

SUMMER SCHOOL

ON

**Environmental Impact Assessment
and Management of Coastal Zone:
An Integrated Approach**

7 – 27 August, 2001

**Central Institute of Fisheries Education
(Deemed University-ICAR)
Versova, Mumbai**

EIA MODELLING FOR CZM APPLICATIONS (PART –I)

P. Vethamony and M. T. Babu

Introduction

Human life depends on healthy ecosystems, which supply life-sustaining resources and absorb wastes. However, current growth of industries and consumption patterns place increasing stress on ecosystems. Environmental degradation, bio-diversity loss, deforestation, and the breakdown of social and economic systems are a few of the signs which indicate that ecosystems are under stress.

Ecosystems threatened by over-harvesting and/or overwhelmed by more wastes than can be absorbed lose the ability to absorb shocks and disturbance and may suddenly break down and/or settle into a different system with less resilience. This implies that there are thresholds at which the levels of stress can lead to disruption of the system. Pollutants are released into the marine environment, where they cause more rapid growth of algae, bacteria and other species and even change the environment.

Environmental models are the scientific tools to bridge the gap between the understanding of the complexity of nature and the need to predict its behaviour due to impact by man.

Environmental modelling is an integrated part of environmental impact assessment studies. These studies can be a part of infrastructure projects, cooling water studies, urban sewage master plans, wetland restoration and tourist site developments. Hydrodynamic and ecological modelling is also becoming a part of operational monitoring activities which can reduce expensive monitoring costs, increase time and spatial data coverage and add a predictive capability to the monitoring.

Environmental models are used to find a proper solution to environmental problem. The use of environmental models for tackling environmental issues is rather a new field. The results of the models can be used to select environmental

technology best suited for the solution of specific environmental problems and accordingly, environmental management plan can be set up.

Basic environmental modelling

- Various mathematical operations enable us to predict the environmental changes, when the external parameters are changed.
- Linear models (first order equations) have simple mathematical formulation.
- Non linear models (higher order equations) contain hyperbolic or exponential expressions.
- Any environmental model must have atleast the following 5 components:
 - (i) forcing functions – any external driving force that influences the environment – when the forcing function changes, the ecosystems will also change.
 - (ii) state variables – it is the state of the system any environmental – model will have a no. of state variables. For example, in an eutrophication model, phytoplankton and nutrients are state variables.
 - (iii) mathematical equations - processes (physical-chemical-biological) are represented in the model as mathematical equations. These relate (i) and (ii) above.
 - (iv) parameters involved – required physical, chemical, biological, atmospheric and other environmental parameters.
 - (v) various constants.
- Reliable measured data and sound knowledge of various physical, chemical and biological processes are very essential to set up good models. Sensitivity analysis to be carried out to the model before calibration. Models should be calibrated and results should be validated using measured data. Calibration and validation carried out for the hydrodynamics of Gulf of Kachchh will be explained during the lecture.
- Parameters are to be estimated either by field measurements or lab experiments and they are not error free. As these errors are carried through into the model, they will contribute to the uncertainty of the prediction, derived from the model. Hence, in order to derive accurate model output, reliable input data have to be provided.

- Simple processes in the ecosystem are described as changes of a state variable in time or space, taking into account the principle of mass and energy conservation.
- The most ambitious goal in environmental planning is, to construct models that simulate nature to that extent, that reliable predictions of the response from a system due to changes in stress are possible.

Representation of processes in mathematical modelling

Only basic processes are mentioned:

- pollution problems are caused by an anthropogenic transfer of mass and/or energy to the ecosystems. The transfer and transport processes are of physical nature.
- the relation between the concentration of a component in an ecosystem and the effect on the biota is a biological process.
- many components undergo chemical reactions in the ecosystem such as oxidation, reduction, hydrolysis, photolysis, etc. – chemical processes.
- transport processes:
diffusion is one of the most basic processes in transport, which accounts at molecular level; diffusing phase is to all states, but dispersing phase is most often to liquid or gas.
- If we consider mass balance of diffusion,
accumulation = mass in - mass out

$$\frac{1}{dA} \frac{\partial m}{\partial t} = \left(-D_m \frac{dc}{dx} \right) - \left(-D_m \frac{dc}{dx} \right) \text{ along x direction}$$

m = mass, dA = area = $dy \cdot dz$, D_m = mol. diffusion coefficient,
 c = concentration

For the general 3D case the equation can be written as,

$$\frac{dc}{dt} = D_m \left(\frac{\partial^2 c}{\partial x^2} \right) + \left(\frac{\partial^2 c}{\partial y^2} \right) + \left(\frac{\partial^2 c}{\partial z^2} \right) = D_m \nabla^2 c$$

when both advection and diffusion occur, the effect of the two phenomena are additive.

$$\frac{dc}{dt} = u_x \frac{dc}{dt} = D_m \nabla^2 c$$

where u_x is flow rate (currents), ∇ is an operator

ions in water is thermal diffusion

salts and gases in water is mol. diffusion

vertical diffusion is turbulent.

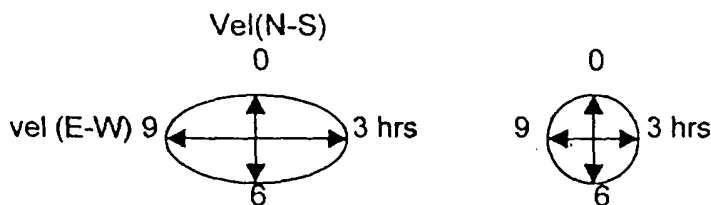
Transfer and transport process is a major environmental interest.

Important factors which control the movement of wastes in tidal regime:

- tidal excursion – an approximate distance a particle will travel along the main axis of an estuary in going from low to high water or vice versa

$$x_{te} = \frac{2}{T} (\bar{U}_{max}) \left(\frac{T}{2} \right) \quad T\text{-tidal period; } \bar{U}_{max} = \text{avg. max. tidal velocity.}$$

- if the current reversal is marked, it contributes substantially to the mixing of waste effluents.
- the non-sinusoidal nature of the reversal - period of ebb is different from period of flood.
- if freshwater influence is more, ebb period will be greater than flood period
- rotary tidal currents: tidal currents in open offshore waters move about a point in circular direction or elliptical pattern, depend on velocity along E-W and N-S directions.



- what will happen to the waters released at such tidal regimes? However there may be superimposed a net current drift

- vertical current structure (especially different levels at different directions) is significant in the transport of wastes.

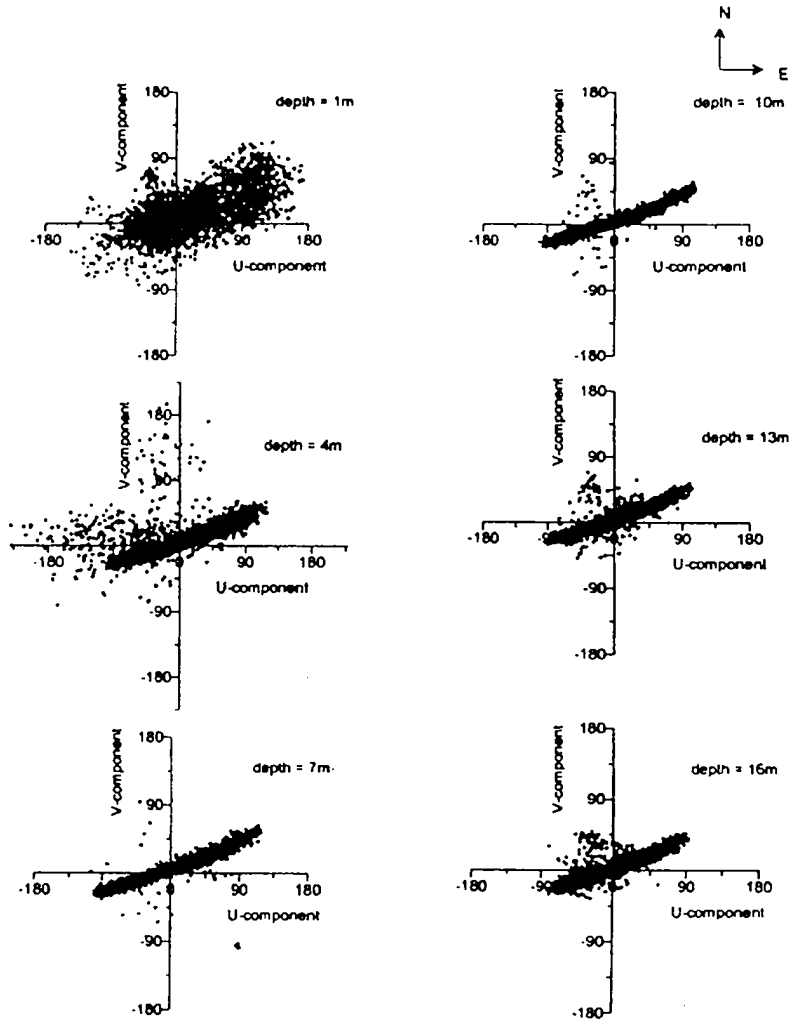
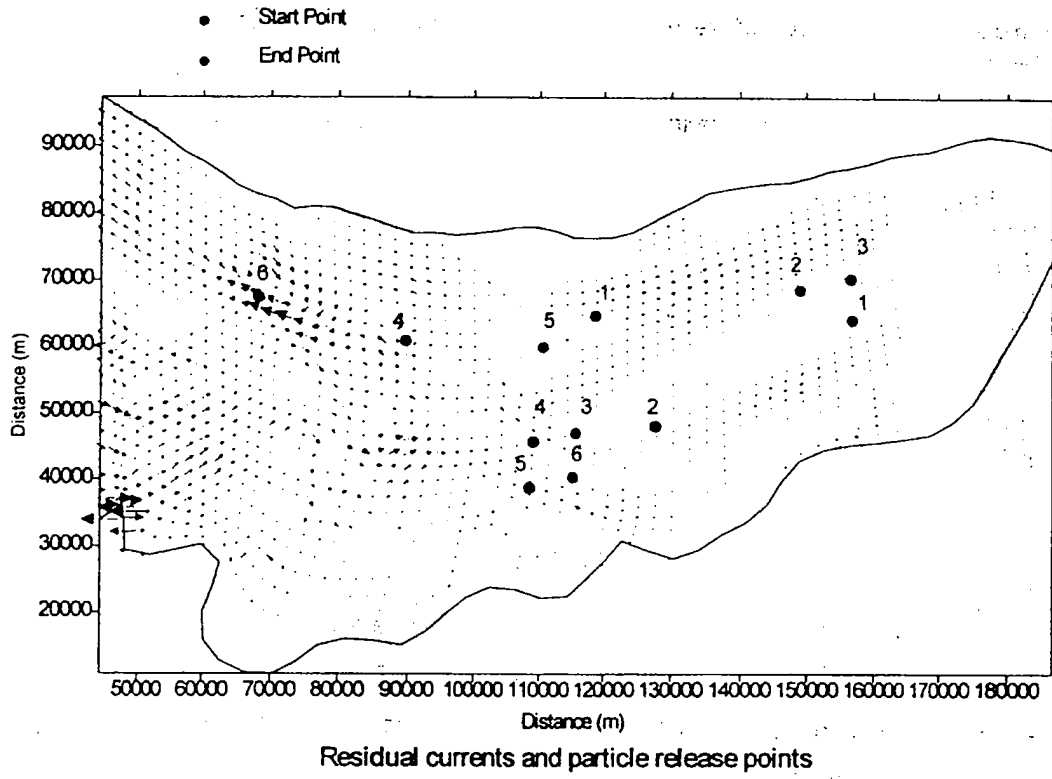
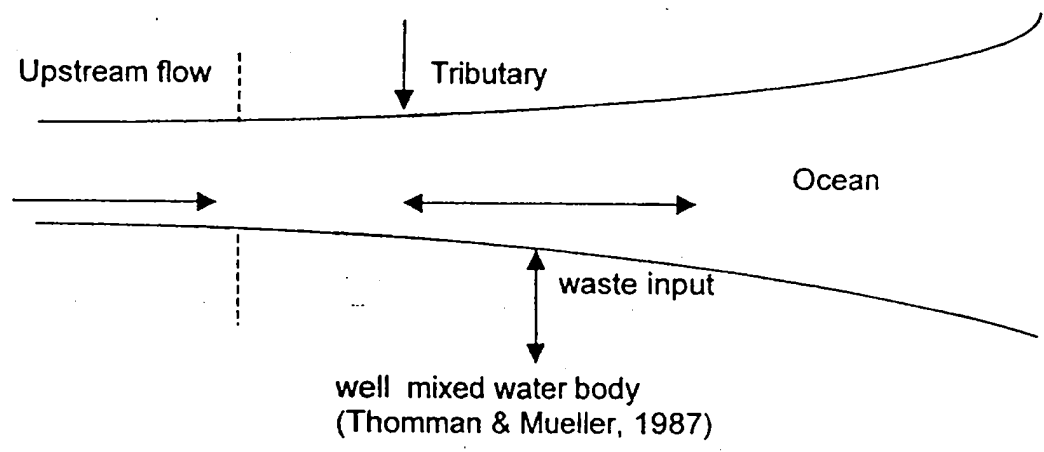


FIGURE 3 Vertical current pattern off Sikka

- The net flow over a period of several days or weeks flushes materials out of a given water body and is a significant parameter in the estimation of water quality of the water body.

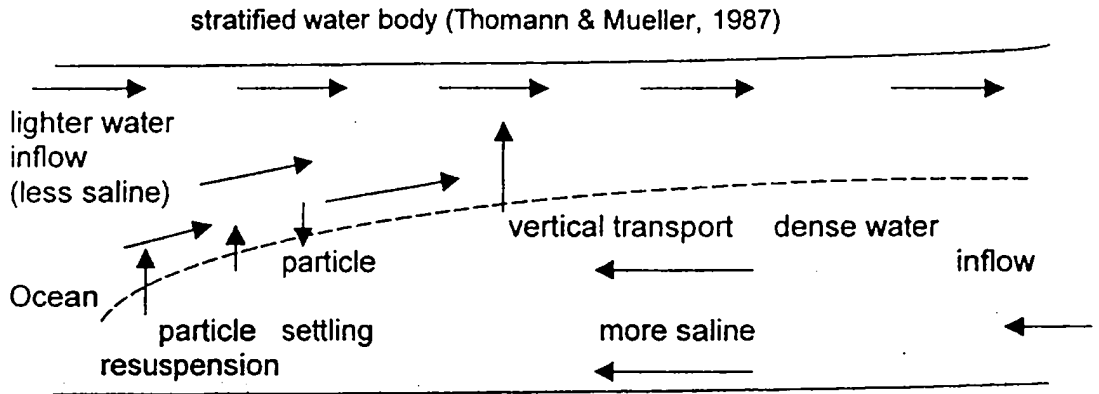


- If the estuary is well mixed (vertically and horizontally), then the net flow at any location in the estuary is approximately equal to the sum of upstream external flow to the estuary. Therefore this flow must, on balance, be leaving the estuary at any cross section. This is typical of an estuary that has oscillatory tidal flow in one direction.



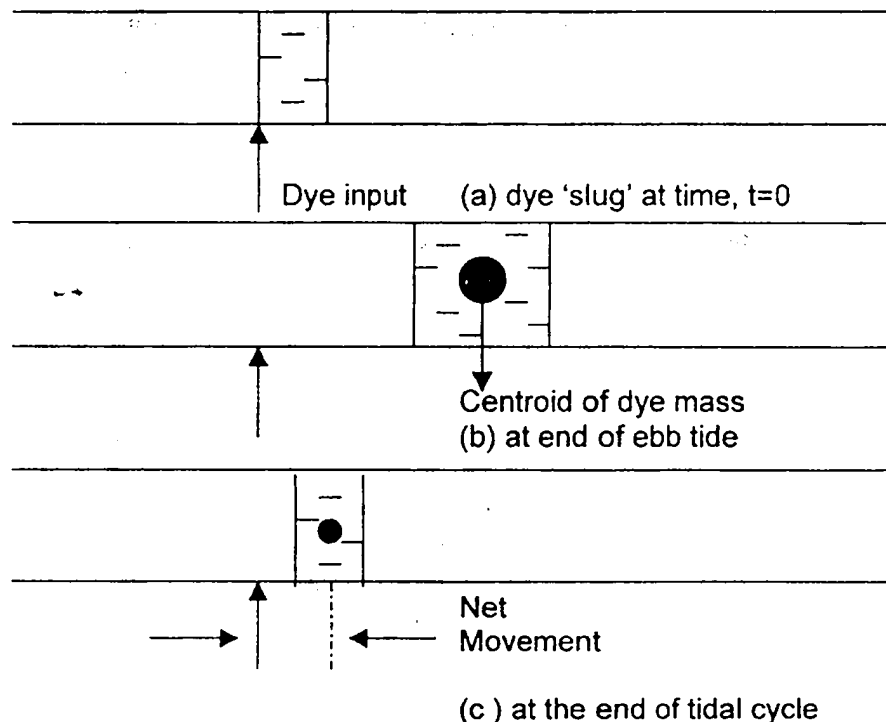
Circulation in stratified region: in such regions, less denser water tides over denser water

- Net seaward transport in surface layer and net landward transport in bottom layer
- Vertically stratified water body has significant effect on DO and nutrient cycling



- Resuspension zone has high velocity gradients; concentration of suspended solids maximum
- Turbidity maximum occurs in this zone

Dispersion and water quality:
(Thomman & Mueller, 1987)



Dye is injected in the water body at time $t=0$, when it is slack tide. As ebb tide begins, the dye patch proceeds downstream and gradually disperses due to vertical and lateral velocity gradients. When the flood begins, the dye patch begins to return upstream. However, the centroid of the mass does not return to the exact point of injection. The net movement gives an indication of 'flushing' of the water body. The mixing due to winds, tidal velocity, lateral and vertical velocity gradients, density differences is termed **tidal dispersion**. This **dispersive mechanism is central to the analysis of water quality of a water body such as estuarine or Gulf.**

APPLICATION OF COASTAL MODELLING FOR CZM

Coastal hydraulics and morphodynamics

Sedimentation is critical for harbours and navigation channels located on exposed coasts with strong littoral drift. Numerical modeling technology offers the most comprehensive and advanced tools for studies of processes in the coastal zone. The prediction of sedimentation/erosion rates is not sufficient in cases when the morphological response needs to be described. Hydrodynamic and sediment transport models are to be coupled into a complete morphological model complex, that includes feedback from the changing bathymetry on coastal processes.

Monitoring the aquatic environment

Monitoring of environmental quality enables managers to assess the state of the environment, detect changes in status and guard effects of specific activities. It provides the rationale for setting quality standards, determines compliance with regulations and permits, and supports evaluation of abatement plans. The combination of model and field survey significantly reduces the cost of a monitoring programme

Environmental impact assessment

Impact assessment should guide the design and planning process and lead to balanced ecological, economical and technically feasible projects. Ecological modeling is a prime tool for quantitative environmental impact assessment. Monitoring and modeling merge to provide an ever more complete and integrated description of the state of the environment. The environmental impact arising from

coastal projects attracts increasing attention. The protection of, for example, mangroves, coral reefs, sea grass beds or recreational beaches, is already an integrated part of the planning of coastal structures. Detailed data on the baseline conditions is necessary for any environmental impact assessment.

Integrated coastal zone management

Coordinated management of coastal resources in relation to local, national and international goals and regulations should be based on the understanding of the physical, environmental, socio-economic and political interconnections.

Filed data collection is thus an integrated part of all coastal structure projects. The data collection typically includes water levels, wave climate, current, sediment characteristics, turbidity, historical records of coastline development, sedimentation and construction of coastal structures. The need for data has increased considerably with the development of numerical models. The increasing complexity of the models demands consistent boundary and calibration data. Once the models have been set up, independent data is needed for validation and control.

Monitoring of dredging spoils

Increasing environmental restrictions on dredging and landfill activities have entitled a need for environmental control systems, which make it possible to avoid unacceptable environmental impacts. Such a system should give fast and reliable information, including forecasts to the decision-makers in order that potential environmental impact is minimized through mitigative action.

Feedback monitoring is based on a combination of planning, monitoring and evaluation. Initially model forecast are made of the environmental impact of the plan dredging operations. Secondly, measurements of hydrodynamic and biological conditions and sediment spills are used to hindcast actual impacts of the operations. Thirdly, all data are stored in a GIS as part of the data management and information systems. This is applied for online decision-making (during dredging operations).

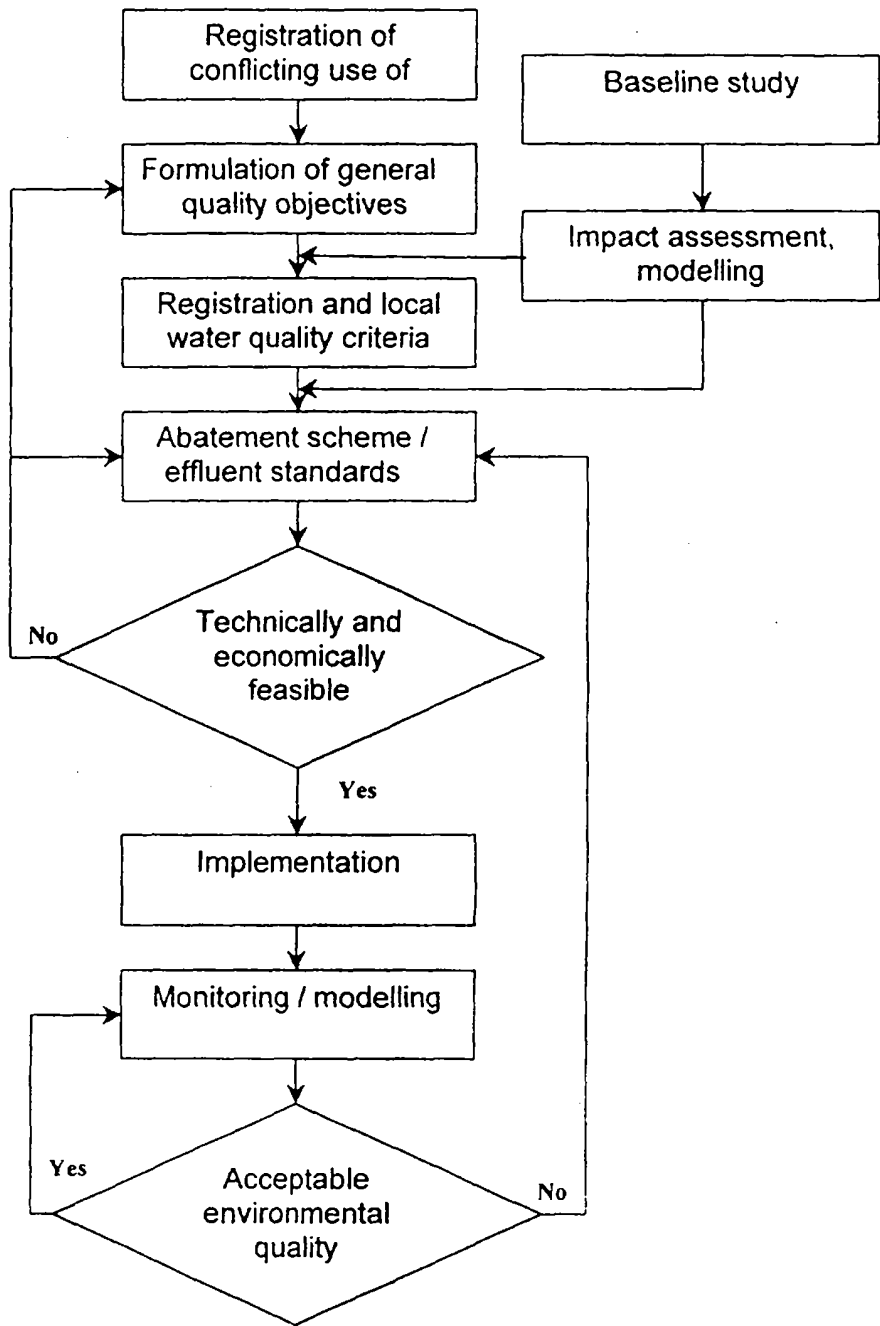
Eutrophication due to excessive loading of nutrients is a problem in many marine and fresh bodies. Consequences can be oxygen depletion and fish dead. Increased computer power has made 3D modeling an effective tool for managing eutrophication problems.

Also harmful and even **toxic algae** are more frequently reported. This has occurred in Danish and Baltic waters during summer, threatening for example bathing beaches or fish farms. An operational model can be used to predict the spreading and decay of algae blooms when combined with, for example, satellite image of chlorophyll-A assimilated into the model.

CONCLUSIONS

The aim of any coastal and marine EIA study is to predict a future state of the aquatic environment. In general, this requires a mapping of the specific baseline conditions and of the most important physical and biological processes in the area. An insight in the processes is a necessity for describing the consequences of future loadings or of physical changes imposed by coastal projects, which is possible through modelling.

The challenge of the future is, from an **ecological modelling** point of view, to simulate ecosystems undergoing changes due to increasingly more complicated issues. Examples are the cause-effects of organic pollutants on the primary production or changes of coastal ecosystems due to morphologically induced changes caused by climate change. These requires cross-disciplinary input studies.



Environmental modelling is an integral part of the environmental management procedures