

WATER QUALITY TEACHER'S NOTES

Scientific testing for water quality

Various government departments and other groups regularly monitor the health of the waterways in WA. These include the Department of Water, Department of Environment and Conservation, Water Corporation, Swan River Trust, and many regional catchment councils and local catchment groups. Schools can also monitor water quality through the Ribbons of Blue program. All water quality data is stored in, and freely available from the Department of Water's Water information (WIN) data base.

Until recently in humanity's history, pollution has been primarily a local problem. The industrialization of society, the introduction of motorized vehicles and the explosion of the human population however, have caused an exponential growth in the production of goods and services. A tremendous growth of waste by-products has accompanied this growth. The discharge of industrial and domestic wastes into the environment has a number of serious effects on the quality of air, water and soil.

An environmental biologist should not consider the air, water and soil pollution as separate issues because, for example, pollutants in the soil might be leached into surface or ground water, or air borne contaminants might dissolve in surface water. Water quality is therefore an excellent indicator of the overall health of the environment.

All of the following water quality tests will help us understand various aspects of the processes affecting the aquatic environment. Taken together, and compared over time, these will indicate how a given body of water is coping with the human impacts upon it and whether its health is stable, deteriorating or improving.

The Australian Government has developed a National Water Quality Management Strategy which includes the Australian and New Zealand Guidelines for Fresh and Marine Water Quality, 2000 (known as the ANZECC Guidelines) to improve the management of fresh and marine water quality. In order to protect the ecosystem health of a waterbody, the guidelines set 'trigger values' for substances that might impair water quality. If these values are exceeded they may be used to trigger

further investigation or initiate a management response. These trigger values are set for different regions around Australia for six types of aquatic ecosystems, namely:

- upland rivers (over 150 metres in altitude);
- lowland rivers; freshwater lakes and reservoirs;
- wetlands; and
- estuaries and marine (offshore and inshore).

Trigger values for south-western Australia are included in these notes for each water quality variable.

School groups wishing to undertake water quality monitoring and who require assistance should contact the Ribbons of Blue State coordinator (08) 6467 5127 for advice, information and loan of equipment.

Much of the information in these notes comes from the Waterwatch Australia National Technical Manual; Module 4 Physical and Chemical Parameters 2002, unless otherwise noted.

The basic tests for water quality

1 Physical measurements

1.1 Water temperature

Many of the physical, biological and chemical characteristics of a waterway are directly affected by temperature:

- Warm waters are more susceptible to eutrophication (a build up of nutrients and possible algal blooms), because photosynthesis and bacterial decomposition both work faster at higher temperatures.
- Oxygen is less soluble, and salt is more soluble in warmer water, which will affect aquatic life (dissolved oxygen is essential for aquatic life).

- Aquatic species have evolved to live in specific water temperatures and changes can affect their metabolic rate and susceptibility to toxins, parasites and diseases. With extreme temperature change, many organisms will die.
- Changes in long-term temperature average may cause differences in species that are present in the ecosystem.

Water temperature varies in response to:

- air temperature
- exposure to sunlight and the amount of shade
- turbidity of the water, which is often the result of erosion in the catchment
- groundwater in-flows into the waterbody
- discharge of warm, or cold, water from industry and dams
- vegetation, and
- type, depth and flow of waterbody.

Small upland streams have a more consistent temperature profile throughout their depth (i.e. are not stratified) than do large rivers, due to the churning and mixing of the water. In slow moving deep rivers, the non-turbulent water does not mix well, the temperature can vary across the river and from the top to the bottom of the water column. The large volume of water in large streams also prevents rapid changes in temperature, so, in a deep river, temperature varies throughout the depth due to the stratification of the layers, but water temperature will not change as rapidly as in a small stream, due to the volume of water.

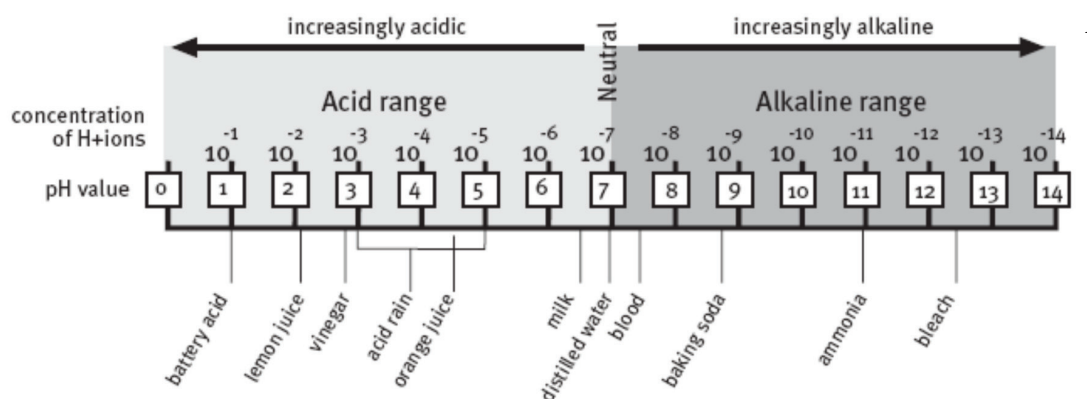
Interpreting Test Results

Aquatic organisms can experience stress where a temperature change of $\pm 2^{\circ}\text{C}$ occurs in a 24 hour period. Interpreting temperature readings requires information about the natural range of temperatures at that site. This can be from a series of measurements at that site over time, or by comparing to other data collected at that site (data for a range of sites is available through the Department of Water's WIN database).

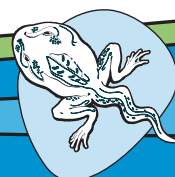
1.2 pH

pH is a measure of the activity (concentration) of hydrogen ions (H^+) in the water and indicates how acidic or alkaline the sample is. pH is measured on a scale of 1-14 with a pH of 7.0 being neutral. Solutions with a pH of 7.0 to 14.0 are basic (alkaline) while solutions with a reading of less than 7.0 are acidic. (The pH is the negative logarithm of H^+ , so a pH of 7.0 is H^+ concentration = 10^{-7} mole/L and pH 14 is H^+ concentration = 10^{-14} mole/L. Because pH is measured on a logarithmic scale, change from say 8 to 9 is equal to a ten fold decrease in H^+ concentration; an additional rise in pH to 10 is a 100 fold decrease. Thus a pH of 10 is 100 times more alkaline than a pH of 8.

All animals and plants are adapted to specific pH ranges, generally between 6.5 and 8.2. Changes in pH also affect the solubility of chemical species. For example most metals are more soluble in lower pH water.



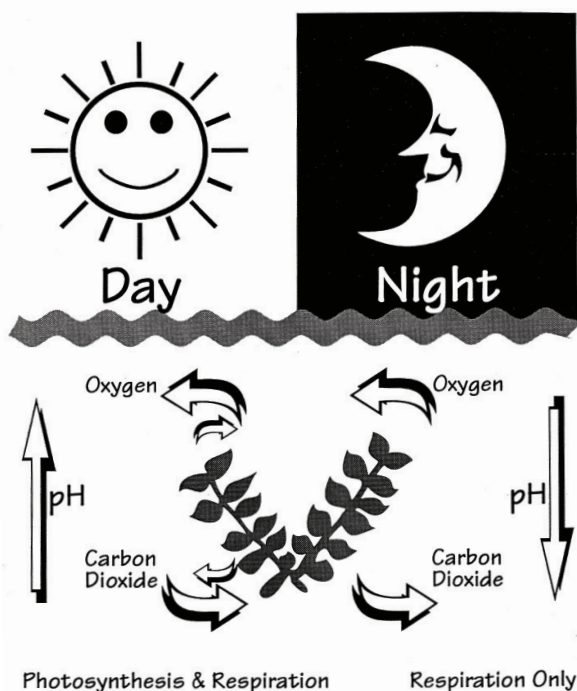
¹ Waterwatch Australia National Technical Manual: Module 4



pH can be affected by:

- The geology and soils in the area - water running through limestone will have a higher pH than water running through peaty soils.
- Salt content. Increased salinity causes an increase in pH.
- Discharges of industrial waste, including the burning of fossil fuels by cars and industry.
- Rainfall; as it is slightly acidic due to the dissolution of atmospheric carbon dioxide forming carbonic acid ($\text{H}_2\text{O} + \text{CO}_2 = \text{H}_2\text{CO}_3$)
- Disturbance of acid sulfate soils.
- Photosynthetic activity (i.e. the amount of plant growth) - when dissolved carbon dioxide is removed from the water by plants during photosynthesis, the pH of the water is increased. When an algal bloom occurs, pH and dissolved oxygen values are highest mid afternoon because plants are removing carbon dioxide and releasing oxygen. See diagram below.

Aquatic Plant Photosynthesis & Respiration ²



Interpreting test results ³

Normal	May be polluted	Pollution problem
5.0–7.0 no limestone present	8.5–9.0 or 4.0–5.0	<4 or >9
7.0–8.5 limestone		

ANZECC pH trigger values for south-western Australia ⁴

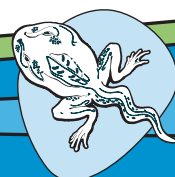
Ecosystem type	pH Lower limit – Upper limit
Upland river >150m altitude	6.5–8.0
Lowland river <150m altitude	6.5–8.0
Freshwater lakes and reservoirs	6.5–8.0
Wetlands	7.0–8.5
Estuaries	7.5–8.5

Note: For ANZECC Guidelines wetlands are shallow waterbodies, often with light penetration to the bed, while lakes are far deeper.

² Diagram from the Pondwater Tour. La Motte.

³ Source: Ribbons of Blue 'Environmental Awareness to Action'

⁴ Australian and New Zealand Guidelines for Fresh and Marine Water Quality, 2000. p 3.3-14



1.3 Electrical Conductivity/Salinity

Salty water conducts electricity more readily than fresh water, therefore electrical conductivity is routinely used to measure salinity. Salty water contains the following ions (charged atoms) chloride, sulfate, carbonate, sodium, magnesium, calcium and potassium.

The basic unit of measurement of electrical conductivity (EC) is microSiemens per centimeter ($\mu\text{S}/\text{cm}$), sometimes called EC units (many instruments measure in milliSiemens per centimeter, mS/cm , which can easily be converted to $\mu\text{S}/\text{cm}$ by dividing by 1,000). Water salinity is expressed as ppt (parts per thousand), per mille (‰), practical salinity units or total dissolved solids (or TDS) in milligrams per litre (mg/L). The sample's EC can be converted to TDS or TDS or may be determined directly through evaporation of a known volume of water and weighing the residual salt.

Salinity affects:

- all life forms: while an appropriate concentration of salts is vital for aquatic plants and animals, water salinity that is outside the normal range will cause stress or even death (for example osmotic stress in fish)
- the availability of nutrients to plant roots.

Salinity is affected by:




- the geology and soils of the catchment. Some groundwaters contain high concentrations of salt rendering the water undrinkable
- the rate of flow in a waterway: Salinity is usually lowest during high flows and increases during low flows
- over-clearing of native vegetation in the catchment. Clearing deep rooted perennial vegetation leads to the water table rising and bringing with it dissolved salt that had previously accumulated in the soil.

Other determining factors are:

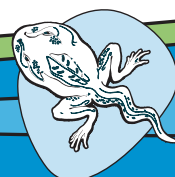
- evaporation and dilution (brackish waters may become saline through evaporation of the water)
- temperature
- runoff
- groundwater inflow.

Interpreting test results

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Electrical conductivity $\mu\text{S}/\text{cm}$		
Fresh	Brackish Moderate/very	Salty
0-800	800-2500 2500-5000	>5000
		

⁵ Source: Ribbons of Blue 'Environmental Awareness to Action'



ANZECC Electrical Conductivity trigger values for south-western Australia

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Ecosystem type	pH Lower limit – Upper limit
Upland river >150m altitude	120-300
Lowland river <150m altitude	120-300
Freshwater lakes and reservoirs	300-1,500
Wetlands	300-1,500
Estuaries	Not specified

Note: For ANZECC Guidelines wetlands are shallow waterbodies, often with light penetration to the bed, while lakes are far deeper.

1.4 Turbidity

Turbidity is the muddiness or opaqueness of water due to suspended particles in the water causing a reduction in the transmission of light⁷. In general, the more material that is suspended in the water, the greater is the water's turbidity and the lower its clarity. Suspended material can be particles of clay, silt, sand, algae, plankton, micro-organisms and other substances. Turbidity affects how far light can penetrate into the water. It is not related to water colour: tannin rich waters that flow through peaty areas are highly coloured but usually clear, with very low turbidity. Increased turbidity can indicate the presence of sediment that has run off from construction, agricultural practices, agricultural practices, logging or industrial discharges or discharge from dredging operations.

Turbidity is an important measure for water quality for several reasons:

- Suspended particles absorb heat, so water temperature rises faster in turbid water, which means turbid water can be more susceptible to changes in dissolved oxygen than clear water. Oxygen diffuses to the atmosphere in warmer water.
- If penetration of light into the water is restricted, photosynthesis of green plants in the water is also restricted. This means less food and oxygen is available for aquatic animals.
- Suspended silt particles eventually settle into the spaces between rocks and gravel on the bed of a waterbody and decrease the amount of available habitat for aquatic animals.

⁶ Australian and New Zealand Guidelines for Fresh and Marine Water Quality, 2000. p 3.3-14

⁷ (Source: Water facts 1, Water words, Water and Rivers Commission 1998)

⁸ No References

⁹ Australian and New Zealand Guidelines for Fresh and Marine Water Quality, 2000. p 3.3-14

- Fine particles suspended in the water carry harmful bacteria and attached contaminants, such as excess nutrients and toxic materials.

Turbidity is affected by:

- rainfall and catchment runoff
- catchment soil erosion
- bed and bank erosion
- bed disturbance, e.g. by introduced fish species such as carp
- waste discharge
- stormwater discharge⁸
- excessive algal growth
- riparian vegetation
- flow
- waterway type, and
- soil types.

Regular turbidity monitoring may detect changes to erosion patterns in the catchment over time. Event monitoring (before, during, and immediately after rain) above and below suspected sources of sediment can indicate the extent of a particular runoff problem.

Turbidity is a relative measure and is usually expressed as nephelometric turbidity units (NTU – Nephos is the Greek word for cloudy). Turbidity is easily measured with a turbidity tube: a long thin plastic tube with a scale on the side. Alternatively, turbidity may be estimated from Secchi depth determination.

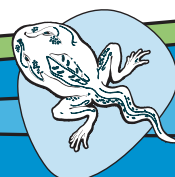
ANZECC Turbidity trigger values for south-western Australia

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Ecosystem type	pH Lower limit – Upper limit
Upland river >150m altitude	10-20
Lowland river <150m altitude	10-20
Freshwater lakes and reservoirs	10-100
Wetlands	10-100
Estuaries	1-2

Note: For ANZECC Guidelines wetlands are shallow waterbodies, often with light penetration to the bed, while lakes are far deeper.

* Turbidity is not a very useful indicator in estuarine waters, a more appropriate measure for WA is light attenuation coefficient (ANZECC Guidelines).



1.5 Dissolved Oxygen (DO)

Dissolved oxygen is a measure of the quantity of oxygen dissolved in water (and has nothing to do with the oxygen atoms within the water molecules). Oxygen is essential for all forms of life. Aquatic plants, animals and bacteria need it for respiration (getting energy from food), as well as for some chemical reactions.

The concentration of dissolved oxygen is an important indicator of the health of the aquatic ecosystem. Persistently low dissolved oxygen will harm most aquatic life.

In some circumstances, water can contain too much oxygen and is said to be supersaturated with oxygen. This can be dangerous for fish. Supersaturated conditions occur in highly turbulent waters in turbines and at spillways and waterfalls, because of aeration, and also on sunny days in waters experiencing algal blooms or with many aquatic plants, because of photosynthesis. When the fish swim out into water that has less dissolved oxygen, bubbles of oxygen may quickly form in their blood, disrupting the circulatory system.

Factors affecting dissolved oxygen

The atmosphere is the major source of dissolved oxygen in water; production through photosynthesis by aquatic plants, including algae, is another. The speed at which oxygen from the air enters and mixes through a waterbody depends on the amount of agitation at the water surface, the depth of the waterbody and the rate at which it mixes itself. As water temperature rises, oxygen diffuses out of the water into the atmosphere.

Shallow flowing waterways usually have high dissolved oxygen concentrations. In still waters, such as lakes, dissolved oxygen concentrations often vary from the surface to the bottom, with little dissolved oxygen in the deep poorly mixed layers.

Warm or saline water holds less dissolved oxygen than cold water or freshwater.

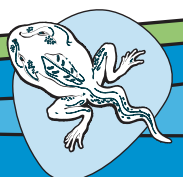
Deep muddy lowland rivers, which contain more organic matter than upland streams, are likely to have lower dissolved oxygen than upland streams because bacteria are using the oxygen to break down the organic matter. Likewise, dissolved oxygen is usually lower than normal after storms have washed organic materials into the waterbody.

Aquatic plants photosynthesize during daylight and increase dissolved oxygen concentrations locally. Conversely, plants respire at night consuming oxygen and thereby reducing the DO.

In summary, dissolved oxygen concentrations are affected by:

- water temperature
- photosynthesis by aquatic plants
- respiration by aquatic plants and animals
- breakdown of organic materials in the water
- water movement and mixing
- flow (discharge)
- salinity
- altitude
- depth
- daily and seasonal cycles
- presence of nutrients
- chemicals in the water.

Oxygen concentrations are expressed as milligrams per litre (mg/L), but percentage saturation allows direct comparison between results from sites with different salinity and temperature. Warmer water, even if it is 100% saturated, will have less oxygen dissolved in it than cooler water at the same percentage of saturation, and fresh water will have a higher DO than salty water at the same temperature. For example, fresh water saturated with oxygen contains 10.1 mg/L dissolved oxygen at 15°C and 8.2mg/L at 25°C. Salty water with an EC = 10,000µS/cm (salinity = 5.6ppt) contains 9.7mg/L at 15°C and 8.0mg/L at 25°C.






If a waterbody has consistently high DO, it is usually considered healthy because it is stable and able to support a diversity of organisms. Sudden or gradual reduction in DO levels can change the types and numbers of organisms present in the waterbody. Usually, this drop in oxygen will reduce the number of pollution sensitive organisms such as mayflies and stoneflies as well as larger animals such as gilgies and fish.

A standard measure of the water quality is the biochemical oxygen demand (B.O.D.). This is a chemical procedure for determining the uptake rate of dissolved oxygen by the biological organisms in a body of water. The oxygen levels in water are usually reduced by bacteria which consume oxygen to break down organic matter such as sewage, agricultural run-off, industrial discharge or natural organic material in the water such as dead plants or animals. Aerobic bacteria use oxygen to convert dead organic matter into energy, water and carbon dioxide. If the oxygen levels drop to zero, anaerobic bacteria take over and convert the organic matter into energy, methane and hydrogen sulfide. The 'rotten egg' smell experienced at some wetlands is due to anaerobic respiration.

In environmental chemistry, the chemical oxygen demand (COD) test is commonly used to indirectly measure the amount of organic compounds in water. Most applications of COD determine the amount of organic pollutants found in surface water (e.g. lakes and rivers), making COD a useful measure of water quality. It is expressed in milligrams per liter (mg/L),

Interpreting test results

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Dissolved Oxygen % saturation		
Normal 80-120	Some Pollution 120-135 OR 55-80	High Pollution >135 OR >55
		

ANZECC Dissolved oxygen (DO) Trigger Values for south-western Australia

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Ecosystem type	DO % saturation Lower limit - Upper limit
Upland river >150m altitude	90-na
Lowland river <150m altitude	80-120
Freshwater lakes and reservoirs	90-no data
Wetlands	90-120
Estuaries	90-110

Note: For ANZECC Guidelines wetlands are shallow waterbodies, often with light penetration to the bed, while lakes are far deeper.

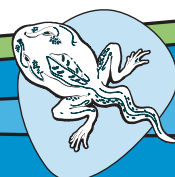
2. Nutrients

Nutrients are minerals dissolved in water. The nutrients that most commonly cause problems in Western Australian waterways are the various species of nitrogen and phosphorus. Total nutrient levels include the inorganic forms of these plus any bound in organic molecules. (Source: Water facts 1, Water words, Water and Rivers Commission 1998). For nitrogen these include the inorganic forms (nitrate, nitrite and ammonia) as well as organic nitrogen, all of which may be converted from one form to another through the processes described in the nitrogen cycle (see the diagram below). Phosphorus occurs in natural waters almost exclusively as phosphates, of which orthophosphate is the major form.

High levels of nitrate, ammonia and/or phosphate can lead to excessive algal growth (algal blooms). This can only occur if all other factors for growth are also present at high levels.

¹⁰ Source: Ribbons of Blue 'Environmental Awareness to Action'

¹¹ Australian and New Zealand Guidelines for Fresh and Marine Water Quality, 2000. p 3.3-14



Excessive algal growth is damaging to waterways health as it:

- consumes oxygen at night (through respiration) that is required by other organisms
- depletes the water of oxygen as the algae dies and decays: the micro-organisms which decay the algal mass consume oxygen through this process
- causes noxious odours as it decays and may emit toxic chemicals.

2.1 Nitrates

Nitrogen (chemical symbol N) is an element that is essential for all forms of life. It is also the most abundant element in the atmosphere as gaseous nitrogen (i.e. N₂ gas). Few living things can use gaseous nitrogen directly, but most depend on compounds of nitrogen.

Nitrogen in the water occurs in three main forms:

- Nitrates (NO₃⁻)
- Ammonia (NH₃)
- Organic Nitrogen

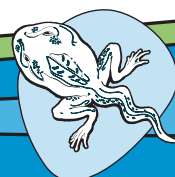
Nitrogen is continually recycled by plants and animals, and is usually present in freshwaters at higher concentrations than phosphorus. Because both nutrients are required for plant growth, phosphorus is therefore considered to be the limiting factor in freshwater. In saltwater ecosystems, however, nitrogen is much less abundant, and it becomes the nutrient that limits growth.

Nitrates and ammonia are the forms which are immediately available for plant growth. Organic nitrogen can be converted to either nitrates or ammonia by the decay of animal and plant material.

The factors affecting nitrate concentrations in water are:

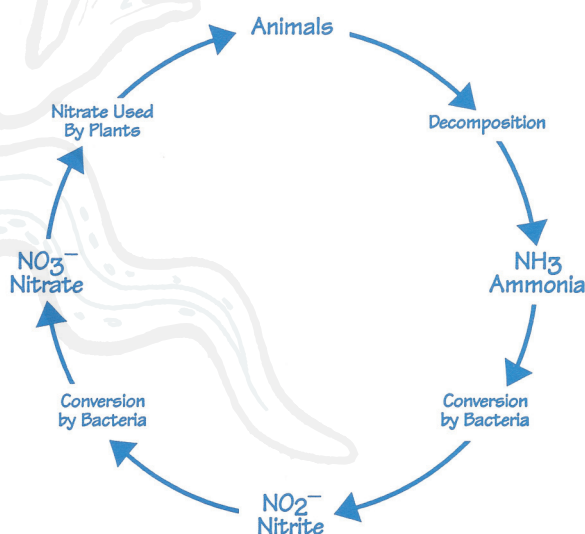
- rock type and geology
- soils types
- vegetation
- seasonal conditions
- animal waste (e.g. effluent from feedlots and piggeries) and human waste (sewage)
- decomposing plants and animals
- nitrogen containing fertilisers
- industrial discharges
- run-off.

If a waterbody is brown but clear, it may contain dissolved tannins from the surrounding native vegetation. Not as much light can penetrate this water and so it can have higher levels of nutrients without algal blooms occurring. Use the section on the following table which refers to Tanin water when interpreting results.



Nitrogen Cycle

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Interpreting test results

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Nitrate content (µg/L) Standing water only			Nitrate content (µg/L) Flowing water only			Nitrate content (µg/L) Tannin water only		
LOW 0—25	MEDIUM 25- 250	HIGH >250	LOW 0—25	MEDIUM 25- 400	HIGH >400	LOW 0—250	MEDIUM 250- 1500	HIGH >1500

Note: A low reading may be obtained but a high amount of algae is evident in the waterbody, or the Chlorophyll "a" reading is high. This means that the nitrate has been used up by the plants for plant growth.

Note: To convert micrograms (µg) to milligrams (mg) divide by 1000.

ANZECC Nitrate trigger values for south-western Australia

These trigger values are for NOx, which also includes nitrite.NO2-

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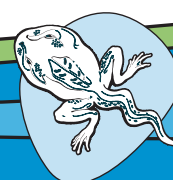
Ecosystem type	Nitrates upper limit µg/L
Upland river >150m altitude	200
Lowland river <150m altitude	150
Freshwater lakes and reservoirs	10
Wetlands	100
Estuaries	45

Note: For ANZECC Guidelines wetlands are shallow waterbodies, often with light penetration to the bed, while lakes are far deeper.

¹² Diagram from The Pondwater Tour. La Motte

¹³ Source: Ribbons of Blue 'Environmental Awareness to Action'

¹⁴ Australian and New Zealand Guidelines for Fresh and Marine Water Quality, 2000



2.2 Phosphorus

Phosphorus (P) is a mineral nutrient essential for all forms of life. The phosphorus found in both groundwater and surface water is most commonly in the form of phosphate. It is naturally derived from the weathering of rock and the decomposition of organic material. It can also enter the water as run-off or discharge—soil and fertiliser particles can carry phosphorus, and sewage is also rich in phosphorus. Fertiliser contains a high concentration of phosphate and may be a major contributor to the load of phosphorus in waterways.

Phosphorus in water comes in three forms:

- Phosphates (PO_4^{3-}) – freely available phosphorus, mostly orthophosphate.
- Organic phosphorus – formed primarily by biological processes (from living plants and animals).
- Phosphorus attached to silt particles.

Phosphates available to plants and animals are called orthophosphates and exist in water bodies as dissolved and particulate (suspended) and colloidal forms. Dissolved orthophosphate is immediately available to plants and animals. Suspended orthophosphate is potentially available to plants and animals. Colloidal polyphosphates are dissolved but not immediately available to plants and animals.

Phosphorus is a nutrient needed for growth and metabolic processes in plants and animals. In most waters, phosphorus functions as a 'limiting factor' because it is usually present in very low concentrations. Plant growth is limited by the amount of dissolved orthophosphate. A sudden increase in orthophosphate in inland waters can stimulate great increases in the growth of algae in particular as well as other aquatic plants. Algal blooms potentially produce toxins as well as cause large deficits of dissolved oxygen.

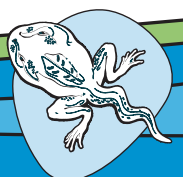
Phosphates do not pose a direct health risk to animals or humans, and therefore are not regulated in our drinking water.

The factors affecting phosphate concentration in water are:

- rock type and geology
- soil type
- seasonal conditions
- animal and human wastes
- phosphate containing fertilisers
- disturbed land
- urban run-off.




Phosphate in domestic waste enters the waterway from leaking septic systems, sewage treatment facilities and stormwater drains.




The total phosphorus test (TP) measures the immediately and potentially bioavailable forms of phosphorus in the sample. Total phosphate concentrations are often many times higher than orthophosphate reported as phosphorus in the same sample. TP is determined on an unfiltered sample, so it includes insoluble forms of phosphorus e.g. bound to particulate material.






Interpreting test results

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Nitrate content (µg/L) Standing water only		
LOW 0—5	MEDIUM 5- 50	HIGH >50
		

Nitrate content (µg/L) Flowing water only		
LOW 0—10	MEDIUM 10- 100	HIGH >100
		

Nitrate content (µg/L) Tannin water only		
LOW 0—50	MEDIUM 50- 200	HIGH >200
		

Note: To convert micro-grams (µg) to milligrams (mg) divide by 1000.

ANZECC Total phosphorus (TP) trigger values for south-western Australia

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Ecosystem type	Nitrates upper limit µg/L
Upland river >150m altitude	20
Lowland river <150m altitude	65
Freshwater lakes and reservoirs	10
Wetlands	60
Estuaries	30

Note: For ANZECC Guidelines wetlands are shallow waterbodies, often with light penetration to the bed, while lakes are far deeper.

¹⁵ Source: Ribbons of Blue 'Environmental Awareness to Action'.

¹⁶ Australian and New Zealand Guidelines for Fresh and Marine Water Quality, 2000. p 3.3-14

