

# THE JERVIS BAY MODEL - RATIONALE AND APPROACH

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## **Introduction**

Jervis Bay is a moderately sized and relatively pristine coastal embayment on the south coast of New South Wales. There is a small naval base located on the shore of the bay. In the late 1980s Jervis Bay was chosen as a potential site for a proposed major naval base relocation. In this context, the Department of Defence commissioned a major environmental baseline study of the bay as a component of an Environmental Impact Assessment. CSIRO directed the baseline study which ran over three years and involved a number of research agencies. During the course of the study a decision was made against relocation of the naval base to Jervis Bay and the context of the study changed somewhat. A more detailed history and description of the Jervis Bay baseline study may be found in Ward and Jacoby (1992).

One of the original objectives of the study was to develop recommendations for longer term environmental monitoring of the bay for Defence. The Jervis Bay modelling project was developed as part of the later phase of the environmental baseline study. The modelling project had the specific objective of supporting the design of a long term environmental monitoring for the bay.

## **Rationale and approach**

Given the relatively low level of current and projected Defence activities in Jervis Bay, and given the likelihood of continuing or even accelerated growth in residential and tourist development in the bay, the modelling group decided that the main challenge for any Defence-funded monitoring program would be to distinguish impacts of Defence activities from the impacts of other activities and developments in and around the bay. The modelling group took the view that an environmental monitoring program must do more than detect changes in environmental variables. If it is to be useful in environmental management, it must also be capable of attributing cause to any changes observed so that appropriate remedial action can be taken. In this view, then, a monitoring program must consist not only of a specified set of observations and measurements, but also of a diagnostic model to interpret those observations.

However taking this view of the nature of an environmental monitoring program (observation set plus diagnostic or interpretive model) raises a further difficulty: how to evaluate *a priori* different monitoring programs. To resolve this problem, the modelling group adapted an approach used in the fisheries assessment and management literature. In this approach, performance (for example of a stock assessment and management strategy) is evaluated by applying the strategy to a detailed simulation model

of the fishery. Examples of this approach may be found in Hilborn and Walters (1992). In the fishery examples, the assessment and management strategies usually involve both collection of data (e.g. catch and effort) and their interpretation using some simple stock assessment model (e.g. a surplus production model) which in turn is used as the basis for a management decision (such as a quota). The detailed simulation model incorporates complex process understanding to an extent not possible in the simpler stock assessment models. The detailed model provides an artificial world which will not be a faithful replica of the real fishery, but which captures enough of the complex levels of interaction and feedback in the real world to test the robustness of the simpler models and strategies.

We have attempted to adapt this approach to the problem of designing an environmental monitoring program for Jervis Bay. The detailed simulation model, used to test candidate monitoring programs, we have called the "deep" model. The environmental monitoring programs comprise a combination of an observation program and a set of diagnostic models used to interpret the data collected and turn them into management advice. The diagnostic models are referred to as "shallow" models. The diagnostic models may include statistical models (from analysis of variance through to general linear models) or simple process-based models which are fitted to data from the observation program. The deep model is then used to evaluate the performance of a set of shallow models (applied to "data" from the deep model) relative to management objectives.

Two workshops have been held, the first to identify environmental management objectives for the bay and to explain the deep model / shallow model approach, and the second to develop the scope and content of the deep model. The first workshop identified a set of key environmental indicators which were of concern to various environmental management agencies in Jervis Bay (including Defence). The indicators included items such as water quality, algal

blooms, extent and health of seagrass beds and other key habitats, recreational and commercial fish yields, and species diversity on intertidal and subtidal reefs. The workshop also identified activities and processes which were likely to affect the environmental quality of the bay, including existing and projected Defence operations and facilities, existing and projected community (non-Defence) activities (such as urban development and tourism), and natural environmental forcings, potentially including longer term climate change.

The next section provides a brief description of the deep model (the detailed simulation model of Jervis Bay) which was developed before, during and after the second workshop.

## Deep model description

### *Overview*

The deep model is a detailed simulation model of Jervis Bay including a representation of surrounding catchments, creeks and estuaries, the bay itself, together with several key habitats in the estuaries and the bay. The model has been developed as a series of modules, includes a real time graphical (spatial) display, and has been programmed in Professional Basic to run on a 486 PC. Figure 1 is a flow diagram showing the main modules and their interaction at daily and monthly time steps.

### *Spatial and temporal resolution*

One innovative feature of the model is that there are two distinct sets of space and time scales operating simultaneously. The water column (in both the bay and estuaries) is represented at a relatively coarse spatial scale, with 4 estuary cells, 8 cells around the bay edge, and 6 cells in the centre of the bay. The bay centre cells are resolved in 2 vertical layers. There are also 9 shore catchments represented. The water column and runoff from the catchments operate at a daily time step.

The benthic components of the model, such as the sediment and the benthic habitats, are resolved at a much finer spatial scale but the representation does not comprise a complete spatial coverage. Instead, benthic components are represented by a kind of stratified random sample, comprising 640 benthic "pixels". These involve a representative sample of local sites (which for the purpose of evaluating monitoring programs can be thought of as sampling sites or "quadrats") grouped into local sets or "boxes" (see below). The dynamics of these pixels operate at a time step of one month.

Thus there is one set of variables which operates at a coarse spatial scale but a fine temporal scale, and another set which is represented at a fine (though sparse) spatial scale and a longer temporal scale. The remainder of this section provides a very brief description of the main modules in the deep model.

#### *Climate, weather and tides*

The climate module provides a prescribed seasonal cycle and periodic ocean forcing at the mouth of the bay. Weather models are stochastic, with autoregressive models determining fluctuations in daily temperature, wind (strength and direction) and solar irradiance about the seasonal mean. A Markov chain model is used for daily rainfall and there is a four constituent tidal model.

#### *Catchments*

The nine shore catchments are described in terms of land use patterns, human population levels, industrial development and soil moisture. Land use is described by percent cover of land used for forests, grazing, agriculture and urban activities. Daily rainfall and temperature determine daily runoff for each land use type using a simple "bucket" model. Runoff is described by volume and composition of nutrient, detritus, silt and pollutant.

The human population comprises residents and tourists. Both population and industrial development can grow exponentially over time.

#### *Bay circulation*

Given the coarse spatial scale at which the water column is represented in the model, the circulation of water in the bay is modelled fairly simply. Advective exchange between water column cells is modelled using an imposed mean circulation pattern, modulated by a linear wind-response model. Mixing exchange is driven by tides and winds.

#### *Water column dynamics*

The variables represented in the water column dynamics include dissolved inorganic nitrogen, detritus (organic nitrogen), phytoplankton, suspended silt, dissolved and particulate pollutants, and turbidity. Inputs affecting the dynamics of these variables include runoff volume and composition (from catchments, through estuaries and into the bay), resuspended particulates, and solar irradiance. Settling particulates are deposited onto benthic pixels. Phytoplankton dynamics involve nutrient uptake, growth (affected by light attenuation), and mortality. Processes affecting other variables include remineralization of organic nitrogen, sinking of silt and particulates, and sorption and dissolution (for example of pollutants).

#### *Sediment dynamics*

Sediment composition within pixels is described by detritus and pollutant concentrations and silt fraction. Resuspension is driven both by certain types of human disturbance and by resuspension velocities which in turn are a function of bay water circulation, wave action and creek flow. The sediment dynamics are made more complex by the need to balance processes at the disparate scales of water column cells and benthic pixels.

#### *Benthic habitat dynamics*

Benthic habitats are divided into four broad types: creeks, bay edge, bay centre and rocky reefs. Habitat "boxes" of each of these types are distributed about the bay and estuaries. Each box is represented by a number of benthic pixels and each pixel is defined by a pixel habitat type

(effectively, a sub-habitat type within each broad habitat type):

Box Type	Pixel Habitat Type
Creek	Mud, Zostera, Mangrove, Saltmarsh, Terrestrial
Bay Edge	Sand, Posidonia
Bay Centre	Sediment, Bivalve Clump
Reef	Shore, Kelp, Barren

Each pixel habitat type has associated with it one or more variables which describe its current state. For example, the mangrove pixel type is described by biomass of both wood and leaf; Posidonia is described by sea grass biomass and epiphyte cover; and reef shore pixels (intertidal rock platforms around parts of the bay edge) are described by levels of encrusting algae, foliose algae, barnacles and gastropods. All the (habitat) state variables are represented as either biomass or percent cover, and are driven by processes of recruitment, mortality and growth. Recruitment is generally a function of local density (density in other pixels within the same habitat box). Growth of plant species (e.g. *Posidonia*) is affected by water column variables such as dissolved nutrients and light and/or by sediment nitrogen. Mortality is a function of physical and anthropogenic disturbance, as well as certain types of pollutants, and in some cases other biotic variables (grazers or predators).

In some cases, pixels can change from one habitat type to another. For example, a creek pixel may change from type *Zostera* to mangrove, or a kelp dominated reef pixel may change to barren (or vice versa). These processes can result in long term changes in habitat cover.

#### *Overall model behaviour*

The circulation dynamics capture the broad patterns observed in the bay, though small scale patterns and local effects can not be represented. The water column and sediment modules repre-

sent a fairly conventional model of nutrient transport and cycling through phytoplankton and detritus. In the short term, water quality is dominated by runoff and wind-mixing events. In the longer term, the trophic status of the bay is determined by patterns of nutrient accumulation and cycling in the sediment. As one might expect, the benthic habitat dynamics are much harder to capture and more work is required to represent these adequately. It is intended to incorporate fish dynamics into the model in the next stage of development.

#### **Development of the shallow models**

This project has reached the stage where the deep model has been developed and partially tested. However development and testing of the shallow models has not yet begun. This phase of the project is seen by the modelling group as the most innovative and interesting, and is in fact the rationale for development of the deep model in the first place. However this second phase seems unlikely to proceed in the short term due to the winding up of the Jervis Bay baseline study, and the lack of interest by environmental managers in Jervis Bay in developing a comprehensive longer term environmental monitoring program, at least for the moment.

#### **Acknowledgements**

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## References

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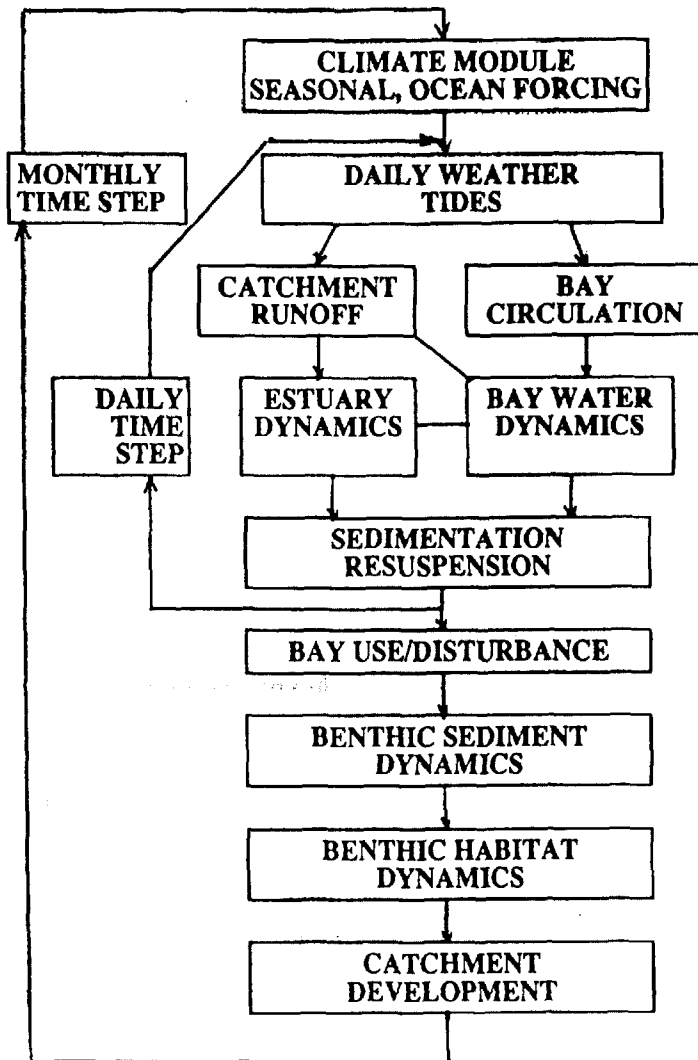


Figure 1. Jervis Bay Environmental Modelling- Overview of deep model.