GUIDELINE FOR ENVIRONMENTAL MANAGEMENT

RISK-BASED ASSESSMENT OF ECOSYSTEM PROTECTION IN AMBIENT WATERS

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Foreword

State environment protection policies (SEPPs) aim to safeguard the environment. Policies express the community's expectations, needs and priorities for using and protecting the environment.

The SEPP (Waters of Victoria) (WoV) has provided significant steps forward in the management and protection of our aquatic ecosystems. A key part of this is the adoption of a risk-based approach to the policy environmental quality objectives. This is a relatively new approach reflecting current scientific knowledge and direction. The increasing adoption of risk-based methods by environmental agencies and resource managers has evolved from the need to develop transparent processes that better deal with the complexity and variability of aquatic ecosystems.

This guideline has been produced to provide support to catchment management authorities, coastal boards, water authorities and other resource managers in the implementation of the SEPP (WoV) risk-based approach. It provides decision frameworks and information on how to undertake risk-based assessments, with practical case study examples of these.

MICK BOURKE
CHAIRMAN

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1. INTRODUCTION

State environment protection policies help to protect our environment by providing a 'blueprint' of agreed environmental outcomes and strategic directions. They enable the community to set the uses and values of aquatic environments that are to be protected, to set objectives or 'goal-posts' that indicate when they are protected, and to provide clear guidance and tools on how to achieve this.

The State Environment Protection Policy (Waters of Victoria) (Gazette no. S 107) (SEPP (WoV)) introduces a risk-based approach to the management and protection of our aquatic ecosystems.

Clause 25(1)(a) of the SEPP (WoV) identifies that EPA will provide guidance to stakeholders to assist in implementing the policy, in particular, develop guidance on the application of an environmental risk assessment framework.

1.1 Purpose

This document provides guidance on how to undertake risk-based assessments in ambient waters[1]. As such, these guidelines can be considered a user manual to support catchment management authorities, coastal boards, water authorities and other resource managers.

Case study examples are included in this guideline to provide practical applications of risk-based assessments. They were conducted in partnership with water resource managers to ensure the applications were both practical and appropriate within a regional context.

This guideline is designed for use by experienced people with an appropriate level of aquatic ecosystem knowledge.

1.2 Context

Environmental agencies and resource managers are increasingly adopting approaches that incorporate risk or risk-based assessments as the best way to protect aquatic ecosystems. Such assessments provide an explicit and transparent process for coming to terms with the need to make management decisions for complex ecosystems that may not always be fully understood.

A risk-based approach was developed under the National Water Quality Management Strategy – *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC and ARMCANZ, 2000). This approach has been adopted in the SEPP (WoV) and was used as the basis for the development of the SEPP (WoV) environmental quality objectives.

Under this approach, the SEPP (WoV) environmental quality objectives are no longer a simple pass-fail number, which ignored spatial and temporal variability and, most importantly, the complexity of aquatic ecosystems. The environmental quality objectives now represent levels at which there is a potential risk that adverse ecological effects may occur. Where the environmental quality objectives are not met, a risk-based investigation needs to be conducted to ascertain if there is an adverse risk to the ecosystem. The size and detail of the investigation required will vary, depending on prior

[1] Ambient waters are defined in the ANZECC and ARMCANZ Guidelines (2000) as "all surrounding waters, generally of largely natural occurrence". These include fresh, estuarine and marine waters.

knowledge and/or investigations of the system, the potential scale of the impact, the immediacy and acceptability of the risk, and the degree to which a particular waterbody has been impacted by previous activities.

2. RISK-BASED ASSESSMENT

In general terms, a risk can be understood to be the likelihood of an undesirable effect occurring due to a 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" (ANZECC and ARMCANZ, 2000)
- "the probability in a certain timeframe 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" (National Environment Protection Council, 1999)
- "the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors" (USEPA, 1998)
- "the probability of a prescribed undesirable effect" (Warren-Hicks and Moore, 1998).

While no strict definition has been used in the SEPP (WoV), the interpretation of risk should encompass all the elements and intent of the above definitions. In simple terms, risk can be considered to be the probability (likelihood) of an adverse outcome or event.

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. However, qualitative analysis of risk is based on subjective assessments of the likelihood and consequences of the hazards. That is, perception of risk, cultural, personal and professional values, and past experiences all influence the risk assessment. As a consequence, it should be recognised that these estimates of risk represent views or opinions for which there are likely to be many alternatives. These issues are minimised and made transparent by incorporating a quantitative approach to assessing risk (Burgman, 1999).

Quantitative risk assessment differs from qualitative risk assessment in that it also incorporates the use of formal mathematical tools, which ensure internal consistency and the explicit recognition of the uncertainties and the assumptions made in the assessment (Burgman, 1999).

Ecological risk assessment (ERA) is a formal quantitative risk assessment process for determining the level of risk posed by stressors to the health of ecosystems. ERA evolved from the need to develop processes that better deal with the complexity of aquatic ecosystems, that is, the difficulties in assessing multiple stressors for a wide range of species within inherently variable 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. Where appropriate, this approach is increasingly being adopted by environmental agencies and research bodies for the evaluation of adverse ecological effects. In most cases, ERA is used if the level of risk is initially perceived to be high and the ecological and community benefits outweigh the costs of conducting the ERA, or in areas of high conservation value.

Due to the time and likely significant resources required to conduct a full ERA, it is not practicable for assessing potential risks posed to ecosystems at a Statewide or regional level. In recognition of this, the SEPP (WoV) adopted the **risk-based approach** of the ANZECC and ARMCANZ Guidelines (2000). While this approach still incorporates an assessment of the level of risk that stressors pose to ecosystems, both the level and method of investigation required vary and depend on a number of factors. These include the perceived level of risk posed to the ecosystem, conservation issues, available resources, cost-benefit analysis and community concern. The intensity of investigations may range from simple desk-top studies to a full ERA. In all cases however, the level of uncertainty and the assumptions made throughout an investigation must be both explicit and transparent.

3. ISSUES, INDICATORS AND OBJECTIVES FOR VICTORIA'S AQUATIC ECOSYSTEMS

There are three essential characteristics of the SEPP (WoV) environmental quality objectives. They are:

- **Ecosystem-based** – There is a variety of aquatic ecosystem types (for example, alpine rivers and streams, lowland rivers and streams, estuaries and coastal waters), which all function quite differently and therefore need to be assessed independently. In recognition of this, the SEPP (WoV) established environmental quality objectives for seven different aquatic ecosystem types.
- **Issues-based** – Issues or problems in waterbodies usually arise due to a combination of factors. The focus is, therefore, not on assessment of an individual indicator, but an assessment of the issue.
- **Risk-based** – The SEPP (WoV) environmental quality objectives represent levels at which there is a low probability of adverse ecological effects to the ecosystem, that is a low level of risk to the ecosystem. If the environmental quality objective is not met, this signifies a potential risk to the ecosystem and a site-specific investigation should be conducted to assess the level of risk.

As part of the SEPP (WoV) risk-based approach, the key issues for Victoria's aquatic ecosystems and indicators of environmental health for these issues were identified. Where possible, environmental quality objectives were set for these indicators. For example:

- excessive plant growth and/or algal blooms in rivers and steams was identified as a key Statewide issue;
- total phosphorus concentration was chosen as an indicator of the potential risk of excessive plant growth and/or algal blooms in rivers and steams; and
- objectives were set for the rivers and streams segments at a total phosphorus concentration that poses a low risk of excessive plant growth and/or algal blooms. For example, a 75^{th} percentile of 25 µg/L was derived for the SEPP (WoV) Forests A segment.

A brief summary of the key issues for Victoria's aquatic ecosystems is provided in Appendix 1. Table 1 provides a summary of the SEPP (WoV) indicators and the issues they reflect. The SEPP (WoV) environmental quality objectives are provided in Appendix 2.

An appropriate understanding of waterbodies requires assessment of biological, habitat, and physical and chemical indicators of both surface waters and sediment. Where possible, indicators were selected to allow this integrated assessment.

The environmental quality objectives for rivers and streams were set for five ecologically distinct segments across the State[2]. The water quality and biological objectives were derived using long-term reference data from across Victoria.

The biological objectives are considered to be the key SEPP (WoV) indicators of ecosystem health in rivers and streams. They are able to reflect a range of water quality issues, and are also considered to reflect impacts on aquatic ecosystems from in-stream habitat and riparian degradation, for which there are currently no direct measures. More importantly, they provide a means of directly assessing the health of the biota themselves.

Due to limitations in cause-effect and reference data, the environmental quality objectives for other ecosystem types (marine, estuarine, lakes and wetlands) default to the trigger values in the ANZECC and ARMCANZ Guidelines (2000).

While toxicants are not generally considered to be a Statewide issue, they can be locally important and objectives are included in SEPP (WoV). Since most persistent toxicants are quickly eliminated from waters, but tend to accumulate in sediments, sediment toxicant objectives are also included. The toxicant objectives for water and sediment default to the ANZECC and ARMCANZ Guidelines (2000) for all ecosystem types. Appendix 3 contains more information and guidance on the implementation of the toxicant objectives.

In summary, for each identified ecosystem type, the key environmental issues and appropriate indicators of these have been defined, level of risk assessed and environmental quality objectives set in SEPP (WoV). If these objectives are not met, a potential risk to the ecosystem exists which triggers a risk-based investigation. More detailed guidance on risk-based investigations is provided in section four and Appendix 3 of this guideline.

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[2] Rivers and streams segments are given in clause 9, SEPP (WoV)

Table 1: Key issues for Victoria's aquatic ecosystems and indicators for which SEPP (WoV) environmental quality objectives have been set for rivers and streams, estuarine and marine waters

Issues to Aquatic Ecosystems	Altered Natural Flows	Habitat Degradation and Loss [a]	Loss and degradation of riparian and catchment vegetation [a]	Salinisation	Excessive plant and algal growth	Effects of increased sediment inputs[a]	Reduced oxygen availability	Increasing acidity or alkalinity	Heavy metal, oil or chemical toxicity	Aquatic Pests
SEPP (WoV) Indicators										
biological[b]	X	X	X	X	X	X	X	X	X	X
total phosphorus					X					
dissolved inorganic phosphorus					X					
total nitrogen					X					
dissolved inorganic nitrogen					X					
chlorophyll a					X					
dissolved oxygen					X		X			
turbidity						X				
suspended solids						X				
transparency/PAR attenuation						X				
electrical conductivity				X						
pH								X		
metals									X	
non-metals									X	
ammonia									X	
sulphide									X	
sediment toxicants									X	

[a] Specific indicators and objectives for these issues will need to be developed on a regional basis due to the current lack of data. The development of objectives and indicators has been identified as a priority during the life of the SEPP (WoV).

[b] The biological objectives have been set as an indicator of overall ecosystem health, not as an indicator of any one particular issue.

4. FRAMEWORK FOR RISK-BASED ASSESSMENT IN AMBIENT WATERS USING SEPP (WOV) ENVIRONMENTAL QUALITY OBJECTIVES

This guideline provides the decision framework for risk-based assessment of aquatic ecosystems in ambient waters using the SEPP (WoV) environmental quality objectives (Figure 1). The decision framework (Figure 1) is designed to be implemented in conjunction with the information and guidance provided in sections 4.1 – 4.3.

It is important to remember that the SEPP (WoV) environmental quality objectives for the protection of aquatic ecosystems:

- only apply to ambient waters;
- are no longer a simple pass-fail number;
- represent levels beyond which there exists a potential risk that adverse ecological effects may occur; and
- if not met, trigger further investigation that is linked to the implementation of risk management actions.

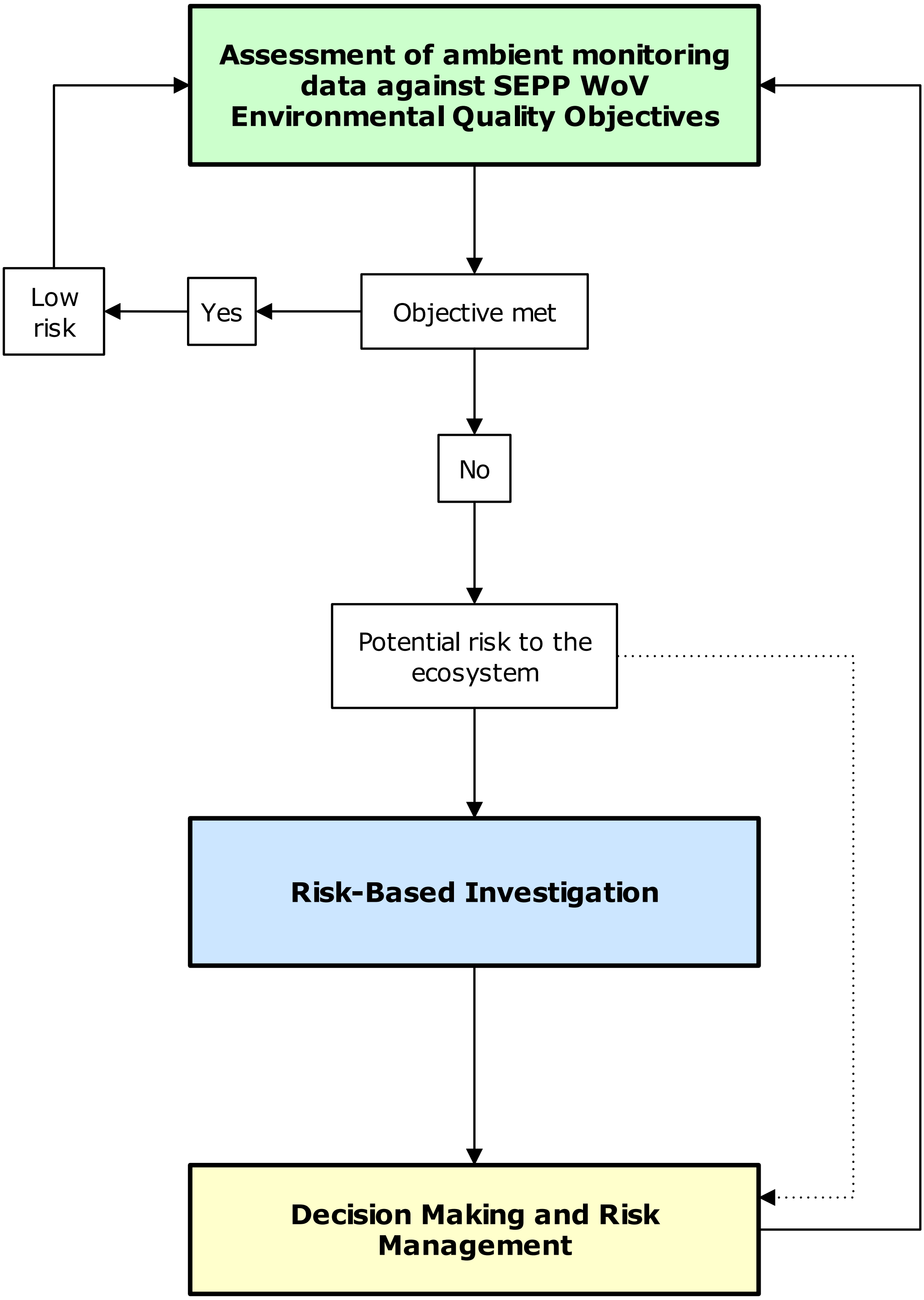

Figure 1: Framework for risk-based assessment in ambient waters using SEPP (WoV) environmental quality objectives

4.1 Assessment of Ambient Monitoring Data Against SEPP (WoV) Environmental Quality Objectives

Ambient monitoring data is assessed against the SEPP (WoV) environmental quality objectives in accordance with the requirements stated in Schedule A1 (5) of the SEPP (WoV).

Sites that meet all the SEPP (WoV) environmental quality objectives are identified as having a low risk to the ecosystem and do not require a risk-based investigation. Sites not meeting one or more of the objectives are identified as posing a potential risk to the ecosystem. As shown in Figure 1, where an objective is not met, and an investigation has not previously been undertaken to ascertain the level of risk posed by an issue to the ecosystem, a risk-based investigation should be conducted (section 4.2) and/or risk management action implemented (section 4.3).

Due to resource limitations it may not be possible in the short term to conduct risk-based investigations of all sites not meeting one or more objectives. These sites should therefore be investigated on a priority basis in accordance with regional strategy priorities.

4.2 Risk-Based Investigation

Figure 2 provides the framework for the risk-based investigation of triggered SEPP (WoV) environmental quality objectives. This framework is based on current internationally accepted ecological risk assessment frameworks (USEPA, 1998, Suter, 1993). In summary, the risk-based investigation framework can be considered to be a process for evaluating the probability of adverse effects to the ecosystem, that is an assessment of risk to the ecosystem.

The framework is intended to provide general guidance for what will be varied and, in some cases, complex investigations.

There are three main phases in the risk-based investigation framework:

- problem formulation;
- risk analysis; and
- risk characterisation.

While these are shown in a linear fashion for ease of presentation, investigations are interactive and iterative processes and the framework should be interpreted in this manner. For example, as more is learnt about the risk, this may lead to a re-evaluation of previous assumptions and problem formulation, and/or collection of new data and other analyses being conducted.

ASSESSMENT OF AMBIENT MONITORING DATA AGAINST ENVIRONMENTAL QUALITY OBJECTIVES
(Potential risk 'triggered' not previously investigated)

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RISK-BASED INVESTIGATION FRAMEWORK

PROBLEM FORMULATION

Identify and define issue(s) to be investigated and gather information for conducting the risk analysis:

- Identify and define **issue(s)** triggered by objectives for investigation
- Develop a **conceptual model** (update as information becomes available)
- Identify potential **hazards** and possible **sources,** modifying factors (environmental variables) that influence the **likelihood** of the issue(s) occurring and **effects to the ecosystem**
- Collate existing **information** and **data** on the waterbody and surrounding catchment
- Update the **conceptual model** with all the above information
- Develop a **risk analysis plan** based on the conceptual model

↓ ↑

RISK ANALYSIS
Implement the **risk analysis plan** developed in problem formulation:

- Analysis of data and information to estimate risk to the ecosystem
- Collection of new data or information and/or re-evaluation of problem formulation phase if required
- Assessment of **uncertainties** in the data, assumptions and analysis methods

↓

RISK CHARACTERISATION

- Identification of risk to the ecosystem
- Indication of the level of impact to the ecosystem
- Summary of assumptions, uncertainties, and strengths and limitations of the analyses
- Discussion of information gained during investigation useful to guide risk management decisions and actions

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DECISION MAKING AND RISK MANAGEMENT

Figure 2: Framework for risk-based investigation of triggered SEPP (WoV) environmental quality objectives

The extent and intensity of an investigation can range from:

- very limited, where much is already known about the issue and risk to the ecosystem can easily be identified; to
- intensive site-specific studies when the system or issue is poorly understood, ecological risk is believed to be high and/or the waterbody is of high value.

The level of investigation required to reduce the uncertainty in risk assessment needs to be balanced with resource and data availability, and the current level of scientific understanding. A balance is also required between the time needed to ascertain if there is a risk to the ecosystem, and that in which a decision may need to be made on risk management actions in order to prevent the issue occurring and adversely affecting the ecosystem.

It should be noted that, at any stage an investigation can be terminated (or not commenced) if risk to the ecosystem is instead acknowledged and appropriate risk management action implemented. For example, where the risks are obvious or already known and well understood, it may be decided that resources are better spent directly managing the issue(s), rather than investigating and identifying an obvious high risk.

When investigating an issue in a waterbody an integrated assessment approach should be taken. All factors that affect aquatic ecosystems need to be taken into account including, for example, water quality, physical habitat requirements and activities in the surrounding catchment.

As more than one issue may be of concern at a site, and in many cases, these do not operate independently, a holistic approach needs to be taken when investigating risks to an ecosystem. For example, direct effects from increased sediment inputs include abrasion and scouring, reduced light and habitat availability, and smothering of organisms. However, high levels of sediment inputs may also contribute excessive nutrients. This can result in excessive plant growth or algal blooms, which in turn may lead to lower oxygen availability for biota.

Problem Formulation

The problem formulation phase establishes the goals, scope and focus of the risk assessment (Hart *et al,* 2003). Problem formulation primarily involves:

- identifying and defining the issue(s);
- gathering and integrating available information;
- developing a conceptual model of the issue(s); and
- developing a risk analysis plan.

In situations where the person or people assessing the risk (risk assessors) are not responsible for managing the risk (risk managers), it is essential that the risk assessors involve risk managers in the problem formulation phase. This will ensure that the scope of the investigation is appropriate, all relevant aspects of the issue are identified, and the investigation outcomes are suitably linked to any required risk management actions.

Initially the **issue(s)** indicated by the triggered objective(s) at a site needs to be identified and appropriately defined. It is the risk of this issue(s) causing an adverse effect to the ecosystem that will be investigated. For example, if total phosphorus (TP) objective is not met in a stream, this would indicate the potential risk of an excessive plant and/or algal growth. It is the issue of an excessive plant and/or algal growth that is investigated, not just the TP levels in the waterbody. Table 1 in section 3 provides some guidance on the potential issues that are indicated by the various SEPP (WoV) environmental quality objectives.

The scope of the investigation needs to be defined. It is important that the full spatial and temporal extent of the potential issue(s) is incorporated. This includes defining the entire catchment area that may be both contributing to the issue (for example, surrounding and upstream catchment) and also impacted by the issue (for example, surrounding and downstream catchment), and the appropriate timeframe that needs to be assessed.

A preliminary **conceptual model** of the issue(s) to be investigated should be developed. The model(s) are updated throughout the investigation as information and data become available. Conceptual models for an issue qualitatively describe the:

- relationships between human activities, hazards, sources and stressors;
- factors influencing the likelihood of the issue occurring; and
- effects to ecosystems.

Conceptual models are an important initial step in the analysis of multiple stressors and provide the basis for formulating hypotheses on potential cause-effect relationships (Ferenc and Foran, 2000).

The development of a conceptual model has several benefits. It:

- aids in simplifying complex processes that may not always be completely understood, so that resource managers can assess risks to ecosystem health (USEPA, 1998);
- compels risk assessors to think through and clarify their assumptions about cause-effect relationships (Suter, 1999);
- identifies knowledge gaps and determines research and or data needs (USEPA, 1998);
- can be easily updated as information becomes available (USEPA, 1998); and
- provides an easily understandable communication tool for conveying the issue, assumptions and uncertainties to risk managers and stakeholders (Suter, 1999).

Figures 4 and 9 provide practical examples of conceptual models that were developed for the case studies (refer to section 5).

As part of developing the conceptual model for the issue, potential **hazards**, possible **sources** of these hazards, factors influencing the **likelihood** of the issue occurring and **effects to the ecosystem** need to be identified. For example, if the issue is excessive plant and/or algal growth:

- potential hazards could be excess nutrients such as phosphorus or nitrogen;
- possible sources may be sewage treatment plants (STPs), stormwater and agricultural run-off;
- factors influencing the likelihood of the issue occurring may include levels of turbidity,

shading of the river, discharge levels and bioavailability of the nutrients;

- effects to the ecosystem may include stress or death due to decreased dissolved oxygen levels and/or blue green algae toxicant releases.

All relevant **information and data** for the waterbody and surrounding catchment that will aid in the assessment of risk to the ecosystem needs to be collected. This may include:

- long term water quality data for the objectives not met;
- other relevant water quality data for parameters not used in the initial assessment against the SEPP (WoV) environmental quality objectives;
- biological data;
- site history records and photos;
- site/catchment visit(s);
- catchment/coastal strategies, action plans and reports;
- local expert knowledge; and
- scientific literature.

It is important to remember that the conceptual model is not static and should be updated as more information and data becomes available.

Finally, a **risk analysis plan** is developed. This is based on the conceptual model and information collected during problem formulation. The risk analysis plan defines the **assessment and measurement endpoints** that will be used to assess risk to the ecosystem and how the analysis will be undertaken. Where necessary, it may also identify knowledge gaps for which new data or information needs to be collected in order to assess ecosystem risk.

Assessment endpoints are explicit expressions of the ecological value(s) that is to be protected and measurement endpoints are the aspect of the assessment endpoint that can actually be measured (Suter, 1993). For example, if the risk of an algal bloom in a river is being investigated, the endpoints selected may be:

- assessment endpoint – the river phytoplankton community; and
- measurement endpoint(s) – chlorophyll *a* and/or phytoplankton diversity and abundance in the river.

Selection of appropriate assessment and measurement endpoints is essential. Suter (1995) suggests that endpoints should be:

- biologically relevant;
- susceptible to the hazard(s);
- unambiguously defined;
- predictable and measurable;
- operationally feasible, and;
- important to society.

Risk Analysis

Risk analysis is the actual determination of the probability and magnitude of an adverse effect to the ecosystem (Suter, 1993).

In the risk analysis phase, the products of problem formulation are used to assess risk to the ecosystem as described in the analysis plan. This could involve a variety of approaches ranging from a simple desk-top study to full ERA predictive modelling. The analysis tools used will vary and may include:

- simple examination of data trends, patterns or correlations;
- analysis and interpretation of biological data at family or species level, or of particular taxa sensitive to the issue;
- desk-top studies using published or previously collected data in a predictive modelling or 'Multiple Lines of Evidence' approach[3];
- the use of decision or logic trees, risk matrices or other methods that assist decision making;
- quantifying risks and predicting outcomes through empirical or bayesian modelling; and
- comparison of management or risk scenarios and testing of assumptions using appropriate techniques such as Monte-Carlo analysis[4].

As the analysis is conducted and more information becomes available, it may be necessary to re-evaluate how ecosystem risk will be assessed, including the need to update the conceptual model and analysis plan developed in the problem formulation phase.

Ecosystems and the interactions within them are generally not fully understood. Even when understanding is high, a degree of uncertainty exists with all data and information, and their analyses. There are limitations in the type and amount of data that is available or can be collected, and uncertainties associated with the accuracy and/or quality of this data. Added to this is the uncertainty and limitations associated with different methods for analysing the data and information. For these reasons, uncertainties in the information from the problem formulation and subsequent risk analysis phases should be identified, and estimated or described. This provides transparency and credibility for the assessment, and confidence that more informed and appropriate management decisions can be made. Where possible this should include:

- identification of assumptions made and the rationale for these assumptions;
- identification and description of knowledge gaps and data limitations. With respect to data, this includes limitations in both the type and amount of data available, and also uncertainties in the accuracy and/or quality of the data;
- identification and description of the strengths and limitations of analysis methods used; and
- quantitative estimates of uncertainties in mathematical data analyses.

Risk Characterisation

Risk characterisation is the summary and description of the risk analysis results that provides the information needed for risk/resource management (Suter, 1993).

There are four main outputs from the risk characterisation phase. These are:

- Identify if a risk to the ecosystem exists.
- If a risk to the ecosystem has been identified, an indication of the level of change or effect to the ecosystem should be provided. Where much

[3] A 'Multiple Lines of Evidence' approach is described in Section 9.2 of Downes *et al*, 2002

[4] Monte-Carlo analysis is described in chapter 2 of Suter, 1993.

is known about the issue and ecosystem this can be quite specific and/or detailed. Where there is more limited knowledge of the system, at the very least, a qualitative and general indication of the risk should be given, such as low, medium, high or catastrophic.

In applying the precautionary principle, as expressed in the SEPP (WoV)[5], it is important to consider that estimates of risk are not independent of their associated uncertainties, and that methods for estimating risks may be sensitive to particular assumptions. Thus, an activity that has a low likelihood but high uncertainty should be assumed to be a high risk, unless there is evidence to suggest otherwise.

- A summary of the assumptions, uncertainties, and strengths and limitations of the analyses.
- A discussion of all information gained during the investigation that is relevant to decision making and risk management. It is important that risk assessors not only state whether there is a risk to the ecosystem, but also pass on all information, advice or opinions that may assist in managing the risk to risk managers. This may also include advice on risks outside the scope of the investigation, and where risk is low, the potential for risk to the ecosystem to occur under changed conditions.

All of the above information must be made readily available and communicated in an appropriate form to risk managers and community stakeholders.

It is important to note that the risk investigation is an objective and transparent process that evaluates the risk of adverse effects to the ecosystem. Factors such as social and economic implications are not incorporated in the process until the decision making and risk management stage (section 4.3).

4.3 Decision Making and Risk Management

Decision making and management of the issues identified as posing a risk to ecosystems will primarily be implemented through regional planning processes. This will involve incorporating the issues into regional catchment strategies, regional river health strategies, coastal planning processes, and subsequent action plans and works programs. In addition, these issues need to be incorporated into any other decision making processes that effect aquatic ecosystems. For example, works approvals and licences related to wastewater discharges, and environmental effects statements (EES's).

Due to resource limitations, it is generally not possible to manage all of the risks identified within a region and decisions need to be made in prioritising management actions. The issues and risks to the ecosystem need to be communicated to key stakeholders and the community, so that they can effectively be a part of this decision making process. Factors that need to be addressed when deciding on and prioritising management actions include:

- probability of the risk occurring and level of impact to the ecosystem;
- environmental, economic and social values/assets;

[5] The precautionary principle is described in clause 6(2), SEPP (WoV).

- resources required versus likely environmental gain;
- multiple benefits of certain activities;
- high value waterbodies; and
- level of community concern and commitment.

Where the environmental quality objectives are not met and an ecological risk has been identified, management actions and targets should be set. These should aim to achieve the SEPP (WoV) environmental quality objectives within an identified period of time, whether these be in the short or long term. In highly modified systems, management actions aiming for continual improvement in environmental quality should be set even though the environmental quality objectives may not be met within the lifetime of the SEPP (WoV).

Avoidance, mitigation, abatement, remediation or treatment actions to achieve management targets within a specified timeframe must be determined and implemented. The effectiveness of management actions in meeting defined targets needs to be monitored and evaluated, and updated where necessary. This is an iterative process and it is important that appropriate indicators are selected to evaluate management actions.

5. CASE STUDIES

This section details two case studies that provide practical examples of conducting SEPP (WoV) risk-based assessments in ambient waters.

The case studies were developed and undertaken in partnership with water resource managers, to ensure they are both practical and provide sufficient guidance for subsequent use and application by others within a regional context.

To further facilitate implementation of risk-based assessments, additional case studies will be undertaken with water resource managers and made available via the EPA Victoria website[6] as they are completed. These will cover a variety of issues in fresh and marine waters.

5.1 Upper Loddon Catchment

This case study was conducted with the North Central Catchment Management Authority (NCCMA) in the Upper Loddon catchment, upstream of Cairn Curran Reservoir. This region had previously been identified by NCCMA as a high priority management area.

The objective of the case study was to identify if there were areas where aquatic ecosystems were at risk that required risk management action. It involved an assessment of the available ambient monitoring data in the case study area, against the SEPP (WoV) environmental quality objectives.

5.1.1 Assessment of Ambient Monitoring Data against Objectives

The Victorian Water Quality Monitoring Network (VWQMN) water quality data for 2001 and all EPA biological data collected in the past five year period were assessed against the SEPP (WoV) environmental quality objectives. The assessment was conducted in accordance with requirements stated in Schedule A1 (5) of the SEPP (WoV). The assessment results are presented in Tables 2 and 3, with site locations shown in Figure 3.

[6] http://www.epa.vic.gov.au

Table 2: Upper Loddon - Assessment of ambient water monitoring data (2001) against the SEPP (WoV) environmental quality objectives

Site	**WoV Objective** - Cleared Hills and Coastal Plains Segment					
	TP µg/L	**TN µg/L**	**DO %**	**EC µS/cm**	**Turbidity NTU**	**pH**
	75th percentile	**75th percentile**	**25th percentile**	**75th percentile**	**75th percentile**	**25th - 75th percentile**
	25	**600**	**85**	**500**	**10**	**6.5-8.3**
Jim Crow Creek at Yandoit - 407221	42	955	84	438	5	7.4–7.7
Loddon River at Newstead - 407215	66	610	74	1025	5	7.1–7.6

The shaded results indicate that the objective was not met.

As required by Schedule A1 (5) of the SEPP (WoV), a minimum of 11 samples collected from monthly monitoring over a one-year period was used to assess against SEPP (WoV) water quality objectives.

Data sourced: VWQMN 2001.

Table 3: Upper Loddon- Assessment of ambient biological monitoring data against the SEPP (WoV) environmental quality objectives

Site	Year	**WoV Objective** - Cleared Hills and Coastal Plains Segment			
			AUSRIVAS	**SIGNAL**	**No of Families**
		Riffle **Edge**	**A (0.82)** **A (0.85)**	**5.5** **5.5**	**23** **26**
Jim Crow Creek at Yandoit - GGF	1998	riffle	A (0.93)	5.6	23
		edge	A (1.05)	5.3	32
Campbells Creek at Muckleford-Yapeen Road - GGY	1999	edge	C (0.57)	4.4	13

The shaded results indicate that the objective was not met.

Data sourced: EPA, available data 1997 – 2002 .

The results indicated potential risk to the ecosystems of the Upper Loddon system. Of the six water quality objectives, three were not met in Jim Crow Creek and four were not met in the Loddon River. Jim Crow and Campbells creeks did not meet the biological objectives[7]. Therefore, a risk-based investigation of these areas in the Upper Loddon catchment was conducted.

[7] For this segment all biological indicators must be met for the site to meet the SEPP (WoV) biological objectives.

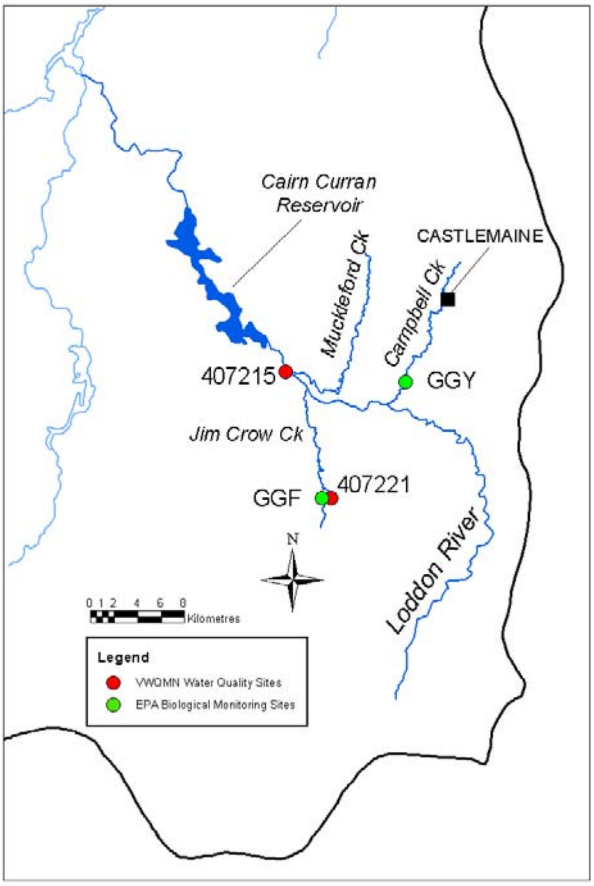

Figure 3: Assessment sites in the Upper Loddon Catchment

5.1.2 Risk-based Investigation

Problem Formulation

Total phosphorus (TP) and total nitrogen (TN)objectives were not met at both Jim Crow Creek at Yandoit and Loddon River at Newstead (Table 2). TP and TN are both indicators for the issue of excessive plant growth and/or algal blooms (Table 1). The biological index SIGNAL objective, shown to be a particularly good indicator of organic pollution, was also not met at Jim Crow Creek at Yandoit (Table 3). In addition, there had been previous reports of blue-green algae (cyanobacteria) blooms downstream of these sites in Cairn Curran Reservoir. Based on these results (Tables 2 and 3), current local knowledge of the Upper Loddon catchment and community concern, the risk of excessive plant growth and/or algal blooms was identified as the main **issue** for investigation in the Upper Loddon catchment.

The issues of reduced oxygen availability and elevated salinity were also incorporated into the investigation. Dissolved oxygen (DO) objectives were not met at both Jim Crow Creek at Yandoit and Loddon River at Newstead (Table 2). DO levels appear to be of greater concern in the Loddon River

(74 per cent saturation) than in Jim Crow Creek which only just didn't meet (84 per cent saturation) the objective. If excessive plant growth and/or algal blooms are an issue at these sites, this may explain the lowered DO levels. Salinity was identified for investigation at the Loddon River site only, where the electrical conductivity (EC) objective was not met.

The biological community responds to a wide variety of disturbances, and the different SEPP (WoV) biological indices may be indicative of any one or combination of these disturbances. As all the biological objectives were not met at Campbells Creek at Muckleford-Yapeen Road, more information was required before it was possible to identify any particular issue(s) of concern at the site. However, it is obvious from the results in Table 3, that the invertebrate biota in Campbells Creek were adversely affected in some way.

A simple **conceptual model** for the issue of excessive plant growth and/or algal blooms was developed for the Loddon River and Jim Crow Creek sites (Figure 4).

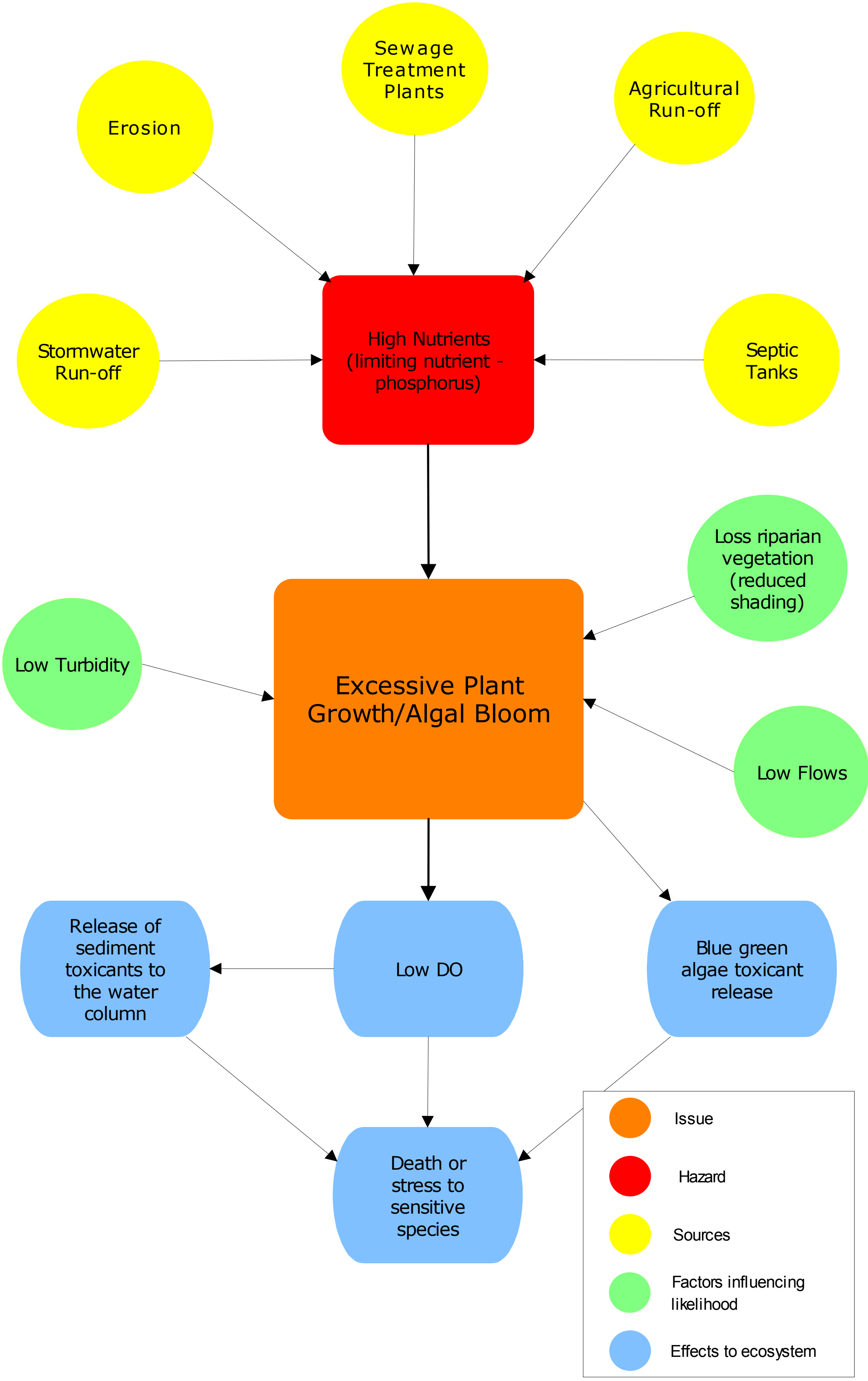

Figure 4: Upper Loddon conceptual model for the issue of excessive plant growth and/or algal blooms

Information and data was then collated on the different components of the conceptual model. This included:

- hazards – nutrients: VWQMN water quality data for 1998 – 2001 was collated for TP and filterable reactive phosphorus (FRP) (a measure of the bioavailable phosphorus in the water);
- sources – sewage treatment plants (STPs), septic tanks, agricultural run-off, stormwater run-off, erosion;
- factors influencing the likelihood of the issue occurring – VWQMN water quality data for 1998 – 2001 was collated for flow and turbidity; and
- ecological effects – reports to the CMA of excessive plant growth and/or algal blooms or fish kills.

The TP, FRP, turbidity and flow data are available on the Victorian Water Resources Data Warehouse website[8]. The general catchment information is summarised below.

There are several water storages in the area, the largest being Cairn Curran Reservoir, with a 148,000ML capacity. Other smaller storages include Lake Daylesford, Wombat Creek Dam, Jubilee Lake, and Hepburn, Bullarto, Poverty, McKay, Expedition Pass and Barkers Creek reservoirs. Extensive blue-green algae (cyanobacteria) blooms have been reported in Cairn Curran Reservoir and Hepburns Lagoon (NCCMA, 2002).

The region is mostly cleared and is predominately agricultural. The major urban centres are Castlemaine and Daylesford, which both contribute stormwater discharges to tributaries of the Loddon River. Castlemaine has a STP that discharges to Campbells Creek. The STP underwent a tertiary treatment upgrade, which became fully operational in early 2000. Elevated nutrients in Cairn Curran Reservoir were previously attributed to the Castlemaine STP, however it was expected that the tertiary upgrade significantly reduced this source (SKM, 2001). Daylesford has a STP that discharges secondary treated effluent to land. The smaller townships in the region have septic tanks that may contribute some run-off, which is currently being investigated by NCCMA.

The **proposed risk analysis plan** was to initially conduct a simple desk-top study. Then based on the results of the study, determine if and what type of further analysis may be required. The desk-top study included examination and pattern analyses of the water quality data and information collated to ascertain:

- The proportion of total phosphorus in the bioavailable form (FRP).

  Phosphorus is generally the limiting nutrient for plant growth and/or algal blooms in river and stream ecosystems such as those present in the Upper Loddon catchment. Thus, the amount of bioavailable phosphorus generally determines the nutrient potential for plant growth and/or algal blooms. The investigation therefore concentrated on phosphorus rather than nitrogen levels at the sites.
- Any relationship between the data patterns for phosphorus, flow and turbidity.

[8] http://www.vicwaterdata.net

The likelihood of excessive plant growth and/or algal blooms increases in periods of low flow and turbidity; that is, the risk of the issue occurring increases.

Comparison of the phosphorus and flow time-series data may also indicate whether phosphorus sources are predominately diffuse or point source. Diffuse source inputs are indicated when phosphorus levels only peak with high flow events; that is, most of the nutrient load enters waterways from catchment run-off during high rainfall events. Point sources generally provide a more consistent input of nutrients to waterways. These are indicated by less fluctuation in phosphorus levels compared to diffuse sources, and by phosphorus levels peaking in low as well as high flow periods.

- Any other evidence that may be apparent from general examination of the data and information that indicates the level of risk to the ecosystem.

Risk Analysis

Initially, the simple **desk-top study** was conducted and is summarised below.

Examination and pattern analysis of the 1998 – 2001 water quality data for Jim Crow Creek at Yandoit showed:

- Approximately 15 per cent of the phosphorus (Figure 5) was present in the water column in the bioavailable form of FRP. That is, most of the phosphorus was not readily available for plant/algal uptake and growth. It should be noted however, that these nutrients have the potential to become bioavailable under changed conditions.
- Phosphorus peaks at the Jim Crow Creek site occurred during high and low flow periods, indicating both diffuse run-off and point sources of phosphorus.

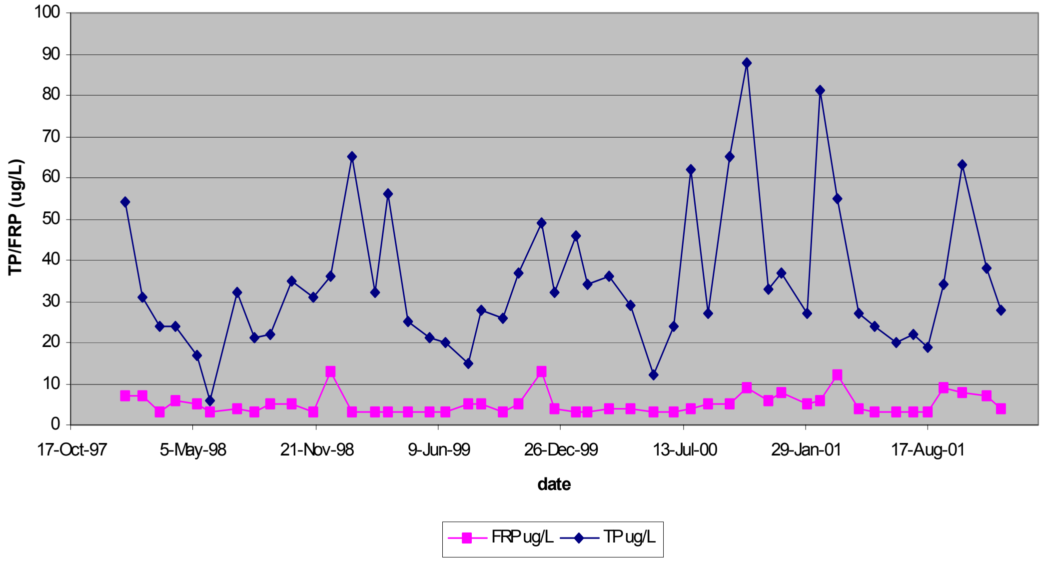

Figure 5: Jim Crow Creek at Yandoit – Filterable Reactive Phosphorus (FRP) and Total Phosphorus (TP) (1998-2001).

Examination and pattern analysis of the 1998 –2001 water quality data for Loddon River at Newstead showed:

- High bioavailable phosphorus (FRP) concentrations occurred when both flow and turbidity (Figure 6) were low, thus increasing the risk of excessive plant growth and/or algal blooms.
- Phosphorus levels in the Loddon River, while still at a level of concern, were substantially lower from April 2000 (Figure 7). Prior to April 2000, approximately 60 per cent of the phosphorus in the water column was present in the bioavailable form of FRP. That is, a large proportion of the phosphorus was readily available for plant/algal uptake and growth. After April 2000, only approximately 25 per cent of the phosphorus was present in the bioavailable form of FRP. Although considerably decreased, this is still a substantial amount of bioavailable phosphorus readily available for plant/algal uptake and growth.
- The phosphorus levels in the Loddon River at Newstead were much higher than that of Jim Crow Creek at Yandoit (Figures 5 and 6). In addition, the phosphorus peaks at the Loddon River site did not correspond with those at the Jim Crow Creek site. This indicated that Jim Crow Creek was not a major contributor of phosphorus loads into the Loddon River.
- As discussed, point sources are generally indicated by less fluctuation in phosphorus levels compared to diffuse sources, and by phosphorus levels peaking in low as well as high flow periods. The Loddon River site had phosphorus peaks occurring at both high and low flow, indicating both diffuse run-off and point sources. Furthermore, the fluctuations in

phosphorus levels were less than those at Jim Crow Creek, indicating point source(s) may be a greater influence at the Loddon River site than Jim Crow Creek.

- The Castlemaine STP discharges to Campbells Creek, a tributary that enters the Loddon River upstream of the Newstead site (Figure 3). The observed decrease in phosphorus levels at the Loddon River site early 2000 coincided with the Castlemaine STP tertiary upgrade becoming fully operational. This upgrade lowered the total phosphorus levels in the STP discharge from previous years[9]. The similarity in TP trends for both the Castlemaine STP discharge and the Loddon River site, indicated that the discharge was the major source of excess nutrients entering the Loddon River before the tertiary upgrade. Further analysis would be required to ascertain if the STP remains a major source of the elevated phosphorus levels in the Loddon River.
- If the assumption that the STP remains a major source of elevated phosphorus in the Loddon River was correct, it would also follow that Campbells Creek itself would be at an even higher risk, as the STP discharges directly to the creek. That is, the issue of excess plant growth and/or algal blooms, could be a potential cause of the reduced invertebrate health in Campbells Creek shown by the SEPP (WoV) biological indices in Table 3. The TP water quality measurements taken at the time of the biological sampling were examined. These measurements represent only two discrete samples and, as such, cannot be compared against the SEPP (WoV) objectives or assumed, with any statistical confidence, that they would reflect the range of water quality at the site over the year. However, they clearly show phosphorus levels were extremely high, with TP concentrations of 11,000µg/L and 5,300µg/L on the 22/4/99 and 4/11/99, respectively. It should be noted that these levels are indicative of TP levels before the STP tertiary upgrade became fully operational, and further sampling would be required to determine the level of reduction in TP levels in Campbells Creek following the upgrade.

[9] According to monitoring data results in the Castlemaine sewage treatment plant Annual Reports 1996-2001.

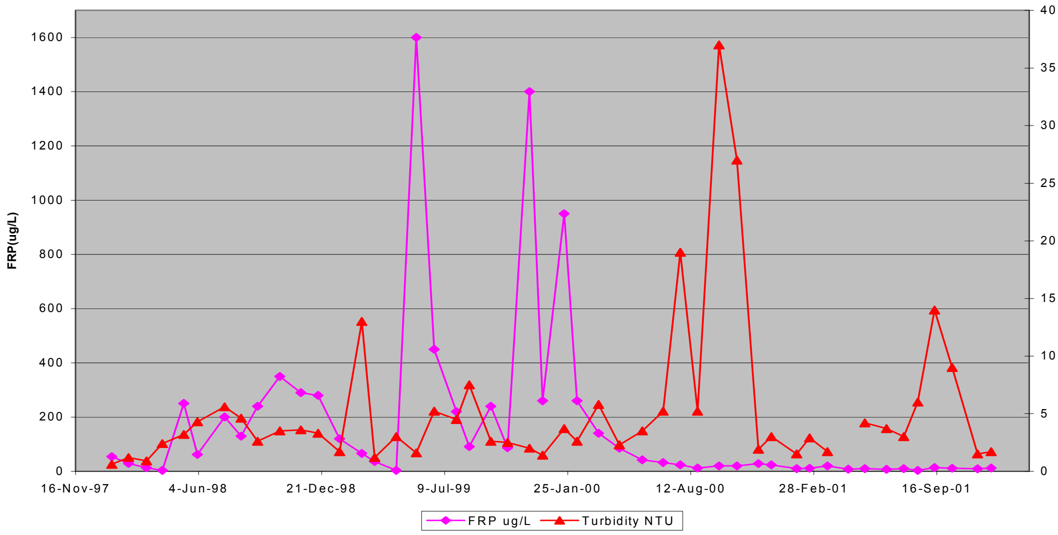

Figure 6: Loddon River at Newstead – Filterable Reactive Phosphorus (FRP) and Turbidity (1998-2001).

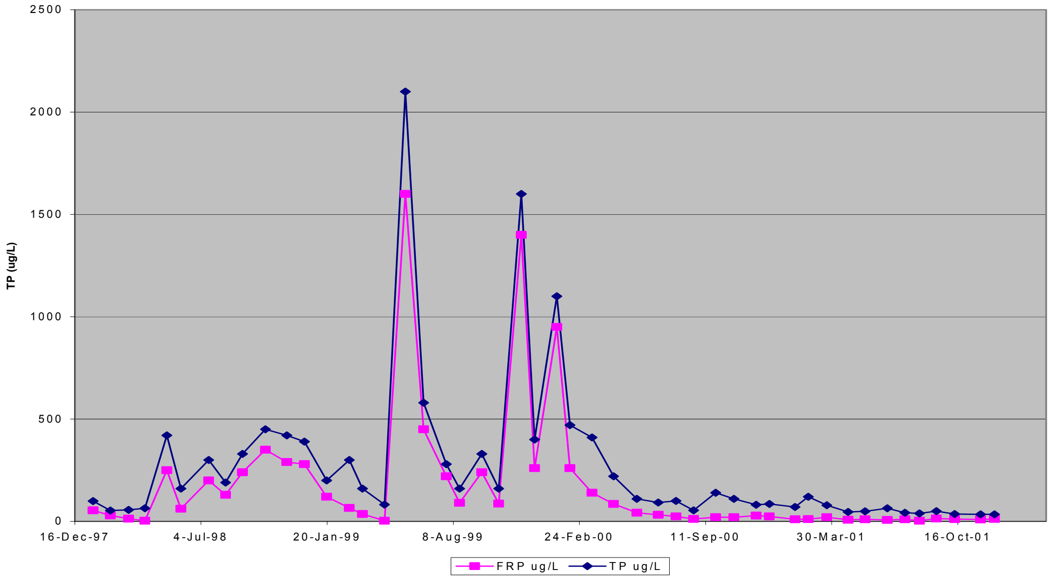

Figure 7: Loddon River at Newstead – Filterable Reactive Phosphorus (FRP) and Total Phosphorus (TP) (1998-2001).

A **catchment site visit** was conducted to better understand the information gathered and analysed in the desk-top study. In particular, to:

- assess the overall condition of the sites and the tributaries entering the Loddon River in the upper catchment;
- observe if there were any plant growths/algal blooms occurring in the Upper Loddon catchment;
- assess the condition of riparian vegetation and also the shading potential provided at the sites; and
- assist in identifying potential issues in Campbells Creek and any impacts it may have on the Loddon River.

The catchment site visit enabled the identification of much of the risk posed to the ecosystems in the Upper Loddon catchment. In summary:

- excessive plant growth was already occurring at the Loddon River and Campbells Creek sites, both of which had substantial nuisance growths of *Azolla sp*.
- There was a small amount of filamentous algae growth at Jim Crow Creek. Although this algae growth was not at a level of concern, it did indicate that under changed conditions (for example, more of the phosphorus being present in bioavailable form (FRP) or less riparian shading) there may be the potential for excessive plant growth and/or algal blooms.
- At the time of the site visit, only Campbells Creek and Jim Crow Creek had flow entering the Loddon River upstream of Newstead. All other tributaries were dry. That is, there were no other potential nutrient sources to the Loddon River from other tributaries.

Information from both the desk-top study and catchment visit indicated that the STP discharge into Campbells Creek was likely to be a major source of the nutrients causing excess *Azolla sp*. plant growths at the Campbells Creek and Loddon River sites. This assumption was further investigated. **Snapshot water quality sampling** was undertaken in Campbells Creek near its confluence with the Loddon River, and in the Loddon River upstream and downstream of the confluence. This included sampling for total and bioavailable phosphorus and nitrogen (TP, FRP, TN, NOx), pH, EC, temperature and DO.

The snapshot water quality results (Table 4) showed very high nutrient and salinity levels in Campbells Creek. Phosphorus and EC levels in the Loddon River downstream of the confluence with Campbells Creek were approximately three and two times higher, respectively, than levels upstream of the Campbells Creek confluence. This confirms that, at the time of sampling, Campbells Creek was a major contributor to elevated phosphorus and salinity levels in the Loddon River.

To further assess whether the major source of these nutrients in Campbells Creek was the Castlemaine STP discharge, additional data from a study conducted for Coliban Water was examined (WSL, 2001). As part of the study, water quality sampling was conducted at two sites, 10 and 50 metres upstream of the Castlemaine STP discharge, and four sites downstream of the discharge. The downstream sites were approximately 10m, 50m, 6km and 11km below the discharge, the last site being approximately 50m upstream of the Campbells Creek confluence with the Loddon River. The water quality sampling was conducted monthly from December 2000 to June 2001. On these sampling occasions, the mean TP levels at the four sites downstream of the discharge ranged from approximately three to 20 times greater than the mean of the two upstream sites. The TP levels were high at all downstream sites, with the furthest site from the discharge (near the confluence with the Loddon River) ranging from 230–690µg/L, compared to the upstream sites that ranged from 30–140µg/L. These sampling results, and those from the snapshot conducted for this investigation, together with the information and water quality patterns found in the desk-top study, all indicate the STP discharge is likely to be the main source of the high nutrient levels in Campbells Creek, and further downstream in the Loddon River.

Table 4: Upper Loddon Catchment - Snapshot Water Quality Sampling (July 2002)

	Loddon River upstream of confluence with Campbells Creek	Loddon River downstream of confluence with Campbells Creek	Campbells Creek near its confluence with the Loddon River
Total phosphorus (µg/L)	20	57	160
Filterable reactive phosphorus (µg/L)	<3	17	61
Total nitrogen (µg/L)	455	540	2070
Nitrate + nitrite (µg/L)	95	150	1100
pH	7.54	7.77	7.73
Electrical conductivity at 25°C (µS/cm)	366	706	1730
Temperature (°C)	8.46	8.94	8.28
Dissolved oxygen (mg/L)	10.14	11.18	9.40

Risk Characterisation

Jim Crow Creek at Yandoit

There is currently a low risk of excessive plant growth or algal blooms in Jim Crow Creek. However, a moderate nutrient hazard exists. The nutrient levels are slightly elevated and, although they are predominately present in forms that are not readily bioavailable for plant/algal uptake and growth, they still have the potential to become bioavailable under changed conditions. Dissolved oxygen (DO) levels only just didn't meet the environmental quality objectives and are not of immediate concern to the ecosystem.

Loddon River at Newstead and Campbells Creek at Muckleford-Yapeen Road

There is a very high risk to the aquatic ecosystems of both Campbells Creek and the Loddon River downstream of Campbells Creek, with excessive *Azolla sp*. plant growths present in both these waterbodies. The effect on the invertebrate community in Campbells Creek pre-tertiary upgrade of the Castlemaine STP is clear from the results in Table 3. The study conducted for Coliban Water (WSL, 2001) provided a post-tertiary upgrade assessment of the potential impact of the STP discharge on the invertebrate community in Campbells Creek. The results of this study showed that while the invertebrate communities upstream of the discharge were impacted, the communities directly downstream of the discharge were clearly further degraded. Recovery was evident approximately 6km downstream of the discharge, however this was not to the same level of environmental quality seen at the most upstream site and a change in the community structure was clear. The study attributed much of the change in community structure to nutrient levels contributing to increased algal and macrophyte growth. The study also acknowledged that there were other potential land use impacts on the invertebrate communities of Campbells Creek, in addition to the STP discharge.

The catchment site visit conducted as part of this investigation was in July 2002. It is important to note that the excessive *Azolla sp*. plant growths in both waterbodies were present in winter, and not confined to only the lower flow periods of summer. A subsequent post-investigation visit to the sites in December 2002 showed the nuisance plant growths to be even more extensive in summer, with 100 per cent cover in large sections of Campbells Creek and some sections of the Loddon River downstream of Campbells Creek.

In order to protect aquatic ecosystems in Campbells Creek and downstream in the Loddon River, nutrient levels in Campbells Creek should be reduced. This investigation showed that the Castlemaine STP discharge is likely to be the major source of nutrients causing excess *Azolla sp.* plant growths in Campbells Creek and downstream in the Loddon River.

Information in EPA indicated that the natural flow in Campbells Creek was intermittent prior to the Castlemaine STP discharge inputs. The discharge has been operating for many tens of years and comprises almost all of Campbell Creek's flow in summer and a substantial amount in winter. Now treated to a tertiary level, the discharge has a substantially reduced phosphorus load to

Campbells Creek, compared to previously secondary treated discharges. However, the low natural flow in the Creek and subsequent lack of dilution of the discharge waters, appear to be resulting in nutrient levels that are posing a risk to aquatic ecosystems in both Campbells Creek and downstream in the Loddon River.

If greater certainty is required than that provided by this investigation on the contribution of the STP discharge, further sampling could be conducted that more accurately quantifies the relative phosphorus contribution of the discharge compared to other potential sources such as sediment nutrient stores, septic tanks, stormwater and rural run-off.

Salinity levels above 1000mg/L total dissolved solids (approximately 1670 µS/cm EC) begin to have adverse effects on freshwater ecosystems (Metzeling et al., 1995). It would therefore be expected that the salinity level in Campbells Creek at the time of the snapshot water quality sampling (1700 µS/cm EC) would also pose a risk to the aquatic ecosystem, and contribute to elevated salinity levels downstream in the Loddon River. It is also likely that the STP discharge is a potential contributor to elevated salinity levels in Campbells Creek. If required, the relative salinity contribution of the STP discharge to other sources could also be incorporated in the above mentioned phosphorus sampling.

Excessive plant growths generally result in lowered oxygen availability. The excessive *Azolla sp*. growths at the Loddon River site are likely to be contributing to the observed lowered DO levels (Table 2). Continuous monitoring of diurnal DO levels would be required to investigate this assumption.

However, it may be more practical to first ascertain if management actions to reduce nutrient levels and corresponding *Azolla sp*. growths raises the DO levels at the site before undertaking further investigation.

5.1.3 Decision Making and Risk Management

Jim Crow Creek at Yandoit

Management actions are currently being implemented by NCCMA that should reduce nutrient levels in Jim Crow Creek. These include:

- Development of a stormwater management plan for the Hepburn Shire, which includes the Hepburn, Daylesford and Creswick areas; and
- Undertaking stream rehabilitation works along Jim Crow Creek. These targeted works include:
  - weed management;
  - provision of fencing materials to control stock access;
  - off-stream watering infrastructure (where applicable); and
  - riparian plantings.

It is proposed that a 'watching brief' be kept on Jim Crow Creek to ensure that conditions do not change and increase the risk of excessive plant growth and/or algal blooms. In particular, changes that may lead to:

- increased nutrient inputs to the creek;
- higher levels of phosphorus in the creek becoming bioavailable; and

- loss of riparian vegetation that would cause a decrease in shading potential and filtering of nutrients from diffuse sources;

need to be assessed.

The watching brief should also include monitoring and evaluation of the effectiveness of the management actions in reducing nutrient levels in Jim Crow Creek, and monitoring of DO levels.

Loddon River at Newstead and Campbells Creek at Muckleford-Yapeen Road

The main focus of management actions in this area should be on the reduction of nutrient and, to a lesser extent, salinity inputs to Campbells Creek.

The Castlemaine STP is the likely main source of nutrients and salinity to Campbells Creek. The STP upgrade to tertiary treatment began in mid 1999 and was fully operational in early 2000. Coliban Water undertook public consultation prior to these works as part of the upgrade process. This resulted in limited public support for any discharge to land scheme, as the flow provided by the discharge to the Creek was considered to be important to the community. While the upgrade to tertiary treatment has greatly reduced the nutrient and salinity inputs to Campbells Creek, this investigation has shown that the current discharge does not ensure the protection of aquatic ecosystems in both Campbells Creek and further downstream in the Loddon River.

Effectively, an initial decision has been made by stakeholders not to protect the aquatic ecosystems in Campbells Creek and/or in part of the Loddon River downstream of its confluence with Campbells Creek. If it is subsequently proposed to protect either or both of these ecosystems, then the nutrient and salinity levels in the STP discharge would need to be reduced to an appropriate level and/or the option for greater reuse or disposal of the discharge to land be re-evaluated. It should be noted that Coliban Water are currently working to implement environment improvement plans (EIP) and environmental management plans (EMP) to further reduce the impact of the Castlemaine STP discharge (as part of their EPA licence conditions).

NCCMA have developed a stormwater management plan for the Mount Alexander Shire, which includes the Castlemaine and Newstead areas. Implementation of the stormwater management plan began in the 2003-2004 financial year. This should further support reduced nutrient levels in Campbells Creek and the Loddon River.

5.2 Upper Barwon Catchment

This case study was conducted with the Coranagamite Catchment Management Authority (CCMA) in the Upper Barwon catchment, upstream of Winchelsea. Sediment issues in the Upper Barwon had been identified by the CCMA as a high priority management area for which there was little available information. The objective of this case study was to use the risk-based approach in managing these issues. That is, to assess the potential risks posed to aquatic ecosystems in the Upper Barwon Catchment from sediment inputs.

5.2.1 Assessment of Ambient Monitoring Data Against Objectives

The Victoria Water Quality Monitoring Network (VWQMN) water quality data for 2001 and all EPA biological data collected in the past five year period were assessed against the SEPP (WoV) environmental quality objectives. The assessment was conducted in accordance with requirements stated in Schedule A1 (5) of the SEPP (WoV). The assessment results are presented in Tables 5 and 6, with site locations shown in Figure 8.

There are currently no direct quantitative measures of sediment inputs to waterbodies (Appendix 4). The surrogate indicators for this issue are the SEPP (WoV) turbidity and biological objectives (Table 1). The turbidity objectives were not met at all three water quality sites (Table 5), thereby indicating a potential risk from excess sediment inputs. Six of the nine biological sites did not meet the SEPP (WoV) biological objectives (Table 6), indicating the invertebrate biota are adversely affected in some way, which may potentially include effects from sediment inputs. A risk-based investigation of sediment issues in the Upper Barwon catchment was therefore conducted.

It is recognised that there are other issues in the Upper Barwon Catchment that should also be addressed by a risk-based approach. This is indicated by the overall water quality being generally poor at all these sites (Table 1). Of the six water quality objectives, four were not met at Barwon River (east branch) at Forrest and Barwon River at Ricketts Marsh, and all six were not met at Boundary Creek at Yeodene.

Table 5: Upper Barwon catchment - Assessment of ambient water monitoring data (2001) against the SEPP (WoV) environmental quality objectives

	TP µg/L	TN µg/L	DO %	EC µS/cm	TurbidityNTU	pH
	75^{th} percentile	75^{th} percentile	25^{th} percentile	75^{th} percentile	75^{th} percentile	25^{th} - 75^{th} percentile
SEPP (WoV) Objective (Forests B Segment)	**25**	**350**	**90**	**500**	**5**	**6.4-7.7**
Barwon River (east branch) at Forrest - 233214	55	410	67	173	12	6.6-7.0
SEPP (WoV) Objective (Cleared Hills and Coastal Plains Segment)	**40**	**600**	**85**	**1500**	**10**	**6.5-8.3**
Barwon River at Ricketts Marsh - 233224	83	1230	72	1025	23	7.0-7.4
Boundary Creek at Yeodene - 233228	48	1160	52	1850	11	3.6 – 4.3

The shaded results indicate that the objective was not met.
As required by Schedule A1 (5) of the SEPP (WoV), a minimum of 11 samples collected from monthly monitoring over a one-year period was used to assess against SEPP (WoV) water quality objectives.
Data sourced: VWQMN 2001.

Table 6: Upper Barwon catchment – Assessment of ambient biological monitoring data against the SEPP (WoV) environmental quality objectives

			AUSRIVAS/ Key Families combined habitat score[10]	SIGNAL	No of Families	EPT
SEPP (WoV) Objective (Forests B)		**Riffle** **Edge**	**A (0.87)** **A (0.86)**	**6.0** **5.8**	**23** **24**	**10** **9**
Site	**Year**					
Barwon River (west branch)(lower) d/s west Barwon Dam – NLQ	1997	edge	B (0.63)	5.4	23	5
East Barwon River at Yaugher – NLS	1997	riffle	24[a]	6.5	14	5
	1997	edge	C (0.57)	5.5	26	2
West Barwon River at Seven Bridges Road – NLT	1997	edge	A (1.03)	5.8	31	8
Callahan Creek at Mahers Road – NLP	1997	edge	B (0.75)	5.6	27	6
Dewing Creek at Griffiths Road – NMA	1998	edge	B (0.69)	5.5	29	6
SEPP (WoV) Objective (Cleared Hills and Coastal Plains)		**Riffle** **Edge**	**A (0.82)** **A (0.85)**	**5.5** **5.5**	**23** **26**	**N/A**
Site	**Year**					
Pennyroyal Creek at Station Road - NLR	1997	edge	A (0.91)	6.1	28	
Mathews Creek at Kildeen Road - NLZ	1998	edge	A (0.98)	5.3	29	
Barwon River at Kildeen Road - NLH	1998	riffle	A (0.96)	5.9	27	
	1998	edge	A (1.05)	5.0	32	
Barwon River at Winchelsea - NLX	1998	edge	A (1.05)	5.6	37	

The shaded results indicate that the objective was not met.
Data sourced: EPA, available data 1997 - 2002.
[a]The riffle habitat at NLS was outside the experience of the AUSRIVAS model and the Key families combined habitat score was used instead.
N/A – No SEPP (WoV) objective set.

[10] EPA Publication 793.1 states that the 'Key families combined habitat score should be used if access to the AUSRIVAS models is not possible or it does not give a result for the site due to it being 'outside the experience of the model'.

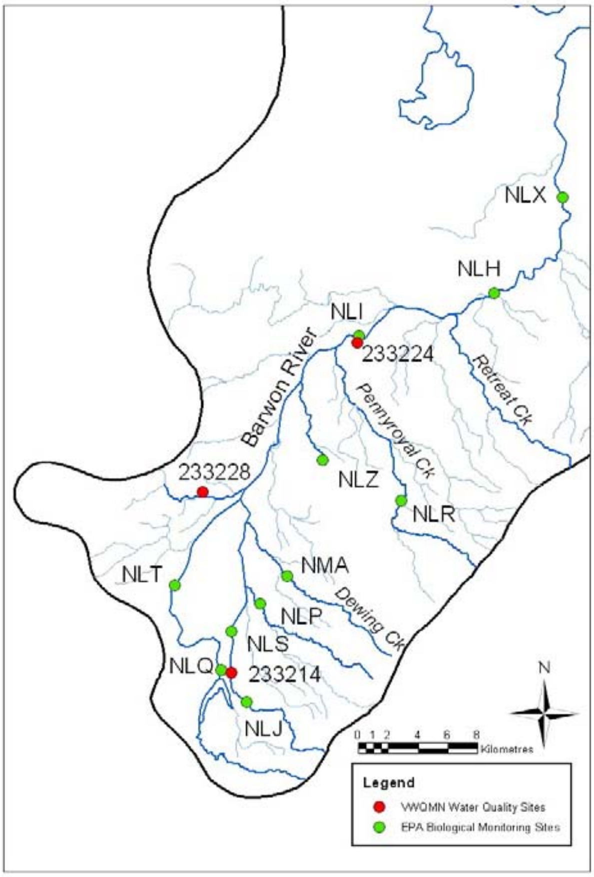

Figure 8: Assessment sites in the Upper Barwon Catchment upstream of Winchelsea

5.2.2 Risk-Based Investigation

Problem Formulation

At the outset of the case study, the **issue** being assessed was identified as the perceived risk of excess sediment inputs in the Upper Barwon catchment. The subsequent assessment of the SEPP (WoV) objectives indicated the issue as a potential risk, initiating this investigation.

A **conceptual model** was developed for the Upper Barwon catchment that summarised the hazards, potential sources, factors influencing the likelihood of excess sediments entering the system, and potential effects on the aquatic ecosystems. This was updated throughout the investigation as information became available and the final model is presented in Figure 9.

Information and data was collated on the different components of the conceptual model. This included:

- hazards – sediment inputs: VWQMN turbidity data for three sites from 1997 to 2001;
- sources – catchment information on land use activities; and
- factors influencing the likelihood of the issue occurring - flow data for three VWQMN sites

from 1997 to 2001; and catchment information on soil type and structure, riparian vegetation and bank stability.

The VWQMN turbidity and flow data are available on the Victorian Water Resources Data Warehouse website[11]. The catchment information is described in the risk analysis section.

The **proposed risk analysis plan** was to initially conduct a simple desk-top study. Then based on the results of the study, determine if and what type of further analysis may be required. The desk-top study included examination of the VWQMN water quality data and catchment information, including:

- examination of the turbidity and flow data to obtain an estimate/indication of the amount of sediment entering the Upper Barwon system;
- interpretation of the biological assessment results to try and ascertain the level of effect sediment inputs may be having on the ecosystems; and
- general examination and interpretation of the data and information to increase current understanding of the issue.

[11] http://www.vicwaterdata.net

Figure 9: Upper Barwon catchment conceptual model for the issue of excessive sediment inputs

Risk Analysis

Examination and interpretation of the turbidity/flow data patterns and biological assessment results

Most of the sediment entering and transported within rivers and streams occurs during a few high flow/flood events (Beckett et al., 1992; Wren et al., 2000). During these events, a high proportion of the sediment is suspended in the water column, with the highest turbidity levels occurring during the rising stage of a high flow event, before the peak flow occurs (Grayson et al., 1996). In other periods, sediment is generally deposited on streambeds, that is, the majority of the sediment is not present in the water column and turbidity readings at these times do not reflect the total amount of sediment within a system. Therefore, the amount of sediment within a waterbody may be greatly underestimated from monthly sampling data, such as that collected under the VWQMN, if these events are missed.

Examination of the turbidity and flow data for the three VWQMN sites showed that turbidity samples were never taken at the rising limb of any high flow events. This would indicate that sediment inputs at the three sites would be substantially higher than indicated by the monthly turbidity sampling data. In addition, a study by Gippel (1995) shows that it is also not possible to estimate these peaks from the available VWQMN data with an appropriate level of certainty.

A more direct indication of the health of aquatic ecosystems is provided by the biota themselves. The assessment results for the biological objectives (Table 6) show that the invertebrate communities in many areas of the Upper Barwon catchment are in poor health. However, it was not possible to isolate the degree to which increased sediment inputs may be contributing. This is due to the range of potential risks indicated in Table 5, including excessive nutrients, high salinity, low DO and low pH, which would all be contributing to the reduction in biota health to varying degrees.

Given the limitations in assessing the current turbidity and biological data, it was decided to investigate potential sampling and analysis methods that would enable:

- a more quantitative estimate of sediment loads entering and being transported within the Upper Barwon system; and
- the subsequent impacts these sediment levels would have on the ecosystems of the Upper Barwon catchment.

Methods for estimating sediment inputs to the Upper Barwon system and subsequent effects on biota

The literature was reviewed for data collection and analysis methods that would better estimate the sediment loads entering and being transported within the Upper Barwon system (Appendix 4 provides a more detailed discussion of this review). The review established that any estimates based on discrete samples (for example, weekly or monthly) would be inadequate and have been shown to greatly underestimate sediment loads. Instead, continuous sampling that incorporates all high flow events would be required (Gippel, 1995; Anderson and Svendsen, 1997) for sediment load estimation.

Sediment loads may be derived from continuous sampling of suspended particulate matter (SPM) concentrations. However, there is considerable difficulty and expense involved in directly sampling

SPM on a continuous basis, even if this was to only incorporate high flow events. A cheaper and easier alternative is to derive SPM and flow relationships or SPM and turbidity relationships for estimating loads, and then measure flow or turbidity on a continuous basis. This still requires a substantial amount of resources and while they will provide more accurate estimations than discrete SPM samples, there remains a substantial level of uncertainty associated with these relationships (Campbell and Doeg, 1989; Gippel, 1995; Grayson et al., 1996; Riley, 1998).

Studies of sediment inputs into rivers and streams have mostly addressed the measurement of SPM and turbidity in the water column. Another alternative would be to directly measure sediment deposition (sedimentation) on streambeds, particularly as the greatest impacts to biota appear to occur as a result of sedimentation (Campbell and Doeg, 1989, Prosser et al., 2001, Metzeling et al., 1995). For example, deposited sediment causes degradation and loss of habitat and sediment smothering is directly lethal to biota such as fish eggs. There have been far fewer investigations into the measurement of sedimentation (e.g. Brown, 1994 and Brunet, 1994) and these have mostly been confined to deposition onto streambeds and substrate surfaces, with little attention to deposition within the interstitial spaces of streambeds. Subsequently, direct measures or standardised surrogate measures of sedimentation have not been developed.

Should the considerable resources needed to quantitatively estimate sediment inputs be allocated, there would still be a substantial level of uncertainty associated with interpreting the effect these levels would have on the biota of the Upper Barwon catchment. Few studies have examined the effects of increased sediment on Australian species and these have generally studied effects at high concentrations of sediment inputs. While there is enough evidence to indicate that increased sediment loads have a deleterious effect[12] on Australian aquatic organisms (Campbell and Doeg, 1989; Metzeling et al., 1995), more data is needed to ascertain at what concentrations and/or loads these effects begin to occur and to what extent the ecosystem is affected.

Given the significant amount of resources required, the level of uncertainty associated with sediment load estimates and the paucity of data for interpreting the effects these loads have on aquatic ecosystems, it was decided that further work would not be conducted to more quantitatively estimate sediment inputs. Instead, it was decided to qualitatively assess the condition of the catchment focusing, in particular, on the factors identified in the conceptual model (Figure 9) as contributing to the risk of adverse ecological effects in the Upper Barwon system.

Catchment Condition Review

In the problem formulation stage, catchment information on potential hazards, sources, and factors influencing the likelihood of the issue occurring was collated from literature and discussions with CCMA staff. Additional information was then gathered from two catchment site visits conducted during this analysis phase. All the information was collectively reviewed and is discussed below.

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[12] The effects on biota are summarised in Figure 7

The **forested headwaters of the catchment** are mainly native forest and have only small sections of forestry activity. The surface soil is predominately loam. High rainfall, moderate permeability, leaching and loss of organic matter and soil structure has led to soil compaction. The steep slopes are prone to sheet and rill erosion, with clay subsoils on steep slopes prone to landslips when saturated (Pitt, 1981). The waterbodies generally have continuous riparian zones greater than 30 metres, unmodified channels, relatively stable banks and the substrate type is generally a mixture of boulder, cobble, pebble, sand and silt. However, some stream beds exhibited substantial amounts of easily disturbed fine sediment.

The **catchment downstream of the forested headwaters** has been almost entirely cleared for grazing and agriculture. There is an abandoned mine site on Coalmine Creek that ceased operation in the 1950's leaving behind eroding tailings and overburden. There are obvious signs of increased sedimentation downstream of these mine works along the length of Coalmine Creek, into Wormbete Creek and the Barwon River. There are also unsealed roads.

In this area of the catchment, semi-continuous to isolated riparian zones generally less than 5 metres wide provide limited protection for the waterways. Most of the tributaries are incised by one to two metres, with obvious signs of bank erosion and instability in many sections. Channelisation and drainage works have been conducted in some of the waterways, the effects of which are most obvious in Retreat Creek where works have led to significant incision problems (up to 5 metres) and severe bank erosion. The substrate of the waterways is almost exclusively sand and clay.

The surface soil in this part of the catchment is predominately sandy loam. The area immediately adjacent to the Barwon River itself is predominately fine sandy clay loam. The catchment generally has weakly structured soils, with steeper slopes prone to sheet erosion, streambanks prone to erosion and siltation, and areas of dispersible clay subsoils prone to gully and tunnel erosion (Pitt, 1981).

The catchment condition review further supported an identified risk to the aquatic ecosystems of the Upper Barwon catchment. Poor soil structure, extensive land clearing, channelisation, drainage and abandoned mine works, stream incision and bank erosion all indicate that excess sediments would be entering the Upper Barwon system. Many waterways were exhibiting obvious signs of the resulting sedimentation.

Risk Characterisation

The risk analysis qualitatively showed that a potential risk from excess sediment inputs exists for rivers and streams in the Upper Barwon catchment, based on:

- examination of the turbidity and daily flow data which indicated that sediment inputs at the three VWQMN sites would be substantially higher than that observed in the turbidity monthly sampling data;
- the invertebrate assessment showing the biota to be adversely affected at many sites (although the degree to which sediment inputs may be contributing to effects is not clear); and

- the catchment review. In summary, the poor soil structure combined with extensively cleared land, poor riparian zones and channelisation and drainage works indicates a high likelihood that excess sediment would be entering the Upper Barwon system during rain events. In addition to this, there are specific sites that have obvious bank instability and erosion where sediment is entering the rivers and streams. The abandoned mine site was also an obvious point source, with sedimentation evident downstream.

It was decided to accept that a risk existed to ecosystems of the Upper Barwon catchment from excess sediment inputs, based on expert judgement of the information gained during risk analysis phase. Quantitative or statistical measurement of sediment inputs and/or the effects of these inputs would be both resource intensive and still carry a substantial level of uncertainty. It was for this reason that it was decided not to conduct any further analysis, but rather accept the risk to the ecosystem and invest resources into management of the issue.

It should be possible to commence (and/or continue) risk management actions in those areas of the catchment with obvious sedimentation problems. However, given the limited knowledge and data on the issue, more information will be necessary to appropriately direct longer-term management needs and evaluate the effectiveness of management actions.

5.2.3 Decision Making and Risk Management

In the short-term, it is expected that a number of management actions currently being implemented as part of the Corangamite Nutrient Management Plan (CCMA, 2000), should work towards decreasing sediment inputs to the Upper Barwon catchment. These particular actions are aimed at reducing soil erosion and movement in some areas of the catchment.

In the longer-term, resource condition and management action targets for suspended solids and/or turbidity will be developed for the Corangamite CMA region, including the Upper Barwon system, as part of the National Action Plan for Salinity and Water Quality (NAP). These targets aim to work towards the attainment of the SEPP (WoV) objectives; in this case to reduce the identified risk of excess sediment inputs. Management plans are currently underway to fill knowledge and data gaps to:

- enable appropriate targets to be derived;
- direct appropriate and effective management actions to where they are needed to achieve management targets; and
- enable development of appropriate indicators and methods for evaluating management actions.

This will initially involve:

- a review of all VWQMN monitoring sites, to assess the usefulness of current monitoring sites and determine what new sites are required. As part of this review, the ability to better assess turbidity levels as an indicator of sedimentation across the region will be investigated; and
- the use of the *SedNet* model (CSIRO Land and Water, 2002) to identify sediment sources, predict transport processes and evaluate

management options across the region. The outputs of the model may also assist in identifying any further data or information that can be collected to fill knowledge gaps, and appropriate indicators and methods for evaluating management actions.

From this information, directions for setting resource condition and management targets, and implementing management actions will be assessed and decided.

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7. GLOSSARY

Ambient waters –are defined in the ANZECC and ARMCANZ Guidelines (2000) as “all surrounding waters, generally of largely natural occurrence”.

Assessment endpoint – is an explicit expression of the ecological value(s) that is to be protected.

Beneficial use – A beneficial use is defined in the *Environment Protection Act* 1970 and includes a current or future environmental value or use of surface waters that communities want to protect.

Environmental quality objective - the concentration or level of an indicator that describes the environmental quality required to protect designated beneficial uses.

Indicator - a measurement that provides information on the environmental quality of an environment.

Measurement endpoint - is the aspect of an assessment endpoint that can be measured.

Precautionary principle – As described in SEPP (WoV), ‘if there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental problems being addressed. Decision-making should be guided by: a careful evaluation to avoid serious or irreversible damage to the environment wherever practicable; and an assessment of the risk-weighted consequences of various options’.

Riparian - inhabiting or situated on a river or stream bank or where vegetation interacts with surface waters.

Sedimentation - is the suspended sediment (SPM) deposited onto the streambed and other substrates (for example, woody debris, boulders) and into the interstitial spaces of the streambed.

Surface waters - for the purposes of SEPP (WoV), surface waters include any reservoir, billabong, anabranch, canal, spring, swamp, natural channel, lake, lagoon, waterway, natural dam, tidal water or coastal water. Surface waters exclude groundwaters and waters within tanks, artificial waste treatment systems, reticulated water supply distribution systems, off-stream private dams, and piped and underground drains.

Suspended particulate matter (SPM) - is the material that is suspended (not dissolved) in the water column. SPM may also be referred to as 'suspended sediment', 'suspended solids' or 'non-filterable residue' (NFR).

Turbidity - refers to the clarity ('muddiness') of water and is caused by suspended matter such as clay, silt, fine organic and inorganic matter, colloids, plankton and other microscopic organisms.

8. ACRONYMS

ANZECC	Australian and New Zealand Environment and Conservation Council
ARMCANZ	Agriculture and Resource Management Council of Australian and New Zealand
AUSRIVAS	Australian Rivers Assessment System
CCMA	Corangamite Catchment Management Authority
CMA	Catchment management authority
DO	Dissolved oxygen
EC	Electrical conductivity
EPA	Environment Protection Authority (Victoria)
EPT	Ephemeroptera, Plecoptera, Tricoptera
ERA	Ecological risk assessment
FRP	Filterable reactive phosphorus
GEM	Guideline for environmental management
NAP	National action plan for salinity and water quality
NCCMA	North Central Catchment Management Authority
NOx	nitrate and nitrite
SEPP	State environment protection policy
SIGNAL	Stream Invertebrate Grade Number Average Level
STP	Sewage treatment plant
TN	Total nitrogen
TP	Total phosphorous
VWQMN	Victorian Water Quality Monitoring Network
WoV	Waters of Victoria

APPENDIX 1. KEY ISSUES FOR VICTORIA'S WATERBODIES

The key issues for Victoria's aquatic ecosystems were identified as part of the process of deriving the SEPP (WoV) environmental quality objectives. The information below briefly describes these key issues for the State. It does not provide an extensive review or detailed understanding of the issues.

Altered Natural Flows

Reduced environmental flows and altered flow regimes have had significant impacts on the aquatic ecosystems of many rivers, wetlands, lakes and estuaries throughout Victoria.

The natural flow in a river continually changes, mainly due to the variability of rainfall. Many of these changes are important for the growth of trees and plants on the floodplain, and for the breeding habits of fish, waterbirds and other biota. When dams are built or water is extracted from rivers, the characteristics of these natural flow regimes are altered. Reduced flows eliminate habitat for local aquatic biota, result in higher concentrations of pollutants and greatly reduce natural flood events. When large dams are present, water is generally collected in winter and released in summer, reversing the natural seasonality of flow. Problems can be compounded by the presence of introduced species, which may prosper under the changed flow conditions.

Loss and Degradation of In-stream Habitat

Changes to habitat such as removal of woody debris and in-stream vegetation, alteration of river channels and construction of in-stream barriers, can significantly affect aquatic ecosystems.

Removal of woody debris and in-stream vegetation reduces the habitat and food sources available for aquatic biota, such as fish and invertebrate organisms. For example, fish require woody debris as sites for spawning and rearing juveniles, and for protection from strong currents and predators. Removal of woody debris and in-stream vegetation also reduces the stability of streambeds and banks.

Rivers channels have been modified to improve drainage for agriculture and reduce flooding. These modifications change the natural course and form of the river. This can result in increased flows that increase bank erosion and sediment deposition. Much of the habitat for aquatic biota can be either washed away or covered with sediment. When a river is completely channelised, all the in-stream habitat is removed, which results in a uniform fast flow that prohibits aquatic biota moving upstream and, in some cases, may wash them downstream.

Introduced barriers to fish movement may also severely limit the survival and distribution of many fish. For example, about 70 per cent of native fish need to migrate so they can spawn and reproduce. Barriers to fish migration can be anything from a culvert under a road, to a small weir or a large dam.

Loss and Degradation of Riparian Land and Catchment Vegetation

Clearing and degradation of native vegetation has a number of serious impacts on waterways. The main impacts from catchment clearing are increased salinity and an increase in the total volume, timing and velocity of peak flows of run-off. The increased run-off carries more sediment and nutrients into waterways and also contributes to erosion of streambeds and banks.

Of particular importance is riparian vegetation, which:

- protects the stability of stream beds and banks;
- filters out sediment, nutrients and chemicals from surface run-off;
- provides shading, shelter and a source of food for aquatic biota; and
- provides important habitat for land animals and birds, and may often be a last refuge.

Salinity

There are two major causes of increasing salinity (salinisation):

- the clearing of deep-rooted native vegetation and replacement with shallow-rooted crops and pastures; and
- large-scale irrigation.

Both result in the water table moving closer to the surface, bringing accumulated salts that cause salinisation of waterbodies and soils. High salinity levels in waterbodies have lethal and sub-lethal effects (changes in behaviour and ecosystem metabolism) on aquatic biota.

Excessive Plant and Algal Growth

Elevated nutrient (nitrogen and phosphorus) levels may cause excessive plant growth and/or algal blooms. Of particular concern are cyanobacteria (blue-green algae) blooms. Major sources of elevated nutrient levels in waterbodies include: sewage treatment plants, urban stormwater run-off, irrigation drainage, intensive animal industries, soil erosion, agricultural run-off and forestry activities. The downstream effects of these inputs should also be considered, including effects on terminal waterbodies such as wetlands, lakes, estuaries and coastal marine waters.

Excessive plant growth, algae blooms and/or cyanobacteria blooms may result in:

- diurnal decreases in dissolved oxygen (DO) that can stress or eliminate biota;
- increase in biochemical oxygen demand (BOD), that is, depletion of oxygen may occur when plant matter is oxidised by bacteria and other micro-organisms;
- displacement of endemic species by tolerant exotic species;
- obstruction of waterways and fish migration;
- reduction in habitat and light availability for other species;
- decaying plant matter which may lead to odours and an unsightly appearance; and
- the production of toxins (by some cyanobacteria) that threaten human uses of water and aquatic ecosystems.

Effects of Increased Sediment Inputs

Sediment entering waterways is a natural process, but human activities may cause excessive quantities to enter streams. Sources of increased sediment inputs include vegetation clearing, urban development, agriculture, forestry activities, roads, industrial and sewage discharges, dredging and housing development The downstream effects of these inputs should also be considered, including effects on terminal waterbodies such as wetlands, lakes, estuaries and coastal marine waters.

The greatest impact of sediment entering waterways is on in-stream habitat. Sediment can fill pools, cover and fill in rocky bottoms and coat snags. This can reduce the available habitat and affect the breeding and feeding habits of native fish and aquatic invertebrates.

Sediments suspended in the water column increase turbidity, which reduces the amount of sunlight entering the water and inhibits plant growth. Suspended sediments can also interfere with fish and invertebrate gills, and make it difficult for visual predators to hunt.

Reduced Oxygen Availability

Dissolved oxygen (DO) levels in a water body are dependent on temperature, salinity, biological activity and rate of transfer from the atmosphere. Under natural conditions, DO may change considerably over a daily period, and is generally highest during the day when plant photosynthesis exceeds respiration and lowest overnight when only respiration occurs. Although DO levels naturally fluctuate, excessive sources of organic matter such as sewage effluent, excessive plant growth or decaying plant material, has the potential to greatly deplete DO levels in a waterbody. Low DO levels may cause stress or death to aquatic biota by:

- directly reducing respiration (the oxygen requirements of biota varies between taxa, species within taxa and life stages within a species);
- increasing the toxicity of chemicals present in the water column; and
- causing anaerobic conditions at the sediment water interface, which can result in the release of nutrients and toxicants from the sediment to the water column.

Increasing Acidity or Alkalinity

Natural freshwater systems generally have a pH range between 6.5 to 8.0 and natural marine waters are generally close to 8.2. Changes in pH outside natural levels may adversely affect biota by:

- affecting physiological functioning of biota (for example, enzymes and membrane processes);
- diminishing spawning and hatching success in fish; and
- increasing the solubility and toxicity of metals and other toxic chemicals.

Oil, Chemical and Heavy Metal Pollution

Oils, heavy metals and other chemicals enter waterways from a variety of potential sources, including urban and agricultural run-off, industrial and mining operations, landfill leachate, dredging, and transportation or industrial spills. The downstream effects of these inputs should also be considered, including effects on terminal waterbodies such as wetlands, lakes, estuaries and coastal marine waters.

The effects on aquatic ecosystems will vary from directly lethal to sub-lethal effects (for example, reduction in growth and reproduction). The effects of many toxic chemicals are increased by their ability to remain and build up in the environment over a long period of time. In wetlands and bays where flushing is limited, the results can be particularly destructive.

Aquatic Pests

Aquatic pests can drastically alter water environments and out-compete native plants and animals for food and shelter. Aquatic pests can enter water environments through accidental or purposeful release, through ballast water discharge or attached to the hulls of vessels and fishing gear. Aquatic pests currently in Victorian fresh and marine waters include the infamous carp and northern-pacific seastar.

APPENDIX 2. STATE ENVIRONMENT PROTECTION POLICY (WATERS OF VICTORIA) ENVIRONMENTAL QUALITY OBJECTIVES

Table A1: Environmental quality objectives for rivers and streams – water quality

SEGMENT	**INDICATOR**							
	Total phosphorus (µg/L)	Total nitrogen (µg/L)	Dissolved oxygen % saturation		Turbidity (NTU)	Electrical conductivity (µS/cm)	pH (pH units)	
	75^{th} percentile	75^{th} percentile	25^{th} percentile	maximum	75^{th} percentile	75^{th} percentile	25^{th} percentile	75^{th} percentile
Highlands								
• all areas	•20	•150	•95	110	•5	•100	•6.4	•7.7
Forests – A								
• Wilsons Promontory, Strzelecki Ranges & East Gippsland Coast	•25	•500	•90	110	•5	•500	•6.4	•7.7
• upper Murray, Kiewa & Mitta Mitta catchments	•25	•350	•90	110	•5	•100	•6.4	•7.7
• the Grampians	•25	•350	•90	110	•5	•500	•6.4	•7.7
• all other areas	•25	•500	•90	110	•5	•100	•6.4	•7.7
Forests – B								
• Otway Ranges	•25	•350	•90	110	•5	•500	•6.4	•7.7
• all other areas	•25	•350	•90	110	•5	•100	•6.4	•7.7
Cleared Hills and Coastal Plains								
• lowlands of Barwon, Moorabool, Werribee, Maribyrnong, Curdies & Gellibrand catchments	•45	•600	•85	110	•10	•1500	•6.5	•8.3
• lowlands of Yarra, Western Port, Latrobe, Mitchell, Tambo, Snowy, Thomson & Macalister catchments	•45	•600	•85	110	•10	•500	•6.4	•7.7
• uplands of Moorabool, Werribee, Maribyrnong, Campaspe, Loddon, Avoca, Wimmera and Hopkins catchments	•25	•600	•85	110	•10	•500	•6.5	•8.3

Table A1: Environmental quality objectives for rivers and streams – water quality……. continued

SEGMENT	INDICATOR							
	Total phosphorus (µg/L)	Total nitrogen (µg/L)	Dissolved oxygen % saturation		Turbidity (NTU)	Electrical conductivity (µS/cm)	pH (pH units)	
	75th percentile	75th percentile	25th percentile	maximum	75th percentile	75th percentile	25th percentile	75th percentile
• mid-reaches of Ovens, Goulburn and Broken catchments	•25	•600	•85	110	•10	•500	•6.4	•7.7
Murray and Western Plains								
• lowlands of Kiewa, Ovens, Goulburn & Broken catchments	•45	•900	•85	110	•30	•500	•6.4	•7.7
• lowlands of Campaspe, Loddon & Avoca catchments	•45	•900	•80	110	•30	•1500	•6.5	•8.3
• lowlands of Wimmera catchment & Mallee Basin	•40	•900	•80	110	•10	•1500	•6.5	•8.3
• lowlands of Glenelg & Hopkins catchments, & Portland, Corangamite and Millicent Coast Basins	•40	•900	•85	110	•10	•1500	•6.5	•8.3

Table A2: Environmental quality objectives for rivers and streams – biological

SEGMENT	INDICATOR					
	Number of families	SIGNAL index score	EPT index score	AUSRIVAS		Key families combined habitat score
				O/E score	Band	
Highlands						
all areas						
• riffle	22	5.8	10	n/a	n/a	18
• edge	13	6.2	4	n/a	n/a	
Forests – A						
urban areas						
• riffle	18	5.6	6	0.61	B	18
• edge	18	5.4	5	0.57	B	
all other areas						
• riffle	21	6.0	9	0.87	A	22
• edge	22	5.7	7	0.86	A	
Forests – B						
urban areas						
• riffle	20	5.8	8	0.6	B	24
• edge	21	5.6	7	0.61	B	
all other areas						
• riffle	23	6.0	10	0.87	A	26
• edge	24	5.8	9	0.87	A	
Cleared Hills and Coastal Plains						
urban areas						
• riffle	21	5.3	n/a	0.47	B	20
• edge	23	5.3	n/a	0.55	B	
all other areas						
• riffle	23	5.5	n/a	0.82	A	22
• edge	26	5.5	n/a	0.85	A	

Table A2: Environmental quality objectives for rivers and streams – biological….continued

SEGMENT	INDICATOR					
	Number of families	SIGNAL index score	EPT index score	AUSRIVAS		Key families combined habitat score
				O/E score	Band	
Murray and Western Plains						
urban areas						
• edge	22	5.0	n/a	0.61	B	16
all other areas						
• edge	23	5.3	n/a	0.87	A	21

n/a indicates the objective is not applicable for that indicator.
SIGNAL scores for families are listed in Table A5. Key families are those listed in Table A6.
For urban areas, AUSRIVAS needs to score A or B to attain SEPP (WoV).
For other areas, AUSRIVAS must score A to attain SEPP (WoV).

Table A3: Environmental quality objectives for marine and estuarine segments – nutrients status and water clarity indicators

SEGMENT	INDICATOR									
	Total phosphorus	Dissolved inorganic phosphorus	Total nitrogen	Dissolved inorganic Nitrogen	Chlorophyll *a*	Dissolved oxygen		Transparency/ PAR Attenuation	Suspended solids	Turbidity
	µg/L	µg/L	µg/L	µg/L	µg/L	%		m	µg/L	NTU
	75th percentile	75th percentile	75th percentile	75th percentile	75th percentile	Annual minimum	Annual maximum	25th percentile	75th percentile	75th percentile
Open Coasts	•25	•10	•120	•20	•1	90	110	•R25	•R75	•R75
Western Port	F8									
Port Phillip Bay	F6									
Gippsland Lakes	F3									
Estuaries and Inlets	•30	•5	•300	•30	•4	80	110	•R25	•R75	•R75

The environmental quality objectives are those values specified in the ANZECC and ARMCANZ Guidelines (2000).

Table A4: Environmental quality objectives for rivers and streams and estuarine and marine segments – toxicants in water column and sediments

SEGMENT	INDICATOR				
	Metals	Non-metals	Ammonia	Sulfide	Sediment toxicants
	maximum	maximum	maximum	maximum	maximum
Highlands	T (99%)	T (99%)	T (99%)	T (99%)	ISQG-low
Forests – A	T (99%)	T (99%)	T (99%)	T (99%)	ISQG-low
Forests – B	T (99%)	T (99%)	T (99%)	T (99%)	ISQG-low
Cleared Hills and Coastal Plains					
• urban areas	T (95%)	T (95%)	T (95%)	T (95%)	ISQG-high
• all other areas	T (95%)	T (99%)	T (95%)	T (95%)	ISQG-low
Murray and Western Plains					
• urban areas	T (95%)	T (95%)	T (95%)	T (95%)	ISQG-high
• all other areas	T (95%)	T (99%)	T (95%)	T (95%)	ISQG-low
Open Coasts	T (99%)	T (99%)	T (99%)	T (95%)	ISQG-low
Port Phillip Bay	F6				
Western Port	F8				
Gippsland Lakes	F3				
Estuaries and inlets	T (99%)	T (99%)	T (99%)	T(95%)	ISQG-low

T refers to the concentrations for toxicants in Table 3.4.1 of the ANZECC and ARMCANZ Guidelines (2000). The percentages (95%, 99%) denote the levels of ecosystem protection and assessment values that correspond to the values in Table 3.4.1.
ISQG-Low and ISQG-High refer to the values for sediment quality in Table 3.5.1 of the ANZECC and ARMCANZ Guidelines (2000).

Table A5: List of SIGNAL index scores

Family	Grade	Family	Grade	Family	Grade
Aeshnidae	6	Gelastocoridae	6	Neurorthidae	8
Ameletopsidae	10	Gerridae	4	Notonectidae	4
Amphipterygidae	8	Glossiphoniidae	3	Notonemouridae	8
Ancylidae	6	Glossosomatidae	8	Odontoceridae	8
Antipodoecidae	10	Gomphidae	7	Oligochaeta	1
Aphroteniinae	7	Gordiidae	7	Oniscigastridae	10
Athericidae	7	Gripopterygidae	7	Orthocladiinae	6
Atriplectididae	10	Gyrinidae	5	Osmylidae	8
Atyidae	6	Haliplidae	5	Paramelitidae	7
Austroperlidae	10	Haplotaxidae	5	Parastacidae	7
Baetidae	5	Hebridae	6	Philopotamidae	10
Belostomatidae	5	Helicophidae	10	Philorheithridae	8
Blepharoceridae	10	Helicopsychidae	10	Physidae	3
Caenidae	7	Hydraenidae	7	Planorbidae	3
Calamoceratidae	8	Hydridae	4	Pleidae	2
Calocidae	8	Hydrobiidae	5	Podonominae	9
Ceinidae	5	Hydrobiosidae	7	Polycentropodidae	8
Ceratopogonidae	6	Hydrochidae	7	Protoneuridae	7
Chironomidae	1	Hydrometridae	5	Psephenidae	5
Chironominae	4	Hydrophilidae	5	Psychodidae	2
Clavidae	2	Hydropsychidae	5	Ptilodactylidae	10
Coenagrionidae	7	Hydroptilidae	6	Pyralidae	6
Coloburiscidae	10	Hygrobiidae	5	Sciomyzidae	3
Conoesucidae	8	Hymenosomatidae	1	Scirtidae	8
Corbiculidae	6	Hyriidae	6	Sialidae	4
Corduliidae	7	Isostictidae	7	Simuliidae	5
Corixidae	5	Janiridae	5	Sphaeriidae	6
Corydalidae	4	Kokiriidae	10	Sphaeromatidae	4
Culicidae	2	Leptoceridae	7	Staphylinidae	5
Dixidae	8	Leptophlebiidae	10	Stratiomyidae	2
Dugesiidae	3	Lestidae	7	Synlestidae	7
Dytiscidae	5	Libellulidae	8	Synthemidae	7
Ecnomidae	4	Limnephilidae	8	Tabanidae	5
Elmidae	7	Lymnaeidae	3	Talitridae	7
Empididae	4	Megapodagrionidae	7	Tanypodinae	8
Ephydridae	2	Mesoveliidae	4	Tasimiidae	7
Erpobdellidae	3	Muscidae	3	Thaumaleidae	7
Eusiridae	8	Nannochoristidae	10	Thiaridae	7
Eustheniidae	10	Naucoridae	5	Tipulidae	5
Gammaridae	6	Nepidae	5	Veliidae	4

Table A6: Lists of key families

SEGMENT				
Highlands	Forests A	Forests B	Cleared Hills and Coastal Plains	Murray and Western Plains
Aeschnidae	Aeschnidae	Aeschnidae	Aeschnidae	Aeschnidae
Acarina	Acarina	Acarina	Acarina	Acarina
Aphroteniinae	Ameletopsidae	Ameletopsidae	Ancylidae	Ancylidae
Austroperlidae	Ancylidae	Ancylidae	Atyidae	Atyidae
Baetidae	Athericidae	Athericidae	Baetidae	Baetidae
Blepharoceridae	Austroperlidae	Atriplectidae	Caenidae	Caenidae
Calocidae	Baetidae	Atyidae	Calamoceratidae	Calamoceratidae
Ceratopogonidae	Blepharoceridae	Austroperlidae	Ceinidae	Ceinidae
Chironominae	Caenidae	Baetidae	Ceratopogonidae	Ceratopogonidae
Coloburiscidae	Calocidae	Caenidae	Chironominae	Chironominae
Conoesucidae	Ceratopogonidae	Calamoceratidae	Coenagrionidae	Coenagrionidae
Dixidae	Chironominae	Calocidae	Conoesucidae	Corbiculidae
Dugesiidae	Coloburiscidae	Ceinidae	Corixidae	Cordylophora
Elmidae	Conoesucidae	Ceratopogonidae	Dixidae	Corixidae
Eusiridae	Corduliidae	Chironominae	Dugesiidae	Culicidae
Eustheniidae	Corixidae	Coenagrionidae	Dytiscidae	Dytiscidae
Gripopterygidae	Corydalidae	Coloburiscidae	Ecnomidae	Ecnomidae
Helicophidae	Dixidae	Conoesucidae	Elmidae	Gerridae
Hydrobiosidae	Dugesiidae	Corduliidae	Gomphidae	Gomphidae
Hydropsychidae	Dytiscidae	Corixidae	Gripopterygidae	Gripopterygidae
Hydroptilidae	Ecnomidae	Corydalidae	Gyrinidae	Gyrinidae
Leptoceridae	Elmidae	Dixidae	Hydrobiidae	Hydrobiidae
Leptophlebiidae	Empididae	Dolichopodidae	Hydrobiosidae	Hydrometridae
Limnephilidae	Eusiridae	Dugesiidae	Hydrometridae	Hydrophilidae
Nannochoristidae	Eustheniidae	Dytiscidae	Hydrophilidae	Hydroptilidae
Neoniphargidae	Glossosomatidae	Ecnomidae	Hydropsychidae	Hyriidae
Notonemouridae	Gomphidae	Elmidae	Hydroptilidae	Janiridae
Oligochaeta	Gripopterygidae	Empididae	Leptoceridae	Leptoceridae
Orthocladiinae	Gyrinidae	Gerridae	Leptophlebiidae	Leptophlebiidae
Philopotamidae	Helicophidae	Glossosomatidae	Mesoveliidae	Mesoveliidae
Philorheithridae	Helicopsychidae	Gomphidae	Nepidae	Naucoridae
Psephenidae	Hydrobiosidae	Gripopterygidae	Notonectidae	Nepidae
Scirtidae	Hydrophilidae	Gyrinidae	Oligochaeta	Notonectidae
Simuliidae	Hydropsychidae	Helicophidae	Orthocladiinae	Oligochaeta
Siphlonuridae	Leptoceridae	Helicopsychidae	Parastacidae	Orthocladiinae
Tanypodinae	Leptophlebiidae	Hydrobiidae	Physidae	Parastacidae
Tipulidae	Limnephilidae	Hydrobiosidae	Psephenidae	Physidae
	Notonemouridae	Hydrophilidae	Pyralidae	Planorbidae
	Oligochaeta	Hydropsychidae	Scirtidae	Pleidae
	Oniscigastridae	Hydroptilidae	Simuliidae	Pyralidae
	Orthocladiinae	Leptoceridae	Stratiomyidae	Simuliidae
	Philopotamidae	Leptophlebiidae	Tanypodinae	Stratiomyidae
	Philorheithridae	Mesoveliidae	Tipulidae	Tanypodinae
	Polycentropodidae	Notonectidae	Veliidae	Veliidae
	Psephenidae	Odontoceridae		

Table A6: Lists of key families….continued

SEGMENT				
Highlands	Forests A	Forests B	Cleared Hills and Coastal Plains	Murray and Western Plains
	Ptilodactylidae	Oligochaeta		
	Scirtidae	Oniscigastridae		
	Simuliidae	Orthocladiinae		
	Tanypodinae	Parastacidae		
	Tipulidae	Philopotamidae		
	Veliidae	Philorheithridae		
		Physidae		
		Planorbidae		
		Polycentropodidae		
		Psephenidae		
		Ptilodactylidae		
		Scirtidae		
		Simuliidae		
		Stratiomyidae		
		Synlestidae		
		Tanypodinae		
		Temnocephalidea		
		Tipulidae		
		Veliidae		

APPENDIX 3. THE AUSTRALIAN AND NEW ZEALAND GUIDELINES FOR FRESH AND MARINE WATER QUALITY (ANZECC AND ARMCANZ, 2000)

The ANZECC and ARMCANZ Guidelines (2000) are intended to provide governments, regulators, water planning and catchment managers, consultants, industry and community groups, with the tools to assess and manage ambient water quality. The primary objective of the ANZECC and ARMCANZ Guidelines (2000) is:

> "To provide an authoritative guide for setting water quality objectives required to sustain current, or likely future, environmental values (uses) for natural and semi-natural water resources in Australia and New Zealand".

The **environmental values** recognised in the ANZECC and ARMCANZ Guidelines (2000) are:

- *Aquatic ecosystems* – guidelines are provided for biological indicators, physical and chemical stressors, toxicants and sediments (more detail on the aquatic ecosystem guidelines is provided below);
- *Primary industries* – guidelines are provided for irrigation and general water uses, stock drinking water, aquaculture and human consumption of aquatic foods;
- *Recreation and aesthetics* – guidelines are provided for recreation and aesthetics. Updated *Guidelines for Recreational Water Quality and Aesthetics* (NHMRC, ARMCANZ and ANZECC), are currently being prepared and will replace this section in the ANZECC and ARMCANZ Guidelines (2000) when they are completed;
- *Drinking water* – defers to the *Australian Drinking Water Guidelines* (NHMRC and ARMCANZ, 1996);
- *Industrial water* - water quality guidelines are not provided for this value; and
- *Cultural and spiritual values* - water quality guidelines are not provided for this value.

The ANZECC and ARMCANZ **Guidelines for aquatic ecosystems** promotes assessment that integrates biological and physico-chemical monitoring of ambient waters and sediments. Guidelines are provided for biological indicators, physical and chemical stressors, toxicants and sediment quality. These guidelines were developed and are intended to be implemented using a risk-based approach.

The ANZECC and ARMCANZ Guidelines provides **information and guidance to assist in the investigation of risk to aquatic ecosystems**. This information is also useful for natural resource managers and/or risk assessors assessing potential risks to aquatic ecosystems triggered by the SEPP (WoV) environmental quality objectives. The relevant sections of the ANZECC and ARMCANZ Guidelines (2000) are indicated below:

- Background information on **biological assessment** of aquatic ecosystems is provided in Section 3.2.1.2.
- Where possible, 'packages' have been developed within ecosystem types, for investigating issues triggered by **physicochemical indicators**. These 'packages' consist of background information, key performance indicators, 'trigger' values and guidance for considering effects of environmental modifiers in reducing or

enhancing the risk to aquatic biota. Only a limited number have been developed at this stage and these are found in sections 3.3.3 and 8.2.3.

- Further guidance on investigating the **water quality guidelines for toxicants** are provided in the Guidelines and associated journal papers. A general decision tree for investigating triggered toxicant values and a more specific decision tree for metal speciation are provided in section 3.4.3.2. More detailed guidance and information in implementing the decision trees; and on the derivation, application and investigation of the toxicant 'trigger' values is provided in the following series of associated journal papers:
  - Chapman, J. (2001). The revised Australian and New Zealand Water Quality Guidelines for toxicants: Approach to their derivation and application. *Australasian Journal of Ecotoxicology*. 7: 95-108;
  - Chapman, J. and van Dam, R.A. (2001). Direct toxicity assessment (DTA) for Water Quality Guidelines in Australia and New Zealand. *Australasian Journal of Ecotoxicology*. 7: 175-198;
  - Chapman, J.C., Warne, M.StJ. and Patra, R.W.R. (2001). Considerations when applying the revised toxicant guidelines. *Australasian Journal of Ecotoxicology*. 7: 157-174;
  - Markich, S.J., Brown, P.L., Batley, G.E., Apte, S.C. and Stauber, J.L. (2001). Incorporating metal speciation and bioavailability into water quality guidelines for protecting aquatic ecosystems. *Australasian Journal of Ecotoxicology*. 7: 109-122; and
  - Warne, M. StJ. (2001). Derivation of the Australian and New Zealand Water Quality Guidelines for toxicants. *Australasian Journal of Ecotoxicology*. 7: 123-136.
- A general decision tree for applying the **sediment quality guidelines** is provided in section 3.5.5.2.
- A preferred hierarchy for **deriving trigger values** is provided in section 3.1.1.2.
- More extensive **background information on aquatic ecosystems** is available in Chapter 8 (Volume 2), including detailed descriptions of various physico-chemical stressors, toxicants and sediment quality in sections 8.2.1, 8.3.7 and 8.4, respectively.

APPENDIX 4. REVIEW OF COMMON ISSUES AND INCONSISTENCIES IN THE MEASUREMENT OF SUSPENDED PARTICULATE MATTER (SPM), TURBIDITY AND SEDIMENTATION (UPPER BARWON CATCHMENT CASE STUDY)

Turbidity and SPM

Turbidity refers to the clarity ('muddiness') of water and is caused by suspended matter such as clay, silt, fine organic and inorganic matter, colloids, plankton and other microscopic organisms.

Suspended particulate matter (SPM) is the material that is suspended (not dissolved) in the water column. SPM may also be referred to as 'suspended sediment', 'suspended solids' or 'non-filterable residue' (NFR).

Currently there are no methods for directly measuring turbidity and SPM. Consequently, they are defined as their surrogate experimental measures, which vary according to the methodology used. For the Victorian Water Quality Monitoring Network (VWQMN), they are defined as follows:

- Turbidity is the light scattered at right angles to the incident light beam passed through a water sample, as measured by a Hach 2100A Turbidity meter; and
- SPM is the 'total suspended solids' filtered through a Whatman GFC filter and dried at 103-105°C.

The collection of representative SPM or turbidity samples to estimate sediment loads is a complex problem that usually requires a series of compromises based on acceptable error limits balanced against resource limitations.

Most of the sediment entering and being transported within rivers and streams occurs during a few high flow/flood events (Beckett et al., 1992; Wren et al., 2000). Studies have shown that estimates of sediment loads based only on discrete SPM samples (for example, weekly or monthly) greatly underestimate loads as these high flow events are often missed (Gippel, 1995; Anderson and Svendsen, 1997).

However, there is considerable difficulty and expense involved in sampling SPM on a continual or event basis. Therefore, estimates of sediment loads have generally been calculated using flow, which is more easily measured. First, a relationship between flow and SPM concentration must be derived, which is then used to estimate sediment loads from continuous flow measurements. However, these relationships have been shown to greatly underestimate sediment loads (Campbell and Doeg, 1989; Grayson et al., 1996). For example, Olive and Rieger (1987) found that studies in NSW using these relationships underestimated loads by 73 to 82 per cent.

A more recent alternative method is the use of turbidity readings as a surrogate measure of SPM. Again turbidity and SPM relationships must first be derived and then turbidity can be used in the estimation of sediment loads. Compared to SPM, turbidity measurements can be more easily and cheaply collected as continuous remote readings using an electronic data logger. Estimations of sediment loads from these relationships have been shown to be more accurate than the previously used flow and SPM concentration relationships (Grayson et al., 1996). However, there are still conflicting results in the literature as to whether these can be used to reasonably estimate SPM loads, in particular for compliance purposes (Gippel, 1995; Grayson et al., 1996; Riley, 1998).

It should be recognised that there is also uncertainty and error associated with the actual measurement of SPM and turbidity. SPM measurements will vary according to the methodology used. There can also be up to a 20 per cent error margin associated with the measurement of SPM samples taken in the field and then analysed in a lab (Wren et al., 2000). Turbidity measurements, often quoted as NTU units, are also not consistent. These turbidity units are somewhat arbitrary and are dependent on the meter used and the nature of the SPM (Grayson et al., 1996). Variations in particle size, shape and composition, instrument stability, light conditions and organic load can lead to different turbidity and SPM relationships. It is therefore important to recognise that these relationships are not universal and need to be calibrated for different turbidity meters, SPM measurements and site-specific conditions (Grayson et al., 1996; Riley, 1998).

Sedimentation

Sedimentation is the suspended sediment (SPM) deposited onto the streambed and other substrates (for example, woody debris, boulders) and into the interstitial spaces of the streambed.

Studies of sediment inputs into rivers and streams have mostly addressed the measurement of SPM and turbidity. There have been far fewer investigations into the measurement of sedimentation (for example, Brown, 1994 and Brunet, 1994) and these have mostly been confined to the deposition onto streambeds and substrate surfaces, with little attention to deposition within the interstitial spaces of streambeds. Subsequently, unlike SPM and turbidity, standard methods for the measurement and monitoring of sedimentation have not been developed. These need to be investigated, including the relationships between sedimentation and standard SPM or turbidity measurements, given that both SPM and/or turbidity may be used for investigation and/or monitoring.