Simplified Tool for Estuary Erosion/Deposition Risk Assessment

Elliott, A.H.[1], M.O. Green[1] , A. Altenberger[1] and L.Basher[2]

[1]National Institute of Water and Atmospheric Research, Hamilton, New Zealand
[2]Landcare Research, Palmerston North, New Zealand
Email: s.elliott@niwa.co.nz

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EXTENDED ABSTRACT

Abstract:

Increased sediment runoff from the land poses serious threats to estuaries in New Zealand that need to be managed to enhance and protect estuarine ecosystems. In the past, sediment risks have been assessed using detailed physically-based erosion and deposition models. However, a recent survey found that resource managers have a need for relatively simple and accessible tools for conducting risk assessment associated with sediments (at both the long-term and event timescales) as a function of land-use and potential mitigation measures. To satisfy this need we have developed a prototype decision support tool for application by resource managers. The tool allows for capturing the summary properties of more detailed models, or the expert-based assessment of system component behaviour, within a desktop-based tool. The tool enables the land manager to rapidly identify changes in risk and costs associated with modifications to proposed land-uses and mitigation scenarios. In this paper, we summarise the findings from the user needs survey, outline the design of the decision support framework, and present the features of a prototype model.

1. INTRODUCTION

The erosion of sediment and its effect on stream and coastal ecosystems is a prime concern for land and water managers in New Zealand. Of particular interest, especially in the upper North Island, is the effect of sediment on the biota in estuaries. Existing catchment–estuary models tend to focus on nutrients or organic contaminants, rather than on the sediment itself. Moreover, sediment erosion and deposition models are generally not well suited for use by land and water managers, as they are too complex or they do not directly address the management issues. To address these shortcomings, NIWA and Landcare Research are developing management-level erosion and sedimentation models.

A first task in this model development was to obtain a clear idea of the types of model that land and water managers want, and the features that they would find useful. We held workshops with a range of managers and conducted written surveys to define their needs. The findings from the workshops are documented in the first part of this paper.

In the second part of this paper we describe an interactive tool that is being developed to address these user needs. We present the outline of the user interface, the data structures and interactions with component models, and we discuss aspects of the tool implementation.

2. USER NEEDS WORKSHOPS

2.1. Sediment-related issues

A series of workshops was held in 2006 to identify the types and features of models that could be used by North Island local, district and regional authorities to help manage on-site erosion and sediment impacts in streams, lakes, estuaries, and coastal areas (Elliott et al. 2007). A written survey complemented the workshops. The workshops involved discussion of the sediment-related issues faced by resource managers, the roles that models could play in addressing those issues, and the type of information and outputs that the models would ideally provide. The surveys addressed similar questions. A review of erosion models was provided to the participants to provide background information on the attributes of a range of existing erosion/sedimentation models.

Estuarine sedimentation was identified as a key issue. Urbanisation, forest-felling operations, and erosion from pasture were identified as key pressures in relation to estuarine impacts. Acute effects (smothering of habitats and biota by sediment eroded from the land and deposited in the estuary in the aftermath of individual rainstorms) and long-term shifts in sedimentation rate and types of sediments depositing in estuaries (which cause associated broad-scale changes in habitats) were of concern. Linking estuarine impacts to the surrounding land-use was seen as an important management goal.

Several other sediment-related issues of high importance were identified, including: loss of soil from farm areas and associated loss of farm production; river turbidity and water clarity; nutrients and metals pollution associated with sediment; infiltration of fines into stream beds and associated effects on biota; and effects of the accretion of coarse sediment on channel flood conveyance.

It was anticipated that models could be used in the following ways to help address these environmental issues: development of farm, forestry and urban earthworks plans by quantifying soil loss rates and the effect of soil conservation and erosion control measures; identification of erosion “hotspots” within a catchment where mitigation measures might be focused; prediction of the environmental effects of sediment under various land-use and mitigation scenarios, to assist with policy and planning and to meet environmental targets; guiding the timing and location of gravel extraction; aiding communication with communities and councillors; and refining the design of monitoring programmes.

It is clear that no single model will meet all these needs and uses. Rather, a suite of models is required. We identified a set of potential models and their features to serve as a framework for future model development. In addition to linked catchment-estuary models for estuary sediment risk assessment, the suite includes components for: farm, forestry and earthworks erosion on single sites; gravel river sediment transport and accumulation; linking catchment and stream models for stream water quality and infiltration of fines into streambeds; regional or national erosion rate model; and regional erosion risk model.

2.2. Linked catchment-estuary model desirable attributes

The desirable features of a range of management-level models were addressed in the workshop and survey. Here we focus just on those features relevant to a linked catchment–estuary model.

Parameters to predict

Sediment deposition thickness in the estuary at the event (rainstorm) scale is a key variable related to ecological effects. Since both deposition and biological communities vary strongly spatially within an estuary, it is important to be able to predict the spatial variation of deposition, or at least to be able to quantify the deposition rates for locations of high-value communities. Long-term (decadal and greater) accumulation of sediment in the estuary is also important in relation to estuary infilling and associated loss in habitat. Changes in sediment texture in the estuary are of interest in themselves, and they also drive habitat change (e.g., mangrove spread), so it is desirable for the catchment model and estuary model to be able to deal with a range of sediment size classes.

The ability to break sediment loads down into source areas (subcatchments, slope classes, land-uses) or processes (sheet erosion, bank erosion) was also seen as useful, so that deposition in the estuary can be ascribed to different source areas or processes, and management intervention can be targeted accordingly. Hence, the catchment model should have a spatial component, and be able to break the load down into different source types.

Finally, the ability to quantify the uncertainty surrounding predictions was desirable.

Spatial scale and resolution

There was strong support for a catchment-scale model that incorporated sub-catchment partitions, which are in turn broken down into ‘response units’ based on factors such as land-use and soil type. Finer resolutions were seen as being more relevant to farm, forestry-block, or earthworks management models. Typically, the catchment size associated with the estuary is 10 to 1000 km^2.

For the estuary model, prediction at the resolution of km-scale sub-compartments (e.g., specific intertidal flats or subtidal areas adjacent to channels) was seen as sufficient for management purposes, although such predictions may be underpinned by finer-resolution 2D or 3D process models.

Temporal scale and resolution

There was most interest in models that can provide outputs broken down into storm events over long time periods (decades). This would serve as a suitable basis for assessing environmental effects. The temporal probability distribution of sediment deposition depths is of ecological importance. This could be estimated from a long time series of deposition events, which would enable an assessment of the likelihood of a threshold deposition thickness being exceeded (where that threshold would result in severe ecological impact), or the frequency of occurrence of smaller deposition events, which chronically stress biological communities (Lohrer et al. 2006). It would be sufficient for the probabilities of different deposition events to be predicted, rather than a time-series of deposition events.

There was also interest in models providing annual average predictions of sediment sources in the catchment and sedimentation in the estuary. This would serve as a simpler summary of the effectiveness of mitigation measures, and would highlight dominant sources of sediment in the catchment, which might help with prioritising management intervention.

There was little interest in model predictions at the sub-event scale.

Mitigation measures

A strong desire was expressed for a wide range of mitigation measures to be included in the models, to allow for their comparison and prioritisation. The highest priority mitigation measure needed to be evaluated by models was vegetative bank stabilisation, followed by riparian filter strips, ponds and wetlands, track and road erosion, conservation planting, forest harvesting controls, and pasture-cover management. Pasture retirement, streamside stock access, and controlled floodplain deposition were seen as less important for inclusion in the models, but they were still evaluated as high or medium priority by about half the survey participants.

Processes

There was strong support for including processes of bank erosion, stream down-cutting, and track and road erosion in the models, as these were perceived as important source types to which estuarine loads could be ascribed. Raindrop/overland-flow erosion, gully erosion, slips, landslides, bedload transport and deposition, and settling in estuaries were also seen as processes of high priority. Rilling, debris flows, floodplain deposition, flocculation, re-mobilisation of estuarine deposits, and coastal sediment dispersion were of intermediate importance. Long-term stream shape and landscape evolution, and estuarine hydraulics and wave mechanics were seen as having lowest priority.

Target users and other model features

The survey participants thought that the models should be targeted primarily for use by regional council technical staff, rather than by research specialists, specialist consultants, planners or the public. This class of user requires a user-friendly model interface (graphical or spreadsheet-based), preferably based on GIS.

There was support for erosion models to link to water quality and ecological models (for example, to classify the habitat of stream reaches or to identify impacts of sedimentation on estuarine biota). There was little support for links to an economic module.

3. PROTOTYPE DSS

3.1. Overview

In response to the workshops, a new decision support tool (CESIT – Catchment to Estuary Sediment Interactive Tool) for managing impacts of land-derived sediments in estuaries and targeted at resource managers in local councils is being developed. This tool is intended to provide many of the features identified in the user-needs survey – but it is not realistic to provide all those features. The structure of the tool is outlined in Figure 1.

A key feature of CESIT is that it allows the user to define and manipulate mitigation measures in the catchment, and then to see the implications in terms of environmental outcomes in the estuary, all of which is done with a spatial component. The ability to define and apply mitigation measures is similar in some respects to the CMSS catchment model (Cuddy and Reed 2005).

CESIT is not a specific set of models; instead, it is a framework for accommodating and linking various component models, such as a catchment sediment erosion model or an estuarine sediment-transport model, which may be process-based or may rely more on expert knowledge or heuristics. A potentially large range of component models can be accommodated and linked, provided they can exchange information with each other across the framework through defined exchange formats (such as simple text tables) at a prescribed level of spatial division.

The framework is designed primarily to enable definition of mitigation measures and to provide access to the underlying component model predictions. It enables the user to control exposed model parameters, at the same time hiding irrelevant or overly technical information.

The component models need to be implemented for the particular catchment and estuary at hand, then CESIT gives the resource manager access to the implemented component models, including the ability to alter key mitigation scenarios and view the associated system response.

In the prototype CESIT, information on sediment load and source types is passed from a catchment model to a stream model and then to an estuary model in a simple cascade. This information is passed at nodes corresponding to subcatchment outlets to streams, or stream outlets to the estuary. The load may be expressed as a time series or a probability distribution. In the current version, the exchange of information between models is not managed by CESIT – rather, this is the responsibility of the component models.

CESIT makes use of xml files and associated xsd schema to define the range of mitigation measures and the number and format of input and output data elements. In this way, the user interface can be dynamically adapted to any particular component model, and different component models can be readily substituted. For example, in one application a time-based simulation model may be used for estuarine deposition, whereas in a different application a probabilistic model might be used. So long as the inputs and outputs for the component model conform to the types permitted by the user interface, and an appropriate xml file is developed, alternative component models can be readily accommodated within CESIT.

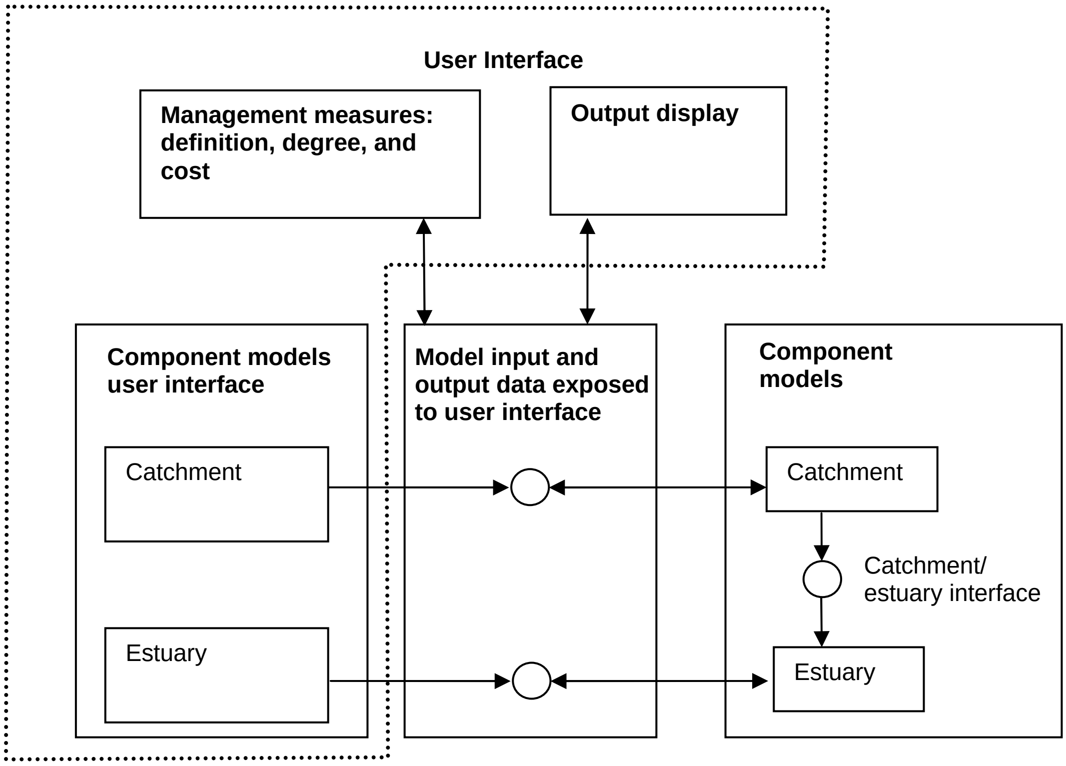

Figure 1. Overview of CESIT DSS with two component models (catchment and stream).

3.2. User interface

The user interface consists of controls for defining and modifying mitigation measures and their cost, defining and modifying exposed parameters of the component models, and displaying model outputs.

The home screen of the user interface is shown in Figure 2. Here, previously-defined mitigation measures can be modified using sliders, which is expected to be the key feature of interest for the user. The home screen contains a map of the catchment and estuary, which is used to display spatially-variable outputs. Summary numerical outputs (such as the total cost of mitigation measures or the total catchment sediment load) are also displayed on the home screen. The intention is that the user will be able to modify the degree of the mitigation measures and readily see the associated implications.

From the home screen the user can navigate to other screens or use tabs to define and manipulate management measures, alter exposed model input parameters, and display model output in more detail.

3.3. Catchment model

The catchment is broken into spatial units (such as subcatchments). Spatial units are further broken down into response units based on attributes such as slope classes, soils type, and land-use. The locations of the response units within a spatial unit are not specified, however. These response units are similar conceptually to the hydrologic response units in SWAT (Neitsch et al. 2005). Each response unit may have a number of mitigation measures applied (for example, area of conservation planting or area with overland flow intercepted by buffer strips). The areas and other attributes of the response units, their corresponding spatial units, and the degree of mitigations are passed to the catchment model. In addition, model parameters for each spatial unit and global model parameters can be passed to the catchment model, depending on the interface attributes as specified in the xml.

At present, a simple catchment model based on yields for each land-use, slope class, and soil type and an additional yield associated with bank erosion has been developed for insertion into the CESIT framework. The yields are defined for a range of event size and source type.

3.4. Management options

The two main types of management option are land-use conversions and the introduction of mitigation measures. Mitigation measures serve to reduce sediment yields (at present according to user-defined removal efficiencies which vary linearly with extent of the measure). When defining a new mitigation measure, the user selects from a list of candidate measures that are contained within the xml-based component model description. For example, the list of mitigation measures may include conservation planting, buffer strips, or mulching of earthworks sites. The user then selects the attributes of the spatial units where the mitigation measures apply (for example, specific subcatchments or slope classes). Once the mitigation measure is defined, a new control slider is introduced dynamically to the home screen of the interface to control the degree to which the measure is implemented.

The user also specifies the unit cost of the mitigation measure. The number of units of that measure (for example, area of conservation planting) is used to derive the cost of the measure. This can be totaled over response units and mitigation measure types.

Land conversions are specified in a similar way. The land-uses being converted from and converted to are chosen, and the spatial units or response unit attributes where these apply are also specified by the user. Once the land-use conversion is defined, a slider to control the degree of conversion is introduced. This information is used to modify the areas of the response units or, where necessary, to add a new response unit. A cost per unit for land-use conversion is also specified to determine the total cost of the conversion.

3.5. Estuary model

Typically, estuarine sediment-transport and sedimentation predictions are based on complex 2D or 3D grid or mesh-based simulations. These are too complex or costly for resource managers to use, and too computationally-intensive to use for rapid assessment of the implications of land-use and mitigation scenarios. Furthermore, long-term simulations to obtain probabilities of sediment dispersion and deposition would be computationally infeasible. To overcome this, we use simplified representations of the behaviour of detailed estuary models (Green et al. 2003). Specifically, results from detailed 2D and 3D estuary models are summarised in terms of sediment dispersion patterns or transfer functions between locations where freshwater discharges into the estuary and various sub-compartments in the estuary. This is compatible with the CESIT structure. The dispersion patterns can be applied either to a long-term time-series of catchment inputs or to various probability breakpoints. Either approach can be incorporated into CESIT.

3.6. Exchange of data across user interface.

Several data types and file formats have been defined for exchange across the user interface. These include global model parameters, model summary output values, and spatial value files. The latter, which may be displayed as maps or in tabular form, are used for transferring attributes that can vary by spatial unit, including model outputs. Shapefiles are used for specifying the boundaries of spatial units, the locations of nodes for data exchange, and the locations of stream reaches. Time series may be defined either for the model as a whole or for each spatial unit, and these can be displayed as charts or in tabular form.

3.7. Implementation

A feature of the model implementation is the use of xml schema (xsd files) to specify the interfaces to component models, such as the name and type of variables, filenames, and lists of land-uses and types of mitigation measures. These schema are used to define related data objects within This allows a flexible dynamic specification of the user interface.

Public-domain libraries are used for graphical displays. The GeoTools library is used for map components, while JFreeChart is used for charting. Tabular data are displayed using standard Java components.

4. DISCUSSION

While the workshop and survey process was valuable in identifying priority issues and a framework for model development, there was less guidance provided on the specific features of the models than was anticipated at the outset of tue user needs assessment. There is probably a need for more specific user-driven model development guidance for any individual model. There are a range of model needs, so that one model will not be able to address all these needs. Even within one type of model, the user needs are greater than can be provided for in the short term. This is a common result of user needs surveys for software development.

At present, CESIT is still being developed. The testbed is the Raglan Harbour and its catchment, and the purpose of the testbed application is risk assessment of sediment effects in estuarine ecosystems. A parallel application of CEASIT with component models that simulate generation and dispersal of sediment-related heavy metals is also being developed for catchments of estuaries near Auckland and Tauranga, where more detailed models are currently being used.

A future extension to the model will be to add an ecological assessment component. We anticipate that this will fit within the current structure and concepts of the CESIT scheme.

5. CONCLUSION

Guided by an understanding of user needs that was established in a series of workshops, we are developing a new decision support scheme for managing impacts of land-derived sediments in estuaries. CESIT is a framework for accommodating and linking component models, such as a catchment sediment erosion model or an estuarine sediment-transport model. The key feature of the tool is that it allows the user to define and manipulate mitigation measures in the catchment, and then to see the implications in terms of environmental outcomes in the estuary. The component models will need to be implemented for the particular catchment and estuary at hand. An expert-based assessment may be installed in the framework in place of a process-based model. The testbed is the Raglan Harbour and its catchment, with the purpose of risk assessment of sediment effects in the harbour. A parallel application concerning ecological effects of heavy metals is also being undertaken.

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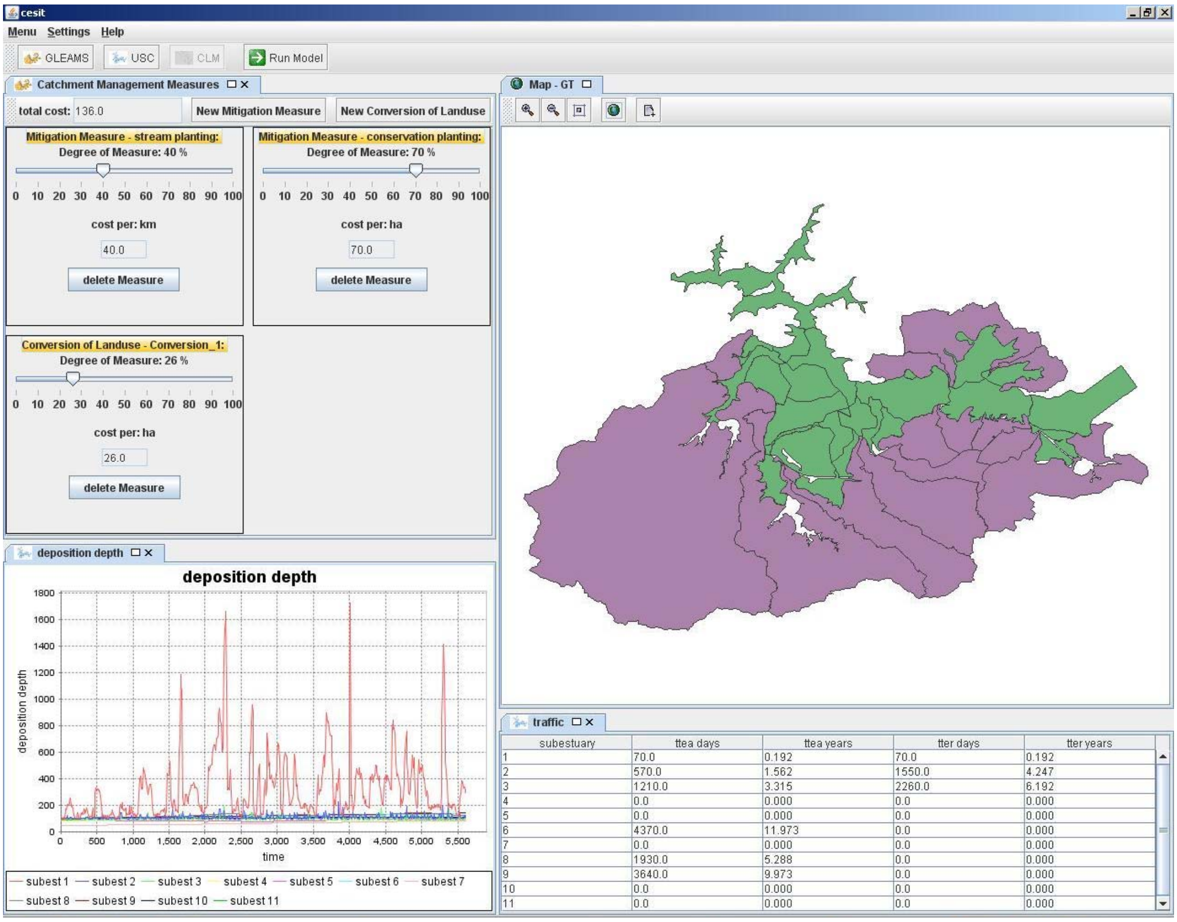

Figure 2. Screenshot of main user interface screen, including mitigation measure sliders and a range of model outputs.