Quantifying Nutrient - Algae Relationships in Freshwater Systems

Outcomes of a Workshop held at Monash University on the 8th August 2000

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- Environment Protection Authority, Victoria
- Goulburn-Murray Rural Water Authority
- Griffith University
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This report has been based on the discussions and presentations delivered at the workshop on the 8th August 2000. The input and enthusiasm of those who attended the workshop (Appendix 1) was greatly appreciated. Presentations by Ian Lawrence (CRC for Freshwater Ecology), Mike Harper (Monash University, CRC for Freshwater Ecology) and Rod Oliver (Murray Darling Freshwater Research Centre, CRC for Freshwater Ecology) were particularly helpful in generating discussion and ideas (Appendices 2-4). Thanks also go to the Department of Natural Resources and Environment and the Victorian Nutrient Management Program for funding the workshop.

1 INTRODUCTION

There has been considerable investment in the development and implementation of catchment based nutrient reduction strategies across Australia in response to algal management issues. While most strategies have been based on best available information, key gaps for most strategies are the ability to:

- Quantify the relationship between nutrient loads, nutrient availability and algal growth in waterways and reservoirs; and
- Identify the time frame over which reductions in nutrient loads are likely to result in reduced algal bloom frequency and intensity.

In simple terms, managers require answers to two key questions:

1. If the load of a limiting nutrient entering a waterbody from the catchment is reduced by x%, what will be the corresponding reduction in algal bloom frequency?
2. How long will it take for the estimated reduction in algal bloom frequency and intensity to occur?

The complexity of nutrient-algae relationships (e.g. Harris, 1994) means that there is likely to be only limited information available to directly answer these questions for the range of waterbodies that exist across south-eastern Australia. One way of overcoming this problem is to adopt some form of classification of waters and develop conceptual models for each waterbody type. Computer modelling could then be developed to provide information on nutrient generation and transport processes, the interaction of algae and nutrients in freshwaters, and an assessment of factors or modifiers that might affect the response of algae to available nutrients. This information could then be used for further assessment of the response of algae and cyanobacteria to management actions that reduce nutrient inputs.

The CRC for Freshwater Ecology and the Department of Natural Resources & Environment convened a workshop attended by specialists in freshwater ecology, ecological modelling and water resource management (Appendix 1), at which approaches to classifying freshwaters in Victoria and assessing the likely effect of catchment based nutrient management strategies were examined. The workshop, held at Monash University on the 8th August 2000, focussed on *in situ* effects if the load entering a waterbody was reduced by x%, rather than on how management agencies and others may actually achieve the desired reduction of catchment nutrient load entering waterways.

Another aim of the workshop was to scope out the development of a predictive nutrient-algae response model to address the two main questions above, including the organisations and individuals to be involved.

2 MANAGEMENT PERSPECTIVES

Considerable investment has been made in the development of strategies and plans that seek to reduce the input of nutrients to waterways in Victoria (Government of Victoria, 1995), as a means to reduce the incidence and severity of nuisance algal blooms, especially those arising from potentially toxic blue-green algae (cyanobacteria). Cost-benefit analysis plays an important part in helping to identify local and statewide priorities for nutrient management. While the costs associated with implementing nutrient reduction strategies and actions may be relatively easy to calculate, their benefits are harder to estimate. Answering the following questions will be an important part of assigning priorities and ensuring that resources are best directed to activities with the best chance of success:

- Can we quantify the relationship between nutrient loads, nutrient availability and algal growth in waterways and reservoirs?
- Can we identify the time frame over which reductions in nutrient loads are likely to result in reduced algal bloom frequency and intensity?

Catchment-based nutrient management plans have generally been based on the estimation of current nutrient loads entering waterways and the reductions possible with the implementation of various best-management practices, for example reduced nutrient discharge in STP effluent, irrigation drainage and runoff from diffuse agricultural sources. The plans have generally been based on numerous assumptions (H. Adams and P. Feehan, pers. comm.), including:

- That the reduction of nitrogen and phosphorus inputs were of equal importance;
- Nutrients from different sources are equivalent in terms of their affect on algal growth;
- That there is no cycling of nutrients between the water column and the sediments;
- That reducing nutrient inputs will lead to a reduction in algal blooms;
- All blue-green algal blooms are potentially toxic; and
- The results of nutrient reduction activities will be seen over a 30-year timeframe.

In addition, some plans assumed that degraded waterbodies require larger reductions in nutrient load than systems in good condition, while others assumed no difference between systems that were degraded and those that were in good condition.

Other potentially important inputs, such as nutrient rich groundwater and organic matter from various sources, were not considered. Information on internal processes, such as nutrient transformation and cycling, in waterbodies such as terminal lakes and wetlands would have been particularly useful during the development of the nutrient management plans, even at coarse levels. While it was generally recognised that many of the assumptions were erroneous or did not apply to all systems, there was insufficient information available to warrant other approaches.

Most nutrient management plans included ecological risk assessment (ERA), usually prepared by some form of expert panel, to help set priorities. This led to different answers depending on the panel and in the absence of any clear relationship (or sufficiently detailed input data) between nutrient reduction and algal blooms. The lack of clear relationships between nutrients and algae also led some planners to abandon attempts to develop nutrient load and concentration targets that would maintain algal populations below bloom levels (e.g. in the Goulburn-Broken; P. Feehan, pers. comm.). Transparency in the process and robust discussion was very important for gaining community acceptance of nutrient targets.

Distinguishing between storm and low flow nutrient loads and availability for management purposes has also been found important for changing perspectives about approaches to nutrient management (R. Grayson, I. Lawrence, D. Robinson, pers. comm.).

The Goulburn-Broken nutrient management plan arrived at a P:algal bloom reduction ratio of 1:1.8 (i.e. a 50% reduction in TP load will result in a 90% reduction in bloom frequency). This ratio has been adopted elsewhere, as has a ratio of 1:1 (e.g. Avoca River catchment), often with little justification. The waterbody with the best information to quantify nutrient-algae relationships is Lake Wellington, where data suggest a P:chlorophyll-a ratio of 1:1. (similar ratios of available P-Chla have been recorded for other lakes – R. Oliver, pers. comm.) Deriving similar relationships for other waterbodies will be difficult, given the level of resources required. Clearly there is a need for tools that help quantify potential nutrient-algae relationships and the benefits that might be achieved by implementing nutrient reduction strategies.

3 MODELLING STRATEGIES

3.1 IMPORTANT ECOSYSTEM PROCESSES

Recent research has resulted in an improved understanding and changed perspective of the key ecosystem processes (e.g. nutrient transport and transformations) related to water quality and algal growth in freshwater systems. This has led to the generation of new conceptual models, for example of the factors conducive to algal growth in reservoirs (Oliver and Ganf, 2000; Lawrence *et al*., 2000), and provides important new insights for the development of dynamic models that may be useful for water resource management.

It is now recognised that biota, along with physical & chemical processes, are important in mediating water quality. For example, bacteria play an important role in the cycling of nutrients between the sediments and water column of rivers and lakes (Lawrence *et al*., 2000), especially in the presence of carbon and sulphate rich groundwater. In-stream and in-lake algal responses are frequently an indirect response to catchment discharges or flow events, and processes such as light climate modification, mixing and redistribution of dissolved oxygen, temperature, and the adsorption or chelation of nutrients. It is now clear that algae, and the nutrients on which they depend for growth, are affected by a range of dynamic processes. Managing algal blooms is a multi-factor problem.

3.1 ANZECC ECOLOGICAL RISK ASSESSMENT FRAMEWORK

The recently released ANZECC Guidelines for Fresh & Marine Waters (ANZECC & ARMCANZ, 2000) provide a rigorous framework for assessing waterbodies in terms of their management issues and objectives, associated values and potential risks (Appendix 2). This framework can be used to develop a conceptual approach as the basis for further modelling and assessment (Table 1), for example to develop decision trees to assess risk.

Table 1: Example of a risk assessment framework as the basis for future modelling (from I. Lawrence, pers. comm.)

Issue: nuisance plant growth	**Ecosystem: lowland streams**
Condition	**Response pathways and processes**
Event flow conditions	Transport suspended solids, organic material, sedimentation, re-suspension, sloughing of biofilm/organic material
Post event median flows	Aeration/oxidation of sedimented organic material. Limited retention time - low algae
Post event low flows with pt source discharge	Decomposition of organic material - release P, N. Direct uptake discharged P or N by algae, biofilm
Prolonged low flow condition with pt source discharge and groundwater discharge	Depletion of organic material - low release of P, N. Direct uptake discharged P, N by algae, biofilm. Potential sulfate reducing conditions - release of P, algal growth

3.2 APPROACHES TO MODELLING

The key questions that might be addressed by modelling are:

- At the catchment scale, will nutrient management lead to a reduction in blue-green algal (BGA) blooms in the long term (e.g. 20 years)?
- Will nutrient management lead to a reduced duration or biomass of BGA blooms in individual waterbodies?

Nutrient management plans have mostly identified the costs associated with managing algal blooms. If the reduction in bloom frequency or duration can be predicted, then it should be possible to estimate cost savings resulting from nutrient management. It was agreed at the workshop that modelling the response of algae to nutrient reduction is possible, but would require a careful balance between available resources, model complexity (Figure 1) and the quality of outputs for management purposes. Spatial and temporal scales should be carefully balanced with the capabilities of the model.

Model Types

Increasing complexity of formulation and data requirements ↓

Conceptual: **Identification of connectivity between compartments and processes**

Heuristic: **Intuitively determined formulae based on endpoints and chosen from simple functional form**

Empirical: **Formulae based on experimental data only**

Semi-empirical: **Formulae based on theoretical considerations, with experimentally determined constants and variables**

Mechanistic/ Probabilistic: **Formulae based on theoretical considerations of underlying processes only**

Figure 1: Examples of modelling approaches and input requirements (from R. Oliver, pers. comm.)

As information is likely to be limited, existing and modelled data will be required to provide information to support management decision making. The difficulty will be in balancing the complexity in modelling the various interactions that affect algal growth with providing a decision-making framework that may be widely understood and applied. Participants at the workshop agreed that a conceptual approach similar to that of Figure 2 was required to include ‘hard’ modelling (i.e. complex, quantitative or deterministic) for the supply of data to underpin a decision framework that may be widely applied by managers (i.e. simple, semi-quantitative or qualitative).

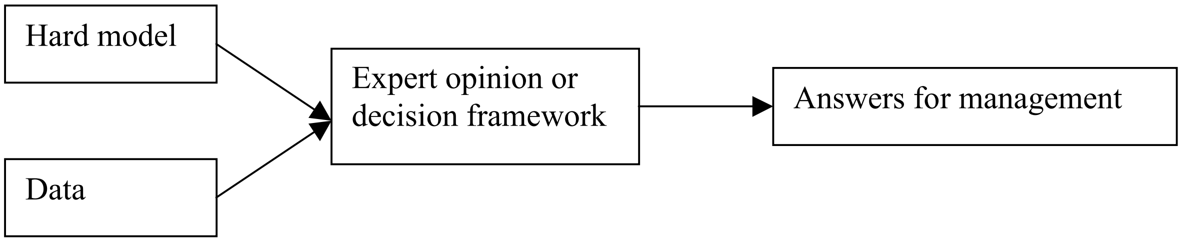

Figure 2: Conceptual approach to modelling nutrient-algae relationships

The number of parameters required will vary depending on the purpose of the model and:

- The number of environmental variables considered important;
- The number of biological variables considered important;
- The non-linearity of response functions; and
- The relevant time and space scales that are to be addressed.

The questions to be answered must be carefully framed to limit model complexity or relate model complexity to the availability of input data. Describing biological interactions adequately with a minimum number of parameters remains a challenge. The modelling of natural systems is faced with 5 key problems outlined in Table 2.

Table 2: Modelling issues and approaches (from I. Lawrence, pers. comm.)

Issue	**Traditional Approaches**
Complexity	Empirical (black box), bio-geochemical process based (single issues & ecosystems), stochastic, neural network models.
Variability	Steady state (deterministic), gradually varying state (time series deterministic), dynamic (stochastic).
Scale	Local plot or reach (process based); Sub-catchment or tributary stream (process or system empirical values); Catchment or primary stream (system empirical values).
Integration	Conservation of flow, energy, mass. Differential equations or small time step approximations.
Delivery of information	Mega-models or input to wider analysis process.

The following sections outline the complexity of factors, both in the water column and the sediments, which may affect nutrient availability and algal growth.

3.3 FACTORS AFFECTING ALGAL GROWTH

Some of the important factors affecting the survival of algae discussed at the workshop included the sources (internal and external), transformation and availability of nutrients for uptake by algae, the influence of light, temperature and mixing conditions, and processes such as grazing by predators (Figure 3). The modelling of any or all of these components is complex, even for a single species or in a single reservoir (Appendix 3), and the availability of good quality data will be critical. For example, while research of Chaffey Dam (NSW) has identified an overall P:chlorophyll-a ratio of 1:1, it was not possible to model the variation of species in this relationship (R. Oliver, pers. comm.). To do this would have required examination the effects of phosphorus and nitrogen limitation on algal species, the effect of mixing and sinking processes on the entrainment of algal cells in the euphotic zone, and buoyancy regulation (controlled by carbohydrate metabolism), amongst other factors. Research in the Darling River found that algal growth was controlled by turbidity, which in turn was affected by electrical conductivity. Algal growth in the Murray River is thought to be limited by light intensity. Developing a widely applicable approach to modelling such processes will be difficult due to the variability between and within species, and different waterbodies.

One potential approach to modelling is that based on investigations of urban ponds and wetlands (Lawrence and Breen. 1998). This used a mixed box reactor based on:

- Shallow mixed lake systems with high suspended solids loading;
- The assumption that P is only associated with sediments and adsorption is a function of particle size; and
- Nutrient release from the sediments is driven by available (labile) carbon.

The models are considered quite robust (I. Lawrence, pers. comm.) and dependant on data for inflow, suspended solids concentration, nutrient concentration and BOD. The application of the models to systems such as deep, stratified lakes, or streams requires confirmation.

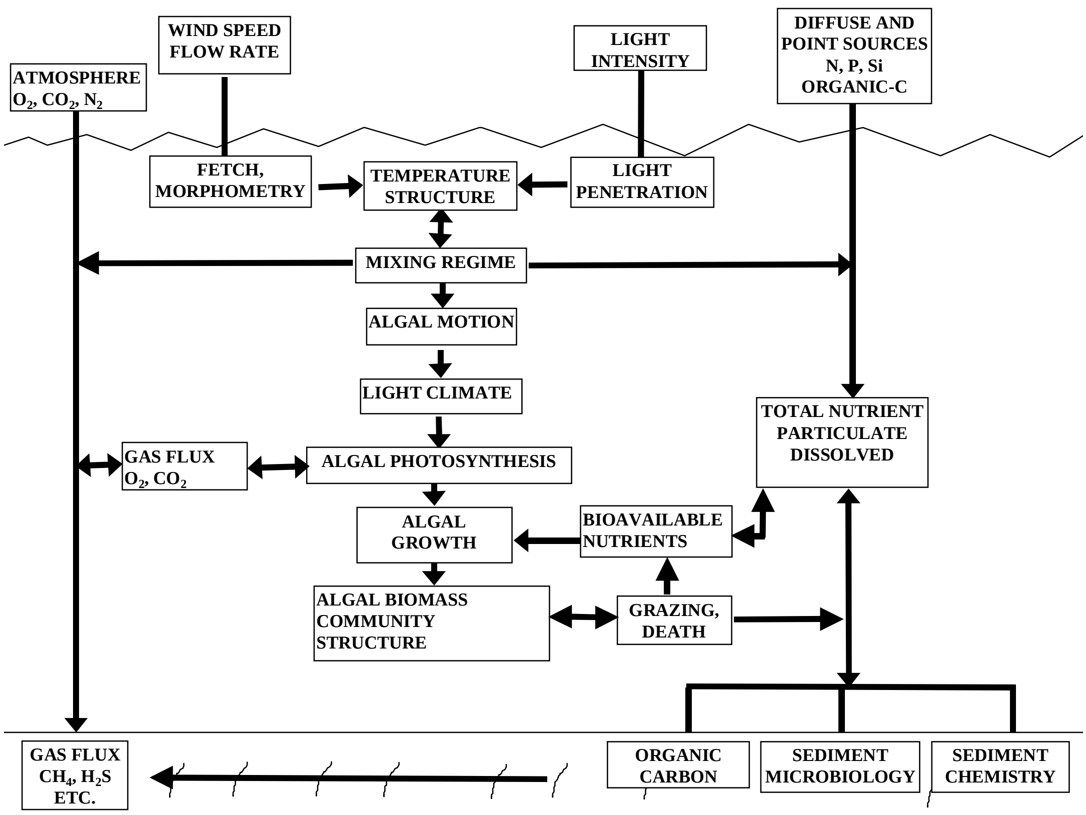

Figure 3: Conceptual model of factors affecting algal growth (from R. Oliver, pers. comm.)

3.4 SEDIMENT NUTRIENT PROCESSES

It is now widely recognised that the release of nutrients from the sediments plays an important role in supporting algal growth in rivers, lakes and streams. The sources and fate of nutrients in sediment are briefly described in Table 3. The top 20 cm of the sediments is where most transformations occur (Figures 5-7; Appendix 3). Below this layer nutrients are generally buried and effectively lost to the system.

Recent research has confirmed that many sediment processes are driven by the input of organic matter, which provides a direct input of nutrients and indirectly influences redox driven processes such as denitrification (Hart and Grace, 2000). To successfully model nutrient behaviour in the sediments will require information on:

- Inputs of carbon (sedimentation rates);
- Carbon transformation rates;
- Transport rates within the sediments; and
- Nutrient input rates.

Table 3: Source and fate of nutrients in the sediments (from M. Harper, pers. comm.)

Nutrient	Recruitment	Release	Removal
Phosphorus	• Sedimenting particulate organic phosphorus • Sedimenting adsorbed phosphorus	• Sediment-water phosphate flux • (Irrigation?, bioturbation?) • Resuspension & desorption?	• Mineral precipitation • Burial
Nitrogen	• Particulate organic nitrogen • Nitrate flux (Irrigation? bioturbation?)	• Ammonium flux • Nitrate flux? • (Irrigation? bioturbation?)	• Denitrification • Burial • Ammonification

Aspects that suggest modelling sediment nutrient processes is possible include:

- Processes were generally well understood;
- It should be possible to simplify models to describe only processes over relevant time scales;
- Even complex short-term dynamics could be modelled;
- Established modelling theory could be applied;
- The work was not difficult conceptually; and
- It is possible to build on recent work (CSIRO, CRCFE and others).

However, some difficulties include:

- Some key processes not well quantified (particularly transport within sediments and at the sediment-water interface);
- Heterogeneity at all scales;
- Complexity: high computational requirements, parameterisation, testing, application;

- Parameterisation difficult; and
- Difficulty in interfacing coupled water column – sediment models with other model components, especially that of the water column.

The time scale for modelling was considered critical (M. Harper, pers. comm.), with long-term modelling (> 1 year) likely to be more feasible than short-term modelling (days, weeks) due to the difficulty of quantifying Fe-P dynamics in particular. While previous sediment process modelling has provided results down to a 3-week timestep, there was doubt about the accuracy of results if combined with a water column model that attempts to capture information at a finer scale. However, modelling at the time-scale relevant to algal blooms was considered desirable, rather than at an annual time-scale, as this would provide better information for management.

It was recognised at the workshop that modelling of sediment processes had been relatively primitive to date. The current situation offers an opportunity to take a different approach, for example by using 'hard' sediment process models to provide information that can be used within the framework of a broader decision support system. Issues to consider include the type of model required, the level of complexity and number of variables required and potential to link sediment models to water column models.

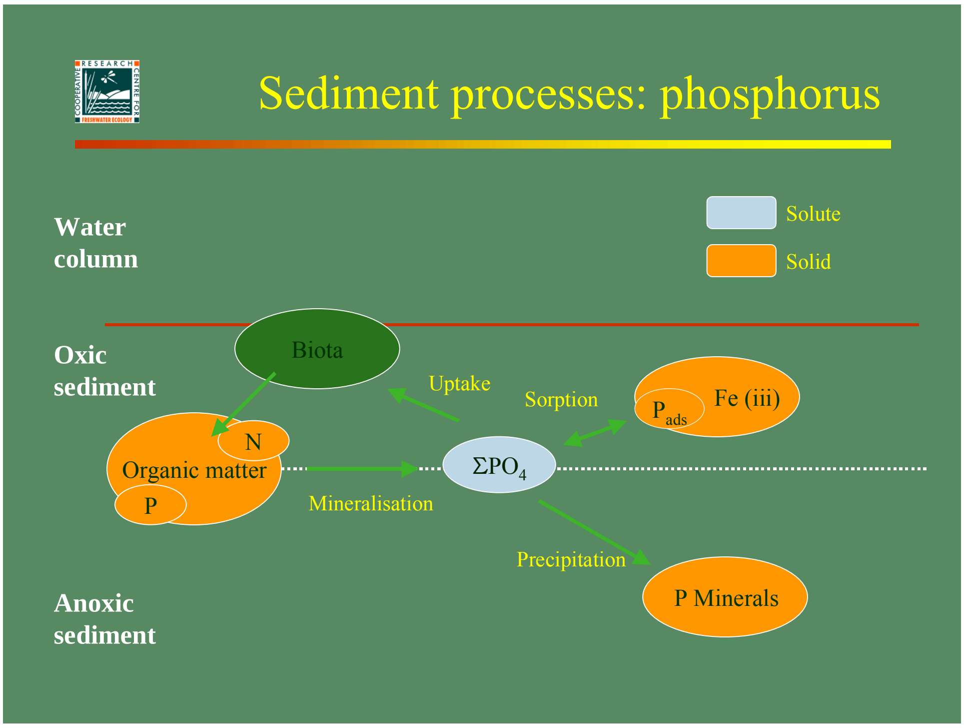

Figure 5: Sediment phosphorus processes (from M. Harper, pers. comm.)

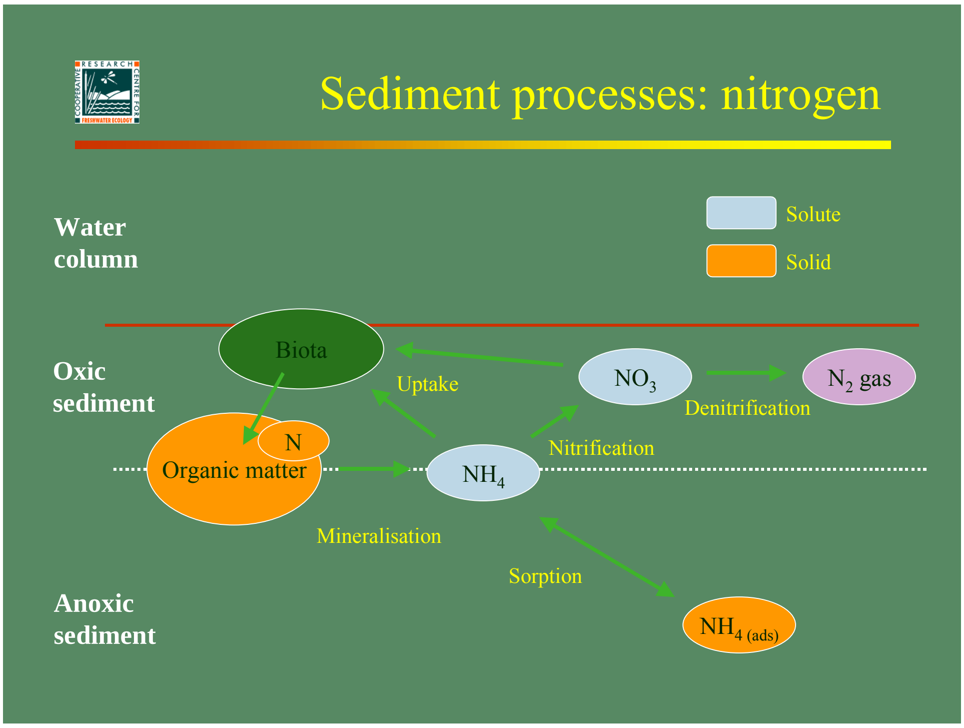

Figure 6: **Sediment nitrogen processes (from M. Harper, pers. comm.)**

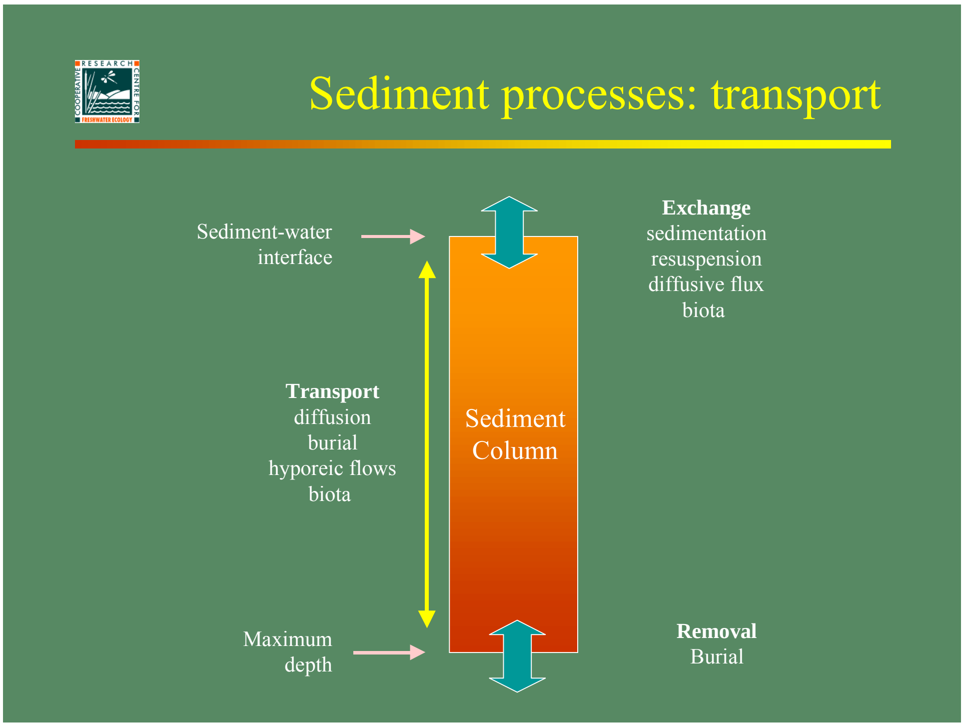

Figure 7: **Nutrient transport processes through sediments (from M. Harper, pers. comm.)**

4 DEVELOPMENT OF AN ALGAL RESPONSE CLASSIFICATION

Many different types of waterbodies exist in Victoria, and it is expected that these will respond to nutrient additions in different ways. Some of the most obvious types of waterbodies include (ANZECC & ARMCANZ, 2000):

- Upland streams;
- Lowland streams;
- Coastal streams;
- Shallow lakes and reservoirs (< 5m);
- Deep lakes and reservoirs (> 5m); and
- Wetlands.

The Workshop considered that using the above waterbody definitions and the major factors affecting algal growth (rated as high or low risk) it should be possible to develop a system for classifying waterbodies to assess the likelihood of algal bloom development. Upland, lowland and coastal streams were combined into one category in recognition of flow being the most likely determinant of algal bloom formation (i.e. nutrient availability was unlikely to be a limiting factor in algal bloom formation). The classification system (Table 4) aims to identify the key drivers of algal growth in various waterbodies, and can be used to assess whether nutrient availability is likely to play a major role in algal bloom formation, duration or biomass levels.

Table 4: Trial classification system – Lake Corangamite

Indicator	Process Affected	Shallow Lakes and Reservoirs	Deep Lakes and Reservoirs	Wetlands	Streams
Flow	Retention time, mixing	Low			
Nutrients (N & P)	Nutrient availability, limitation	High			
Organic carbon	Organic loading, BOD, sediment processes, denitrification	High			
Suspended particulate matter	Light regime, nutrient availability	Low			
Wind speed	Mixing, stratification' sediment resuspension	High			
Temperature	Stratification, algal growth rates, nutrient regeneration rates	Low			
Emergent plants	Nutrient uptake and availability, DOC and phenolic compounds (i.e. potential growth inhibitors for phytoplankton)	Low			
Morphology	Retention time, mixing, light regime	Shallow arms			
Electrical conductivity	Coagulation, turbidity, light regime	High			

Algal bloom-nutrient loading curves will be generated for those systems in which nutrient availability is an important factor in algal bloom formation. The curves can then be used to quantify the decrease in algal bloom duration expected with nutrient load reduction (Figure 8).

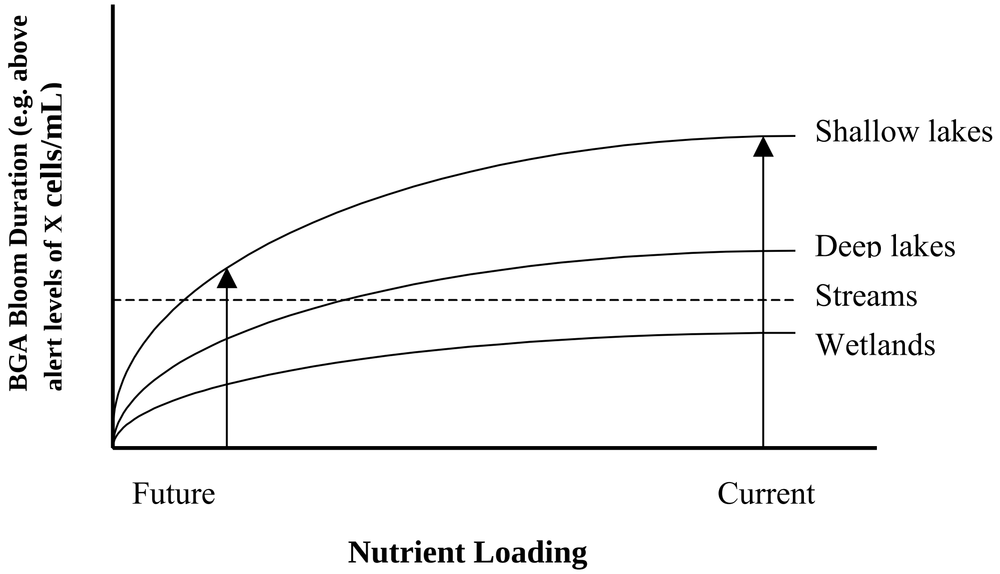

Figure 8: Hypothesised nutrient-algae response curves

The process for producing the nutrient-algae response curves identified by workshop participants is summarised in Figure 9. A ‘family’ of curves will be required to account for different types of waterbodies that require management. The aim is to condense a multivariate problem (many factors including nutrients influence the triggering, duration and biomass of a bloom) into a two factor problem (i.e. nutrients & algal bloom) by considering all the other factors in the classification of waterbody types.

Important considerations include hysteresis effects – the nutrient load reduction required to reduce algal bloom duration to acceptable levels may be higher than the load that contributed to the onset of eutrophication. Other considerations include the time scale over which nutrient reduction targets are met and the time for a system to respond to the new nutrient loading. It is possible that the effects of reduced nutrient loading may take years or decades to become apparent, for example, if there is a high nutrient and carbon load contained in the sediments of a waterbody.

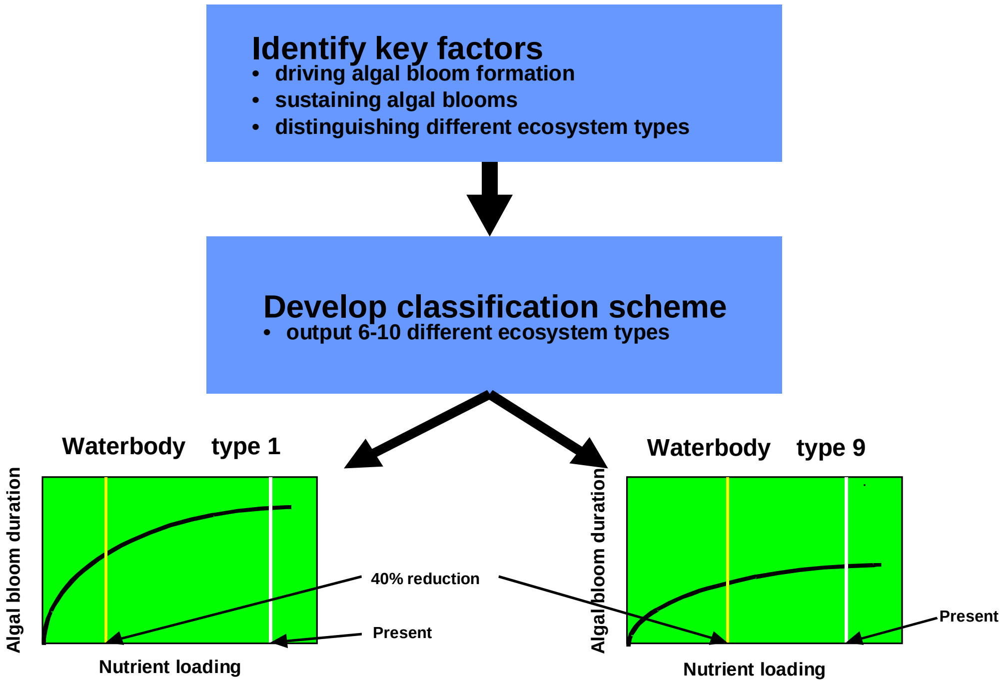

Figure 9: Process for developing nutrient-algae response curves for various waterbodies

5 SUMMARY OF WORKSHOP OUTCOMES

Participants at the workshop concluded that:

- An algal bloom assessment framework could be developed to assist management decision making;

- Hard modelling will be necessary to provide data and information to support the assessment framework. Comprehensive monitoring may be required to support modelling; and

- It should be possible to develop nutrient-algae curves for waterbodies in which nutrient availability may be limiting, although these have not yet been prepared for Australian waterbodies.

Participants at the workshop recommended that a proposal be prepared for the trial of the methods identified by the workshop, including:

- Formation of a steering committee to oversee the project;
- Appointment of a project manager to coordinate inputs from participants;
- Progress to a pilot study to develop the logic of the approach and trial several curves;
- Confirm that modelling outputs meet the needs of management; and
- Approach potential funding bodies to fund work to apply the method further.

All participants expressed a willingness to be involved in future work that expanded on the ideas generated at the workshop.

6 REFERENCES

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APPENDIX 1 WORKSHOP ATTENDEES, MONASH UNIVERSITY 8TH August 2000

Heather Adams	Department of Natural Resources and Environment
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Jane Doolan	Department of Natural Resources and Environment
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Roger Grayson	CRC for Catchment Hydrology, Melbourne University
David Hamilton	University Western Australia
Mike Harper	CRC for Freshwater Ecology, Monash University
Barry Hart	CRC for Freshwater Ecology, Monash University
Brynn Hibbert	University of New South Wales
Ian Lawrence	CRC for Freshwater Ecology, Canberra
Rod Oliver	CRC for Freshwater Ecology, Murray Darling Freshwater Research Centre
David Robinson	Environment Protection Authority, CRC for Freshwater Ecology
Peter Vollebergh	Department of Natural Resources and Environment
John Whittington	CRC for Freshwater Ecology, Canberra

APPENDIX 2 ISSUES AND ECOSYSTEM PROCESSES
Presentation by Ian Lawrence, CRC for Freshwater Ecology

Algae Nutrient Workshop
Issues & ecosystem processes

- Changing perspectives regarding water quality & ecological processes - implications for modelling
- Assessment approach adopted by ANZECC Guidelines for Fresh & Marine Waters
- Development of a framework for identification of models appropriate to issue, ecosystem & dominant 'driver/response' process or conditions
- List of models

Water quality & ecological processes

- Biota directly implicated, together with physical & chemical processes, in mediating in-stream water quality
- Instream & in-lake algal responses frequently an indirect response to catchment discharges or flow or mixing events
- Overlay of modifiers of processes such as light modification, mixing (oxygen flux), temperature, adsorption of nutrients, chelation of nutrients
- Dynamic processes comprising a succession of states

ANZECC Water Quality Guidelines approach:

Ecosystem issues based:
- Target specific mgmt issues
- Mgmt objectives: protection, restoration, modified system values.
- Biological indicators based reference system.

Ecosystem based:
- The range of conditions & processes specific to each ecosystem category - how they work

Risk assessment based, recognising a range:
- of potential drivers or stressors,
- of potential modifiers,
- of potential direct & indirect response processes

Decision trees, guiding assessment of risk

Development of a model selection framework

Issues - ecosystem - catchment discharge or mixing condition - driver/response pathways & processes

Example: Issue nuisance plant growth; ecosystem deep lake/reservoir

Condition	Response pathways/processes
Event flow conditions	Transport & sedimentation within lake Inlet depositional zone or extended area
Post event median flows with pt source discharge	Reduct sed org matl - release nutr, alg uptak Adsorption SS & sedimentation
Prolonged low flow condition with pt source discharge	Minor mixing deep zone by wind - low algae Direct uptake by algae
Lake/reservoir turnover	Major mixing high nutrient in surface layer Algal growth limited by temp & retent time
Reservoir drawdown	Remobilis of anoxic sediment pore water high in ortho-P. Rapid algal growth
Reservoir drawoff level	Top water release > inflow --> entrainment of bottom layer --> algal growth

Development of a model selection framework

Issue: nuisance plant growth; Ecosystem: lowland streams.

Condition	Response pathways/processes
Event flow conditions	Transport suspended solids, organic mat'l, sedimentation, re-suspension, sloughing of biofilm/organic mat'l
Post event median flows	Aerat/oxidat sedimented organic mat'l Limited retention time - low algae
Post event low flows with pt source discharge	Decomposit organic mat'l - release P, N Direct uptake discharged P, N by algae, biofilm
Prolonged low flow condit with pt source discharge with groundwater disch	Deplet of organic mat'l - low release nut Direct uptake discharged P, N by algae, biofilm. Potential sulfate reducing conditions - release of P, algal growth

Information needs:

Issue: Nuisance plant growth, oxygen depletion, etc

Ecosystem: Upland river; lowland river; lake/reservoir; wetlands; estuaries.

System condition: median/low flows (point & grndw sources); high (event) non-point sources, post event.

Decision: qualitative justification of mgmt responses; estimate current load/conditions (data avail); predict conditions for future develop/mgmt; compliance or performance assessment.

Confidence: General order; broad range; probability; precise.

Data availability: Comprehensive variable & spatial scope; Limited spot data.

Modelling strategies

Modelling of natural systems is faced with 5 key problems:

Complexity
- **Empirical (black box), bio-geochemical process based (single issues & ecosystems), stochastic, neural network models**

Variability
- **Steady state (deterministic), gradually varying state (time series deterministic), dynamic (stochastic)**

Scale
- **Local plot or reach (process based);**
- **Sub-catch or tributary stream (process or system empirical values);**
- **Catchment or primary stream (system empirical values)**

Integration
- **Conservation of flow, energy, mass;**
- **Differential equations or small time step approximations**

Delivery of information in a form relevant to managers
- **Mega-models or input to wider analysis process**

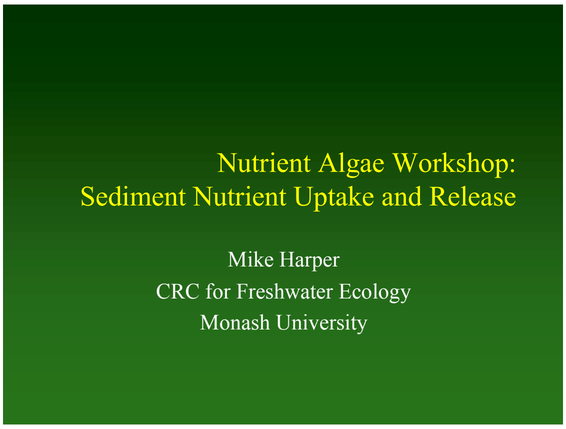
List of Model categories

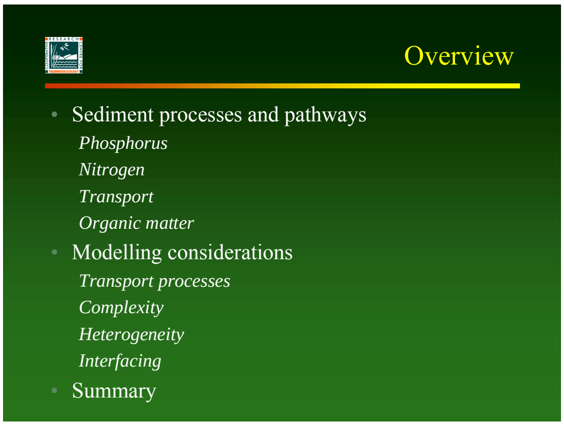
1. **Hydraulic - advective & mass balance models (integrative system)**
2. **Particulate transport, sedimentation & re-suspension models**
3. **Particulate adsorption & de-sorption models**
4. **Water density, stratification & mixing depth models**
5. **Chemical equilibrium models**
6. **Gas adsorption/desorption models**
7. **Light attenuation models**
8. **Biological growth models**
9. **Diagensis models**
10. **Food web profile models**

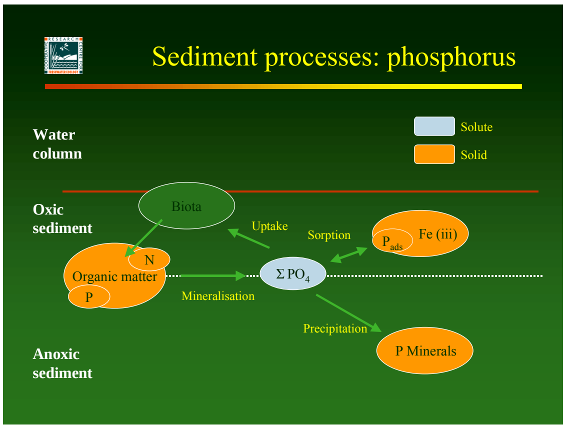
List of commercial software packages

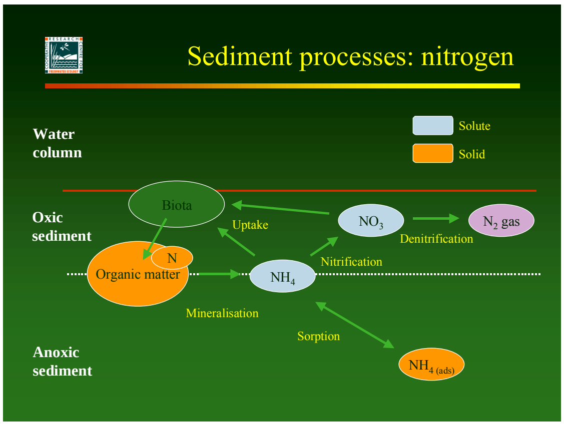
AQUALM	WASP
AGNPS	CANDI
MEDLI	SNAPP
SWMM	DSSM
STORM	EUTR4
LASCAM	DYNHYD4
CREAMS/GLEAMS	EXAMS
SWRRB-WQ	XP-RAFTS
SWAT	RORB
HSP-F	WBNM
ANSWERS	MIKE 21
MIKE SHE	HEC 6
TOPOG	QUAL 2E
WEC-C	CE QUAL W2
QUAL2E	
IHACRES	
WEPP	
CMSS	
MOSS	
AEAM	
HYDRA	
IQQM	
MIKE 11	
THALES	
USLE	

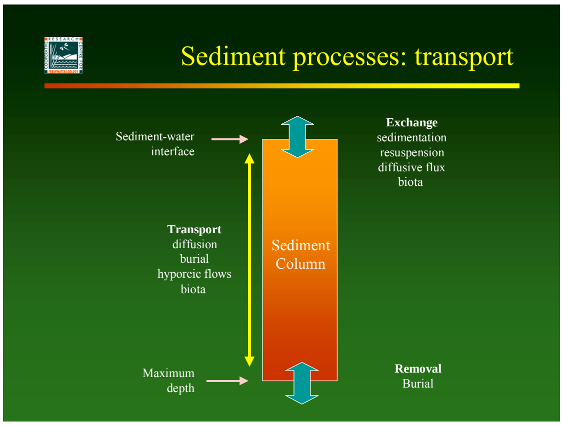
APPENDIX 3 SEDIMENT UPTAKE AND RELEASE
Presentation by Mike Harper, CRC for Freshwater Ecology

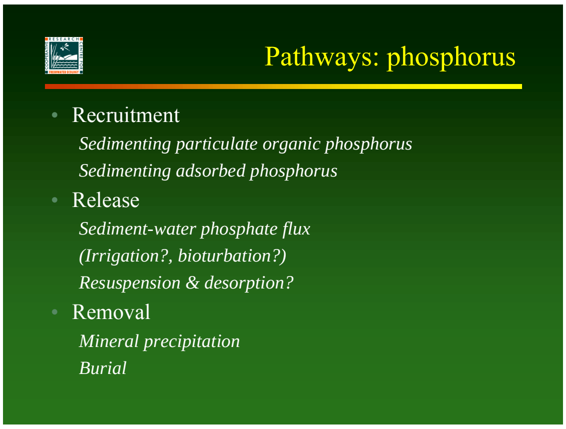












Pathways: nitrogen

- Recruitment
  - *Particulate organic nitrogen*
  - *Nitrate flux (Irrigation? bioturbation?)*
- Release
  - *Ammonium flux*
  - *Nitrate flux?*
  - *(Irrigation? bioturbation?)*
- Removal
  - *Denitrification*
  - *Burial*

Organic matter

- Sediment processes driven by input of OM
  - *Direct input of nutrient*
  - *Indirect influence on redox processes* e.g. *denitrification*
- Critical to have…
  - *Inputs (sedimentation)*
  - *Transformation rates*
  - *Transport rates*

Modelling considerations

- Good news
  - *Processes generally well understood*
  - *Can simplify models to describe only processes over relevant time scales*
  - *Can model even complex short-term dynamics*
  - *Established modelling theory*
  - *Not that difficult*
  - *Build on recent work*

Modelling considerations

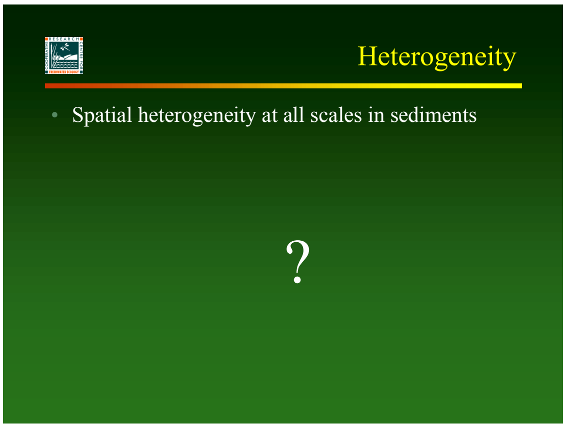
- Bad news
  - *Some key processes not well quantified (particularly transport)*
  - *Heterogeneity*
  - *Complexity: overhead, parameterisation, testing, application*
  - *Parameterisation difficult*
  - *Interfacing with other model components*

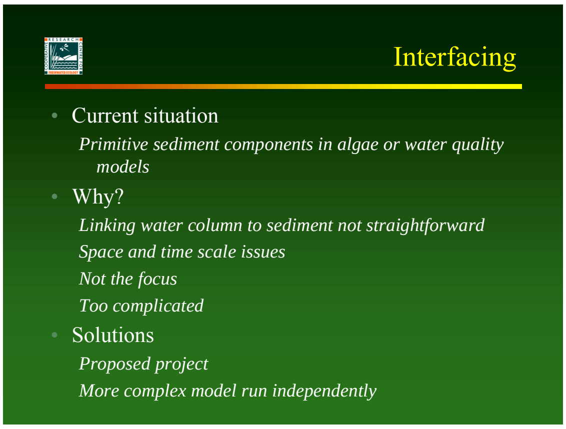
Transport processes

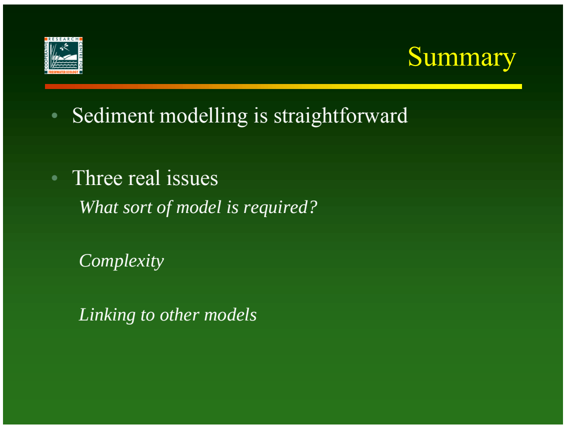
- Non-diffusional transport
  - *Biological (mixing solids, exchanging solutes across sediment-water interface*
  - *Physical (resuspension, hyporeic flows)*
  - *Carp, benthic invertebrates, current*
- All poorly quantified
  - *System specific*
  - *Not easily measured*
  - *Order of magnitude increase in mixing rates or fluxes*

Complexity

- Overhead
  - *Cost of developing, modifying, debugging, implementing etc.*
  - *Proportional to cube of complexity*
- Parameters
  - *SNAPP 'Simplified' sediment nutrient model: 33 parameters*
  - *Longer timescales, perhaps half this*
- Testing?


Heterogeneity
Spatial heterogeneity at all scales in sediments
?


Interfacing
Current situation
Primitive sediment components in algae or water quality models
Why?
Linking water column to sediment not straightforward
Space and time scale issues
Not the focus
Too complicated
Solutions
Proposed project
More complex model run independently


Summary
Sediment modelling is straightforward
Three real issues
What sort of model is required?
Complexity
Linking to other models

APPENDIX 4 MODELING ALGAL GROWTH

Presentation by Rod Oliver, CRC for Freshwater Ecology (not to be reproduced without the permission of the author)

Modelling Algal Growth

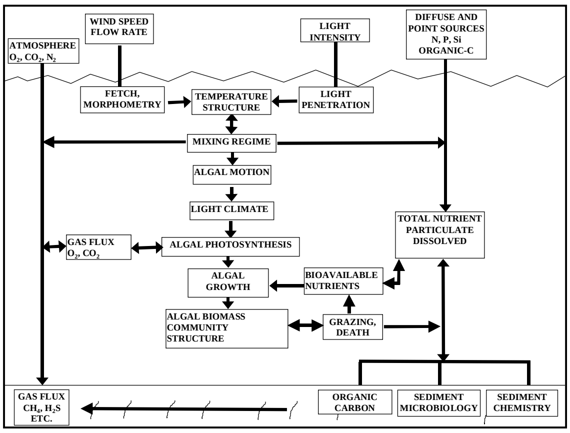
Rod Oliver
Murray Darling Freshwater Research Centre
CRC-Freshwater Ecology

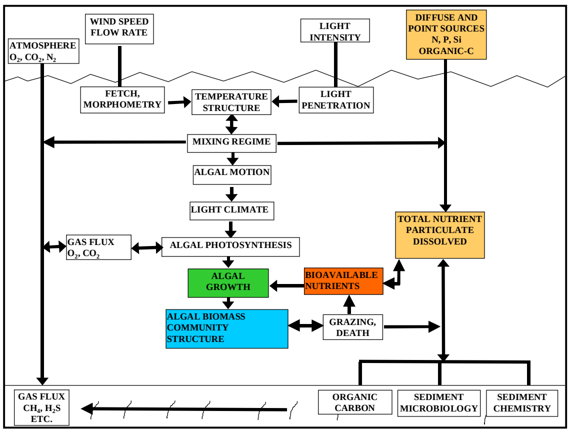
Model Types

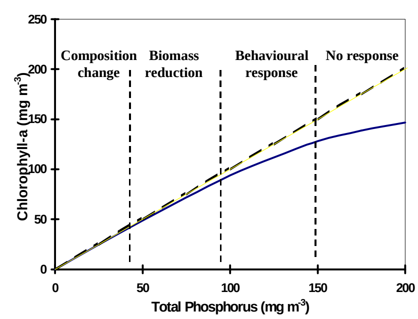
Increasing complexity of formulation and data requirements

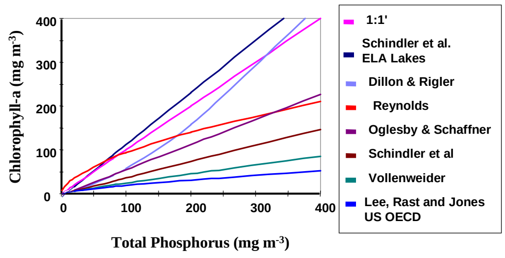
- **Conceptual:** Identification of connectivity between compartments and processes
- **Heuristic:** Intuitively determined formulae based on endpoints and chosen from simple functional form
- **Empirical:** Formulae based on experimental data only
- **Semi-empirical:** Formulae based on theoretical considerations, with experimentally determined constants and variables
- **Mechanistic/ Probabilistic:** Formulae based on theoretical considerations of underlying processes only

- The number of parameters required varies with the purpose of the model
- The number of parameters will depend on:
  - the number of environmental variables
  - the number of biological variables
  - non-linearity of response functions
- Questions must be carefully framed to limit model complexity. This requires identification of relevant processes
- The challenge is to describe biological acclimation adequately with a minimum number of parameters.



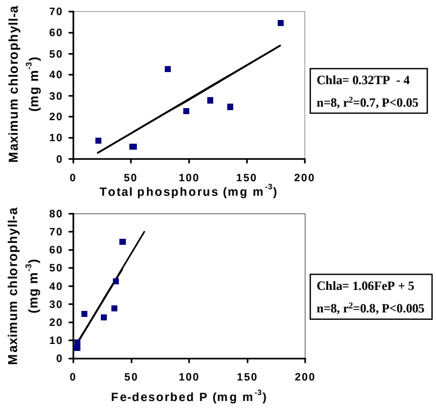


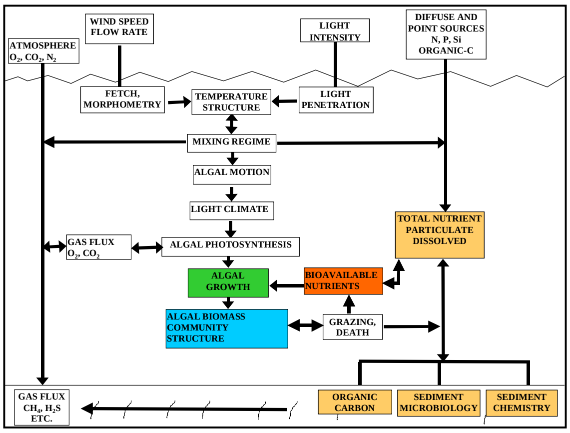


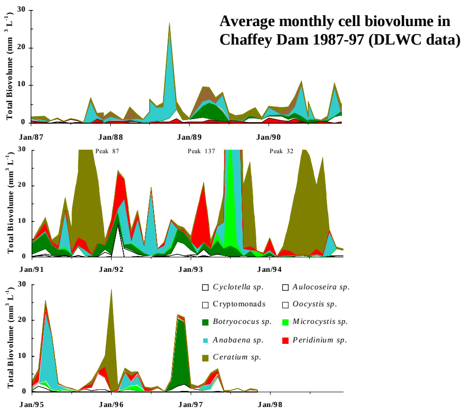


Cellular contents of chlorophyll-a and phosphorus are ca. 1:1

Reservoir	TP (mg m^{-3})	Fe-P desp (mg m^{-3})	Peak Chla (mg m^{-3})
Batyo Catyo	135	9	25
L. Buffalo	52	2	6
Green Lake	118	35	28
Lake Makoan	179	42	65
Melton	97	26	23
Myponga	81	36	43
Sugar Loaf	21	3	9
Tarrago	51	3	6







Chaffey Reservoir

Maximum hypolimnetic P and mean annual algal volume in the following year