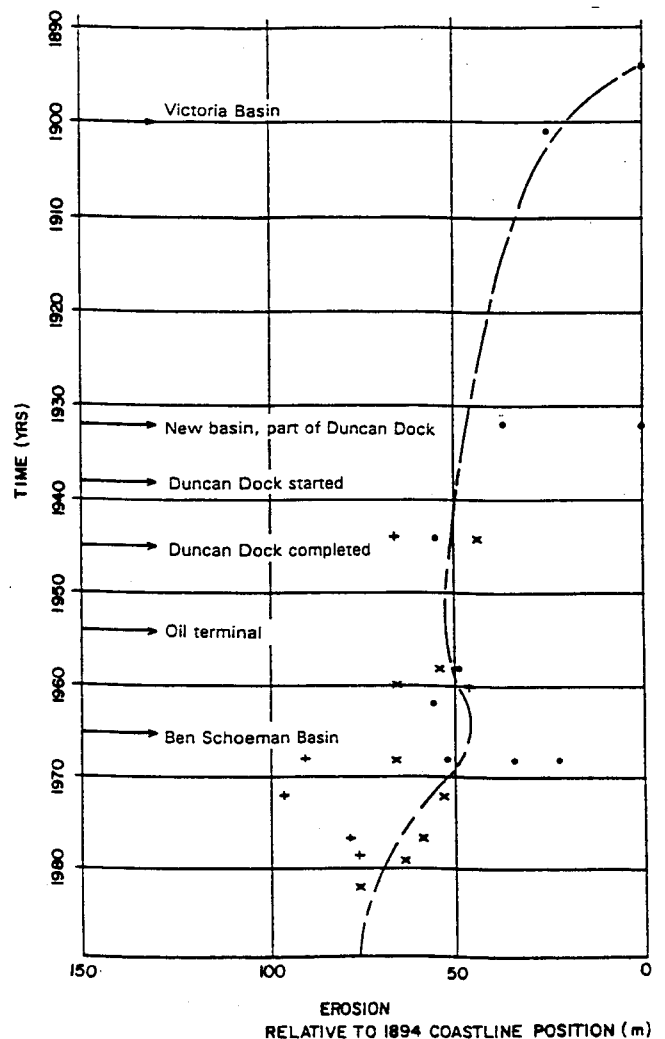To examine the effect of a 1-m rise in sea-level, we analysed

Fig. 2. Historical shoreline changes (after ref. 9).

the coastal zone at Milnerton with respect to the following: the potential degree of horizontal shoreline displacement; the result of the increase in tidal level on the channel and river mouth; the effect of reduced protection from extreme coastal storms on the position and size of the coastal dunes and river mouth and the reduced protection from river floods. Other factors that will be discussed include: the effect of increased saline intrusion into aquifers and estuaries; and the effect of elevated groundwater levels.

The gradient of a beach in the nearshore and swash (that is, the wetted area of the beach) zone depends mainly on three variables: the particle size of the beach material, the predominant period, and height of the waves. For a given beach, the slope will change with wave climate — the gradient decreasing with increasing wave height and period. This dynamic balance will consequently have a seasonal overprint with the winter storms tending to move sediment offshore and the gentler wave action in summer pushing the material back onshore. Eroding beaches tend to have steeper upper slopes and, where the upper part of the beach is characteristically steep and deficient in hummocky foredunes, like much of Milnerton, this is often indicative of a shoreline undergoing long-term erosion. Bathymetric surveys of Table Bay have shown little change between 1894/5 and 1965.[11] For the purpose of this study it is assumed that the relative summer and winter gradients will not change significantly with a rise in sea-level. 'Average' nearshore and offshore profiles taken from the most recent hydrographic chart, SAN 1014, are therefore used and topography is taken from plans obtained from Milnerton Municipality.

Potential horizontal shoreline displacement

Increased coastal erosion as a result of sea-level rise can be modelled by application of the Bruun Rule,[7] which is applicable to mobile sandy shorelines with no rocky outcrops. The primary assumption of the Bruun Rule is that the inner continental shelf will maintain a constant shape and position relative to the sea surface by translating upwards and landward as the sea-level rises, balancing volumes of sediment in the cross-shore direction (Fig. 3). The basic equation is given by;

$$\text{shoreline erosion } (R) = \frac{\text{profile width } (l) \times \text{sea rise } (a)}{\text{profile depth } (h + d)}$$

The beach berm height is represented by h, the limiting depth of sediment movement by d, and the horizontal distance over which the profile is active by l. This is a two-dimensional model which is used to describe a 2-D section of a three-dimensional situation. As such it is simplistic and should be regarded as giving only an order of magnitude for the change.

Thirteen sections were drawn normal to the coastline at approximately 250-m to 500-m intervals along the coast. The
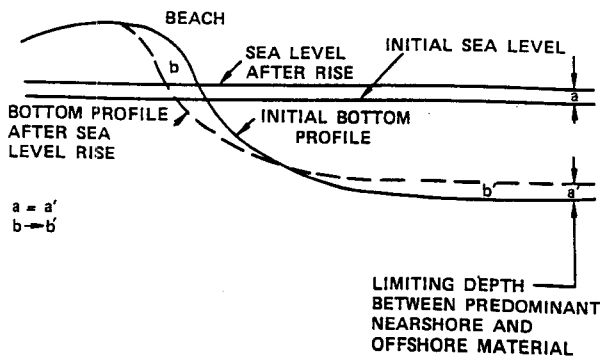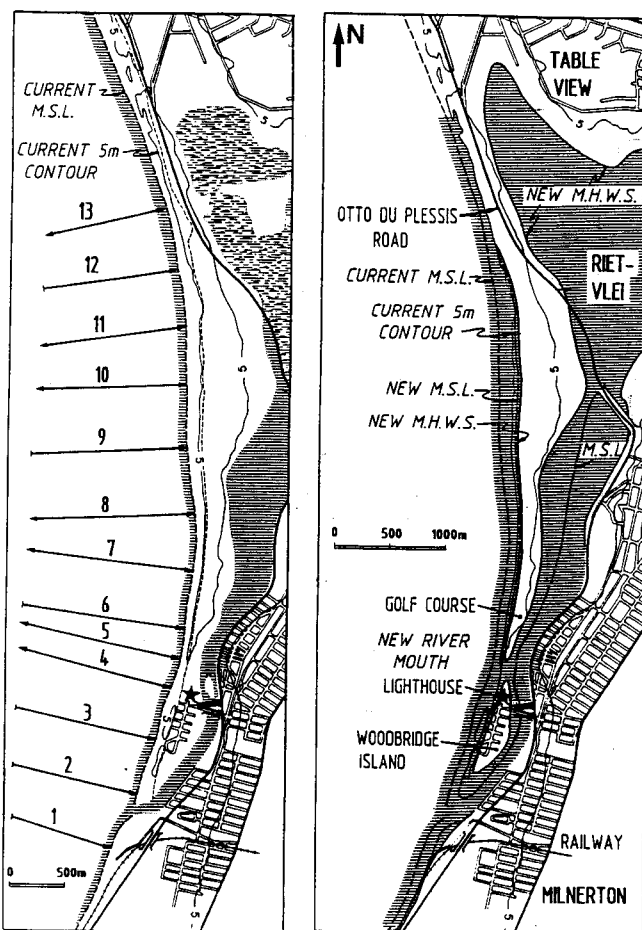
Fig. 4. Location of profiles and position of current mean high water springs (MHWS) and the new MHWS after a 1-m rise in sea-level.

Bruun Rule[7] was applied and the new profile plotted. The maximum depth of significant sediment transport was taken as 18 m. The position of the new mean high water springs (MHWS) and mean sea-level (MSL) were plotted as a shoreline change. Figure 4 shows the location of the sections and the position of the new shoreline relative to its present position.

Table 1 shows the shoreline recessions calculated from the Bruun Rule[7] for each profile. Profile 5 is highlighted in Fig. 5, as it shows that the transgression will break through to the Milnerton Lagoon at MHWS (1.86-m elevation) after a rise in sea-level of 1 m. However, when considering the combined

Fig. 3. The Bruun Rule (after Bruun[7]). After a rise in sea-level (a), sediment volumes (b and b') are balanced in the cross-shore direction such that at the limiting depth, water depth is maintained.

Table 1. Erosion predicted from application of the Bruun Rule.[7] The profiles refer to locations indicated in Fig. 4.

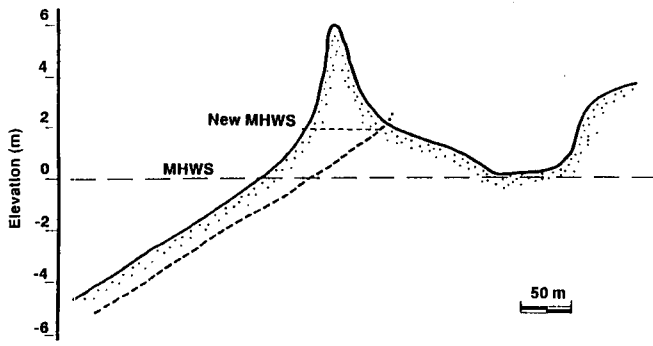| Profile	Erosion (m)
1	135
2	115
3	80
4	75
5	80
6	70
7	80
8	80
9	65
10	60
11	55
12	65
13	60

Fig. 5. Detail of profile 5, showing the break-through point to Milnerton Lagoon after a 1-m rise in sea-level.

effects of elevated water-levels due to storm surge, wave set-up and other meteorological conditions, it seems likely that the breakthrough will occur prior to the full 1-m rise and, once open, will remain open permanently. If this does occur it will effectively shorten the channel length from the open sea to Rietvlei by some 1500 m.

Effect of the increase in tidal level on the channel and river mouth

On an open coastline the effect of increased flooding and inundation may be modelled by adding the magnitude of sea-level rise to the MHWS tide level or highest astronomical tide (HAT). In sheltered environments (where the effects of increased coastal erosion can be ignored) the impact of sea-level rise on the relationship between the newly flooded area and channel dimensions can be evaluated. The US Army Corps of Engineers' Shore Protection Manual provides a useful empirical basis[14,15] which can be used to examine the Milnerton tidal inlet: from a wide range of dynamically stable inlets on Atlantic, Gulf and Pacific coasts of the United States, Jarrett[14] showed a robust empirical relationship between the mid-tide cross-sectional area (A_c) of the inlet channel and the tidal prism (P) of the inlet: $P/A_c \sim 10^4$ m.

It has been shown that any inlet with a soft channel which does not reach the required minimum dimensions will use the eroding power of its high tidal flow to increase the channel size until it satisfies this stability relationship. Conversely, if the channel dimensions are too large, the tidal flow will be too slow to carry all its sediment load and so deposit some in the channel. Siltation will then occur until the correct channel dimensions are obtained (Fig. 6).

For a given channel of known dimensions, King[15] determined the maximum flow velocity in it and tidal amplitude in the inlet by considering mass and momentum balance along the channel in non-dimensional form. Applying this solution to the dimensions of a newly enlarged channel and inlet after a conjectured sea-level rise, a possible new channel velocity and inlet tidal range, and hence tidal prism, may be calculated. If the proposed tidal prism is not consistent with Jarrett's stability relationship, the channel dimensions will need to be adjusted. The calculation may be repeated by iteration to find the minimum channel dimensions which can support the new tidal prism. Other factors such as increased coastal erosion may exert a controlling influence on the dimensions of the real channel but it is likely that, with the tidal cycle, the actual dimensions will oscillate around the calculated mean. The expected tidal range in the inlet and channel dimensions can then be used to derive building or development limits.

With a 1-m rise in sea-level, Rietvlei will effectively become a large shallow body of sea water connected to the sea via a long narrow channel, the Milnerton Lagoon. In the open water, MSL and MHWS will change respectively from 0.15-m and

0.86-m elevation to 1.15-m and 1.86-m elevation (relative to land-levelling datum). The spring tidal amplitude in the open sea will probably remain at 0.71 m. Inside the wetland system, MSL will also be at 1.15-m elevation but frictional losses in the channel and vlei will reduce the tidal range.

For the analysis, the bottom of the vlei was assumed to be a smooth surface with its gradient taken from the relative separation of the 0- and 2-m contours. The area flooded at MSL (1.15-m elevation) was calculated to be of the order of 1.72×10^6 m^2. The channel was assumed to be of uniform depth 1 m below MSL, 150 m wide and 4 000 m long. Using these values in King's solution,[15] the inlet's tidal prism will be 1.61×10^6 m^3 and the tidal amplitude in the inlet will be 0.47 m.

This calculated tidal prism is in good agreement with Jarrett's empirical stability criterion[14] and the expected tidal channel should therefore not enlarge itself beyond its present dimensions under normal flow conditions. MHWS inside the vlei should be approximately 1.62 m (1.15 m + 0.47 m), that is, the tidal range in the vlei will be approximately 66% of the open-water value.

However, as previously discussed, the effects of increased coastal erosion and breakthrough of the coastal dunefield (at profile 5) will shorten the channel to 2 500 m. Using King's solution[15] and assuming a channel depth of 1 m, a channel 185 m wide is required to satisfy Jarrett's stability criterion.[14] This shorter, wider channel will have less frictional resistance than a long channel and will allow for an increased tidal range within the flooded area. The tidal range will be of the order of 1.3 m (0.64 m × 2), or 90% of the open-water value. The MHWS level in the inlet will be at 1.79-m elevation under calm conditions.

Figure 7 shows the position of MHWS inside the vlei and MHWS and MSL on the shoreline. Note that if shortening of the channel is prevented and the inlet's tidal range is kept to 0.94 m (66% of the open-water value), then the areal extent of the flooded area at high tide will be reduced.

Reduced protection from extreme events

Short-term erosion as a result of extreme storms is modelled by application of the Swart technique,[8] and storm flood levels are calculated by combining the new MHWS with the expected surge and wave set-up of a large storm. The Swart technique[8] calculates the shape of the beach profile at any specific time,
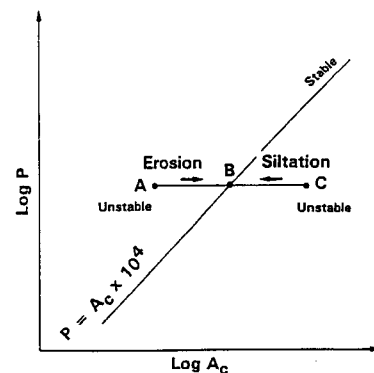

Fig. 6. Jarrett's empirical relationship between mid-tide cross-sectional area of inlet channel (A_c) (m^2) and tidal prism (P) (m^3). An inlet at position A will erode its channel, increasing A_c, and will tend towards the stable dimensions at B. An inlet at C has too large a channel and will silt up as its dimensions tend towards B. This example is for a short channel length where changes in channel width will not appreciably alter the tidal prism. The slope and shape of log A_c against log P is a function of the channel length and section, which will in turn affect the prism. Long channels will tend to be described by graphs with steeper slopes.
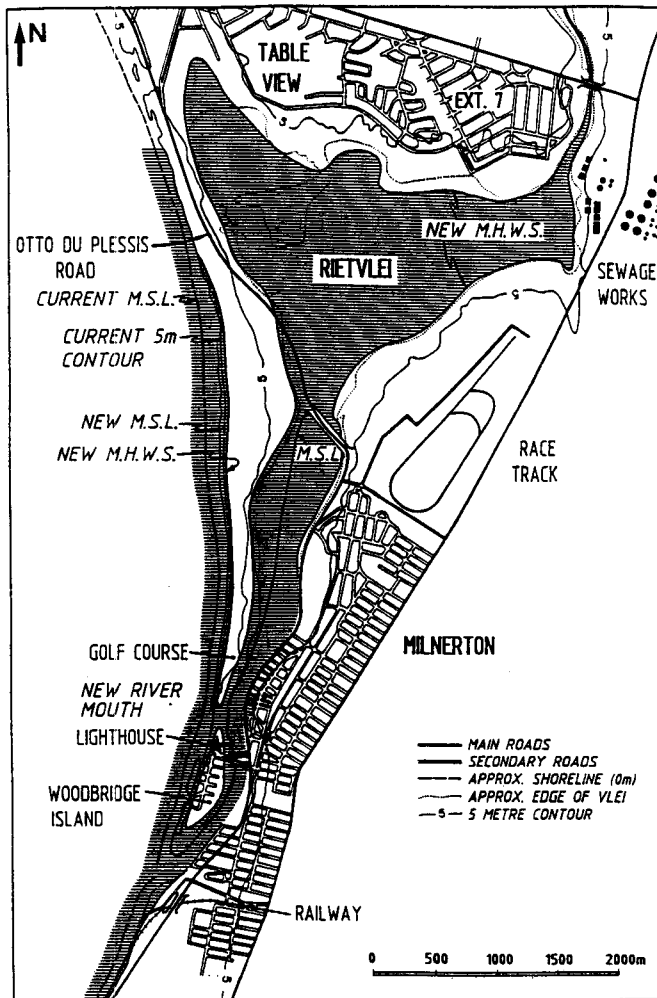
Fig. 7. Position of the new shoreline and new MHWS in Rietvlei after a 1-m rise in sea-level.

based on the assumption that a beach under constant wave attack at a constant water-level will reach an equilibrium shape for those wave conditions. The technique was developed by Swart using an extensive set of laboratory and field data in which he found that the initial beach profile approaches the equilibrium shape at an ever decreasing rate.[8] A function can then be derived[8] to describe the fraction of total change from initial to equilibrium profile that has occurred over a specified period. Wave data from Slangkop, Table Bay and Koeberg wave-rider buoys were used for this study.

Mean initial beach profiles were calculated using a combination of profiles 1–13 employed for the Bruun Rule and previous surveys.[13] Profiles calculated from the two sources were found to be compatible and in good agreement where they overlapped. The Segar 2 model of the Swart technique[8] was then calibrated to give a set of dynamically stable profiles using the wave data set representative of the Milnerton coastline,[13] which consisted of 2 200 individual consecutive recordings each of 6 hours' duration. Wave data were derived from wave-rider buoys at Slangkop, Table Bay and Koeberg and the wave climate for the Milnerton area was determined using available refraction techniques. The data capture and treatment are described in a previous report.[13]

After calibration, the model was run using a data set[13] corresponding to the storm of 15/16 May 1984. On the basis of wave data, Swart[13] considers this storm to have been an approximate 1-in-50- to 100-year event. In this simulation, 25 m of erosion of the beach at the waterline was predicted, which is in good agreement with the actual erosion measured

in this area after the storm.[13] However, the calculation is likely to be an underestimation as the technique assumes a linear dune barrier with no breaks. In reality gaps do occur and no account has been taken of the possibility of washover.

Figure 8 shows the effect of 25 m of storm erosion in conjunction with a 1-m rise in sea-level. The analysis shows that this storm would probably erode half of Woodbridge Island, widen the breakthrough point on the river bend to about 500 m, exposing the Milnerton coastline to direct wave action and erode the dunes to the north of the island by 20–25 m.

With an elevated background sea-level, smaller and therefore more frequently occurring extreme events will produce water-levels capable of overtopping existing flood defences. Storm damage and flooding are likely to become more common and more severe and the occurrence of extreme storms will have more serious consequences. Protection from extreme sea conditions is likely to become a matter of great importance.

The storm surge and wave set-up during the storm of 15/16 May, estimated by Jury *et al.*[16] to be only a 1-in-40- to 50-year event, was calculated to be 1.20 m. If this type of storm were to re-occur on a high spring tide after a 1-m rise in MSL, the water-level could rise to 3-m elevation (1.0 m + 0.86 m + 1.20 m) relative to land-levelling datum. This inundation would probably completely swamp Woodbridge Island and flood all those parts of Milnerton adjacent to the shoreline below 3-m elevation (Fig. 8).

The effect of increased saline intrusion and elevated groundwater

Although some water is extracted from the coastal aquifer for garden irrigation, the bulk supply of fresh water for the Milnerton area is not obtained from this source. Water in the aquifer along the Milnerton coast is known to be brackish (pers. commun. R. Stanley, Milnerton Municipality) and increased salt pollution of this aquifer will not therefore interfere with future provision of industrial or domestic freshwater supply.

The elevation of the coastal water table may be assumed to increase at the same rate as the rising sea-level if no external forces are acting on the water table. Problems associated with waterlogging, seepage into basements and other engineering
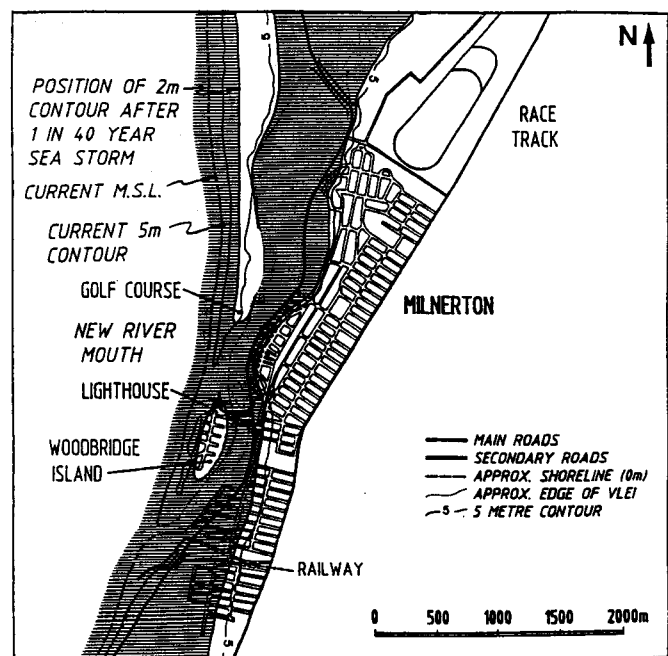

Fig. 8. Shoreline position after an additional 25 m of coastal storm erosion and the storm flood level from a 1-in-40- to 50-year storm.

problems resulting from elevated ground-water tables are likely to become more prevalent in areas such as immediately adjacent to the vlei near Otto du Plessis Bridge (Fig. 1) on the eastern bank. While the present areas and those likely to be problematic are generally quite local in extent (pers. commun. R. Stanley, Milnerton Municipality), further detailed investigation of ground-water conditions are recommended.

Appropriate model application

Accurate predictions of coastal erosion require detailed knowledge of longshore sediment transport. Applications of the Bruun Rule[7] and Swart technique[8] involve using a two-dimensional model in a three-dimensional application. These methods cannot address the problem of longshore sediment transport and can therefore be used only as a guide to future geomorphological changes.

The main difference between the two methods of modelling increased erosion is that the Bruun Rule[7] takes into consideration rates of sea-level change whereas the Swart technique[8] requires a constant water-level as one of its basic assumptions. Calibration of this model is not possible with changing water levels. However, the two methods are complementary. Application of the Bruun Rule[7] gives the long-term erosion of the coastline due to sea-level rise shifting the profile upwards and landward. The Swart technique[8] is able to predict short-term (days or weeks) erosion as it uses actual wave conditions of known return frequency to determine a new, dynamically stable profile and expected variability about the stable profile. As a management tool, the two methods may be combined to predict the likely areas vulnerable to storm erosion after a rise in sea-level.

Conclusions

The Diep River system has a historical and geological background of mobility.[9,11,12] The sediment budget for the study area is not confidently known and the Bruun Rule is therefore applied in its simplest form. This paper therefore represents a 'best estimate' of geomorphological changes to the Milnerton, Diep River/Rietvlei area in the event of a 1-m rise in sea-level under present wave and wind conditions.

Under normal meteorological conditions the shoreline will recede between 60 m and 90 m on Woodbridge Island. To the north of the Island the transgression will be between 50 m and 80 m and, to the south, the shoreline will recede approximately 135 m, putting the embankment of the Otto du Plessis Road and the railway within easy reach of storm wave action. A further 10 m of erosion is anticipated in the Woodbridge Island area as a result of existing harbour developments.[9]

If no shore protection work is carried out, the sea will break through to the river on the bend north of the lighthouse. This second mouth will erode to a channel width of 185 m and will become the main inlet for Rietvlei, which will have a mean water level at 1.15-m elevation. The shortened channel will reduce the resistance to water movement into and out of the vlei and hence its level of protection. As a result the vlei will have a tidal range of about 1.3 m, or 90% of the open-water value. MHWS inside the lagoon will be at 1.79-m elevation relative to land-levelling datum (Fig. 7). The west side of Milnerton will become vulnerable to direct wave action through the new mouth and may experience some erosion. If shore protection work is carried out and the breakthrough prevented, the long channel will reduce the tidal range within the vlei to approximately 0.95 m, or 66% of the open-water value. Note that the restrictive effects of bridges along the channel have not been considered.

In the event of a 1-in-50-year sea storm in conjunction with a 1-m rise in sea-level, the Swart technique[8] predicts Woodbridge Island will be eroded approximately another 25 m and the area to the south of the present river mouth will be eroded between 25 m and 30 m. This would allow direct wave action onto the Otto du Plessis Road embankment and railway. The coastline north of the Island will be eroded between 20 m and 25 m and the Island will be totally swamped by the storm surge. The Milnerton coastline up to 3-m elevation has the potential to be flooded by the storm surge (Fig. 8). The new river mouth will temporarily widen to around 500 m, further exposing the previously sheltered Milnerton coast to direct wave action. Should an extreme sea storm and river flood coincide, then flooding and associated damage would result in proportion to the storm's duration.

Although this example illustrates the type of changes that may occur in an inlet or estuary as a result of a 1-m rise in sea-level, it has not taken into account the coastal wetland ecology that will be affected by the change. The ecological impact will depend on future exploitation, which may or may not allow the ecosystem to migrate and develop naturally as water depths increase and new areas become wetlands. Estuaries and inlets are vulnerable to sea-level rise, so that careful planning at an early stage in the development of a location is essential to maintaining its ecological and aesthetic quality.

A national strategy for the amelioration of impacts of sea-level rise on the South African coastal environment should be developed, complete with the necessary legislative authority.

1. Barnet T.P. (1983). Recent changes in sea-level and their possible causes. *Climate Change* 5, 15.
2. Gornitz V., Lebedeff S. and Hansen J. (1982). Global sea-level trend in the past century. *Science* 215, 1611–1614.
3. Gornitz V. and Lebedeff S. (1987). Global sea-level changes in the past century. In *Sea-level Change and Coastal Evolution*, eds. O.M. Pilkey and J.D. Howard, Soc. Econ. Pal. and Min. Special Publ. 41, pp. 3–16.
4. Barnet T.P. (1984). The estimation of 'global' sea-level; a problem of uniqueness. *J. geophys. Res.* 89, 7980–7988.
5. Thomas R.M. (1987). Future sea-level rise. *Prog. Oceanogr.* 18, 23–40.
6. Hughes P. and Brundrit G.B. (1990). Impacts of the projected rise in sea-level on the False Bay coastline. Proc. False Bay Symp., Cape Town 1989. *Trans. R. Soc. S. Afr.* 45, 501–508.
7. Bruun P. (1962). Sea-level rise as a cause of shore erosion. *Proc. Am. Soc. civ. Engrs J.* Waterways Harbours Div. 88, 117–130.
8. Swart D.H. (1974). Offshore sediment transport and equilibrium beach profiles. *Delft Hydraulics Lab. Publ. No.* 131.
9. CSIR (1983). Assessment of Zonnekus Development, Milnerton. *CSIR Report* C/SEA 8373.
10. Woodborne M.W. (1983). Bathymetry, solid geology and quaternary sedimentology of Table Bay. Joint Geol. Surv./UCT Marine Geoscience Unit Tech. Report 14.
11. CSIR (1972). Effects of proposed harbour developments on the Table Bay coastline. V.I and II. *CSIR Report* ME 1086.
12. CSIR (1988). Estuaries of the Cape, Part II. Synopsis of available information on individual systems. Report No. 28. Rietvlei and Diep. *CSIR Res. Report* 427.
13. CSIR (1986). Woodbridge Island development: Coastal recession at Zonnekus Homestead. *CSIR Report* C/SEA 8601.
14. Shore Protection Manual. US Army Corps of Eng. CERC. 4-158 (1984).
15. Shore Protection Manual. US Army Corps of Eng. CERC. 4-162 (1984).
16. Jury M.R., Shillington F.A., Prestidge G. and Maxwell C.D. (1986). Meteorological and oceanographic aspects of a winter storm over the south-western Cape Province, South Africa. *S. Afr. J. Sci.* 82, 315–319.
17. Beaumont R.D. and Heydenrych P.J. (1980). The effects of development on the Diep River estuarine system near Cape Town. *SA Waterbulletin*, April, pp. 10–18.