INFORMATION BULLETIN

RISK ASSESSMENT APPROACH – ECOSYSTEM PROTECTION

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Publication 790.1
ISBN 0 7306 7605 6

CONTENTS

1 INTRODUCTION **1**

2 WHAT IS ECOLOGICAL RISK? **1**

3 ECOLOGICAL RISK ASSESSMENT **2**

4 THE WATERS OF VICTORIA APPROACH **4**

5 CASE STUDIES **6**

5.1 Introduction 7

5.2 Case Study 1 - Example Creek at Sample Bridge 7

5.3 Case Study 2 - Risk of toxicity from arsenic in the water column of Port Phillip Bay 12

5.4 Case Study 3 – Assessing the risk of cyanobacterial blooms in a lowland river (adapted from the *Guidelines* [2]). 15

6 REFERENCES **17**

1 INTRODUCTION

Aquatic ecosystems are very complex. The effective management of aquatic ecosystems, and in particular the management of human influences, struggles with this complexity. Nonetheless, day-to-day and, more importantly, long-term strategic decisions are required if we wish to maintain and restore aquatic ecosystem values. Therefore, we have to come to terms with this complexity even if it is not completely understood. The intrinsic uncertainties, however, must be made explicit, or the decision making process will not only be ambiguous but may also lead to the development and implementation of inappropriate strategies and plans.

The approach used by Environment Protection Authority Victoria (EPA) to develop ecosystem protection objectives for the *State Environment Protection Policy* (SEPP) (*Waters of Victoria*) (WoV)[1], is based on a risk assessment approach called ecological risk assessment (ERA).

2 WHAT IS ECOLOGICAL RISK?

In general terms, a risk can be understood to be the likelihood of an undesirable effect occurring due to some hazard (a situation, event or substance that can become harmful). Risk has been variously defined as:

- "a statistical concept defined as the expected likelihood or probability of undesirable effects resulting from a specified exposure to known or potential environmental concentrations of a material. A material is considered safe if the risks associated with its exposure are judged to be acceptable"[2];
- "the probability in a certain time frame that an adverse outcome will occur in a person, a group of people, plants, animals and/or the ecology of a specified area that is exposed to a particular dose or concentration of a hazardous agent, that is, it depends on both the level of toxicity of the hazardous agent and the level of exposure"[3];
- "the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors"[4];
- "the probability of a prescribed undesirable effect"[5].

While no strict definition has been used here, the interpretation should encompass the intent and, therefore, all the elements of the above definitions.

3 ECOLOGICAL RISK ASSESSMENT

ERA is a process for determining the level of 'risk' posed by stressors to ecosystems. The ERA process not only incorporates complexity and uncertainty into the decision making process, but also avoids ambiguity as it is transparent and clearly defines the problem and desired outcomes. Increasingly, this approach is being adopted by environmental agencies and research bodies for the evaluation of adverse ecological effects.

The ERA process involves organising and analysing data, information, assumptions and uncertainties to evaluate the possibility of adverse ecological effects. It is a systematic process where hazards are identified and goals established. There are several benefits in using an ERA approach. These include:

- effective and efficient use of information and resources;
- the ability to incorporate new information into the risk assessment at any stage, improving the capacity of subsequent environmental decision making;
- the exploration of ecological effects of stressors and other variables;
- a process that explicitly evaluates and identifies uncertainties, that is, the degree of confidence in the assessment;
- a basis for comparing, ranking and prioritising risks;
- an effective focus for research needs.

Perception of risk, cultural, personal and professional values, experience and emotions all influence risk assessment. As a consequence, it should be recognised that estimates of risk represent views or opinions for which there are likely to be many alternatives. These issues are minimised and/or made transparent by incorporating a quantitative approach to assessing risk[6].

Qualitative and quantitative approaches to risk assessment primarily differ in their analysis phases. In both approaches, problem formulation is the most important phase, particularly the identification and modelling of predicted relationships and uncertainties. Problem formulation is a critical step in ensuring that the aims are met and where issues, such as perception and values, are addressed.

Qualitative risk assessment can be an important tool in decision making as it provides a good basis for developing an understanding of the problem and the desired outcomes. These outcomes can be used to identify high-risk periods, situations or activities, or alternatively, risk avoidance actions. However, there are no formal analysis tools and the analysis of risk is based on subjective assessments of the likelihood and consequences of the hazards. The approach recommended as the Australian Standard for Risk Management[7] is an example of qualitative risk assessment.

Quantitative risk assessment differs from qualitative assessment in the use of formal mathematical tools, which ensure internal consistency and the explicit recognition of the uncertainties and the assumptions made[6].

The biggest impediment to the use of quantitative risk assessment tends to be institutional rather than a lack of scientific or technical knowledge. While model building benefits from having both understanding and data, lack of either should not be seen as an impediment. Model building provides the framework for the development and exploration of concepts and consequences, management scenarios and research needs. That is, most of the value comes from the process of building the model rather than from the interpretation of its output[5].

4 THE WATERS OF VICTORIA APPROACH

A risk-based approach (RBA) was developed for the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*[2], based on the ERA method[8]. The Government of Victoria has endorsed the *Guidelines*[2] and EPA used the approach as the basis of the SEPP WoV ecosystem objectives for fresh and marine waters. In general, the RBA reflects current scientific understanding and opinion, and is consistent with the ecosystem approach employed by EPA for a number of years to investigate issues and develop ecosystem guidelines (for example, nutrient guidelines[9]).

There are three essential characteristics of the RBA approach:

1. *ecosystem-based* – for example, estuaries, rivers (upland or lowland) or lakes;
2. *issues-based* – for example, nuisance aquatic plant growth, changes in flow regime or effects due to increased salinity;
3. *risk-based* – derived from ecological risk assessment methods. Includes a conceptual model to assess the consequences, likelihood and spatial and temporal extent of stressors or threatening process.

Thus, for each ecosystem, the issues are defined, risks assessed, appropriate indicators identified and objectives set.

EPA's goal of a high level of protection for all segments is balanced by the recognition that there have been irreversible human impacts and ongoing influences. In essence, the focus of the environmental quality objectives is to maintain the ecological health of the best parts of each segment and use these as management goals for the restoration of other parts.

A fundamental element of the SEPP WoV environmental quality objectives is that potential hazards to aquatic ecosystems are assessed through monitoring a core set of key indicators. The likelihood of an undesirable effect is assessed using the objectives for these indicators. When the objective is not met, there is a potential risk to the ecosystem, which is then investigated.

Determining the Objectives

The process for setting SEPP WoV objectives followed the approach outlined in the *Guidelines*[2]. In summary:

- an objective is preferably determined on the basis of known cause-effect information for a specific ecosystem. Unfortunately, cause-effect information is only available for a small number of issues and for an even smaller number of ecosystems;
- where no cause-effect information is available, objectives for specific ecosystems were determined on the basis of long term reference site data, which become the benchmark conditions for that ecosystem. Reference sites are generally the best sites in an ecosystem and are either unimpacted or little changed;
- if neither cause-effect nor reference data were available, then SEPP WoV objectives default to the *Guidelines*[2] Tables 3.3.2 and 3.3.3. For further details of this approach, see section 3.1 in the *Guidelines*[2].

Sites with a healthy ecosystem would be expected to have water quality characteristic of that ecosystem. The development of both the biological and water quality objectives were therefore based on healthy reference sites.

In Victoria's rivers and streams, healthy reference condition was determined using aquatic macroinvertebrates (which includes aquatic insects, worms, snails and crustaceans). Biota provides a more direct measure of ecosystem health, and therefore reference condition, than other alternative methods (for example, professional judgement or water quality).

In contrast, in marine and estuarine ecosystems, where data and information on ecosystem health are limited, healthy reference condition was determined using professional judgement.

Applying the Objectives

The objectives are 'packages' for assessing the potential risks associated with specific issues and ecosystems. These consist of a:

- *concentration or level* for each core indicator which, if met, presents a low risk of adverse ecological effects. These are called 'trigger levels' in the *Guidelines* [2];
- *protocol for assessing the objective*, which consists of monitoring requirements and appropriate data analysis;
- *decision framework for further investigating the risk* where the objectives are not met (Figure 1).

The objectives are no longer a simple pass-fail, which substantially ignored spatial and temporal variability and, most importantly, the complexity of aquatic ecosystems. If not met, the objectives signal a potential risk and initiate an investigation. This substantially increases the level of variability and complexity that can be incorporated into the assessment and decision making processes.

Monitoring protocols vary for different indicators and ecosystems, and provide the data requirements and methods for comparing monitoring results to an objective. For most water quality indicators, the method involves calculating a population statistic[10,11]. For toxicants, however, it is a maximum concentration[2]. A very different approach was taken for the biological indicators for rivers and streams. These indicators are based on the structure and diversity of the invertebrate community and include biodiversity indices and model predictions[12].

The decision frameworks for investigation (Figure 1) are the critical new component of the objectives. The intensity and extent of an investigation will range from very limited where other factors lower the risk or where actions are already initiated, to intensive site-specific studies where an adverse ecological risk is believed to be high.

Simple investigations include assessing potential pollutant sources, likelihood and magnitude of the potential impacts, and the importance of modifiers. There may also be current management actions that are aimed at or influence the problem. Where a high risk is identified, an intensive site-specific study will be required to assess the risks. Where the risks are known and well understood, management actions could be directly implemented to mitigate the risk.

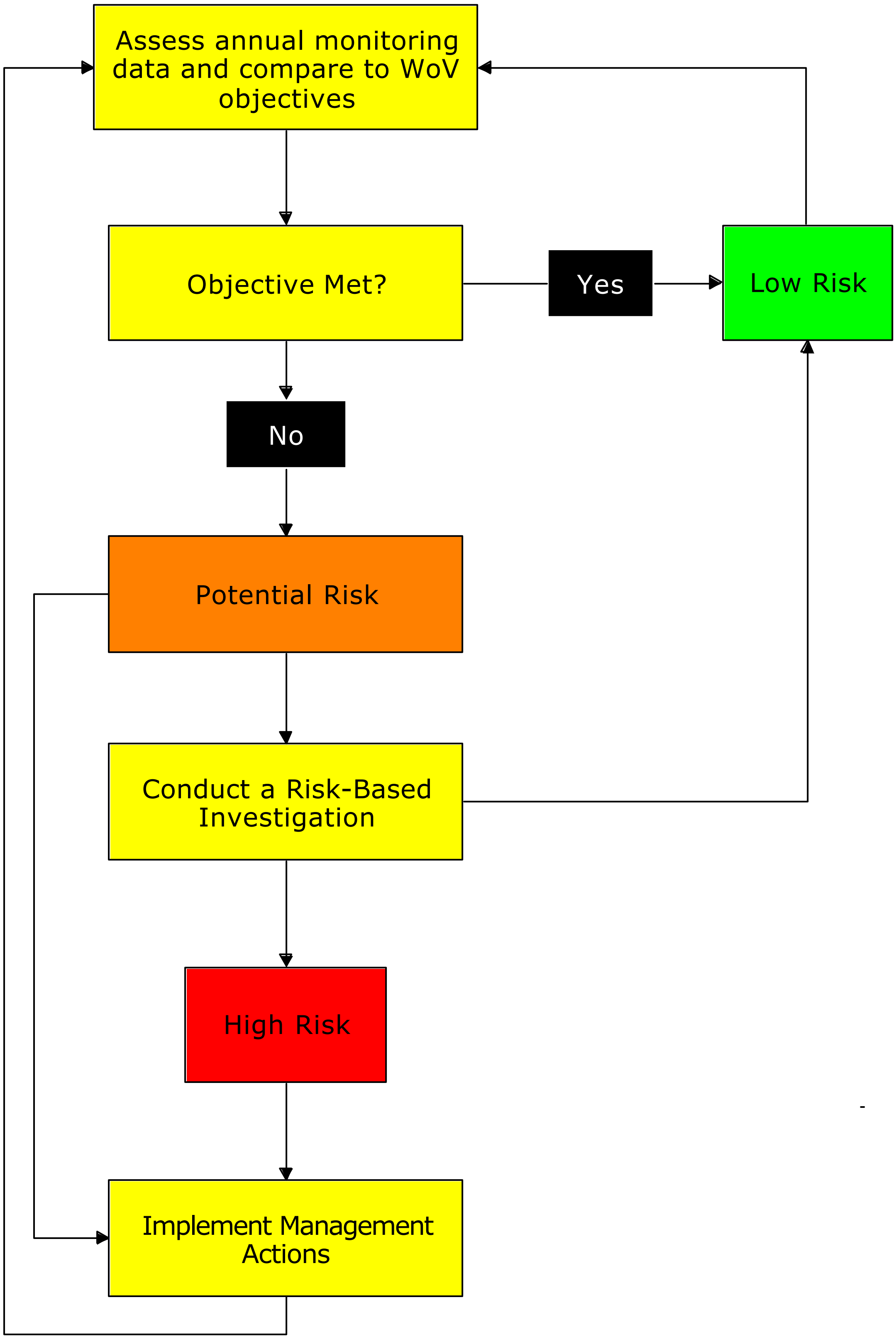

Figure 1. Risk-based Decision Framework (SEPP WoV)

5 CASE STUDIES

5.1 Introduction

This section contains case studies that illustrate the application of the risk-based decision framework for the assessment of aquatic ecosystem objectives.

If the SEPP WoV objectives are not met then an investigation of the potential risk to the ecosystem is undertaken. Examples of three investigations are provided:

- a hypothetical case study in a freshwater system;
- an actual EPA risk-based investigation of a marine system;
- a case study taken from the *Guidelines* [2], which shows the use of a decision tree for assessing potential risk to an ecosystem.

Where applicable, the case studies refer to documents that contain useful information for interpretation or methodologies.

It should be noted that a sound knowledge of aquatic ecosystems is required to appropriately investigate the potential risk to an ecosystem. Suitably qualified and experienced persons should undertake these investigations.

5.2 Case Study 1 - Example Creek at Sample Bridge

Background

Example Creek is situated in a relatively undisturbed and mostly forested catchment within Segment Forests B of the SEPP WoV[1].

The site at Sample Bridge is clear with a rocky bottom, up to 1 m deep, 10 m wide, at an altitude of about 500 m and is permanently flowing. In the previous year the site had an annual mean daily discharge of 52 ML; the mean daily discharge varying between 23 ML in March and 84 ML in September. It is situated in a partly cleared area of the catchment, approximately 8 km downstream of a small town (population 1200), which has a sewage treatment plant and a small amount of agricultural grazing activity in the surrounding area. There is a fish farm 6 km upstream of the site.

Monitoring and Assessment Results

The biological assessment results (Table 1) show that Example Creek has not met the SIGNAL and EPT biological objectives. This suggests that there is a problem (that is, a potential risk to the ecosystem) and is a ‘trigger’ for further action. Depending on the current status of the site:

1. If risks to the ecosystem have been identified and appropriate management actions are already being implemented, then continued monitoring and assessment of management effectiveness should be conducted;
2. If risks to the ecosystem have been identified and management action has not been implemented, then appropriate management actions should be implemented;
3. If risks to the ecosystem have not been identified an investigation of risk to the ecosystem should be conducted by a suitably qualified person(s).

For the purposes of this case study, the site on Example Creek falls into the third category, and a risk-based investigation is required.

Risk-based Investigation

DESKTOP STUDY

AUSRIVAS appears to be more sensitive to habitat impairment than water quality problems, while SIGNAL and EPT are generally most sensitive to changes in water quality. However, all three indicators will reflect both habitat and water quality issues[12]. Given the SIGNAL and EPT objectives were not met and the AUSRIVAS objective was only just met, the corresponding annual water quality results and habitat field sheets were examined for the site.

The water quality at the site (Table 2) was good except for total phosphorus, which exceeded the SEPP WoV[1] objective by 12 µg L^{-1}. An examination of the habitat field sheets show that attached algae were present, with the percent of reach covered by algae recorded as 65-90%. All other observations indicated an otherwise healthy habitat at the site.

An excess of phosphorus can stimulate nuisance growths of aquatic plants. In particular, excess nutrients commonly result in nuisance growths of attached algae in stream types such as Example Creek.

Aquatic plants are net oxygen producers during the day when photosynthesis exceeds respiration, but are net consumers of oxygen at night when they respire. If nutrient levels stimulate enough algal growth, they may cause excess diurnal fluctuations in dissolved oxygen (DO). Of most concern would be substantial decreases in DO overnight, which may stress or eliminate sensitive species of aquatic biota[13]. This could potentially be the cause of the low SIGNAL and EPT biological objective results seen at this site.

The elevated phosphorus levels could originate from an organic input such as sewage or an industrial effluent. If enough organic matter were entering the Creek, there would be a sustained decrease in DO due to the oxygen-consuming breakdown of organic matter by bacteria. However, this is not evident at the site as the 25th percentile for DO percent saturation was 92%. It is therefore reasonable to expect that bacterial breakdown of organic matter is not contributing to the low SIGNAL and EPT results.

Given the site has been shown thus far to:

- have not met the SIGNAL and EPT biological objectives;
- have elevated total phosphorus;
- have significant attached algae present;
- appear to be healthy in all other respects (except for the above),

the next step is to undertake an investigation of whether there is a DO problem associated with the algal growth at the site.

The sites 12 individual DO measurements for the year were examined. Ten of the samples were taken between 12pm and 4pm and the DO levels ranged between 92% and 110%. The other two DO samples were taken earlier in the day at 8.00 am and 10.00 am, and were at 59 and 67% saturation, respectively. This is below the SEPP WoV[1] DO objective and indicates there may be a problem of low overnight DO levels. The full diurnal range of DO over a number of days should be measured to determine the lowest DO levels in the Creek (which will most likely occur just before sunrise).

FIELD STUDY

An automatic datalogger was set up in the Creek to measure DO every 15 minutes over a four-day period. These measurements are presented in Figure 2.

The overnight levels of DO saturation are well below the SEPP WoV[1] objective of 90%. The lowest DO levels were recorded at about 6.00 am and ranged from 46% to 58% over the four-day period. Given the Creek has a reasonable flow (at least 23 ML per day), it would be expected that the depression in overnight DO would vary by less than 10%.

It is therefore highly likely that the overnight DO levels at this site pose a risk to the Creek's ecosystem, that is, taxa intolerant to low DO levels would be adversely affected. This is reflected in the low SIGNAL and EPT biological scores.

Table 1: Biological Monitoring and Assessment Results for Example Creek.

	Segment	AUSRIVAS O/E score (Band)		SIGNAL		Number of Families		EPT Taxa	
		Edge	Riffle	Edge	Riffle	Edge	Riffle	Edge	Riffle
Example Creek at Sample Bridge	3	0.88(A)	0.90(A)	4.9	5.6	24	26	5	7
SEPP WoV biological objectives	3	0.87(A)	0.87(A)	5.5	6.0	24	23	9	10

(Solid indicates the objective was not met, shading indicates the objective was met)

Table 2: Water Quality Monitoring and Assessment Results for Example Creek.

	Total Phosphorus ($\mu g\ L^{-1}$) (75^{th} percentile)	Total Nitrogen ($\mu g\ L^{-1}$) (75^{th} percentile)	Dissolved Oxygen Saturation (%) (25^{th} percentile/ maximum)	Turbidity (NTU) (75^{th} percentile)	Electrical Conductivity ($\mu S\ cm^{-1}$) (75^{th} percentile)	pH ($25^{th}/75^{th}$ percentile)
Example Creek at Sample Bridge	37	335	92/110	4	96	6.7-7.2/
SEPP WoV water quality objectives	25	350	90/110	5	100	6.4/7.7

(Solid indicates the objective was not met, shading indicates the objective was met)

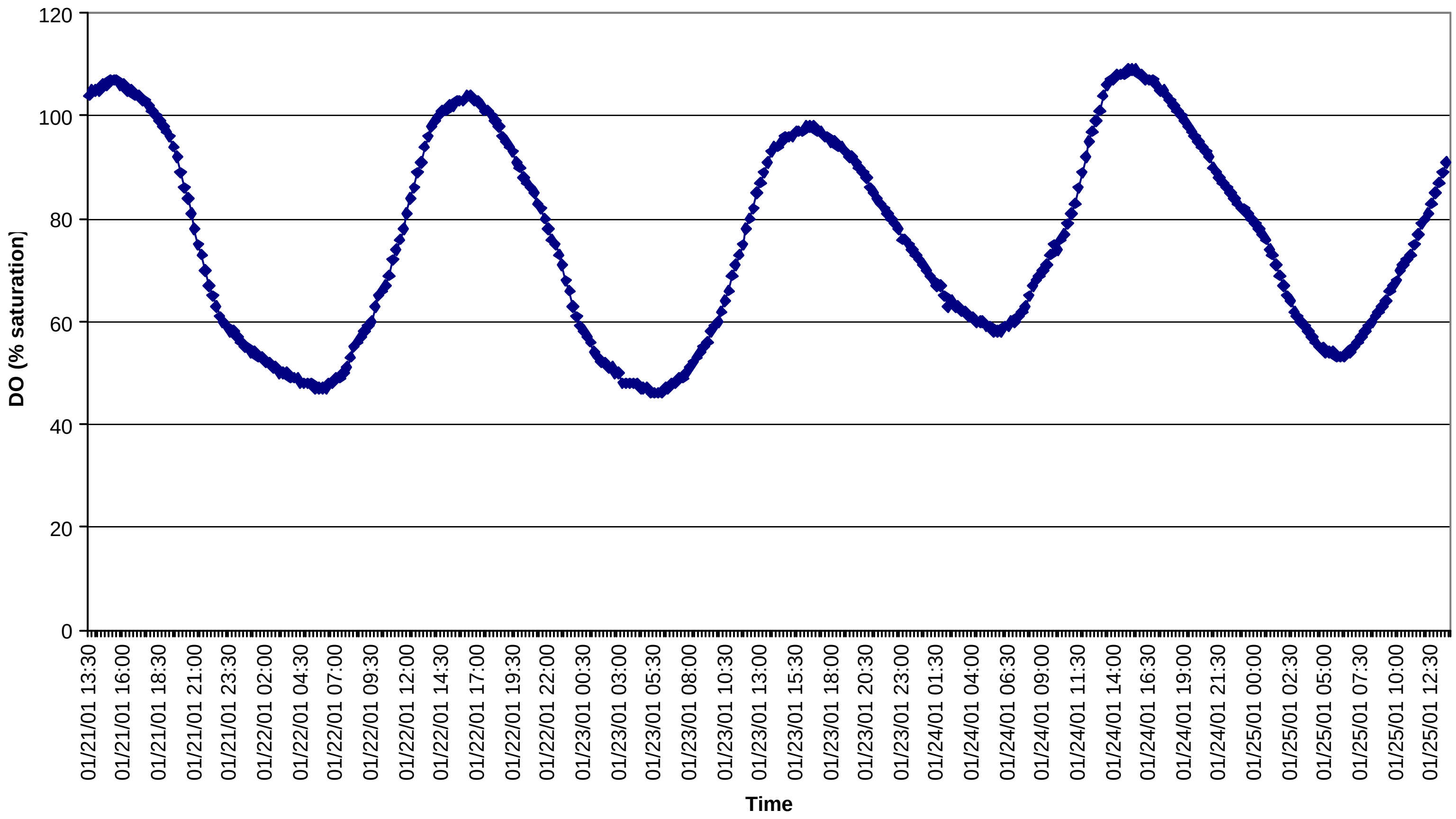

Figure 2: Four Day Diurnal Range of DO for Example Creek at Sample Bridge

SUMMARY OF INVESTIGATION OUTCOMES

- Excess phosphorus levels in the Creek would be contributing to the excess attached algal growth, with 65-90% of the reach being covered by algae.
- The excess attached algal growth appears to be causing overnight reductions in DO (as low as 46-58%) that pose a RISK to the Creek's ecosystem.
- Management to reduce phosphorus loads to the Creek needs to be implemented.

Further Action

- Identify source(s) of excess phosphorus into the Creek (for example, the sewage treatment plant, town stormwater, fish farm, grazing).
- Estimate the relative phosphorus contribution to the Creek from the identified source(s).
- Implement management action to effectively reduce phosphorus loads, giving priority to those sources identified as having the most significant contribution(s).
- Establish appropriate monitoring of macroinvertebrates, phosphorus and DO to assess the effectiveness of management actions. If this assessment shows these actions to be ineffective, re-evaluate potential sources and management options.
- When management goals are reached, resume standard site monitoring.

5.3 Case Study 2 - Risk of toxicity from arsenic in the water column of Port Phillip Bay

Background

Port Phillip Bay (PPB) is a large marine embayment which has restricted water exchange with Bass Strait. Of the total surface area, approximately half of PPB is less than 14 m deep. Tides are semi-diurnal with a maximum amplitude of one metre. PPB is vertically well mixed such that temperature and salinity do not stratify. Annual catchment discharge is about five per cent of the mean Bay volume and approximates annual evaporation. The catchment area is significantly modified. Urban and industrial development surround most of PPB, with the city of Melbourne situated along the northern and eastern shorelines, and the city of Geelong to the west. Although this urbanisation will contribute to arsenic levels in the waters of the Bay, internal loading from the sediments is thought to be a substantial source.

Arsenic (As) compounds are generally extremely toxic, with toxicity decreasing in the order of As (III) > As (V) > organic As compounds. There is limited information on toxicity of arsenic species in marine waters. This led to only 'low reliability trigger values' (LR TV's) being derived in the *Guidelines* [2]. Exceedance of LR TV's should be used as a cue to search and test for more site-specific information to assess the risk of toxicity[2].

Monitoring and assessment results

The LR TV for As (III) (2.3 $\mu g\ L^{-1}$) is lower than the trigger value for As (V) (4.5 $\mu g\ L^{-1}$). In the first instance the worst case scenario was assumed, that is, measures of total Arsenic were all present as As

(III). The organic compounds of Arsenic were not considered due to their lower toxicity and lower prevalence in the marine environment. The median chemical concentrations of the four assessment sites in Port Phillip Bay exceeded the 'low reliability trigger value' for As (III), with the highest value being 3.5 µg L^{-1} (Table 3). The median values at the assessment sites were calculated from 24 monthly values, commencing January 1997 and ending December 1998.

Risk-based investigation

The exceedance of the LR TV at all four sites in PPB justified a site-specific investigation of the risk of arsenic toxicity.

The risk-based investigation is a staged process where the effects of important site-specific modifiers are eliminated one at a time. If it is completed and there is still a potential risk of toxicity, the source of arsenic would have to be identified before management action could be taken.

The first stage of the risk-based investigation for metals in marine waters[2] is to determine the bioavailable or soluble fraction. This is defined as the proportion of arsenic that passes through a 0.45 µm or smaller filter. The concentrations in the filtrate are then re-assessed against the trigger value. If a potential risk is still present, the next step is to assess the speciation and toxicity.

The results of the first step showed that the arsenic concentrations in the filtrates were over 95% soluble (bioavailable), therefore the trigger value was still exceeded. As the concentrations of arsenic in the water column still present a potential risk the next stage of the risk assessment was conducted.

The arsenic in the filtrates was speciated into As (III) and As (V). Less than 20% of the total Arsenic consisted of the most toxic species, As (III). The worst case scenario would be when arsenic is most bioavailable and the toxic form is most prevalent. This is characterised by 100% of the total Arsenic being soluble, with As (III) and As (V) representing 20% and 80% of the total, respectively. Assuming this scenario, the concentrations of As (III) and As (V) in the water column at all four sites in PPB fall below their respective trigger values (Table 4). Therefore, even in the worst case, the risk of arsenic toxicity is still low.

SUMMARY OF INVESTIGATION OUTCOMES

- The investigation showed that the background levels of arsenic in the water column of PPB were below the low reliability trigger value for both As (III) and As (V).
- The level of risk to PPB is categorised as low, and the investigation need not proceed any further. This is supported by the conservative nature of the low reliability trigger values[2].

Further Action

- The information generated from the risk investigation should be used to develop site-specific trigger values for arsenic in PPB.
- These site-specific trigger values, characterising the background or baseline level, should be used to indicate changes in the risk of arsenic toxicity in future assessments of PPB.

Table 3: Exceedance of the low reliability trigger value[2] for As (III) in the water column of assessment sites in PPB.

	Long Reef Total As (µg L^{-1})	Central Total As (µg L^{-1})	Corio Bay Total As (µg L^{-1})	Hobsons Total As (µg L^{-1})
Assessment Site	2.8	2.7	3.5	2.6
LR TV As (III)	2.3	2.3	2.3	2.3

(Solid indicates the LR TV was exceeded, shading indicates the LR TV was not exceeded)

(Total Arsenic in the water column is assumed to be present as 100% As (III))

Table 4: Exceedance of the low reliability trigger values[2] for As (III) and As (V) in the water column of assessment sites in PPB.

	Long Reef		Central		Corio Bay		Hobsons	
	As (V) (µg L^{-1})	As (III) (µg L^{-1})	As (V) (µg L^{-1})	As (III) (µg L^{-1})	As (V) (µg L^{-1})	As (III) (µg L^{-1})	As (V) (µg L^{-1})	As (III) (µg L^{-1})
Assessment Site	2.2	0.6	2.2	0.5	2.8	0.7	2.1	0.5
LR TV As	4.5	2.3	4.5	2.3	4.5	2.3	4.5	2.3

(Solid indicates the LR TV was exceeded, shading indicates the LR TV was not exceeded)

5.4 Case Study 3 – Assessing the risk of cyanobacterial blooms in a lowland river (adapted from the Guidelines2).

The following presents an example of the use of a rather simple but effective decision tree, for assessing the risk of algal blooms arising from nutrients released to a lowland river in irrigation return drains. The protocol was initially developed as part of an environmental audit protocol developed for Goulburn-Murray Water[14,15]. More complex (and significantly more expensive) models have been developed for Port Phillip Bay[16], Hawkesbury-Nepean river[17] and the coastal waters off Perth[18,19].

The conceptual model for this case study (Figure 3) assumes that algal growth in lowland rivers is controlled by three major factors:

- the concentrations of the nutrients phosphorus (P) and nitrogen (N);
- the light climate (turbidity is used as a surrogate for light intensity because of a lack of data);
- the flow conditions in the river that are required for algal growth occur.

The 'guideline package' in this case includes values for the nutrient concentrations (TP, TN) as the key stressors, and values for turbidity and flow as the modifiers. The numbers provided in the decision boxes for TP, TN and turbidity (Figure 3) should be taken as indicative only because they will depend upon the particular ecosystem being considered.

The decision box for flow was based on the requirement that there be a sufficient period of low flow to allow algal numbers to increase to an alert level of 5000 cells mL^{-1}. A period of 6-10 days was estimated, based on an algal doubling time of two days and an initial algal concentration of 10-100 cells mL^{-1}. A 'growth event' was then defined as a period consisting of at least six consecutive days when the flow was less than the 25^{th} percentile flow obtained from the long term flow record for the system.

For the system in Figure 3, a high risk situation is indicated if the TP concentration is greater than 15 $\mu g\ L^{-1}$, the turbidity less than 30 NTU, and there is more than one 'growth event' of greater than six days duration per year. In this case, further investigation and appropriate management actions would be warranted.

Further refinement of this simple model could include:

- determining a more quantitative relationship between turbidity and the light climate for algal growth;
- validation of the assumption that the $<25^{th}$ percentile flows are the most appropriate low flow conditions to use. The present simple protocol does not take into consideration stratification that is now known to have a significant influence on cyanobacterial growth in lowland rivers[20];
- introduction of measures of the 'bioavailable' fractions of the nutrients rather than TP and TN[21];
- including the possibility that sediment release of nutrients (particularly phosphorus) may occur under low flow conditions;

- incorporation of the various decision 'rules' into a user-friendly computer program for ease of use by managers.

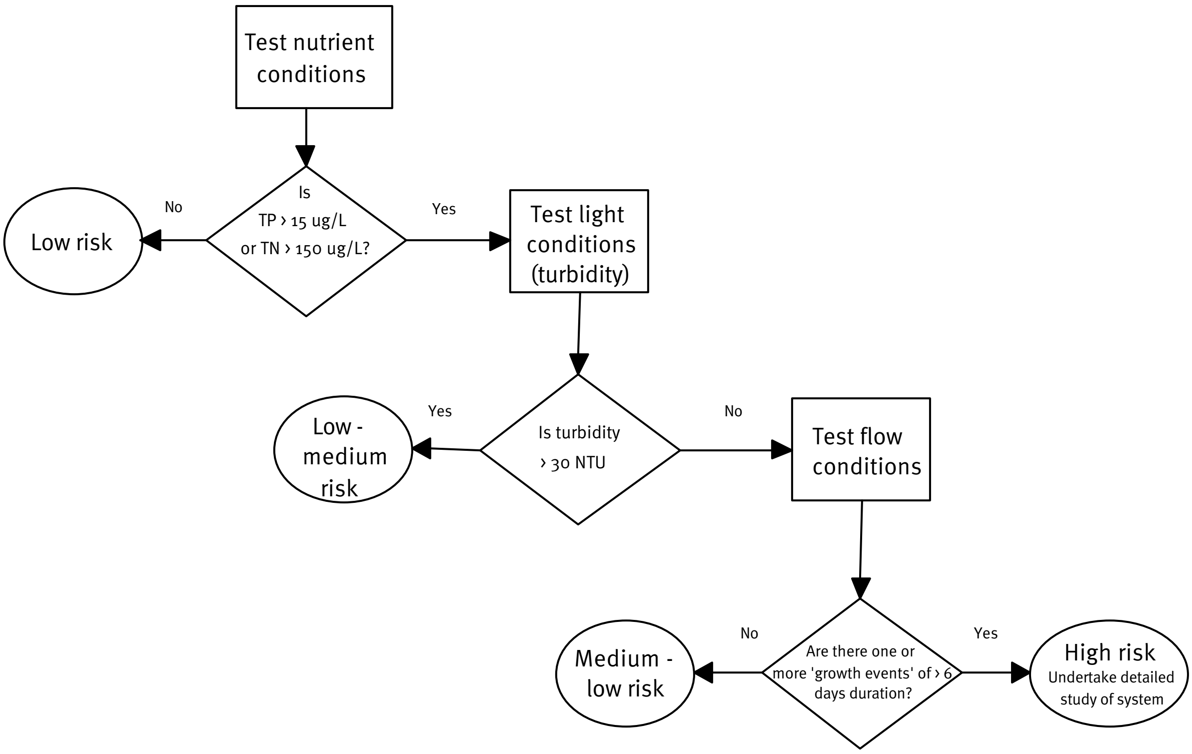

Figure 3: Decision tree for cyanobacterial blooms in lowland rivers

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