**PG: Science supporting integrated spatial and development planning in complex urban coastal systems**

**Focus area 2: Resolving Coastal Biophysical Processes/Responses**

**Task 2.5 - Shoreline Modelling**

By Andre K Theron 18 January 2013

# Aim and Research Objectives

This research aims to contribute towards *developing innovative science-based models and methods for decision-making in coastal management within an African developing society context, focusing on CSDP in urban coastal systems.*This will be achieved through 2 focus areas. The research proposed within Focus Area 2 (FA2) aims *to harness scientific capabilities and innovative predictive technologies to resolve coastal biophysical processes/responses to multi-development scenarios at the strategic environmental assessment (SEA) or planning phases*. The challenge here lies in reducing the complexity inherent in coastal systems to a degree relevant to inform decision-making for multi-development, urban CSDP.

The objective of this specific sub-component of FA2 is resolving abiotic coastal processes/responses i.t.o. sediment processes/dynamics, addressing aspects such as available shoreline habitat and recreational beach amenity, which require quantification of beach morphology and shoreline evolution. Shoreline modelling was foreseen to be a means of bolstering understanding of the inshore sediment regime and a primary tool to quantify important parameters defining these aspects. The specific focus of this task is on shoreline (UNIBEST) modelling, defining set-up criteria for application in multi-development coastal planning evaluation, calibration and initial testing aimed at sufficiency for application in strategic, multi-development scenario testing in a case study with a selected suit of variables.

*Note, the NRE-Coast group lost major coastal biophysical processes/responses & modelling capacity during 2012, notably P de Wet, J Wilms & Dr H Diedericks. We mentored an M.Eng student (P-M Hugo U.Stell - covering some aspects under PG Task 2.5 at a different site); He was earmarked to continue with some of this research and applied for our NRE-Coast job advert, but unfortunately decided to join a private consulting engineering firm. Thus we experienced a major capacity constraint; no modeller was available to conduct specific aspects of the shoreline modelling planned under Task 2.5. However, we still managed to make good progress on some of the aspects (see PG progress report) and also achieved significant results i.t.o. other directly related & parallel research conducted in lieu (see PG progress report). New employee Christo Rautenbach (as of December 2012) could start to make further progress on aspects of the Durban shoreline modelling, as planned under Task 2.5…..*

# Prerequisite to Durban shoreline modelling – understanding the sediment regime

In the above discussion, the intention is stated to use the shoreline modelling tool to address the research objectives. However, in-house experience as well as subject knowledge as reflected in the literature, strongly argue that the numerical modelling is but a tool assisting in the resolution of abiotic coastal processes/responses i.t.o. sediment processes/dynamics and should not be the starting point of such studies. A prerequisite to any such modelling studies is to have a good understanding of the sediment regime (e.g. Kamphuis 20..). The modelling can then be used to test and improve the understanding and only then utilized to quantify certain abiotic shoreline/coastal process/response parameters of interest.

## Examples of development scenarios having significant major effects on coastal biophysical processes/responses

### Present understanding of Durban pier/groyne effects on shoreline morphology (especially the beaches):

The hydrodynamic & morphologic functioning of the Durban piers are actually due to the low-level rock groynes underneath the piers. Groynes create very complex current and wave patterns. The orientation, length, height, permeability, and spacing of the groynes determine, under given natural conditions, the actual effects on breaking wave conditions, local currents, sand transport and changes in the bottom configuration.

The direction of the incident waves is such that in many instances a weak longshore current, generally flowing towards the north, would be generated in the surf zone. The wave incidence angle would often generate currents parallel to the shore and flowing towards the groyne & past its head. However, a reversal of the general longshore current direction also occurs often, especially during strong easterly or north-easterly winds & waves. Adjacent to the northern side of the groyne, a wave generated counter-clockwise eddy current is generally found. The contributing factors to the formation of the counter-clockwise current could be described as follows: due to the wave shadow region on the leeward side of the groyne, the wave energy entering the constrained embayment between 2 groynes is reduced and a wave height gradient is induced in the wave shadow area. The wave height gradient generates (due to so-called radiation stress) a counter-clockwise eddy current in the wave shadow area of the groyne. This eddy current could be reinforced during times of waves approaching the beach more obliquely (more from the south).

Sand is normally transported along the shore to the north. Significant transport also takes place seawards of the head of the groyne, especially during storms. Most of the sand is transported in the surf zone. This sand moves alongshore towards the groyne. Once at the head of the groyne, wave action & local currents then transport some of this sand towards the shore. The rest of the sand transport carries on alongshore in the outer surf zone. In the lee of the groyne, the longshore transport direction is reversed. Some of the sand going round the tip of the groyne therefore ends up in the anti-clockwise current (eddy) formed in the embayment between 2 groynes. Another part of the sand arrives along the beach further along between the 2 groynes and is transported towards & around the second groyne.

The groyne acts as a partial (and non-permanent) trap for sediment moved by both north- and southbound longshore transport. The relatively persistent anti-clockwise current (eddy) brings some sand into the embayment between 2 groynes. The reduced wave energy and limited current velocity in the lee of the groyne cannot always transport all of the sediment out of the area, resulting in some of the deposition & sandbars being formed. Part of the deposition between 2 groynes is due to sand transport over the crest of the low-level rock fill in the groyne (especially during high tides), as well as transport to the leeward side by means of the eddy.

### Possible implementation of a FIXED BYPASS SCHEME

This was to have been implemented in 2009. Despite major components already having been constructed and the previous scheme having been dismanteled, it was belatedly decided not to go ahead with the planned scheme. Such a scheme may be well be mooted again in future. The CSIR/PRDW report (CSIR - PRDW (2000): Durban Bight Beach Study; Draft *Report* for NPA/DURBAN METRO COUNCIL) indicated a predicted increase in average beach width of 65 m on the southern beaches and 50 m on the northern beaches (i.e. north of Somtseu Road). With a variability and prediction accuracy of ±20 m, the predicted worst case is about 85m, while historical data indicated an increase of as much as 70 m to 100 m for a perhaps comparative situation. Below are most of the *possible* impacts (not only due to beach accretion) that are foreseen:

**Potential impacts:**

* The new beach may be much too wide (existing width + up to say 85 m accretion). Wind-blown sand problems are likely (maintenance is already required in some areas of the Bight). A mathematical “shoreline” model may be suitable to determine the need for and effects of different nourishment strategies.
* A wide expanse of hot sand (in summer) may require walkways/paths over the beach (as, for example, in Spain) with the associated maintenance and other problems.
* The present system of sandbars and gullies/troughs near the piers result in relatively good surfing waves and entry "rip" currents. These features may be reduced significantly, resulting in a relatively smoother bottom, which would obviously not be conducive to good surfing.
* The present piers may lose some/much of their appeal to anglers and strollers, due to their being less "out in the sea".
* Over the past three decades large volumes of sand have regularly been placed on (and near) the mound (in the order of 150 000 m3/year). If this is stopped, the mound may eventually reduce in height, with unpredicted results on the shoreline (for example due to increased wave energy). The evolution of the mound as well as the effects this may have on currents and waves and therefore on the shoreline can be modelled to determine if this is a significant impact. Some dredging of the harbour will still be required and perhaps virtually all of this material could be placed on the mound (the available amount of suitable material also needs to be quantified). Alternatively, the shoreline itself could be protected if need be.
* Sedimentation in the vicinity of Vetch's Pier may increase with detrimental effects on the marine life/ecology.
* The Mgeni Mouth may close more and remain closed for longer. More silt may enter the estuary or salinity may change significantly, perhaps requiring more maintenance/intervention or detrimental effects to the mangroves, biota, etc.
* Existing storm-water outfalls will terminate relatively higher up the beach/not as far into the sea. An outfall that terminates above the high-water mark may result in the outfall being blocked (more frequently) by sand and/or the formation of stagnant pools of dirty/unhygienic water on the upper beach. In any case, the outfalls would be relatively shorter where dispersive wave action is less effective, perhaps leading to water quality problems or sand build-up if the outfall has a high sediment load. Similarly, water intakes (such as for the aquarium) may become blocked (more often).
* Undesirable material (perhaps even large amounts thereof) may end up on the beach if all material drawn into the intakes of the jet pumps is fed directly to the beach. This may include stones/boulders, rubble, branches, garbage and silty or muddy material. It is believed that at present large amounts of such material (also dredged from Cave Rock Bight) are either dumped out at sea or removed at the hopper.
* The increased volumes of material (and perhaps more stones/boulders) transported through the system may result in significantly increased wear of the pipelines and booster pumps, requiring increased maintenance and earlier replacement (to whose account?).
* As the beach accretes, the outlets of the existing bypassing scheme may have to be extended towards the sea to prevent the material from being placed out of reach of the spreading and transporting action of the waves.
* To place more material further along the Bight may require expansion of the present system (pipelines, motors and pumps). (Also increased energy/electricity requirements.

## Measurements and theoretical methods to determine sediment transports along the Durban Bluff

(for amount of sand available to feed into the Bight shoreline or amount to be bypassed at proposed new (“digout/2nd”) port etc.)

### 1 General

Most of the methods that have been used to “measure” sediment transport rates, can be summarised as follows (e.g. Theron, 2004 and several other references):

* Sedimentation (/erosion) from bathymetric surveys and dredging records
* Accretion against a breakwater or groyne
* Accretion plus bypassing
* Erosion downdrift of a barrier
* Growth of a spit
* Sediment concentration and current measurements
* Sediment tracers (usually radio-active or fluorescent)
* Sediment samplers
* Many kinds of mobile sediment traps

Transport rates can also be calculated with theoretical or empirical formulae and computer models. This sometimes enables a comparison of the “actual” and theoretically calculated rates and subsequent calibration of theoretical methods.

*In the following section, a brief discussion is given of some of these measurements and calculation methods to determine components of the sediment transport regime.*

### 2 Brief description and evaluation of the above “measurement methods” to determine sediment transports along the Bluff

***Sedimentation rates from bathymetric surveys and dredging records***

Seafloor contour maps can be analysed to identify changes in bottom topography, areas of sediment deposition or erosion and volume changes. Consecutive surveys should be selected between which no or very limited dredging took place, as changes due to dredging will then not distort the observed changes resulting from natural processes. Difference maps can be produced that show changes in vertical elevation between consecutive surveys as well as volume changes per unit area. Consistent deposition/infilling patterns and directions can show from which directions sediment is transported into these areas, and can also provide good information on the magnitude of these transports.

Based on the basic principle, that sediment transport in an area must ultimately be balanced, deductions about sediment transport can also be made by analysing dredging records. If there is no long-term net erosion or build-up of the sea-floor in an area, the amount of sediment moving into the area must be approximately equal to the amount of sediment dredged from this area (plus the amounts possibly moving out of that area). Sediment can relatively easily move into areas that are significantly deeper than the adjacent sea-bed (especially so-called “sand traps” and “dredge pits”), but cannot easily move through or out of these areas. By implication therefore, the average sediment transport rate to each of these areas must approximate the average long-term dredging rate from each of these areas.

Thus, the Durban Port sand trap dredging records can be utilised to derive estimates of the mean annual sediment transport rates into the trap area. This can be further interpreted to give estimates of the Bluff alongshore transport rate, which estimates could be improved by interpreting repeat bathymetric surveys of the area and entrance channel dredging records.

***Longshore transport rates calculated from shoreline evolution***

If the longshore sediment transport is interrupted by an obstruction such as a groyne or a breakwater, accretion will occur on the updrift side and erosion on the downdrift side. The latter is due to the fact that the sand that previously fed the downdrift beach is trapped and thereby prevented from reaching the downdrift beach. Harbour breakwaters sometimes function as effective (nearly total) sediment traps. By calculating the measured beach accretion over time against such a breakwater (and taking account of the aeolian transport if relevant in this area), the actual longshore transport in this area can also be determined.

***Accretion against a temporary groyne***

The basis of this method is the same as described in the foregoing paragraph, and entails measuring and calculating the accretion plus bypassing adjacent to a temporary groyne. In essence, it entails measuring beach profiles (including sub-tidal area) in detail (and/or Lidar/scanner topographic survey), then constructing a temporary groyne and measuring the build-up of sand on the updrift (southern) side (as CSIR did in False Bay; Theron & Schoonees, 1999).

This method has the advantage of being an “integrative” longer term type of measurement. A disadvantage is that the length of the temporary groyne will be insufficient to span the entire surf zone under all conditions, and thus that the portion of the longshore transport that bypasses the groyne has to be estimated by mean of calculations. Another disadvantage is that the groyne construction, although temporary, would need some form of authorisation. Weather permission could be obtained under scientific field research, or under a “limited EIA scoping type agreement” is uncertain.

***Other longer term / “integrative” methods***

The other usual longer term / “integrative” methods, namely erosion downdrift of a barrier, and growth of a spit, are not viable in this case, as such morphologic features do not occur along the Bluff.

***Sediment load calculated from concentration and current measurements***

If simultaneous measurements of sediment concentration (by e.g. OBS) and current velocities (by e.g. ADCP) are available in an area, the sediment transport rate can be directly calculated. General relationships between concentration and depth, as well as between current velocities and depth can be determined from the measurements. The product of the sediment concentrations and current velocities is integrated over depth, which gives the suspended sediment load. (In a few instances the sediment load (both concentration & current flow) has been derived from one instrument e.g. calibrated ADCP, but this appears to remain a difficult highly technical research type methodology.) Unfortunately, bedload measurements are usually not available, as it is extremely difficult to obtain such measurements in practise. Thus, theoretical relationships between the bedload and the suspended load are used to compute the bedload from the calculated suspended load. The total load is then simply the sum of the suspended and bedloads, and is usually converted to a sediment transport rate.

This method could well be applied to derive shorter term sediment transport rates outside of the surf zone along the Durban Bluff. However, due to the extreme turbulence and aeration within the surf zone as well as the practical difficulties of installing, maintaining & extracting equipment in/from the surf-zone (amongst other significant problems), this is considered to be a virtually unsuitable method to determine the longshore transport rate along the Bluff.

***Other “instantaneous / short-term” or “detailed/spot” methods***

These are mainly: sediment tracers (usually radio-active or fluorescent), sediment samplers (e.g. vacuum pump) and many kinds of mobile sediment traps (e.g. streamer traps). However, these are all very difficult to accurately and practically apply within the surf zone. Provided that large enough quantities of appropriate sediment tracers can be discharged into the surf zone and that a sufficiently high recovery/sampling rate is achieved, tracers can give a relatively good indication of sediment transport rate.

*While Sections 1 & 2 addressed field measurement/recording methods, Section 3 gives a brief discussion of numerical/mathematical (“theoretical”) methods to calculate or model the sediment transports.*

### 3 Main theoretical methods employed to determine sediment transports

***Theoretically determined longshore transport***

The longshore (wave induced) sediment transport rate is a notoriously difficult physical parameter to determine accurately. Even the best theoretical methods and the most accurately measured field data have an accuracy of ± 50% or poorer (Schoonees and Theron, 1993). Numerous means are available to theoretically determine the longshore sediment transport rate (e.g. Horikawa, 1988, Schoonees and Theron, 1994 and Swart and Fleming, 1980, Tomasicchio *et al* 2012). If at all possible, the transport rates computed in the study area should be compared with transport rates measured nearby; for example, accretion at an adjacent harbour (as proposed by CERC, 1984). However, if no data are available with which to calibrate these theoretical methods, confidence in the results is significantly reduced. In this case practitioners *may* be considered fortunate (perhaps sometimes even arrogant) to claim accuracies of factor 2.

Longshore transport rates are usually determined as follows:

A wave refraction study of the particular study area is conducted in order to calculate the nearshore wave climate. This climate is then used to compute the longshore transport for each wave condition at a specific location in the study area. The waves can cause either up- or downcoast longshore transport. By adding up all the transport rates caused by the different wave conditions in the upcoast direction, the total upcoast longshore transport rate is obtained. The total downcoast transport rate is determined in a similar way. The gross longshore transport rate is then determined by adding the upcoast and downcoast rates, while the net rate is equal to the difference between the upcoast and downcoast rates.

Although the theoretical basis of sediment transport formulae vary significantly, many such formulae express the sediment transport rate as a function of some or all of the following parameters: wave height, direction and period; the density and dynamic viscosity of the water; profile characteristics such as the slope; and the sediment density and diameter (e.g. Kamphuis, 2002).

***Mathematical sediment transport modelling***

One alternative theoretical method of determining the sediment transports is to utilize a hydrodynamic model. By linking a sediment transport model to the simulations of the current regime, the potential transport rates can be determined. Such relatively simple modelling does not have an interactive coupling between the calculation of currents, sediment transport rates and the resulting bed level changes. In fact, the calculated transport rates are the final model output, and the sediment mass balance (and associated bed level changes) is not determined.

A more sophisticated approach is to apply a full morphological model to simulate sediment transports and morphological changes. This entails the numerical modelling of the hydrodynamics, sediment dynamics and morphological changes due to the sediment fluxes induced by waves and currents. Such models provide an interactive coupling between the calculation of waves, currents, sediment transport rates and the resulting bed level changes. The driving forces for the model are the offshore waves and currents.

Despite such comprehensive modelling exercises, the accuracy of such simulated transport rates is probably not much better than factor 2. However, if combined with good sand trap and entrance channel dredging records, and repeat bathymetric surveys of the area, a better understanding and quantification of the sediment transport and accretion/erosion patterns in and off Cave Rock Bight could be obtained. The numerical modelling could then be calibrated to some degree, which should enable improved estimates of the Bluff alongshore transport rate.

**4 Draft preliminary conclusion**

Based on the above it seems that the better options for measuring/determining the longshore sediment transport rate along the Bluff are: sedimentation rates from dredging records and bathymetric surveys; possibly accretion against a temporary groyne; possibly sediment tracer field experiments; and mathematical sediment transport modelling. Issues that all need to be considered in choosing the option(s) to follow include (in no particular order):

* time and cost constraints,
* availability of instrumentation,
* authorisation,
* site access,
* ease of deployment, measurements & retrieval
* technical difficulty of methodology,
* capacity (& expertise) of investigators, and importantly
* accuracy, relevance and robustness of “answers” required.

REFERENCES

*Theron, A K (2004). Sediment Transport Regime at East London. M.Eng Thesis. University of Stellenbosch. pp 192.*