EXPERT GEOMORPHOLOGICAL ANALYSIS

Method Indicator		
Bottom-Up	Hybrid	Top-Down
		YES

Summary of key issues

Issue	**Description**
Description	Expert Geomorphological Analysis (EGA) integrates information from various sources to provide a broad-scale and long-term perspective on future change. The approach is reliant upon historical data and an expert understanding of geomorphological interpretation.
Temporal Applicability	EGA can be applied to many different time-scales: • Geological (millions of years): geology of estuaries; • Holocene (thousands of years): creation of estuaries; • Anthropogenic history (in the UK effectively since Roman times): land reclamation and the impact of agriculture; • Near history (100-200 years): written records of data, impacts of industry and of major engineering schemes in estuaries such as dredging and training wall schemes; • Decadal (post-war): accurate data, impacts of dredging and port development, saltmarsh loss; and, • Years: changes in estuary sub-systems, including mudflats and creek systems.
Spatial Applicability	Estuary wide.
Links with Other Tools	Links to modelling tools and numerical analysis, for example, can be used with estuary translation, morphological bed modelling, regime analysis and sediment transport data.
Data Sources	Historical archives, field data and management information.
Necessary Software Tools / Skills	Expertise in estuarine geomorphology.
Typical Analyses	Conceptual models of estuarine systems and predictions of future change.
Limitations	Reliant on expertise and experience of person developing the analysis; data availability and quality.
Example Applications	Poole Harbour.

Introduction

Expert geomorphological analysis seeks to integrate information from numerous sources to provide a broad-scale and long-term perspective on past and potential future change. The approach draws heavily on analysis of historic information, an understanding of landform evolution, and relative importance of the various process-form interactions. In effect, it is a basis for synthesising, or interpreting, the outputs from the various data analysis methods, within a framework guided by our present understanding of geomorphological behaviour.

As yet there are no well-defined methods, or protocols, to guide this type of analysis. The success of the method is very dependent on the extent and quality of the available data and the expertise of those undertaking the analysis. It is therefore important to carefully document the interpretation that is being made, typically identifying the data sources or results that are being relied on and then set out the conclusions that follow. This should rely on accepted behavioural models of geomorphological evolution. An important aspect of the analysis is to consider any information or data that does not support the proposed model, and the inclusion of any data should be explained. This may involve some discussion of the various uncertainties, and possibly some assessment of the likelihood of a number of different outcomes. An example of the use of this approach is given in Paper 15 of the EMPHASYS Report (Pye and Van der Wal, 2000).

The study of estuary geomorphology can be applied to many different time-scales:

- Geological (millions of years): geology of estuaries;
- Holocene (thousands of years): creation of estuaries;
- Anthropogenic history (in the UK, effectively since Roman times): land reclamation and the impact of agriculture;
- Near history (100-200 years): written records of data, impacts of industry and of major engineering schemes in estuaries such as dredging and training wall schemes;
- Decadal (post-war): accurate data, impacts of dredging and port development, saltmarsh loss; and,
- Years: changes in estuary sub-systems, including mudflats and creek systems.

Additionally many underlying physical processes within estuaries occur on much smaller timescales (seconds to a spring-neap cycle) and any investigation of underlying processes will involve consideration of these smaller time-scales. For studies supporting estuary management decisions the timescales of interest relate to “engineering geomorphology”, i.e., years and decades, and generally up to a century. The study of estuary morphology over the whole spectrum of timescales is helpful in understanding the behaviour of any particular system, however, the dominance of the shorter time scales in deciding management policy means that the emphasis in estuary geomorphological studies has to be towards engineering geomorphology, as is the case here. The exceptions to this occur where knowledge of geological or historical geomorphology will aid the understanding of a system so as to improve the quality of the engineering geomorphology studies. Henceforth we will use the following terms to describe the temporal scale of estuary response:

- Short: seconds, through spring-neap cycle to a few years;
- Medium: a few years to a few decades; and,
- Long-term: a few decades to centuries.

An overall framework for geomorphological studies

A framework for predicting estuarine morphological change has been established by EMPHASYS (2000); Townend (2002), and Dearnaley *et al.* (2004), amongst others. Any impact assessment of a particular project in an estuary system will consist of a scoping exercise, analysis of the way the system works, impact prediction, and discussion with client and regulator about the study’s conclusions, possibly leading to further clarification of the issues arising from the project, and additional work leading to refined conclusions and presentation of the study outcomes.

The components of an impact assessment are summarised in Figure 1. This is not definitive but is typical of the broad nature of estuarine studies to support estuary management. Here, the different components presented in the figure will be explained. However, the emphasis in this report is on developing a framework for the second component in Figure 1, that of conceptual model development.

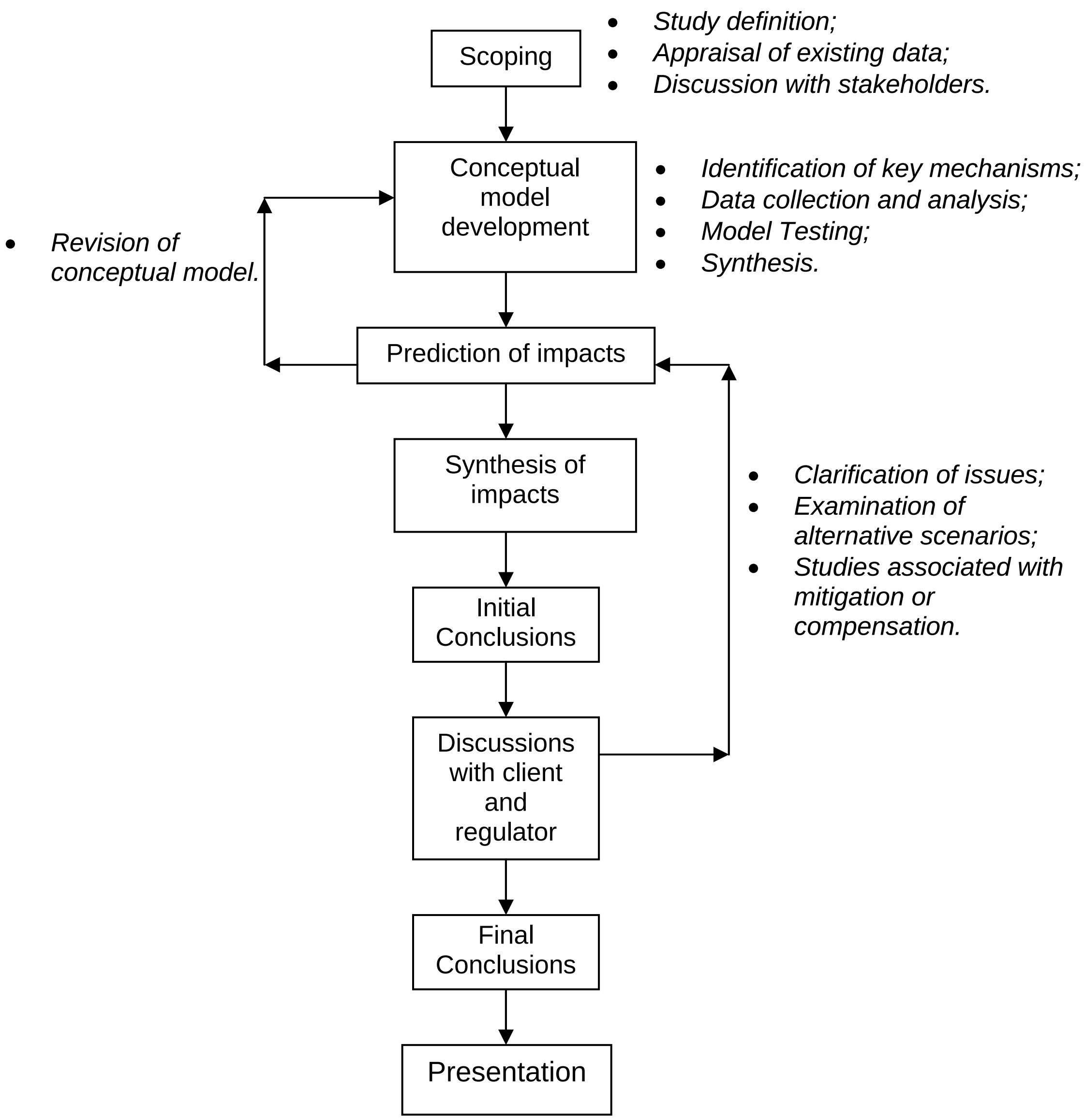

Figure 1. Summary of stages in EGA studies

Scoping is where the objectives and methodology of the project are outlined, considering the potential effects resulting from a man-made project or natural change on local or estuary-wide morphology, evaluation of the availability of and the potential requirement for new data, and the identification of the needs of the client and regulator. In practice this component overlaps with the next component, conceptual model development. The correct application of EGA is heavily dependent on an understanding of the system being studied (a conceptual model), which forms a basis for the correct choice of predictive methods, thus enhancing confidence in the conclusions of the study. An incomplete or incorrectly focused conceptual model may lead to incorrect assumptions about the system, poor utilisation of predictive approaches and incorrect assessment of impact.

The next component in the overall framework is the implementation of predictive assessment (prediction of impacts). If a plethora of model approaches are implemented then some formal synthesis of the different results will be required (synthesis of impacts). New insights may lead to an adjustment of the conceptual model and further predictive assessment. The initial conclusions arising from the synthesis will be explored during discussions with the client and regulator and these discussions may lead to some clarification of the issues and the requirement for further predictive work may be highlighted. Finally, when all the outstanding issues have been addressed the final conclusions of the assessment can be formally presented.

From the viewpoint of shoreline management requirements, the estuary needs to be considered in the context of the adjoining coastline. A range of parameters, methods and features need to be considered when assessing the scale of physical interaction between the estuary and the coastline (Pontee and Cooper, 2005).

A framework for development of the conceptual model

A conceptual model is a formal explanation of how the system (or sub-system) functions, including the key controlling mechanisms and their relative importance, of the reasons for the historical development (if relevant over the defined model area and time-scale) of the system (or sub-system) and of the reasons for present trends within the system (or sub-system). It can be expressed through bottom-up or top-down considerations. However, whatever basis the understanding of the system is derived from, it should be demonstrated how this conclusion is supported by physical processes, i.e. the effect of currents, waves, etc, in forming sediment pathways, sources and sinks in the system. Particular attention should be given to whether sediment supply to the system is sufficiently large/small to accommodate the conclusions regarding long term trends.

Within the context of most EGA studies there is a specific set of management decisions to be addressed and the development of the conceptual model should be targeted towards providing a basis for informing these management decisions. If the study area is, for instance, a specific mudflat then the conceptual model may not have to consider the estuary-wide components and long-term (centuries) evolution of the system. The development of the conceptual model to a particular estuary system (or sub-system) is iterative and can be improved over time with increased data availability. Formally, however, the stages of the development are as outlined in Figure 2, and each of the stages highlighted in Figure 2 are discussed in turn below (see also chapter 4; Study Approach).

Project definition

What are the client's requirements?

An EGA is undertaken in order to provide sufficient information to the assessment process, e.g. Environmental Impact Assessment (EIA), Strategic Environmental Assessment (SEA) or Appropriate Assessment (AA), upon which a management decision can be made. An element includes quantifying the reliability of this information. Data reliability is important, along with how well the bottom-up or top-down methods are applied and how good the conceptual model of the system is.

Identify regulators concerns

Several potential issues exist that are of particular significance to regulators because of the present legislative framework, including:

- Impacts on designated features;
- Disposal of sediment;
- Impacts on navigation;
- Impacts on fishing and fisheries;
- Impacts on flood defences;
- Impacts on Shellfish Waters; and
- Impacts on Water Quality.

A geomorphological investigator must have good comprehension (or access to expertise) of the regulatory issues which will need to be addressed in the geomorphological study.

Define study objectives

As a result of the considerations outlined above the objectives of the study are defined.

Define study area and time-scale

This is estuary specific, and includes all areas that could be affected by the considered management option. Defined spatial scales must be relevant to the morphological evolution observed in the current system and any anticipated evolution resulting from a management option.

Appraisal of existing data

Identify possible sediment pathways, sinks and sources

The mechanisms for change within estuary systems can be summarised as being to do with energy (currents, waves, etc); sediment (type and availability); or man-made effects. The consideration of how these will change is the basis of deriving the key mechanisms within a system. However, it is important to identify the key sediment transport mechanisms at a greater level of detail. Examination of these processes can take place at different levels of sophistication but a background of estuarine processes is likely to be required.

Table 1. Potential mechanisms for mobilisation, advection and deposition

Mobilising Mechanisms	Advection Mechanisms	Sedimentation Mechanisms
• Wave breaking; • Wave stirring; • Fluidisation of the bed; • Fluid mud formation from settlement; • Erosion by currents; • Pick up by wind; • Fluvial input; • Re-suspension by dredging; • Re-suspension by vessel movements; • Side slope subsidence; • Biological effects leading to sediment disturbance or re-suspension.	• Tidal currents; • Fluvial flow; • Near bed flow; • Secondary currents; • Density currents; • Wave-driven flow; • Littoral drift; • Wind driven flow; • Meteorologically induced flow; • Vessel-induced currents; • Movement of fluid mud and other near bed high concentration suspensions; • Mixing/dispersion of material in suspension.	• Reduction of: - wave breaking; - wave-driven flow; - wave stirring; - tidal flows. • Interception of: - littoral drift; - fluid mud; - bed load; - wind load; - side slope subsidence. • Deposition from suspension; • Ecological stabilisation of sediments.

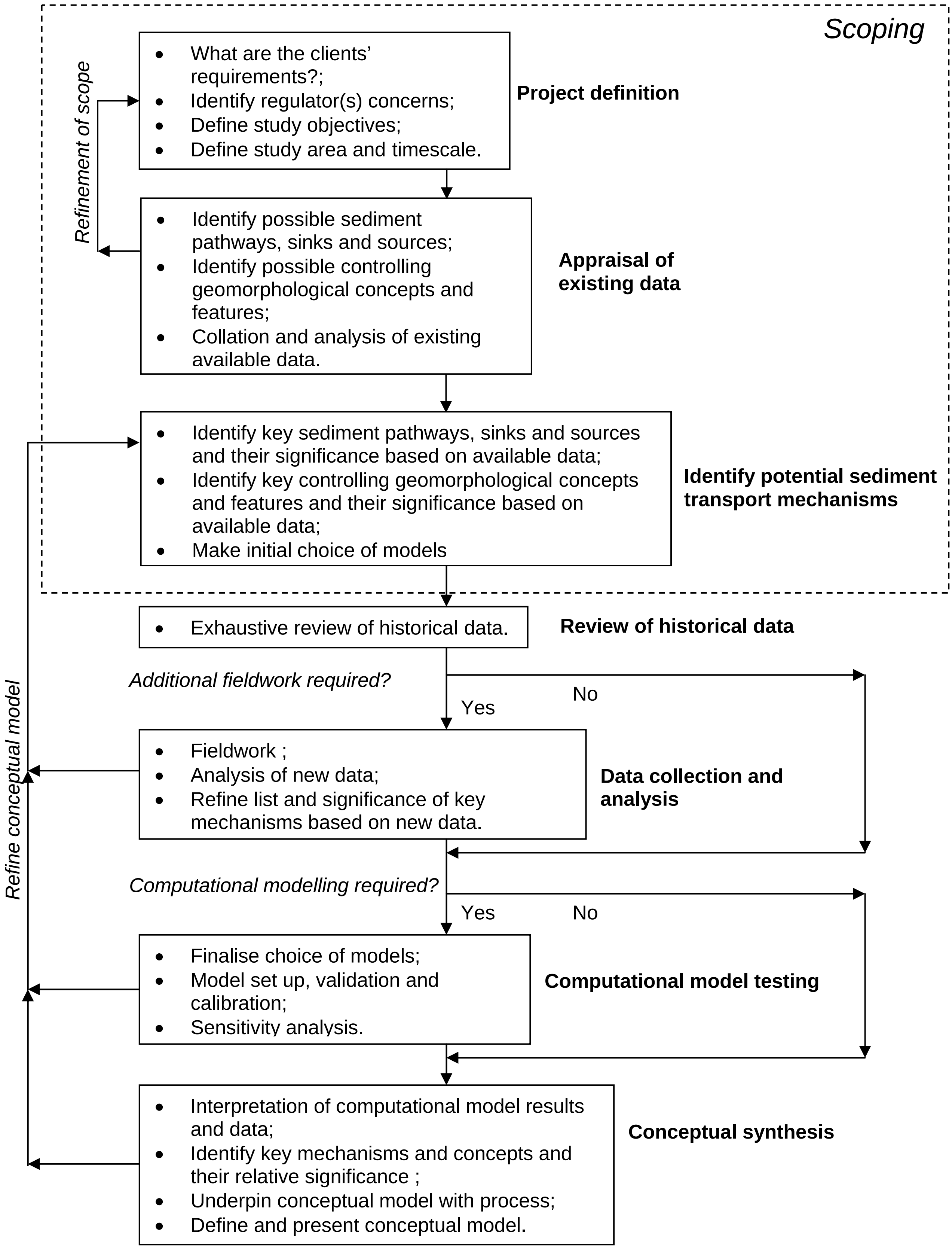

Figure 2. Summary of stages of development of conceptual model

Initially, the key mechanisms will consist of highlighting the potential mechanisms that may be important. This list may be refined as existing data is analysed, and added to by new field data and modelling (if required/undertaken), and their relative significance identified with more certainty.

This process will require answers to the following questions:

- What are the key morphological features and associated sediments in the system at present?;
- Is there input of sediment to, and/or export of sediment from, the system (or sub-system) that is being considered?;
- Where does the input of sediment come from (if at all)?;
- How is sediment exported (if at all)?;
- What are the reasons for the sources and sinks within the system (or sub-system)?.

Identifying the key sediment transport mechanisms effectively defines the routes for sediment supply to and from the system (and parts within the system), which goes a long way to defining a conceptual model. Sediment supply will have a large effect on the potential direction and rate of any predicted morphological change. The potential list of mechanisms is large (Table 1), but can be rapidly reduced by applying back-of-the-envelope calculations or more in-depth analysis of available data. Further refinement to this list comes from the use of more numerate approaches during the conceptual synthesis phase.

The process of identifying key mechanisms relies heavily on a thorough examination of the historical data (charts, dredging and disposal records etc.) associated with morphological change. Failure to consider this historical information could result in the identification of sediment transport mechanisms that are incorrect, leading to a weak or even flawed conceptual model.

Identify possible controlling geomorphological concepts

Additionally, there may be controlling top-down mechanisms which affect or describe the functioning of the estuary system. It is best to start with an “inclusive” list of mechanisms that might potentially be important and to discard the less relevant ones as more knowledge about the system is derived. The controlling concepts could include:

- Net sea level rise and anticipated response of estuary, e.g. as expressed by the Rollover model;
- Sediment supply: quality and amount, e.g. as expressed by the sediment budget modelling;
- Status of system with respect to equilibrium state, e.g. as determined from the Regime method); and,
- The geological context of the estuary, including accommodation space.

Collation and analysis of existing data

The assessment of data quality and abundance is an important part of the scoping process. The results of which dictate any further data collection requirements and also influence the selection of models used, either to aid the development of the conceptual model or to predict impact. The assessment may also provide insights into the key controlling mechanisms or possibly provide an initial suggestion for the conceptual model. Failure to appraise the available data in detail may lead to: erroneous conclusions through over-confidence in the existing data, if errors are not spotted early, or, if errors are discovered early on, possibly the requirement to collect additional data; or having to disprove or adopt an alternative perspective of the estuary system at a late stage in the project, reducing confidence in the overall project results.

Site visit

Site visits provide an invaluable visual perspective of the study area, valuable information and an opportunity to meet managers, experts and end-users involved with the site, and can help to identify important concerns at an early stage. The purposes of the inspection include:

- To confirm that there are no significant differences between data provision and reality, e.g. sometimes changes to the coastline have been implemented or there are important activities which have a bearing on the system, that are not documented;
- To provide an opportunity to spot geomorphological evidence which will aid conceptual model development;
- To collect a small amount of field data (e.g. grab samples) to aid the initial stages of conceptual model development.

The following key physical features could be assessed during a site visit:

- Single channel: straight or meandering, narrow or wide, shallow or deep; multiple channel including shoals, banks or islands, ebb or flood channels;
- Ebb or flood deltas;
- Seawalls or other shoreline structures; intertidal or subtidal structures;
- Beaches; Sand dunes; Mud and/or sand flats; saltmarsh: cliffing, erosion/deposition, pioneer marsh;
- Intertidal areas: concave or convex, erosive or depositional;
- Changes in sediment cover and substrate type indicating erosion or deposition;
- Large or small river flow;
- Intertidal drainage channels;
- Tidal asymmetry;
- Geological constriction; littoral drift or bar at mouth;
- Evidence for turbidity/turbidity maximum; salinity gradient: surface expression of fronts between water bodies; and,
- Dredging/disposal or other anthropogenic activity.

Initial appraisal of need for new data

Here, it is possible to highlight gaps in the available data and make some initial conclusions about what field data (if any) might need to be collected. This will be refined when the key mechanisms within the system are explored and the use of models for investigating the system are considered.

Identify potential sediment transport mechanisms

Identify key sediment pathways, sinks and sources and their significance based on available data

The identified list of the potential sediment pathways sinks and sources needs to be focussed in on the key mechanisms acting with the system; the identification of which will be based on the appraisal of existing data, the information gleaned from the site visit and additional analysis, invariably “back of the envelope” analysis.

Identify key controlling geomorphological concepts and features and their significance based on available data

Any top-down concepts used in the conceptual model must be consistent with the observed bottom-up processes and key mechanisms. An exhaustive review of historical data may identify that certain processes (e.g. dredging or development) are so dominant that they dominate the evolution of the estuary or the review may reveal information about longer-term changes, which highlight a particular geomorphological concept.

Initial choice of models

The initial assessment of what models might be applied to aid the conceptual model development and predictive studies will be made on the criteria listed below:

- Time and spatial scales of the cause of change (summarised in Table 2);
- The nature of the key mechanisms identified (summarised in Table 3);
- Data availability;
- The context of the specific question that the study is trying to address; and
- All of these criteria need to be considered together.

The suitability of the various top-down approaches together with hybrid and bottom-up approaches to different causes for change and different temporal and spatial scales is summarised in Table 2 (see also Chapter 4: Study Approaches). Local changes and shorter timescales usually correspond to the use of bottom-up models while large-scale changes and longer time scales are more likely to require top-down methods to be considered. The problem is exacerbated if small changes to mechanisms, which by their nature can be thought of as process-based, episodic and corresponding to very short time-scales, dominate the long-term evolution of the estuary system, especially with wave activity under sea level rise. In such circumstances the application of a range of top-down/hybrid/bottom-up approaches may be required to assess the resulting changes in morphology.

Data availability is also important in the choice of models. The less data available, the more relevant top-down methods become. However, after consideration of the issues in Tables 2 and 3, insufficient data may give rise to a decision to collect more data, rather than to restrict the study scope to top-down approaches.

The context of the reasons for the study also affects the choice of models used. The set of models used must include those allowing assessment of the impacts of estuary change under the relevant temporal and spatial scales and examination of different strategies for managing the impact of change, the combined effect of formative events and long term processes that influence the estuary morphology. These formative events include both natural, e.g. extreme storms and the 18.6 year tidal cycle, and anthropological events, and the manner in which these interact with sea level rise will often result in morphological studies having to consider timescales of at least decades, suggesting a common role for top-down methods. However, whatever spatial and temporal scales are relevant to the evolution of an estuary system the impact of this evolution on end-users will often be small-scale issues and such issues will tend to require the application of bottom-up models.

Table 2. Generic models and applicability to causes of change

Cause of Change	Spatial Scale	Temporal Scale	Data Analysis Methods			"Top Down" Methods					Process Based "Bottom Up" Methods	Hybrid Methods	
			Accommodation Space	Historical Trend Analysis	Sediment Budget Analysis	Regime Relationships	Analytical Methods	Tidal Asymmetry Analysis	Intertidal Form Analysis	Estuary Translation (Rollover)		Regime Based	Energy/Entropy Based
Freshwater	Xt	Lg		x		x		x				x	x
	Xt	S/M					x				x		
Tide	Xt	S/M					x				x		
	Xt	Lg		x		x		x				x	x
Sea level	Xt	Md					x				x		
	Xt	Lg	x	x	x	x		x		x		x	x
External waves	Xt	S							x		x		
	Xt	M							x		x		
	Xt	Lg				x						x	x
Local waves	Lc	S							x		x		
	Es	S/M									x		
	Es	Lg										x	x
Sediment inputs	Xt	S			x				x		x		
	Xt	M			x				x		x		
	Xt	Lg	x	x	x	x						x	x
Barrage	Lc	Fx								x	x		
	Es	Fx				x	x	x			x	x	x
Barrier	Lc	Fx									x		
	Es	Int					x	x			x		
Deepening	Lc	S		x	x						x		
	Es	M/Lg		x	x	x		x		x	x	x	x
Fauna	Lc	M									x		
	Es	M									x		
Flora	Lc	M									x		
	Lc	Lg											
Intake/outfall	Lc	Fx									x		
	Es	Fx									x		
Jetty or pier	Lc	Fx									x		
Reclamation	Lc	Fx									x		
	Es	Fx				x		x		x	x	x	x
Sea defences	Lc	Fx									x		
	Es	Fx				x		x		x	x	x	x
Training works	Lc	Fx									x		
	Es	Fx				x					x	x	x
Managed realignment	Lc	Fx							x		x		
	Es	Fx	x	x	x	x		x		x	x	x	x
Intertidal recharge	Lc	S							x		x		
	Es	S		x	x	x		x			x	x	x

KEY:

Spatial scale of action		**Time scale of action**	
Lc	Local	S	Short-term (days to month)
Es	Estuary	M	Medium term (seasons to a decade)
Xt	External	Lg	Long-term (decades to a century)
		Int	Intermittent
		Fx	Fixed (in human terms)

Table 3. Summary of generic models applicable to different key mechanisms

Mobilising Mechanisms	Advection Mechanism	Sedimentation Mechanisms
Mechanisms specifically requiring process models for investigation: • Wave breaking; • Wave-driven flow; • Fluidisation of the bed; • Fluid mud formation from settlement; • Pick up by wind; • Re-suspension by dredging; • Re-suspension by vessel movements; • Side slope subsidence; • Biological effects leading to disturbance or re-suspension of sediment.	*Mechanisms specifically requiring process models for investigation:* • Secondary currents; • Wave-driven flow; • Littoral drift; • Wind driven flow; • Meteorologically induced flow; • Vessel induced currents; • Movement of fluid mud and other near bed high concentration suspensions.	*Mechanisms specifically requiring process models for investigation:* • Reduction of: - wave breaking; - wave-driven flow; • Interception of: - fluid mud; - wind load; - side slope subsidence; • Ecological stabilisation of sediments.
Mechanisms which can be investigated using a range of techniques: • Wave stirring; • Erosion by currents; • Sea level rise.	*Mechanisms which can be investigated using a range of techniques:* • Tidal currents; • Fluvial flow; • Sea level rise; • Mixing/dispersion of material in suspension; • Density currents.	*Mechanisms which can be investigated using a range of techniques:* • Reduction of: - wave stirring; - tidal flows; • Interception of littoral drift; • Deposition from suspension; • Sea level rise.

Identify objectives for fieldwork

Fieldwork, if necessary, may require long-term planning due to the scale of the fieldwork, resources required, and the practical and environmental limitations of measuring in the field. Some further information on the selection of fieldwork tools, with applications to sedimentation in harbours and for Coastal Zone Management is provided by Dearnaley *et al.* (1997) and Mulder *et al.* (2001).

Review of historical data

Conceptual model development relies on knowledge of all the contributing factors that have led to the present morphological trends in the estuary system. A process of searching the available historical and archival records is required, often revealing that specific anthropogenic activities or even natural episodic events have been dominant controlling mechanisms in the estuary rather than response to more obvious drivers such as sea level rise. Examples of this are:

- Many estuaries in the south and south-east of the UK had major populations of a hybrid species of cord-grass in the early part of the 20th century. This species enhanced the sediment deposition on intertidal areas until the 1930's when the species throughout the south-east began to die back, increasing the susceptibility of the surface sediment to erosion and has led to rates of erosion which are many times greater than sea level rise (e.g. Stour Estuary near Harwich (Beardall *et al*., 1991)).

- Over the 20th Century, the Thames Estuary has experienced significant morphological change through anthropogenic intervention, particularly through dredging and disposal. The changes in water level over this period are primarily dominated by the estuary response to these activities rather than to sea level rise (Siggers *et al*., 2006).
- Many of the UK estuaries (e.g. the Blythe Estuary in Suffolk) have experienced major reclamation in the Roman, Norman and/or 16th/17th century periods (Beardall *et al*., 1991). Any assessment of the longer term trends in an estuary system must therefore appraise the possibility of this type of large-scale anthropogenic disturbance (Table 1).

The purpose of the example given in Box 1 is the identification of key mechanisms, not the conceptual model itself which must be more all encompassing and aided by modelling and field data.

Box 1. Identification of key mechanisms for Poole Harbour

Poole Harbour is on the Dorset Coast in the south of the UK (Figure 3). The Harbour is located at the north-western corner of Poole Bay, a sandy bay extending from Swanage in the west to Christchurch in the east. There is very limited freshwater input to the Harbour system and so the Harbour is considered to be a "tidal inlet", comprising sandy channels with extensive muddy intertidal areas with saltmarsh predominantly in the more quiescent waters to the south of the Harbour. There is a maintained navigation channel leading to ferry berths in the north of the Harbour. Starting with the list of mechanisms in Table 1 we produce the following initial and inclusive list of potential mechanisms:

- Sediment in the Harbour could be mobilised by waves and tidal currents and potentially by vessels and wind-generated currents in the quiescent areas;
- Sediment in Poole Bay could be mobilised by tidal currents and waves;
- Sediment in the Harbour is advected by tidal currents and wind-generated currents could be present in the quiescent areas;
- Sediment in Poole Bay could be advected into Poole Harbour on the flood tide;
- Sediment in the Harbour will deposit on intertidal areas in the absence of wave activity and in the deepened areas associated with the ferry terminal and navigation channel; and,
- The dredging process may mobilise and advect sediment out of the Harbour system.

Examination of the available data (Gray and Raybould, 1997, HR Wallingford, 1988, 1990a, 1990b, 1990c, 1990d) allows the following likely conclusions:

- Wind-generated currents are insignificant in terms of the major sediment transport processes;
- Ebb tidal currents are more dominant than flood tides through Poole Harbour entrance;
- Wave disturbances produced by vessel traffic are small compared with the wind-generated wave climate;
- There is no evidence of major sources of fine sediment in Poole Bay, and hence it is unlikely that there is significant fine sediment input from Poole Bay;
- Poole Harbour has experienced significant die-off of salt marsh (specifically *Spartina Anglica*) throughout the 20th century. Saltmarsh in the south of the Harbour is currently experiencing erosion;
- Maintenance dredging in the Harbour is relatively low (40,000-50,000m^3/yr) and this is placed in Poole Bay; and,
- Littoral drift produces a flux of coarse material in a SW direction towards Poole Harbour Entrance leading to a classic spit feature.

This allows us to reduce the list of possible transport mechanisms to:

- Sediment in the Harbour (both sand and mud) is mobilised by waves and tidal currents;
- No significant amount of fine sediment is brought into the Harbour from Poole Bay and there is no significant net input of sandy sediment into Poole Harbour from Poole Bay;
- The dredging process may mobilise and advect sediment out of the Harbour system;
- Sediment in the Harbour is advected by tidal currents; and,
- Sediment in the Harbour will deposit on intertidal areas in the absence of wave activity and in the deepened areas associated with the ferry terminal and navigation channel.

Consideration of this information leads to the basis of a conceptual model of Poole Harbour as a system which has, for historical reasons, considerable muddy intertidal areas but which has no external sediment supply. All of the sedimentation in the deepened areas is a redistribution of sediment within the system and there is a net loss of sediment from the system, which is enhanced to a small extent by placing dredged material outside of the Harbour system. The system will not be able accrete at the same rate as sea level rise and therefore over the long term one would expect an underlying trend of relative erosion as well as the more significant erosion trend which is currently observed on saltmarsh areas.

This erosion of salt marsh is a long term feature which started with the well-documented *Spartina* die back in the early part of the 20th century. These factors mean that the long term trend may be obscured, which potentially could cause problems for energy-type or equilibrium-based top-down approaches.

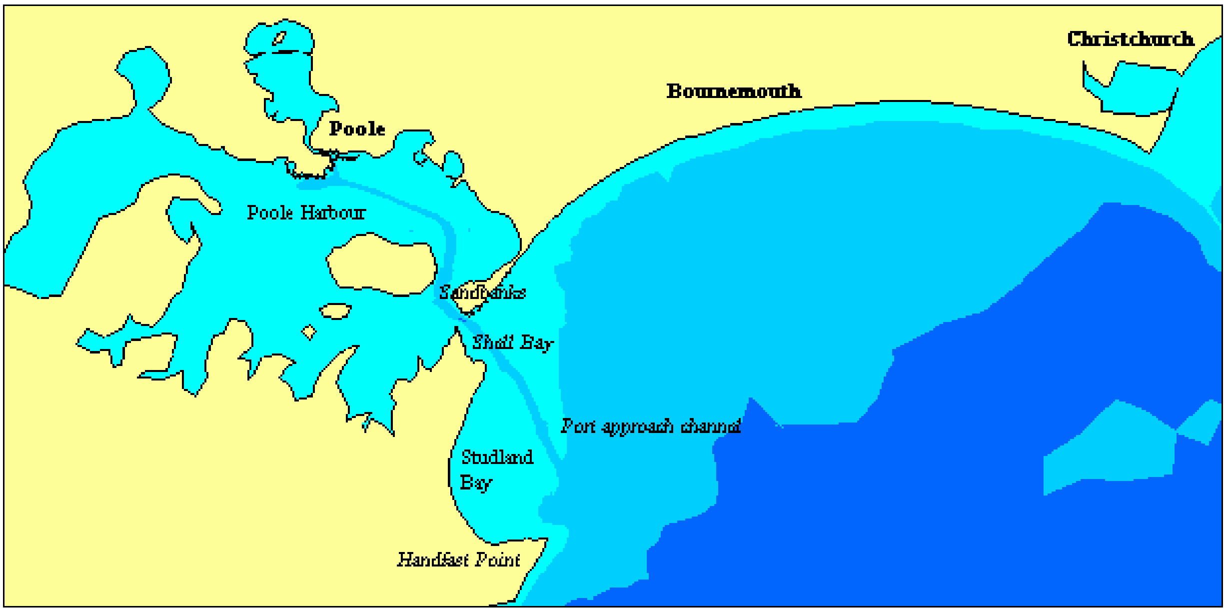

Figure 3. Poole Harbour on the south coast of England

The above information can be summarised in a flow diagram as follows:

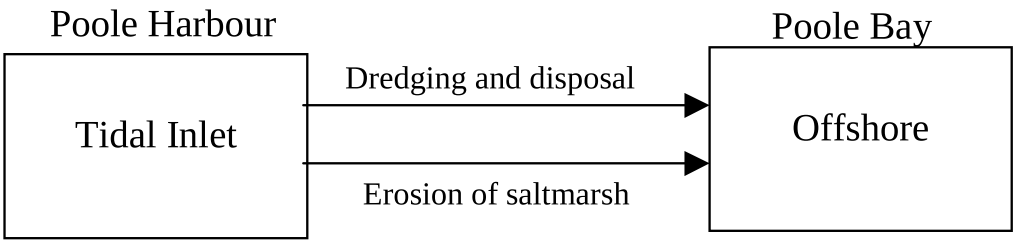

Figure 4. Summary of the key transport mechanisms in Poole Harbour

Data collection and analysis

This stage includes the following steps: fieldwork, analysis of new data and, on the basis of this new data, a refinement of the key mechanisms and their significance.

Computational model testing

Finalise choice of models

Tools for EGA can include the numerical flow, wave and sediment transport models associated with the numerical modeller, top-down models examined, hybrid models which seek to use both bottom-up and top-down considerations for morphological prediction, and simpler (bottom-up) predictive methods such as the use of standard flow, wave and sediment transport equations. Generally, top-down methods are more applicable to large-scale (estuary-wide) changes over the longer term and do not give information at the detailed spatial scale. In general, bottom-up methods are designed to reproduce short-term changes and can provide information at a detailed spatial level.

For the development of the conceptual model, these modelling tools are applied to investigate the current behaviour of an estuary system (or sub-system). The choice of models used will usually depend on data availability, the unknowns in the conceptual model; the history of studies in this area (i.e. have specific type of models been applied here before?); the experience of the investigator in specific models; and resources. The use of the more sophisticated models may require specialist experts to provide high quality model output. For more on this topic the reader is referred to Lawson and Gunn (1996), Cooper and Dearnaley (1996) and STOWA (1999).

Model set up, validation and calibration

The quality of modelling, and therefore of the benefits of model results for building up the conceptual model, is very highly dependent on data quality for both model inputs and for validation. It is possible to make very good use of model results based and validated on inadequate data if the output required is a broad answer accurate to an order of magnitude. However, if the answer is required to be correct to a high accuracy then this will only be achieved by good quality and abundant data and thorough calibration.

In sediment transport models, where there is site-specific calibration sand and mud transport, models can reliably reproduce the order of magnitude of sediment transport and the associated changes in bed level. However, in the case of sand transport, calibration means changes in bed level (bathymetric data or dredging records) and for direct calibration, measurements of sand flux near the bed (HR Wallingford 1996, 1997). Without calibration, the reliability of sand transport predictions of sediment transport is often no better than a factor of 3 (Soulsby, 1997) and potentially less reliable if the sand is mixed with a significant proportion of mud. Models that are not validated will still provide indications of areas of erosion and accretion but the reliability of the results cannot be verified.

Depth-averaged flow models provide copious amounts of data (assuming that 3D effects are not an important mechanism in the system). A reliable depth-averaged model immediately gives information about tidal variation, current speeds, places where fine sediment will potentially erode and deposit (essentially high and low current speeds), and the net direction of sand transport. The model allows much more spatially detailed assessment of processes and can provide a lot of information for input to top-down models.

Often, reliable and estuary-wide historical bathymetric data sets are rare, and rarer still with good complementary data relating to anthropogenic activities over the same timescale, and calibration of modelling approaches to reproduce historical change therefore is either unfeasible or unsatisfactory, thus limiting the application of certain types of top-down model. Moreover, confidence in the conceptual model will be reduced if top-down and bottom up modelling cannot be used to investigate historical scenarios. If there is sufficient data to evaluate the present trend (at least one recent and one older bathymetric data set) then there is increased uncertainty in the conceptual model (and thereby the results of predictive modelling). However, if there is only a single good quality recent bathymetric survey, a model cannot be calibrated against the existing trend and there is no way of knowing what the existing trend is, therefore compromising the conceptual model.

Sensitivity testing

Insufficient or unreliable data can only be optimised through sensitivity testing. In this way, it is at least possible to deduce the uncertainty in the model results and thereby to assess how reliable the conceptual model is and how reliable the ensuing prediction of estuary evolution is.

Sensitivity testing can take one of two forms:

(a) Varying the model parameters within reasonable limits and assessing the range of corresponding model outcomes. For some models this can be a constructive exercise which allows the range of outcomes to be limited within a usefully small range. For other types of model (e.g. mud transport models) the sensitivity to parameters is so high that the exercise is often not constructive.

(b) Varying the representative conditions used in the model – e.g. river flow, wave activity, tidal range, sediment type.

If sensitivity testing shows that the model outcomes are not sensitive then the model results can be relied upon. More often than not there is some sensitivity but this can be quantified and useful conclusions can still be made on the basis of the model outcomes. If sensitivity testing shows that the model is very sensitive then essentially the use of that model is compromised, but it may be used to compare qualitative outcomes between a range of model scenarios.

Box 2. Building confidence in model results
The Guide (EMPHASYS, 2000) suggests key ways to enhance the modelling results and build confidence in them and the resulting conceptual model: **Bottom-up models:** • Expect site specific calibration and validation and a measure of accuracy of the key variables; • Seek to understand the difference between model results and measurement. Both may contain uncertainty; • Seek to calibrate sediment transport models against sedimentation patterns (bathymetric changes and/or dredging records); and, • Where at all possible validate against historical records.
Top-down models: • Site-specific calibration is often unlikely for top-down approaches. Generic applicability may be demonstrable; • It is important to ensure that there is a physical basis for morphological change predicted by top-down models; • Are the results consistent for those of other similar estuaries? • Are the results consistent with other top-down approaches? • Be aware of the scope for error in the method; and, • Where at all possible validate against historical records.

Conceptual synthesis

Synthesis is where all the information available and relevant to the estuary system concerned is combined to produce a final conceptual model. This process can be time consuming. The conceptual model can have many forms and layers depending on the nature, scale and sensitivity of the problem being addressed but may include the following key aspects:

Interpretation of model results and data

The modelling, testing and collection of new data can give rise to many disparate pieces of evidence regarding the historical or present trends in the system. These require analysis, interpretation and piecing together.

Identify key and relative significance of mechanisms and concepts

The first step in using the results of model testing to refine the conceptual model is to identify whether the model testing and/or the collection and analysis of field data has led to a refinement of the key (top-down and bottom-up) mechanisms and their relative significance.

Underpin conceptual model with process

The basis for the top-down concepts and approaches vary considerably – some being more directly related to physical process than others. Those approaches and concepts of a more empirical nature, for example those which assume the presence of an equilibrium or which assume an energy related parameter approaches a minimum or maximum in the system, should be applied with care. Whilst top-down approaches are appropriate for considering the long-term trends in an estuary, when the small scale variation of specific physical processes may be less important, for short to medium term changes these methods may not be appropriate precisely because they do not consider the fine resolution temporal or spatial detail (Lamberti, 1988).

For short to medium term estuary changes, both top-down and bottom-up models and concepts should be used, and to justify the conceptual model by considering the key mechanisms from the bottom-up. Without a reference to the key mechanisms, confidence in the resulting conceptual model may be undermined.

Define and present conceptual model

When a robust conceptual model has been developed, it should be formalised into a description which can be conveyed to another party. This is not easy since the system may be complex and have a hierarchy of spatial and temporal scales (Townend, 2002). Forms which have been suggested and or implemented are:

- A flow-diagram approach (e.g. Capobianco *et al.*, 1999, Townend, 2004);
- A matrix approach (e.g. Townend, 2002); and
- A sediment budget approach (e.g. HR Wallingford, 2001).

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