



## 4 | SPECIFIC INDICATORS

### WHY MONITOR PHOSPHORUS?

Phosphorus is often the limiting nutrient in freshwater systems. This means that increased concentrations of phosphorus provide increased opportunity for growth of algae and other plants. If phosphorus concentrations are high enough, they can contribute to algal blooms and infestations of aquatic macrophytes. Excessive algal and macrophyte growth can lead to smothering of habitat, clogging of waterways and overnight 'oxygen troughs'. Oxygen troughs occur when plants respire during the night (consuming oxygen) but are not photosynthesising (and therefore not producing oxygen). Under normal circumstances, a cycle of oxygen peaks during the day and troughs during the night (Figure 4.5, p.31). However, in eutrophic waters this cycle becomes exaggerated, with oxygen concentrations reaching very high levels during the mid afternoon and then dropping to very low levels just before sunrise (Figure 4.5, p.31). Levels can be low enough to severely stress, or even kill, the fauna of the stream.

At the end of an algal bloom, when the plant material is decaying (oxidising), the micro-organisms that break down the plant material consume large amounts of oxygen during the process, also adding oxygen stress to the ecosystem (Figure 4.4, p.23).

### SOURCES

Natural sources of phosphorus in waterways include: inorganic phosphates dissolved from weathered rocks; organic material from plants that have taken up the inorganic phosphate; organic material from animals (including wastes and decaying tissues); and remineralised phosphate that has been converted by bacteria from organic particulate phosphorus into dissolved inorganic phosphate (Figure 4.3, p.22).

Human derived or accelerated inputs of phosphorus to waterways can include those associated with eroded soil that is deposited as sediment (including particles with phosphate fertiliser attached), discharges from sewage treatment plants, stormwater runoff, discharges from intensive agriculture/dairying, stock access to streams and poor land management (Figure 4.4, p.23).



Courtesy of Corangamite Waterwatch.

### NATURAL VARIATIONS

Phosphorus concentrations can vary over time in relation to seasonal phenomena and episodic events. For example, higher flows (whether seasonal or episodic) are typically associated with increased inputs of suspended particulate matter, which carry attached TP. If storms follow bushfires within a catchment, extremely high levels of TP may be measured, associated with ash deposition and massive sediment inputs.

Concentrations of phosphorus also vary spatially across the State and this has formed the basis of the nutrient regions defined within SEPP (WoV). Objectives for TP range from  $20 \mu\text{g L}^{-1}$  in the highlands, up to  $45 \mu\text{g L}^{-1}$  in lowland plains. Typically, concentrations of most nutrients increase from headwaters to lowlands and this is the case for phosphorus.

Total phosphorus concentrations greater than  $50 \mu\text{g L}^{-1}$  in upland rivers and streams are likely to lead to excessive plant growth while in lowland reaches, concentrations greater than  $100 \mu\text{g L}^{-1}$  may lead to algal blooms if light is high (turbidity low).

## 4.2 Nitrogen

### WHAT IS IT?

Nitrogen is a naturally occurring element (chemical symbol 'N'), originating from the atmosphere (chiefly as  $N_2$ ) and from minerals in rocks. Nitrogen is essential for all animal and plant life and is continually cycled through ecosystems. Few living things can use atmospheric nitrogen, and instead rely on compounds of nitrogen.

However, there are forms of bacteria that turn atmospheric  $N_2$  into nitrogen compounds that can be taken up by plants. This process is termed 'nitrogen fixing' and the bacteria are called 'nitrogen fixers'. Some nitrogen fixing bacteria live within the roots of land plants such as wattles and legumes or within the roots of aquatic plants, such as the fern *Azolla*, common in many of Victoria's waterbodies. Other forms of nitrogen fixing bacteria are found within soils and waterbodies, including cyanobacteria (often called 'blue-green algae').

In natural circumstances, nitrogen typically enters water bodies from the weathering of rocks (inorganic nitrogen) and the decomposition of plant and animal material (organic nitrogen) (Figure 4.3, p.22). Unlike phosphorus, which is readily adsorbed to soil and sediment particles, nitrogen compounds dissolved in water can be easily transported through groundwater to receiving waterbodies. Therefore, human inputs of nitrogen to the groundwater (e.g. through fertilisers, septic systems or animal waste, see Figure 4.4, p.23), are typically much more likely to reach waterbodies than human inputs of phosphorus (Although in some landscapes where the soil is very sandy, phosphorus can also be transported readily through the groundwater to surface waterbodies. This is because sand grains are more inert than other soil particles and therefore less able to adsorb nutrients. Also, very sandy soils are often more porous, leading to more rapid throughflow of groundwater).

Nitrogen is one of many nutrients required by plants and animals in freshwater systems. However, along with phosphorus it can be a limiting nutrient, with low concentrations restricting plant growth and high concentrations contributing to excessive growths of algae and other plants. Therefore, similar to phosphorus, the monitoring and management of nitrogen is important in the protection of waterbodies.

The most common forms of nitrogen found in waterbodies are:

- the oxides of nitrogen - nitrate ( $NO_3^-$ ) and nitrite ( $NO_2^-$ ), together often written as  $NO_x^-$ ;
- ammonia ( $NH_3$ )/ammonium ( $NH_4^+$ ); and
- organic nitrogen (particulate and dissolved) derived from the breakdown of plant and animal tissue within the water body.

Oxides of nitrogen and ammonia/ammonium are the most available forms of nitrogen for uptake by plants, although organic nitrogen can be broken down by bacteria and converted into a more readily available form. Ammonia, in the form of un-ionised ammonia ( $NH_3$ ) is toxic to aquatic life.

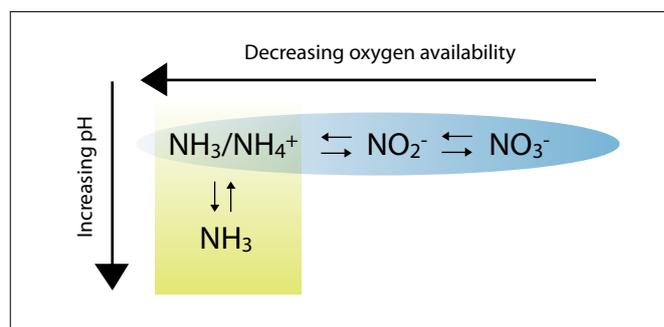
Laboratory measurement of nitrogen in water samples is undertaken through a variety of means which focus on different forms of nitrogen. The measurements of most interest to Waterwatch are:

- oxides of nitrogen ( $NO_x^-$ ) – typically measured using a colorimetric method;
- ammonia/ammonium ( $NH_3/NH_4^+$ ) – typically measured using an ammonia probe;
- Total Kjeldahl Nitrogen (TKN) – uses heat and acid to digest the sample and extract the nitrogen. This method loses the  $NO_x^-$  from the sample and therefore only measures the organic nitrogen (ON) and the  $NH_3/NH_4^+$ ; and
- Total nitrogen (TN) – usually derived by adding results of  $NO_x^-$  and TKN analyses.

Water quality reporting usually includes TN, and often  $NO_x^-$  and  $NH_3/NH_4^+$ . As a general rule, the following equations are useful in assessing and describing the various nitrogen forms and combinations:

$$\begin{aligned} NO_x^- &= NO_3^- + NO_2^- \\ TKN &= ON + NH_3/NH_4^+ \\ TN &= TKN + NO_x^- \end{aligned}$$

Nitrogen can be converted between forms, depending on the concentration of each form and also the environmental conditions within the river. For example, Figure 4.2 shows that a higher ratio of  $NO_3^-$  to  $NO_2^-$  is typically indicative of greater oxygen availability, whereas higher proportions of  $NH_3/NH_4^+$  are indicative of very low oxygen availability. Similarly, higher pH levels will tend to result in more  $NH_4^+$  being converted to  $NH_3$ .



**Figure 4.2** Forms of nitrogen in response to environmental conditions.



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### HOW IS IT MEASURED?

Water quality reporting usually includes measures of TN and often  $\text{NO}_x$  and  $\text{NH}_3/\text{NH}_4^+$ . Within Victoria, the SEPP (WoV) objectives for nitrogen use TN. Similar to TP, TN is likely to be an overestimate of the biologically available form of the nutrient in a water sample. However, biochemical processes such as nitrification and other conversions between the various forms, mean that measures of the total nitrogen give a reasonable indication of the amount ultimately available.

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

The different measures of nitrogen cannot be substituted. However, if a measure of  $\text{NO}_x$  was approaching or greater than the SEPP (WoV) objective for TN, this would be a strong indication of excessive nitrogen concentrations. If the concentration of  $\text{NH}_3/\text{NH}_4^+$  was approaching the TN objective, this would also be a strong indication of excessive nitrogen concentrations as well as organic wastes, a chemical spill and/or low oxygen conditions.

### WHY MONITOR NITROGEN?

Nitrogen is a key nutrient in freshwater systems. This means that increased concentrations of nitrogen provide increased opportunity for growth of algae and other plants. Nitrogen can act as a limiting nutrient if phosphorus concentrations are high. However, if both nitrogen and phosphorus concentrations are high, they can contribute to algal blooms and infestations of aquatic macrophytes. Excessive algal and macrophyte growths can lead to clogging of waterways, overnight 'oxygen troughs' and massive oxygen demand at the end of a bloom when the plant material is decaying (oxidising). These conditions result in the deaths of aquatic biota such as aquatic macroinvertebrates and fish. Ammonia ( $\text{NH}_3$ ) is also toxic to aquatic life.

### SOURCES

Natural sources of nitrogen in waterways include inorganic dissolved forms from weathered rocks, organic material from plants that have taken up inorganic nitrogen, organic material from animals (including wastes and decaying tissues), organic nitrogen that has been converted to nitrate by bacteria and nitrogen that has been fixed within the river (Figure 4.3). The source pathways are many and often overlap. For example, nitrogen contributed through the groundwater may have come from:

- mineral nitrates dissolved from rocks,
- gaseous  $\text{N}_2$  fixed by bacteria in the roots of wattles,
- organic nitrogen that has been converted to nitrate by other bacteria,
- organic nitrogen that has been converted to ammonia by other bacteria,
- dissolved organic nitrogen.

Human derived or accelerated inputs of nitrogen to waterways can include: organic nitrogen associated with eroded soil that is deposited as sediment;  $\text{NO}_x$  and  $\text{NH}_3/\text{NH}_4^+$  from fertiliser that has reached the groundwater; discharges from sewage treatment plants (mostly  $\text{NO}_x$  and  $\text{NH}_3/\text{NH}_4^+$ ); stormwater runoff (ON/TKN); discharges from intensive agriculture/dairying (ON,  $\text{NO}_x$  and  $\text{NH}_3/\text{NH}_4^+$ ); stock access to streams and poor land management (Figure 4.4).

### NATURAL VARIATIONS

Concentrations of nitrogen vary across the State and this has formed the basis of the nutrient regions defined within the SEPP (WoV). Nitrogen is usually present in higher concentrations than phosphorus in freshwater environments. In catchments where there is a high percent coverage of wattles (*Acacia* sp.) there are indications that high levels of nitrogen fixation are contributing to elevated nitrogen concentrations in the groundwaters, which are ultimately reflected in the waterbodies that receive the groundwaters. This is likely to occur in catchments where substantial wattle regrowth is occurring after disturbances such as bushfires or vegetation clearance.

Reduced flows caused by drought or climate change result in a smaller proportion of streamflow being derived from surface runoff and therefore, a greater proportion of streamflow being sourced from groundwater. In many areas of Victoria the groundwater has high concentrations of  $\text{NO}_x$ . As a consequence, substantial flow reductions are often accompanied by large increases in  $\text{NO}_x$  concentrations, with  $\text{NO}_x$  often constituting almost all the TN at a site.

Nitrogen concentrations can also vary over time in relation to seasonal phenomena and with episodic events. For example, higher flows (whether seasonal or episodic) are typically associated with increased inputs of suspended particulate matter, which carry attached TN. If storms follow bushfires within a catchment, extremely high measures of TN may be measured, associated with ash deposition and massive sediment inputs.

SEPP (WoV) objectives for TN range from 0.15 mg L<sup>-1</sup> (150 µg L<sup>-1</sup>) in the highlands, to 0.9 mg L<sup>-1</sup> (900 µg L<sup>-1</sup>) in lowland plains. Similar to phosphorus, concentrations of nitrogen typically increase from headwaters to lowlands.

Total nitrogen concentrations greater than 0.25 mg L<sup>-1</sup> (250 µg L<sup>-1</sup>) in upland rivers and streams are likely to contribute to excessive plant growth while in lowland reaches, concentrations greater than 1.2 mg L<sup>-1</sup> (1200 µg L<sup>-1</sup>) may contribute to algal blooms if light is high (turbidity low).

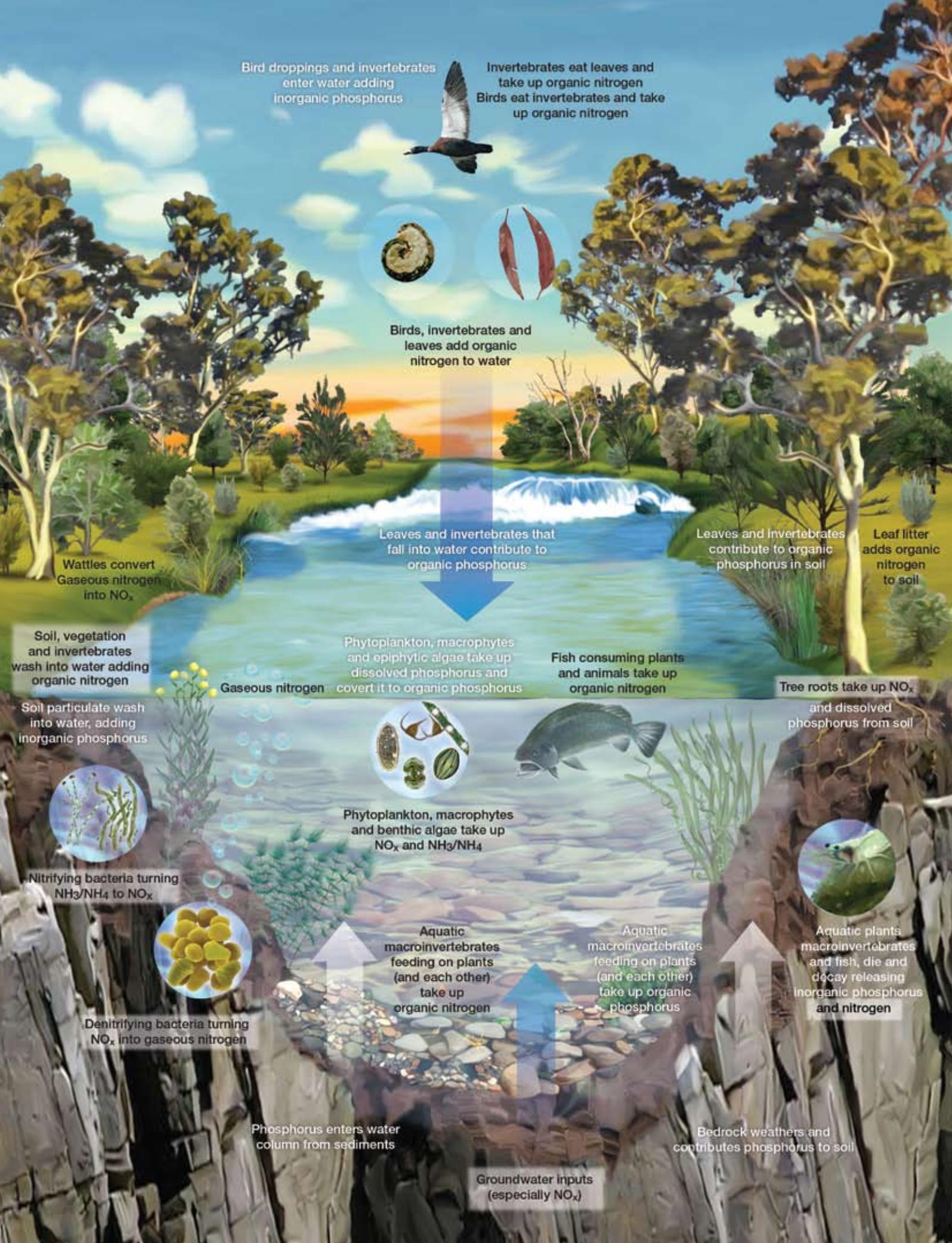


Figure 4.3 A phosphorus and nitrogen conceptual model for a healthy catchment.

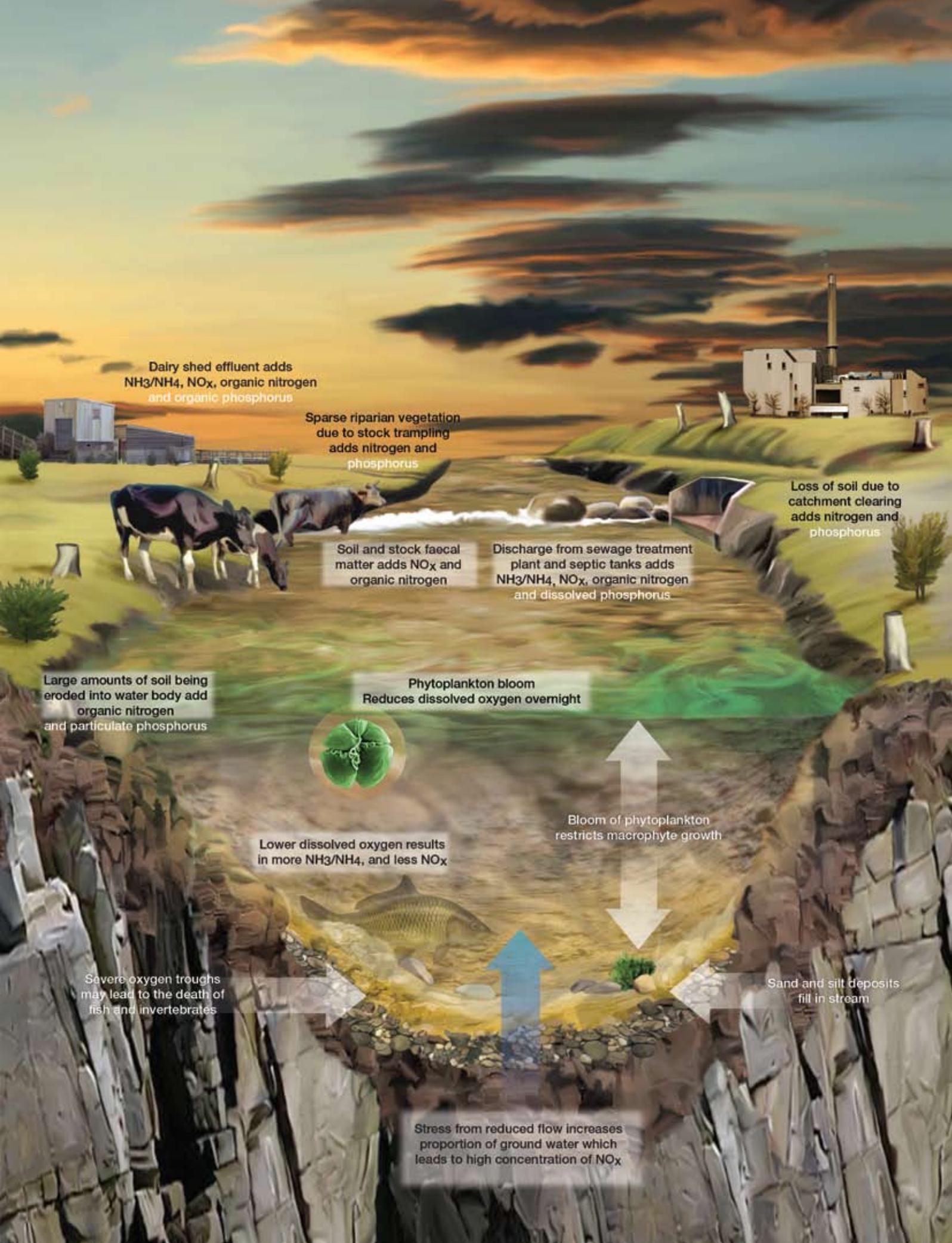


Figure 4.4 A nitrogen and phosphorus conceptual model for an unhealthy catchment.

### 4.3 Electrical conductivity

#### WHAT IS IT?

Electrical conductivity (EC) measures the flow of electricity in a solution. Conductivity in a solution increases as the amount of salts dissolved in the water increases. The relationship between conductivity and dissolved salt concentrations is used as a measure of salinity. The units of EC in water are usually expressed as micro Siemens per centimetre ( $\mu\text{S}/\text{cm}$ ).

#### WHY MONITOR ELECTRICAL CONDUCTIVITY?

While some dissolved salts are needed for metabolic processes by aquatic organisms, excessive amounts may be toxic. Freshwater aquatic organisms have different tolerances to salinity with a few, such as the emergent macrophyte *Phragmites sp.* and many of the micro-crustaceans, tolerating levels higher than seawater (around 53,000  $\mu\text{S}/\text{cm}$ ). Nonetheless, most freshwater aquatic organisms will not survive in high levels of salinity. Unfortunately, salinity levels in many places have been increasing substantially and have impacted on the condition of aquatic ecosystems.

#### HOW IS IT MEASURED?

The direct measure of salinity involves measuring the mass of dissolved salts in the water. This is done by first filtering a known volume of river water to remove the suspended matter. This filtrate is then dried and weighed, giving a mass per volume result. Units are usually mg/L. Because there is a relationship between EC and salinity, EC can be converted to salinity by multiplying the EC by the conversion factor of 0.64 (although some meters may be different so check the meter's manual).

An electrode is placed in the water and the flow of electricity is measured. Units are usually  $\mu\text{S}/\text{cm}$ , but some meters may read it as mS/cm and this should be converted to  $\mu\text{S}/\text{cm}$  for consistency (one milli Siemen is 1000 micro Siemens).

EC varies with temperature. The higher the temperature, the higher the EC for a given salt concentration. EC meters will measure either at ambient temperature or will standardise at 25°C. It is important to standardise to 25°C as SEPP (WoV) objectives are measured at 25°C. If data have been collected at ambient temperature they can be converted to 25°C using the formula:

$$K_{25} = \frac{K_t}{1+C(t-25)}$$

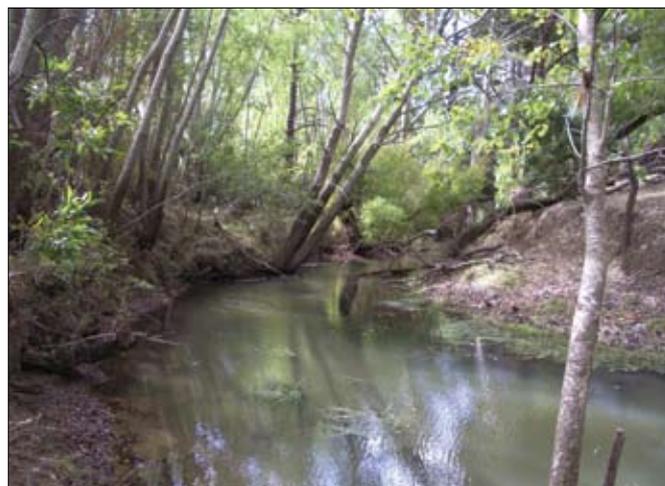
Where:

C (constant) = 0.0191

$K_{25}$  = EC at 25 °C

$K_t$  = EC at ambient

t = ambient temp in °C



Courtesy of Corangamite Waterwatch.

#### SOURCES

Salinity levels will vary due to the influences of geology, proximity to the coast, urban and agricultural runoff, sewage and industrial effluent and, most importantly, groundwater (Figure 4.6, p.33). Groundwater can have very high salt concentrations, and rising groundwater tables have elevated salinity levels in many rivers in Victoria.



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### NATURAL VARIATION

Salinity levels vary substantially across Victoria (Table 4.1). In general, levels below 1,500  $\mu\text{S}/\text{cm}$  are considered to have minimal short-term effect on aquatic biota. Toxicity studies suggest a step-wise impact on biota, with more and more taxa being removed from the aquatic community as salinity rises. Some very tolerant taxa are not affected until levels are above 30,000  $\mu\text{S}/\text{cm}$ .

In the alps, highlands and forested catchments salinity is unlikely to reach levels that would be toxic to aquatic life. On the other hand, after prolonged dry periods in western Victoria, salinity may reach critical levels even after a short period of no flow, resulting in substantial changes to the aquatic ecosystem. In these systems groundwater is the major contributor of water to rivers, lakes and wetlands and much of the groundwater is high in salt. There is a natural cycle of high salinity water during a dry period followed by lower levels when runoff contributes to flows. In these catchments water harvesting has reduced runoff so groundwater contributions are now higher and base level salinities are therefore higher. In addition, evaporation in pools concentrates salts to even higher levels, especially after long periods of zero inflows.



Courtesy of Goulburn Broken Waterwatch.

**Table 4.1** SEPP (WoV) objectives and typical levels in late summer and after a prolonged dry period ( $\mu\text{S}/\text{cm}$  @ 25°C).

Segment/region	SEPP (WoV) objective	Late summer levels	Extreme levels after prolonged dry period
Highlands (including the alps)	100	200	500
Forests	100	400	700
Cleared hills	500	1,000	3,000
Coastal plains	500 – 1,500	1,500	5,000
Murray plains	500	1,000 – 3,000	1,000 – 10,000
Western Victoria	1,500	2,000 – 10,000	6,000 – 40,000

## 4.4 pH

### WHAT IS IT?

The pH of water is a measure of its acidity or alkalinity. The actual component of the water being measured is its concentration of hydrogen ions ( $H^+$ ). In water, some of the  $H_2O$  molecules will dissociate into  $H^+$  ions (also called protons) and  $OH^-$  ions (hydroxide). These ions will be taken up differentially by other molecules through chemical and biochemical reactions. When there are more  $H^+$  ions than  $OH^-$  ions the water will have a pH below 7 and is said to be 'acidic'. Conversely, when there are more  $OH^-$  ions than  $H^+$  ions the water will have a pH greater than 7 and is said to be 'alkaline'. When the pH of a water body is 7, the  $H^+$  concentration is the same as the concentration of hydroxide ( $OH^-$ ) ions and the water is said to be 'neutral'. When the water is approximately neutral, it is called 'circum-neutral'.

The pH scale is logarithmic, which means that a change of two units (e.g. from 7 to 5) is ten times the change of one unit (e.g. from 7 to 6). In other words, lowering pH from 7 to 6 represents a ten-fold increase in  $H^+$  ions, whereas a reduction from 7 to 5 represents a hundred-fold increase, and a reduction from 7 to 4 represents a thousand-fold increase. As a consequence, the further the pH is from neutral (7), the greater the impact of any further movement from 7. Therefore, although changes in pH from 7 to 6 are generally not considered a problem, changes from 6 to 5 will usually require explanation or investigation as they represent substantially greater increases in  $H^+$  ions. Similarly, changes from 8 to 9 represent a substantially greater change in water quality conditions than changes from 7 to 8.

Note that although waters with high pH values are said to be 'alkaline', this is not the same as the water quality indicator 'alkalinity'. Alkalinity does not refer to pH, but instead refers to the ability of water to resist change in pH. The alkalinity of a river is a measure of its buffering capacity, or its capacity to neutralize acids, including acidic pollution. Waters with high pH but low alkalinity are likely to be unstable and could change quickly from high pH to low pH.

### WHY MONITOR pH?

The pH of a water body can have serious direct and indirect impacts on the organisms living within the water and on the potential uses of the water. Changes to pH may directly affect the physiological functioning of aquatic biota, including enzyme functioning and membrane processes. Low pH has been reported to have adverse effects on fish and aquatic macroinvertebrates, including physiological functioning, spawning failure and diminished egg hatching. Changes to pH also have indirect impacts. For example, increased pH raises toxicity of ammonia, while decreased pH can increase the toxicity of some metals. Low pH levels can also increase the solubility of toxic metals that would otherwise be bound to sediments.

### HOW IS IT MEASURED?

The best way to measure pH for water quality monitoring is *in situ*, with a pH probe and meter. In situ measurement is preferred over laboratory measurement, as the pH of a water sample can change once removed from the waterway.

A probe with a meter is preferred over pH paper (pH strips), as the probe and meter provide greater accuracy. However, in the absence of a pH probe and meter, use of pH paper is better than no measurement.

### INFLUENCES ON pH

The pH of a water body is naturally influenced by geology, soils, salinity, algal and other plant photosynthesis and respiration, and rainfall (Figure 4.5, p.31).

The geology of the catchment can influence pH through the bedrock (Figure 4.6, p.33). For example, granitic rocks typically contribute to a lowering of groundwater pH, whereas basaltic rocks and rocks with carbonates tend to increase pH. Soil characteristics also influence pH, with soils high in organic acids typically reducing the groundwater pH and soils high in salts typically increasing the pH of groundwater.

The photosynthesis and respiration of algae and other plants within a water body can have a marked effect on pH, through altering the concentration of dissolved carbon dioxide ( $CO_2$ ) in the water (Figure 4.6, p.33). Dissolved  $CO_2$  forms a weak acid (carbonic acid). During daylight, photosynthesis results in the uptake of  $CO_2$ , thereby reducing the concentration of  $CO_2$  in the water body and in turn reducing the acidity (therefore increasing pH). In contrast, during the night (when respiration is the dominant process), dissolved  $CO_2$  concentrations can increase markedly thereby creating more acidic conditions (low pH). In water bodies where there is high algal biomass, these diurnal (day-night) fluctuations can be clearly identified and are usually accompanied by significant diurnal fluctuations in dissolved oxygen.

Similarly, rain typically dissolves some atmospheric  $CO_2$  as it falls and consequently, rainfall often contributes to a minor reduction in the pH of water bodies. However, this reduction may be overridden by inputs of dissolved salts washed in from the catchment, which typically raises pH.



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Human-induced changes to pH in water bodies can include agricultural land practices (leading to soil acidification), waste discharges, and air pollution (Figure 4.6, p.33). Soil acidification typically occurs through leaching from the upper soil horizons, leaving an excess of  $H^+$  ions. Water flowing through the acidic soils enters the receiving water body with low pH.

Agricultural practices can also lead to increased nutrients, which increases algal growth and consequently leads to the greater diurnal fluctuation of pH as described previously.

Changes to the hydrology of rivers and wetlands can also lead to acidification. Sulphides naturally form in anaerobic (oxygen free) river and wetland sediments where sulphates from groundwater or seawater accumulate and where iron oxides and organic matter levels are high. Bacteria are responsible for the conversion of sulphate to sulphide in anaerobic conditions. Left covered with water, these sediments are stable and the sulphides remain bound in the sediments. However, if the water level drops due to drought or drainage, the sediments become exposed to oxygen and sulphuric acid is formed. When the sediment is re-wetted, acid can be mobilised from the sediments.

Discharges from factories, mine sites and other industrial locations can often contain liquids with high or low pH. Urban and industrial land uses should be investigated as potential causes to rapid or large changes to pH and for anomalous sites within a region.

Emissions from car exhausts and coal-burning power plants increase the concentrations of nitrogen oxides ( $NO_2$ ,  $NO_3$ ) and sulphur dioxide ( $SO_2$ ) in the air. These pollutants can react in the atmosphere to form nitric acid ( $HNO_3$ ) and sulphuric acid ( $H_2SO_4$ ). These acids can affect the pH of streams by combining with moisture in the air and falling to the earth as acid rain.



Courtesy of Goulburn Broken Waterwatch.

### NATURAL VARIATION

Most natural freshwaters within Victoria have a pH in the range 6.5 to 8.0. The more saline areas in western and north-western Victoria generally have higher pH. This is reflected in the SEPP(WoV) objectives for the State, which are:

- 6.4 (25<sup>th</sup> percentile) to 7.7 (75<sup>th</sup> percentile) for the eastern half of state (SEPP obj) plus the Grampians and Otways Ranges; and
- 6.5 (25<sup>th</sup> percentile) to 8.3 (75<sup>th</sup> percentile) for the western half of state.

At pH levels less than 6 and greater than 9 harmful effects may occur. At pH levels less than 5 and greater than 10 harmful effects are almost certain.

## 4.5 Turbidity

### WHAT IS IT?

Turbidity is a measure of the clarity of water. As suspended particulate matter including clay, silt, detritus and plankton in the water increases, the clarity decreases and the water takes on a muddy appearance. Turbidity does not measure the quantity of suspended matter in the water. This is measured as suspended particulate matter (SPM), also called suspended solids (SS). While turbidity is not a direct measure of SPM, they are highly correlated and turbidity can be used to indicate the likely effects of suspended matter.

### WHY MONITOR TURBIDITY?

Turbidity reduces the amount of light entering the water, which will reduce the growth of submerged aquatic plants including most phytoplankton. Cyanobacteria ('blue-green algae'), however, may be favoured as they can float to the surface to find light, ultimately covering the surface with a thick layer of cells reducing light almost completely. Lack of light also makes it difficult for predators like fish and birds to hunt successfully.

Turbid waters absorb more heat. Increasing water temperatures may affect plant growth, the behaviour and breeding of animals and if extreme levels are reached, kill biota.

Although not a direct measure of SPM, turbidity is indicative of SPM levels. High SPM levels interfere with the uptake of oxygen by fish and invertebrates and when particulate matter settles, causes sedimentation.

The greatest impact of sediment entering waterways is on habitat. Sediment will smother rocky bottoms, coat snags and fill deep pools, reducing the available habitat and affect the feeding and breeding of fish and aquatic invertebrates.

Nutrient and toxicants can bind to suspended particles. SPM is therefore important in the transport and fate of nutrients and toxicants in rivers.

### HOW IS IT MEASURED?

There are several ways turbidity can be measured but all relate to nephelometry, which is a measurement of the size and concentration of particles in water by analysis of light scattered by the water. The greater the scattering of light by suspended particles the greater the turbidity. The measurement unit for turbidity is the nephelometric turbidity unit (NTU).

Correlations between turbidity and SPM are difficult because differences in size, shape and composition of the suspended particles will affect reflective and absorbance characteristics and hence the scattering of light. Therefore, SPM and turbidity measures within a single site may show a reasonable correlation (as long as the sediment sources are consistent) but this correlation is unlikely to be transferrable to other sites.

Turbidity should be measured as soon as a sample is taken, as suspended matter may stick to the walls of the container or bind together through physical and chemical processes (e.g. temperature).

Turbidity tubes measure the absorbance of light rather than the scattering of light. While they will at times overestimate or underestimate turbidity and do not measure very low levels accurately, they are generally a good estimate of the true turbidity.

The Secchi disk has been used extensively in the past to measure water clarity, particularly in deep water environments such as lakes. Secchi disks are not recommended for monitoring turbidity as there are no related water quality guidelines.

### SOURCES OF TURBIDITY

Most of the sediment in rivers and streams comes from catchment and stream bank erosion (Figure 4.6, p.33). Sediment entering waterways is a natural process but human land use can result in excessive quantities entering waterways. Agriculture, forestry and housing developments can all lead to extensive soil disturbance, erosion and sediment runoff to rivers and streams. Unsealed roads can also contribute substantial quantities of sediment to waterways. Carp, an introduced pest fish species, can increase the mobilisation of sediment due to its habit of digging in stream sediments and dislodging macrophytes, resulting in unstable stream beds.

Other sources of sediment include sewage effluent discharges, industrial discharges, septic tank discharges and destabilisation of bed and banks after the removal of snags and macrophytes.



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### NATURAL VARIATION

Levels of turbidity in water will vary depending on the physical and chemical activities in the river. Typically, turbidity levels increase from headwaters to lowlands (Figure 3.9, p.17). The old geology and associated high levels of clays result in naturally higher levels of turbidity in our rivers and streams compared to those overseas. Extensive clearing has made Australian soils more prone to erosion, increasing sediment loads and turbidity.

Turbidity levels vary over time. High flows (whether seasonal or episodic) are typically associated with increased inputs of sediment. If storms follow bushfires, even higher sediment loads can be expected. SEPP (WoV) objectives for turbidity and typical levels in healthy and disturbed catchments are detailed in Table 4.2.



Courtesy of Goulburn Broken Waterwatch.

**Table 4.2** SEPP (WoV) objectives - typical levels in healthy waterbodies and levels that may result in ecosystem damage.

Segment/region	SEPP (WoV) objective (75th percentiles) (NTU)	Typical range in healthy waterbodies (NTU)	Level which may cause ecosystem damage (NTU)
Highlands (including the alps)	≤ 5	≤ 5 – 10	≥ 20
Forests	≤ 5	≤ 5 – 10	≥ 25
Cleared hills	≤ 10	≤ 10 – 20	≥ 100
Coastal plains	≤ 10	≤ 10 – 20	≥ 100
Murray plains	≤ 30	≤ 30 – 100	≥ 200
Western Victoria	≤ 10	≤ 10 – 20	≥ 100
South western Victoria	≤ 10	≤ 10 – 20	≥ 100

## 4.6 Dissolved oxygen

### WHAT IS IT?

Dissolved oxygen (DO) is a measure of the concentration of oxygen dissolved in water.

### WHY MONITOR DISSOLVED OXYGEN?

Oxygen is essential for respiration by all aquatic plants and animals. Without it they will die. Oxygen in water comes primarily from the atmosphere. Diffusion across the water-air interface transfers oxygen to the water and this is substantially increased by turbulent mixing of water with air. In a standing water body the transfer process is slow, whereas in a fast flowing, turbulent upland stream, oxygen uptake is considerably higher. Oxygen in water can also come from plants as it is produced during photosynthesis. The contribution of plants and in particular algae, is generally relatively small in a healthy river but may be substantial in highly eutrophic (nutrient enriched) waterbodies where plant productivity is high.

Oxygen is used by not only plants and animals but also bacteria and other micro-organisms. The breakdown or decay of organic matter by micro-organisms is an important process in the carbon and nutrient cycles of a river. As the amount of organic matter increases the amount of oxygen used also increases. This is called oxygen demand. If the demand exceeds the ability of the system to take up oxygen then levels may fall dramatically.

Organic matter often builds up on the bottom of a river where much of the breakdown by micro-organisms occurs, thereby consuming available oxygen. If oxygen levels at the sediment-water interface become low enough, this could result in the sediments releasing molecules that are bound to the individual sediment particles. Nutrients and toxicants are among the molecules that the sediment particles could release, potentially creating high nutrient or toxic conditions in the stream.

### HOW IS IT MEASURED?

There are two common methods of measuring oxygen in waters; the Winkler or iodometric method and electrometric methods.

The Winkler method is a titrimetric procedure based on the oxidising properties of oxygen. The Winkler method is the most accurate way of measuring oxygen concentrations in water, however, the water must be tested immediately after a sample has been taken as water can lose or gain oxygen very quickly due to mixing or a change in temperature. Adding a preservative can extend analysis by up to eight hours.

Electrometric methods use the principle that oxygen will generate a current on metal electrodes and this current is proportional to the concentration of molecular oxygen. The current is converted to oxygen concentration, usually in mg/L, and most meters can calculate percent saturation. Calibration of the meter is critical and correction for temperature and high salinity is essential. While not as accurate as the Winkler method, portable meters have the advantage of undertaking instantaneous readings, depth readings and can be deployed for continuous monitoring.

Dissolved oxygen can be expressed as either a concentration, usually milligrams of O<sub>2</sub> per litre of water (mg/L), or as percent saturation. At a given water temperature, salinity level, air pressure (altitude), and with sufficient mixing, oxygen will reach an equilibrium in water. That is, a stable concentration where oxygen entering and leaving the water is equal. This is called saturation and the water is said to contain 100% of the oxygen it should be able to hold.

Because of the temporal and spatial variability, single measurements may not provide the complete picture of the oxygen regime. Monthly sampling and an assessment against the SEPP (WoV) objective will provide a good assessment of condition. If the objective is not met then an investigation of spatial and temporal differences is needed to gain a better understanding. A more complete picture of the oxygen regime can be acquired through continuous diurnal monitoring, particularly during likely critical periods, such as during low flow. In deeper rivers and in pools depth profiles can be undertaken.

### SOURCES OF OXYGEN DEMAND

Major sources of oxygen demanding substances include:

- Sewage effluent discharges
- Industrial discharges
- Septics tank discharges
- Leaf litter from the floodplain, river banks and dry waterways
- Instream plant material (Macrophytes and algae)
- Blackwater events – low oxygen, organically rich waters entering a river from floodplain wetlands, backwaters and tributaries.

Where low oxygen concentrations are believed to be due to oxygen demand, the biochemical oxygen demand (BOD) or chemical oxygen demand (COD) of the river can be investigated. However, these measures have been developed primarily for sewage and industrial wastes which quickly use up oxygen in waters. Therefore, they may not be useful for assessing the demand from natural organic matter such as terrestrial leaves or aquatic plant material which break down much more slowly.



## 4 SPECIFIC INDICATORS

### NATURAL VARIATION

Concentrations of oxygen in water will vary depending on the physical, chemical and biochemical activities in the river. Under most natural conditions a water body will be at least 80% of saturation. Oxygen concentrations will vary over a 24 hour (diurnal) cycle, even in pristine waterbodies. Plant respiration at night will reduce oxygen levels over night while during the day, photosynthesis will produce oxygen and raise oxygen levels (Figures 4.5 and 4.6). In eutrophic conditions where there are blooms of algae or other aquatic plants, there are more plant cells respiring (which consumes oxygen), creating very low oxygen concentrations overnight. Conversely, the high number of plant cells photosynthesising during daylight hours can result in very high dissolved oxygen concentrations (called 'supersaturation'). Dissolved oxygen levels above 110% saturation are indicative of eutrophic conditions and levels of 130% or more are almost certainly due to blooms of algae or other aquatic plants.

Oxygen demanding substances will reduce oxygen levels, sometimes to very low levels. Often the demand originates from the sediments, where large quantities of organic matter accumulate and bacterial activity removes much of the oxygen from the bottom waters (Figure 4.6). If the demand is substantial then the de-oxygenation may reach the surface.

The process of de-oxygenation is a natural part of most lowland rivers and billabongs where organic matter accumulates after runoff. However, in these healthy waterbodies the period of low oxygen will be relatively short as the river quickly processes the organic matter. The biota are likely to be tolerant of these short periods of low oxygen. For example, most native fish in lowland rivers can tolerate levels down to 50% saturation (or around 5mg/L) for extended periods of time and short term levels even lower. However, complete de-oxygenation will kill most lowland aquatic organisms. Very low oxygen levels may also cause the formation of hydrogen sulphide (H<sub>2</sub>S), which is highly toxic to most native fish species.

Oxygen demanding substances can also originate from human sources such as ongoing discharges of sewage and industrial effluent, which may result in long periods of moderate to low oxygen levels, particularly during low flow periods in rivers and streams. Raw sewage and chemical spills can result in massive oxygen demand, although usually only for short periods of time.

In standing water bodies, primarily lakes but also large pools in rivers, stratification can occur where the bottom waters are cut off from the surface. This occurs due to either the warming of a surface layer of water or a saline intrusion into the bottom waters. The result is that the bottom waters are cut-off from oxygen from the surface. If there is an oxygen demand from the sediments then oxygen concentrations will decrease (Figure 4.5). If prolonged, conditions may become almost anoxic and will not support aquatic plants or animals. In addition, when the bottom waters turn over and mix with the surface, oxygen levels in the surface may also drop substantially.

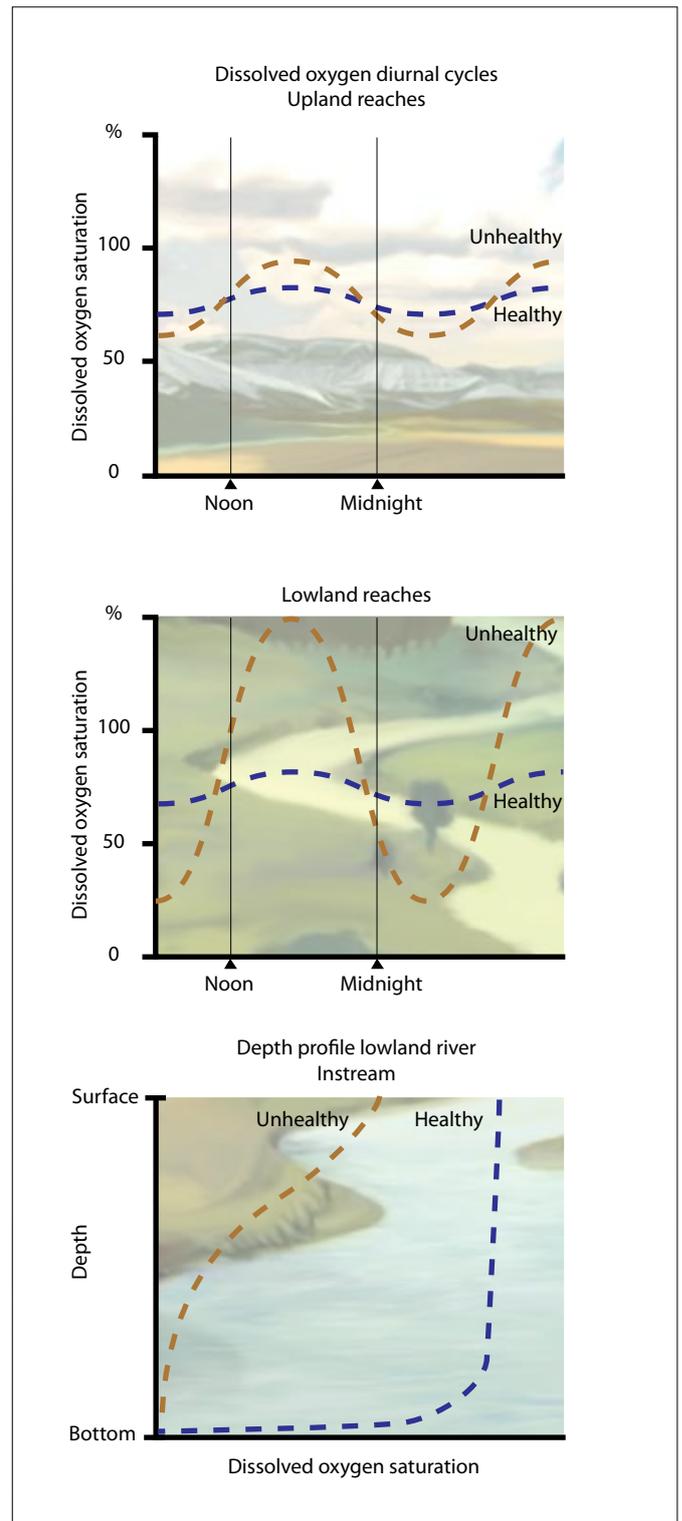


Figure 4.5 Dissolved oxygen diurnal cycles and depth profiles.

Oxygen in excess of 100% saturation is called supersaturation. As with low oxygen saturation, supersaturation may be harmful to aquatic life. For example, fish may suffer 'gas bubble disease' where bubbles of oxygen can form in the blood. Mountain streams and waterfalls may naturally have oxygen levels above 100% saturation, but generally not above 110% saturation.

Most aquatic species will tolerate some variation in dissolved oxygen, particularly lowland species where variation is greatest. More is known about fish species tolerances than invertebrates and very little known about plant species tolerances. SEPP (WoV) objectives for dissolved oxygen (Table 4.3) reflect not only regional differences but also the health of aquatic biota.

**Table 4.3** SEPP (WoV) objectives - typical levels in healthy waterbodies and levels that may result in ecosystem damage.

Segment/region	SEPP (WoV) objective (% saturation*)	Typical range in healthy waterbodies (% saturation**)	Level which may cause ecosystem damage (% saturation**)
Highlands (including the alps)	≥ 95 ≤ 110	80 – 110	≤ 60
Forests	≥ 90 ≤ 110	70 – 110	≤ 60
Cleared hills	≥ 85 ≤ 110	60 – 110	≤ 60
Coastal plains	≥ 85 ≤ 110	60 – 110	≤ 50
Murray plains	≥ 85 ≤ 110	50 – 110	≤ 40
Western Victoria	≥ 80 ≤ 110	50 – 110	≤ 40
South western Victoria	≥ 85 ≤ 110	60 – 110	≤ 40

\* SEPP WoV Objective is both a 25th percentile of annual data and a maximum level, that is from any reading

\*\* From any single reading

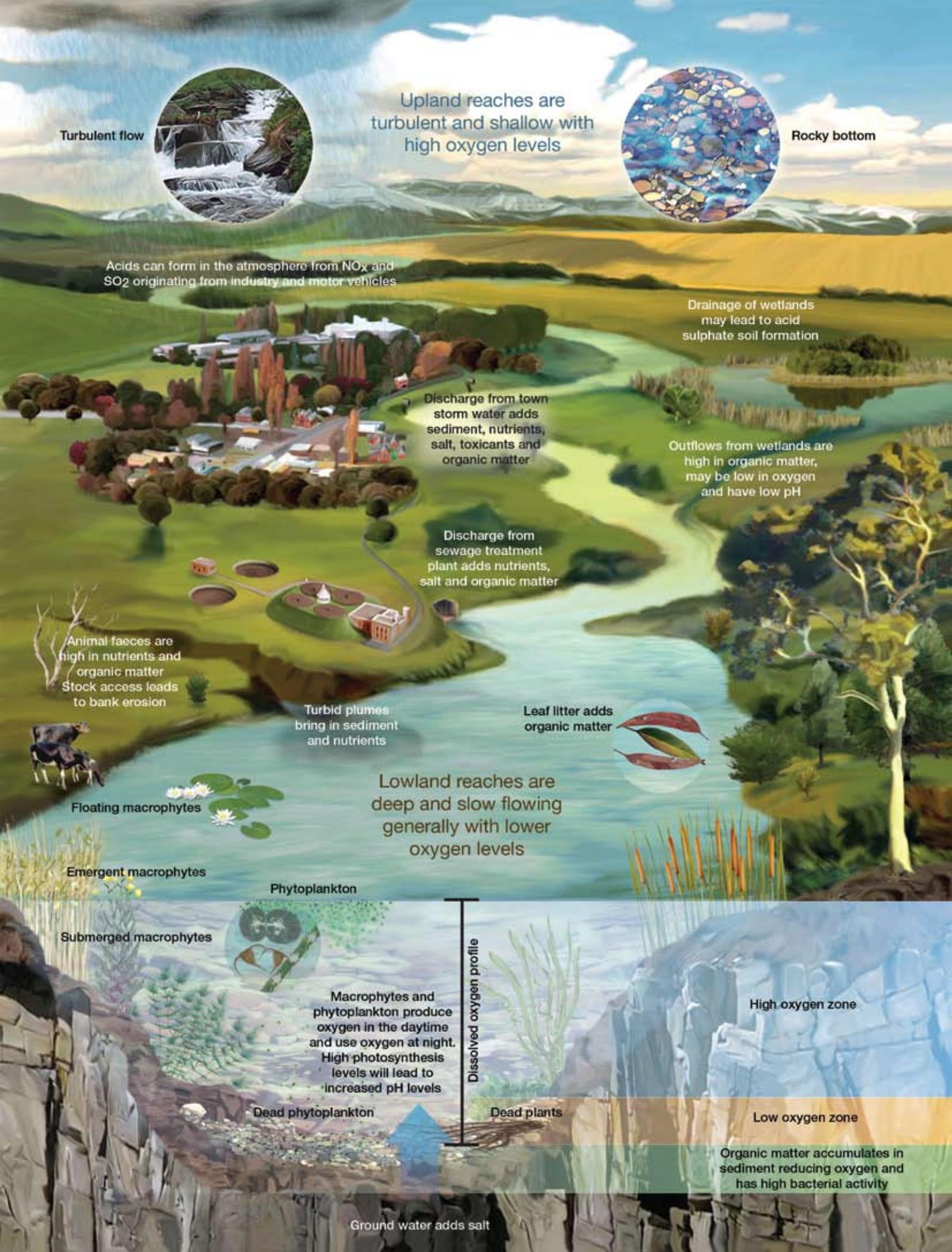


Figure 4.6 Salinity, pH, turbidity and dissolved oxygen conceptual model.

## 4.7 Temperature

### WHAT IS IT?

Temperature is a measure of the amount of heat in the water, that is, how hot or cold a river is. It is measured as degrees Celsius, (°C).

### WHY MEASURE IT?

The temperature of water influences and regulates many chemical, physical and biological processes. When water temperatures are very low (less than 4°C) many biological processes slow down, for example, bacterial breakdown of organic matter. As water warms up processes generally speed up, including the metabolic rates of plants and animals. However, at very high temperatures metabolic rate drops off and at extreme levels plants and animals may die. Plants and animals usually have a temperature range that they best grow, feed and reproduce in. When temperatures move outside the range of one species it is likely to be replaced by a species that can tolerate the new temperature range. Climate change is likely to increase water temperature causing many species which cannot tolerate the higher temperature to be removed from an ecosystem. Importantly, temperature regulates oxygen solubility in water and as temperature increases solubility decreases (section 4.6).

### HOW IS IT MEASURED?

Temperature is measured with either a glass thermometer or a thermistor (digital thermometer).

### SOURCES

Water absorbs heat from the air, from sunlight falling directly on the water or from the surface or groundwater water inflows. Water may also heat up as a result of bacterial breakdown of organic matter, although usually by only a very small amount.

The greatest human induced changes arise from hot water discharges from industrial and power generation and cold water discharges from the bottom waters (hypolimnion) of large dams. The removal of shading and increased turbidity arising from human activities will also increase water temperatures due to the increased heat absorption by the water.

### NATURAL VARIATION

While water temperatures can vary from 0°C to 100°C (frozen to boiling) in rivers and streams, temperatures are more likely to be between 2°C and 35°C. Alpine streams will be at the low end of this scale whereas small pools in ephemeral streams will be at the top end of the scale and may even exceed 35°C. Temperatures will vary during the day and by seasons, just as air temperatures vary. The clarity and colour of water will affect temperature as darker, more turbulent waters adsorb more sunlight and therefore heat up more. Due to the substantial temporal and spatial variation in water temperatures there are no specific objectives or guidelines. In general, substantial deviations from background levels due to hot or cold water discharges are likely to affect the behaviour or survival of native biota. Smaller deviations due to atmospheric warming, decreased flow or increased turbidity are likely to result in the removal of temperature sensitive species and changes in the structure of the ecosystem.



Courtesy of West Gippsland Waterwatch.



## 4 SPECIFIC INDICATORS

### 4.8 *E. coli*

#### WHAT IS IT?

*Escherichia coli* (*E. coli*) is one of a group of coliforms called faecal coliform bacteria which is natural bacteria found in the gut of warm blooded animals. There are both pathogenic and non-pathogenic strains of *E. coli*. A non-pathogenic strain of *E. coli* is used as an indicator of human and animal faecal contamination in waterbodies. The presence of faecal contamination is indicated by the number of *E. coli* cells (measured as colonies) per 100 mL.

#### WHY MEASURE IT?

Faecal contamination of water bodies may lead to potential human health risks from disease-causing pathogens. Pathogens include bacteria such as *Vibrio cholerae* and *Salmonella*, viruses such as hepatitis A and parasites such as *Giardia* and *Cryptosporidium*. *E. coli* is an indicator of the potential presence of these and other human pathogens.

#### HOW IS IT MEASURED?

*E. coli* has traditionally been used as an indicator to assess potential faecal contamination of waterways. It is not a measure of the abundance or even presence of human pathogens. Methods for determining *E. coli* counts require the plating and culturing of the bacteria. Sterile conditions are needed or contamination of the plates will occur. To measure, a water sample is applied to an *E. coli* specific nutrient rich agar gel in a petri dish which is then placed into an incubator for a period of time (usually more than 24 hours). After this time the colonies of bacteria are counted.

#### SOURCES

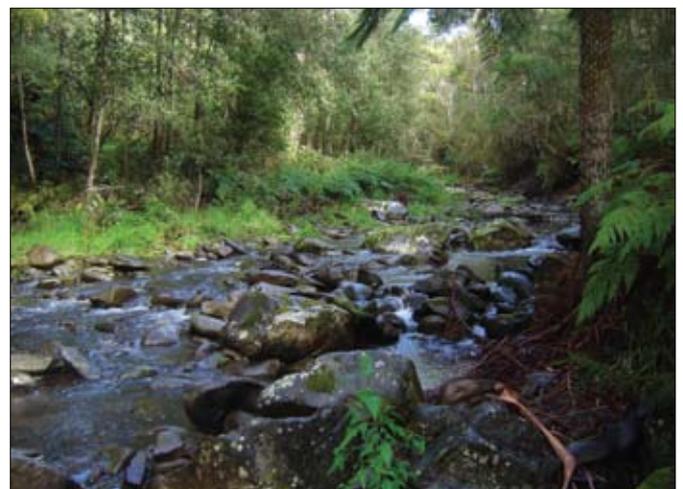
Potential sources of human faecal contamination include:

- Sewage overflows
- Poorly treated sewage
- Leaking sewerage systems
- Illegal sewerage connections to stormwater
- Septic tanks
- Untreated sullage or grey water discharges
- Runoff from contaminated areas

#### NATURAL VARIATION

*E. coli* do not survive in water and will die off. Persistence will depend on factors including exposure to UV light, grazing by microorganisms, turbidity and water temperature. Unfortunately, the die off of *E. coli* is not related to the die off of human pathogens, which may live much longer than *E. coli*. In near pristine catchments, *E. coli* counts may be high due to runoff of native animal faecal material.

*E. coli* counts should be less than 200 cells per 100ml for primary contact such as swimming (SEPP (WoV)). In drinking water there should be no faecal contamination and *E. coli* should not be detected in a sample of drinking water (see the *Australian Drinking Water Guidelines* from the National Health and Medical Research Council, 2008).



Courtesy of Corangamite Waterwatch.