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LONG TERM EVOLUTION OF COASTAL MORPHOLOGY AND GLOBAL CHANGE

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ABSTRACT

Long-term prediction of sediment transport and of morphological behaviour in the coastal zone, in response to human interference or to change in environmental conditions (collectively global change) is an increasingly important issue in coastal zone management, especially in relation to the needs for environmentally compatible development.

Having in mind those aspects of the response of the coastal system related to long term dynamics of coastal morphology, the paper briefly describes possible approaches to environmental modelling, particularly the modelling of coasts in a typical context of poor experimental information and process knowledge. These approaches will be of help in the impact and vulnerability assessment required for coastal zone management. Reference will mainly be made to long term modelling activities currently performed in the context of the MAST (Marine Science and Technology Program) morphodynamic project on coastal morphology and to possible approaches to "qualitative" modelling which may be used to define tendencies of evolution. It is argued that significant progress in long-term modelling can be made by adopting an appropriate conceptual framework, particularly a top-down approach. This involves formalizing knowledge and experience and integrating data and available models.

INTRODUCTION

Climatic change is expected to take place (IOC, 1992; IPCC, 1992) and it will likely affect coastal environment in terms of sea level rise, salinity increase and changes in temperature and weather patterns. This will have serious implications because coastal areas are very valuable in terms of natural resources and related economic activities. While there is a tremendous lack of information and understanding of the integral functioning of these systems, there is a strong need to determine possible morphological changes due to climate change and hence understand coastal vulnerability to climate change, such that informed decision making can be made.

This need for morphological predictions concern not only the behaviour of the coastline and its immediate surroundings but also the evolution of more complex coastal systems, such as estuaries and deltas, inlets and coastal lagoons. Considerable research is being focused on developing a preliminary predictive capability of such morphological evolution that may be used for planning and decision making.

In addition we have to consider that the transport of sediments and the resulting morphological evolution also interact with water and groundwater and with bottom quality aspects, hence the character of coastal ecosystems. Above all there is the ultimate effect on safety, on economic and social activities in the coastal zone. In other words the coastal zone is affected as a whole and not as a set of distinct physical, chemical, biological and social systems.

It is thus relevant to consider aspects of *vulnerability of the coastal environment* in relation to *global change* and particularly to the *long term evolution of coastal morphology*.

However, there are two distinct problems which greatly limit our existing predictive capability and introduce uncertainty about the future (ECOPS, 1993):

- a lack of sufficient long-term observations to give insights into the quantitative aspects of phenomena and mechanisms of interest;
- and limitations in our understanding of phenomena and mechanisms of interest at the proper scale with a consequent lacking of adequate and reliable response models.

Both for the ecological and physical systems significant modelling progress has been made during the last decade, but what is lacking is their integration and the definition of realistic boundary conditions derived from global climatic change, management policies and field measurements. This requires the adaptation of the physical-ecological models to long-term predictions, which is a true research task (processes acting at a short time scale may act as "noise" at a long-time scale, where other processes, negligible at a shorter term, may play a dominant role). At the same time it may be possible to improve the description of interactions and allow for more quantitative assessments.

Most of the available studies which address the vulnerability of coastal areas to climatic change are of a qualitative or at most semi-quantitative nature and are extremely site specific when it concerns their integral (basically physical-ecological) response including socio-economic aspects and feed-back (e.g: Delft Hydraulics, 1991; Nicholls et al., 1992). To a large degree this is due to the absence of reliable monitoring data and, to a lesser extent, due to the absence of integral response models. Thus in principle we have to deal more with qualitative rather than quantitative knowledge. What is needed and what we are doing is to define possible approaches to formalize as much as possible of the qualitative and semi-quantitative analysis and try to obtain quantitative assessments from it.

Previous modelling work has tended to focus on particular geographical components of the coastal zone, such as models of vegetation succession, land-use runoff, river transport, estuarine circulation, water quality, and coastal ocean hydrodynamics. Such studies are necessary and appropriate in the early stages of model development. As a next necessary step it is required to begin linking these components into unified coastal system models. While process knowledge is not yet sufficient for such an integration using classical approaches, qualitative and semi-quantitative knowledge and experience can be usefully employed. In addition, recent developments modelling "fuzzy" defined systems, and in our ability to couple GIS (Geographic Information Systems) technology to simulation models, have eliminated some of the practical barriers to achieving such a synthesis.

NEED FOR VULNERABILITY ASSESSMENT

There is a need for methodologies which can be used to describe the complex interactions between the resource system and its potential users. Coastal Zone Management (CZM) aims to plan and control this process in a systematic and sustainable way, including present and future problems in the coastal zone and finding a balance between economic welfare and environmental well-being. This may be achieved by using a careful analysis of the natural processes and socio-economic developments (EUCC, 1993; ECOPS, 1993). A central role in CZM is played by the evaluation of impacts and vulnerability (Fig. 1).

In order to evaluate coastal vulnerability, the object (or the coastal function) of the assessment has to be defined and the response of that object to changes has to be identified.

As an example, if we refer to the onshore coastal strip extending landward from the beach, the area, either urbanized or under cultivation, can be damaged during severe storms or exceptionally high water. Its principal defense from natural hazards is represented by morphological elements of emerged and submerged beaches and by maritime structures. In this way we qualitatively define the object, a class of possible forcing causes and a set of mitigating aspects.

Because of higher relative sea level rise, estuaries and deltaic wetlands will be affected earlier by an acceleration in eustatic sea level rise (Stevenson et al., 1986). In Europe several estuarine systems have disappeared and the remaining systems are impaired and polluted. The restoration of estuarine systems requires enhanced knowledge of the physical, chemical and biological response of estuaries to disturbances. In particular, deltaic wetlands may serve as models for the effects of sea level rise in other coastal systems.

Rising sea level will first affect regions with low tide range such as the Mediterranean because the elevation range of coastal vegetation is related to tide range (Jeftic et al., 1990; Sestini et al., 1989; Sestini, 1993). Sea level rise, salinity increase and changes in weather patterns and temperature will have serious implications on Mediterranean deltas in terms of agriculture, natural resources, and tourism, etc (cf: Arcilla et al., 1993; El-Raey et al., 1993). These deltas are extremely vulnerable to climate change because they are already sediment starved (mainly due to river regulation), the coastal fringes are eroding and the direct hinterland is very near present sea level. Consequently, slight increases in sea or storm surge levels have the potential to flood and breach large areas. In addition, the vertical growth range of coastal marsh vegetation is small because of the low tidal range. This means that slight increases in mean sea level will relatively quickly lead to inundation and deterioration of significant areas of wetland vegetation (Stevenson et al., 1986). Additionally, and because of Mediterranean weather characteristics, any change of weather pattern may dramatically affect the occurrence of episodic events, such as storm surges.

Coastal recession is a global problem: it is estimated that 60-70 % of the world coastline is subject to ongoing erosion. Low lying areas in the world are becoming more vulnerable to flooding as a consequence of subsidence and coastal erosion. Inland changes in river basin management and land use often affect the coastal morphology as a result of changing sediment loads. Changing discharges of fresh water and nutrients also have repercussions on the coastal ecosystem. Another issue is in fact the stability of the ecosystem in the coastal seas and the possibility to maintain biodiversity. What is the sensitivity of coastal ecosystems to natural changes and to human interventions? What are the regional effects of global change, and how can they be identified? (IGBP, 1993).

The starting hypothesis is that these systems can continue to exist in the face of rising water levels and weather changes if there is sufficient supply of sediments to the system. Another general hypothesis is that sensitive coastal areas can be managed to withstand significant rates of sea level rise by enhancing the natural functioning of coastal fringes (e.g. promoting natural dune formation, uniformity of longshore transport, etc.) and ecosystems (e.g. primary productivity, fisheries, material processing, interaction among subsystems, etc). An adequate CZM framework and tools of analysis are needed for this purpose.

The above problems have also been identified in recent international studies such as IPCC (Intergovernmental Panel on Climate Change) and IGBP (International Geosphere Biosphere Programme). In order to respond to these problems it is necessary to elaborate and implement strategies for a sustainable development of coastal zones (IPCC, 1990; IPCC, 1992). A major barrier to the elaboration of adequate strategies is the limited capability of present research tools to predict effects at large time and space scales (IGBP, 1993; ECOPS, 1993). The idea defined by the IPCC working group on CZM was to establish a Common Methodology to assess coastal vulnerability to accelerated sea-level rise since it is important to have a balanced and objective method to handle the information (IPCC, 1992). They developed a seven step "procedure":

- delineate the case study and specify sea-level rise boundary conditions;
- inventory study area characteristics;
- identify relevant development factors;
- assess physical changes and natural system response;
- formulate response strategy and assess their cost and effects;
- assess vulnerability profile and interpretate results;
- Identify relevant actions to develop a long term CZM planning.

Assessment of vulnerability represents an indispensable step in calculating coastal risk and identifying priorities in coastal studies and coastal interventions. Its definition and quantification in a coastal environment is not simple and is highly subjective and depends critically on the availability of data. It is then important to clearly define the subject of vulnerability, i.e. which are the coastal function or values being impacted and how.

The vulnerability profile can be further specified by including subtopics and introducing a "space dependence" obtained identifying and grouping similar coastal stretches on the basis of their physical environmental characteristics (Dal Cin and Simeoni, 1989). Rapid and low-cost methods for assessment in large coastal areas may be based on survey techniques, like the "Aerial Videotape Assisted Vulnerability Analysis" described in (Nicholls et al., 1992). In what follows we examine the possibility to obtain quantitative evaluation of vulnerability by including more knowledge about the coastal system.

INTEGRATED MODELLING

We start from two basic observations:

- precise quantitative functioning of coastal systems and their response to climate change is poorly known, largely because of a lack of long-term observations of their behaviour and response;
- we are considering large and complex systems with many interacting components.

Thus we need to develop a conceptual model which allows us to handle the existing links. The optimal use of any existing field observations as an input to the conceptual model development and validation is also crucial. The necessary building blocks of a conceptual model, to be eventually translated into information bases, can be summarised as follows:

- *data*, resulting from monitoring and experimental activities;
- *information*, built up from collection and analyses of a data set;
- *knowledge* on the processes characterizing the environmental system under examination, resulting from the interpretation and description of data and information;
- *experience*, the knowledge obtained and expressed at a more empirical level, typically formalized in a linguistic form and generalized at the level of reasoning processes.

Data are seen as basic tiles in the construction of information about the processes or about the system to which the they refer. Their intrinsic information content is variable and a function of their practical significance. *Information* is generated by the interpretation of sets of data in relation to their physical meaning. The collection of information results in a growth in *knowledge* that can be formalized up to the implementation of new (computational) tools able to give a higher and different information content from the data themselves. *The experience* collects a set of rules produced by various field experts in the domain of the problem "management of the coastal area" and a set of "facts" expressed with data, information and knowledge.

In the field of long term and large scale modelling of complex interacting systems, we may rely on experience and knowledge rather than data and information. This means that we may use a qualitative, rather than quantitative approach concerning functioning and interrelations.

We consider a possible a top-down modelling approach. Starting from the definition of possible impact categories it is possible to define what has to be observed from the model, i.e. the "matrix of output variables". Socio-economic aspects, in this phase, or at this level, refer to the definition of priorities, the assessment of intervention plans and the establishment of management scenarios to cope with climatic and global change effects and to allow for a sustainable development.

It is only at the lower level that it is required to develop linked and spatially distributed physical (e.g. morphodynamic), ecological models. The link between the two levels is represented by the available "qualitative knowledge" about each system and about their interrelations. We expect also the major part of interrelations between physical and ecological systems to be specified at this intermediate level. Schematically, this results in the scheme shown in Fig. 2 for the conceptual approach.

In general, a distinction can be made between the physical system oriented and the ecological system oriented efforts. The physical components include hydrodynamics, sediment dynamics and morphodynamics, while the ecological components concern the dynamics of wetlands, aquatic habitats and agriculture. Both components can be developed independently in parallel efforts and then the output from the physical system functioning will be used as an input forcing to the ecological system functioning.

In our view the problem should be approached at the first two levels. Using the current knowledge of coastal behaviour as a basis, a conceptual model of various coastal system dynamics (functioning) can be formulated. This conceptual model can incorporate as many quantitative and predictive sub-modules as possible using existing generic (state-of-art) models of physical and ecological response to changing boundary conditions on large spatial and temporal scales.

The resulting set of models can be used to address questions about the functioning of the system and impacts of different intervention and management scenarios.

MODELLING THE PHYSICAL SYSTEM

Local (or relative) sea-level change includes any uplift/subsidence of the coastline as well as rates of change of eustatic sea level. The impact of local sea-level rise, moreover, will be affected by the influence of climate change on wind patterns, wave fields and coastal circulation. Rates of subsidence, particularly in low-lying coastal areas, can be many times greater than the rate of global sea-level rise, and are greatly affected by human activities (Milliman et al., 1989), both directly (e.g. by extraction of water, oil or natural gas) and indirectly (e.g. by dams and other river management practices, causing sediment-starvation of deltas).

A coastal manager deals with relative sea-level rise, so this needs to be defined (Nicholls and Leatherman, 1993). Tide-guage measurements of mean annual elevation are still the most commonly used method to determine local sea-level change, but meaningful change using this technique can only be delineated over tens of years, thus marking it harder to define short-term accelerations in the local rise or fall of sea level. New, more sensitive techniques, are clearly needed. Moreover, spatial variations in local sea level must be known in order to predict large scale changes to coastal systems. Global positioning system (GPS) technology may be useful in this regards.

Physical modelling will firstly concern marine hydrodynamics and river hydraulics and hydrology. The results will provide boundary conditions for morphodynamic and ecosystem modelling. Present and future marine hydrodynamics, as determined by relative sea-level rise, and changing weather patterns and temperature, could in principle be derived by adapting and using state of the art models (Horikawa, 1988). Specific attention should be given to salinity intrusion. Hypotheses to be tested include the effects of river discharge, wind, mean water-level, tide, waves and bottom sediment types on the circulation (with emphasis on stratification and mixing) and wave regime around sensitive areas. These sea and river induced conditions will provide boundary specifications for the ecologic modelling (e.g. spatial and temporal variability of advective currents), and at the same time will be used in the morphodynamic modelling of coastal areas. Much work is in progress on long-term coastal modelling. (De Vriend et al., 1993) describes the state-of-the-art in long term coastal morphodynamic and sediment transport modelling and defines a strategy for further developments. Long-term generalizations are a research task which is far from trivial, considering the very different roles played by one specific process depending on the time and space scales.

When we are in the difficult position of trying to meet the demand for long-term morphological predictions, the available knowledge is:

- short term processes knowledge based on first physical principles
- empirical knowledge based on few observations, similarities, and intuition.

Traditionally these two sources of information have been separated: a study and a model development was either approached from the empirical end or from the process-based end.

More recently another line of thought has come forward: *behaviour oriented modelling.* The idea is to take the behaviour of a coastal system, either observed in the field or using process based model runs with real life input conditions, and map it onto a simple mathematical model which exhibits the same behaviour. This model does not need in principle to have any relationship with the underlying physical processes. The term behaviour has a restricted meaning in this context: it does not refer to the morphological evolution in its whole complexity but only to certain aspects.

Most large-scale coastal problems are associated with complex systems like estuaries, delta and tidal inlets. The amount of sediments which circulate in these systems is often much larger than those moving on an uninterrupted coast. A variety of process based models may be applied to such systems, with very useful results from a diagnostic point of view. Their predictive value, however is still limited, either because they only describe the residual transport field and ignore morphodynamic interactions, or because they include only part of the relevant physical processes. On the other hand, there is a wealth of field information on tidal inlets and well mixed estuaries, in the form of well established empirical relationships between the equilibrium state of large-scale morphological units and properties of the tide as a forcing agent. This approach may also be applied in such a way as to be able to handle situations where qualitative information is available.

In summary, the objectives of the physical system oriented modelling (both process based and behaviour oriented) are:

- To develop hydrodynamic and morphodynamic model concepts for coastal systems and large time and space scales;
- To verify and calibrate these dynamic models by comparison with experimental data;
- To utilize these models to gain insight into the coastal system response for different "forcing" situations;
- To provide hydrodynamic and morphodynamic inputs for the ecological models;
- To provide the basic information concerning vulnerability.

MODELLING THE ECOLOGICAL SYSTEM

Climate and global change will of course affect the ecological component of the coastal system in a direct way. We are however more interested in those changes induced by a changing morphology. Changes in sediment budgets, in addition to fluctuations in sea-level, affect the state of coastal ecosystems (e.g. mangroves, marshes, sea grasses, etc.), which in turn influences sediment retention and coastline geomorphology. The significance of biological interactions is often ignored, mainly because of the lack of precise information regarding the rates of supply of terrigenous and biogenic components to coastal systems, as well as the role of coastal biota in trapping and affecting the cohesiveness of sediments. Future work should focus on the interaction of major ecosystem types with the sedimentary environment, as well as assessing the implications of ecosystem perturbations on coastal stability given a rise in sea level (IGBP, 1993).

Especially in coastal ecosystems, with active benthic systems, there are other feedbacks from ecology to hydrodynamic and sediment transport processes which make it necessary to directly couple complex ecosystems models to morphodynamic models.

Thus, the role of ecosystems in determining coastal geomorphology needs to be investigated (IGBP, 1993). The interactions between sea and land as they affect coastal dynamics are the result of a complex set of processes and responses. The external driving forces are susceptible to change by direct and indirect consequences of human activities at local, regional and global scales, of which climate change is the most obvious. Before anthropogenic changes can be addressed, however, the relative importance of various sediment sources, the effects of changes in relative sea level, and the effects of the wave/wind field on coastal erosion and accretion must be better defined, particularly with respect to episodic events, such as floods and storms. Moreover, an understanding of the role of biological processes in sediment trapping and sediment cohesion is necessary.

Modeling will serve as a tool in formulating and testing complex ecosystem hypotheses, direct future research efforts, making specific predictions about the impacts of major changes in the system (natural and management), and, in the process, advancing the state of the art of ecosystem modelling. There will be a close interaction between modeling efforts undertaken for distinct but interacting physiographic units. Hypotheses concerning both the functioning natural system and the impact of natural and human-induced changes have to be fixed. Because these processes are complex, interdependent, and scale dependent, a suite of models capable of simulating the various processes and their interdependencies in both space and time and at several different spatial and temporal scales is necessary.

Ecosystem simulation models may be developed and tested at two levels of spatial scale:

- individual habitats in the (wetland, agriculture, beach/dune, etc);
- a spatial model of a specific coastal area consisting of a grid of cells.

Spatial landscape models have been developed for the Mississippi delta over the last two decades (Costanza et al., 1988). The development of spatial ecosystem simulation models for the Mississippi delta was aimed at predicting long term habitat succession and horizontal water and material fluxes. They have been applied to practical management problems such as the construction of levees. Other wetland models (Mitsch, 1988) have been quite successful in reproducing historical data and predicting impacts for various long term scenarios (i.e. sea level rise, river switching). New approaches to long term habitat and population succession are also the object of study under the label of "structural dynamic models" (Jorgensen, 1990).

A fully integrated spatial landscape model could be based on a cell division of the study area. Each cell in the grid will contain a copy of the individual unit models developed above. Unit model equations will be integrated into the spatial grid. Different levels of aggregation of these unit models can be evaluated to determine an optimal compromise between accuracy and manageability. Such cell models will naturally interface with raster-based GIS databases.

Special emphasis has to be paid to physical/ecological interactions and feedback. The objective is to predict major changes in habitat distribution in the area. It has to be considered that whenever we move from one physiographic unit to a space dependence inside it, the result will become much more sensitive to parameters. As we go deeper into the definition of details, so the model becomes more data demanding.

QUALITATIVE MODELLING

In the context of CZM, vulnerability assessment is strongly linked to socio-economic value assigned to coastal components. These values will assist in the selection and interpretation of the intervention and management scenarios which will be proposed to cope with the changing boundary conditions (sea level rise, climatic change, human interference).

Vulnerability profiles can also be used to define a framework of analysis: the time-evolution of the coastal system (as predicted by the physical and ecological models) can be compared with a preferred evolution. If the predicted evolution deviates too much from the preferred one, a policy (set of technical and non-technical measures) is formulated, developed and implemented in order to influence the coastal system. The effects of these measures may be expressed in terms of costs, area of accreted land, habitat improvement, space for recreation, area for industrial development, etc.

In a management situation a rapid analysis of processes is necessary. For this task, the environmental engineer behaves as an expert. Judgement criteria and rules of action, progressively constructed through experience are applied to the available data and information. Data and information are translated into qualitative terms to become the basis of reasoning. For instance a time evolution curve of a parameter will be analysed according to its tendencies (increase, decrease, steadiness), at a certain level (high, low, medium), and with a certain speed (fast, slow), or according to its general shape (a set of fundamental shapes or patterns could be identified from experience). Similarly, cause-effect relationships can be specified by identifying the direction of influence of one variable on another (positively affects, negatively affects).

A *qualitative approach* answers some of the problems of integrated environmental modelling, where one can have a clear understanding of a situation without attempting to formalize it as mathematical equations, and where the problem of utilizing both quantitative and qualitative data is always set up. In a qualitative approach we start identifying the components and the fundamental laws governing them and then to derive and explain its behaviour.

Abstraction is the crucial step in model building. In the case of qualitative modelling this step is even more important than it is for quantitative models. In qualitative versus quantitative models that emphasis shifts from precisely measuring parameters to recognizing as many of the relevant variables and their possible associations and grouping as one can. This means going beyond the knowledge of a single academic discipline. Furthermore it means asking questions about the subject in a different way. Above all, the qualitative approach to understanding nature requires more thought about nature itself than about the model details; it is relatively uninterested in precision and it is always represented by *more than one model.*

Giving an interpretation is therefore based on subjective appreciations varying with goals and context. It is a high level approach which integrates global knowledge, simplifying the complexity of the real world to make it understandable and controllable. We expect the representation of such knowledge to contribute in filling the gaps in physical and ecological process modelling. We believe that there is room for a complementary approach aimed at computing all the information available on the system, including the part that is too difficult to formalize as classical mathematical equations. Further, it can be argued that without this complementary approach, the best management solutions will be difficult to identify.

Qualitative modelling is an attempt to formalize in a guided way knowledge and experience (De Kleer & Brown, 1984; Kuipers, 1986). We may consider the definition of the following "objects" as fundamental in this approach:

- *Relationships between qualitative variables*, identification of elementary inferences and possible causes and consequences;
- *Conceptual representation* and definition of a causal influence network;
- *Quantity Space*, a finite set (of symbols) where each variable takes its value;
- *Transfer Rules*, to translate numerical values into qualitative values, to translate linguistic observation into qualitative values, to permit qualitative relationships between variables;
- *Knowledge formalization*, definition of a set of cause-effect relationships according to the transfer rules;
- *Qualitative translation of measurements and observations* where, for a given variable, a "value" is chosen in its quantity space (this is the interface with the quantitative world);

- *Qualitative calculus* where, in relation to the science involved in the model, a set of possible operation is defined.

The simplest situation we can imagine is represented by the use of a signed graph representation where the possible symbols are:

- (+) for increase,
- (-) for decrease,
- () for stationariety.

The possible relationships among variables are chosen in the same set:

- (+) for positively affect,
- (-) for negatively affect,
- () for no affect.

What is particularly interesting in this case is that matrix computations can be applied to analyse the graph (and the model) characteristics (see Puccia and Levins, 1985). This formulation is particularly useful to gain insights into the "tendencies of evolution" for systems in local equilibrium, moving equilibrium or "sustained bounded motion" where some periodical forcing is applied. It is practically equivalent to a stability analysis for a system in equilibrium. A good introduction to the topic is given in (Kalagnanam, 1991).

Fig. 3 is an example. Sea-level rise has a positive effect on erosion, which has a negative effect on dune stability and coastal vegetation and a positive effect on salinity of the groundwater. Coastal vegetation has a positive effect on dune stability and a negative effect on erosion, and so on. On each variable a negative feedback is applied, which means that in principle the variable is bounded by other "processes" not considered in the model.

At the level they can be specified, qualitative models may play an important role in testing hypotheses and verify assumptions about the effects of a variation induced to one variable. This means that instead of one model, a number of models will exists. A successive approximation scheme for qualitative model development could be defined as follows:

- begin with very few variables and (possibly) known links;
- add one variable and/or try all kind of possible connections where the model predictions are ambiguous or not satisfying;
- determine the "most correct" connections on the basis of model results and of any available "data and information";
- repeat previous steps for variables that seem important to be included on the basis of a priori knowledge.

Of course as far as we move further in the definition of the relationships between variables and in the formalization of knowledge we implicitly enter the field of expert systems. Moreover when we move from the level of the description and comprehension of the coastal dynamics to the vulnerability assessment level and to CZM level, we deal with a framework of analysis suitable for a possible implementation in a decision support system (DSS). The DSS can represent a structuring element in the top-down modelling approach. It may implement the framework of analysis for coastal management and represent a support tool for the utilization of the suite of detailed models together with the available set of data.

The vulnerability profile can guide the developments in integrated modelling and can list priorities to be considered in the qualitative models development. We expect most of the qualitative modelling to be developed for the ecological system and for purposes of integration. The physical system oriented modelling, namely the morphodynamic modelling, should be quantitative as much as possible. This is necessary, because of the importance of the definition of the driving forces in the coastal zone, and it is realistic, given the amount of research currently in progress. In order to be confident about their response, the results will be however considered mainly in qualitative terms. The final result can be a software structure (let us say: an information system) as depicted in Fig. 4. We consider a knowledge based system able to handle the set of available models, and the available data, information and knowledge.

CONCLUSION

Our general starting hypothesis is that the coastal environment can be managed to withstand significant rates of sea level rise by making suitable use of natural processes and, in particular, enhancing natural morphological characters and natural ecosystem functioning. In order to do this it is necessary to start "thinking in an integrative manner".

A suitable opportunity to test the outlined approach may be represented by studies eventually undertaken for Mediterranean Deltas, given their relevance and their significance.

In particular we deem it necessary to combine use of available field measurements (accretion, sedimentation, soil formation, coastal response) with an integrated (physical/ecological) spatially distributed conceptual model of the overall behaviour, with a central role played by morphology in response to global change.

It is argued that significant progress in long-term integrated modelling can be made by adopting an appropriate conceptual framework, particularly a top-down approach. This formalizes knowledge and experience and then integrates data and available models. In particular, to gain insights into the integral functioning of the coastal system, we see the possibility of integrating the few quantitative models available with qualitative models still to be developed. We implicitly assume that, even if we cannot rely on the quantitative aspects of the response of the available models we could at least be confident about the qualitative aspects. Considerable work is necessary to translate the available information into the qualitative reasoning schemes that may help us with the vulnerability assessments and coastal zone management.

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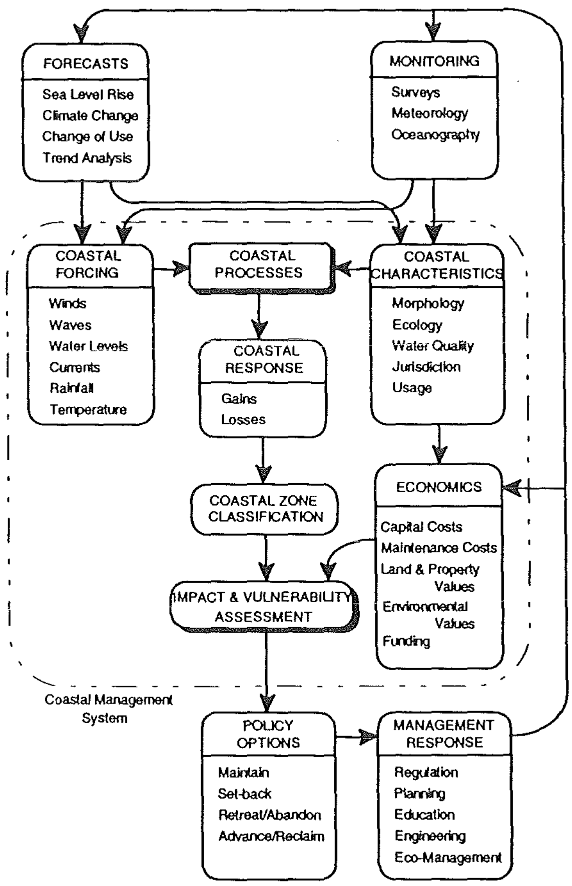

Fig. 1 - Integrated Coastal Management Framework (Modified from Townend, 1990)

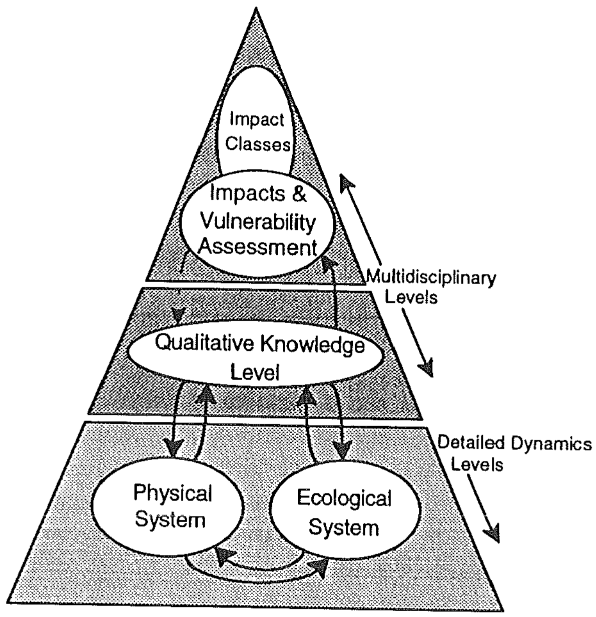

Fig. 2 - Top down modelling

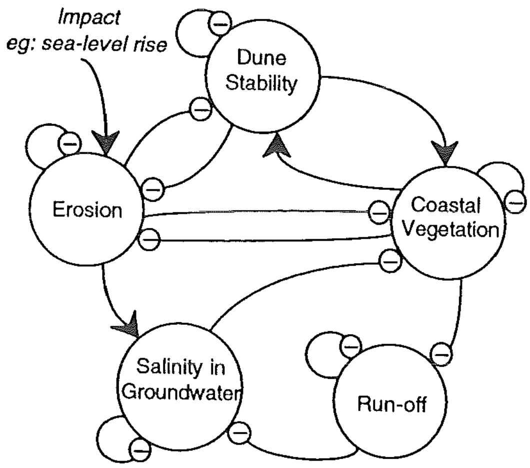

Fig. 3 - Qualitative Model for Shift from Equilibrium

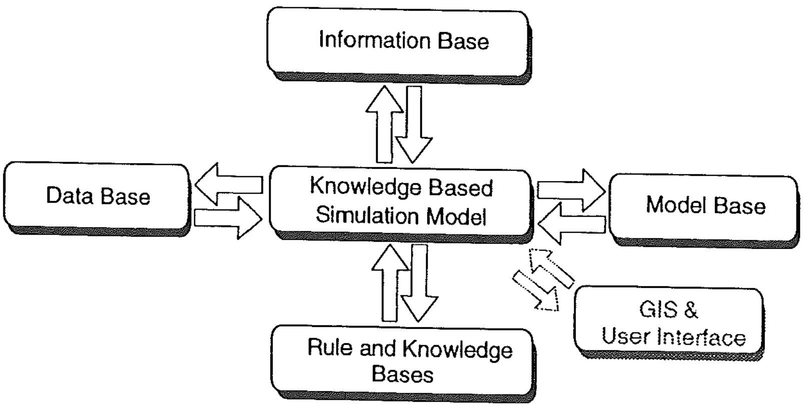

Fig. 4 - Framework for Integrated Modelling