APPLICATION OF A PARAMETRIC LONG TERM MODEL CONCEPT TO THE DELRAY BEACH NOURISHMENT PROGRAM

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ABSTRACT: At scales larger than those where processes are well understood (≥ years), it is difficult to set up traditional process-based models. However, there is a growing demand for predictions of shoreline behaviour at these longer timescales, particularly for beach nourishment. Therefore, we are developing a framework based on parametric (*behaviour-oriented*) modelling which may be applied to areas where limited observations are available. With the present paper we examine the application of our concepts to a real world case, viz. the beach response at Delray Beach, Florida, to nourishment over a 20 year period. The problems of dealing with profile data are considered. The simple diffusion-based model we utilize cannot reproduce non-uniform behaviour. However if beach volume above a reference contour is considered, the model works well and predicts the erosive losses between renourishments quite effectively. Further improvements and application of the model is considered.

INTRODUCTION

Shore nourishment is increasingly being applied as a method of erosion control as it maintains a wide beach, providing both coastal protection and recreation. Of

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course, sand placed in this manner along a uniform sandy beach can be viewed as a perturbation which tends to be smoothed out by long-shore transport and modified by cross-shore transport. Models of this longshore smoothing phenomenon on the medium and long term range (scales of years to decades) are usually *diffusion-type* models which are able to take into account the long-shore evolution. For coastal management applications and for realistic evaluation of nourishment performance, the cross-shore evolution is also of prime interest. As an example, the study of (Lippman & Holman, 1990) underlines the importance of cross-shore processes for the coastal response to hydrodynamic forces. Practical questions related to nourishment are:

- How much sand has to be placed and where?
- What will the directions of transport be?
- How will be the beach affected?
- How will the Nourishment affect the behaviour of the beach in time?
- When will it be necessary to renourish?

In order to quantify project benefits and the cost of restoration it is also important to define the speed of response of profile nourishments. Erosion of the nourished volume can be described by the sum of a linear and an exponential term (Verhagen, 1992). Present design methods for nourishments are simple and reliable enough for many applications and no complex models are in principle required for this purpose. The disadvantage is that time history of beach profile data need to be available. Unfortunately sufficient experimental data are not always available and, in order to assess something about the distribution of nourishment across the profile and to possibly have some quantitative evaluation of beach erosion when cross-shore processes are important, it is necessary to use models for the evaluation of cross-shore evolution. Examples of optimum beach fill design cross-section through the use of a numerical model to simulate storm induced beach changes are given by (Hansen & Byrnes, 1991).

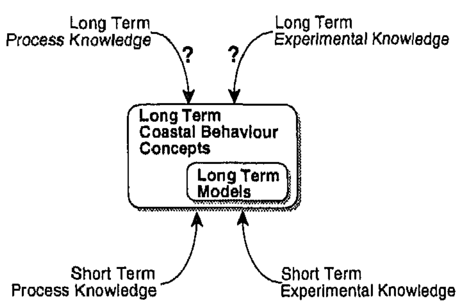

Figure 1. Approach for the development of long term models.

(Larson & Kraus, 1993) examine calculation procedures for the cross-shore transport rate at different scales. However, at scales larger than existing detailed process understanding (≥ years) it is difficult to set up traditional process-based models. Therefore, we are working to obtain a framework, based on some parametric (*behaviour-oriented*) modelling tools, that may be applied in a context where little experimental information (especially historical data) is available, with the aid of validated short term process-based models (Capobianco et al., 1993). The idea is to link the available quantitative knowledge about short term processes with the available qualitative knowledge about long term processes (Figure 1). In the application to the evaluation of nourishment performance, they should be able to reproduce both static conditions and give an assessment of the transitions between different static conditions.

DELRAY BEACH

First we tested the validity of our concept for a hypothetical test case against a detailed process-based model used with real-life input (Stive et al., 1992; De Vriend et al., 1993). The idea was to generate extensive sets of reference profile evolution data to be reproduced by the parametric model. With the present paper we examine the application of our concepts to a real world case, thus making a further step toward the development of a practical and usable tool.

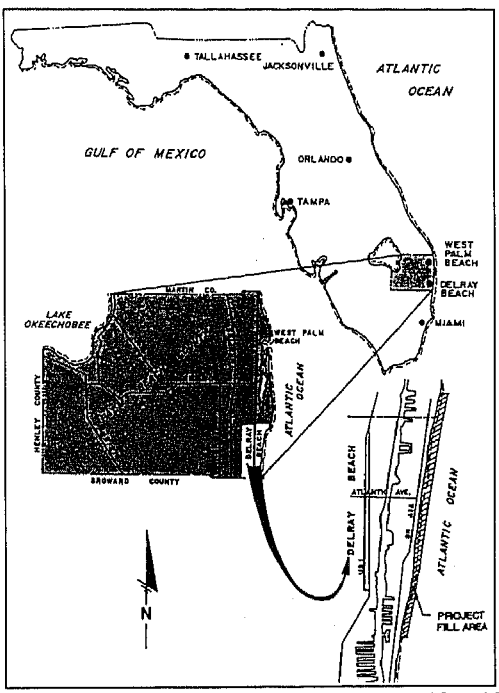

Figure 2. Delray Beach, location map (from Beachler, 1993)

We consider the beach response to the 20-year renourishment program performed at the City of Delray Beach, Florida (Figure 2). A description of the nourishment program can be found in (Beachler, 1993); we briefly review some basic information. The first beach nourishment was put into place in 1973. A total of about 1.250.000 cubic meters of sand were placed along 4.350 meters of shoreline. In 1978 the beach was renourished by placing 550.000 cubic meters of sand along 2.700 meters fronting public beach areas. In 1984 a second renourishment was carried out and placed approximately 1 million cubic meters of sand along the original 4.350 meters of shoreline.

As part of the monitoring program, beach profile surveys have been conducted from a point landward of the dune seaward to beyond the 18-feet (5.5-meters) depth contour. Volumetric information concerning the evolution of the nourishment has been derived from these data (Beachler, 1993; see Figure 3). More detailed data are available concerning the second periodic nourishment (post-1984). This consists of the evolution of 16 profiles from plus 10 to 15 feet to minus 20 to 30 feet. The 16 profiles are labelled from R175, corresponding to the north limit, and R190, corresponding to the south limit.

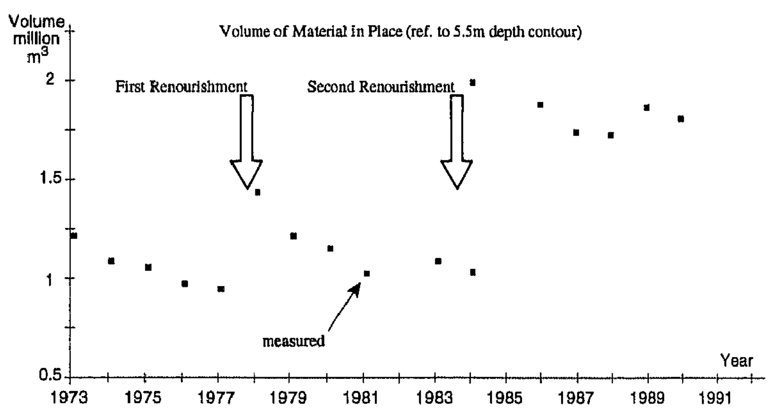

Figure 3. Volume of material in place.

The details of the beach profiles are not presented here, however we review some qualitative aspects of them. Shoreline positions indicate that there are some effects of longshore spreading at the site. However, it seems reasonable to assume that the central beach section is dominated by cross-shore processes. The profiles in the central part of the nourished area all show the following behaviour:

- a tendency of the upper subaerial beach to accrete (the only exception being the last year),
- a general tendency of the shoreline to erode,
- a general tendency of the upper subacqueous profile to erode,

- a systematic accretion of the middle part of the profile,
- a generally erosive tendency interrupted by occasional accretive periods such as in 1989 (also visible in Figure 3).

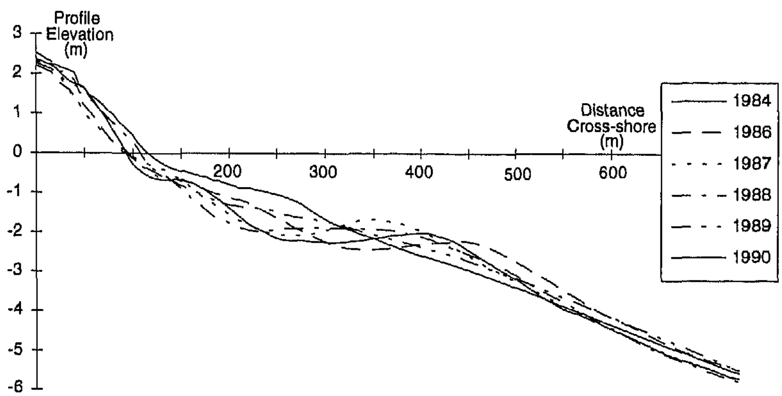

Figure 4. Mean Profiles (R179-R186)

Figure 4 shows the evolution in time of the averaged central part of the nourished area (which we intended to model). It is still possible to note the general erosive tendency and the tendency to form a bar in the upper part of the profile. Unfortunately the possibility to compare with the pre-nourishment profile is missing.

APPLICATION OF A DIFFUSION-TYPE MODEL

Formulation

Using this set of profile data we explored the application of our diffusion-type formulation for a behaviour oriented model of coastal profile evolution. The reference scheme is defined in Figure 5.

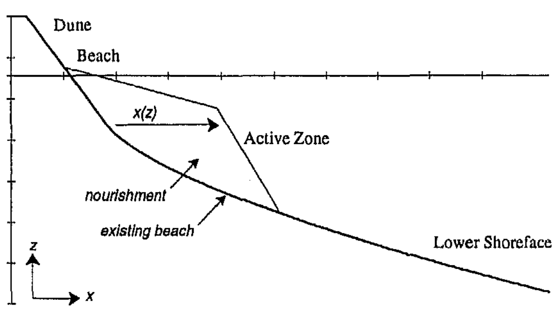

Figure 5 - Schematics of the Beach Nourishment

With appropriate initial and boundary conditions the *displacement of the cross-shore position with respect to the initial profile (x)* can be described as a function of *profile depth (z):*

$$\frac{\partial x}{\partial t} = \frac{\partial}{\partial z}(D(z)\frac{\partial x}{\partial z}) + S(t, x, z)$$

The formulation is an extension of the n-line model with an infinite number of contour lines. S(t,x,z) is an external source function. In our application we use S(t,z) as a function of time and depth (thus we use the linear formulation of the model) to reproduce in a simple way the nourishment and the subsequent renourishments.

D(z) is a depth dependent *diffusion coefficient.* The spatial variation of the diffusion coefficient allows us to represent the variation of morphological timescale with position across the profile. The idea is to summarise all the information about the typical site climate, the sand characteristics and the degree of activity of the various profile zones into a single parameter: D(z). The calibration of this parameter is the key element of the model definition: all information, on hydraulic and sediment characteristics as well as on shorter-term dynamics is stored in it. The long-term objective of this work is to be able to directly express the parameters that give shape and value to D(z) as functions of mean environmental parameters (wave input and water level variations) and geometric characteristics of the profile.

A practical limitation to the approach is represented by the choice of a stationary diffusion term (and resulting transport) in the formulation. What we may expect in terms of output is a sort of "mean evolution" for the modelled period; in other words the model as such can only reproduce constantly accreting or constantly eroding situations. The stationarity also has strong implications on the behaviour of the solution and, in the ultimate analysis, on the character of the profile evolution that has to be reproduced. The evolution in the diffusion model is in fact influenced by the way we compare the profiles (modelled and measured ones), viz. raw data or "filtered/weighted" data. The implicit assumption is that the prevailing wave energy or the wave climate is approximately constant over time, so that a constant erosion rate is a meaningful representation of the actual profile behaviour.

When averaged over the shorter time scales, the upper part of the profile tends to maintain its shape as the coast progrades or retreats. At the upper end of the profile, the invariance of the profile shape is reflected in the model by the boundary condition $\partial x / \partial z = 0$, while at the lower end of the profile, the fixed position of the shoreface root implies that x = 0. This is the critical condition for the overall sediment balance. If the diffusion coefficient is not zero at that point, then we allow for sediment to move (out of the domain). In such a case we need to quantify this movement in order to balance it with the flux of sediment going out of the domain in the real world situation.

Practical Problems

The first problem using the profile data was the lack of pre-nourishment profiles or of a description of the spatial distribution of the nourishment. This was solved empirically by assuming an equilibrium reference profile. Then we conducted an exploratory calibration of D(z) against the available profile data (1984-1990).

The available set of data is far from having the ideal characteristics that we require for the application of our model as it is currently formulated. In order to briefly show the reasons, in Figures 6 to 9 we present some Empirical Orthogonal Functions (EOF) analysis of the data set, a technique which we also normally use for comparison with the model results. Figures 6 and 7 show the comparison of the first two eigenfunctions (both in cross-shore and longshore directions) for 1984 and 1990; they register the situation of the nourished area in the two periods.

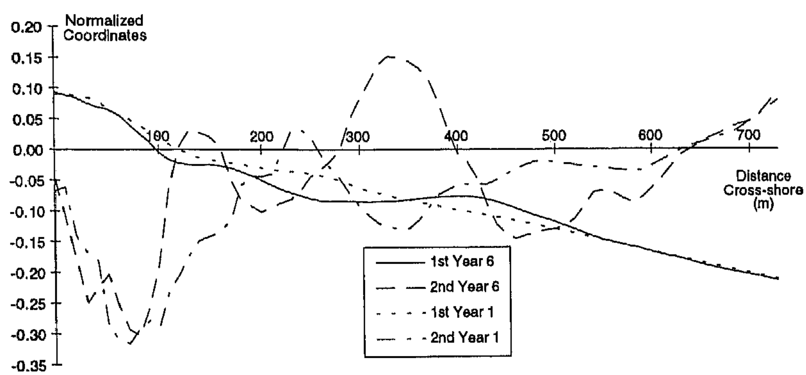

Figure 6. Cross-shore Eigenfunctions 1984 (Year 1) and 1990 (Year 6).

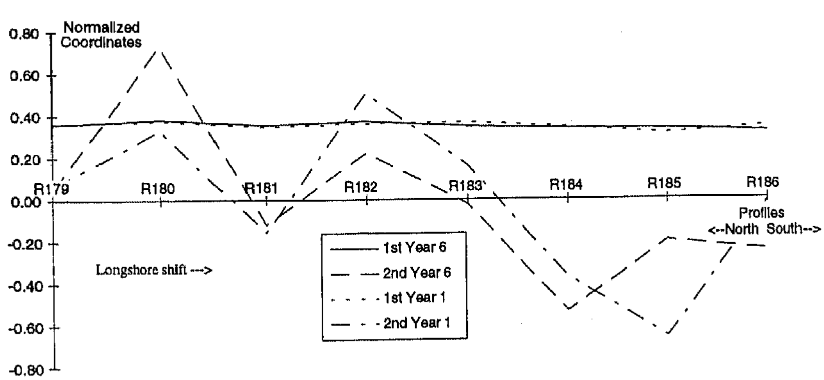

Figure 7. Longshore Eigenfunctions 1984 (Year 1) and 1990 (Year 6).

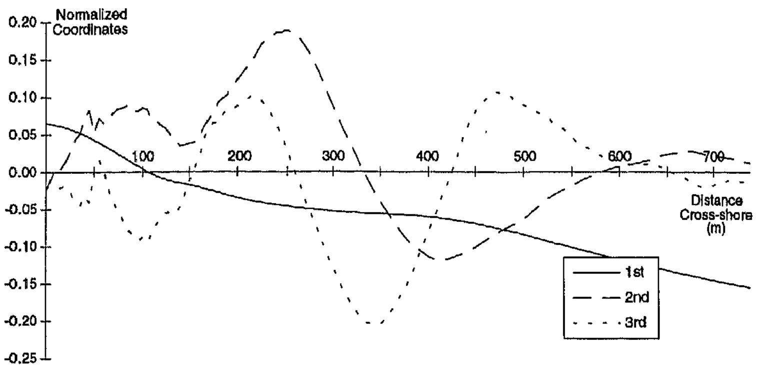

Figure 8. Cross-shore Eigenfunctions (Mean Profiles R179-R186).

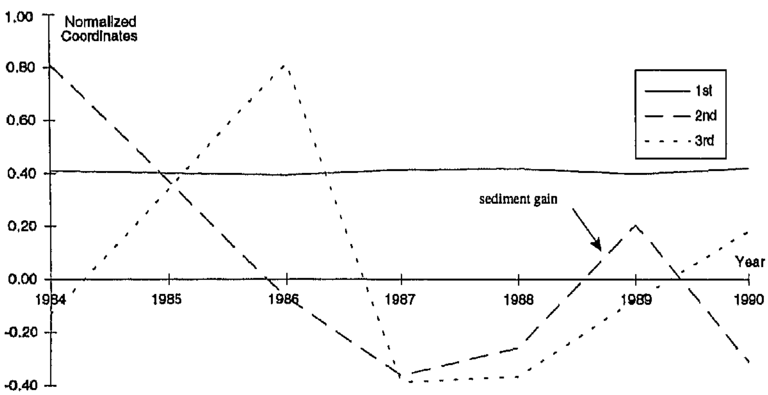

Figure 9. Temporal Eigenfunctions (Mean Profiles R179-R186).

Figure 8 and 9 show the EOF analysis (first three eigenfunctions) for the evolution of the average profile, which is what we try to reproduce with our model. Apart from the third temporal eigenfunction which shows a modification in the structure of bars along the profile, the second temporal eigenfunction clearly shows the volume gain of the 1989 survey.

The non uniform behaviour in time together with the occurrence of bars in the profile did not allow for a satisfactory result of the model calibration. One way to deal with the bars is to apply a spatial "filter" which removes the smaller-scale features, for example by considering only the first empirical eigenfunctions of the profile, rather than the actual shape. However this does not solve the fact that the model in its current formulation is intrinsically unable to reproduce non-uniform behaviour.

Application to Volume Data

We then decided to reduce our objectives to a more reasonable goal, thus considering as a way to calibrate the scale of the diffusion coefficient and to verify the model, the total sand volume between the dune crest and the reference 18 feet (5.5 m) depth contour. At Delray Beach, the total volume (and the sediment supply) is known as a function of time between 1973 and 1990. We might look at the volumetric data as an extreme synthesis of the profile data to be used to compare model results and field data. Figure 11 shows a comparison of the time evolution of the measured volume of sand and the model results with the maximum value of the diffusion coefficient calibrated at 1 m^2/day (Figure 10).

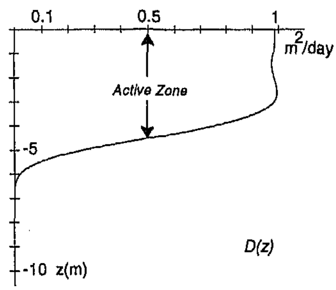

Figure 10. Applied shape of diffusion coefficient.

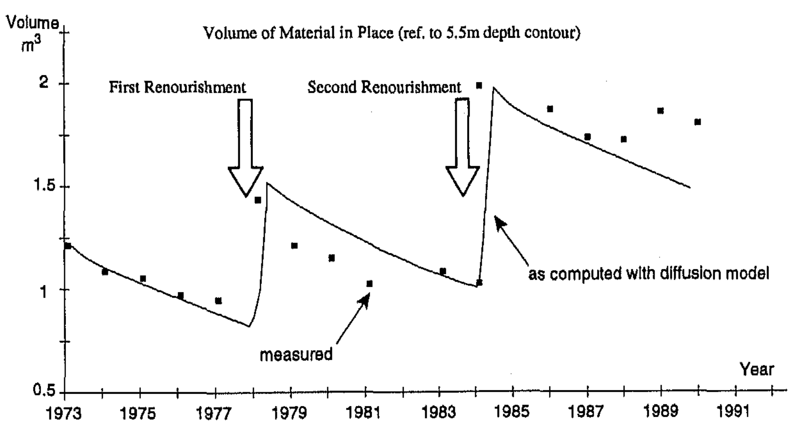

Figure 11. Evolution of the Volume of Material in Place (measured vs. computed)

The supply of sediment due to nourishment and renourishment is known. The influence of a sea-level rise is also considered in the model by using a time varying transformation of the z-domain. Together with possible longshore losses, wind losses and volumetric losses due to sink, these have been quantified in a *equivalent sea-level rise* of about 2 mm/year. This is the average value of sea-level rise for the Atlantic coast of Florida from 1950 to 1986 (Lyles et al., 1988).

Given the scatter of the basic data, the result is rather satisfactory, in that the rate of erosion is approximately correct whenever the coast is losing sand. In agreement with the observation of (Verhagen, 1992), such erosion is basically the sum of a linear and a non-linear (exponential) term, at least in the initial response to each renourishment (also see Kriebel & Dean, 1993). While the model used here fails to reproduce accretion, such events might be seen as perturbations around the long-term trend. Further, we model the evolution of the mean profile quite well and in future work we will investigate how well the shoreline displacements are reproduced.

CONCLUSION

The diffusion-type profile evolution model, when run as an initial value problem, is basically restricted to monotonous behaviour in time, i.e. either erosion or accretion. In the case of shore nourishment, this basic behaviour is erosion. Assuming that the nourishment has no influence on the long-term natural behaviour of the coast, which means that the erosion rate before the nourishment equals the erosion rate after the nourishment, we should be able to consider the diffusion coefficient to be only dependent on the reference (say equilibrium) profile and on extrinsic conditions (wave climate).

Although in every new application there is much to be calibrated about the model (in its present formulation and with the present knowledge), the verification of the total sand volume evolution at Delray Beach gives promising results. Once the total volume evolution is correct, the consideration of the mean profile evolution, which is directly reproduced by the model, is a logical next step. The concept seems to offer good perspectives in the long-term, assumed that it could be able:

- to take into account information about the wave climate, like that available from CERC (1993),
- to help in design and operate nourishments when limited profile data is available,
- to include the extra supply or extraction of sand to take into account possible losses,
- to investigate the effects of placement location and timing of nourishment.

In particular, with reference to the first point, we expect to be able to define correlations between maximum values and shape of the diffusion coefficient and the wave climate. Further availability of beach profile surveys and wave and water level information will provide the necessary basis to make the next step in the model development and to test beach fill design alternatives.

ACKNOWLEDGEMENTS

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