ESTSIM PROTOTYPE SIMULATOR

Method Indicator		
Bottom-Up	Hybrid	Top-Down
	Yes	

Summary of key issues

Issue	Description
Description	The purpose of developing the Prototype Simulator was to take a systems-based description of the geomorphological elements present within an estuary, and through a mathematical formalisation of the influences between the morphological and process components, investigate its response to natural and anthropogenic changes. The Prototype Simulator is based on a Boolean network approach and is able to describe an evolutionary trajectory for a specified estuary given the present rule-base and associated function library.
Temporal Applicability	Medium to long term (Decades to centuries).
Spatial Applicability	Estuary wide.
Links with Other Tools	The Simulator may be useful for evaluating quantitative models by providing information on the direction of change. The Simulator could provide benefits as both an educational tool and as a geomorphological resource to guide the conceptual development of modelling studies.
Data Sources	• Understanding of past functioning of estuary • Morphological components of an estuary • Gross geomorphological properties of estuary
Necessary Software Tools / Skills	• Geomorphological expertise • Access to / experience of MATLAB Code
Typical Analyses	Assessment of evolutionary trajectory of estuary following specified intervention.
Limitations	The Simulator in its present form is not a suitable tool for evaluating estuary management options. This is because of the inability of the Simulator to distinguish between large and minor effects; a result of the Boolean architecture (i.e. due to its “all or nothing” binary approach). This makes it inappropriate for use as the only source of information with which to inform decisions regarding regulation and development. Formulation of mathematical functions to characterise the known geomorphological behaviour and linkages within a system involves a high degree of ‘operator variance’. As a result, much of the geomorphological knowledge formalised within the Simulator is subjective. The Prototype Simulator requires some knowledge of estuary morphology, both to set up for specific estuaries and to interpret the results. This limits the range of users that can apply it in estuary

	studies. As with the output of any modelling exercise it is necessary to verify the output state in context and against observations or objective judgments. The Prototype Simulator in its current state is a research tool and as such a number of the logical relationships within the Prototype Simulator, as it currently stands, require further validation. These issues are not a criticism of the method but an acknowledgement that the development of this type of model is an ongoing process. Within the Boolean network approach, estuary evolution is modelled as a series of steps but these are not linked to any real time scales. The timescale of a given behavioural response to a specified action can therefore not be determined. The Simulator provides a reasonable guide to the direction of change of the estuary system following a change in forcing, but it does not capture the complexities of real estuary systems. In fact a major strength of the Simulator is its simplicity but this means that it cannot determine whether the associated change resulting from intervention is negligible or considerable.
Example Applications	Research was completed within FD2117 to identify an up to date and relevant list of management questions applicable to UK estuaries, mapped against relevant legislation. These questions were used to derive a series of scenarios for undertaken a targeted pilot testing exercise. Pilot testing was undertaken on the Teign and Thames estuaries.

Background: R&D Project FD2117

The Prototype Simulator was developed within R&D project FD2117, Development and Demonstration of Systems Based Estuary Simulators (EstSim) (EstSim Consortium, 2007). The project has investigated an alternative, yet complimentary, approach to help understand morphological behaviour in estuaries. This involves the application of a systems-based approach to estuary environments. One of the key aims of the approach developed is to provide a qualitative framework to understand and explain the behaviour of geomorphological features within estuaries, the linkages that exist between them and hence their response to change.

A system-based approach involves defining the individual components that make up a given environment and characterising how these components interact in order to understand the system organisation and define its behaviour, see Behaviour systems. Systems-based thinking is a well-established conceptual framework in geomorphology, but methodologies for converting system diagrams into practical simulation tools have not previously been investigated.

EstSim has applied these systems-based concepts to estuaries to define and subsequently formalise the understanding of the system in a way that allows the qualitative prediction of long-term estuary morphological evolution and responses to environmental change (e.g. sea-level rise or sediment supply changes) or interventions (e.g. dredging or coastal protection). This research has been used to demonstrate the potential of such a systems-based approach.

Further details of the research undertaken within FD2117 can be found at the web based interface developed for the project: http://www.discoverysoftware.co.uk/estsim/EstSim.html

Background: The prototype simulator

EstSim reviewed the systems approach and provided background understanding for developing system diagrams for estuaries, as well as a diagram for each of seven generic UK estuary types (ABPmer, 2007). In each case, the system diagram maps a set of influences between the morphological and process components within the estuary, and the adjoining coastal system, including positive and negative feedback between components. The systems approach was formalised with a series of Boolean variables and functions; i.e. essentially a rule-based approach. The behaviour of each system component (variable) in response to combined inputs from other components is defined using the Boolean functions. The continuous non-linear behaviour of the system is approximated by a discontinuous Boolean variable; functions are available for the coast-estuary sub-system, the outer estuary sub-system and the inner estuary sub-system. This keeps the complexity of the proof of concept model to a manageable level, although there is nothing inherent in the approach that would prevent further complexity being added in future developments. The Boolean functions are operated simultaneously at discrete time steps. These functions determine whether components (Boolean variables) exist in on or off states (e.g. presence or absence). The discrete time step and synchronous updating of all state variables at each step can lead to spurious cycles, and a decay term was included in the simulator to damp out these cycles, as they can lead to unrealistic intermediate configurations. The decay term also represents the temporal lag effect that conditions the response of morphological components to changing processes in geomorphological systems.

Input

Input to the Prototype Simulator is via the selection of an estuary type from one of the pre-defined seven. The presence or absence of components in the estuary definition can be modified including the external forcing, outer estuary morphology and inner estuary morphology to (1) set up a user-defined estuary with specific (non-standard) features or (2) impose a change to system state, e.g. to represent anthropogenic input. The setting up of a user-defined estuary currently requires expertise in estuary geomorphology to ensure a realistic interpretation of the estuary system.

Output

The output of the Prototype Simulator is a table showing the final state of the estuary in terms of presence or absence of each of the external forcing, system state, outer estuary morphology and inner estuary morphology variables. The final state can be approached in a monotonic or cyclic fashion, and should be interpreted as a tendency rather than an absolute answer. Interpretation of the output requires some expertise in estuary geomorphology, as with any modelling, the results need to be taken in context.

Temporal scales

The Prototype Simulator can be applicable across the medium to long term, which is implicit in the top-down approach. The approach predicts steps in the evolutionary path, however, the steps do not have an associated real timescale within the estuarine system.

Validation

The approach has been applied to the Ribble Estuary and Southampton Water and to the Thames and Teign (Rossington *et al.*, 2007). In all cases, the simulator can obtain a largely correct depiction of gross estuary properties with the generic estuary types and rule base. This conclusion is made in terms of the qualitative model output when compared with

observed estuarine features and responses; in reality these are value judgements rather than quantifiable results. French & Burningham (2007) conclude that there are subtle estuary-specific aspects of inherited morphology, sediment transport, hydrodynamics (e.g. the double high water in the Solent), and intervention history that would require customisation of the model functions. The ability to customise was investigated to a limited extent by Rossington *et al.* (2007) who concluded that the Prototype Simulator was able to reproduce the observed features of the Thames and Teign. Further validation studies are recommended to obtain more confidence in the results, i.e. by verifying the rule-base and examining the response to particular effects in specific documented cases.

Range of applicability

In its generic form, EstSim can be applied to any one of the seven UK estuary types, as well as user-defined estuaries, based on factors for external forcing, system state variables, outer estuary morphology and inner estuary morphology. EstSim requires expert knowledge of estuary morphology to set up the model for specific estuaries. The present implementation of the model does not allow for the magnitude of an effect to be determined, or for the scale of the presence of a morphological variable, e.g. saltmarsh; it cannot distinguish between a few square metres of marsh or a hectare of marsh. The approach makes use of system-based abstractions (idealised simplifications) of the estuary as a whole and its component geomorphological features. It provides a means of formalising some of the more qualitative geomorphological knowledge. The model can be used to determine the directions of change but, in its present form, is not able to determine sensitivities of the estuary system to change due to its discrete (all or nothing) approach.

Accessibility

The MATLAB research level code is available on-line (http://www.geog.ucl.ac.uk/ceru/estsim) and the Java version available through the web-based Interface (http://www.discoverysoftware.co.uk/estsim/EstSim.html).

References

ABPmer, 2007, EstSim Behavioural Statements Report, Project Record 2. Prepared for the FD2117 for the Estuaries Research Programme Phase 2 Project FD2117 for Defra and the Environment Agency Defra and the Environment Agency, ABPmer Report No. R.1153.

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French, J.R. & Burningham, H., 2007, Methods and Software Tools for Estuary Behavioural System Simulation, Project Record 4. Prepared for the FD2117 for the Estuaries Research Programme Phase 2 Project FD2117 for Defra and the Environment Agency.

Rossington, K., Spearman, J. & Whitehouse, R., 2007, Development and Demonstration of Systems Based Estuary Simulators (EstSim): Pilot testing: Performance evaluation of prototype simulator, Project Record 7. Prepared for the FD2117 for the Estuaries Research Programme Phase 2 Project FD2117 for Defra and the Environment Agency.