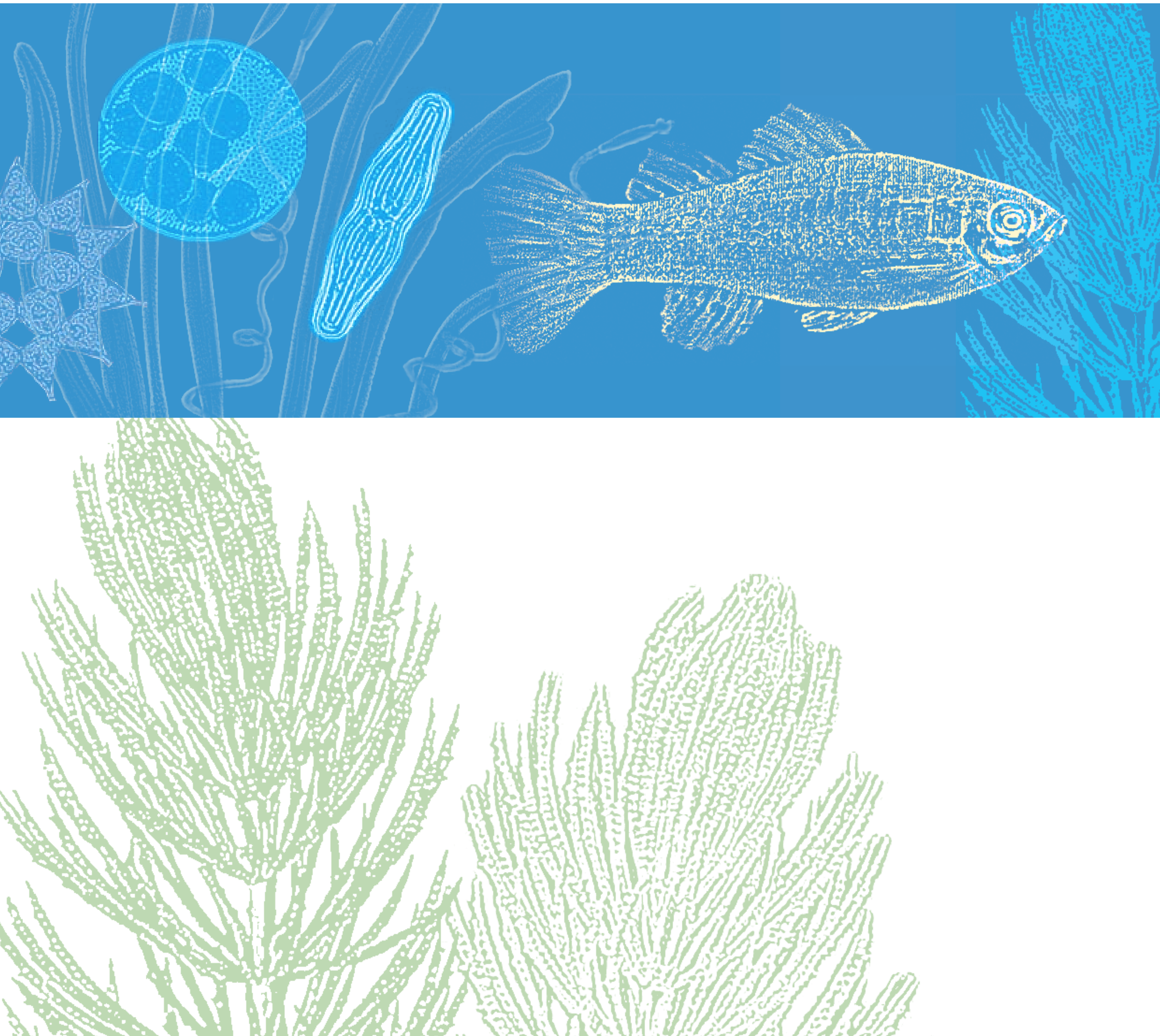
Interpreting River Health Data

Waterwatch Victoria



FOREWORD

By Dr. Ian Rutherfurd

**Director of Integrated River Health,
Department of Sustainability and
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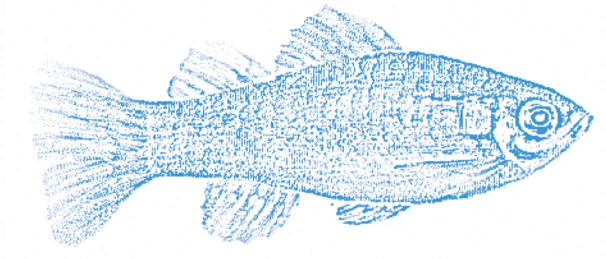
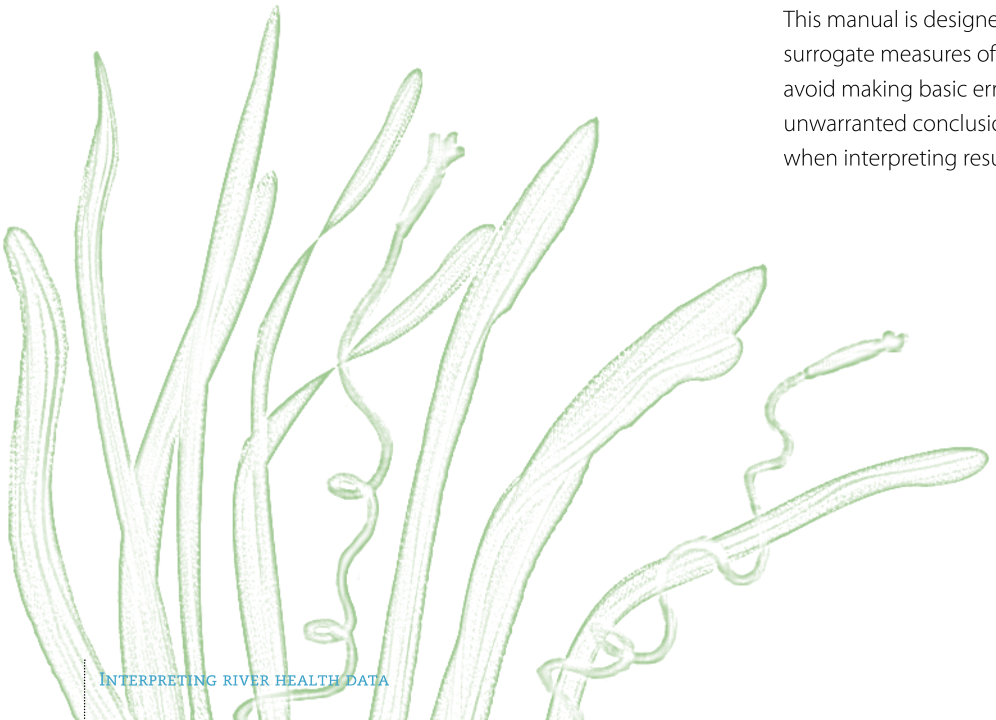
Taking a water quality sample is a complicated act. "No", you rightly say, "surely anybody can look down a tube and estimate turbidity; it's a bit harder to measure nutrients, but most people can be trained to do it competently. So what is complicated?"

It is what the sample *means*. Taking a water quality sample is to river health, what measuring a person's temperature is to human health. Parents take a child's temperature because it provides a surrogate for health. The parent may have only a vague idea why illness seems to lead to increased temperature, but they know that a temperature over 37°C could indicate sickness, perhaps an infection. This example provides some useful analogues for Waterwatch samplers.

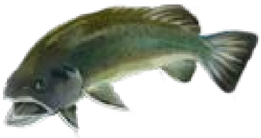




- First, there was probably some reason that the parent measured the temperature of the child. They suspected that there was something wrong. They had a question that they wanted answered.
- Second, they were confident that the measure they made was accurate and the thermometer was put in the correct place.
- Third, the measurement was compared against a standard. In this case the average human core temperature.
- Fourth, a parent will continue to measure to look for change or a trend. An upward trend is bad and will trigger further action.
- Fifth, that further action might be to take the child to a doctor, an expert in interpreting what is causing the change in the temperature (the generic surrogate measure).
- Sixth and finally, a parent does not believe that temperature is the only measure of health. Very old people might not have an elevated temperature, but they might also believe that they are no longer as healthy as they were. Human 'health' is a complicated idea, just as river health is a complicated idea.

So what is this manual for? To extend the medical analogy, this could be described as a 'community health centre' manual for community water quality monitors. Many parents have gone to the community health centre nurse for reassurance, advice or referral. That nurse has to be well educated in basic medicine, but they will also know when to refer to an expert.

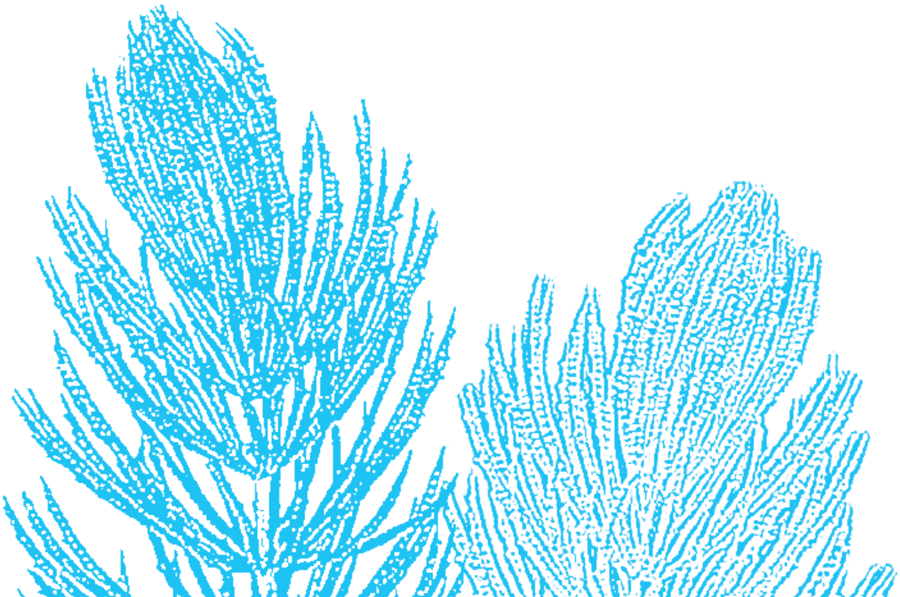
This manual is designed, in essence, to help interpret the basic surrogate measures of river health that we use. It is also designed to avoid making basic errors of interpretation, in particular, leaping to unwarranted conclusions and mistaking association for causation when interpreting results.



Following the example, here are the basic questions that this manual will help you to address (although they are not expressed in this order in the manual, you will find the answers throughout):

1. **What is the question?**
   Waterwatch monitors will be involved in the program for many reasons, but it is worth clarifying the questions that they have, so that you can make sure that their monitoring will answer them! For example, monitors may have a suspicion that the water quality in their creek is declining and they want to explore whether it is. Will their routine monitoring tell them? Alternatively, they may care about the condition of a receiving water body (such as a lake), in which case load is much more important than sample concentration.
2. **How good is the measure?**
   The Waterwatch program is underpinned by basic measurement protocols that are becoming more rigorous each year. This is because there is basically no point having water quality samples that we cannot trust. Similarly, our confidence in a measure is increased if that measure is supported by other measures and follow-up sampling.
3. **How does a result compare to the 'standard'?**
   Waterwatch monitors should know what the standards are around each class of measure (so many mg/l etc.), and how they were arrived at. Are they, for example, based on toxicity, on potable water standards or on averages from unimpacted areas? What are the error bars around those standards?
4. **What does a change in a value mean from sample to sample?**
   Trend is the hardest thing for a Waterwatch monitor to interpret. The value has changed dramatically over a week, is that normal? We should know the basic processes that influence the variables that we measure (the most important of which is usually simple discharge / rate of water flow). This also relates to basic knowledge about concentration and load. Your load could be increasing dramatically, but your concentration could be going down, simply because discharge is rising. Key to this issue is to understand natural variability as opposed to human influence.
5. **When do we need to act on water quality measures?**
   The Waterwatch network is an important part of the water quality reporting network in Victoria. So what constitutes a problem and when do you report or 'act' on problems? This will relate to standards that are exceeded or to unusual trends. There are formal protocols for when to call in the regulators or the experts. We should know when to seek help.
6. **How do my water quality measures relate to stream health?**
   Water quality is only one aspect of stream health, albeit a critical one. But we should all be aware of where our piece of stream and the water that flows past us day by day, fits into the larger goals of river health. What are the overall plans for this river and how can I help?

Above all, we hope that this manual will help Waterwatch staff and monitors to do more than watch the water – but to question, to measure and to act.



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Courtesy of Goulburn Broken Waterwatch.

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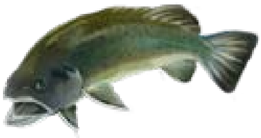


1 INTRODUCTION

Waterwatch Victoria is a community waterway monitoring and engagement program that connects local communities with river health and sustainable water management issues. Waterwatch coordinators and community volunteers have been collecting water quality data across Victoria for over 15 years, with a strong emphasis on data confidence and quality data since 2000.

This manual has been developed to improve and support coordinator feedback to monitors and communities on what their water quality data says about their local sites. The manual will be an initial reference for coordinators wanting to explore and interpret water quality data before producing data reports.

The manual assumes users have some knowledge and skills in *Microsoft Excel* and that the manual is read in conjunction with relevant state and regional documents including the *Waterwatch Victoria Methods Manual (1999)*, *Waterwatch Victoria Data Confidence Guidelines* and regional *Data Confidence Plans and Equipment Manuals*. By using this manual only, coordinators cannot expect to become experts in interpreting water quality data. Coordinators are encouraged to access other resources for assistance in water quality data interpretation, some of which are listed in Section 7, 'Sources of data and expert advice'.

The manual covers water quality indicators regularly measured in the Waterwatch program - the plant nutrients (phosphorus and nitrogen), dissolved oxygen, turbidity, electrical conductivity, pH, temperature and *E. coli*. Macroinvertebrates are not covered in the manual and detailed information on sampling and interpretation can be found in the EPA Victoria publication *Rapid Bioassessment Methodology for Rivers and Streams.* (2003, Publication no. 604.1).

Courtesy of Goulburn Broken Waterwatch.

2 WHAT IS RIVER HEALTH?

An ecologically healthy river is a river that retains its major ecological features and functioning similar to that prior to European settlement and which would be able to sustain these characteristics into the future. By this definition, an ecologically healthy river need not be pristine. For example, exotic species may be present or fish passage may be provided by fishways. However, overall, the major natural features, biodiversity and functions of a river are still present and will continue into the future.

Water quality is traditionally measured to assess river health, although in more recent years biological indicators, such as macroinvertebrates, have also been used. Both water quality and biological assemblages vary from year to year, between seasons and from turbulent high mountain streams to large, meandering lowland rivers. Understanding these temporal and spatial differences is important in assessing river health.

Indicators of river health

Various indicators may be used to assess river health. Indicators are the best practical representation of issues impacting river health. For example, phosphorus is used as an indirect measure (indicator) of potential excessive plant growth (the issue). Phosphorus is a major plant nutrient and when there is excess phosphorus there is likely to be greater plant growth. However, a more direct measure would be to assess plant biomass or productivity, but this is time consuming and difficult so is not generally undertaken. Indicators are a tool and must not be the focus of an assessment. The issue must be central to the assessment.

The most regularly used direct measure of river health is the macroinvertebrate community. The macroinvertebrate community is the outcome of environmental conditions, primarily water quality regime, habitat quality and flow regime. Changes in these conditions will change the community.

Another measure sometimes used to assess river health is pollutant load. Pollutant load is the amount of a pollutant that passes a point over a given period of time, usually a year. Regular monthly monitoring is not sufficient to estimate loads. To accurately measure loads, event based monitoring is needed. This requires substantial sampling effort at the time of high flows, in particular floods.

Concentrations provide a measure of immediate availability or effect on biota or ecosystems, whereas loads are more applicable to sinks such as lakes, estuaries and marine environments where pollutants accumulate in sediments to be potentially released when conditions are favourable. Loads are not reported by *Waterwatch* and therefore are not addressed any further in this manual.

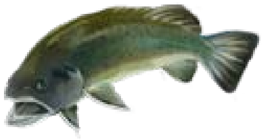
Impacts on river health

Pollution from human activities has impacts on river health. Pollutants may enter rivers continuously, as with a sewage discharge, or intermittently, as with stormwater. Common pollutants entering rivers include plant nutrients (in particular, phosphorus and nitrogen), sediment, salt and oxygen demanding substances and toxicants such as heavy metals and biocides. Changes in water quality may be short or long term depending on the pollutant. For example, oxygen demanding substances such as raw sewage will break down within hours or days whereas heavy metals may remain for decades. While some pollutants are broken down or will pass downstream quickly, others bind to particles of sediment in the water and will settle out, accumulating in the river sediments. Nutrients and many of the toxicants that accumulate in the sediments will remain there and have minimal impact on the aquatic environment. However, under certain environmental conditions they may be released from the sediment to the water column where they can impact river health. Low oxygen levels in the sediment or low pH levels can facilitate this remobilisation.

It is important to note that impacts from pollutants may not be detected by regular monitoring because of the timing of a discharge, the fate of a pollutant and/or where measurements are taken.

Climate change

Climate change will have a substantial impact on aquatic ecosystems including increased water temperatures, decreased stream flows, more extreme events, such as bushfires and a shift from perennial to intermittent stream flows. These are potentially profound changes to aquatic ecosystems. It is possible that the climatic conditions experienced over the last decade are a result of climate change rather than prolonged drought conditions. Water quality and biological data gathered prior to this period are therefore likely to represent different environmental conditions to the current conditions.



3.1 Introduction

This section briefly describes approaches and methods that can be used to explore patterns in data and identify what those patterns may mean. Before looking at the data it is valuable to clearly state the questions you are seeking answers to. Often these questions are best formed through the development of conceptual models. These two aspects of data exploration are examined first. Important features of the data are also discussed, including the use of summary statistics, time series graphs and spatial graphs. The section finishes with an examination of the influences of environmental setting upon water quality indicators.

3.2 Preliminaries

THE QUESTIONS

Before beginning the exploration or interpretation of water quality data, you need to form a clear set of questions that you are seeking answers to. Usually these questions come from management objectives or focus on specific water quality issues at the site or in the reach or catchment. For example, the questions could simply be "What is the condition or health of the site, reach or catchment?". Health or condition can be assessed by comparing the data collected against State Environment Protection Policy (Waters of Victoria (SEP WoV)) water quality and biological objectives. Other questions may include examining the improvements that have arisen from management action taken in the catchment; the changes resulting from drought, flood or climate change; and the assessment of human impacts such as sewage discharges and town and agricultural runoff. Be clear as to why you are looking at the data.

CONCEPTUAL MODELS

Conceptual models may help develop the right questions.
A conceptual model is an illustrative representation of an issue and its relationships with other environmental factors. The issue is usually a specific ecosystem value or a threat to that value. For example, a healthy native fish community may be a value you want to manage and protect, whereas an algal bloom may be a threat you want to protect against. A model should represent all relevant details known about the ecosystem, including relationships between the value or threat and factors influencing it. Conceptual models can provide the basis for developing questions on potential cause-effect relationships and for communicating understanding of the issue.

Figure 3.1 provides an example of a conceptual model for causes of increased phosphorus concentrations. The sort of things that may explain increased phosphorus at a site include the loss of native vegetation in the catchment, recent bushfires in the catchment, stock access to the stream, discharges to the stream (e.g. from sewage treatment plants), intensive agricultural activities (e.g. dairying) and poor riparian zone cover. Many of these factors may be exacerbated by storm events in the catchment in the hours or days prior to sampling as storm events wash sediments into streams, increasing phosphorus inputs.

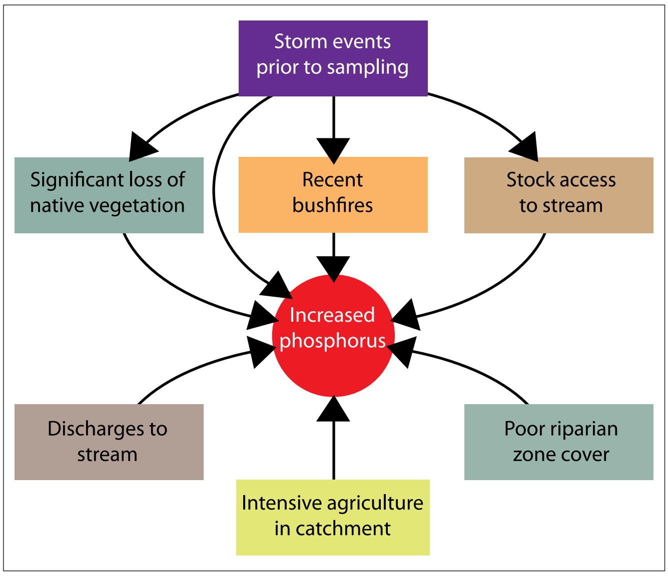


Figure 3.1 Conceptual model for factors causing increased phosphorus concentrations.

Although 'increased phosphorus' may be a trigger for concern, low phosphorus itself is not a value of the stream (i.e. a stream is not 'valued' for its low phosphorus concentrations). It is the impact that increased phosphorus concentrations may have on the stream ecosystem that may affect the stream's value. For example, increased phosphorus concentrations may increase the risk of an algal bloom thereby threatening the recreational and aesthetic values of the stream.

Conceptual models can also be used for problem solving issues and risks to values in natural systems. Figure 3.2 shows an example of an issue-based conceptual model focusing on algal blooms in a lowland reach of river. In this model, increased phosphorus concentrations, warmer waters and reduced water turbulence will increase the risk of an algal bloom. The indirect factors that lead to these conditions include climate change, catchment disturbance and reduced river base flows. Although it is only necessary to monitor the algal levels to identify the growth of a bloom, data needs to be collected for all of the parameters in the conceptual model to understand the drivers of the bloom. This data provides information that can then be used to assist in managing future blooms.

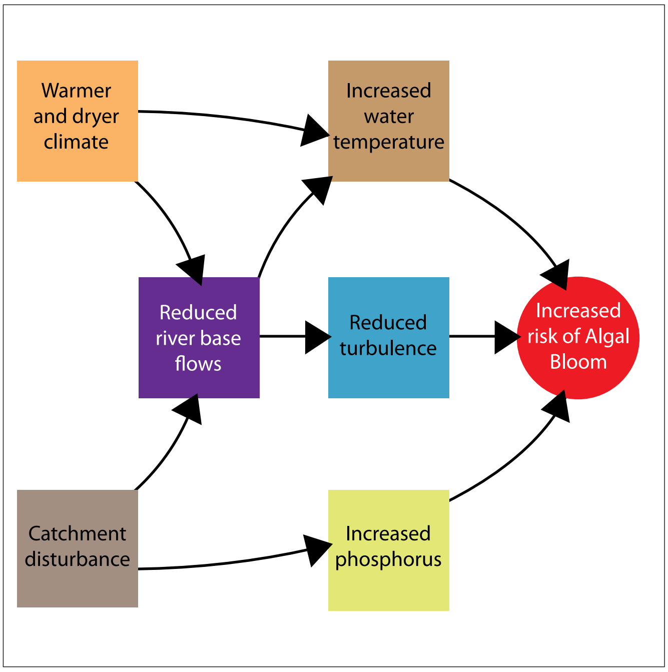


Figure 3.2 Conceptual model for algal bloom risk in a lowland river reach.

The model shown in Figure 3.2 is a simple one and could contain more causal factors and arrows, including factors and arrows related to reducing the risk of algal blooms. The important point is that conceptual models can be used to help you determine the questions that you are asking of your data and to help you visualise the importance of your results within the context of the whole system.

3.3 The Data

To be able to answer your questions about the water body you are sampling, you need to have appropriate measures and sample results. When you take a measurement or a sample from a river, you obtain a single piece of information about that river. That piece of information gives you an indication of the condition of the river at the time of sampling. However, you do not know whether you sampled at a time when the water quality measure was unusually high or unusually low. In other words, you have low confidence in a single measure being an accurate representation of 'typical' conditions.

Some sampling programs use the approach of taking one-off samples of a suite of measures (e.g. nutrients, salinity, dissolved oxygen, suspended solids) at many sites within a region to gain a 'snapshot' of rivers in an area. These programs are useful for gaining some understanding of conditions across a broad region but suffer from having low levels of confidence that any single site has been adequately characterised.

Increased confidence in the information provided by a data set is gained through increased numbers of data points for each site. Once you have a site with many data points, two questions that arise are:

1. What does the data tell me about typical conditions of the site? and
2. What does the data tell me about the range of conditions at the site – i.e. not just the typical conditions.

While data interpretation is best undertaken with a complete or large data set, this is not always possible. Data interpretation should be undertaken with whatever data is available, noting this limitation and any assumptions that are made.

Interpretation of data is helped by using standard, recognised approaches that allow you to compare the data against other sites, objectives or guidelines and data from previous years (to determine trends).

One of the more common ways of defining the typical state of a water body is to use a measure of central tendency, such as the mean or the median.

Calculating the mean

Calculating the mean (sometimes called the 'average') requires adding together all the data points then dividing the total by the number of data points. For example, consider the following 13 results:

5, 5, 6, 6, 4, 6, 97, 6, 5, 5, 45, 88, and 55

The mean value of these results is obtained by adding them all together and dividing by 13:

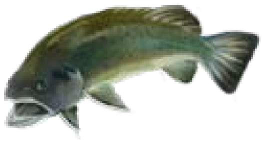
(5 + 5 + 6 + 6 + 4 + 6 + 97 + 8 + 5 + 6 + 45 + 88 + 5) ÷ 13 = 22

Calculating the median

The median of a set of figures is obtained by arranging them all from the lowest number to the highest and taking the middle value. Using the same 13 results, the median is found to be 6:

4, 5, 5, 5, 5, 6, 6, 6, 6, 8, 45, 88, 97

The median is also known as the '50TH percentile', as it is the half way point in the data array (i.e. 50% of the way from the lowest to the highest data point).



DISTRIBUTION

A graph of the data set presented in the 'Mean' and 'Median' boxes is shown in Figure 3.3. This type of graph is known as a frequency distribution. The frequency distribution of the above data displays a feature that is common in water quality data sets – a 'skew', with most values located at the lower (left) end of the x-axis, and a long 'tail' to the right created by a few, much larger values. As displayed in Figure 3.3, most of the data points (measures) are either 5 or 6 (with a frequency of 4 readings for each). The median of the data set (6) reflects this distribution, whereas the mean value (22) is strongly effected by three high values (45, 88 and 97).

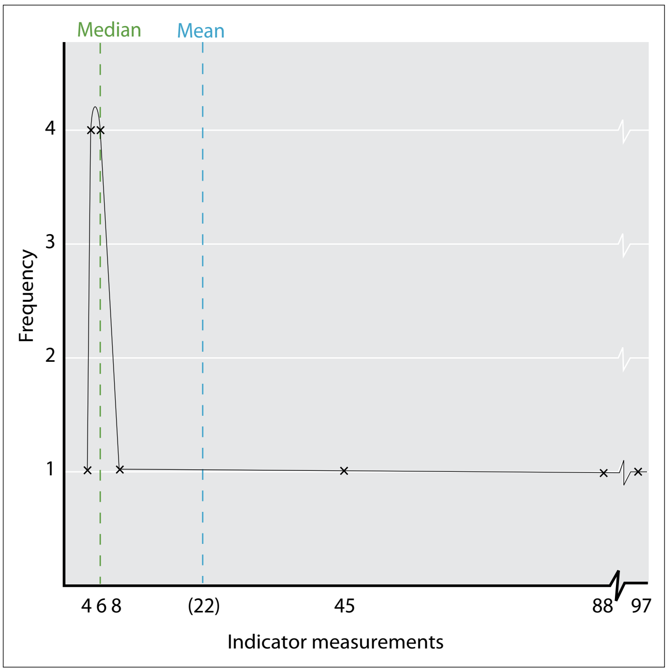


Figure 3.3 Frequency Distribution, Median and Mean Values of a Hypothetical Data Set.

The data presented in Figure 3.3 could represent turbidity measures from a headwater stream in an alpine area. The majority of the time the water is very clear (turbidity between 4 and 8 NTU) but on three occasions – possibly during or following storm events – the turbidity ranged from 45 to 97 NTU. In terms of water quality management, it is more useful to know that the water is generally around 6 NTU than to know that its mean is 22 NTU. If the highest recording (97) had been missed (for example, due to a faulty meter or a lost sample), the median value in the data set would remain 6, whereas the mean value would drop by approximately 30% to 15.75.

In skewed data sets, median values are generally more useful than mean values in reporting the typical water quality at a site. This is why water quality summaries typically use median values rather than the mean. When reporting water quality for Waterwatch, it is recommended that the median be used for summarising central tendency.

SUMMARY STATISTICS

The mean and median are examples of summary statistics. Summary statistics are characteristics of a data set that provide information about the data without needing to reproduce the whole set.

In addition to identifying central tendency, it is often important to summarise the range of conditions that occur within the data set. The highest and lowest values recorded at a site provide the full range, although these may be influenced by extreme events that are rarely encountered. Percentiles are often used to gain some understanding of the range without including extremes. Percentiles are summary statistics that identify the value of a variable within the data set, below which a certain percent of observations fall. For example, the 20th percentile is the value (or score) below which 20 percent of the observations may be found.

EPA Victoria has set many of its SEPP objectives as 75th percentiles (see "Assessing against water quality objectives", p.12). For the data set used in the previous example, the 75th percentile is 8, which is the value that is 75% of the way from the lowest to the highest data point:

median
↓
4, 5, 5, 5, 5, 6, 6, 6, 6, 8, 45, 88, 97
↑ ↑
25th percentile 75th percentile

This data set is indicative of relatively stable water quality conditions (median 6; 75th percentile 8), with infrequent disturbances. If the data set were different, for example -

4, 5, 5, 5, 5, 6, 6, 6, 40, 48, 55, 88, 97;

then the 25th percentile and the median would be unchanged but the 75th percentile would be 48, indicative of more frequent disturbances, probably due to more than just storm events. When reporting against SEPP, you will need to use the 75th percentile for most of the Waterwatch water quality indicators, as well as the 25th percentile for pH and dissolved oxygen.

Many software spreadsheet packages, such as EXCEL, can be used to quickly and easily calculate medians and other percentiles.

USING TIME SERIES

Variability is a natural part of the aquatic environment. Typically with water quality data there is a 10-20% difference between consecutive samples. For example, where salinity is measured at 500 µS/cm, changes of up to 100 µS/cm four weeks later may be due simply to natural variation and not a significant change in the aquatic environment. However, there will be more substantial changes due to floods or after long dry periods. For example, turbidity may go up ten fold during a flood event and salinity can more than double as flows decrease and groundwater becomes the main source of flow.

Displaying the data in a time series provides a picture of change over time. Time series plots are useful to illustrate seasonal patterns, major events or when 'one-off' high or low levels are measured. Figure 3.4 illustrates long term patterns in turbidity in the lower Ovens River. Note the seasonal patterns where turbidity rises during winter/spring and drops in summer/autumn. Also note the occasional high levels in winter, likely to be associated with flood events. Drought in 2002 can be seen in low turbidities during the winter and the effects of fires in 2003 can be seen in the elevated levels post fires.

Trend lines can also be added to determine if there have been substantial increases or decreases over time. For the clearest picture, a long time period is required to show temporal changes. Usually less than five years will not provide a good assessment. Figures 3.5 and 3.6 display five and 14 years of monthly data respectively. The trend lines suggest substantial changes at both sites. Phosphorus levels in Bennison Creek (Figure 3.5) appear to have decreased. Note the lack of very high levels in the later years compared to earlier years, suggesting that drought may have been the cause of this result. In Broken Creek, turbidity levels have increased between 1993 and 2007 (Figure 3.6). Levels gradually increased over time and there is no obvious inflection point, suggesting gradual increases from the catchment rather than a change in activity in the catchment. By 2002, turbidity levels were consistently above 50 NTU and often above 100 NTU. Such levels are likely to be harmful to aquatic life.

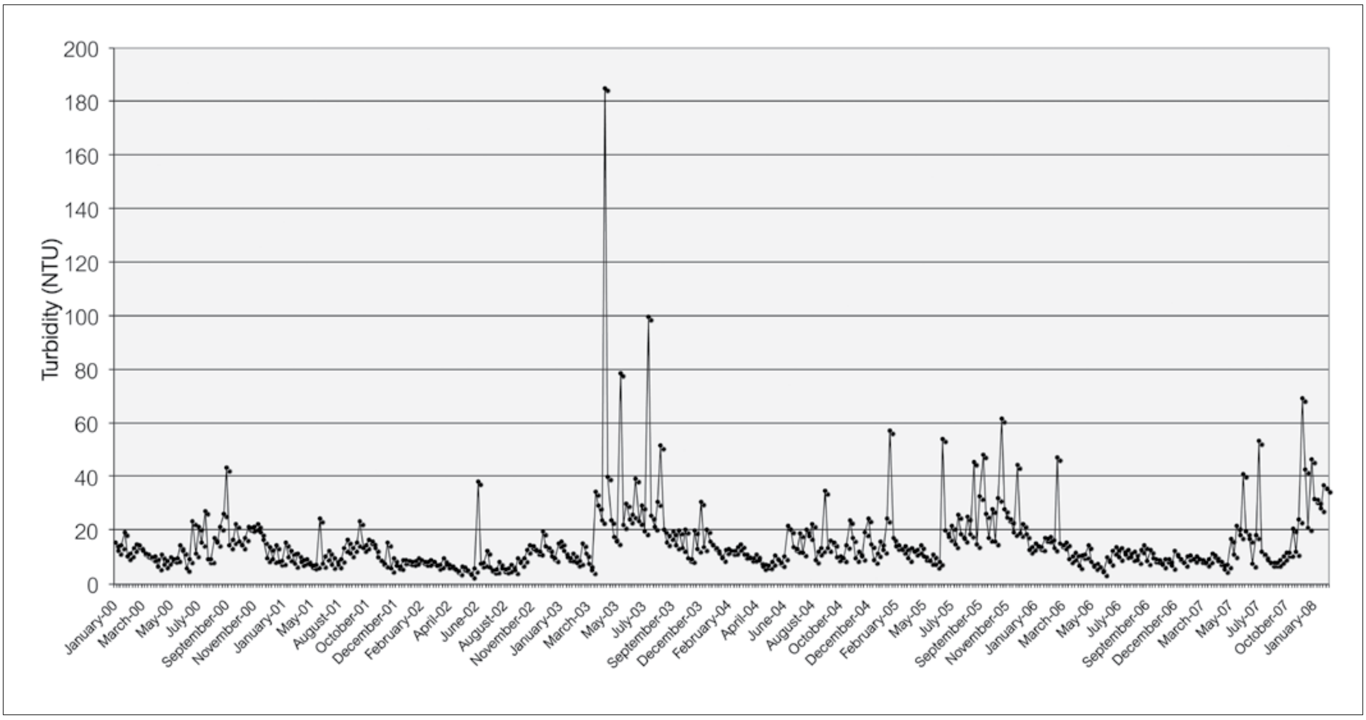
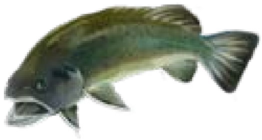


Figure 3.4 Turbidity time series 2000 to 2008 for Ovens River at Peechelba (VWQMN site no. 403241).
Source: VWQMN Data Warehouse. Graph generated using Microsoft Excel.



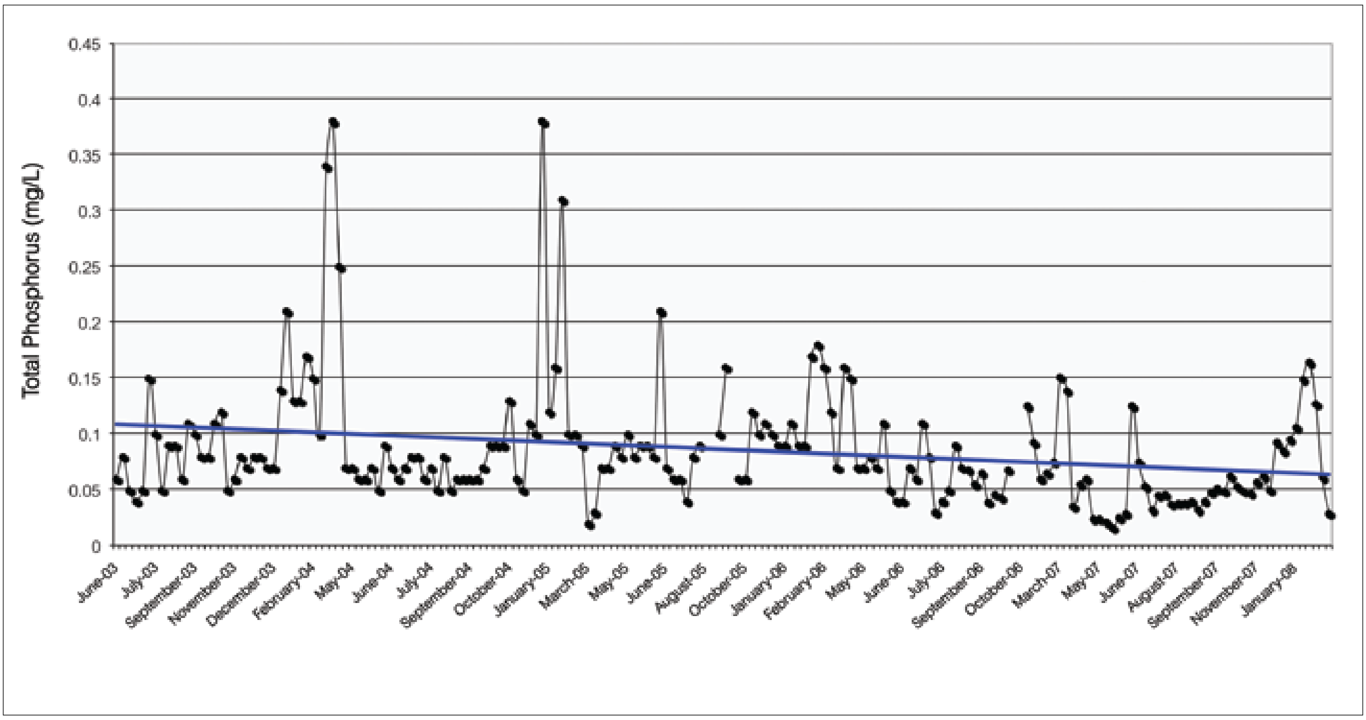


Figure 3.5 Total phosphorus time series and trend line for Bennison Creek at south Gippsland Highway (site no. BNN020). Source: West Gippsland CMA. Graph generated using Microsoft Excel.

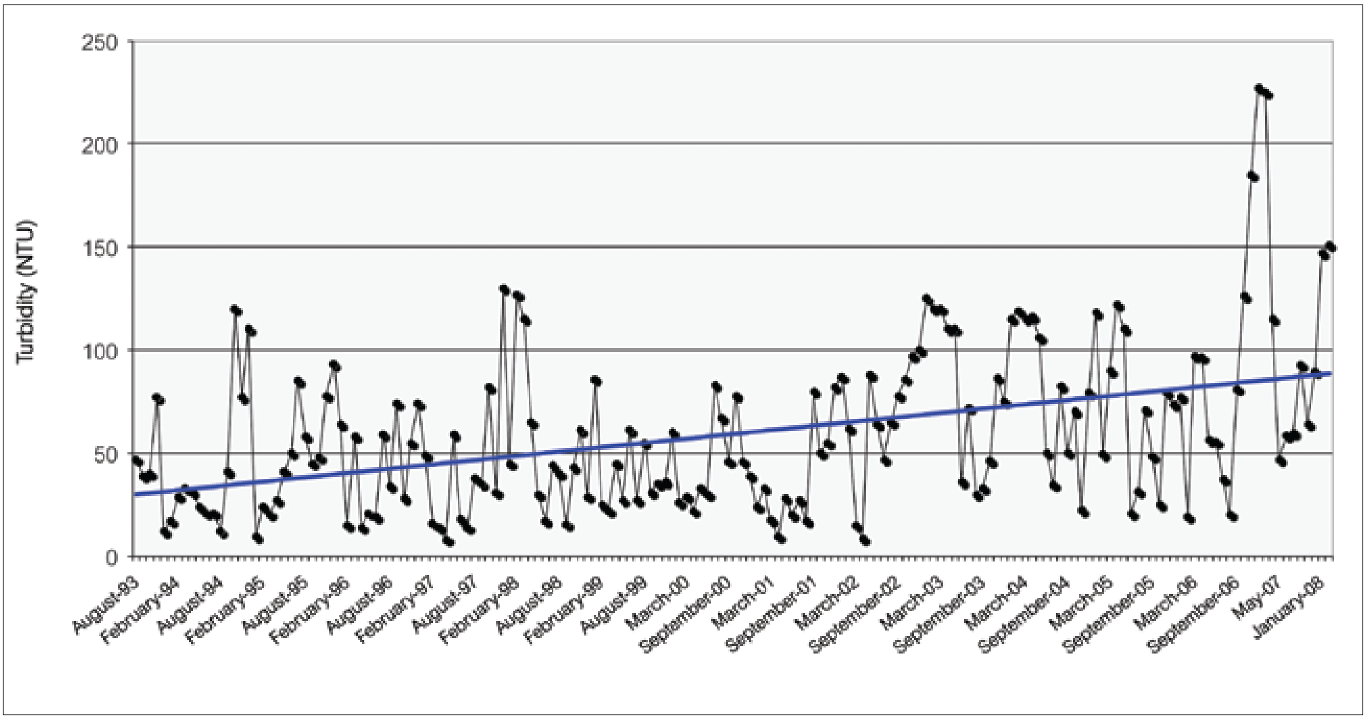


Figure 3.6 Turbidity time series and trend line for Broken River at Gownagardie (site no. BAR010). Source: Goulburn-Broken Waterwatch. Graph generated using Microsoft Excel.

Assessing water quality against objectives

The majority of assessments using water quality data collected for Waterwatch will be against the objectives provided in the SEPP (WoV). There are some important points to note about the SEPP (WoV) objectives:

1. They are ambient objectives and are not designed for use in single or short-term sampling programs. The objectives are designed to indicate low-risk conditions within a region or segment over an extended period of time (months to years). However, single sampling or a few samples from a site can still be used to provide some indication of condition and may suggest that further sampling is warranted
2. They are typically provided as 75th percentiles (e.g. total phosphorus, total nitrogen, turbidity, electrical conductivity, pH-high) or 25th percentiles for indicators that should not fall below particular values (e.g. pH-low, dissolved oxygen-low). The use of 75th and 25th percentiles requires a minimum of 11 samples for adequate confidence. Therefore, an annual monthly monitoring program should be sufficient for assessment against SEPP objectives
3. They are 'trigger' values. It is important to recognise the difference between trigger values and pass/fail objectives. If a pass/fail objective is not met, the site is deemed to have failed an assessment of its ecological condition. Although this is useful for auditing or catchment condition reporting, it does not necessarily trigger follow-up action. In contrast, if a trigger value objective is not met, then this should 'trigger' some action. The action that is triggered may range from spending a few hours to identify possible reasons (such as natural disturbances like storms, droughts or bushfires), through to undertaking ecological risk assessments or target-setting programs.
4. The objectives have been derived for regions based on ecological condition (Figure 3.7).

A data set collected from monthly sampling at a site can be compared to the SEPP (WoV) objectives for the segment (waterway section) to determine whether any results trigger further action. The SEPP (WoV) and its background documents provide important information for the assessment of data against objectives.

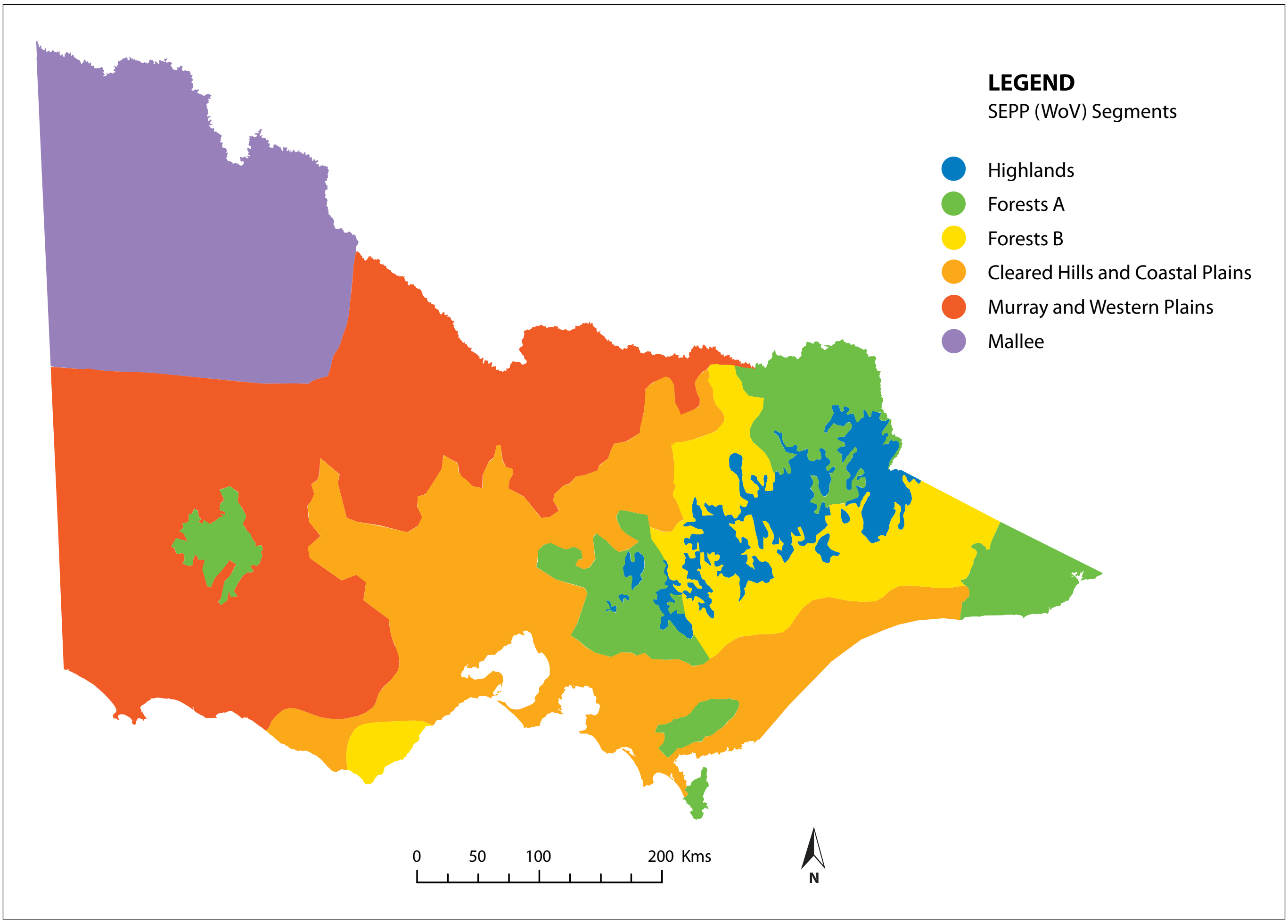
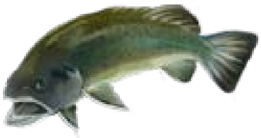


Figure 3.7 State Environment Protection Policy (Waters of Victoria) segments.



A single indicator triggering by a small amount for the first time (i.e. it hasn't triggered previously), may be considered a result worthy of 'watch' status. In contrast, a suite of indicators (e.g. total phosphorus, total nitrogen and dissolved oxygen) that continually trigger by a substantial amount and/or are increasing in their magnitude of triggering may warrant a full risk assessment. Between these two scenarios, further assessment by waterway managers or an aquatic ecologist may be warranted. Further details on the SEPP (WoV) approach can be found in *Risk-based assessment of ecosystem protection in ambient waters* (EPA Victoria 2004).

An example of assessing site data against SEPP objectives is provided for Bennison Creek (Table 3.1). In this example, only pH and turbidity meet the SEPP objectives for the Cleared Hills and Coastal Plain segment. Although not likely to be a risk to the ecosystem, the results are an alert that there may be an issue at the site. Electrical conductivity is over the objective, although not substantially and no single measurement is above potential toxic levels (greater than 1,000 µS/cm). While total phosphorus is also just over the objective, some of the measurements were particularly high and if sustained could result in excessive plant growth. Further investigation of total phosphorus is likely to be warranted. With this process there is a need to look at past results and see if a pattern is emerging or whether the events are one off and are unlikely to occur again or occur infrequently.

The SEPP (WoV) objectives do not provide a scale of outcomes (e.g. very good condition, good condition, poor condition, etc.). However, they do indicate if a site is good (i.e. the site meets the trigger value), or possibly bad (the site does not meet the trigger value). The distinction is not always clear when results are close to the trigger values, as demonstrated in the Bennison Creek example.

Table 3.1 Water quality data and annual percentiles for 2007 for Bennison Creek at South Gippsland Highway. SEPP (WoV) Cleared Hills and Coastal Plain segment. (site no. BNN020) Source: West Gippsland CMA

Date	Electrical Conductivity (µS/cm)	pH (pH Units)	Total Phosphorus (mg/LP)	Turbidity (NTU)
2 Mar	777	6.99	0.151	8
6 Apr	591	6.72	0.035	3
4 May	625	6.9	0.06	11
25 May	680	7.16	0.021	6
15 Jun	492	6.73	0.029	10
6 Jul	290	6.68	0.053	25
27 Jul	310	6.85	0.046	8
17 Aug	253	6.9	0.038	12
7 Sep	325	7.02	0.04	5
28 Sep	304	7.06	0.049	8
19 Oct	263	7.15	0.049	9
2 Nov	328	7.1	0.057	5
23 Nov	325	7.12	0.092	10
Annual 75th percentile	591	7.1	0.057	10
Annual 25th percentile	-	6.85	-	-
WoV Objective (annual percentile)	75th ≤ 500	75th ≤ 7.7 25th ≥ 6.4	75th ≤ 0.045	75th ≤ 10

3.4 Interpreting the Data in terms of Environmental Setting

Relationships between indicators and other ecological components

The results obtained from any sampling event or program will reflect a variety of physical and biological features that may be affecting water quality at each site. These include:

- the nature of the surrounding catchment (steepness, soil type, vegetation cover);
- site location within the catchment (headwater/upland, lowland plains);
- weather conditions during or prior to sampling (storms, droughts);
- land use within the catchment, particularly close to the sampling site (urban/industrial, agricultural, nature reserve); and
- in-stream inputs and actions (stock access, waste discharges, water removal, storages).

Similarly, the water quality at a site affects other components of the water body, including other aspects of water quality and the biota that the water body supports. A few of the more common relationships between water quality indicators and other ecological components are presented in this section. Greater discussion of the most sampled indicators is provided in section five.

The surrounding catchment

One of the most important natural features of the surrounding catchment is soil erodibility (which itself is a function of vegetation cover, slope steepness and length and soil type). In particular, catchments that have steep slopes and/or sparse vegetation cover are particularly susceptible to soil erosion, with potentially serious implications for water quality.

Soil that is eroded from the catchment and subsequently deposited in streams can directly and indirectly impact on the condition of the receiving water bodies. One direct impact is physical, with coarser grained sediments (sand, fine gravel) filling in deep pools required by fish and filling in interstices (gaps) between rocks and stones that are vital habitat for some macroinvertebrate species. The deposition of finer sediments derived from soil (such as silts and clays) can smother habitat and clog the gills of fish and invertebrates.

A measure of the extent to which finer particles are present in the water column is provided by an analysis of suspended particulate matter (SPM) concentration in the water (often also called suspended solids (SS), total suspended solids (TSS), or non filterable residue (NFR)). Finer particles can also act to reduce light transmission through the water column, inhibiting growth potential for aquatic macrophytes and algae and impacting on fish species that are visual predators. Turbidity is a surrogate measure of light transmission through the water. High turbidities are often an indication of poor land use management within the catchment, including the riparian zone. Elevated turbidity and SPM are often correlated with increased total nutrient concentrations (total nitrogen and total phosphorus), as soil particles often have nutrients attached to them.

Site location within the catchment

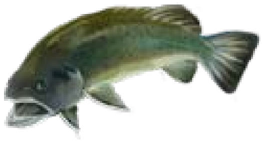
Sites that are high within catchments are often more prone to marked swings in water quality, as they have little buffering from rainfall events. This is because headwater streams are often small and drain a small catchment area, so any rain event within that catchment has the potential to cause substantial fluctuations in water quality. In contrast, large rivers in the lower reaches typically have many tributaries feeding into them and at any time may be receiving waters from some tributaries that have experienced storms, and others that have not. Therefore, water quality changes are often only small. Of course, changes in water quality from a major catchment-wide storm event will be readily observable even at lowland sites.

Weather conditions prior to sampling

Under typical flow conditions, a perennial stream within a given catchment will be expected to have a reasonably predictable set of water quality measurements and variability. However, unusual weather conditions prior to sampling can lead to large changes in water quality. For example, during droughts the gradual reduction in flows leads to an increased proportion of groundwater contributing to streamflow. Large parts of Victoria have groundwater with substantially higher salt and nitrate concentrations than typically found in flowing surface waters. Concurrently, the reduced inputs of water from overland flow and throughflow result in less sediment being washed into the stream and therefore less associated nutrients.

As a result, prolonged drought conditions are often reflected by reduced stream flows with greater electrical conductivities (EC), increased nitrate concentrations and reduced turbidities, SPM and total nutrient concentrations.

In contrast, high flows following storm events or substantial rainfalls are typically associated with greater dilution of groundwater and increased sediment loads being washed into the stream (Figure 3.8). Typical impacts on water quality are therefore reduced EC and nitrate concentration, accompanied by higher turbidities and associated increased concentrations of SPM, total nitrogen (TN) and total phosphorus (TP) (Figure 3.8). Increases in nutrient concentrations can lead to further problems associated with eutrophication (see sections on nutrients and oxygen).



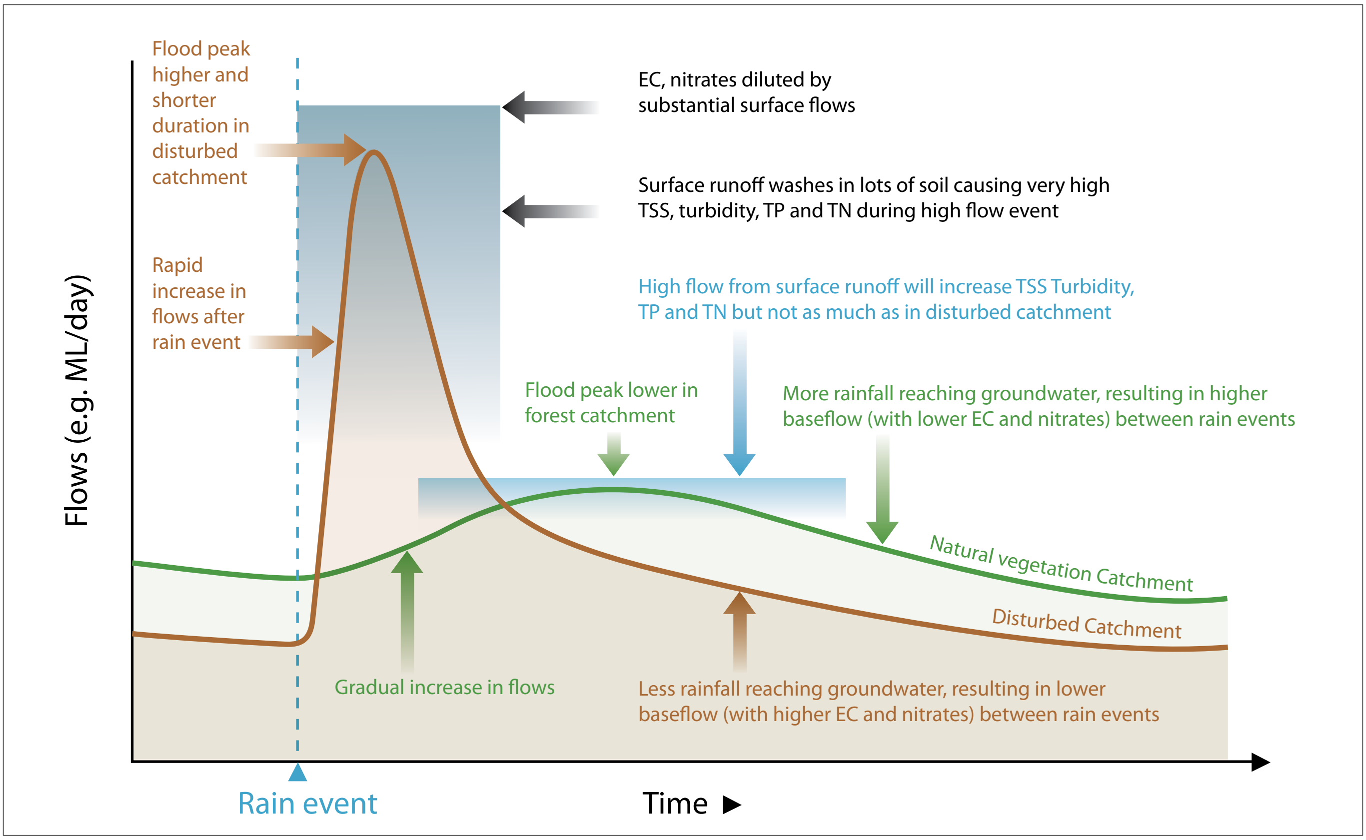


Figure 3.8 Typical flow hydrograph after rainfall in a forested and a disturbed catchment.

CATCHMENT LAND USE

Land use within a catchment can have a major influence on the water quality of stream systems. Catchments that have a large proportion of native vegetation, nature reserves and national parks will have lower rates of erosion and therefore less inputs of sediment into streams. In pristine or near pristine catchments, a large percentage of water from rainfall events tends to soak into the ground, recharging groundwater and gradually contributing to stream base flow over an extended period of time.

In contrast, catchments with a large degree of disturbance (such as urbanisation, large scale vegetation clearance or poor agricultural practices) tend to have higher surface runoff during rainfall events. The surface runoff will pick up pollutants (from urban areas) and soil particles (particularly in agricultural areas) and deposit them into the receiving waterways. Another feature of increased overland flow in disturbed catchments is that the rainwater is delivered more quickly to the streams, resulting in a higher flood peak that passes quickly through the system (Figure 3.8). The higher flood peak results in increased washing away erosion of streambeds and banks, in turn contributing more sediment to the stream system. The rapid draining of catchments also leads to reduced groundwater recharge and once the flood peak has passed, there is less groundwater to contribute to base flow, resulting in a greater potential for streams to dry during low rainfall periods.

Therefore, streams that drain catchments disturbed by land uses such as urbanisation, intensive agriculture and large-scale clearing can be expected to have higher concentrations of contaminants, sediments and associated total nutrients, particularly during and soon after large rainfall events.

Closer to the stream channel, removal of riparian vegetation can intensify these impacts and also add to temperature fluctuations, particularly through reduced stream shading in summer. The warmer waters can directly stress in-stream biota, as well as lead to reduced dissolved oxygen concentrations (see oxygen section), further stressing the biota.

IN-STREAM INPUTS AND ACTIONS

Other common influences on water quality that may be reflected in routine sampling include direct discharges to streams (e.g. from sewage treatment plants, dairy effluent or stormwater), stock access to streams and flow regulation or extraction. The effects of discharges will vary according to the discharge and its make-up.

Sewage discharges will often have high nutrients (including reactive phosphorus, ammonia/ammonium and nitrates), high oxygen-demanding substances (which may lead to low dissolved oxygen further downstream), high salts (reflected in EC readings) and miscellaneous organic and metal contaminants (depending on the sources to the sewage treatment plant).

Howqua River upstream of Running Creek Campground (looking downstream).

Stormwater may also contain contaminants such as metals from industry and from roads, as well as particulates with nutrients and high oxygen demand. Dairy effluent discharging to streams will often have very high oxygen demand from the organic matter, as well as high nutrients (including reactive phosphorus, ammonia/ammonium and nitrates).

Direct stock access into waterways typically results in increased bed and bank erosion, which contributes to increased turbidity, SPM and associated TN and TP. Faecal matter from stock also contributes to oxygen demand and high nutrients (including reactive phosphorus, ammonia/ammonium and nitrates).

Stream flow regulation can lead to greater temperature fluctuations. This can be attributed to cold water discharges from deep storages and reduced flow having less thermal mass and therefore heating up and cooling down more rapidly with the ambient air temperatures. Rapid fluctuations in flows associated with some regulation can also create bank instability, leading to bank failure and increased sediment input.

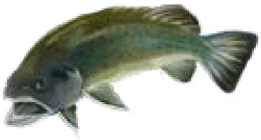
Looking for spatial patterns

Water quality changes as you go downstream. Small, shallow headwater streams change to bigger, deeper lowland rivers. Water clarity decreases naturally and nutrient and salinity levels increase naturally. The magnitude of changes will depend on the catchment. Forested catchments with little land disturbance change gradually, while more disturbed catchments will have rapidly changing water quality. Human activities including agriculture and urbanisation can have substantial effects on water quality.

Assessing downstream water quality is a valuable tool to determine point source discharges, such as sewage or stormwater discharges, and diffuse sources, such as from agriculture. To give a good spatial representation of changes and good differentiation of likely sources, sites need to be relatively close together. In addition, using longer term data (at least twelve months) will give a more effective and accurate assessment.

An example of spatial patterns is given in Figure 3.9 for the Broken River/Broken Creek catchment. In this catchment, turbidity levels are low in the forested reaches of the catchment upstream of Lake Nillahcootie (around the SEPP WoV objective of 5 NTU). Downstream of the lake, turbidity levels increased to more than five times the upstream levels. However, the increase at Caseys Weir is far greater, to more than twice the SEPP WoV objective of 30 NTU for this lowland segment. The increase is almost certainly due to the very turbid waters entering from an off-line storage (Lake Mokoan). Surprisingly, even greater increases were measured further downstream of Caseys Weir, even though obvious sources have not been identified. The continued increase is likely to come from one or more sources, most probably from the bed and banks, irrigation return waters or surface runoff.

In this example, sites are relatively close together which gives a good spatial representation of changes and good differentiation of reach changes, however it has not identified sources. Sources could be investigated by undertaking site inspections, discussions with local landholders and/or further sampling designed specifically to identify potential sources.



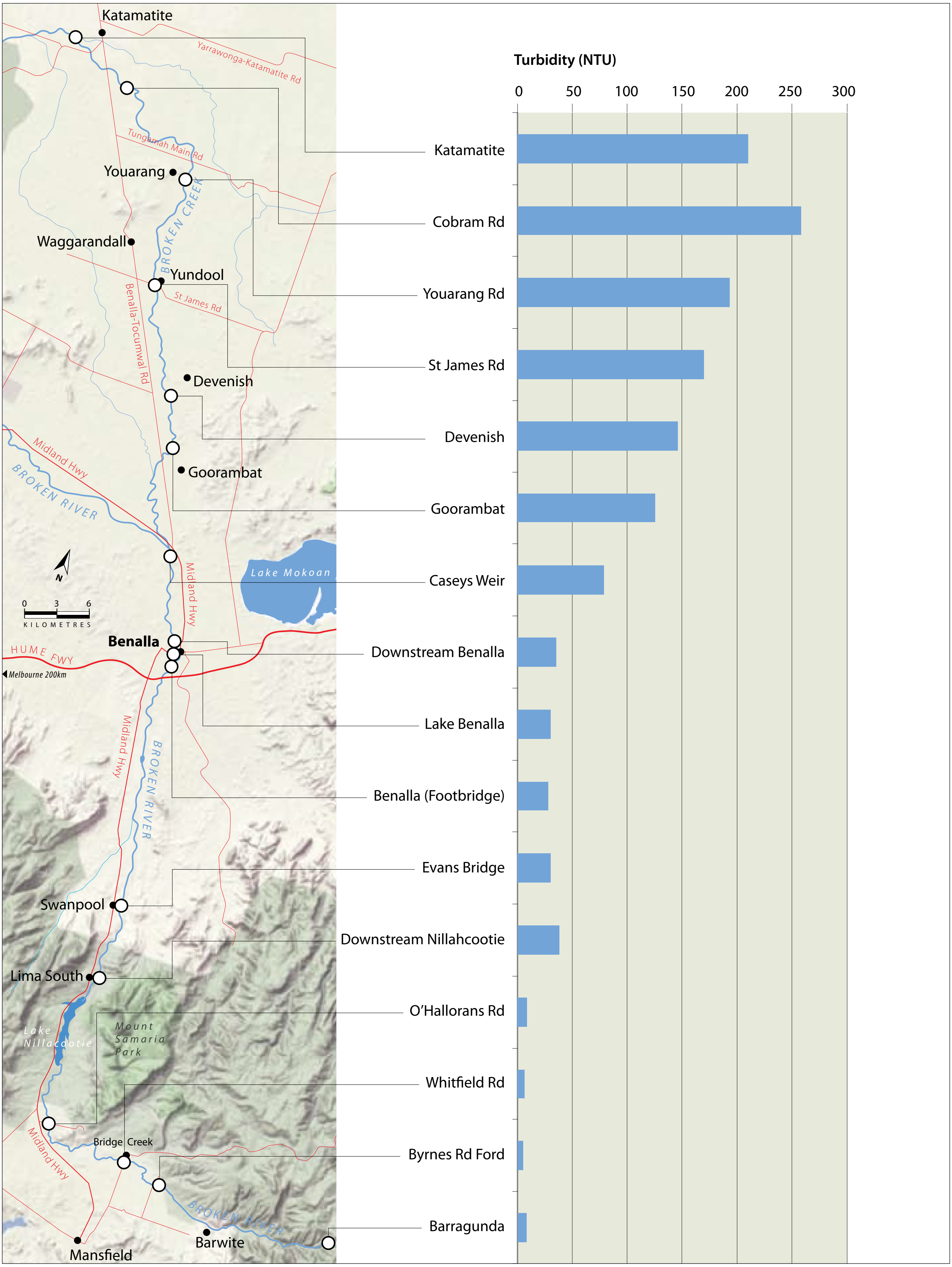


Figure 3.9 Turbidity in Broken River and Broken Creek. Long term 75th percentiles (1996-2008). Data Source: Goulburn-Broken Waterwatch.

4.1 Phosphorus

What is it?

Phosphorus is a naturally occurring element originating from minerals in rocks and is essential for animal and plant life. In natural circumstances, phosphorus usually enters waterways from the weathering of rocks (inorganic phosphorus) and the decomposition of plant and animal material (organic phosphorus).

Although phosphorus is one of many nutrients required by plants and animals, in freshwater systems it is often the nutrient limiting plant growth (i.e. it is the nutrient in shortest supply). This places a special importance on the monitoring and management of phosphorus.

Phosphorus is rarely found in its elemental form (P). It usually occurs in waterways as a form of phosphate (PO_4^{3-}). Different forms of phosphate are categorised as either chemically based forms or analytical methods-based forms. Chemically based forms of phosphate include:

- **Orthophosphates** These are the forms most readily available to plants and include the simple inorganic forms of phosphates, such as PO_4^{3-}, $HPO4^{2-}$, $H_2PO_4^-$, and H_3PO_4.
- **Condensed Phosphates** These are complex, tightly-bound, inorganic phosphate compounds sometimes referred to as 'polyphosphates'.
- **Organic phosphorus** This refers to a phosphate molecule associated with a carbon-based molecule, as in plant or animal tissue.

Organic and inorganic phosphate can be dissolved in the water or suspended (attached to particles in the water column).

The three most commonly used analytical methods for measuring phosphorus concentrations are:

- **Reactive Phosphorus (RP)** This measures any form of phosphorus that reacts with reagents in a colorimetric test without prior filtering or digestion (acid and heating). This method is also known as 'total reactive phosphorus' and is largely a measure of orthophosphates. However, the procedure isn't 100 per cent accurate and so results will include a small fraction of some other forms of organic and inorganic phosphorus that are easily broken down in water.
- **Filterable Reactive Phosphorus (FRP)** This is the fraction of the total reactive phosphorus that is in solution in the water (as opposed to being attached to suspended particles). It is determined by first filtering the sample, then analysing the filtered sample for reactive phosphorus.
- **Total Phosphorus (TP)** This is the sum of organic and inorganic forms of phosphorus in unfiltered water samples. The procedure uses sample digestion (acid and heating) and measures both dissolved and suspended orthophosphate.

A simple conceptual model of the different measured forms of phosphorus is presented in Figure 4.1. A measurement of filterable reactive phosphorus (FRP) is a component of measuring reactive phosphorus (TRP or, more usually, RP), which itself is a component of total phosphorus (TP).

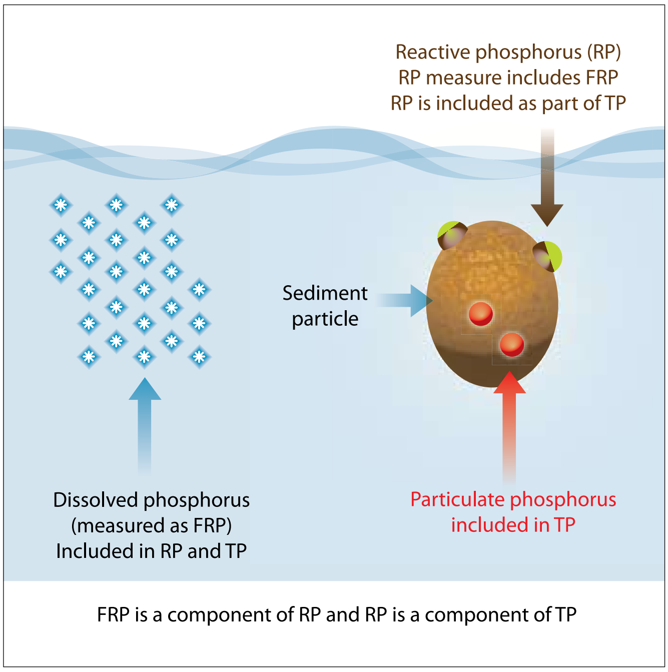


Figure 4.1 Conceptual model of common forms of phosphorus in water.

How is it measured?

As described above, the three most common ways to measure phosphorus are RP, FRP and TP. Within Victoria, the SEPP (WoV) objectives for phosphorus use TP. Although TP is likely to be an overestimate of the biologically available phosphorus in a water sample, biochemical processes such as remineralisation of organic phosphorus and conversions between the various forms, mean that measures of TP give a reasonable indication of the amount of phosphorus ultimately available.

The SEPP (WoV) objectives are presented as 75th percentiles and vary between segments of each waterway.

The different measures of phosphorus cannot be substituted. However, if a measure of FRP or RP was approaching or greater than the SEPP (WoV) objective for TP, this would be a strong indication of excessive phosphorus concentrations.