ECOSYSTEM MODELS: VALUABLE, BUT NOT YET MANAGEMENT TOOLS - PERTH COASTAL WATERS STUDY

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Introduction

The rapid growth in the power of computers has caused an unprecedented explosion in their applications, particularly where computers are put to the task of making very large numbers of complex calculations, such as is required in numerical modelling.

Models now provide the cornerstone for most endeavours (science, economics, humanity), and no self-respecting programme can afford to be without one. However, before being ensnared by the promises of piles of printouts, and dozens of diagrams - all in contrasting colours and pleasing perspectives, the hard boiled scientist would be well advised to examine some of the well known "home truths" about modelling and the expectations surrounding the results which can be obtained from models.

Home truth No 1: Models are too important to be left in the hands of modellers

This maxim stems from the repeatedly reported sighting (but not confirmed) of glazed-eyed modellers sitting in front of a computer screen and including another differential equation or third order term in what is already an averaged representation of a process.

Biological systems are highly variable, and it is frequently necessary to make major assumptions and simplifications in representing these processes in a model. It is always far better to use actual measurements – such as a time series data set – to improve the capability of a model, than to rely on complex mathematical relationships to do this. Consequently, the modelling process must be driven by the need to provide as much realism as possible rather than the mathematical structure.

Home truth No 2: If you interrogate data hard enough, they will finally confess

This well-known adage has had a rebirth in today's era of statistical packages that can straighten any crooked line, or find the most unexpected relationships between variables.

Minor details, such as reality, are fearlessly disregarded in the headlong rush to find a better value for r-squared.

Note: An important corollary to this home truth, and one which has recently fallen into disuse, is: "if you can't see it, it is not there".

Home truth No 3: If they can't get tomorrow's weather right, how can you expect to predict:a) The stock market, b) Fish catches, c) Algal blooms?

How often have you heard the virtues of a given model as being, "user friendly, and with the ability to predict...". The only features that a model can predict accurately are those that have occurred in the past because the model was set up based on those experiences. As hindsight is highly regarded as the most exact form of science, such a recommendation is not of great significance.

The error comes in the unreasonable expectations that are associated with complex models of natural systems.

Home truth No 4: It must be correct; the results came from the computer

This is the most brazen of all of the seductive influences of computer models. Some would say that graphics have done more to enhance the progress of models, than model content itself. This is not such a bad thing, as a picture is worth a thousand words. What is important, is, how accurate is the picture?

A manager wants information for taking decisions, and does not normally have the time, and quite reasonably, the technical insight to appreciate the errors associated with model results. This is where the role of the modeller is fulfilled, and that is, in the sensible interpretation of the results, clearly separating fact from fiction.

The modeller should be blessed with two human characteristics, namely ethics and humility. Ethics is important, as there is a strong requirement for ensuring that models have been properly "tested" for representation of processes, for coding, and most importantly calibration with field data. Humility too is essential with any sophisticated model, to ensure that recognition is given of the incapability of any model to represent complex systems, and therefore not to allow the interpretations to be taken too far.

Conclusion

After this introduction, which could be seen as a strong call for a return to the slide-rule, if not the abacus, it would seem that the author's views on models are totally jaundiced.

Not so! Models are invaluable for summarising and representing all of the features of interest or concern, and for assisting in the understanding of complex systems. Models, especially of biological systems, should not be expected to produce accurate forecasts. This can be illustrated in a light-hearted manner by reference to Figure 1, modified from Mann (1982), which compares the estimates from a typical "engineering" model with that from a typical "biological" model.

In the engineering model all links are positive and direct, and for each input there is a specific output. However, for biological models, many of the links are indirect, flexible, with some more responsive than others. As a result, the output has only a very general relationship to the input, depending not only on the magnitude of the input, but also the exact starting point. Consequently models of physical processes are far more predictable. Typically, hydrodynamic models are capable of accounting for better than about 50% of the observed variance in response. In comparison ecological models generally have orders of magnitude errors associated with the final output, making them clearly unsuitable for setting management objectives.

The present COASEC (Coastal Ecology) model being developed in Western Australia has been invaluable in enhancing the understanding of the marine system of interest and is regarded as a framework that demands that the existing knowledge of the system is expressed explicitly, with all assumptions included. These assumptions then in turn have to be tested and justified, or modified. The model outputs reflect the thinking of the combined marine biological and physical science community; however it does not necessarily mean the outputs are "correct" or that the model will be able to predict accurately beyond the range of data from which the model was built. Modelling must proceed in close association with monitoring of the important processes and variables.

Such ecosystem models have not been used as predictive tools for management successfully anywhere in the world. They are useful, but management needs to be a continuing process involving the following steps in an iterative process:

- Set clear goals. These can be stated in terms of specific objectives to be maintained, with appropriate numerical and narrative indices listed as Environmental Quality Objectives (EQOs).
- Obtain understanding of system. Simple to complex ecosystem models are used to achieve this, and can be used to test various management options.
- Effective monitoring, data analysis, and review.
- Management decisions. These should place greater emphasis on field data than on model forecasts.

PERTH COASTAL WATERS STUDY

Introduction

The Water Authority of Western Australia (the Authority) has the responsibility for providing potable water and for disposing of treated wastewater for metropolitan Perth, where flows of treated wastewater are anticipated to increase at an annual rate of about 3% from their present flows of about 220ML per day, to 600ML per day in the year 2040. Details of this area are shown in Figure 2.

Presently, virtually all of the treated wastewater from Perth is discharged to sea through well designed marine outfalls from three locations. Regular monitoring has shown that beaches are always within the most stringent health criteria, while sediments and marine organisms are free from elevated levels of heavy metals or trace organic compounds. Nutrient enrichment of coastal waters is the main concern with any future increases in discharges of treated wastewater.

With one of the outfalls discharging into a marine park, stringent environmental conditions must be maintained.

The Authority is presently preparing a strategy for the disposal of treated wastewater for the next 50 years. This programme - Wastewater 2040 - includes comprehensive community consultation, detailed evaluations of alternate (land) disposal options, and a thorough study of the influences of present discharges to sea as well as a forecast of the effects of increases in discharges of treated wastewater to sea. This latter study is the Perth Coastal Waters Study (PCWS).

Perth's coastal waters are shallow, clear, of moderate energy, and of low productivity. Nitrogen is considered to be the limiting nutrient in these waters. The principal objective of the PCWS is to examine in detail the historical and present influences of nutrient discharges to sea off Perth, and to determine the future loads of nitrogen that can be discharged to these coastal waters and retain acceptable environmental values. An integrated ecological model COASEC (Coastal Ecology) is being developed to represent the main marine process of interest with regard to nutrient enrichment with appropriate field measurements being made to calibrate and validate the model, as well as to provide important information on processes that are not included in the model.

The COASEC model

Physical processes

Physical processes in the model are represented by a two-layer barotropic model (Backhaus 1985). Regional circulation patterns are controlled largely by the Leeuwin Current and wind stress, and influenced by local topography. Simulated surface flow patterns for a region approximately 150km (north-south) by 50km (east-west) (Figure 3), show the dominant southward flow of offshore waters (ie. deeper than 20m) regardless of wind direction, as well as an eddy south of Rottnest Island under most conditions (Pattiaratchi and Backhaus 1992).

Hydrodynamic models are also being prepared for the immediate vicinity of each of the outfalls using a 250m x 250m grid. For the Ocean Reef area the model domain extends 10km (north-south) by 5km (east-west). Presently, the regional model and the local models are not nested, and are run independently. The time step for this application of the local model is 1 hour.

Transport and advection/dispersion

The concentration of chemical materials in the water column is represented using a transport expression that considers diffusion (horizontal and vertical) as well as loss or gain of material such as the settling of particulates or the remineralisation of organic material. Presently, dissolved inorganic nitrogen, particulate organics and phytoplankton are included in the transport equation, with other materials assumed to behave conservatively and to have no transport between cells. Sources, such as groundwater, outfalls, or nutrients from remineralisation processes in the sediment are included in appropriate cells.

The time step for the calculation of concentration fields is the same as for the hydrodynamic segment, namely, 1 hour.

Water quality

Plume characteristics and water quality details which are used for model validation are obtained from a combination of physical (CTD) and chemical measurements. Surveys confirm a number of features of the area, such as:

- inshore waters are of cooler/lower salinity in winter, and warmer/higher salinity in summer,
- background static nutrient and chlorophyll levels vary substantially. Summer values are usually lower than winter levels, and
- the plume from the Ocean Reef outlet is still buoyant at the surface.

The routine water quality programme that has been undertaken by the Authority in the vicinity of the Ocean Reef outlet shows that the discharge commonly elevates surface nutrient and bacterial levels in the Whitfords Lagoon (Figure 2) to twice background levels up to 2km from the diffuser. Summary median values for nutrients in surface samples for the period 1981-1991 are shown in Table 1 below (Kinhill 1991).

Table 1. Median values of nutrients in surface water samples 1981-1991

	Background	Diffuser	250m	500m	1000+m
NH_3 g/l	<10	80-100	30-40	20-30	10-20
TIN g/l	10-50	15-200	30-60	40-50	15-50
PO_4 g/l	7-15	70-80	50-70	20-30	10-20

Ecology

The main processes of significance which are included in the COASEC model are shown schematically in Figure 4.

The model represents the stimulation of primary production of 5 separate plant groups. These are: phytoplankton; 2 species of seagrasses namely *Posidonia* and *Amphibolis*; and 2 groups of macroalgae, namely kelp which includes *Sargassum* and *Ecklonia*, and macroalgae assemblages, which includes all other macroalgal species. Epiphytic growth occurs on seagrass leaves, and field studies distinguish filamentous, foliose, and encrusting forms, even though epiphytes are considered as a single group in the model.

Particulates can be formed from eroding or decomposing plant material, while organic material that settles to the sea floor is included in the detrital pool, and is available for remineralisation.

Light attenuation within the water column is a feature of major interest, with any reductions in light to seagrass leaves due to shading (especially from epiphytes) of importance.

The model is not able to represent subtle changes in communities of plants and animals. For example, it is known that one of the first indicators of nutrient enrichment in these oligotrophic waters is the increased presence of green algae such as *Cladophora*, *Ulva*, and *Enteromorpha*. Such information is collected as part of a routine sampling programme close to, and at a distance from, the outfalls.

The COASEC ecology module calculates responses over different time scales. Phytoplankton concentrations (and therefore light) are calculated for each three hour period, while plant growth and animal responses are calculated each day, or even each week. Apart from the phytoplankton, all of the ecological features that are represented, are sessile plants, animals, and detritus.

Each of the 250m x 250m grid cells in the model is ascribed one habitat type. The matrix used to prepare the habitat allocation includes five geomorphological units, namely: sand, pavement, low reef, high reef, and coastal platforms. Sandy substrates are defined as bare, or with seagrass meadows (either *Posidonia* or *Amphibolis*). The remaining units are all hard substrates, and are defined in terms of cover by kelp or macroalgae. Field information used to define these habitat types has been mapped at a scale of 1 in 10000, using a rectified GEOSCAN MkII image.

For the area around the two northern outfalls, approximate habitat distributions are: seagrasses 14%; sand 48%; hard substrates 38%. There is no seagrass within 4km of the southern outfall (Cape Peron, Figure 2). Initial model conditions, as well as data for model validation and for monitoring, have been obtained from local as well as comparable studies. Substantial seasonal variations in biomass of important primary producers occurs; examples are given in Table 2 (Kinhill 1993).

The present detailed field studies will be providing further model validation data, as well as establishing reference information for the future use of indicators for the monitoring of incipient eutrophication, such as presence of green algae, community structure of epiphytes, epiphyte to leaf biomass ratios, and significance of encrusting epiphytes in the epiphyte biomass as measured by epiphyte calcium carbonate content.

Empirical estimates of nutrient loading rates to these waters indicate eutrophication to be unlikely at present, but possible in the future. Consequently, the forecasting of future influences is an important requirement of the PCWS. Laboratory experimentation is being used to determine the effects on plants of the continuous exposure of elevated concentrations of nutrients.

Table 2. Biomass of Primary Producers in Perth Coastal Waters

Biomass: Mean and Standard Deviation g dry wt m^{-2}					
Habitat	Category	Spring	Summer	Autumn	Winter
Seagrass					
- *Posidonia*	Seagrass	330 (130)	500 (100)	375 (75)	250 (50)
	Epiphytes	2 (2)	25 (25)	55 (55)	100 (100)
- *Amphibolis*	Seagrass	420 (170)	800 (160)	700 (140)	600 (120)
	Epiphytes (total)	410 (230)	600 (600)	350 (350)	180 (180)
	Epiphytes (leaves)	2 (1)	6 (6)	4 (4)	2 (2)
Reef	Kelp *(Ecklonia)*	200 (130)	1800 (1800)	1200 (1200)	600 (600)
Pavement	Kelp *(Sargassum)*	not present	1000 (1000)	700 (700)	0
Coastal platform	Kelp *(Ecklonia)*	160 (90)	1800 (1800)	1200 (1200)	600 (600)

Seagrasses constitute a known "sensitive" plant type in these waters, with light reduction due to increases in water column turbidity, epiphytes and algal assemblages being the main cause for their demise. Despite the relatively low seagrass component of the area of interest, the PCWS continues to use seagrasses as one of the important indicators of change, but mindful of the fact that the system may be well advanced towards nutrient enrichment before a decline in seagrasses is observed.

The Role of Models in Water Quality Management

Models are valuable tools for integrating the significant features of complex marine systems, and for guiding measurement and monitoring programmes.

Physical (or hydrodynamic) models are sufficiently well developed to provide reliable estimates of features such as water column structure, and flows. Ecological models can not achieve this precision, and because of the oversimplification that is a necessity in ecological modelling, ecological models are not able to provide forecasts that are suitable for direct use in management. Well designed monitoring programmes are essential to meet that objective.

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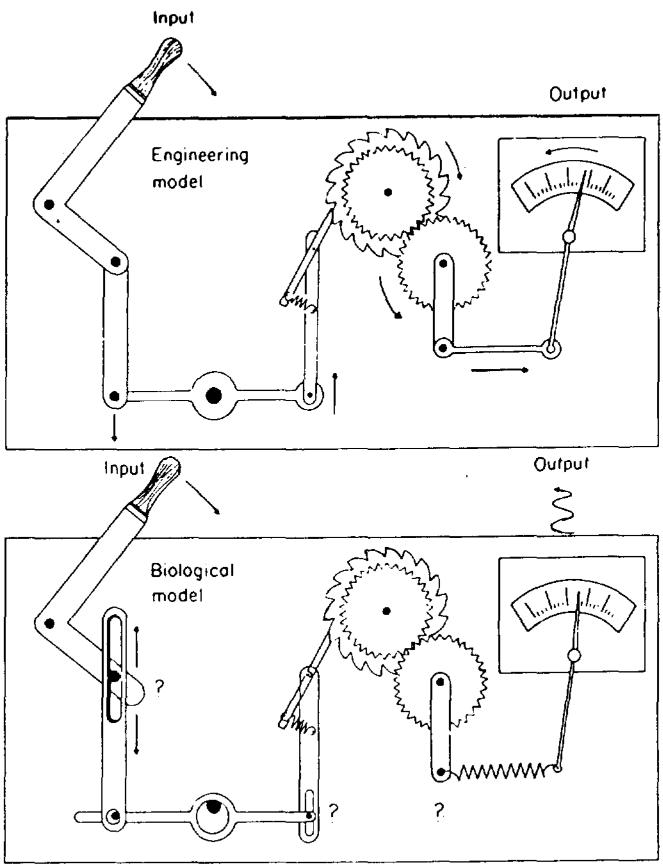


Figure 1. The "Engineering -Type" model and the "Biological Model". The former is constructed on the best engineering principles with well-fitting joints. A known input (movement of lever on left) leads to a unique output (movement of pointer on right). The biological model has a great deal of variability built into the connections between elements. A known input on the left may give rise to many possible outputs. Biological simulation models are like this, on account of the genetically programmed variability of the properties of the components.

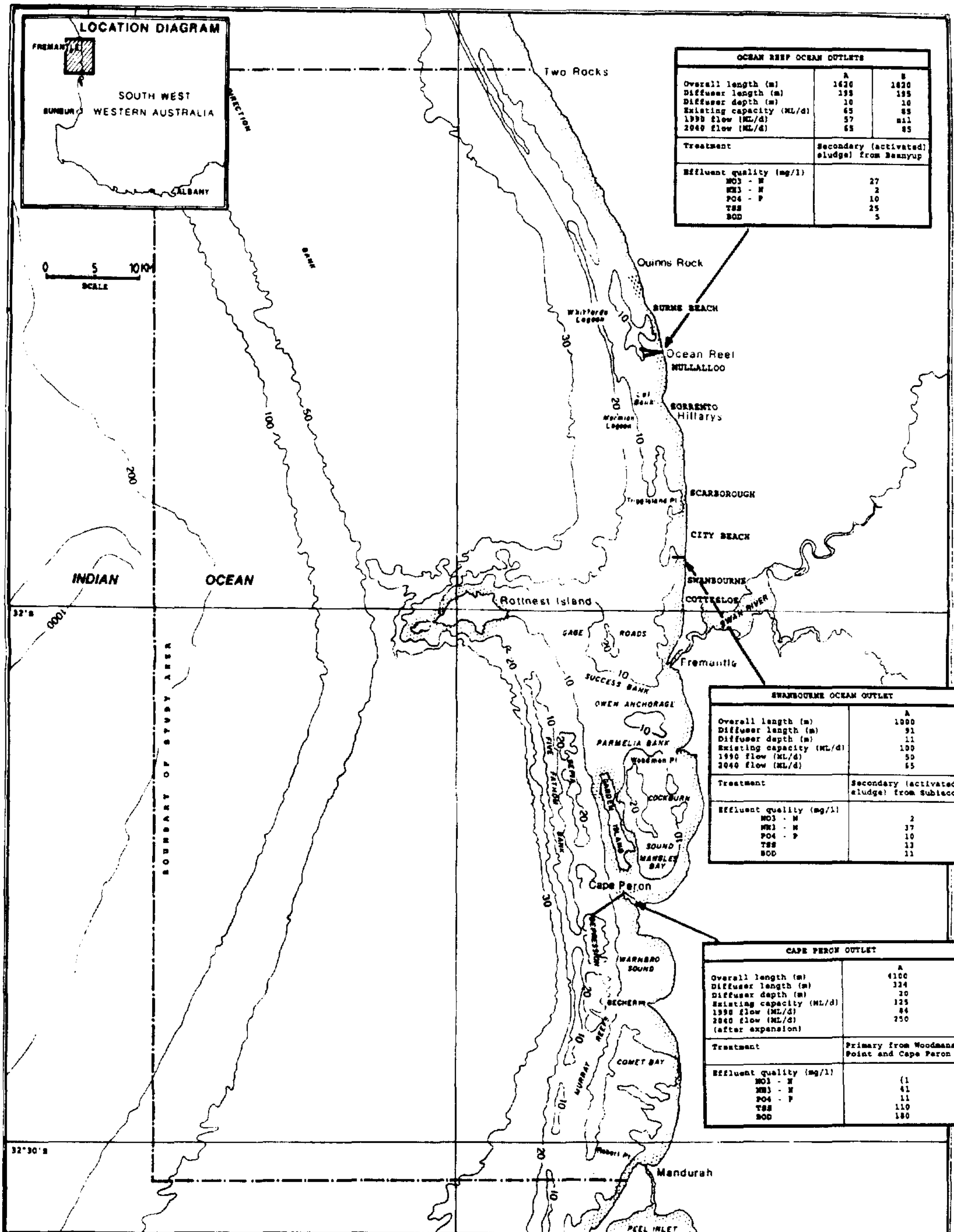
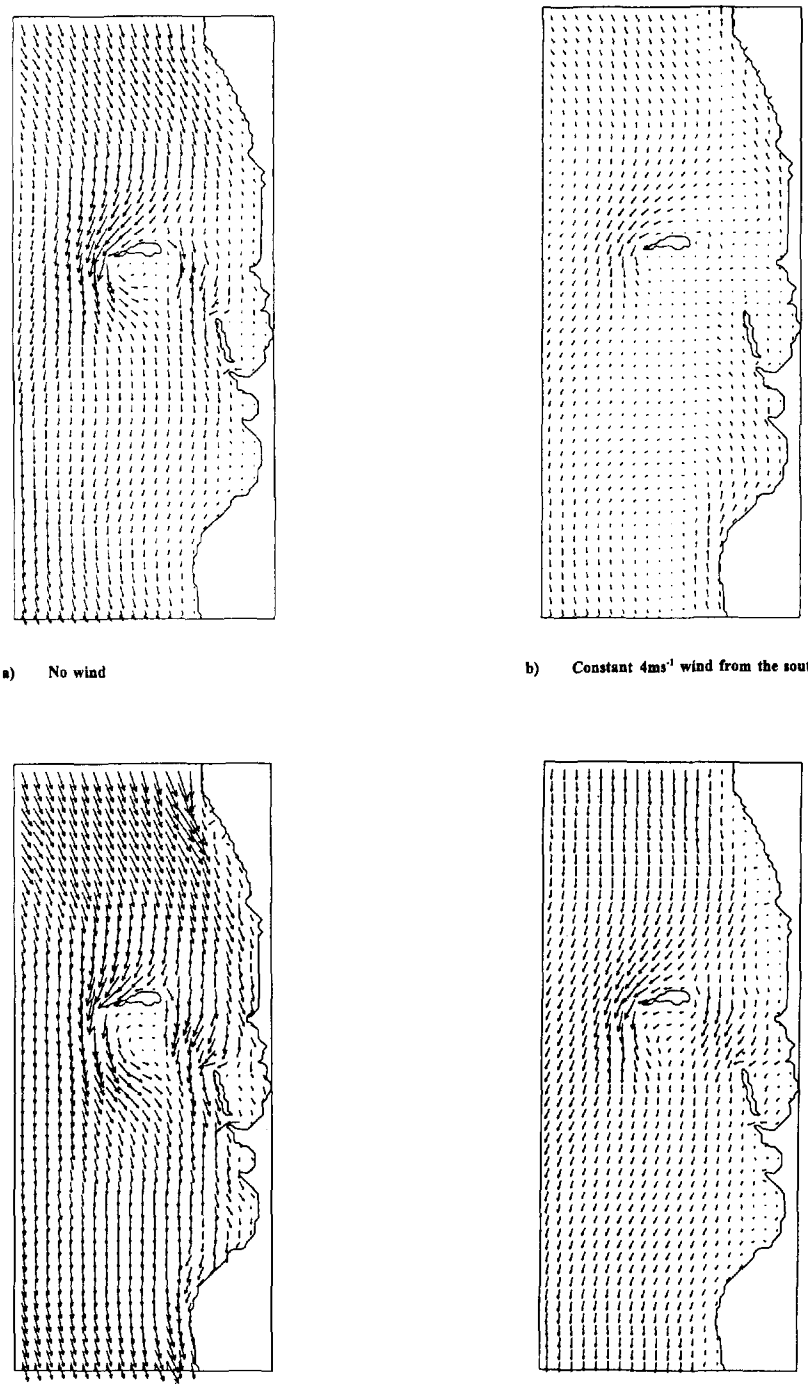


Figure 2. Perth coastal waters showing ocean outlets and bathing beaches.



a) No wind

b) Constant $4ms^{-1}$ wind from the south

c) Constant $7ms^{-1}$ wind from the north

d) Constant $7ms^{-1}$ wind from the east

Figure 3. Simulated surface flow patterns in Perth coastal waters after 48 hours under constant conditions. Note the dominant southwards flow of offshore waters (deeper than 20m) regardless of wind direction.Also, an eddy is generated south of Rottnest Island under most conditions.

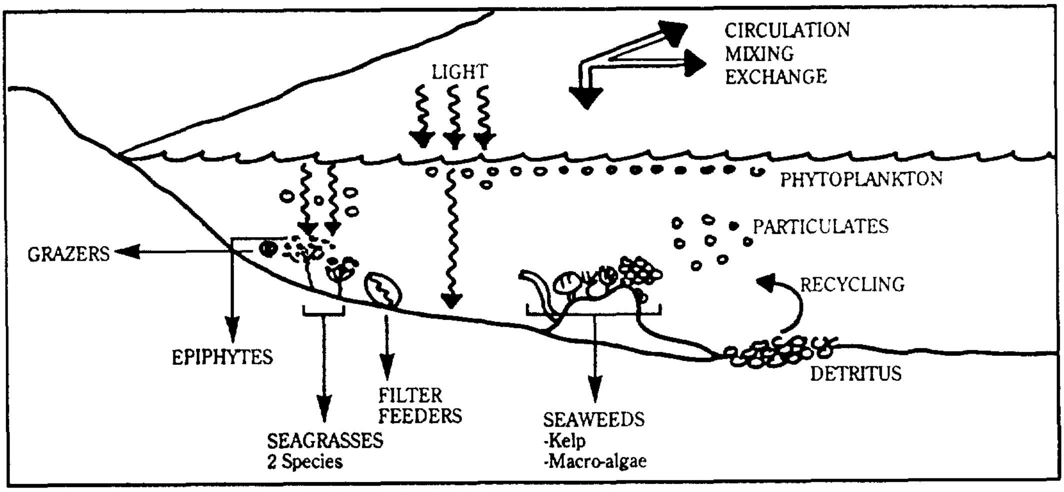


Figure 4. Marine process included in the COASEC model.