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The development of a tool for examining the morphological evolution of managed realignment sites

Jeremy Spearman *

HR Wallingford Ltd., Coast & Estuaries Group, Howbery Park, Wallingford, Oxon, UK

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ABSTRACT

This paper describes the development of a model for prediction of local changes in morphodynamics resulting from managed realignment, undertaken as part of a UK project funded by Defra. The methodology builds on the conceptual modelling approach to habitat development employed successfully by Di Silvio (1989, 1998), Di Silvio and Gambolati (1990) and others for lagoon environments. The overall approach can be described as hybrid – combining bottom-up (process-based) and top-down (simplified and/or empirical) predictive techniques – to describe the essential inlet functioning.

The model described in this paper is used to predict the evolution of a managed realignment site under the action of tides and waves and sediment supply. Validation of the managed realignment model is undertaken using the available survey data from before the realignment and from several years afterwards. The performance of the model is promising in this respect, producing the right magnitude and the main qualitative features of bathymetric change. Longer simulations are used to see how the growth of saltmarsh itself affects the evolution of the setback field and how sea level rise would affect the development of saltmarsh.

1. Introduction

When considering flood risk and coastal protection issues, estuary management must take account of the effects of sea level rise and of the implemented flooding and coastal protection measures on important estuarine habitats. In estuaries, the important habitats tend to be areas of mudflat and saltmarsh which are usually designated because they provide important habitat for bird populations but also, potentially because they contain important individual species of flora or fauna.

The main instrument that is deployed to mitigate the impact of sea level rise on habitat in the UK (and commonly used elsewhere) is managed realignment. This generally involves the deliberate breaching of an existing sea wall to allow tidal waters to flow onto the land behind the breach (often termed as the setback field), although it can also be achieved (albeit over a longer time frame) by allowing sea defences to degrade over time and breach naturally. The land, which is often agricultural in origin, will then, if well designed, turn over a period of years into an intertidal habitat with mudflat and saltmarsh.

The tools available for resolving the issues particularly relating to the evolution of habitats created by managed realignment are not well developed, partly because of the site-specific complexity of these systems and the significant roles of tides, waves, sediment, vegetation and biology at small spatial and temporal scales. However, by adapting models which have been used in other related systems, real progress could be made towards provision of a tool which can be used to inform management decisions.

This paper describes the development of a model for prediction of local changes in morphodynamics resulting from managed realignment. The methodology builds on the conceptual modelling approach to habitat development employed successfully by Di Silvio (1989, 1998), Di Silvio and Gambolati (1990) and Dal Monte and Di Silvio (2004) and others for lagoon environments. The overall approach can be described as hybrid – combining bottom-up (process-based) and top-down (simplified and/or empirical) predictive techniques – to describe the essential inlet functioning.

One of the important aspects to solve this is that by definition a managed realignment site is a "virgin" terrestrial site with no representative hydraulic, sedimentological, vegetative or biological functioning upon which any prediction can be based. The method must, therefore, be viable in predicting *a priori*, and at least qualitatively, what will occur following breaching.

2. Di Silvio's approach

Di Silvio (1998) created a hybrid sediment transport model characterised by:

- time averaged flow and concentration;
- simplified erosion/deposition equation based on the concept of an equilibrium concentration;
- equilibrium concentration based on empirical formulae.

* Tel.: +44 0 1491 822462.
E-mail address: jez@hrwallingford.co.uk

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If T_x and T_y are the sediment flux then the net erosion/deposition, E, at any point is given by,

$$\frac{\partial T_x}{\partial x}+\frac{\partial T_y}{\partial y}=E \tag{1}$$

where $T_x=h(CU_x-D_x(\partial C/\partial x))$ and $T_y=h(CU_y-D_y(\partial C/\partial y))$ and where h is the water depth, C is the suspended sediment concentration, U_x and U_y are the components of the current speed in the x and y directions and D_x and D_y are the dispersion coefficients relating to the x and y directions. Eq. (1) assumes that conditions are virtually steady-state which is a reasonable assumption as long as the rate of change of suspended sediment concentration and the second derivatives $(\partial^2 C/\partial x^2)$ and $(\partial^2 C/\partial y^2)$ are small.

The erosion/deposition rate, E, is given by the first order approximation (e.g. Gallappatti and Vreugdenhil, 1985),

$$E=w(C_E\text{-}C) \tag{2}$$

where C is the concentration, C_E is the equilibrium concentration and w is the rate parameter governing exchange with the bed of the same order as the settling velocity, dependent on grain size and the local tidal velocity.

As well as Eqs. (1) and (2) Di Silvio's model consisted of another equation relating the observed deposition/erosion to changes in bed level,

$$\frac{dh}{dt}=\frac{w}{\rho_{dry}}(C_E-C)+\alpha_e+\alpha_s \tag{3}$$

where ρ_{dry} is the dry density of the sediment bed and where α_e and α_s relate to sea level rise and land subsidence.

To estimate the values of the equilibrium concentration, Di Silvio separated areas within the model into "channel" elements and shallow subtidal or intertidal elements, which he termed "shoal" areas. Di Silvio reasoned that, since sediment transport within channels is principally a function of current speed, it scales as $S\sim u^n$ (where $4<n<6$). Further, since current speed scales inversely with depth (for a given discharge), the equilibrium concentration for a given current speed scales as $C_E=f_c/h^5$. For shoal areas, he reasoned that sediment transport is principally a function of wave action, which varies inversely with water depth (for a given wave height), and hence he chose the simple relationship $C_E=f_s/h_{HW}$ for shoals and intertidal areas (h_{HW} being the water depth over the shoal at high water and f_c and f_s being constants). In later papers (e.g. Dal Monte and Di Silvio, 2004), these formulae were refined to give a better representation of wave effects.

The approach of Di Silvio represents a basic approach which offers great promise for application to the prediction of morphological evolution of managed realignment schemes. In particular, the simplified time-averaged erosion/deposition model of Gallappatti and Vreugdenhil (1985) affords a great reduction in model complexity (and, therefore, run time) without sacrificing too much in the way of realistic processes. However, this type of model requires a considerable amount of data from existing estuary systems to evaluate the parameters needed for the relationships defining equilibrium concentration. Managed realignment is by definition concerned with a virgin terrestrial system where there is no information available *a priori*. A different approach is, therefore, required to establish these relationships. In this paper, this problem is solved by using a process-based approach.

The use of equilibrium-based hybrid approaches has been used by other researchers in estuary environments. The ASMITA (Stive et al., 1998) and ESTMORF (Wang et al., 1998) models are 1D or *quasi*-2D hybrid estuary models (although the term "behavioural model" is sometimes used to describe these models in the literature) incorporating the morphological development of channels and flats, both using the equilibrium approach (Eq. (2)) as a basis for erosion/deposition in muddy and sandy conditions. The approach proposed in this paper makes use of the 2D approach of Di Silvio and combines it with the insights that have come from the *quasi*-2D behavioural models.

In the UK, the use of managed realignment is principally (but not exclusively) associated with the development of mud and saltmarsh habitat. For this reason, the model outlined in this paper is developed with muddy cohesive sediment in mind.

3. Description of the model

3.1. Overall structure

The model structure (See Fig. 1) consists of a flow model, TELEMAC-2D, (LNHE, 2001) a wave model, a routine which derives the important morphological parameter of equilibrium concentrations and the time-averaged dispersion characteristics and a "Di Silvio-type" sediment transport model based on SUBIEF-2D (LNHE, 2000). However, within this model the calculation of erosion and deposition were changed from the normal formulations of Krone (1962) and Partheniades (1965) to the simplified equilibrium equation (attributed here to Gallappatti and Vreugdenhil, 1985) given in Eq. (2). It should be noted also that the SUBIEF-2D model, when modified in this manner, solves the full 2D advection dispersion equation,

$$\frac{\partial C}{\partial t}+U_x\frac{\partial C}{\partial x}+U_y\frac{\partial C}{\partial y}-\frac{1}{h}\left[\frac{\partial}{\partial x}\left(hD_x\frac{\partial C}{\partial x}\right)+\frac{\partial}{\partial y}\left(hD_y\frac{\partial C}{\partial y}\right)\right]=\frac{w(C_E-C)}{h} \tag{4}$$

and hence, unlike Eq. (1), does not assume quasi-steady-state conditions. The evaluation of the equilibrium concentration, C_E, is described in Section 3.4.

In greater detail the model structure is as follows:

1. Set up initial bathymetry;
2. Work out time-averaged wave heights and periods at every point in model domain;
3. Use TELEMAC-2D flow model to get flow conditions in setback field;

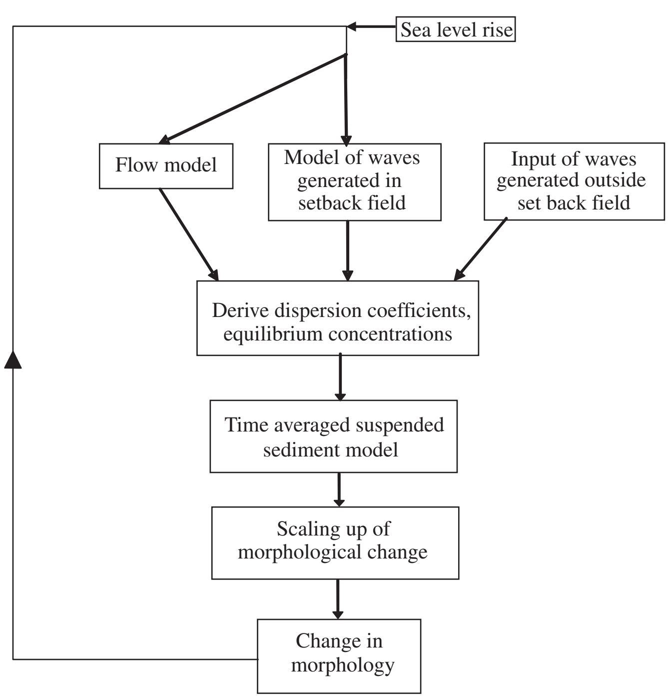

Fig. 1. Basic structure of morphological model.