

Farm water quality and treatment

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Agriculture NSW Water Unit

Farm water comes from a number of different sources and so its quality varies. Water sources include dams, bores, wells, rivers, town water, channels and recycled water.

Water from various sources may be of an unsuitable quality for its intended use for irrigation, stock, household or other farm activities.

It is important to identify and correct water quality problems that may effect on-farm use and productivity.

Knowing your water quality

If you have any doubt about the quality of water you intend to use for irrigation, stock or domestic purposes, get it tested by an accredited laboratory. You should have your water tested before, and sometimes during, use.

Your Local Land Services advisory officer may provide assistance to find information and identify options to manage specific problems in your water supplies.

Knowing your water quality allows you to plan for water treatments to avoid problems such as poor plant growth, blocked irrigation or stock watering pipes, staining and other undesirable effects of poor water quality.

Water quality issues

Problems with water quality may be chemical (for example, acidic or alkaline water or concentrations of certain elements) or physical (for example, plant growth such as algae). Some problems may be more obvious than others, and some may require more extensive treatment.

Water quality can affect plants, soils, livestock, irrigation equipment, domestic use and general farm activities. Water quality problems may affect a range of uses, or be restricted to more specific uses.

This Primefact discusses the following common water quality issues, and methods of treating them:

- pH
- iron
- hardness
- corrosion
- salinity
- sodicity
- turbidity
- algae
- colour, taste and odour
- bacterial growth.

It also discusses the following processes aimed at improving overall water quality:

- disinfecting irrigation water
- filtration systems

- monitoring water quality,

A list of references and further reading is also provided.

pH

The pH balance of a water supply describes how acidic or alkaline it is. The acidity (or alkalinity) of a water supply can affect plant growth, irrigation equipment, pesticide efficiency and drinking water suitability.

The balance of positive hydrogen ions (H⁺) and negative hydroxide ions (OH⁻) in water determines its pH level. The pH scale goes from 0 to 14, and a pH of 7 is neutral. Water with a pH below 7 is increasingly acidic and pH above 7 is increasingly alkaline.

Most natural waters are between pH 5 and 8.

The generally acceptable range of pH for irrigation water is between 5.5 and 8.5, but some problems can still occur within this range.

For example, alkaline water may contain high concentrations of bicarbonate (generally in water of pH 8 and above) and carbonates (generally pH 9 and above). High bicarbonate and carbonate levels in water can cause calcium to precipitate from the soil. This reduces the soil's exchangeable calcium content and increases soil sodicity. Magnesium can also be lost in this way. In extreme cases, the loss of soil calcium and magnesium will affect plant growth. Some trace elements, like copper and zinc, will also be less available to the plant in this situation.

The precipitation of calcium carbonate from water can also cause equipment blockages.

Precipitation: In chemical terms, when a substance separates out of a solution in solid form.

A pH greater than 7.5 is likely to reduce the effectiveness of chlorine disinfection.

Acidic water can have a detrimental effect on plant growth, particularly causing nutritional problems, while strongly acidic water (below pH 4) can contribute to soil acidification. A pH less than 6 indicates corrosiveness, which can lead to damage to metal pipes, tanks and fittings.

Water with pH less than 6.0 or greater than pH 8.5, when used in spray mixes, can lessen the effectiveness of some pesticides. Check with your pesticide supplier.

An acceptable pH for domestic purposes is between 6.5 and 8.5. This range is set primarily for aesthetic, corrosion and encrustation reasons rather than health-related reasons. For example, drinking water with a pH of 5 will not cause health problems – in fact, some soft drinks may be 10 to 100 times more acidic than this. However, if you have any concerns with your drinking water quality you should contact the NSW Department of Health.

Treatment

If you need to adjust your water pH, try to keep it between pH 5.5 and pH 7. Water in this pH range:

- maintains nutrient balance
- prevents scale formation in irrigation equipment
- provides effective chemical disinfection.

Water pH can be adjusted by adding an acid or an alkaline substance to the water supply. The appropriate substance may be injected into the pipeline for automated systems or mixed in a tank for manual systems or larger volumes of water. The use of an acid (such as sulfuric acid) will lower the pH, while an alkaline substance (for example, lime) will increase the pH. The selection of pH treatment will depend on the intended use of the water and the particular situation. The local office of Local Land Services may be able to provide some assistance in developing treatment options.

Iron

Soluble iron and iron-loving bacteria can cause blockages in pipes, drippers and sprinklers and can damage equipment such as pressure gauges. If water with high soluble iron is applied by spray, it can discolour leaves and reduce the efficiency of transpiration and photosynthesis.

High levels of soluble iron are usually associated with deep bores and dams where oxygen supply is limited. Iron is soluble in water where there is little or no oxygen. Aeration oxidises the iron, forming solid particles that can then settle out of solution. Dissolved iron can promote the growth of iron bacteria in groundwater. The presence of bacteria worsens the impacts of soluble iron, as they extract the iron out of solution and convert it into sludge. Oxidised iron, even in low concentrations of 0.2 mg/l, stimulates some aerobic slime deposits. These slimes are sticky and can attach themselves to irrigation pipes causing blockages.

Heavy iron deposits can make pasture unpalatable to stock. If eaten, the iron deposits may cause dairy cattle to scour and milk production to drop. Iron deposits on vegetables, fruit and ornamental plants make them difficult to sell because of their stained appearance.

As a general guide, iron bacteria will develop in water where the concentration range of iron is 0.3 to 1.5 mg/L (0.3 to 1.5 parts per million, ppm). Concentrations above 1.5 mg/L (1.5 ppm) tend to favour the development of iron deposits.

Irrigation systems used for fertigation (liquid feeding of nutrients) should not use water high in iron. Injecting unchelated phosphates or calcium salts into the water will accelerate the precipitation of iron, and should be avoided.

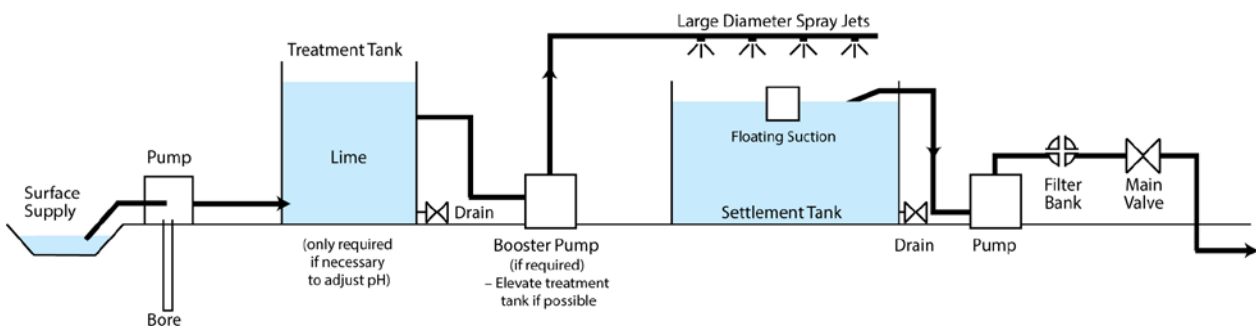
In domestic water supplies, iron and manganese will turn the water yellow-brown to black and will stain plumbing fixtures and laundry. Iron can also dramatically reduce the efficiency of water-softening units.

Treatment

Iron is soluble in water where there is little or no oxygen. Oxidising the iron makes it form solid particles that can then settle out of solution or be caught in a filter.

The recommended treatment to remove iron is oxidation, sedimentation and then filtration. Procedures used include aeration and settling (Figure 1), chlorination and use of potassium permanganate.

Figure 1. Aeration and settling to remove iron



Aeration and settling

Aeration and settling is an inexpensive and almost foolproof method of iron removal. Aeration means the water is mixed with air, by:

- spraying the water into the air
- bleeding air into the intake side of a pump
- agitating the water with propellers or paddles
- cascading it over baffles into a settling tank.

The iron then settles out of the aerated water.

Because iron is more soluble at lower pH values, the best precipitation is likely to occur at a pH of 7.2. You can add hydrated lime, that is, calcium hydroxide $\text{Ca}(\text{OH})_2$, to raise the pH values. Rates of 30 grams per 1000 litres of water are often used but other features of water quality and types of treatment, storage and delivery must all be considered. Too much hydrated lime can create “hard” water for example (see ‘Hardness’).

In dams, problems caused by iron can often be reduced or eliminated by attaching the suction pipe of the pump to a raft or drum to bring it within 20 to 30 cm of the surface (Figure 2).

The most commonly used aerators are cascade aerators. The simplest cascade aerator is a series of steps that spread the water and allow it to fall from one level to another. A one-metre head (4 to 5 steps of 20 cm height) is usually sufficient, but more steps will give a more complete aeration. Increasing the number of steps extends the exposure time and adds obstructions to increase turbulence. (Figure 3)

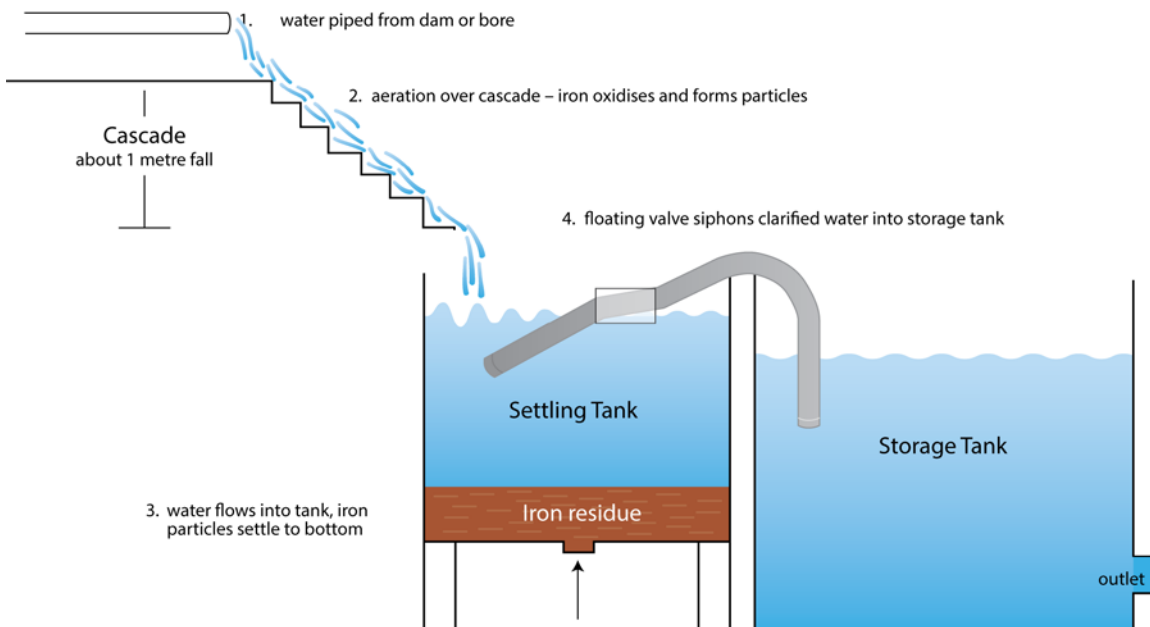
Aeration can also be achieved using an aerating pump (see Figure 8 in the section on 'Algae').

For household use, cascade water into a tank, allow it to settle for a few hours and then draw off through a pipe set 30 cm below the surface. A plug in the bottom of the tank allows sediment to be flushed out periodically. With two tanks, one can be used while the other is filled and allowed to settle (see Figure 3). In many instances, chlorine may be added following aeration to aid oxidation.

Figure 2. Using a floating suction will reduce iron problems



Figure 3. A simple cascade used to aerate water for iron removal



Chlorination

As a further control, following aeration and settling, chlorination can be used to control iron deposits if pH is below 6.5 and the iron concentration is less than 3.5 mg/L (3.5 ppm). If pH is above 6.5, the iron concentration must be below 1.5 mg/L (1.5 ppm) to use chlorination effectively.

Chlorine also kills iron bacteria on contact.

Potassium permanganate

Potassium permanganate (Condy's crystals) oxidises iron into insoluble oxide. Potassium permanganate is often used with manganese greensand, which acts as a filter, trapping the oxide.

The main advantage of potassium permanganate oxidation is the high rate of reaction, which is many times faster than that of chlorine. The reaction is not sensitive to pH within the range of 5 to 9.

Other products such as zeolite (manufactured greensand is manganese dioxide-coated zeolite) can be used instead of greensand and potassium permanganate to improve the oxidation process.

Filtration to remove oxidised particles

Filtration alone does not remove iron efficiently because it only removes particles of oxidised iron. Filter media such as sand or anthracite have proved to be the most effective for removing ferric oxide.

Remember that aeration and oxidation should take place before the water is filtered.

Hardness

Water that contains high levels of dissolved calcium or magnesium salts, or both, is described as being 'hard'. Other cations such as iron, manganese, aluminium and zinc can also contribute to hardness.

Water hardness is defined in terms of calcium carbonate (CaCO_3 , also known as 'lime'). The level of hardness (Table 1) is expressed as the total amount of CaCO_3 in milligrams per litre of water (mg/L).

Table 1. Classification of water hardness

Description of water	Hardness expressed as mg/L of CaCO_3
Soft	less than 50
Moderately soft	50–75
Slightly hard	75–150
Hard	150–300
Very hard	greater than 300

Hard water can affect soil, stock and domestic water use, and pipes and equipment.

Effect on soils

Hardness does not affect plants directly, but hardness caused by bicarbonates can affect soils, thus having an indirect impact on plant growth. A bicarbonate (HCO_3) compound is a soluble compound often found in saline–sodic water. Bicarbonates cause calcium and magnesium from soil and water to precipitate as insoluble carbonates. The relative concentration of sodium in the soil – which remains bonded to the clay particles – therefore increases as a percentage of total exchangeable cations, and increases soil sodicity (see 'Sodicity'). The risk of this occurring is low if the water contains bicarbonates at a concentration of less than 90 mg/L, and high if the concentration is greater than 335 mg/L.

Calcium is barely soluble, while magnesium is more soluble. Neither is toxic in water, and they are seldom deficient in soils. Water with high magnesium content, like water with a high sodium content, can affect soils by causing dispersion.

Effect on stock and domestic use

In domestic use, the calcium and magnesium in hard water react with soap to form insoluble scales, seen as greasy scums in bathtubs and on kitchen ware.

Hard water also leads to poor laundry results. Hard water will not lather with soap until all the calcium and magnesium have reacted, and so more soap needs to be used. The more soap required to produce lather, the harder the water.

Domestic or livestock consumption of hard water is generally not a problem unless magnesium salts predominate. Drinking water hard in magnesium could lead to gastrointestinal problems due to the laxative effect of magnesium sulfate, better known as Epsom salts.

While it is desirable that domestic water supplies contain less than 100 mg/L hardness, there are suggested upper limits for specific farm uses, and these are listed in Table 2.

Table 2. Hardness limits suggested for various farm water purposes

Farm water needs	Hardness (CaCO ₃ mg/L)
Dairy equipment and hot water systems	up to 150
Domestic uses such as washing and cooking	up to 200
Dips and chemical sprays	up to 300
Septic tanks and hosing down	over 300

Effect on pipelines, irrigation and farm equipment

Calcium salts can form a white encrustation of lime (calcium carbonate). These deposits:

- accelerate the formation of milkstone on dairy equipment (Figure 4)
- eventually block irrigation equipment, and
- affect hot water systems. Deposits on heating elements make them overheat and burn out.

Figure 4. Lime build-up in pipes and equipment affects their performance.



Treatment

Reducing hardness is called water softening. Ways to soften water include:

- ion exchange
- water-softening agents
- desalination processes such as reverse osmosis
- use of lime

- pH adjustment
- controlling water temperatures

Ion exchange

The most effective way to treat hard water for domestic use is to install an ion exchange resin softener. This softening equipment works best when pH is between 7.0 and 8.0 and water temperatures are less than 32°C. When hard water is passed through the softener, the calcium and magnesium are replaced by sodium from the exchange resin.

Health note: The exchange of calcium and magnesium by sodium may be a concern to people on a low-sodium diet. Check with your doctor.

The reaction is reversible, and the 'exhausted' exchange resin can be regenerated by flushing with a solution of sodium chloride (common salt). After this regeneration, it is important to dispose of the salty solution safely.

If regular recharging is undertaken, the resins will last for a number of years. Without recharging, bacteria can grow on the resins. If a build-up of iron scale occurs, then acid treatment may be necessary.

There are a number of commercial pressure water softeners on the market. They can be one-tank manual operations or two-tank automated systems.

The exchange process in a water softener does not alter the total amount of dissolved salts, and so the salinity of the water will be unchanged by this process.

Water-softening agents

If the installation of softening equipment is not possible, detergents provide some relief from laundry problems. However, these also lose some efficiency in hard water. Using water-softening agents (or scale inhibitors) together with everyday soap or soap powder prevents lime scums. They may also form a lining on pipe walls to deter scale deposits.

One water-softening agent, sodium hexametaphosphate, is available as tablets, powder or gel (in products like Calgon™, for example) and can be bought from most produce stores.

Desalination processes

Hard waters with a salinity level greater than 2.5 dS/m (1500 mg/L) and chloride level greater than 600 mg/L need desalination for domestic and home garden use. For small operations, saline water can be treated to remove most of the salt. Various processes, such as reverse osmosis, deionisation and electrodialysis, are commercially available. These methods will remove more than 90% of the salts from saline water. Since a moderate level of salinity can be tolerated in domestic and home garden use, using a mix of saline and desalinated water may be more economical than desalinated water alone.

A byproduct of desalination is wastewater high in salts. This can pose a disposal problem and you should seek advice from your local council or NSW Department of Environment and Heritage or EPA.

Use of lime

In lime softening, hydrated lime, that is, Ca(OH)_2 calcium hydroxide, is added to water to precipitate calcium carbonate before the water is used. The amount of lime required depends on hardness levels. The process requires a settlement period and its effectiveness is governed by the pH of the water. Lime softening is a complex process and therefore usually limited to situations where constant monitoring is available.

pH adjustment

The aim of pH adjustment is to acidify the water to keep scale-forming calcium and magnesium ions in solution and not allow them to precipitate. Even complete blockages can be treated with acid. Acidifying the water can be done by adding acid to the irrigation system at metered rates (Figure 5). Hydrochloric or sulfuric acid is commonly used.

There is a risk that reducing pH may cause corrosion in metal pipework. If you have metal pipework, use 'inhibited' hydrochloric or sulfamic acid (also called aminosulfuric acid) to minimise attack on metal surfaces.

Controlling water temperatures

Scale formed by hard water increases with water temperature. In hot water systems, lowering the thermostat below 70°C reduces scaling and minimises maintenance costs.

Figure 5: Automatic acid injection to adjust pH



Where pipelines are at or near the ground surface, they can absorb sufficient heat to cause carbonates to precipitate, which leads to scaling of pipes and fittings. This is most likely to happen where flow is intermittent and the pipes are likely to be lying in the hot sun for long periods with no flow. Scaling can be minimised by burying pipes to keep them cool, thus reducing the rate of precipitation of salts from the water. Draining the pipes when they are not in use may also help.

Corrosion

Metals are used on the farm in buildings, fences, pipelines, pumps, sprinklers, tanks, troughs and many other applications ranging from concrete reinforcing steel to simple nails.

Metal corrosion is the gradual action of agents such as air and water that wear away or dissolve the metal. Metal corrosion leads to defects that commonly affect water supply installations and equipment.

On the farm, the most recognisable example of corrosion is the rusting of iron and steel. Although common, it is a complex chemical reaction in which the iron combines with oxygen and water to form hydrated iron oxide. This oxide is the familiar weak and brittle solid we see on rusted iron pipes and equipment.

Other common metals such as aluminium and copper and its alloys (bronze and brass) can also become corroded. Dissolved copper shows up as green stains on washbasins and baths when the water comes into contact with soap or other alkaline materials.

Factors causing corrosion in farm water distribution systems include acidity, (very low) hardness, bimetallic contact, high chloride concentration, dissolved oxygen and biological action. On the farm, the most common and easily adjusted of these factors are acidity, low hardness (soft water) and bimetallic contact.

Acidity is one of the most important factors in corrosion. Acid water is always corrosive.

In addition, soft water is relatively more corrosive than **hard water**. A galvanised iron tank holding water with some hardness (35 mg/L calcium carbonate) lasts 10 times longer than a similar tank holding soft water (5 mg/L calcium carbonate).

Some water hardness is necessary so that a thin protective film of calcium salts can be deposited on the metal surface. Alkalinity levels of 50 to 100 mg/L and calcium levels of 30 to 50 mg/L should be present at normal temperatures to give some protection to metal parts and fittings. The amount of protection depends on pH, temperature and the concentration of dissolved salts in the water. (The index used to assess the scaling or corrosive potential of water is the **calcium carbonate saturation index**. This index is described in detail below.)

Bimetallic or galvanic corrosion occurs when two different metals are in contact with one another. This contact does not have to be physical and can occur through the water running between one metal part and another.

Metals have different degrees of corrosion potential. The severity of bimetallic corrosion increases when the corrosion tendencies between the metals in contact are very different. For example, copper roofing should not drain into galvanised steel gutters or downpipes: the flow of water from the copper roof will lead to serious corrosion of the galvanised steel gutters and downpipes. Similarly, aluminium should not be used in contact with copper pipe or fittings, as the aluminium will corrode through bimetallic corrosion.

Prevention

Corrosion is easily detected but, if it is allowed to proceed, it will make metal pipes, tanks, pumps and fittings unusable.

Coatings are used to protect against corrosion.

- **Protective coatings** are used to separate the metal from corrosive water: for example, coating the inside of metal pipes with bitumen, or lining them with cement.
- **Sacrificial coatings** corrode in preference to the metal they are coating. A good example is galvanised steel, where the galvanised coating (zinc) corrodes in preference to the steel.

Further protective measures against corrosion include substituting galvanised steel with copper (or copper alloys) or plastic pipes and fittings and the use of corrosion-resistant pumps.

Treatment

Chemical treatment can supplement prevention measures, but is not a substitute for them. Chemical control cannot overcome incorrect flow conditions, poorly designed distribution systems, defective materials or faulty coatings.

Adding lime or soda ash (Na_2CO_3) makes water less corrosive by raising the pH.

- For the treatment of soft water (less than 30 mg/L calcium carbonate), lime is best. It neutralises acidity and provides calcium salts that form a thin protective film of calcium carbonate on metal pipes and fittings.
- For acidic domestic water supplies, treat water that has more than 100 mg/L hardness with soda ash. This makes the water less corrosive by raising the pH but not the calcium hardness.

Do not use soda ash in irrigation water because it is toxic to plants and breaks down soil structure.

The amount of lime or soda ash required depends on the water acidity. Use a pH meter, like the ones pictured in Figure 6, to check that the final pH is between 7.0 and 8.0. If a meter is not available, treat water at the rate of 50 to 100 g/1000 L.

Calcium carbonate saturation index

The calcium carbonate saturation index gives the relationship between pH, salinity, alkalinity and hardness. It is used to assess the scaling (encrustation) or the corrosive potential of water.

Figure 6. Hand-held pH meters like these are simple to use.



Your Local Lands Service office can arrange for the calcium carbonate saturation index of your water supply to be determined.

NSW DPI's water-testing service presents the calcium carbonate saturation index in positive and negative units. Positive (+) index figures refer to scaling potential and negative (-) index values refer to corrosion potential.

The index is divided into three ranges:

1. between -0.5 and $+0.5$

No scaling or corrosion: If the index is between -0.5 and $+0.5$, there is little likelihood of either scaling or corrosion of pipes and fittings.

2. less than -0.5 or greater than $+0.5$

Scaling risk: If the index is more than $+0.5$ there is a risk of precipitating calcium and magnesium salts. When these salts precipitate and settle they form a scale on the inside of pipes and fittings or on the outside of heating elements.

This is important in irrigation systems that use small emitter or pipe diameters, such as drip and micro irrigation systems. In these systems the drippers, microjets, microtubes and small lateral pipes can block, reducing flow rates and affecting water distribution patterns. In automated irrigation systems, the tubes serving solenoids can also block, and the valve will not operate properly.

The effect on heating elements creates maintenance problems and shortens element life. Scaling can also impede the operation of float valves on tanks and troughs.

3. less than -1.5 or greater than $+1.5$.

Scaling risk: When the index exceeds 1.5 , the risk of scaling is very strong and the water should not be used without prior treatment. Treatment methods are discussed under the section on 'Hardness'.

Corrosion risk: If the index is less than -0.5 the water may be corrosive. Values below -1.5 indicate that the water is highly corrosive and corrosion-resistant pipes and fittings may be necessary.

Slight scaling is desirable in metal pipes and fittings because the thin film of calcium or magnesium salts can protect the metal surface from corrosive elements in the water that might affect the system. Such water may still be hard and scum formation can occur when attempting to lather soap, but scale (calcium carbonate) will not form.

Adjusting the pH to between 7.0 and 8.0 by liming can help minimise the problem. Other factors such as chloride, dissolved oxygen and biological agents can also cause corrosion (see 'Corrosion').

Salinity

Salinity is the concentration of all soluble salts in water or in the soil.

In water, salinity is usually measured by its electrical conductivity (EC), which is a measure of the concentration of ions in water or in the soil solution.

Ions are positively charged, that is, cations, and negatively charged, anions.

Salinity meters measure the amount of salt in a solution by recording the resistance to an electrical current between two electrodes. The international standard for measuring salinity is decisiemens per metre (dS/m), but several other units of measurement are still in use.

List of dS/m equivalents

1 dS/m = 1000 EC ($\mu\text{S}/\text{cm}$) (microsiemens per cm)
 = approximately 640 ppm
 = 1 mS/cm (millisiemen per centimetre)

Table 3 shows how to convert between the various units used to measure salinity.

Table 3. Conversion for units used to measure salinity

To convert EC ($\mu\text{S}/\text{cm}$) to decisiemens per metre (dS/m)	divide by 1000.
To convert ppm (mg/L) to decisiemens per metre (dS/m)	divide by 640.
To convert dSm to EC	multiply by 1000.

The conversion from parts per million to dS/m varies a little, above and below 640 ppm, depending mainly on the type and relative concentration of salts present in the water.

Water with a salinity of 1 dS/m contains about 640 kg of salt per megalitre, while 1.6 dS/m water contains about one tonne of salt per megalitre. A typical EC value for sea water is 55 dS/m.

Salinity affects both stock and domestic water use and plants and irrigation water use.

Stock and domestic water use

For domestic consumption, contact NSW Department of Health for advice. As a guide, on taste considerations only, drinking water should not exceed levels of 1000 mg/L total dissolved solids.

For **livestock drinking water** supplies, the salinity levels in Table 4 can be used as a guide. The suggested limits apply when salinity is due mainly to sodium chloride. Some salts, like magnesium sulfate and sodium sulfate, have purgative effects on stock (that is, they cause scouring and diarrhoea) and affect stock health. If purgative salts are present in appreciable quantities, the suggested concentrations must be reduced, and you should seek advice from your **Local Land Service**.

Table 4. Total dissolved solids (salinity) concentrations (mg/L) for livestock drinking water

Stock	Desirable maximum concentration for healthy growth	Maximum concentration at which good condition might be expected*	Maximum concentration that may be safe for limited periods*
Sheep	5000	5000 to 10,000	10,000 to 13,000
Beef cattle	4000	4000 to 5000	5000 to 10,000
Dairy cattle	2500	2500 to 4000	4000 to 7000
Horses	4000	4000 to 6000	6000 to 7000
Pigs	4000	4000 to 6000	6000 to 8000
Poultry	2000	2000 to 3000	3000 to 4000

* The level depends on the type of feed.

Adapted from *Australian and New Zealand Guidelines for Fresh and Marine Water Quality 2000/ Paper No 4, Chapter 4, Table 4.3.1; page 4.3-4.*

How does salinity affect plants?

Plants are adversely affected by salinity in several ways. The most important of these is the osmotic effect, which limits the ability of plants to take up water. Plants absorb water from the soil (or growing medium) through their roots. A key process that allows the roots to do this is osmosis.

Dissolved substances within the roots such as salts and sugars attract water through the root membrane, from where it moves to the rest of the plant. This process continues as long as the concentration of dissolved substances inside the roots is higher than that of the soil water available to the plant. If the soil water salt concentration is too high the plant will not be able to absorb water: it will wilt and begin to die. The point at which this happens depends on the type of plant, the salt concentration of the water, and the type of salts in the soil water.

As a general guide, chloride and sodium ions in the salts do the most damage to plants. Irrigating with water high in these salts can be detrimental to plant growth, affect plant yields and ultimately threaten the plant's survival.

EC readings are a general indicator of the salt concentration. They do not tell you the type of salts or their relative concentrations. When EC levels are high you should find out what the specific ions are so that you can adjust your irrigation practices accordingly (see elsewhere in this PrimeFact).

Plants can also be affected by the toxicity of some elements in saline water, especially chloride, sodium and boron. Increased ion concentration within the plant can interfere with growth processes.

The early effects of salinity are often difficult to detect. Some of the early signs that salinity in water or soil is affecting plants are:

- poor germination and establishment
- reduced plant vigour and stunted growth
- leaves smaller than normal, and coloured bluish-green
- slight yellowing of leaves
- a burnt appearance on tips of leaves.

Later the signs become more obvious, but by then it may be too late for that particular crop or pasture. Visible signs of a more advanced salinity problem are:

- new wet patches or boggy areas in paddocks
- whole plants become yellow and bronzed
- crops haying-off early
- legumes dying out
- increasing numbers of salt-tolerant plants such as sea barley grass and couch
- increase in number and size of bare areas
- greasy black patches and salt crusts on the soil surface
- trees dying in low areas and along drainage lines.

Plant types and plant varieties vary in their tolerance of salinity. Tolerance also varies with the stage of growth, especially at germination and at the seedling stage when plants are most susceptible. Other factors that should be considered include soil type and method of irrigation.

Salinity and irrigation

For irrigation purposes:

- the salt tolerance of the particular crop
- the characteristics of the soil
- the salinity of the irrigation water, and
- the method of irrigation

also need to be considered, as well as the effect of salinity on plants.

Plant tolerance to salinity

The tolerance of plants to salinity is related to the salinity of the soil, described as EC_{se} . Salinity at any level will affect most plants, but growth or yield reductions of less than 10% are hard to pick and would be

regarded as insignificant by most growers. This level of yield reduction has therefore been chosen as the initial salinity threshold, where crop yields are within 10% of optimum (that is, crop yields where water containing no salt was available). The second threshold level is an estimated 25% yield reduction, regarded here as the upper limit of losses for a profitable farming enterprise.

Experience in northern NSW shows that cotton yields decline rapidly after the first threshold is reached, due to the toxic effect of the sodium inducing a potassium deficiency, not the increase in salinity.

Table 5 shows the soil salinity for both thresholds for plants commonly irrigated in NSW. The initial threshold of 'up to 10%' yield reduction does not mean that 10% yield loss will occur at the soil salinity figure shown, but that yields are expected to be reduced slightly, to a maximum of 10%.

Table 5. Rootzone soil salinity (ECse) tolerances, crops and pasture plants commonly irrigated in NSW**

Plant type	Rootzone salinity (dS/m) for yield reduction of	
	up to 10%	25%
Pasture legumes		
White clover	1.2	3.1
Sub clover	1.2	3.1
Strawberry clover	2.4	4.0
Lucerne (most varieties)	2.0	5.4
Lucerne (some varieties)	3.6	5.9
Berseem (Jemalong) clover	6.0	10.0
Rose clover	1.0	3.8
Red clover	1.5	3.6
Persian clover	3.0	na
Balansa clover	3.0	na
Barrel medic (Jem)	1.0	4.2
Stylo (Townsville)	2.4	3.6
Cowpea	1.3	3.0
Pasture grasses		
Perennial ryegrass	5.6	8.9
Phalaris	4.2	8.0
Cocksfoot	1.5	5.5
Fescue	3.9	8.6
Paspalum	4.0	6.6
Kikuyu	3.0	11.3
Buffel (Gayndah)	5.5	7.9
Green panic (Petri)	3.0	6.6
Rhodes (Pioneer)	7.0	14.8
Sudan grass	2.8	8.6
Couch	6.9	10.8
Tall wheatgrass	7.5	13.3
Puccinellia	16	22
Winter crops		
Wheat	6.0	9.5
Barley	8.0	13

Oats	5.0	6.3
Canola	6.5	11
Linseed	1.7	12
Safflower	6.5	na
Faba beans	1.8	4.0
Summer crops		
Cotton	2.5	(see text)
Rice	3.0	5.1
Maize	1.7	3.8
Grain sorghum	1.4	2.2
Sunflower	5.5	6.5
Soybean	2.0	6.3
Sugarcane	1.7	5.9
Millet	6.0	9.0

Table 6 shows the soil salinity for a range of horticultural plants commonly irrigated in NSW. The rootzone salinity levels are the salinity threshold (that is, the level for no yield reduction) and the levels at which a 10% and a 25% yield reduction could be expected.

Ask NSW Department of Primary Industries for information on salinity tolerances of many other plants not in this table.

**Some of the salinity thresholds shown in Tables 5 and 6 are based on field research and experience with varieties grown in Australia. However, most are from *Australian and New Zealand Guidelines for Fresh and Marine Water Quality – 2000*, Paper No 4 volume 1, chapter 4, and chapter 3, chapter 9 Primary Industries.

Table 6. Rootzone soil salinity (EC_{se}) tolerances of horticultural plants commonly irrigated in NSW**

Plant type	Rootzone salinity (dS/m) for yield reduction of		
	0%	10%	25%
Almond	1.5	2.1	2.9
Apple	1.0	1.6	2.4
Apricot	1.6	2.0	2.7
Avocado	1.3	1.8	2.5
Bean	1.0	1.5	2.3
Boysenberry	1.5	2.0	2.6
Broad bean	1.6	2.6	4.2
Broccoli	2.8	3.9	5.5
Cabbage	1.8	2.8	4.4
Capsicum (pepper)	1.5	2.2	3.3
Carrot	1.0	1.7	2.8
Celery	1.8	3.4	5.8
Cucumber	2.5	3.3	4.4
Date	4.0	6.9	11.4
Eggplant	1.1	2.5	4.7

Grape	1.5	2.6	4.1
Grapefruit	1.8	2.4	3.4
Lettuce	1.3	2.1	3.2
Olive	4.0	4.5	5.5
Onion	1.2	1.8	2.8
Orange	1.7	2.3	3.3
Peach	3.2	3.7	4.5
Plum	1.5	2.0	2.9
Potato	1.7	2.5	3.8
Radish	1.0	1.3	3.1
Rockmelon	2.2	3.6	5.6
Spinach	2.0	3.3	5.3
Strawberry	1.0	1.3	1.8
Sugar beet	7.0	8.7	11.2
Sweet corn	1.4	1.7	3.8
Sweet potato	1.5	2.4	3.8
Tomato	2.3	2.8	3.6
Turnip	0.9	2.0	3.7
Zucchini	4.7	5.8	7.4

Salinity tolerances for many other agricultural, horticultural and ornamental plants can be found in the Guidelines (http://www.daff.gov.au/_data/assets/pdf_file/0018/316143/gfmwq-guidelines-vol3-9-2.pdf), or can be obtained from Local Land Services. Other factors frequently experienced in the field, such as waterlogging, moisture stress, stage of growth and soil pH, can affect the salinity tolerance of plants.

Irrigation method and salinity damage

Spray irrigation concentrates salts and chlorides on leaves and could cause leaf scorching. Where plants sensitive to chloride burn are to be spray-irrigated using overhead sprinklers, water should be of a lower salinity (and lower chloride levels) than if the same plants are surface- or drip-irrigated or irrigated with under-tree/vine sprinklers. The adverse effects of chloride burn will be reduced if watering on hot or windy days is avoided. See 'Other elements' for more information on chloride.

Effects of soil type on salinity

Salinity in soils can be only temporary. Sometimes salt can be leached deeper than the rootzone with rainfall and low-salinity irrigation water.

If the saline water cannot drain away from the plant's rootzone, it can cause more damage. When salt does build up in the soil, it needs to be leached away quickly to minimise the effect on plants. The additional amount of water that needs to be applied to do this is termed the **leaching fraction**.

Leaching fraction

The leaching fraction required to take salt away from the plants depends on the drainage characteristics of the soil in which they are growing.

- Water can move quickly through light-textured soils such as **sandy soils**. Salt leaches deep into the soil profile, unless there is a shallow watertable holding saline water in the rootzone or close to it. These well-drained soils have an average leaching fraction of 45%. (Citrus and lucerne would do well in these soils.)
- Most of the irrigated soils in NSW have an average leaching fraction of 30%.

- In heavy-textured soils such as clays, where internal drainage is poor, water moves downward more slowly. Salts tend to stay in the rootzone longer, and are likely to harm plants more than in well-drained soils.
- These very slow-draining soils have an average leaching fraction of 15%. They include soils suitable for rice and other soils with near-impermeable clay in the subsoil.

The leaching fraction can also be influenced by factors other than soil texture:

- Leaching fraction increases as salinity increases, because the soil is more permeable.
- Watertables shallower than 2 m can reduce leaching fraction as the movement of water through the soil profile is impeded.

There is a benefit of low water salinity in some heavy soils where infiltration rates are very slow. Salinity helps flocculate clay particles, thus improving soil structure and allowing faster and deeper infiltration in tight clay soils.

The use of even moderately saline water with rice can lead to increased total water use, and, with other surface-irrigated crops, to deep drainage below the root zone. The problem of salt accumulating in the subsoil, watertable or shallow aquifers still remains.

The EC levels in Table 7 are of the saturated extract from a well-drained growing medium. They are about the same EC_{se} for a sandy soil and for the salinity of water used to irrigate that medium.

The rankings in Table 7 are similar to EC_{se} values, but the actual EC_w tolerances are provided in Table 12. (Note that salinity tolerance can vary widely among varieties and cultivars of a species.)

Table 7. Relative tolerance (approximate 25% growth reduction) of ornamental plants to saline growing conditions in media

Very sensitive (threshold less than 2 dS/m)	
Dahlia spp.	Dahlia
Gardenia spp.	Gardenia
Lilium spp.	Lily
Photinia x fraseri 'Robusta'	Photinia
Rhododendron spp.	Azalea, rhododendron
Rosa spp.	Rose
Sensitive (threshold less than 4 dS/m)	
Aster spp.	Aster
Gladiolus spp.	Gladiolus
Magnolia grandiflora	Magnolia
Mathiola incana	Stock
Nandina domestica	Heavenly bamboo
Strelitzia reginae	Bird of paradise flower
Zinnia elegans	Zinnia
Moderately tolerant (threshold less than 6 dS/m)	
Agapanthus spp.	African lily
Chrysanthemum spp.	Chrysanthemum
Dianthus caryophyllus	Carnation
Tolerant (threshold less than 8 dS/m)	
Metrosideros excelsa	New Zealand Christmas tree
Rosmarinus officinalis	Rosemary
Very tolerant (threshold less than 13 dS/m)	
Araucaria heterophylla	Norfolk Island pine
Banksia spp.	Banksia
Casuarina distyla	She-oak

Table adapted from K Handreck and N Black 1999, *Growing Media for Ornamental Plants and Turf*, University of New South Wales Press, with minor additions from *Agricultural Salinity Assessment and Management*, KK Tanji, American Society of Civil Engineers, 1990.

Water salinity limits for plants

The salinity of water is described in EC_w .

To decide whether a crop or pasture should be irrigated with water containing a certain salinity level, you need to know not only the salinity of the water, but also what the resulting soil salinity might be.

Water salinity: When the EC_w (water salinity) is, say, 1 dS/m, the soil salinity that results will be different in each of the three classes of soil:

- well-drained soil – an EC_{se} of 1 dS/m
- moderate to slow draining soil – an EC_{se} of 1.5 dS/m
- very slow draining soil – an EC_{se} of 3 dS/m.

Soil salinity: Conversely, if the crop to be irrigated has an EC_{se} (soil salinity) tolerance of 1 dS/m, the water salinity limits for the soil types are:

- well-drained soils – 1 dS/m water
- moderate to slow draining soils – 0.66 dS/m
- very slow draining soils – 0.33 dS/m.

Salinity limits for plants are given in terms of soil salinity (EC_{se}) rather than water salinity (EC_w). The relationship between the two may be calculated from the following formula:

$$EC_{se} = EC_w \div (LF \times 2.2)$$

where EC_{se} is soil salinity, EC_w is water salinity and LF is leaching fraction.

Irrigators can apply this formula to work out the maximum water salinity level applicable to the intended crop to be irrigated on their farms. For most irrigated soils, if local information about leaching fraction is not available, you can use two-thirds of the EC_{se} limit.

- If the soil is a very well drained sandy or alluvial soil, the water salinity limit can be up to the soil salinity limit.
- If the soil is a poorly drained clay soil, the water salinity limit will be about one-third that of the soil salinity limit.

Alternatively, use Tables 8 and 9 as starting points.

Table 8. Water salinity (EC_w) limits* for some crops and pastures commonly irrigated in NSW by soil type (in dS/m)

* This assumes surface irrigation.

	Soil drainage characteristics					
	Well-drained soils		Moderate to slow draining soils		Very slow draining soils	
Average leaching fraction	0.45		0.3		0.15	
Yield reduction	less than 10%	25%	less than 10%	25%	less than 10%	25%
Pasture (legumes)						
White clover	1.2	3.1	0.8	2.0	--	--
Sub clover	1.2	3.1	0.8	2.0	0.4	1.0
Strawberry clover	2.4	4.0	1.6	2.6	0.8	1.3

	Soil drainage characteristics					
	Well-drained soils		Moderate to slow draining soils		Very slow draining soils	
Lucerne (most varieties)	2.0	5.4	1.3	3.5	--	--
Berseem clover	6.0	10	4.0	6.6	2.0	3.3
Pasture (grasses)						
Paspalum	4.0	6.6	2.6	4.4	1.3	2.2
Phalaris	4.2	8.0	2.8	5.3	1.4	2.6
Perennial ryegrass	5.6	8.9	3.7	5.8	1.8	2.9
Winter crops						
Faba beans	1.8	4.0	1.2	2.6	--	--
Oats	5.0	6.3	3.3	4.2	1.7	2.1
Wheat	6.0	9.5	4.0	6.3	2.0	3.1
Canola	6.5	11	4.3	7.3	2.1	3.6
Summer crops						
Grain sorghum	1.4	2.2	0.9	1.4	0.5	0.7
Maize	1.7	3.8	1.1	2.5	0.6	1.2
Sugarcane	1.7	5.9	1.1	3.9	0.6	1.9
Soybeans	2.0	2.6	1.3	1.7	0.6	0.8
Rice	--	--	--	--	1.0	1.7
Sunflowers	5.5	6.5	3.6	4.3	--	--
Millet	6.0	9.0	4.0	6.0	2.0	3.0
Cotton	2.5	na	1.7	na	0.8	na

Salinity tolerances are based on Australian research data and field experience where available, or otherwise are from *Australian and New Zealand Guidelines for Fresh and Marine Water Quality 2000*.

Sodicity

Sodicity represents the amount of exchangeable sodium cations in water or in soil. In water, sodicity is expressed as a **sodium absorption ratio (SAR)**, which relates sodicity to the amount of calcium and magnesium ions in the water.

The SAR of water is measured in the laboratory, first by determining the amounts of sodium, calcium and magnesium in milliequivalents per litre, and then by relating the sodium to the other two cations.

If the SAR is greater than 3, the water is sodic and is a potential hazard to soils.

Salinity affects plants directly, but sodicity may have an indirect effect on plants, as it first affects the soil. The use of sodic water can in time turn a non-sodic soil sodic, and can worsen sodicity in a sodic soil.

A **sodic soil** has an exchangeable sodium percentage (ESP) of more than 6. This means that sodium comprises more than 6% of the total exchangeable cations in the soil.

Sodic soils are likely to **disperse**, that is, break down into individual clay particles that block pore spaces. This dispersion causes poor water infiltration, slow internal drainage, surface crusting and germination problems. If dispersion occurs in the subsoil, the soil may become almost impermeable and be a poor environment for growing plants (except rice).

The use of saline water may reduce the level of dispersion in the short term due to flocculation of the clay particles. If the rate of leaching is inadequate, the sodium accumulates in the soil, making it more sodic and more difficult to manage.

Unlike salinity, sodicity in soils is virtually permanent, in nature: the only way to reverse it is to apply gypsum. Reduced tillage and a build-up of organic matter can reduce the degree of dispersion in a sodic soil, but will not alter the soil's ESP.

Relationship between salinity and sodicity in water

Water containing salt that has an SAR of more than 3 is termed saline–sodic water.

The SAR of water relative to its salinity has ramifications for both infiltration and the long-term stability of soil structure. In general, there is a risk of reduced infiltration and declining soil structure if the water has moderate to high SAR but low salinity. Using water with moderate to high salinity, regardless of whether SAR is high or low, means there is no reduction in the rate of infiltration, but the sodicity hazard still remains.

Table 9 shows the relationship between water salinity and SAR, and the risk of causing soil sodicity or worsening existing sodicity. As the SAR increases above 3, the risk of water infiltration and soil structure problems is less if the salinity of the water also increases.

Table 9. Risk of increasing soil sodicity at varying water salinity and SAR levels

Water salinity (dS/m) [^]	Water SAR threshold for soil type					
	Well to moderate draining soils (soils with a leaching fraction of 30% or more)			Slow-draining soils (Assumed leaching fraction is 15%. Lower SAR figures should be used for highly sodic heavy clay soils, which usually have leaching fractions from 2% to 10%.)		
	Low risk	Medium risk	Severe risk	Low risk	Medium risk	Severe risk
1	less than 3	3 to 10	greater than 10	less than 3	3 to 8	greater than 8
1.5	less than 4	4 to 13	greater than 13	less than 3	3 to 11	greater than 11
2	less than 7	7 to 16	greater than 16	less than 6	6 to 14	greater than 14
2.5	less than 10	10 to 18	greater than 18	less than 9	9 to 16	greater than 16
3	less than 12	12 to 20	greater than 20	less than 11	11 to 18	greater than 18
3.5	less than 14	14 to 22	greater than 22	less than 13	13 to 20	greater than 20
4 [^]	less than 16	16 to 24	greater than 24	less than 14	14 to 22	greater than 22

[^] Upper limit of water salinity is 4 dS/m: few crops or pastures can cope with water more saline than this.

Fresh water after high SAR

The main danger in using water with a high SAR is a dramatic loss of soil structure when fresher water is reused in surface irrigation.

- If water with a high SAR and moderate to high salinity is used, the sodicity builds up but the soil structure remains stable due to the electrolytic effect of the salinity keeping the clay flocculated.
- If heavy rains occur, or if the irrigator changes to using low salinity water, there is no electrolytic effect, and complete dispersion of the subsoil can occur. Clay particles clog the remaining pore spaces and the soil becomes impermeable and severely waterlogged. This situation has already occurred on farms where heavy soils have been irrigated with high-SAR bore water.

Rice can still be grown in soils which have severe subsoil dispersion, provided the salinity of the soil is within threshold limits, but the soil becomes unsuitable for most other crops and pastures. Large amounts of gypsum would be needed to overcome this problem.

Effect of bicarbonates and carbonates on sodicity

Elevated levels of bicarbonates (HCO_3) and carbonates (CO_3), often found in deep groundwater, can result in increased soil sodicity. Bicarbonates are more soluble and a more common problem than carbonates.

Bicarbonates cause hardness, and can cause calcium and magnesium from the soil and water to precipitate as insoluble carbonates. Sodium is left behind after the stripping of the calcium and

magnesium, thus increasing sodicity. There is little risk of this occurring if the bicarbonate level in the water is less than 90 mg/L, but high risk if it is greater than 335 mg/L.

Carbonates are less of a problem, and are not usually found in water with a pH less than 8.3.

Effect of sodium on plants

Sodium starts to reduce the growth of most crop and pasture plants when its concentration in water exceeds 300 mg/L or SAR 6.

Other elements

Excess levels of some elements in addition to those already mentioned can damage or restrict the growth of plants and affect stock and domestic use if found in water supplies. Standard water quality tests normally determine the levels of these elements:

- pH
- salinity, measured as electrical conductivity
- alkalinity
- hardness
- chloride (see below).

Other elements commonly found in water are:

- boron
- sulfur
- nitrates, phosphorus and potassium
- trace elements and metals.

Chloride

High chloride levels in water may cause poor plant growth and death of sensitive plants, particularly if sprayed on leaves. Foliar damage (leaf burn, bronzing and leaf drop) and uptake through leaves with overhead irrigation can occur at the chloride concentrations in Table 10.

Table 10. Chloride concentrations causing foliar damage	
less than 175 mg/L	175–350 mg/L
almond	pepper
apricot	potato
citrus	tomato
plum	
grape	
many ornamentals	
350–700 mg/L	greater than 700 mg/L
barley	cauliflower
maize	cotton
cucumber	sugar beet
lucerne	sunflower
safflower	
sorghum	

Adapted: *Australian and New Zealand Guidelines for Fresh and Marine Water Quality 2000.*

In surface or drip irrigation, for example, if water is not applied directly onto the plant, the more sensitive plants can tolerate slightly higher chloride levels than shown above, but 360 to 720 mg/L would still be the limit for most crops and pastures.

Treatment of these waters is similar to that used for saline waters, and includes diluting with good quality water, improving soil drainage, managing irrigation, and, for domestic use, desalinating.

Boron

Boron can damage some plants when levels in water are less than 0.5 mg/L, with serious problems when levels in water are greater than 3 mg/L. Fortunately, boron is easily leached, so high levels may only be a temporary problem.

Sulfur

Sulfur in water is not a problem for plants, but is a problem for livestock and people. Magnesium sulfate gives water a bad taste, and water pH decreases as sulfur content increases.

High levels of sulfur may cause diarrhoea in animals and people. In some circumstances, odour may also be a problem.

Aerating and oxidising the water source can alleviate sulfur problems.

Nitrates, phosphorus and potassium

Generally, surface water sources contain low levels of these elements. Higher levels (particularly nitrates) may be found in groundwater and recycled irrigation water.

At low levels these elements do not harm plants and can be used by plants for growth. Elevated levels of nitrates (more than about 25 mg/L, according to the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality 2000*) may affect crop yields.

Nitrates and phosphates in water can encourage the growth of algal blooms and aquatic weeds.

There are limits for nitrates in water for livestock and for human consumption related to health, particularly for young children, and you should seek advice from NSW Department of Health.

Nitrate levels in discharge water are also limited by the Office of Environment and Heritage. You should seek their advice on current guidelines.

Trace elements and metals

Other elements are sometimes found in groundwater, but seldom at troublesome levels. Testing for these is expensive and usually only needed for irrigation water if there is a known problem in an area or if you are a hydroponic grower. Threshold levels can be found in *Australian and New Zealand Guidelines for Fresh and Marine Water Quality 2000* at <http://www.environment.gov.au>

Irrigating plants in soil-less media

Many ornamental and vegetable crops and a limited range of fruit crops are grown in soil-less media and this practice is growing rapidly. There is also a broad range of products used in soil-less media formulations.

The rest of the information in this Agfact relates to crops grown by traditional methods (that is, in soil). There is not enough information to date to provide definitive guidelines on water quality for soil-less production. Until such time, the indicative values in Table 11 can be used as a guide.

Table 11. Irrigation water analysis checklist for ornamentals, vegetables and fruit grown in soil-less media

Test/analysis/parameter	Suitability range	
pH	suitable for all plants	5.5 to 7.0
	possible phytotoxicity	< 5.0
	possible precipitation of salts, consequent blockages in irrigation system; problems with effective chlorination	> 7.5
EC (dS/m) (see Table 12)	sensitive crops	0 to 0.7
	low tolerance	0.7 to 1.3

Test/analysis/parameter	Suitability range	
Alkalinity (mg/L CaCO ₃)	medium tolerance	1.3 to 3.0
	high tolerance	3.0 to 5.0
	very high tolerance	5.0 to 8.0
	suitable for most plants	< 40
	increasing problems	90 to 120
	generally not suitable	> 125
	suitable for most plants	< 70
Chloride (mg/L)	tip burn on sensitive crops	< 200
	not suitable	> 400
Hardness (mg/L CaCO ₃)	soft water	< 75
	hard water	75 to 300
	very hard water	> 300
Nitrates (mg/L) (for plant growth)	suitable for most plants	< 10
	possible precipitation of salts and consequent blockages in irrigation system	> 25
Sodium (mg/L)	suitable for most crops	< 60
	unsuitable for many crops	> 120
	suitable for most plants	< 90
Bicarbonate (mg/L)	increasing problems with plant growth, staining and blockages in irrigation equipment	90 to 120
	unsuitable	> 500
	no problems	< 0.2
Iron (mg/L)	iron bacteria may develop	0.3 to 1.5
	staining and blockages in irrigation equipment	1.5 to 4.0
	very difficult to treat	> 4.0
Copper (mg/L)	suitable for most plants	< 0.02
	becoming excessive for indoor irrigation systems	> 0.05
Fluoride (mg/L)	not recommended	> 0.2
	maximum concentration for most plants	< 1.0
Zinc (mg/L)	suitable for most plants	> 0.2
	not recommended	< 2.0
Manganese (mg/L)	maximum concentration for irrigation	0.5
	will clog irrigation equipment	1.5
Boron (mg/L)	suitable for most plants	< 0.5
	not suitable for most plants	> 2.0
Aluminium (mg/L)	maximum concentration for most plants	5
	limit for phosphorus-sensitive plants	1
Phosphorus (mg/L)	limit for plants already supplied with phosphorus	15

Adapted from *Water quality and nursery crop nutrition* (K Bodman 2002, issue 2002/11 of The Nursery Papers series, Nursery and Garden Industry Australia).

Note: The values and comments in these tables are indicative only. Seek advice for your specific situation.

Table 12. Tolerance of ornamental, vegetable and fruit plants (grown in soil-less media) to salinity in irrigation water EC_w

Irrigation water EC _w
Sensitive crops (less than 0.7 dS/m)
<i>Ornamentals:</i> african violet, azalea, begonia, camellia, dahlia, fuchsia, gardenia, hydrangea, magnolia, primula, violet <i>Vegetables:</i> bean <i>Fruit:</i> strawberry
Low tolerance crops (0.7 to 1.3 dS/m)
<i>Ornamentals:</i> Acacia longifolia, aster, bauhinia, geranium, gladiolus, lily, poinsettia, rose, strelitzia, tea tree, zinnia <i>Vegetables:</i> capsicum (pepper), lettuce

Irrigation water EC_w

Medium tolerance crops (1.3 to 3.0 dS/m)

Ornamentals: bottlebrush, carnation, chrysanthemum, heavenly bamboo, hibiscus, stock

Vegetables: cucumber, eggplant, rockmelon, tomato

High tolerance crops (3.0 to 5.0 dS/m)

Ornamentals: bougainvillea, New Zealand Christmas bush, oleander

Vegetables: zucchini

Very high tolerance (5.0 to 8.0 dS/m)

Ornamentals: banksia, coprosma, Norfolk Island pine, salt bush, she-oak

Turbidity

Turbidity is a measure of water clarity and an indicator of the quantity of suspended solids in the water. Turbidity measures the scattering effect that suspended solids have on light – the higher the intensity of scattered light, the higher the turbidity.

The main contributors to turbid (murky) water include clay, silt, fine organic matter and microscopic organisms, predominantly living algae.

The clay and silt end up in rivers, channels and dams from eroded catchment material washed into them after storm events. This kind of turbidity can be further exacerbated by the re-suspension of bottom sediments due to pump operation, wind mixing, activities of aquatic life such as carp, and thermal inversion (where bottom layers of water rise to become the top layers).

The fine organic matter can also result from catchment vegetation washed into the storage or stream or may be dead organic material produced in the water body itself, such as algae, bacteria and fungi. The microscopic organisms, such as algae, live and grow in the water storage. Odour may indicate decaying organic matter.

Removing vegetation and depleting organic matter will expose soil, making it more vulnerable to erosion. Sodic soils, in particular, readily disperse on wetting and the suspended clay particles make the water more turbid.

The major problem with turbid water is that the matter it contains can remain in suspension for a long time. This is particularly true of colloidal material (very fine clay and organic material) that can stain clothes and plumbing fixtures, block irrigation spray nozzles, contribute to a build-up of sludge in drippers and pipes and reduce the efficiency of water-softening units. Decaying organic material can also lead to a build-up of slime in pipes and drippers.

In extreme cases, turbid water can harm animals and deposit heavy sediment on leaves, reducing photosynthesis. On heavy soils, sediment can reduce water infiltration rates and cause poor drainage. Sediment can also act as a carrier of phosphorus and pesticides. Turbid water will also affect how well disinfection techniques including ultraviolet light and chlorination work, and slow the establishment of crops such as rice.

As organic matter in suspension may harbour microorganisms, turbid water may increase the risk of waterborne diseases. Apart from this, the major effect on human use is aesthetic: most people do not like the look of murky water.

Turbid water is treated by clarification, which is the chemical removal of clay, silt and other suspended matter.

Figure 13. a well-sealed catchment will minimise turbid water



Treatment

Clarification is achieved by adding a flocculant such as alum (aluminium sulfate) in a tank or dam. When added to murky water, the flocculant causes the suspended particles to form into bigger particles and settle out, thereby clarifying the water.

Alum, available in liquid or solid form, is one of the most common flocculating agents used to clarify water. Ferric alum is also widely used, as the small amount of iron it contains increases the effectiveness of alum over a wider pH range. Alum is most effective at pH 6.8 to 7.5; ferric alum is effective over the wider range of pH 5.5 to 8.5.

Ferric chloride is a good alternative to alum if you are regularly treating the water for human consumption. You should contact your local Health Department office for details. Other clarifying agents that may be considered are detailed in Table 13.

Alum treatment in tanks

If possible, treat the water in tanks rather than in a dam. Tanks should have two outlets: one near the base to drain off the sludge deposited in the bottom, and a higher one to take off the clear water. Preferably the treatment tank should be concrete or some other non-corrosive material. Apply ferric alum or alum at 0.5 to 0.75 kilogram per 10,000 litres of water to be treated. If using the solid form, first dissolve the chemical in a bucket of water. Then, using a jet spray, spread the solution evenly over the entire water surface and stir the water as much as practicable.

A flocculant's effectiveness depends on the amount and composition of dissolved salts and the water pH. Total alkalinity in excess of 100 mg/L is required for effective flocculation. Acid water may need a suitable alkali such as agricultural lime added to adjust the pH; otherwise floc formation may be slow and incomplete, with greater amounts of flocculant required. Further, both alum and ferric alum increase water acidity, making it more corrosive to metals.

For non-irrigation domestic use, add lime or soda ash at half the alum rate before applying the alum or ferric alum to counteract water acidity. If water hardness is greater than 100 mg/L, use soda ash instead of lime.

Use separate plastic buckets to dissolve the soda ash and alum. Mixing alum and soda ash together in the same bucket results in a chemical reaction that severely reduces the efficacy of the clarification process.

When adjusting the pH of irrigation and stock waters, use only agricultural lime, because it provides calcium to stock and plants, and may improve soil structure. Do not use soda ash for irrigation water because it is toxic to plants and breaks down soil structure.

Alum treatment in dams

To clarify dam water for stock and irrigation, alum and ferric alum can both be applied as described above. However, you must ensure that **treated water is not allowed to escape** to any watercourses. Water in dams may only remain clear until the next rain, when more suspended matter could be carried into the dam. For this reason it is more economical to treat the required amount of water in a holding tank.

As an alternative, blocks of ferric alum can be placed in channels feeding the dam. Run-off water flowing over these blocks will dissolve enough alum to keep the water clear. Well-grassed catchments will also reduce farm dam turbidity.

Commercial filters are available as a final step in water clarification. This is particularly important to avoid blockage when micro or drip irrigation systems are used (see 'Filtration' for further information).

Repeated and regular dosages, or dosages above those listed, may result in water quality detrimental to aquatic life and in certain circumstances may render the water unsuitable for domestic or livestock use.

Table 13. Characteristics of various flocculating agents

Flocculating (clarifying) agent	Typical dosage for every 10,000 litres of water treated	Comments
Alum (aluminium sulfate)	0.5 to 0.75 kg	Most effective between pH 6.8 and 7.5; still works outside this range, but not as well. Will increase water acidity slightly. Floc formation is slow in acidic water. Takes between 2 and 24 hours to flocculate and settle into a stable sludge. Do not use if water pH is less than 5.5 due to likely release of toxic levels of dissolved aluminium.
Ferric alum (crude alum with iron impurities)	0.5 to 0.75 kg	As above, but most effective over a wider pH range of 5.5 to 8.5.
Ferric sulfate	up to 2.5 kg	pH greater than 5 is required, or it may lower oxygen levels.
Ferric chloride	up to 3 kg	pH greater than 5 is required, or it may lower oxygen levels. Very corrosive.
Gypsum (calcium sulfate)	0.5 to 3 kg	Little pH change. Slight increase in salinity. Needs to be spread evenly across water surface. Can cause scum deposits in equipment. Takes 36 to 72 hours to flocculate and settle.
Lime (calcium hydroxide)	up to 3 kg	Increase in pH. Slight increase in salinity. Usually contains insoluble impurities and requires constant stirring due to being sparingly soluble in water.

Algae

Algae are small forms of plant life that exist in a wide range of habitats. They are commonly thought of as aquatic organisms but many are terrestrial or live in association with other organisms like fungi and animals. They lack roots, stems and leaves, but, like other plants, have **chlorophyll** as their primary photosynthetic pigment.

In water sources, algae occur quite naturally in both fresh and brackish waters. Like all plant life, algae respond to sunlight and fertilisers, and when environmental conditions are right, excessive algal growth will occur. For example, excessive algal growth (Figure 7) can occur when nutrients, particularly phosphorus and nitrogen, pollute the water. As little as 0.01 mg/L phosphate in freshwater lakes and streams stimulates the growth of algae and other aquatic life that may clog irrigation systems and make water unpalatable to stock.

Figure 7. Algal growth can block irrigation equipment and may affect human health.



Excessive algal growth can affect the taste of drinking water, produce odour problems, block pump foot valves, clog filters, reduce the aesthetic and recreational amenity of water bodies and affect water treatment processes.

Some algae produce toxins that can cause stock deaths and affect human health.

When algae die, their decomposition depletes the oxygen levels in the water source. If too much oxygen is lost, further water quality problems can arise, including the release of iron and nutrient from sediments, kills of fish and other aquatic animals and the production of noxious gases such as hydrogen sulfide.

A considerable range of algae is found in freshwater. These include green algae, blue-green algae, diatoms, dinoflagellates and cryptomonads.

- Green algae are the most diverse and may be microscopic or present as large clumps or mats of tangled filaments.
- Diatoms, dinoflagellates and cryptomonads are generally only visible under a microscope.
- Blue-green algae are also microscopic but large colonies and aggregated filaments can be visible in water.

Algal blooms are excessive growth of a particular algae species. The most obvious sign of an algal bloom is a discolouration of the water. For example, diatoms and dinoflagellates discolour the water to a brown hue; green and blue-green algae make it appear green; and some cryptomonads make the water appear red.

All algal blooms can cause water use problems. However, of most concern are those caused by blue-green algae, as a number of these are toxic.

Blue-green algae

In Australia, there are a number of genera of blue-green algae that are toxic. They include *Dolichospermum*, *Microcystis*, *Cylindrospermopsis* and *Nodularia*. In NSW, *Dolichospermum* and *Microcystis* are the most common types of freshwater blue-green algae causing blooms. *Dolichospermum* generally grows in rivers and lakes and *Microcystis* is often found in lakes and reservoirs.

Blooms may be seen as a green colouration in the water or as a surface scum. Scums are often green or blue-green and vary in consistency from paint-like slicks to small green floating dots.

Toxic blue-green algae can produce three different forms of toxins:

1. Hepatotoxins attack the liver and other internal organs. They can cause gastroenteritis, nausea, vomiting, muscle weakness and visual disturbances.

2. Neurotoxins affect neuromuscular performance and can lead to paralysis and respiratory arrest.
3. Lipopolysaccharides are skin irritants that can cause dermatitis and conjunctivitis. They may also cause stomach cramps, nausea and fever if consumed.

As well as responding to excessive nutrients, algal blooms are most likely to occur when:

- the water is calm
- the water temperature is warm (above 20°C)
- there are low or no flows
- the water is fairly clear
- pH is slightly alkaline
- dam water layers are stratified and do not mix.

Algal blooms have occurred even when the above conditions were not present.

If you suspect blue-green algae are in your water, contact Local Land Services or the NSW Office of Water for advice. In the interim, do not use the water for stock watering or domestic or recreational use, and do not allow stock to graze algal mats.

Effects on irrigation water

Care should be taken if using water contaminated by blue-green algae for irrigation. As many toxins are very slow to break down, human and animal health may be threatened if contaminated water is applied directly to crops and pastures. Do not use water that has blue-green algae in it directly on plants being grown for human consumption. This is particularly so for spray-irrigated salad and leafy vegetables, as dried algal cells on the leaves can remain toxic for several months.

Effects on livestock

Livestock can die from drinking contaminated water. The toxins can cause scouring, red urine, liver damage and sudden death in cattle and sheep. Surviving animals show photosensitivity, which is a form of sunburn restricted to white areas of cattle and the nose and ears of sheep. This may affect feeding and result in cows refusing to suckle their young. Milk production may decrease in dairy cows. Scouring occurs with poultry, resulting in reduced egg production. Deaths have also been recorded in bees and dogs, and toxic algae have been implicated with wildlife deaths.

Effects on domestic usage

Domestic water uses such as cooking, bathing, laundry and recreational activities such as swimming are all affected by blue-green algae. Skin contact through showering or swimming may result in skin irritations, swollen lips, sore throats, eye and ear irritations, rashes and hay fever symptoms. Drinking affected water may result in diarrhoea, nausea, vomiting and muscle weakness. Boiling the water will not reduce the effect of blue-green algae toxins. See your local doctor immediately if you experience symptoms you think result from blue-green algae in your water.

Treatment

If a bloom is suspected, you should find an alternative supply of water for domestic, stock and irrigation use until the algae is identified. If there is no alternative for stock and irrigation use, then use water from deeper in the river or dam, or from areas not covered by scums, as these may be less contaminated. It also may be possible to allow stock to drink from an area on the upwind side of the bloom if the bloom is localised.

The best way to manage algal blooms is to prevent them from happening. A key long-term strategy is to improve nutrient management and erosion control on your farm. This will help control blue-green algae in your farm dam and assist with management of blue-green algae in rivers and creeks.

Algae will not grow in total darkness, so cover the top of domestic storage tanks to exclude all light. Do not use translucent fibreglass tanks.

Figure 8. An aerator will help keep algae levels low.



In farm dams, artificial aeration can help mix up the water and add oxygen. This may help control accumulations of soluble iron, ammonia and hydrogen sulfide, as well as help control algal blooms. Aeration can be achieved in a number of ways. The simplest method is to cascade the water into a holding dam or tank as described in this PrimeFact under the heading 'Iron'. Alternatively, an aerator like the one pictured in Figure 8 can be used.

Chemical dosing to control algae

Previously, copper sulfate was recommended as a treatment for algae, but this is no longer a recommended product.

At the time of publication, in NSW, only Coptrol Aquatic Algicide®, Cupricide Algicide® and Cupricide 110 Algicide® are approved for the control of blue-green algae, green algae, diatoms and flagellate algae. They must be used in strict accordance with their label conditions and directions. These products contain copper as mixed complexes and are registered for use in farm dams, rice paddies and irrigation conveyance systems. **They must not be used** in rivers, streams, creeks, wetlands, lakes or billabongs, and water treated with these products must not be allowed to spill into these water bodies. Their conditions of use further prevent their application when birds are feeding on algae or in water containing fish.

As with all chemicals, read the instructions before use and wear the appropriate safety equipment.

Note: Do not treat drinking waters used by farm animals grazing on heliotrope or ragwort.

Alum and gypsum may be used to protect small dams from blue-green algae, as they remove phosphorus from the water. Gypsum appears to be less effective if pH values in the water are below 10.

Dosing is only appropriate for farm dams, and must not be applied to natural waterways. Ideally dosing should be carried out before summer, and certainly before a bloom has developed. The recommended dose for a farm dam is 50 kilograms of alum and 50 kilograms of gypsum for each megalitre of water. Because of variations in water quality and algae, it is advisable to conduct a preliminary trial in a "44-gallon drum" (200 litre container) to establish the correct dosage.

Activated carbon

Activated carbon filters have long been used to improve the taste of domestic water supplies and reduce odours. They can also be used to remove many types of blue-green algae toxins.

Activated carbon is a processed form of charcoal and comes in two types – granular activated carbon (GAC) and powdered activated carbon (PAC). GAC offers the better method of treatment, particularly when algal blooms are a regular occurrence. The level of toxin removal is dependent on contact time, flow rate and the extent the filter has previously been used.

In-line GAC filters are commercially available for use at a domestic level. Filter the water through a conventional sediment filter before passing through the carbon filter. This will remove larger particles and increase the life of the carbon filter.

Colour, taste and odour

Undesirable colour, taste and odour in water supplies may make domestic use unpleasant or unpalatable and may also deter stock from drinking.

Colour and taste, in themselves, are not an irrigation issue. Odour, however, may be a problem if irrigating crops in close proximity to neighbours.

The various colours, tastes and odours found in some water sources may be the result of suspended matter, bacteria, algae, organic wastes and chemical pollutants.

Colour in water is usually caused by organic substances, such as algae or tannins released from vegetation. Dissolved iron and manganese can also colour water, while suspended clays will make water appear murky.

High concentrations of some elements, like iron, calcium, sodium, magnesium and chloride, will make water taste 'bad', bitter or brackish. Some algae can also cause taste problems.

Odours may come from algae, rotting vegetation, high sulphur content and septic leakage into storages. Decaying iron bacteria can also release an offensive smell, as will dead birds and animals in water sources.

Treatment

Chlorination, clarification, aeration and removal of iron and algae will assist in alleviating problems of colour, taste and odour. These treatments have been previously described in this PrimeFact. In addition, periodic flushing of pipelines, removal of decaying vegetation and prevention of contamination (for example, diverting septic waste) will improve the colour, taste and odour of water supplies.

As a final step to remove bad odour and taste and to ensure acceptable water supplies, use an activated carbon filter preceded by a conventional sediment filter. Activated carbon treatment absorbs many organic impurities. The surface of each carbon particle attracts and holds the impurities as they pass through the filter. Activated carbon filters are more fully described in the 'Algae' section.

Bacterial growth

Farm water can be affected by various sources of pollution including livestock urine and faeces, seepage from septic tanks, run-off from fertiliser sheds and industrial waste. These pollutants can encourage aquatic weeds (Figure 9) and microorganisms such as algae and bacteria to multiply rapidly to large numbers, making the water unfit for stock, domestic and irrigation uses.

Contaminated water is unpalatable to stock and may affect animal health. It is also both unattractive and unhealthy for domestic use. Blockage of irrigation equipment may become a serious irrigation problem.

Figure 9. Nutrient-rich waters can encourage aquatic weeds.



Prevention

Try to eliminate, or at least reduce, the cause of pollution. For example, do not allow stock direct access to the water supply and build dams away from milking sheds, pig pens, septic tanks and fertiliser stores.

Treatment

If contaminated water has to be used, treat water for both general domestic use and stock with a suitable sterilising agent to kill undesirable organisms. Plant pathogen control is discussed in the next section, 'Disinfecting irrigation water'.

If water is for human consumption, consult NSW Department of Health or your council health officer before treatment.

Chlorine, available in various forms, is the main sterilising agent used. When chlorine or chlorine compounds are added to water, they react with organic and inorganic pollutants and destroy bacteria. Thus, the more impurities in the water, the more chlorine needed. For example, for every part of ammonia (a common pollutant found in human and animal urine and faeces) present in the water, it will take eight to ten times the quantity of chlorine to break it down. Therefore, to remove bacterial hazards, add enough chlorine to give a free chlorine residue of 0.2 to 0.5 mg/L.

'Free residual chlorine' is the amount of chlorine left after the chemical has reacted with the bacterial and organic matter.

Table 14. Types and rates of chemicals for chlorination of water

Chemical	Form	Dose per 1000 L required to give available chlorine equivalent to		Effect on water pH
		10 mg/L for very lightly polluted water	50 mg/L for more heavily polluted water	
Sodium hypochlorite (12%)	liquid	100 mL	500 mL	increase
Bleaching powder (30%)	powder	40 g	200 g	increase
Calcium hypochlorite (70%)	powder or solid	18 g	90 g	increase
Chlorine gas	gas	10 g	50 g	decrease

The efficiency of chlorine is best at a pH of 6.5 to 7.5 and a temperature above 25°C, in the absence of strong sunlight.

For best results, treat water in tanks, rather than in dams. Natural water supplies that are generally clear and lightly polluted can be treated effectively with 10 mg chlorine/L of water, with up to 50 mg/L needed for heavily contaminated water. Table 14 lists application rates for different chlorine compounds.

Filtration to remove suspended matter will reduce the amount of chlorine required. Do not use more than 50 mg/L of chlorine because of possible irritation to skin and eyes. Because chlorine compounds break down quickly in strong sunlight, treat water in the evening to allow sufficient time for the reaction to be completed.

Use a swimming-pool test kit (Figure 10) to see how much free chlorine is left. Take a sample of water from about 30 cm below the surface. Add the indicator solution to the water sample and then match its colour to the calibrated chart or disc.

Each of the chemicals listed in Table 14, applied at the specified rate, is equally effective. However, because sodium hypochlorite, bleaching powder and calcium hypochlorite increase the pH of the water, making it more alkaline, their use is preferred where the water supply is acid. Chlorine gas decreases pH, increasing acidity, and is recommended for alkaline water. It is preferable to use it and calcium hypochlorite for irrigation and livestock. Sodium hypochlorite and bleaching powder are preferred for domestic purposes, to avoid increasing water hardness (see 'Hardness').

Treating water in recycling storages

Water held in storages can form into layers (stratify) and may concentrate heavy metals in the lower layers and ammonia in the surface layers. The pH will also change through these layers from as much as 9.5 to 10 at the surface to below 6 at the bottom of the storage. Monitor water quality in these layers carefully

and locate the suction intake of pumping equipment so that the best quality water is extracted. Installing an aeration system (Figure 8) in the dam can:

- destratify the storage and remove bottom sediments
- increase dissolved oxygen levels
- create an environment that is unfavourable for algae growth.

Often these aerators are used in conjunction with liquid organic biological activators that increase bacterial action to break down suspended solids, to lower BOD, ammonia and nitrates and to increase dissolved oxygen. Aeration and chlorination can also control odours.

Figure 10. Swimming pool test kit



BOD = biological oxygen demand – indicates the size of the bacteria population in the water.

Disinfecting irrigation water

Water for irrigation is becoming harder to obtain and more expensive. In addition, the environmental performance of industries, including irrigation farming, is under public scrutiny. For intensive horticulture, in particular, water recycling addresses these issues, but introduces challenges to growers to embrace technologies and procedures to ensure effective and plant-safe water reuse. The provision of disease-free irrigation water is part of this challenge.

Water disinfection controls bacterial growth in the irrigation system and reduces the risk of bringing disease into the farm via irrigation water. Many disease-causing organisms are easily transported in irrigation water from diseased plants. Examples include *Fusarium* and root rot-causing fungi such as *Phytophthora*.

There are a number of disinfection techniques available. Their effectiveness is influenced by different aspects of water quality, but in general disinfection systems require water that is:

- free of sediment, organic matter and colloidal material
- in the right pH range
- low in iron and manganese.

Pre-treatment

Before recycled water is disinfected, try to remove heavy sediments, organic matter and very fine clays. Disinfection will be a lot easier, effective and generally cheaper if you do.

Heavy sediments (sands and gravels) can be removed in a sediment trap (Figure 11) at the end of the open drains. The trap needs to be regularly cleaned to remain effective.

Figure 11. A typical sediment trap

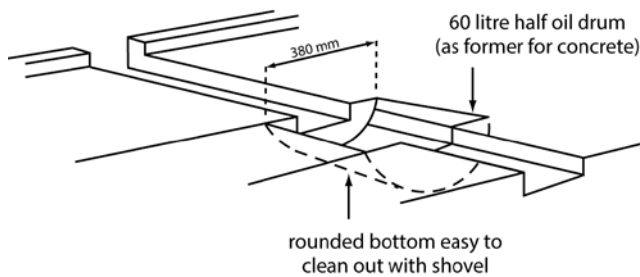


Figure 12. A typical baffled floating debris trap



Floating material can be removed at the collection point of run-off from storage areas, car parks and at the end of drains from production areas. A simple baffle system (Figure 12) removes growing media, oils, polystyrene, plastic and plant material. The baffle needs to be cleaned regularly to maintain efficiency.

Chemical treatments can remove fine clay particles but it is far better to avoid the problem in the first place. To keep fine clays out of your water storage, seal catchments that collect recycling water and keep dam catchments well grassed. If this is not possible or desirable, use a flocculating agent such as alum (see 'Turbidity') to clarify the water, preferably in a tank.

Organic particles are removed by filtration. The best filters to remove these particles are media filters with 1 mm crushed basalt. This material is very angular and hooks organic matter effectively. Disc filters can also be used but must be fitted with at least 60-micron openings.

Disinfection treatments for irrigation waters

Irrigation water can be disinfected using **non-chemical methods** such as heat, ultraviolet radiation and filtration, or **chemical treatments** such as chlorine, chlorobromine, chlorine dioxide and ozone.

Non-chemical disinfection treatments

Heat disinfection is effective in killing waterborne pathogens. Water is treated using two tanks (heat exchangers). The water is preheated in the first tank using the heat lost from the disinfected water that has already been through the system. Next, the water is pumped to the second tank and an external heat source heats the water to the disinfection temperature, 95°C, for at least 30 seconds. After this, the water flows back to the first tank to be cooled down. The disinfected water is then stored in a separate tank until needed.

Micro-filtration of water through 5-micron filters may almost completely eliminate *Phytophthora* and many other waterborne pathogens. However, because the filter pores get clogged, they must be regularly maintained to be reliable and effective. Recent advances in membrane technology and cleaning will make this method more reliable.

Ultraviolet (UV) radiation is widely used in disinfecting drinking water and treated sewage effluent. UV radiation is an effective and environmentally friendly treatment for controlling *Phytophthora cinnamomi*, *Fusarium oxysporum*, *Colletotrichum capsici* and *Alternaria zinniae*. However, the water must be very clear (greater than 60% UV transmission) for the treatment to be effective.

Filtering generally does not greatly improve UV transmission, as dissolved solids are the main absorbers of this radiation. Nevertheless, filtration is a key element in UV treatment because it is needed to remove solids that may protect fungal spores from radiation. Have your water tested for turbidity before considering UV treatment.

Figure 14. UV systems are effective pathogen controls but the water has to be free from suspended particles and tannins. (Iron and manganese ions absorb UV light, as do coloured chelates)



Figure 15. Slow sand filtration can control some plant pathogens at flow rates between 100 and 300 L/m²/h.



In **slow sand filtration**, water passes very slowly through a bed of fine sand at least 800 mm deep at low flows, and microorganisms that are living in the filter kill pathogenic bacteria and fungi (Figure 15). Other material like manufactured basalt rock fibres is also used instead of sand.

Soon after the filter process begins, a skin forms on the surface of the filter bed. It is made up of organic and inorganic material and a variety of biologically active microorganisms that break down organic matter. The microorganisms will die if the filter bed is allowed to dry. Re-establishing them may take several weeks, during which the filter is not effective.

Chemical disinfection treatments

Chlorination is currently the most widely used irrigation water disinfectant in Australia. One of chlorine's biggest advantages is its ability to provide a stable residual that helps clean slimes out of the irrigation systems. If chlorine is to be effective in controlling the spread of pathogens, it is essential to accurately control both the free chlorine content and the pH. Chlorination is unsuitable if the pH of water is above 7.5.

Before chlorine can kill pathogens, it will react with any iron, manganese and organic matter in the irrigation water. Hence, to achieve biocidal concentrations of 1 to 3 mg/L free chlorine, it may be necessary initially to provide a higher dose of chlorine. A trial-and-error approach may be necessary to determine the effective initial chlorine dose for your irrigation water.

Chlorine comes as gas, as liquid or in powder form. Current safety requirements may preclude gas. Liquid (sodium hypochlorite) is more convenient for accurate dosing than powder but must be stored in a rust-resistant tank. Monitor the treated water to gauge how much free chlorine it contains.

Figure 16. A metering pump is used to accurately supply the desired concentration to provide the required residual free chlorine. These pumps can be adjusted to meet variations in water quality throughout the season.



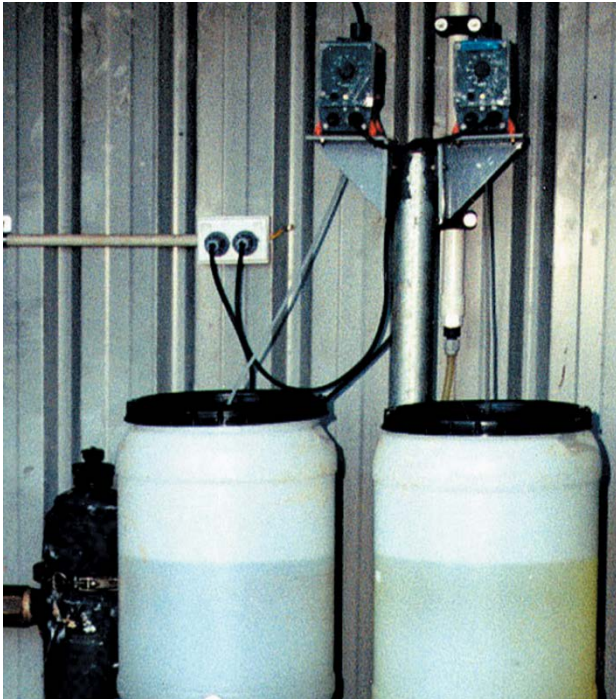
Chlorobromination. Bromine is a member of the same family as chlorine and has similar action in disinfecting water. Just as chlorine needs to form hypochlorous acid, bromine needs to be formed into hypobromous acid. This is best done by adding sodium bromide, a natural compound found in sea water, to sodium hypochlorite. Hypobromous acid is a very effective disinfectant over a wider pH range. At pH 8.5, 60% of bromine is still present as hypobromous acid whereas with chlorine very little hypochlorous acid remains at pH 8.5.

Figure 17. When using chemical solutions in an irrigation system on town water, a suitable backflow device is required to stop reversed flow to the water service.



Recycled water commonly used in horticulture contains various and fluctuating levels of ammonium and other nitrogen-based compounds. Both bromine and chlorine react with these compounds to form bromamines and chloramines. Chloramines are poor biocides, while bromamines show disinfection properties comparable to free bromine, which means less chemical should be required when using bromine.

Figure 18. Chlorobromination provides two oxidising agents, hypobromous acid and hypochlorous acid, for the disinfection of water.



Chlorination tips

- Inject chlorine upstream of the filter to remove bacteria or algae growing in the filter.
- Inject chlorine downstream of the filter for disease control.
- It is not recommended that chlorination be done when the concentrations of dissolved iron or manganese in water are high. This is because chlorine acts to oxidise the iron to form precipitates that could cause clogging.
- Before using chlorine injection pumps, carefully refer to the manufacturer's instructions.

Chlorine dioxide is a greenish-yellow gas that is relatively unstable and cannot be stored or transported. For this reason, it is formed on-site, by combining hydrochloric acid with sodium chlorite. Impurities in the water reduce the amount of chlorine dioxide available for disinfection, and sensors need to be installed to adjust the output from the chlorine dioxide generator to maintain the required concentration.

Work on phytotoxicity thresholds for chlorine dioxide and its breakdown product chlorite have not yet been determined.

Ozone is an unstable blue gas that is a natural component of the earth's upper atmosphere. It is made by passing dry air or oxygen through a high-energy electric field. The cooler the air, the higher the production of ozone.

The oxidation potential of ozone is about twice that of chlorine and it reacts more rapidly and is less affected by pH and temperature. Ozone can control algae and oxidise manganese and ferrous ions and many agricultural chemicals including some herbicides. It also coagulates natural water constituents, which improves filtration.

Ozone does not produce environmentally "unfriendly" byproducts as chlorine and bromine do, but does have a number of disadvantages. For example, it is expensive, and to be effective over periods greater than 10 minutes, water must have a pH below 7 to reduce the rate of ozone breakdown.

Ozone is a popular method of water treatment in the Netherlands where ozone and nitric acid are injected into the water at the same time to achieve a pH of 4 to 4.5. Current research suggests injecting about 14 g/100 L of ozone for one hour kills bacteria, fungi and viruses.

Special consideration must be given to the materials in contact with ozone, as it quickly corrodes brass, rubber and many plastics. Stainless steel is suitable, as are silicon 'O' rings.

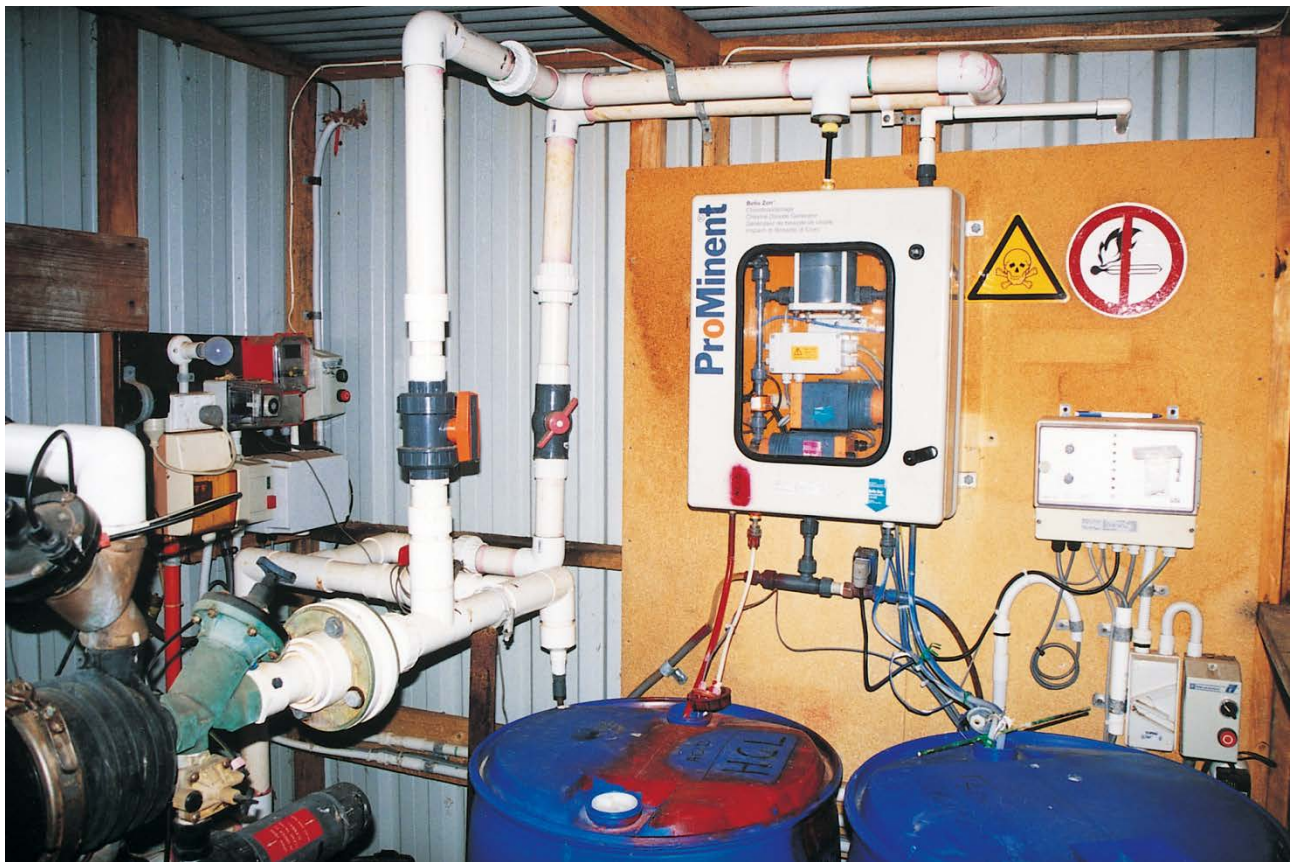
Tips for successful disinfection

Know the quality of the water you are treating. This can change constantly.

Before choosing a water disinfection strategy, do a complete analysis of water quality over an extended period (say, 12 months), as seasonal variation can be substantial.

- Whatever disinfection system you choose, pre-treatment has a big bearing on its success.
- Chemical systems need monitoring to ensure the right dose is available.
- Because most recycled water has a high pH, which is unsuitable for many disinfection systems, you may need to install equipment that automatically adjusts pH.
- If you are adding nutrients to your water, wait 30 minutes after treatment before injection.
- Where frequent backflushing of the filter is required, automation may be desirable.

Figure 19. Chlorine dioxide is a potent oxidant with rapid contact time kill rates at a low concentration and will work in water with pH as high as 10.



Filtration systems

Filters are essential in irrigation systems where low discharge emitters are used (drippers, jet sprays, micro-sprinklers and mini-sprinklers). Low discharge emitters have small outlets and are susceptible to clogging. The best way to stop your system clogging is to use filtration to remove the hazards before they enter the system.

The main causes of clogging include:

- suspended solids such as sand, silt and organic matter (including algae)
- chemical material, including the precipitates of iron and manganese as well as carbonates
- biological material, such as iron bacteria.

Filtration systems can only remove solid material. For example, iron, as ferrous hydroxide, is soluble in water and in this form cannot be filtered out. To remove iron from water, you must precipitate the iron, by either aeration or chlorination (see 'Iron'), to allow its removal by filtration.

Before you buy filtration equipment, have your water analysed so you know what potential clogging hazards you have to deal with. For filtration purposes, this water analysis must at least include information on:

- suspended solids, their quantity (mg/L) and their nature (for example, organic)
- iron (g/L)
- hardness (CaCO₃)
- pH
- manganese (mg/L).

Talk to your local industry association, neighbours or irrigation supplier about local water quality conditions and any problems they have encountered.

Filter selection

The degree to which you need to filter generally depends on the type of irrigation system, the water quality and the emitter installed. A filter that is too coarse will result in frequent emitter blockages, while one that is too fine will result in frequent filter blockages.

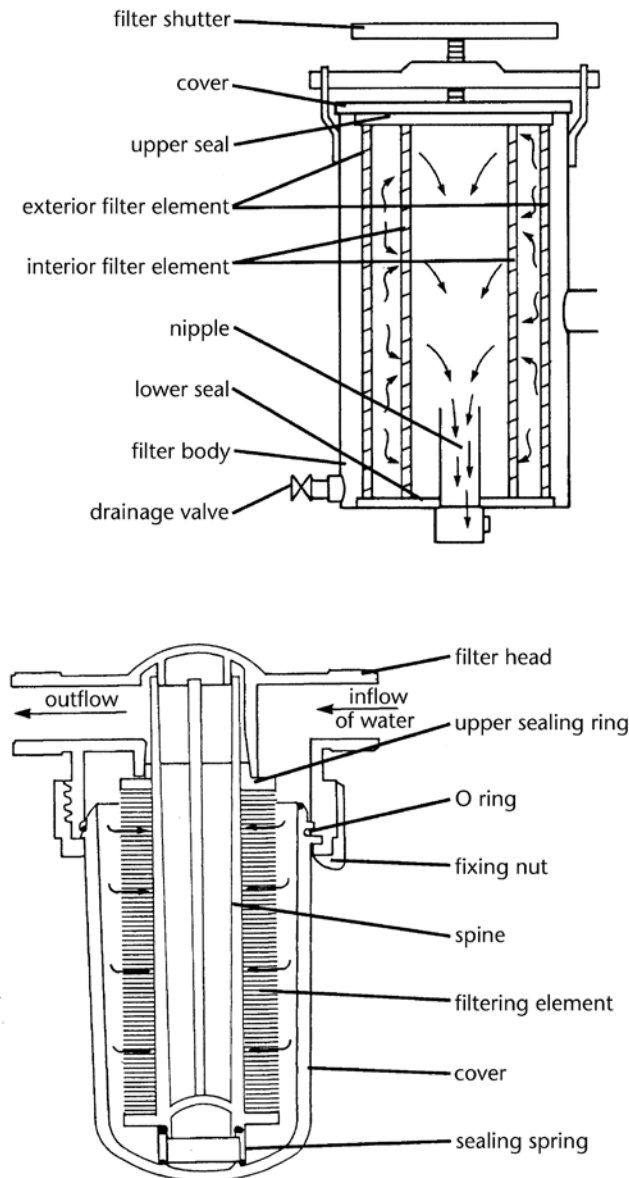
Most emitters have manufacturer's recommendations on the degree of filtration required, but these general guidelines can be used where no recommendations are available:

- In drip irrigation, filter from one-sixth to one-tenth the diameter of the emitter's smallest opening.
- In jet spray, micro-sprinkler and mini-sprinkler irrigation systems, filter one-third to one-sixth of the emitter's smallest opening.

Filtration equipment

Filtration equipment can include centrifugal sand separators, disc filters, screen filters and media filters. There are also pre-filters such as settling basins, trash racks or screens, sediment traps and floating debris traps.

Figure 20. Typical screen and disc filters



Centrifugal sand separators

Centrifugal sand separators can efficiently remove suspended mineral particles. They are used mainly when pumping out of wells or water supplies that produce large amounts of sand, or where a particularly dirty water supply would overload screen or media filters.

A centrifugal sand separator can be installed on the suction side of the pump, thus protecting the pump and the valves from wear and tear, or it can be installed on the delivery side to protect the irrigation system and to pre-filter the water for other filters.

These filters are often self-cleaning and require little maintenance, but they will not remove organic material and should be checked often for proper operation.

Screen filters

A screen filter is a single surface filter with only one retention point for solids. All the apertures on the screen are uniform in size and can range from 600 microns (30 mesh) to 75 microns (200 mesh). The filter element is usually a woven synthetic or stainless steel material; perforated or slotted sheets or rolls are also used. As well as being primary filtration units, screen filters are often used as secondary filters for media filters.

Screen filters can be cleaned manually or automatically.

Disc filters

Disc filters are multi-surface filters and have a uniform filtration size. The filtration element is a series of grooved discs placed one on top of the other, forming a tightly packed stack. The actual filtering process occurs in the space created by the adjoining faces of the adjacent discs: the degree of filtration depends on the fineness of the space between the discs. Disc filters are efficient in retaining large particles.

Backwashing is achieved by reversing the water flow while reducing the pressure that is keeping the discs together.

Media filters

Commonly known as sand or gravel filters, media filters are simply layers of sand, gravel or anthracite, or any combination of these, in a tank. Media filters are especially suited to removing fine suspended materials such as fine sediments and suspended organic material.

Media filters are cleaned by backwashing: the normal downward flow is reversed so that the filter media is lifted and expanded or loosened, allowing trapped sediment to be released. Backwashing can be automated or performed manually.

Secondary or backup filtration is recommended when using a media filter. This secondary filter is usually a screen or disc filter and is located after the media filter to prevent any suspended solids from the media filter entering the irrigation system.

Figure 21. Media filters are effective for removal of organic material and fine sediments.



Monitoring water quality

Water quality does not stay constant. It can vary from season to season and needs to be monitored regularly.

By ordinary observation, you may be able to detect troublesome levels and changes in some aspects of water quality, including colour, odour, iron staining, turbidity and presence of algae at problem levels. Reduced flows through irrigation equipment may indicate clogging or a build-up of scale.

Regular monitoring allows you to take remedial action before too much damage or loss of production occurs.

Testing water quality

Most of the chemical changes to water quality cannot be detected by eye or smell, but need laboratory analysis or testing with portable instruments. Unless this testing and continuous monitoring is in place, a build-up in salinity will first show itself in poor plant growth and reduced production, when it is already too late to rectify the situation for that crop. Increased soil sodicity may only be noticed when chemical and physical changes in the soil reduce infiltration and cause severe waterlogging.

NSW Department of Primary Industries has a water testing service that carries out a standard test for pH, electrical conductivity, alkalinity, hardness, chloride, turbidity, calcium carbonate saturation index and SAR. Other accredited laboratories also carry out these tests.

As the salinity of both surface water and groundwater can change quickly, test them regularly throughout the irrigation season with a properly calibrated hand-held salinity meter. Both sources should be analysed at an accredited laboratory at least every two years, during the early part of the irrigation season.

Water used for surface (or 'flood') irrigation should be tested for its salinity, SAR and pH. An initial test of groundwater should include bicarbonates, chloride and boron as well. If the water is to be used for spray or drip irrigation, testing for its hardness is also advisable.

Test recycled water regularly throughout the season, particularly for changes in pH and salinity.

Testing soil

Where saline or saline-sodic water (with an SAR greater than 3) is used for irrigation, it is advisable to monitor changes in soil salinity and sodicity every three years or so through the standard soil tests carried out by NSW DPI or by the major fertiliser companies. The topsoil (0–10 cm) and subsoil (to, for instance, 50 cm) should be sampled and tested separately. For appropriate soil management decisions in the future, irrigators should keep these soil test records for each paddock or field which is irrigated with water of marginal quality.

Further reading and references

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