# Irrigation of Amenity Horticulture with Recycled Water

*A handbook for parks, gardens, lawns, landscapes, playing fields, golf courses and other public open spaces*

**Dr Daryl P Stevens, Steven Smolenaars and Jim Kelly**

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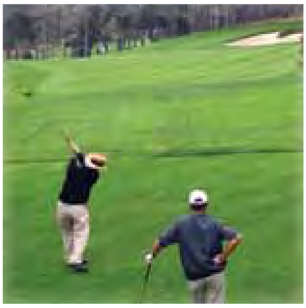



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Smart Water Fund

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# Definitions

| | |
|---|---|
| Amenity Horticulture | Refers to the irrigation of plants grown for our enjoyment, ease and comfort for example, open spaces including parks, gardens, public landscapes and turf (race tracks, ovals and golf courses). |
| Arboriculture | The maintenance and management of trees in private and public gardens, parks and streetscapes; transplanting of large trees; protection and rehabilitation of trees; provision of advice on tree planting and maintenance; and evaluation of tree health and monetary value. |
| Floriculture | The growing and harvesting, or wild harvesting and processing, of commercial flowers, flower seed, foliage and essential oil plants; management and maintenance of field and controlled growing environments; and post harvest treatments and production of plant products. |
| Landscape | The construction and maintenance of domestic and commercial landscapes; design of gardens and commercial landscapes, rehabilitation of urban bush land; construction and installation of amenity and recreational landscape structures; and provision of technical advice and forward estimates on landscape development proposals. |
| Nursery (Retail and wholesale) | The propagation, production and maintenance of plants for sales and/or hire; wholesaling and retailing of plants and associated products; provision of advice on plant selection and garden design; and the marketing and promotion of plant products and services. The major distinction in this sector is the division between production, retail and wholesale nurseries, with some nurseries involved in two or three sectors. |
| Parks and Gardens | The management and maintenance of public and private parks, reserves and gardens; natural bush land and community recreation areas; historic, cultural and special use areas; design and implementation of special plant displays; provision of advice for plant selection; and contract administration and management. |
| Turf Management | The establishment and maintenance of commercial and recreational turf; design and preparation of sports turf playing surfaces; domestic mowing and turf maintenance operations; commercial growing and supply of turf; management of recreational and sport turf facilities; and provision of technical advice. |
| Mains Water | Usually refered to as potable or drinking water delivered through a water main. |

# Abbreviations

| | |
|---|---|
| AGWR | Australian Guidelines for Water Recycling |
| BMP | Best Management Practice |
| Ca | Calcium |
| CF | Crop factor |
| DHS | Department of Human Services |
| Eir | Irrigation efficiency factor |
| Erf | Rainfall efficiency factor |
| EC | Electrical conductivity |
| ECe | Electrical conductivity of a soil saturation paste extract |
| ECi | Electrical conductivity of irrigation water |
| ECsw | Electrical conductivity of soil water |
| EC1:5 | Electrical conductivity of a soil:water extract at a ratio of 1:5 |
| EIP | Environmental Improvement Plan |
| EPA | Environment Protection Authority |
| EPHC | Environmental Protection and Heritage Council Authority |
| ESI | Electrochemical Stability Index |
| ESP | Exchangeable Sodium Percentage |
| ET | Evapotranspiration |
| HACCP | Hazard Analysis Critical Control Point |
| IR | Irrigation requirement |
| Kc | Crop coefficient |
| LF | Leaching fraction |
| LR | Leaching requirement |
| Mg | Magnesium |
| Na | Sodium |
| NRMMC | Natural Resource Management Ministerial Council |
| OHS | Occupational Health and Safety |
| PE | Pan Evaporation |
| QA | Quality Assurance |
| RF | Rainfall |
| RSC | Residual Sodium Carbonate |
| SAR | Sodium Absorption Ratio |

# Preface

This handbook has been designed and written for open space and recreation managers and keepers to help them understand and use recycled water; providing the practical on-the-ground how-to advice. The handbook has been written specifically for those responsible for the management of the site (i.e. Superintendents or Acting Superintendents). State and national guidelines have provided the framework and the boundaries to manage within. The Victorian guidelines (EPA Victoria 2003, 2005) are most relevant for the Victorian context.

This advice and knowledge is documented in a way that is both useful for day-to-day use and also for those who seek greater information to help improve their recycled water use from an economic or environmental perspective.

The authors would like to thank the many individuals that have contributed to drafting and finally publishing the handbook. These people have provided valuable feedback and considerable on-the-ground knowledge.

# Introduction

This handbook is specifically for those involved with the irrigation of recycled water on amenity horticulture such as turf (ovals, golf courses, race tracks) and landscapes (gardens, flowers, shrubs, trees), with the aim to help site operators use recycled water safely and sustainably.

Amenity horticulture refers to the irrigation of plants grown for our enjoyment, ease and comfort. Industry sectors within the broad definition of amenity horticulture include:
- Arboriculture
- Floriculture
- Landscape
- Nursery
- Parks and gardens
- Turf management

# 1.1 What is recycled water?

**Recycled water** is a general term for water that has been reclaimed from wastewater.

This guidance manual focuses specifically on water recycled from treated sewage effluent. This source of recycled water is also sometimes referred to as reclaimed water. Many of the principles covered are also applicable for water recycled for irrigation from other wastewaters.

# 1.2 Quality of recycled water

The quality of recycled water varies depending on the source of the water and the recycling process used (see Appendix 7.3, p 75 for general recycled water characteristics). Generally Class A, B and C recycled water is used in amenity horticulture in Victoria. The quality of recycled water required for irrigation in amenity horticulture depends on the specific use, irrigation method and restrictions during irrigation.

It should be noted that the class of water usually refers to the level of treatment to remove pathogens from the water. It does not guarantee the water is suitable for a specific amenity horticulture use. The physical and chemical properties of the recycled water also need to be checked to ensure that the water is suitable for the soil and plant species to be irrigated.

Victorian guidelines specify four classes of recycled water; A, B, C and D (Appendix 7.3, Table 24). Recycled water can be produced using different degrees of treatment to produce a defined quality of water which will be fit for the intended purpose (Figure 1). The new Australian Guidelines for Water Recycling now refers to recycled water as being "Fit-for-purpose", in place of the Class system. This means that the user must ensure that the quality of water they receive is fit for the purpose they intend to use it for; from a human health, horticultural and environmental perspective; overcoming the limitations of the class terminology.

For detailed information on the different classes of recycled water used in Victoria and their permitted uses see Appendix 7.3, p 75.

Australia's water industry is one of the world leaders in water recycling. They use some of the most developed and robust treatment technology and have a strong commitment to water recycling.

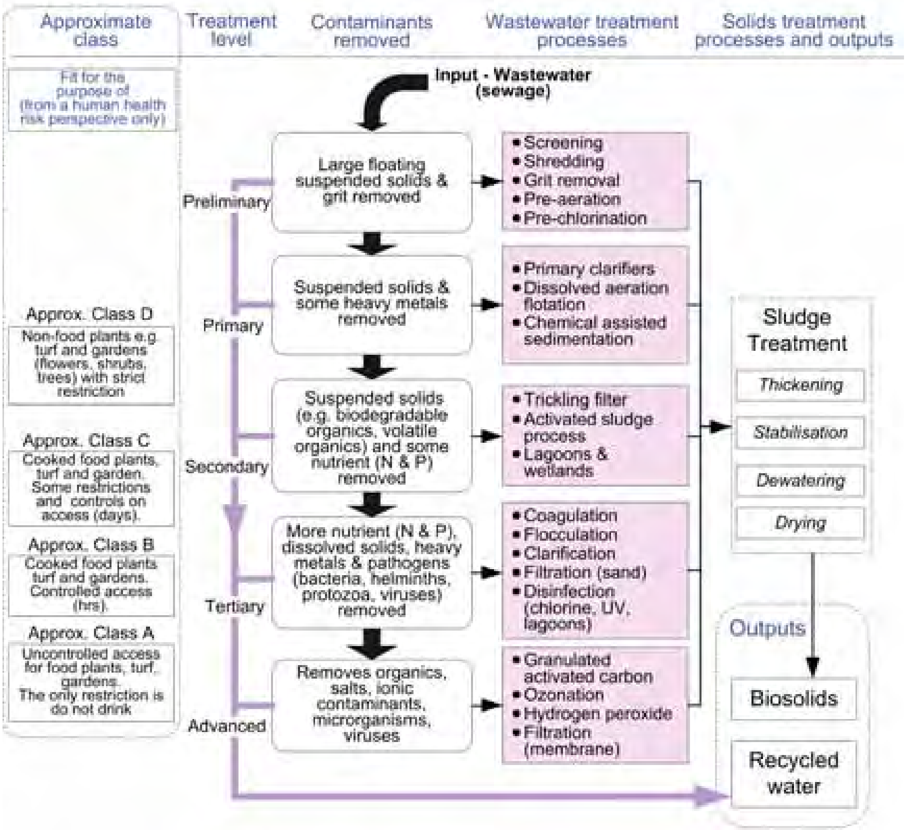


**Figure 1** Treatment levels and processes typically used to treat wastewater. This diagram gives a general indication of parameters; it is not a substitute for specific guidelines and verification processes (Preliminary treated = limited treatment, Advanced = extensive treatment). Note: wastewater can be treated to a level where it is fit for the purpose of drinking.

## 1.3 Why use recycled water in amenity horticulture?

Recycled water is becoming popular for use in amenity horticulture as it:

- Frees up water that can be used more easily for drinking purposes (potable replacement)
- Is usually cheaper than drinking water
- Suffers fewer restrictions, when water restrictions are imposed on drinking water supplies
- Is an integral part of the water cycle

# 1.4 Is recycled water safe for use in amenity horticulture?

Recycling of treated wastewaters in amenity horticulture has been practiced around the world for more than 50 years. Any recycled water scheme developed now is by no means a 'world first'. Recycled water is currently being used in many countries (e.g. United States, Israel and Australia) for irrigating a range of amenity horticulture applications like gardens, ovals, playing fields and race tracks.

Australia now has more than 600 different recycled water schemes operating. Approximately 240 of these schemes use recycled water in the urban environment (e.g. golf courses and recreational parks), 80 are related to industry (e.g. washing and cooling) and 270 are agriculturally based (e.g. horticulture, forestry, pasture, viticulture and cane). Many of these recycled water schemes have now been operating for more than 20 years with no impacts on human health or the environment.

State health and environment protection departments set strict guidelines (Appendix 7.1, p 72) to ensure the health and safety of people working with recycled water and the public using parks, gardens and turf areas. Every recycled water scheme requires the approval of these departments and must show that appropriate safeguards are in place (before the recycling scheme is commissioned) to guarantee a particular water quality to users. These extensive safeguards guarantee protection of human health and the environment.

**Figure 2** Demonstration landscape gardens water with recycled water, San Jose, California, USA.

## Complying with safety standards

A risk assessment needs to be undertaken for recycled water in the same way as it would for water from any other source. Factors to consider include the standard to which the recycled water has been treated (What is it fit for?) and its intended use (e.g. application method, plants grown, soils). If a change of use occurs you should check with you water supplier to determine if the recycled water is fit for the purpose you would like to use it for.

## Documentation from your recycled water provider

A recycled water scheme must go through a verification process and adopt a multi-barrier approach to ensure only recycled water of the specified quality reaches the user. The scheme operator should be able to provide you with information on the:

- Safety of recycled water and standards which are used to obtain the specified class of water.
- Testing which supports and/or verifies that the treatment process can consistently produce the specified quality of recycled water
- Monitoring and treatment process used to ensure the quality of the recycled water is fit for turf and landscape plant species to be irrigated.
- Evidence from other recycled water schemes around Australia and the world where recycled water has been used, indicating that similar standards and treatment processes have been shown to supply water fit for the intended use (see also www.recycledwater.com.au).

# 1.5 Risks associated with recycled water

In most cases, environmental and health risks can be managed through the level of wastewater treatment or by the carefully managed use of recycled water. However, in some cases the recycled water may not be of suitable quality for an intended use and therefore should not be used. Some of the major risks associated with recycled water are outlined below.

## Human health risks

Microbial pathogens in wastewater from sewage effluent are the major concern for human health when recycling water. The major groups of pathogens are:

- Bacteria (e.g. *Escherichia coli, Salmonella* spp, *Campylobacter*)
- Viruses (e.g. Enteroviruses, Rotavirus, Hepatitis A)
- Protozoa (e.g. *Giardia lamblia, Cryptosporidium parvum*)
- Helminths (e.g. *Taenia* spp (Tapeworm), *Ancylostoma* spp (Hookworm))

Bacteria can cause illnesses such as gastroenteritis, dysentery, cholera, respiratory illness, and skin/eye/ear infections in humans. Viruses can cause illnesses such as gastroenteritis, respiratory illness, nervous disorders, infectious hepatitis. Protozoa can cause illnesses such as gastroenteritis, amoebic meningitis and amoebic dysentery. Helminths are intestinal nematodes such as *Taenia* which causes tapeworm in humans, *Cysticercosis* in cattle and pigs, and *Ascaris* that causes roundworms in humans.

Not all exposures make you sick. To become infected by a pathogen you must be exposed to a sufficient number of pathogens. If recycled water is fit for the intended purpose, any possible exposure will be prevented or very low and infection unlikely.

Infection is related to the concentrations of pathogens in the recycled water (i.e. how treated and what class it is (Section 7.3, p 75)) and the amount of water ingested. The more ingested the greater the chance of infection occuring.

Recycled water uses that require particular attention for health risk assessment in amenity horticulture include:

- Irrigation of readily accessible public areas with potential for direct exposure to recycled water (e.g. playing fields, open public spaces, golf courses etc.);
- Discharging recycled water to surface waters that are used for fishing, or water contact sports; and

- Where workers may either come into direct contact with recycled water or ingest aerosols in their normal working environment.

Another risk to human health is on-site workers who come into direct contact with recycled water containing high numbers of blue-green algae, which may lead to skin and eye irritations or gastric upsets. This risk is higher with recycled water than many other sources of water as recycled water often contains high nitrogen and phosphorus levels which feed the algae (p 58).

## Amenity horticultural risks

Some of the common horticultural risks from recycled water include:

- **Salinity**
  a chronic problem that needs to be managed in many urban irrigation systems if using recycled water. Salinity can stress plants and impact on the aesthetics of the garden or landscape.

- **Sodicity**
  can cause soil dispersion and swelling, reducing water infiltration on heavier textured soils leading to excessive runoff or waterlogging, and restrict root growth.

- **Sodium/Chloride**
  can be toxic to plants if sprayed directly on leaves and if it accumulates in soils from ongoing irrigation.

- **Nitrogen**
  a major nutrient required by plants. However, excess nitrogen can cause excessive growth, which can lead to extra maintenance or affect turf wear tolerance.

- **Phosphorus**
  a major nutrient required by plants and is usually of benefit. However, it can be toxic to some native plant species.

- **Hydraulic loading**
  excess can result in excess groundwater recharge, water logging and secondary salinity.

- **Boron**
  can cause plant toxicity in some sensitive plant species in some soils.

To-date no risk from plant pathogens has been identified in water recycled from treated sewage water. However, if recycling water from other sources this may need to be managed (e.g. hydroponic systems).

## Environmental risks

Many of the horticultural risks above can also have environmental impacts. Some of the common environmental risks from recycled water include:

- **Salinity**
  can degrade soils and impact on freshwater plants and invertebrates in natural ecosystems if discharged directly with little dilution.

- **Nitrogen and phosphorus**
  can cause eutrophication (excessive nutrient levels) in land and aquatic ecosystems.

- **Ammonium, pathogens, organic loads and turbity**
  can impact on aquatic systems.

Note: many environmental risks are associated with runoff into local waterways.

# Setting up a recycled water scheme

## 2.1 Access to recycled water

To determine if recycled water is available to you there are usually a number of options for sources. For example, are you near:

- Any supplies of recycled water currently available or planned in the future?
- A waste water treatment plants where you may be able to access and treat the water?
- Sewer mains where you could reclaim water directly from raw sewage?

Your local water authority should be able to help you answer these questions.

## 2.2 Things to consider

If you are considering setting up a recycled water scheme expert assistance should be sourced. Things to consider are:

1. Make contact with the appropriate Water Authority as to the possibility of receiving recycled water.

2. Check what environmental, health and/or planning regulations must be met by making contact with the appropriate regulatory agencies:
   a. Environment Protection Authority (EPA)
   b. Department of Human Services (DHS)
   c. The appropriate local government (e.g. Local Government - Council)

3. Obtain detailed analyses of the recycled water quality to ensure it meets your requirements. This should include:
   a. pH,
   b. Electrical conductivity (EC)
   c. Nitrogen (N)
   d. Phosphorus (P)
   e. Potassium (K)
   f. Sodium Na)
   g. Calcium (Ca)
   h. Magnesium (Mg)
   i. Sodium Adsorption Ratio (SAR)
   j. Carbonate ($CO_3$)
   k. Bicarbonate ($HCO_3$)
   l. Chloride (Cl)
   m. Sulfate ($SO_4$)
   n. Boron (B)
   o. Heavy metals (depends on water source)
   p. Biological oxygen demand (BOD)
   q. Pathogens
   r. Suspended solids (SS)

4. Obtain the Class of the recycled water (Class A, B, C) and determine the appropriate uses and restrictions based on the class of recycled water (Section 7.3).

5. Undertake detailed site assessment – Environmental Improvement Plan or Land Suitability Assessment (EPA or water supplier can advise on requirements).

6. Prepare a Health and Environmental Management Plan (HEMP).

7. Undertake cost analysis of implementing, using and maintaining the use of recycled water, including:
   a. upgrade to irrigation and water supply system
   b. on-site water storage
   c. on-site water treatment (e.g. acid or gypsum injection, algae control)
   d. signage
   e. increased maintenance costs including:
      i. increased mowing/pruning
      ii. use of growth retardants
      iii. modified working hours
      iv. soil amendments (e.g. gypsum)
      v. increased turf renovations

The development and ongoing operation and maintenance of any amenity horticultural activity using recycled water should seek professional advice to ensure all human health, horticultural and environmental risks are managed appropriately.

# Public and Occupational Health and Safety

## 3.1 Guidelines

Any recycled water scheme should comply with the Victorian Occupational Health and Safety (OHS) Act. This act is designed to provide a broad framework for improving standards of workplace health and safety to reduce work-related injury and illness. The Act aims to:

- Secure the health, safety and welfare of employees and other people at work.
- Protect the public from the health and safety risks of business activities.
- Eliminate workplace risks at the source.
- Involve employers, employees and the organisations that represent them in the formulation and implementation of health, safety and welfare standards.

## 3.2 Good OHS practice

A large variety and concentration of pathogenic (disease causing) organisms can be present in wastewater (p 11). The concentration and types of pathogens removed are dependent on the level of treatment during the production of recycled water (Figure 1), the higher the level of treatment the lower the number of pathogens, managing exposure.

Occupational exposures associated with the use of recycled water can also be managed by minimising ingestion and exposure to aerosols (fine air bourne water droplets).

### General good practice

Persons engaged in any operation involving recycled water not fit to drink should:

- Avoid consumption of recycled water (Class A to D are not considered fit for drinking) and unnecessary exposures to sprays and aerosols.
- Wash hands with soap and clean water before eating, drinking or smoking, and at the end of each working day.
- Cover any wounds, open cuts or broken skin.
- Use appropriate protective clothing and equipment if required.

In many cases, the irrigation system used will also govern the risk of exposure and should be considered when planning and operating the reuse scheme (Table 1).

**Table 1** Risk of occupational exposure to recycled water relative to the irrigation system.

| Exposure | Risk level | | |
|---|---|---|---|
| | Drip | Sprinkler | Furrow |
| Ingestion risk | Low | Medium | Medium |
| Contact risk | Low | High | High |
| Aerosol risk | Low | High | Low |

Source: Stevens *et al.* 2006, p 120

### Precautions to protect health of workers

All employees and contractors should be advised of limitations placed on the use of recycled water and of the precautions that need to be taken to protect their health:

- For lower class water (less than A), hepatitis A immunization (a faecal borne disease) may be recommended, although the risk even to workers at a sewage treatment plant is considered low (Brugha *et al*. 1998; Glas *et al*. 2001). Hepatitis B is a blood-borne disease and as such is unlikely to be a risk, so vaccination is not usually necessary (CDCDP 1993). If you require further advice contact the Department of Human Services, Melbourne.
- All external tap outlets on the drinking water service should be fitted with hose connection vacuum breakers to prevent backflow and possible contamination of potable water supply.

# 3.3 Signage and pipe labeling

Signage is an important part of risk management. All recycled water external tap outlets must have a prohibition sign complying with AS1319 (AS 1994). All entrances to sites using recycled water must have adequate signage informing of the use of recycled water.

Victorian recycled water guidelines state that warning signs with both a pictorial sign and words indicating that recycled water is being used should be placed in strategic positions. Content should be consistent with the examples provided (Figure 3).

Two-tone colouring should be used with black picture and text and red symbols. The number of signs and size of wording should be determined on the basis of the visual distance from the observer (for example, 100 mm wide sign at a distance of 3 m, AS1319 - AS 1994).

There is also specific signage and pipe labeling required for plumbing fittings (Appendix 7.2, p 74). If hoses are connected to recycled water outlets they should also be purple in color to identify them as containing recycled water.


**Figure 3** Warning signs indicating not to drink the water and informing the public that recycled water is used on the property.

# 3.4 Training and auditing

## Pre commissioning

Pre commissioning audits must be preformed to prevent any cross connections with the potable drinking water supply. All plumbing work must be carried out by a licensed plumber.

## Induction of new staff

All new staff should be inducted into the work space and given a guided tour of the premises, which identifies all recycled water outlets, applications, best practices when using recycled water, and the importance of maintaining best practice to manage risks associated with recycled water.

## Ongoing training

Up-dated training should be provided yearly to ensure all staff are made aware of any changes made to individual recycled water systems and/or changes to the guideline and regulations covering recycled water use in amenity horticulture.

# 3.5 Restrictions onsite related to OHS

## Storage

### Buffers

Adequate buffers (e.g. 25 to 30 m; NRMMC and EPHC 2006, p 97) should be installed and maintained between the storage area and the boundary of the property.

### Access

No public access to recycled storage sites should be allowed. Signs indicating this should be present on entrances to storages. Locked gates and impenetrable fences should be installed around storages.

### Run-off

Run-off to waterways and neighbouring sites must be prevented through good irrigation scheduling and monitoring (Best practice irrigation, p 53).

### Odours

Odour can be minimised by managing flow in to storages, aeration and volumes of water stored for long periods; with the aim being to prevent the water going stagnant.

Flushing irrigation equipment with fresh water following irrigation can stop the odour associated with stagnant recycled water in irrigation pipes.

### Colour

Piping must be installed as per the state guidelines or plumbing industry guidelines (Appendix 7.2, p 74).

### Algae

The high levels of nitrogen and phophorus in recycled water can lead to algae blooms in water storages exposed to the sun. If an algal bloom is toxic direct contact with humans should be avoided (p 59), all algal blooms should be treated as toxic until species have been identified are considered safe.

## Restricted public access to irrigation site

If lower class water is used (B, C or D) restricted public access to the irrigation site might be a crucial component of minimising health risks (Section 7.3, p 75). Restrictions could include:

- Withhold periods - no access after irrigation, until dry (1–4 hours).
- Buffers - suggested buffer distances from the edge of the wetted area to surface waters for the use of Class C recycled water in Victoria are summarised in Table 2.

**Table 2** Suggested buffer distances for Class C water use in Victoria.

| Irrigation Type | Buffer distance (m) |
|---|---|
| Flood/high pressure spray | 100 |
| Low pressure spray | 50 |
| Trickle or subsurface irrigation | 30 |

Source: EPA Victoria 2003

It may be appropriate to reduce these buffer distances (Table 2) if Class A or B recycled water is used. The following buffer distances (boundary of the irrigation area to the nearest sensitive development areas such as residential areas, public parks, schools and shops) are suggested for spray irrigation applications:

- Class A recycled water quality – no buffer distances are prescribed due to the high microbiological water quality, however, irrigation should ensure no spray drift or water movement off-site to avoid nuisance and environmental impacts to waterways.
- Class B recycled water quality – at least 50 metres from the edge of the wetted area to the nearest sensitive development.
- Class C and D recycled water quality – at least 100 metres from the edge of the wetted area to the nearest sensitive development.

These buffer distances may need to be increased if high pressure spraying is conducted. The buffer distances may be reduced if suggested best practice measures are implemented to reduce spray drift. These measures may include one or a number of the following, dependent upon the sensitivities of the area:

- Tree screens.
- Anemometer switching systems.
- Restricted times of watering.
- Irrigation systems that prevent the generation of fine mist, such as low rise sprinklers, small throw or micro sprinklers, and part circle sprinklers.

Other measures may be approved if you can demonstrate that they significantly reduce the risk to public health and amenity associated with spray drift.

## Irrigation methods and maintenance

### Irrigation times

Irrigation at night or the use of a time buffer (no access after irrigation, until dry (1–4 hours)) between the end of irrigating and public access may be required depending the Class of the recycled water. Buffer requirements are outlined in Victorian guidelines for lower classes of recycled water (i.e. Class B,C,D).

### Irrigation systems

The method of irrigation should be considered as one tool to minimise human exposure to recycled water, while meeting irrigation requirements. For water not fit for direct human exposure, drip irrigation can lower the health risks, compared with sprinkler irrigation, as there is very little risk of human exposure. However, the irrigation systems should be selected considering all site conditions and irrigation requirements.

Other options could include spray drift control through low-throw sprinklers (180° inward throw) buffer zones of 10 – 15 metres, vegetation screening, drip irrigation near boundaries (surface or subsurface) or automatic switches stoping irrigation if wind speeds exceed trigger levels (NRMMC and EPHC 2006).

### Odour control

If odour is a concern, human exposure to odours can be minimised on-site by:

- Flushing irrigation lines/pipes with a non recycled water source after each irrigation.
- Irrigating at night when the public are generally indoors.
- Install and maintain adequate buffers between the irrigation area and the boundary of the property to help diffuse and dilute odours.

# Horticultural and Environmental Considerations

# 4.1 Introduction

## Site selection

The site chosen for irrigation with recycled water will have a large impact on the types of environmental risks and horticultural production undertaken. If the site has not already been selected, things to consider include:

- climate
- soil type
- location
- slope
- plants that can be grown
- nutrient requirements
- hydrology
- other available water sources.

In many established urban landscapes there is no short-term flexibility to replace established plants to suit the various characteristics of recycled water. This means the recycled water needs to be 'fit for the purpose' of irrigating the plants already established in the areas on the specific soils they are already growing in.

In all cases the short and longer term sustainability of the amenity horticultural system should be checked against potential hazards in recycled water discussed in this chapter (e.g. salinity, sodicity, eutrophication).

## Potential impacts

There are a range of possible impacts from irrigation with recycled water on the amenity horticultural system or the environment (Table 3). The impacts are usually manageable and management strategies are discussed in this Section.

**Table 3** A range of potential impacts that may need to be managed when irrigating with recycled water.

| Effects or impact | Description |
|---|---|
| Concentration | Increase in the amount or strength of hazards in recycled water, through evaporation. |
| Contamination | Increasing concentrations of unwanted constituents in environmental end points (e.g. soils, plants, water bodies, biota, etc). |
| Eutrophication | Nutrient enrichment leading to increased productivity. Typically in the form of nitrates and phosphates, and most often from human sources such as agriculture, recycled water and urban runoff. |
| Loss of biodiversity | Mortality of native biota resulting in reduced ecosystems, species or genetic diversity. |
| Nutrient imbalance | Unbalanced supply of plant mineral nutrients resulting in plant deficiencies and toxicities. |
| Odour | A smell, especially one that is unpleasant. |
| Pest and disease | An insect or animal that destroys plants and an illness affecting plants, animals or other biota. |
| Salinity | The presence of soluble salts in soils or waters. Electrical conductivity (EC) and total dissolved salts (TDS) are measures of salinity. |
| Sodicity | Soil with excessive exchangeable sodium (ESP>6%), leading to poor soil structure. |
| Toxicity | The extent to which a compound is capable of causing injury or death, especially by chemical means, to plants and other terrestrial or aquatic biota. |
| Waterlogging | Saturation of soil with water. |

These impacts, the associated risk and their management are discussed below in terms of several key hazards.

# 4.2 Plant selection

There are several specific factors that must be considered when selecting plant species that will be irrigated with recycled water. These include:

- Salinity tolerance
- Sensitivity to chloride, sodium and boron
- Soil type and suitability
- Nutrient requirements
- Water requirements
- Phosphorus sensitivity.

These factors are discussed in the following sections in terms of the major hazards associated with recycled water.

*When assessing recycled water quality for use in amenity horticulture check that the plants to be grown can tolerate the range of salinity, sodium, chloride and boron concentrations found in the recycled water*

# 4.3 Nutrient management

Recycled water contains varying concentrations of nutrients (Table 4). Concentrations vary depending on sewage inflow and the treatment process (Figure 1). Different plant species have varying nutrient demands (Table 5). The aim of amenity horticulture should be to minimise feeding (fertiliser use), watering and mowing/pruning, while maintaining the desired appearance. Fertilisation for establishment (to get to the desired appearance) might be different to fertilisation to maintain the desired appearance.

The annual nutrient applied with irrigation of recycled water (Table 4) should only be used as a guide and further advice should be sought to determine the rates of nutrients to be applied through your fertilisation program. The amount of nutrients added to soils from recycled water depends on the irrigation rate and nutrient concentration in the recycled water.

**Table 4** Nutrients applied with recycled water (kg/ha) at different irrigation rates.

| Recycled water | | | | Annual irrigation | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Concentration mg/L | | | 1 ML/ha 100 mm | | | 3 ML/ha 300 mm | | | 6 ML/ha 600 mm | | | 9 ML/ha 900 mm | | |
| | | | | Annual nutrient applied with irrigation (kg/ha) (divide by 10 = g/m²) | | | | | | | | | | | |
| Nutrient | ave | min | max | ave | min | max | ave | min | max | ave | min | max | ave | min | max |
| Nitrogen (N)[A] | 15 | 3 | 39 | 15 | 3 | 39 | 46 | 8 | 117 | 91 | 17 | 234 | 137 | 25 | 351 |
| Phosphorus (P)[A] | 6 | 0 | 12 | 6 | 0 | 12 | 18 | 0 | 36 | 35 | 0 | 72 | 53 | 0 | 108 |
| Potassium (K)[B] | 18 | 10 | 33 | 18 | 10 | 33 | 55 | 30 | 99 | 110 | 60 | 198 | 166 | 90 | 297 |
| Sulphate (SO)[B] | 124 | 33 | 212 | 124 | 33 | 212 | 371 | 99 | 636 | 741 | 198 | 1272 | 1112 | 297 | 1908 |
| Calcium (Ca)[A] | 35 | 10 | 74 | 35 | 10 | 74 | 105 | 30 | 222 | 210 | 60 | 444 | 315 | 90 | 666 |

[A]NRMMC and EPHC 2006, p 147
[B]Asano *et al*. 2007, Pettygrove and Asano 1985

## Nutrient requirements

Nutrients applied with recycled water should be balanced with plant requirements.
If more nutrients are added through irrigation and fertilisation than is required by the plant (i.e. removed by pruning/mowing, stored by the plant and adsorbed by soil), then nutrients will accumulate in the soil and potentially be leached into surface and groundwater. This wastes money (i.e. the cost of fertilisers and its application) as well as causing potential health and environmental problems offsite. Ammonium fertilisers are known to be toxic to plants if applied at high concentrations. However, ammonium in recycled water (averages approximately 8 mg/L ammonium – N) is usually below levels that will be toxic to plants (i.e. < 30 mg/L Handreck and Black 2002, p 153).

Soil tests should be used to determine available nutrients that remain in the soil and these nutrients factored into the nutrient budget.

In some amenity horticulture situations, the nutrient supply can be used to help manage the landscape. For example, nitrogen can be used to manage turf growth if all other nutrients are adequately supplied. Generally, the more nitrogen, the more growth and a greener more lush turf. However, the aim of turf growing is not to maximise growth, but to provide a turf with an acceptable surface and appearance to the user. Application of excess nitrogen can lead to excess growth, extra resource use (water, fertiliser), extra maintenance (cutting) and can ruin the turf (lower wear tolerance or strength).

Supply of nitrogen excess to what the plant can use, can lead to leaching of nitrogen through the soil profile, where it could end up in ground or surface water causing eutrophication. For most home gardens the requirement for a lawn is simply that it looks good and excess nutrients should not be applied.

An indication of nutrient (NPK) requirements for turf growth is summarised below (Table 5). If these demands are compared with Table 4 (p 27) nutrients applied in recycled water at an annual application rate of 600 mm or greater could apply sufficient NPK requirements (Table 5). This will vary with the source of the recycled water and nutrient levels and should be checked for each specific site.

**Table 5** Typical annual nutrient demand of turf plants and removal with clippings.

| Component | Nitrogen (N[C]) | | Phosphorus (P) | | Potassium (K) | |
|---|---|---|---|---|---|---|
| | (g/m$^2$) | (kg/ha) | (g/m$^2$) | (kg/ha) | (g/m$^2$) | (kg/ha) |
| Annual application | 6–40[A] | 60–400[D] | 3.6–12.4 | 36–124[B] | 6–48 | 40–267[E] |
| Removed with clippings | 24 | 240 | 6 | 60 | 13 | 130 |
| Home lawn application | 12–20 | 120–200 | 2.5–10.5 | 25–105 | 8–13 | 80–130 |

[A]Handreck and Black 2002, p 287

[B]Depending on the P fixing capacity of the soil

[C]Note the 20 to 50% of the nitrogen applied can be lost through volatilisation and denitrification (Handreck and Black 2002, Asano *et al.* 2007)

[D]Depending on turf species, what the turf is being grown for, growth requirements and N losses

[E]Approximately a 3:2 ratio N:K (Handreck and Black 2002, p 294)

Please note all fertiliser requirements should be determined by soil tests for plant available nutrients. Soil tests should include those identified in Table 6. Landscape nutrient requirements vary considerably depending on the composition of plants and their density. For landscape soils a general guide for optimum levels of soil properties is listed below (Table 6).

**Table 6** Estimates of soil test ranges for optimum levels for most landscape plants.

| Soil Property | Optimium level | Unit | Comment |
|---|---|---|---|
| Organic Matter | 3–7 | % | In top 10 cm |
| Permeability | >3 | cm/hr | (Saturated hydraulic conductivity) |
| Electrical Conductivity (EC) | | dS/m | See Table 8 |
| pH | 4.5–6<br>6–7<br>7–8.5 | | Acid loving plants<br>Most plants<br>Alkaline loving plants |
| Nitrate-N | 20–40 mg/kg | mg N/kg soil | Lower level tolerated if regular application of N with recycled water |
| Phosphorus | Olsen / Colwell[A]<br><5 / <10<br><20 / <40<br>15–40 / 30–80 | mg P/kg soil | <br>Plants highly sensitive to P<br>Plants moderately sensitive to P & turf<br>Most plants |
| Potassium (exchangeable) | >0.3 | meq/100g | 2–5% of cation exchange capacity |
| Calcium (exchangeable) | >1 | meq/100g | 60–80% of cation exchange capacity |
| Magnesium (exchangeable) | >0.3 | meq/100g | 10–15% of cation exchange capacity |
| Sodium (exchangeable) | <1.5 | meq/100g | <6% of cation exchange capacity |
| Chloride | <300 | mg/kg | Unless plants tolerate higher |
| Copper | 0.3–5 | mg/kg | DTPA extract |
| Zinc | 0.5–5 | mg/kg | DTPA extract |
| Boron | 0.15–0.4 | mg/kg | Hot water or hot calcium chloride extract |

Source: Handreck and Black 2002

Note: lower trace elements may apply for Australian Natives grown for cut flowers, turf species and nutrient demands will vary with desired appearance and growth rates

[A]Colwell soil extraction method is approximately twice the Olsen soil extraction method

## Seasonal variation

Nutrient requirements for plants vary with their growth and stage of maturity. The greater the growth rate the more nutrients required. Higher growth rates are usually in the warmer months with longer days (more sunlight). Fortunately this coincides with greater water requirements, so to some degree the nutrient delivery through recycled water (Table 5) manages itself.

Unfortunately the nutrient concentration in the water makes it difficult to prevent application of nutrients in situations where sufficient nutrients are available or growth is being restricted to minimise additional maintenance costs (p 27).

## Toughening of plants

Nutrients can also play a role in toughening up the plant to be more resistant to dry conditions, disease and wear. For example, sufficient potassium encourages the thickening of cell walls in turf leaves, toughening the plant so it becomes more wear resistant (Handreck and Black 2002). Thickening of the cell walls also helps the grass become more disease resistant. Optmium levels of potassium also ensures maximum root growth so the plant can access more soil water. In contrast, excess nitrogen can lead to lanky, succulent, weak plants that are susceptible to diseases, do not tolerate dry conditions and easily fall over.

The nutrients in recycled water should be factored into any fertilisation program to ensure nutrients are applied at optimal concentrations, ensuring healthy tough plants.

## Environmental impacts of nutrients

Nutrients are required by all organisms. Often the growth of plants and algae in aquatic environments is limited by the availability of nutrients, particularly phosphorus and nitrogen. Enrichment of aquatic systems with nutrients can stimulate excessive growth ("blooms") of water-plants, particularly algae. This process of nutrient enrichment of water is called eutrophication.

Excessive nutrient application can be a major source of nutrient input to freshwater aquatic habitats; especially phosphorus. Concentrations of phosphorus as low as 0.02 mg/L (20 parts per billion) can cause environmental problems in some surface waters; even limited movement of phosphorus from horticultural sites can have considerable impact.

Eutrophication and algal blooms can negatively affect human users of water bodies and also aquatic ecosystems. Light is blocked from reaching underwater plants by high levels of algae in the water, suppressing their growth. This has follow-on effects for the rest of the aquatic ecosystem, as water-plants provide food and shelter for fish, frogs, water birds and bugs.

Algal blooms can also exclude native species and cause fish kills by reducing oxygen levels in the water when the bloom breaks down (Figure 4). Techniques for minimising the chances of algae blooms are discussed in Section 4.10 Algae management (p 59). The best management method is to prevent nutrients from moving off-site.

**Figure 4** Algal bloom causing fish to die.

## How do nutrients move into aquatic environments?

Dissolved nutrients can be carried off-site with run-off water, or down through the soil to groundwater during leaching (Figure 5). Nitrogen, in the form of nitrate, is particularly susceptible to leaching to groundwater because it is easily dissolved in water and is rarely bound to soil particles. Dissolved phosphorus generally only leaches through soil when there are high concentrations of phosphorus in the soil, overloading the soil's phosphorus holding capacity, leading to movement of phosphorus off-site.

Once in the groundwater, excessive nutrients may cause direct human health issues (e.g. excessive nitrate in drinking water can lead to methemoglobinemia, particularly in babies).

Nutrient polluted groundwater can also discharge into streams and wetlands, causing eutrophication.

Nutrients bound to with soil particles may also be carried off-site into streams and wetlands by soil erosion. Phosphorus, tends to be associated with clay particles and surface run-off water is often dominated by clay particles.

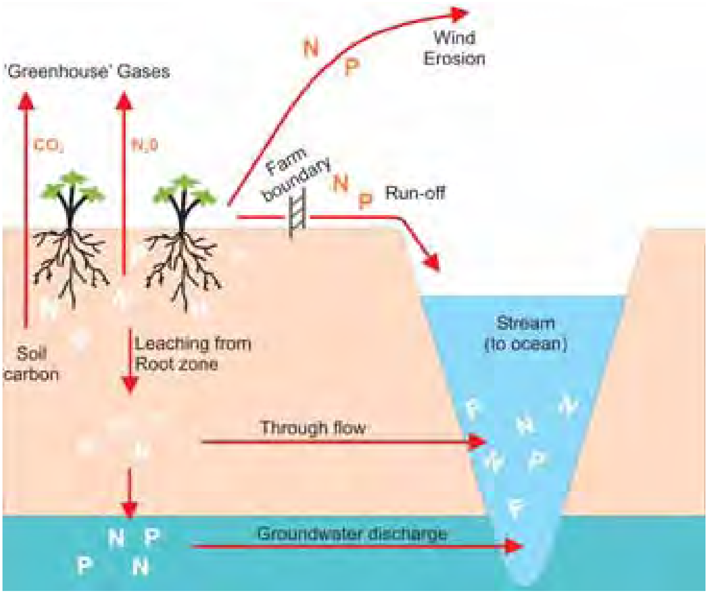


**Figure 5** Routes of nutrient loss from irrigation sites.

## Reduction of nutrient pollution of aquatic systems

### Match nutrient supply to demand

*Recycled water can be a form of fertigation*

Nutrient losses tend to occur when they are in excessive amounts in the soil. Nutrient applications should be matched to the needs of the plant, including nutrients in recycled water as part of the nutrient budget. As plants mature, their nutrient requirements change.

Nutrient movement is most likely when there are high levels of nutrients in the soil and/or when more nutrients are applied than the soil can immobilise and plants can take up. Nutrients are less likely to move off-site when using recycled water and supplementary fertilisation, compared with conventional fertiliser application. This is because small amounts are continually added with the irrigation water rather than higher amounts added to the soil a few times a year. Recycled water can be a form of fertigation because of its relatively high nutrient level (Table 4).

### Keep soil in the garden/landscape/turf area

High concentrations of nutrients, especially phosphorus, are often contained in soil eroding from irrigation sites. Erosion can be minimised by avoiding bare soils through application of mulches and by replanting regeneration sites where lower cover is expected. Well vegetated buffer strips, including native vegetation and ground cover where possible, should be left around water courses, in order to trap eroded soil particles and prevent them from entering the water. Soil sodicity (Section 4.6, p 41) is often a cause of higher levels of water run-off, leading to higher erosion of soil particles and associated nutrients. Soil sodicity should also be managed to minimise erosion and runoff.

### Excessive leaching

If water is more saline than ideal, a leaching fraction will be required to maintain soil salinity at acceptable levels (p 102). Excessive leaching can lead to excessive movement of salts and nutrients past root zones and into ground water systems. If large leaching fractions are required (>5%), the hydrology of the site must be checked to determine the environmental risks associated with nutrients entering ground water or nearby surface waters.

## Phosphorus sensitive plant species

Some plants native to nutrient poor sandy soils in southern Australia and South Africa, particularly of the Proteaceae family (e.g. Banksia, Grevillia, Protea), are adapted to very low nutrient environments and have developed root specialisations for increasing nutrient uptake, particularly phosphorus (Lamont 1982).

Over 800 native Australian plants have been assessed for their relative sensitivity to phosphorus (Section 7.9, p 106). This list serves as a guide for planning and problem diagnosis, however, it should be kept in perspective, with the understanding that this list was determined in a potting medium and in-ground results may vary. There is some evidence that the growth of many exotic taxa are also sensitive to high levels of P (e.g. Viburnum, Camellia, Rhododendron and Magnolia). For example, the Royal Botanical Gardens have landscape experience of iron chlorosis in Magnolia spp. exacerbated by the antagonistic locking up of iron by high levels of soil P.

In landscape and garden plantings, sensitive species might withstand 5 mg/kg available (Olsen) P, and more tolerant species 20 mg/kg (Table 6). Concentrations of >60 mg/kg Olsen-bicarbonate extractable P were suggested to often be fatal to some Banksia species. At high irrigation rates (Table 4) irrigation of recycled water could easily add 20 mg P/kg soil, increasing soil P concentration to levels which could impact on phosphorus sensitive plants. Coarse textured soils with low cation exchange capacity and low P buffering capacity are most at risk. The effect would be even greater if fertilisers containing phosphorus were applied.

**Figure 6** Phosphorus toxicity in poinsettia. Source: www.ces.ncsu.edu/depts/hort/poinsettia/corrective/b5.html

The first symptom of phosphorus toxicity for sensitive plants is grey, rust or black discoloration of the margins of old leaves, the younger foliage yellows through iron deficiencies (e.g. Figure 6). Plants not so sensitive have a dull color appearance and/or reduced growth (Handreck and Black 2002).

# 4.4 Salinity

Salinity is potentially the greatest impediment to plant growth in Australia. Soil and water salinity can be measured as total dissolved salts (TDS; unit = mg/L) or electrical conductivity (EC; unit dS/m or multiply by 1000 for µS/cm).

Salinity tolerance of plant species and variety vary considerably. Some salt tolerant plants can tolerate water or soil salinity (ECe) greater than an electrical conductivity of 16 dS/m, while salt sensitive plants can only tolerate 0.65 dS/m (Appendix 7.6, p 78).

Some soils can be quite saline (ECe up to 19 dS/m) due to a combination of naturally occurring conditions and the accumulation of salts. High salinity means that plants will not grow as well and have undesired appearance.

Soil salinity can change over time due to the salinity of irrigation water, irrigation practices and agronomic mismanagement (e.g. excessive use of saline fertilisers or manures). Soil testing should therefore be undertaken regularly and irrigation practices altered accordingly.

The interaction between saline irrigation water and soil salinity needs to be managed to ensure the ongoing sustainability of any irrigation system. A soil is usually defined as saline when the level of salinity interferes with plant growth.

General classes of soil salinity are described in units of electrical conductivity (Table 8); different plants have different degrees of susceptibility to salts (Appendix 7.5). Plant sensitivity to salinity should be considered when deciding on plant species to be grown at a particular location.

## Causes of salinity

Salinity in soil and water results from the presence of dissolved salts such as sodium (Na), calcium (Ca), magnesium (Mg), potassium (K), chloride (Cl), sulfate ($SO_4$), carbonate ($CO_3$) and bicarbonate ($HCO_3$). A common misconception about salinity is that it is caused by sodium chloride (NaCl = table salt) alone. However, soil salinity arises from the presence of many salts, including soluble fertilisers. The most common sources of salt are irrigation water and rising water tables, but other sources include fertilisers, weathering of rock, pollution and ocean spray from coastlines.

*Salinity is one of the greatest impediments to plant growth in Australia*

The most common method used for the removal of salt from irrigation water is a combination of ultra filtration and reverse osmosis; however, the cost of salt removal is often prohibitive. The most effective way to ensure that irrigation water is of the best quality possible is to identify the sources of salt entering the wastewater and, where possible, exclude it from entering the source water. Many Water Authorities have salt reduction programs to facilitate this. These sources may include trade wastes, saline groundwater incursions into sewers, back flushing of water softeners and detergents used.

## How soil salinity is measured

### Water salinity measurement

Salinity is commonly measured as the Electrical Conductivity (EC) of water with units of dS/m (deci-Siemens per metre). For irrigation water ECi is sometimes used to refer to the electrical conductivity of the irrigation water.

Water salinity can also be measured as Total Dissolved Solids (TDS), which has units of mg/L or parts per million (ppm). The approximate relationship (Asano *et al*. 2007, p 959) between EC and TDS is:

- for ECi $< 5$ dS/m
  TDS $\approx$ ECi x 640 (TDS in mg/L; EC in dS/m)
- for ECi $> 5$ dS/m
  TDS $\approx$ ECi x 800 (TDS in mg/L; EC in dS/m)

### Soil salinity measurement

Soil salinity is measured in the solution extracted from the soil. To measure the salinity of a soil it is usually mixed with water (i.e. a soil:water mixture). There are two main methods of measuring soil salinity in Australia:

- Saturated paste extract (ECe), which is an estimate of the salinity of soil water (ECsw (ECsw ~ ECe x 2)) or what plant roots are exposed to; or
- 1:5 soil:water extract (EC1:5).

When considering salinity measurements, it is important to know which method of measurement was used, as the two methods produce different results. Approximate conversions between the ECe and EC1:5 are given in Table 7. Much of the theoretical information relating to plants, soils and salinity is based on ECe, however, EC1:5 is a much easier measurement to make. Because of this, the 1:5 soil:water method is most commonly used in the field. General soil salinity classes and the relationship between ECe and EC1:5 are summarised in Table 8.

**Table 7** Approximate relationship between ECe and EC1:5 for different soil textures.

| Soil Texture | $EC_e$:EC1:5 Relationship |
|---|---|
| Sand, Loamy Sand | ECe = 15 x EC1:5 |
| Sandy Loam | ECe = 12 x EC1:5 |
| Clay Loam | ECe = 9 x EC1:5 |
| Clay | ECe = 6 x EC1:5 |

Source: modified from Anderson *et al*. 2007, Carrow and Duncan 1998.
Note: if the salt in the soil is dominated by gypsum these conversions are unreliable.

**Table 8** General soil salinity classes expressed and electrical conductivity of soil measure as soil saturation extract (ECe) or in a 1:5 soil:water mix (EC1:5).

| Class of soil salinity | ECe (dS/m) | EC1:5 (dS/m) | | | |
|---|---|---|---|---|---|
| | | Sand | Sandy Loam | Clay Loam | Clay |
| Low | <2 | < 0.13 | < 0.16 | < 0.22 | < 0.33 |
| Moderately low | 2-4 | 0.13 - 0.26 | 0.16 - 0.33 | 0.22 - 0.44 | 0.33 - 0.66 |
| Moderate | 4-8 | 0.26 - 0.53 | 0.33 - 0.66 | 0.44 - 0.88 | 0.66 - 1.33 |
| High | >8 | > 0.53 | > 0.66 | > 0.88 | > 1.33 |

Source: Modified from Handreck and Black 2002, p 303

## Why salinity is important?

High levels of salinity can reduce plant growth and appearance (Figure 7). The severity of salinity damage depends on:

- Plant species and cultivar (including rootstock)
- Growth stage
- Soil properties
- Environmental conditions
- Types and quantities of salts present.

It is important to understand that the concentration of salts in the soil (soil salinity) also changes over time when soil water volume change. For example, the concentration of salts in soil water increases between two and five times between irrigation events as soil water evaporates or is used by plants (i.e. Evapotranspiration). The soil salinity then decreases again as irrigation or rainfall dilutes the salts contained in the soil water.

Hibiscus does not tolerate salt very well, with leaf burn occurring even under the mildest salt treatment. Severe leaf burn is shown above.

Bottlebrush is rated as moderately salt tolerant. Older leaves subjected to salt often exhibit 'tip burn', as seen here.

Xylosma is moderately salt tolerant. Response to salt varies from plant to plant.

Bougainvillea, which is not well-adapted to sand cultures, is highly salt tolerant if grown in soil.

Ivy is only slightly salt tolerant. 'Bronzing' and curvature of the leaves, as shown here, is likely due to chloride toxicity.

Holly has very poor salt tolerance. This specimen exhibits moderate 'bronzing' of leaves.

**Figure 7** Syptoms of salt stress from some ornamental plants.
Source: Tanji *et al*. 2007 courtesy of the WateReuse Foundation.

Table 9 shows salinity ratings and plant tolerance groups for irrigation water salinity. Stresses are likely to occur before visible symptoms of salinity are seen in plants. Symptoms of salinity are generally the same as symptoms of water stress, as the high level of salts reduces the ability of the plant to extract water from the soil. Salt affected plants are generally stunted and have cupped leaves. Some plants initially have a blue-green colour and eventually the leaves become brown and brittle on the tips and edges as the salinity stress continues.

These impacts of salinity are difficult to cure in the short term by giving the plants more water or more frequent waterings. However, a long term irrigation strategy can be used to flush salts from the root zone (Appendix 7.8, p 102).

**Table 9** Irrigation water salinity ratings.

| ECi (dS/m) | TDS (mg/L)[A] | Plant salt tolerance groupings | Water salinity rating |
|---|---|---|---|
| <0.65 | <415 | Sensitive plants | Very low |
| 0.65 – 1.3 | 415 – 830 | Moderately sensitive plants | Low |
| 1.3 – 2.9 | 830 – 1,860 | Moderately tolerant plants | Medium |
| 2.9 – 5.2 | 1,860 – 4,160 | Tolerant plants | High |
| 5.2 – 8.1 | 4,160 – 6,480 | Very tolerant plants | Very high |
| >8.1 | > 6,480 | Generally too saline | Extreme |

Source: ANZECC and ARMCANZ 2000
[A]Calculated as per Section 4.4, p 33

ECi = electrical conductivity of the irrigation water

TDS = total dissolved salts

Note: for detailed salinity tolerances of amenity horticulture plants see Appendix 7.6, p 78

Salinity can negatively affect plants in four ways:

1. Reduced ability to extract water from saline soil (Section 4.4)
2. Direct toxicity of individual salts on plants (Section 4.5)
3. Indirect effects of salts on nutrient uptake and balance (Section 4.5)
4. Negative impacts on soil structure through effects of sodicity (Section 4.6)

In practice, these effects are often hard to distinguish from other causes because of variations in response according to plant species, cultivars and root stocks, plant growth stage, types and ratios of salts, duration of exposure and environmental conditions.

# How can salinity be managed?

### Reduce salt input

It is difficult to avoid adding salt to soils through irrigation as all water contains some salts. However, using irrigation water with low salinity will add less salt (Table 10). Salinity of irrigation water can also be decreased by mixing ("shandying") with water of lower salinity if available. Some salts are essential for plant growth, problems usually arise when they are present far in excess of requirements.

**Table 10** Relationship between salinity of irrigation water, application rate and the salt applied per hectare.

| Irrigation water salinity | | Annual Irrigation | | | | |
|---|---|---|---|---|---|---|
| | | 2 ML/ha 200 mm | 4 ML/ha 400 mm | 6 ML/ha 600 mm | 8 ML/ha 800 mm | 10 ML/ha 1000 mm |
| EC (dS/m) | TDS (mg/L) | Salt applied (t/ha) | | | | |
| 0.65 | 415 | 0.8 | 1.7 | 2.5 | 3.3 | 4.2 |
| 1.3 | 830 | 1.7 | 3.3 | 5.0 | 6.6 | 8.3 |
| 2.9 | 1,860 | 3.7 | 7.4 | 11.2 | 14.9 | 18.6 |
| 5.2 | 4,160 | 8.3 | 16.6 | 25.0 | 33.3 | 41.6 |
| 8.1 | 6,480 | 13.0 | 25.9 | 38.9 | 51.8 | 64.8 |

Note: For irrigation rate mm also = $L/m^2$.

Irrigators should also avoid over-irrigation as this may lead to rising water tables. Water tables within, 2 m of the surface are likely to cause surface salinisation. The more water applied, the more salt applied (Table 10). So the more efficiently the water is used by the plants the less salts applied to the soil. For example, subsurface drip irrigation can minimise water loss through evaporation and delivery of water to the plant directly, but water applied through sprinkler irrigation can increase losses through evaporation during application (i.e. effective irrigation, p 51), leaving the salt behind.

Landscape managers also need to be aware of the salt content of soil amendments. Soluble fertilisers, animal manure and amendments like gypsum and lime contain a high concentration of salts and should only be used in recommended quantities and applied at appropriate times.

### Leaching salt from the root zone

Salt from any irrigation water accumulates in soil when the water evaporates from the soil and/or is used by plants, leaving the salts behind that and not taken up by the plant. This accumulation of salt leads to degradation of soil and also has direct salinity effects on plants. Plants use some salts, but these are usually relatively small amounts compared with salt applied through irrigation with recycled water.

To manage the accumulation of salts in the root zone of plants, a quantity of water called the leaching requirement (LR) needs to be applied. The leaching requirement is applied in the form of excess irrigation water, greater than plant requirements; the excess amount of water leaching salts below the root zone of the plant. Irrigation rates above plant and evaporation requirements (Evapotranpiration) wash accumulated salts downward. However, frequent light irrigations that just meet evapotranspiration rates are likely to leave salts concentrated in the root zone (Section 4.9, p 50).

### Method of irrigation

There are several methods of irrigation available for use in amenity horticulture; drip (surface or subsurface), set sprinkler (impact, spray, micro spray), hand held sprinklers or sprays, and in some cases furrow. These irrigation systems are discussed further in Section 4.9, p 50.

Drip irrigation allows the use of irrigation water with higher salinity, as evaporative losses (and therefore resulting salt concentrations in the soil) are minimsed. Drip irrigation can also reduce the effects of salinity by:

- Keeping the soil around the plant roots continuously moist (p 36);
- Providing steady leaching of salt to the edge of the wetted zone around the plant; and
- Not applying water to plant foliage.

Drip irrigation might apply less salts with less water, however, salt concentration can build up on the outer wetting front of the drip area and should be managed as required (e.g. application of leaching fractions or irrigation during rainfall to help flush the salt from the root zone).

Sprinkler irrigated plants can suffer extra damage through uptake of salts through the leaves; especially if marginally saline water is used. Under these circumstances, evaporation should be minimised to reduce accumulation of salt on the leaves by watering at night, early in the morning or late in the evening. Sprinkling should also be avoided under hot and/or windy conditions. Slow revolution impact sprinklers also allow drying periods, with salt accumulation on the leaves, and they should be avoided when using irrigation water with salinity higher than ideal. Table 11 shows general comparisons between the sustainability of different irrigation methods and salinity levels.

**Table 11** Water salinity and recycled water irrigation system suitability.

| Salinity | Total dissolved Salts (mg/L) | Suitability[A] | | |
|---|---|---|---|---|
| | | Drip | Sprinkler | Furrow |
| Low | <830 | High | High | Medium |
| Moderate | 830–1860 | High | Medium[B] | Medium |
| High | >1860 | Medium | Low | Low |

[A]Assuming soils have reasonable drainage, if drainage is very poor, then drip should be used;
[B]Leaf burn becomes a problem.

Source: Modified from Christen *et al*. 2006, p120.

Note: Clogging of drip irrigation can be a problem if recycled water has excessive concentrations of some components (Table 20); filtering may be required.

## Interaction of salinity with sodicity

Saline irrigation water can have a stabilising effect on soil structure. This effect is called the electrolyte effect. Sodic or dispersive soils are likely to be less dispersive when irrigated with saline water than with rain water. If the sodium adsorption ratio (SAR – defined in Section 4.6, p 41) of irrigation water is high relative to its EC, soils containing clay are likely to exhibit structural instability (Figure 11, p 45).

*Good soil structure allows root development and salt management*

The main concerns with salinity and SAR of irrigation water are their effects on structural stability and hence the hydraulic properties of soil. Good hydraulic properties need to be maintained to enable the appropriate leaching requirement to move salts below the root zone (Section 4.6). Good soil structure also aids root development, improving plant health and drought resistance, and increases soil water holding capacity.

### Managing salinity

Tools that can be used to manage the potential negative affects of saline recycled water include:

- **Plant selection** - select plants that are tolerant to the salinity of the recycled water being used for irrigation.
- **Irrigation scheduling** - irrigate often to keep the soil profile wet reduces the average soil water salinity exposed to the plant roots. Be sure to include a leaching fraction to manage build up of salts (i.e. leaching requirement).
- **Irrigation timing** - irrigation at night reduces the potential for direct leaf burn from marginally saline irrigation water, particularly if spray irrigation is used.
- **Irrigation method** - drip irrigation can be effective in minimising salinity damage by reducing water losses due to evaporation and eliminating plant leaf water contact.
- **Mulching plants** - the maintenance of plant residues and/or the application of mulches can reduce surface evaporation, reducing the build up of salts. The break down of organic wastes also improves soil structure.
- **Irrigation of seedlings** - plants are most susceptible to salinity at germination and early seedling stages. The use of less saline irrigation water at this time can reduce salinity damage. For example, establish plants when rainfall is more likely or shandying recycled water with less saline water.
- **Maintaining soil structure** – via the use of calcium amendments (e.g. gypsum) or physical soil coring, maintaining root densities, applying additional sand or organic matter to heavier soils.

Irrigation managers should continually monitor soil salinity as salt stressed plants can look less appealing and be more susceptible to disease and wear (turf). Visual monitoring and soil and plant analysis should be part of an on-going program to manage the risks from salinity (Section 5.4, p 64).

## 4.5 Sodium (Na) and chloride (Cl) toxicity

Sodium and chloride are specific components of soil and water salinity that can negatively impact on plants. Sodium and chloride can reduce growth and aesthetics in two main ways:

- Direct toxicity
- Indirect effects on nutrient uptake and balance.

Many of the affects of sodium and chloride are difficult to tell apart and these two elements are commonly found together in soil and water. Recycled water can have significant levels of sodium and chloride and horticulturists need to be aware of the potential impacts on plants and the environment. The two major impacts of sodium and chloride and their management are discussed below.

### Sodium toxicity

Sodium is not an essential element; it is a "beneficial mineral nutrient" and is actually beneficial in some plants under certain conditions.

Most plant species are natrophobic ("sodium hating") and have mechanisms to exclude sodium from uptake by the roots. In woody perennial plants, like olives and grapes, the selection of root stock that limits the uptake of sodium forms part of an effective sodium management strategy.

Sodium can also be absorbed through the leaves from sprinkled irrigation water. Hence, plants that can exclude sodium at the roots may still suffer damage from leaf-absorption of sodium.

### Symptoms of sodium toxicity

Symptons of sodium toxicity are leaf burn, scorch and necrotic (dead) tissue along the outside edges of leaves. The symptoms occur first in the oldest leaves. As the severity increases, the symptoms move inwards between the leaf veins towards the centre of the leaf. Sodium toxicity usually decreases in the presence of calcium. Because of this interaction, the sodium adsorption ratio is used for the evaluation of potential sodium damage. Sodium toxicity contrasts with chloride toxicity where leaf burn starts at the leaf tip.

Woody plants (e.g. vines and fruit trees) are particularly susceptible to sodium toxicity. Injury can occur in avocado, citrus and stone fruit at soil:water sodium levels of 115 mg/L. In woody trees, the negative effects of sodium may not be seen for some time as the tree will accumulate sodium in the trunk and roots, with the trees becoming increasingly sensitive over time. Most other plants are more resistant to sodium damage as they can exclude the uptake of sodium at the roots when exposed to low to moderate sodium concentrations (Appendix 7.6, page 78).

Under high sodium concentrations or with poor soil aeration, the ability to restrict sodium uptake can be lost, leading to accumulation in the leaves and subsequent toxicity. Sodium may also be absorbed directly through the leaves. For approximate sodium and chloride concentrations in irrigation water at which foliar injury occurs for a variety of amenity horticultural species see Appendix 7.6, p 78.

### Indirect effects of sodium

High levels of sodium in the soil can interfere with the uptake of potassium and calcium by plants. Potassium and calcium are both essential plant macronutrients and interference in uptake can lead to deficiencies in these nutrients. Calcium also helps plants select what is taken up through the roots, enabling them to take up potassium while excluding sodium.

### Sodium and potassium

- It is unlikely that application of potassium to the soil will correct sodium-induced potassium deficiency.
- Foliar fertilisation may be considered, however its effectiveness needs to be assessed.
- Addition of calcium may help the plant to take up potassium instead of sodium – see below.

### Sodium and calcium

Calcium application in the form of gypsum is likely to help by:
- Reducing sodium-induced calcium deficiencies.
- Increasing potassium uptake by allowing the plant roots to be selective in taking up potassium rather than sodium.
- Improving general plant health by improving soil structure affected by sodicity (Section 4.6, p 41).

# Chloride toxicity

Chloride is an essential plant micro-nutrient, all plants need a small amount of chloride in order to function and grow. Chloride is usually readily available to plants, is found in soil and water, and is easily absorbed by roots and leaves. However, high concentrations can lead to chloride toxicity and can also reduce production through imbalances with other nutrients.

Like sodium, high chloride can be damaging to plants through soil uptake and through direct application to leaves as irrigation water.

Visible symptoms include leaf burn at the tip of older leaves which progresses back into the leaf blade, premature senescence (seasonal wilting of leaves and flowers), bronzing and defoliation.

Similar to sodium toxicity, most non-woody species are not specifically sensitive to chloride toxicity, with the exception of many leguminous species (nitrogen fixing species including pasture plants like clovers and medics) and some cultivars of beans and soybeans. Woody plants are generally more susceptible to chloride toxicity, depending on species, cultivar and rootstock.

### Indirect effects of chloride

Chloride can compete with nitrate-nitrogen and phosphates for uptake by plant roots, and high levels of chloride in soil water can reduce the uptake of nitrate and phosphates by plants. Nitrogen and phosphorus are both essential plant nutrients and reduced uptake can lead to deficiencies of these nutrients.

High levels of chloride can also make cadmium in the soil more available to plants, increasing plant cadmium uptake and leading to potential health risks if the plant is eaten. The impacts of cadmium and its interactions with chloride are discussed in the section on cadmium (Section 4.8, p 48).

### Chloride and nitrate

The interaction between chloride and nitrate seems to operate in the reverse as well. Application of more nitrate than required for optimum growth leads to decreased chloride leaf damage in avocado and citrus. Therefore, increasing the nitrate supply (or using nitrate rather than ammonium fertilisers) may both improve nitrogen nutrition status and provide a way to reduce chloride toxicity in sensitive plants under saline conditions.

However, this approach can lead to nitrate over-supply, contamination of groundwater and off-site environmental risks. Over-supply of nitrate to manage chloride toxicity should only be used when sensitive plants are grown under conditions of high chloride, and should be carried out with great caution.

### Chloride and phosphorus

The addition of phosphorus may help relieve chloride-induced phosphorus deficiency.

# Managing sodium and chloride toxicity

The complexity of interactions between sodium, chloride and other nutrients shows the importance of maintaining a balanced soil nutrient composition in order to maintain plant health under saline conditions. A number of measures can be taken to manage affects of high sodium and chloride concentrations:

- Tissue and soil testing are a good way to identify deficiencies and toxicities and can assist in plant selection.

- Select plants and root stocks that have higher tolerance of salinity, sodium and chloride toxicity.
- Select plants with lower sodium and chloride adsorption rates.
- Choose an irrigation method and schedule irrigations so as to reduce the concentration of sodium and chloride on leaf surfaces and reduce toxic salt uptake:
  a. Use drip or subsurface drip irrigation to reduce/eliminate leaf-water contact
  b. Increase the rate of irrigation to reduce the time for leaf adsorption.
  c. Shandy irrigation water to improve water quality, reducing sodium and chloride toxicity.
  d. Following irrigation with saline water, irrigate with high quality water to wash salts from leaf surfaces.
  e. Irrigate at night to reduce evaporation and water uptake rates.
- Maintenance of soil structural and hydraulic properties allowing the leaching of sodium and chloride so that they accumulate below the plant root zone:
  a. Adding appropriate amounts of calcium in the form of gypsum may help improve salt tolerance and reduce sodium-induced calcium and potassium deficiency in plants.
  b. Apply organic matter to improve soil structure. The application of surface mulch will reduce evaporation and accumulation of sodium and chloride at the surface.
  a. Chlorides are easily leached as they are not readily adsorbed to the soil.

# 4.6 Sodicity

Some recycled water can contain relatively large concentrations of sodium (180 mg/L) compared to other cations like calcium (35 mg/L) and magnesium (19 mg/L - Appendix 7.4, p 76) leading to a high sodium adsorption ratio (see Measuring sodicity, p 43). This can change the cations in the irrigated soil; potentially causing the soils to become sodic, decreasing soil permeability and impeding movement of water through the soil. Sodium in recycled water comes from drinking water, industrial wastes, detergents, salt water incursions into sewer systems, and water softeners.

Any impediment to the application of a leaching requirement will impact on the removal of salt and hence cause it to accumulate. In time this salt can reduce plant health and production, increase the need for leaching and further exacerbate problems associated with sodicity and salinity.

## Sodic soils

A soil is sodic when sodium constitutes a significant proportion of the total cations on the exchange complex (particularly in relation to calcium and magnesium). In sodic soil, there is sufficient sodium to interfere with its structural stability, often affecting plant growth.

Sodicity in soils can lead to a number of other problems including accumulation of salts, poor root penetrability and poor microbial health. Dispersion caused by sodicity can decrease water movement through soil, leading to accumulation of salts (Figure 8), and is therefore considered a significant barrier to sustainable irrigation practice.

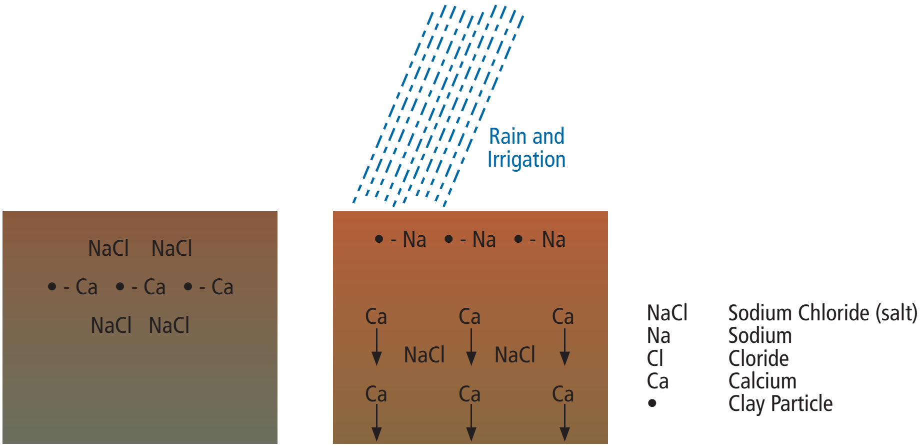


**Figure 8** Saline soil being leached by rain (left) to form a sodic soil (right). Sodium salts, chloride and calcium are washed through the soil leaving sodium in the surface layers bound to clay particles.
Source: Kelly and Rengasamy 2006.

Sodic soils containing clay disperse spontaneously into single soil particles when wet. The amount of dispersed clay is also affected by soil clay content, mineralogy, soil solution constituents (e.g. salinity), and organic matter content. A measurement of the level of dispersion can be used as an indicator of the sodicity of a soil (Figure 9).

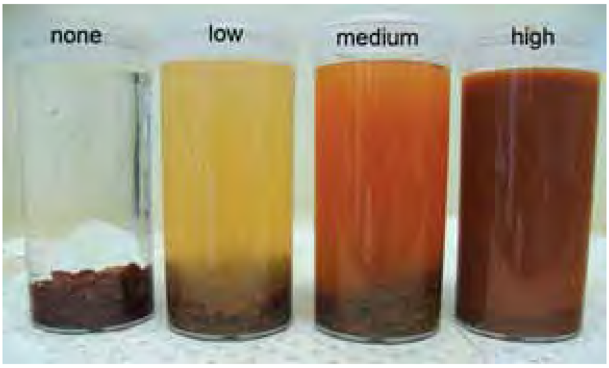


**Figure 9** Levels of soil dispersion due to increasing sodicity.

Sodic soils tend to suffer from poor soil structure with characteristics including:

- Hardsetting
- Hardpans
- High soil strength upon drying
- Surface crusting
- Rain pooling on the surface.

These characteristics can cause problems with water infiltration, drainage, plant growth, cultivation and access of equipment. These problems can lead to significant management and sustainability problems for irrigated sites.

Salinity and sodicity are separate issues (e.g. a soil can be sodic without being saline, or sodic and saline).

Soil structure is the arrangement of soil aggregates (clumps) and pores (spaces filled with air and water) that make up the soil (Figure 10). Well-structured soils are easily broken up into small aggregates (1–20 mm diameter) that stay together when wetted. They also have an adequate mix of small and large pores to allow drainage, aeration and movement of roots through soil, while retaining water for plant use in small pores (Figure 10). Sufficient soil calcium and organic matter content can generally help to maintain or improve soil structure.

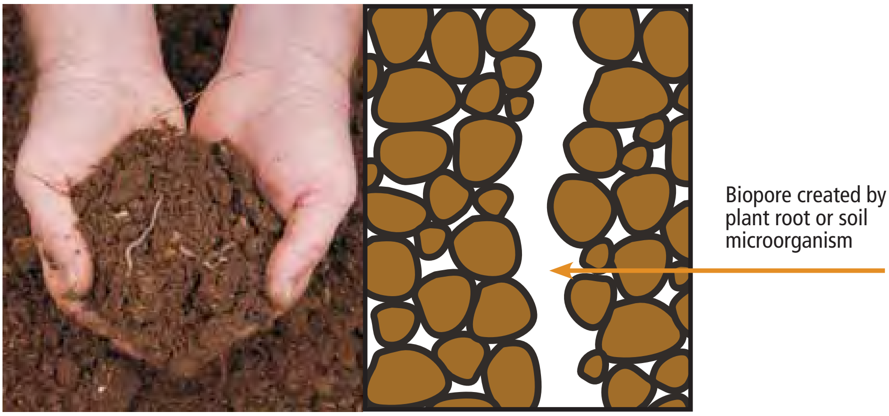


**Figure 10** Well structured soil.
Source: Anderson *et al*. 2007.

Under conditions of high sodicity, clay soils may swell and individual clay particles disperse or separate from soil aggregates when wetted. Soil aggregates may collapse and the tiny clay particles can block soil pores. On drying, the soil becomes hard, dense and cloddy, with poor structure.

## Measuring sodicity

### Water

The sodium adsorption ratio (SAR) is commonly used to assess the potential hazard from sodium affecting soil permeability. The SAR of irrigation water (SAR) can be calculated using Equation 1 if cation concentrations are in milliequivalents or Equation 2 if cation concentrations are in mg/L. Units for SAR are $(mmolc/L)^{0.5}$. The acceptable SAR values of irrigation water vary with the soil type irrigated (Table 12).

**Equation 1** Calculation of sodium adsorption ration (SAR) using milliequivalent concentrations (meq/L)

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$$

where concentrations of cations are expressed in meq/L.

To convert from mg/L to meq/L

| | |
|---|---|
| Na (mg/L)/23 | = meq/L |
| Ca (mg/L)/20 | = meq/L |
| Mg (mg/L)/12.2 | = meq/L |

**Equation 2** Calculation of sodium adsorption ration (SAR) using milligram per litre concentrations (mg/L)

$$SAR = \frac{\frac{Na}{23}}{\sqrt{\frac{\frac{Ca}{20} + \frac{Mg}{12.2}}{2}}}$$

where concentrations of cations are expressed in mg/L.

**Table 12** Relationship between acceptable sodium adsorption ratio (SAR) of irrigation water and soil texture.

| | Acceptable irrigation water SAR | |
|---|---|---|
| Soil texture | Median | Range[A] |
| Sand, sandy loam | 20 | >20 |
| Loam silty loam | 10 | 8-20 |
| Clay loam | 8 | 5-13 |
| Light clay | 6 | 5-11 |
| Medium to heavy clay | 4 | 4-5 |

[A]related to charge of clay

Source: modified from ANZECC and ARMCANZ 2000, p 9.2.3

Note: subsoils should also be considered to ensure that deep leaching is possible if required.

## Soils

The sodicity class of the soil can be calculated by analysis of the exchangeable cations in a soil. The exchangeable sodium percentage (ESP) is then calculated (Equation 3) and the sodicity class of the soil and likelihood of dispersion determined by referring to Table 13.

In Australia, soils with an ESP ≥6 may be sodic (Rengasamy 2002). Such soils tend to have a relatively high pH (approximately 7–10), as sodium carbonate is much more soluble than calcium or magnesium carbonates; thus, higher concentrations of carbonate and bicarbonate are maintained in sodic soil solutions (Rengasamy and Olsson 1991, Brady and Weil 1999). However, although uncommon in Australia, some acidic (approximately pH 5) sodic soils can be found (Rengasamy and Olsson 1991).

**Equation 3** Exchangeable Sodium Percentage

$$ESP = 100 \text{ x} \left(\frac{Exch.Na}{CEC}\right)$$

where Exch.Na = Exchangeable sodium and CEC = Cation Exchange Capacity (i.e. the sum of exchangeable Ca+Mg+Na+K)

**Table 13** Soil sodicity class and dispersion.

| Sodicity Class | Exchangeable sodium percentage | Dispersion |
|---|---|---|
| Non-sodic | <6 | None |
| Low sodicity | 6-10 | Low |
| Moderately sodic | 10-15 | Medium |
| Highly sodic | >15 | High |

Note: Dispersion also depends on the soil type i.e. clay content and clay type (Table 12).

Soil sodium adsorption ratio (SAR) can also be measured and used to determine the risk of a soil becoming sodic. SAR is traditionally used for assessing water (see above), however, since SAR is easier to measure in soil than ESP, many researchers have developed relationships between soil SAR and ESP (Sumner *et al*. 1998, Stevens *et al*. 2003), but these tend to be specific to the soil in which they were derived.

The soil SAR (SAR1:5) is measured by mixing 1 part soil with 5 parts of water for a specific time (e.g. 1 hr) and the concentration of Ca, Mg and Na measured in the water from the mix. SAR is then calculated as show in Equation 1 or Equation 2.

The ESP of some soil in Australia can be estimated (Rengasamy *et al*. 1984) from SAR1:5 by using  Equation 4.

**Equation 4** Estimation of exchangeable sodium percentage (ESP) from sodium adsorption ratio (SAR).

$$ESP = (1.95 \text{ x } SAR1{:}5) + 1.8$$

### Water quality and the likelihood of a soil becoming sodic

When assessing irrigation water for sodic impacts on a soil the salinity of the water should also be assessed. As water or soil salinity increases, it can suppress the on-set of dispersion (Figure 11). Soil texture can also influence the impacts from sodic (high SAR) recycled water. As a general rule, the higher the clay content or heavier the soil the greater the chance of sodicity being displayed (Table 12).

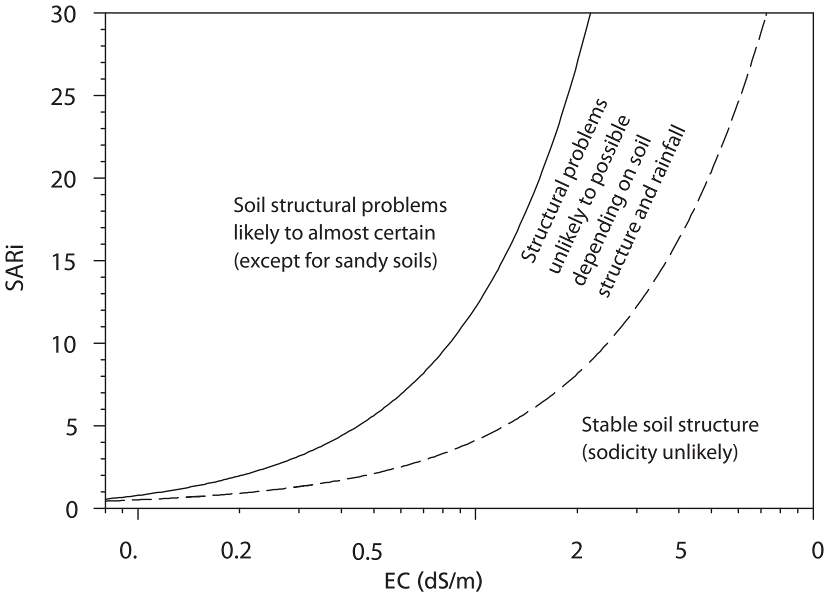


**Figure 11** Relationship between sodium adsorption ratio (SAR) or irrigation water and electrical conductivity (EC) of irrigation water and likelihood of soil structure breakdown.
(modified from ANZECC and ARMCANZ 2000)

Another measure required to ensure SAR calculations will not be impacted by carbonates is the residual sodium carbonate (RSC). RSC gives an indication if carbonates will impact on Equations 1, 2 and 4 and if sodium (Na) will build up in the soil. The more positive the greater the chances of sodium build up (Carrow and Duncan 1998, p 59). The RSC of recycled water can be calculated with Equation 5 below.

**Equation 5** Calculation of residual sodium carbonate (RSC).

$$RSC = (CO_3^{2-} + HCO_3^{-}) - (Ca^{2+} + Mg^{2+})$$

where concentrations of cations and anions are expressed in meq/L.
To convert from mg/L to meq/L:

$Ca^{2+}$ (mg/L)/20 = meq/L

$Mg^{2+}$ (mg/L)/12.2 = meq/L

$CO_3^{2-}$ (mg/L)/30 = meq/L

$HCO_3^{-}$ (mg/L)/61 = meq/L

If the RSC is less than zero, the likelihood of sodium accumulation on soil cation exchange sites is low. If RSC is 0–1.25 meq/L, the likelihood is moderate; if RSC is 1.25–2.5 meq/L, the likelihood is high; and if RSC is greater then 2.5 meq/L, the likelihood is very high (Carrow and Duncan 1998).

# Managing sodicity

## Soil additives

Soil sodicity is created when calcium is displaced by sodium in the soil (discussed above). Similarly, sodicity can be amended through the application of calcium - which displaces sodium (Figure 12) which is then leached away.

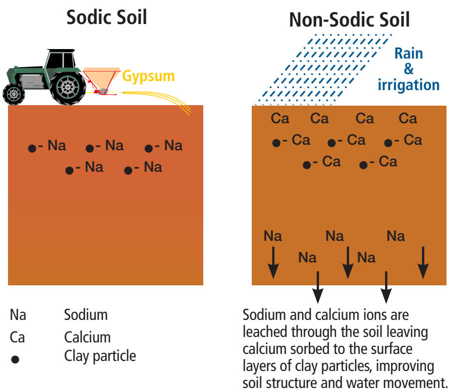


**Figure 12** Correction of sodic soil.
Source: (Kelly & Renagasamy 2006)

The application of gypsum is the most cost effective method of ameliorating sodic soil (Table 13; Table 14). It is important to note that another source of calcium is lime. Lime has very sparing solubility and should only be used in situations where the soil pH is less than 6 and the desired effect is to supply both calcium for sodicity and carbonate for pH amelioration. In these cases combinations of both lime and gypsum are most effective.

**Table 14** Soil dispersion and pH related to gypsum and lime application rates required for the correction of sodicity.

| Dispersion | pH >6 Gypsum (t/ha) | pH <6 Gypsum + Lime (t/ha) |
|---|---|---|
| None | 0 | 0 |
| Low | 2.5 | 1.25 + 1.25 |
| Medium | 5.0 | 2.5 + 2.5 |
| High | 10.0 | 5.0 + 5.0 |

Source: Kelly and Rengasamy 2006.
Note: t/ha × 0.1 = kg/$m^2$

### Soil structural stability and organic amendments

Soil organic matter improves soil structural stability. Organic matter also benefits the soil by:
- Increasing water holding capacity
- Decreasing erosion losses
- Supplying nutrients for plants and food for microorganisms
- Increasing nutrient holding capacity

Developing and maintaining sufficient organic matter in the soil should be an essential part of any integrated approach to the management of sodicity and associated structural problems.

There are generally two recognised methods for building soil organic matter:
- Growing and incorporation of plants (green manure)
- Addition of organic amendments like animal manures and composts. Care should be taken when applying manures as they may contain significant amounts of salt and the nutrients they contain need to be considered in nutrient budgets.

## 4.7 Boron (B)

Special care is needed in the management of boron because there is only a small concentration range in soils between plant deficiency and toxicity. Uptake and removal of boron by plants is usually less than input from soil minerals and irrigation water, depending on the irrigation water quality. As a result, the excess boron accumulates in the root zone if it is not leached down through soil.

The concentration of boron tolerated in irrigation and soil water by various agricultural plants without reduction in yield or vegetative growth is given in Appendix 7.7, p 97. These values provide a guide only, as the rate of uptake of boron by plants (and therefore their tolerance) depends on a range of other factors such as soil texture. Generally, higher uptake rates are seen in sandy soils and lower rates in clayey soils. Uptake rate is also much lower in a soil pH range of 7.5–9.5 and plants can tolerate higher soil boron levels in this range.

Typical symptoms of boron toxicity first appear in older leaves and include a yellowing and brown speckling pattern found between the veins and near the edge of the leaf (Figure 13), followed by the edges gradually turning brown and dying (necrotic tissue). Other symptoms include yellowing (chlorosis), tip burn, cupping of the leaves, reduced size, premature leaf drop and the development of a red, pink, purple or bluish band surrounding the edge of a chlorotic leaf (anthocyanins). Yield reductions are likely to occur before visible symptoms occur, so tissue analysis is an important tool to assess any potential for growth impacts resulting from boron toxicity.

**Figure 13** Boron damage in eucalyptus leaves.
Source: Tanji *et al*. 2007 courtesy of the WateReuse Foundation

## How can boron be managed?

Because of tolerance variations between different plant varieties, one method of management is to grow more tolerant plant species or varieties in areas with high boron concentrations in irrigation water or soil.

Boron can be leached from soil by rainfall or irrigation leaching fractions. However, leaching of boron can be difficult because the rate of removal can be much slower for boron than for other salts, as boron can be attracted to or absorbed by soil particles, requiring about three times more water to leach than more soluble ions such as Cl and Na. In many cases, leaching is unlikely to provide a permanent solution because boron will be re-supplied through irrigation water and the breakdown of naturally occurring boron-containing minerals in the soil.

Boron in recycled water may be a direct hazard to plants irrigated with the water or indirectly if it builds up in a soil. Boron sensitive plants (Appendix 7.7, p 97) should not be grown with recycled water containing greater than 0.5 mg B/L.

## Management tools

Management tools include:

- Boron concentrations of ≤0.5 mg/L in recycled water are manageable in most situations.
- Site specific soil tests are required to determine if there are existing elevated boron concentrations in soil to be irrigated.
- Plant selection. Care should be taken to avoid growing boron sensitive plant species, if boron concentrations in recycled water exceed 0.5 mg/L.

There are a range of plant sensitivities to boron (Appendix 7.7, p 97), and these should be considered along with the soil type and concentration of boron in recycled water. Care must be taken if these sensitive plants are grown, especially on heavier textured soils which may already have elevated boron concentrations.

# 4.8 Heavy metals and other chemicals of concern

## Heavy metals

Most heavy metals of concern are removed from recycled water during treatment and end up in the solids or biosolids (Figure 1). Guidelines for heavy metals in recycled water are usually stricter than other water quality guidelines. Concentrations of heavy metals should be checked against those in the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC and ARMCANZ 2000), but usually are not found to be a problem.

## Cadmium (Cd)

Cadmium concentrations in recycled water are generally low and monitored by the water supplier. The higher the level of treatment, the lower the relative concentration of cadmium. However, irrigation of plants with recycled water can increase plant uptake of cadmium already present in the soil. For example, recycled water can be high enough in chloride (i.e. >350 mg/L) to increase the chance of cadmium uptake by the plant if the soil is relatively sandy. Plant uptake is generally only an issue if it is a food or fodder crop, leading to increases in levels of cadmium in plants or animals eaten by humans.

Ideally the concentration of cadmium in irrigation water should be less than 0.01 mg/L or less than 0.05 mg/L for short-term use (<20 years) (ANZECC and ARMCANZ 2000, p 9.2-55). If greater than 2 kg/ha is applied during irrigation then cadmium concentrations in soils should be checked.

If growing plants where cadmium could accumulate and they could be eaten by animals (e.g. humans, pets), management techniques should include:

- Using low cadmium phosphorus fertilisers, especially on sites already contaminated.
- Testing soil cadmium levels.
- Using a mix of recycled water and fresher groundwater to reduce the chloride concentration if cadmium concentrations are high in produce.
- Adjusting soil pH if necessary.
- Selecting plant varieties with low uptake of cadmium.
- Increasing soil organic matter.
- Adding zinc if necessary.

*High chloride levels can increase uptake of cadmium by plants*

## Copper (Cu) and zinc (Zn)

Copper and zinc concentrations in recycled water are usually insufficient to meet plant nutrient requirements. However, these metals can accumulate in soils after irrigation for 20 to 100 years and concentrations in recycled water should be checked against guideline values to ensure soil contaminant loadings are monitored. (see ANZECC and ARMCANZ 2000).

Ideally the concentration of copper in irrigation water should be less than 0.02 mg/L or less than 5.0 mg/L for short-term use (<20 years) (ANZECC and ARMCANZ 2000 , p 9.2-55). If greater than 140 kg/ha is applied during irrigation then copper concentrations in soils should be checked.

Ideally the concentration of zinc in irrigation water should be less than 2.0 mg/L or less than 5.0 mg/L for short-term use (<20 years) (ANZECC and ARMCANZ 2000, p 9.2-66). If greater than 300 kg/ha is applied during irrigation then zinc concentrations in soils should be checked.

## Chlorine residuals ($Cl_2$)

Recycled water is often chlorinated as a disinfection treatment to minimise pathogens. However, high concentrations of residual chlorine in recycled water can have a negative impact on plants irrigated with the recycled water (Table 15). Usually residual chlorine in recycled water is less than 1 mg/L.

**Table 15** Effect of residual chlorine in recycled water on plants sprinkler irrigated with recycled water.

| Hazards | Unit | Degree of restriction on sensitive plants with sprinkler irrigation | | |
|---|---|---|---|---|
| | | None | Slight to moderate | Severe |
| Residual Chlorine | mg/L | 0–1 | 1–5 | >5 |

Source: Pettygrove and Asano 1985, p 3-11, Asano *et al*. 2007 p 956

Chlorine can also react with ammonia in recycled water to form chloramines, or chloramines can by used directly to disinfect water. Monochloramine (generally the dominant form of chloramine) is usually considered less toxic than chlorine (Table 15). However, there is limited data available for most plants and some may be more sensitive than others.

## Endocrine disruptors (EDC)

Water recycled from wastewater treatment plants is usually low in chemicals that can alter normal endocrine function in animals, i.e. endocrine disrupting chemicals (EDCs) and personal care products and pharmaceuticals. At this stage, there is no evidence that irrigation with recycled water can have a negative impact on the soil and plants irrigated or the immediate environment. Human health concerns are even lower considering the low exposure when irrigating with recycled water.

# 4.9 Irrigation

Understanding irrigation requirements and managing irrigation rates is one of the most important components of using recycled water as it allows management of:

- Water supply and minimising plant water stress.
- Nutrients applied with recycled water (Section 4.3, p 27).
- Soil salinity (Section 4.4, p 32).
- Water to remain on site.

A simple definition of irrigation requirements is the difference between the plant water requirement and the depth of rainfall at a location (Allen *et al*. 1998). Rainfall can be measured using standard meteorological equipment, but the plant water requirement is more complex.

For plant requirements to be met, additional water is required to overcome inefficiencies in irrigation method (i.e. effective irrigation is different to actual) and to leach salt down the soil profile. For steady state conditions the leaching fraction (LF) is defined as the volume of drainage water (passing the root depth) divided by the volume of infiltrating irrigation water. The leaching requirement (LR) refers to an estimate of what the LF must be to ensure soil salinity remains within tolerable limits for the specific plants grown. This steady state approach is usually a good estimate for long term changes in soil salinity. However, it assumes uniform application and does not consider salt precipitation or dissolution, irrigation frequency effects, preferential flow, upward water flow, water chemical composition and salt removal in surface runoff (Corwin *et al*., 2007). There are several transient models available to estimate short-term soil salinity changes from irrigation. However, these are not discussed here, as good soil monitoring will give direct feedback as to the appropriateness of scheduling and application of irrigation water.

## Irrigation requirements

Irrigation requirements (IR) can be calculated from pan evaporation (PE) and a crop factor (CF). Rainfall (RF) measurements should also consider rainfall that:

- Leaches through the root zone of the soil causing deeper percolation where water is inaccessible by the plant.
- Evaporates before it is used by the plant (i.e. lands on leaf area and evaporates).

To consider these losses of rainfall a rainfall efficiency factor (Erf) is used. This is usually a percentage of RF. The IR should also consider any requirements for leaching (i.e. the leaching requirement; LR) and the efficiency of the irrigation system using the irrigation efficiency factor (Eir).

The efficiency of applied water when irrigating (Eir) can be calculated using Equation 6 (Asano *et al*. 2007).

**Equation 6** Irrigation efficiency factor

$$Eir = \frac{I_{ben}\ (mm)}{I_{app}\ (mm)}$$

Where:

*Eir* = Irrigation efficiency

$I_{ben}$ = Water used beneficially (i.e. not lost in wind drift, runoff, or excess application leading to deep percolation in excess of LF due to low distribution uniformity, but accessible to the plant for evapotranspiration, plant cooling and leaching of salts)

$I_{app}$ = Water applied to field (e.g. irrigation water applied)

The irrigation requirement can be calculated using Equation 7, which considers all the factors discussed above.

**Equation 7** Irrigation requirement

$$IR = \frac{(PE \text{ x } CF) - (RF \text{ x } Erf) + LR}{Eir}$$

Where units are:

IR (Irrigation requirement) = mm

Eir (Irrigation efficiency factor) = unitless

PE (Pan evaporation) = mm

CF (Crop factor) = unitless

RF (Rainfall) = mm

Erf (Rainfall efficiency factor) = unitless

LR (Leaching requirement) = mm

## Crop factors (CF)

The CF can be considered the percentage of pan evaporation (PE) used by the plant and lost from the soil via evaporation (Evapotranspiration).

Crops factors (CF) vary considerably depending on the plant type, plant density and the visual appearance desired (Table 16). Crop factors also vary depending on the plant's stage of development. The crop factors in Table 16 give good indications of typical average crop factors for a range of amenity horticultural plants. More detailed crop factors and method for calculation of crop factors are available online (UCCE and CDWR 2000).

**Table 16** Approximation of crop factors (CF) for turf and ornamental plants.

| | Desired look of plant | | | | | |
|---|---|---|---|---|---|---|
| | Excellent (Premium) | Great (Strong) | OK (Medium) | Just OK (Low) | Surviving (minimal) | Range (CF±) |
| Plant type | Crop factor[A] | | | | | |
| Turf – warm season | 0.625 | 0.5 | 0.325 | | | 0.08 |
| Turf – Cool season | 0.825 | 0.725 | 0.675 | | | 0.10 |
| Ornamentals | 0.775 | 0.65 | 0.4 | 0.3 | 0.1 | 0.05 |
| Vegetables | 0.85 | 0.7 | | | | |
| Comments | Vigorous lush growing broad leaf | Strong growth | Some drought tolerance required | Moderate drought tolerance required | Desert plants | |

Source: Handreck and Black 2002

[A]Crop factor × Class A Pan evaporation = plant water requirement (mm). These factors apply when at least 70% of the surface soil is shaded by the plant, if less they can be reduced by 0.1-0.3.

Note: These numbers are rough guides only, measures should be made on-site. For example, plants become larger in containers and their crop factor can increase to as high as 4.

### Reference evapotranspiration

Another term is also used to estimate irrigation requirement, similar to the crop factor and pan evaporation. This term is reference evapotranspiration (ETo) and is the rate of evaptranspiration from a healthy grass, completely covering the ground to a uniform height of 75 to 125 mm, and having an adequate supply of water with no microclimate factors influencing it. A crop coefficient (Kc) is used to determine another specific crops evapotranspiration (ETc) from the ETo. So ETc = Kc × ETo. As a rough guide CF are approximately 80% of Kc values (e.g. if Kc = 0.6 then CF = 0.48).

## Irrigation distribution uniformity

Even distribution of water when irrigating is very important. If uneven, parts of the irrigated area will be overwatered and others underwatered. For sprinkler irrigation, distribution uniformity can by measured with catch-cans distributed in a grid layout throughout the irrigated areas. The catch-cans will collect irrigation water during the irrigation event. By measuring the water level caught in each can, a coefficient of uniformity can be calculated. A similar technique can be used to assess dripper line measuring the volume from each dripper.

A coefficient of uniformity greater than 75% is acceptable for deep rooted permanent horticultural plants and it should be greater than 85% for shallow rooted plants (e.g. turf and garden beds).

To calculate the coefficient of uniformity (CU):

$$CU\% = \left(1 - \frac{Tot}{A \times No.Cans}\right) \times 100$$

Where:

CU = Coefficient of Uniformity

A = Average depth of water delivered in irrigation event (mm)

Tot = Total sum of difference between each individual reading and the average (A).

No.Cans = Number of catch-cans used.

Source: Handrick and Black, 2002

## Best practice irrigation

Once established, best practice irrigation for amenity horticulture should minimise feeding (fertiliser use), watering and mowing/pruning, while maintaining the desired appearance. Adherance to these best practices also minimises impacts on the environment by minimising fertiliser/chemical use and conserving water. With recycled water efficient irrigation will also minimise the nutrients supplied with the recycled water. Some plants may also require less water and fertilisers so plant selection can also help meet environmental goals.

Irrigation techniques should:

- Apply the required water efficiently to different areas (e.g. shrubs, require different water to turf, different turf species and uses often have different water requirements).
- Apply water evenly, despite wind or other influences.
- Provide sufficient water when required considering:
  - plant growth rate
  - soil type
  - daily evaporation rates
  - wind effects
  - available soil moisture
- Use modern soil moisture and air sensing devices such as:
  - tensiometers
  - soil moisture sensors
  - relative humidity measuring devices
  - wind speed detectors.
- Allow multiple applications of water per day (referred to as pulsing) for establishing or rehabilitating areas.
- Apply coarse water droplets to reduce evaporation and wind effects (i.e. careful with young plants).
- Contain flow protection devices to isolate sections if there is a reticulation problem and a warning system to identify malfunctions.
- Irrigate at the coolest part of the day to minimise evaporation losses.
- Irrigate when there is least wind movement.

Irrigation Australia has published a summary of best practice for urban irrigation (IAA 2006). See www.irrigation.org.au/index.cfm?/publications/bookshop

# Irrigation management and scheduling

Irrigation scheduling is an important component of the irrigation management strategy. It ensures that the correct amount of water is applied when required. There are a range of methods for irrigation scheduling that are typical for any irrigation system.

Ultimately texture and structure of the soil dictates its water holding capacity and the water which will be available to the plant grown in the soil. Water should be applied to suite the root depth of the plants irrigated. For example, with turf the top 20 cm of the soil contains the predominant root mass. Therefore any water passing this point will not be available to the plant and will contribute to leaching of water and potentially nutrient losses.

For example, if the plants root depth is 20 cm, there is 20 cm of soil available to hold water. If the soil is a sandy loam texture, for every 1 cm of soil it will hold 1 mm of water (Table 17 – appearance great). That is, approximately 20 mm of water is held by the soil which is available to the plant.

**Table 17** Plant available water (at field capacity) if plants are maintained as indicated.

| | Level of growth/appearance | | | | |
|---|---|---|---|---|---|
| | Excellent (Premium) | Great (Strong) | OK (Medium) | Just OK (Low) | Surviving (minimal) |
| Soil Texture | mm of water available/cm depth of soil | | | | |
| Sand | 0.3 | 0.4 | 0.5 | 0.6 | 0.6 |
| Loamy sand | 0.4 | 0.6 | 0.7 | 0.8 | 0.9 |
| Sandy loam | 0.6 | 1.0 | 1.1 | 1.2 | 1.3 |
| Loam | 0.9 | 1.5 | 1.7 | 1.8 | 2.0 |
| Clay poor structure | 0.5 | 0.8 | 1.0 | 1.1 | 1.3 |
| Clay good structure | 0.7 | 1.1 | 1.3 | 1.6 | 1.9 |

Source: Handreck and Black 2002

If you use the average daily pan evaporation (PE) rates for Melbourne, the average water requirement for a plant and water lost from the soil surface can be estimated (i.e. evapotranspiration rate or ET). For example, in January the average daily PE is 7.8 mm/day (Table 18). If you are growing a warm season turf the approximate crop factor (CF) is 0.5 (Table 16; CF × PE = ET). So for the example above, the soil can hold 20 mm of water for the plant, the plant will use 3.9 mm/day (0.5 x 7.8), or the equivalent of 5.1 days of water (20/3.9).

A good watering of 20 mm every 4-5 days should be adequate to maintain warm season turf with a great appearance through January near the Melbourne airport. Note that these calculations assume average daily evaporation rates. Site specific data should be used were possible to fine tune water requirements. Day to day evaporation can vary significantly and effective rainfall should be factored into these requirements also.

All sites should also have moisture sensors in place or be checked manually by staff daily.

**Table 18** Average daily pan evaporation at Melbourne Airport (mm/day).

| Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 7.8 | 7.1 | 5.8 | 3.9 | 2.6 | 2.0 | 2.0 | 2.8 | 4.1 | 5.2 | 5.9 | 7.6 |

## Water storage

Water requirements/demands of specific plants and turfs must be taken into account when designing systems to ensure that on-site storages are built to provide a constant uninterrupted supply of recycled water when demand is at its greatest and when required. Specific individual requirements should be well understood and supply agreements reflect these requirements.

### Size

The size of your storage depends on the frequency of supply and total plant requirements for highest demand period. Calculations should also consider losses from the storage through evaporation and any leakages that might occur. Leakage from storages can enter streams, waterways and underground watercourses, with possible environmental impacts.

### Requirements

Storages would also need to be constructed in accordance with state guidelines on dams and water storages.

### Eutrophication and algae

Due to the high nitrogen and phosphorus concentrations generally found in recycled water, the risk of excessive algal growth or "blooms" may require specific management programs. There is also a risk of drainage water entering offsite aquatic systems. Algae risk management is discussed in Section 4.10, p 59.

## Irrigation methods

It is important to match plants, soil, recycled water quality and irrigation methods. There can be no definitive answer as to which type of irrigation system is most suitable for use with recycled water, as there are many site-specific variables. However, it is possible to rank the three main irrigation systems against the key criteria related to irrigation with recycled water.

The main areas of assessment for irrigation systems are usually against water quality parameters, minimising environmental problems (including efficiency of water use) and appropriateness for efficient and economic water delivery. For example, Table 19 indicates surface runoff risk relative to irrigation method and soil texture.

**Table 19** Risk of surface run off with recycled water irrigation system and soil type.

| | Surface run off risk | | |
|---|---|---|---|
| Soil texture | Drip | Sprinkler | Furrow |
| Sand | Low | Low | Low |
| Loam | Low | Medium | Medium |
| Clay | Low | High | High |

Source: Stevens *et al*. 2006 Table 6.7 p 121.

### Sprinklers/Sprayers

Sprinkler irrigation is commonly used in horticulture. Sprinklers are systems that apply the water over the whole plant and ground area. For nurseries, sprinklers are generally overhead systems wetting the whole area, but for larger growing systems like golf courses sprinklers are commonly found low to the ground or as popup sprinkler systems.

Application rate can be matched to the soil infiltration rate. Soils with very low infiltration rates (i.e. <3 mm/hour) are prone to runoff and need special measures to increase intake or to provide uniform surface ponding to prevent runoff. Sprinkler irrigation is also suitable for undulating and steep terrain, although surface runoff can still be a problem. Sprinklers have the advantage of providing good germination and plant establishment since small amounts of water can be applied frequently, and with many systems this can be done with low labour requirements. It also has other horticultural advantages in the incorporation/activation of herbicides and fertilisers.

Drawbacks with using sprinklers are: the high capital and operating cost; foliar application of recycled water may cause specific ion injury to plants; higher exposure of recycled water to humans; difficult for aeration as inground sprinklers need to be located before coring; increased risk of plant fungal disease; and decreases in water use efficiency on windy days.

### Surface Irrigation

There are many types of gravity flow systems where irrigation progresses from the higher end of the area to the lower (e.g. furrow, contour bay and border check). For irrigation of horticultural plants a high level of control is required to prevent water logging stress and off-site environmental effects. Surface irrigation is not widely used and not recommended in amenity horticulture as an irrigation technique, as it is hard to control and manage.

The main problems associated with surface irrigation are the non uniformity of water application and over irrigation.

### Drip Irrigation (Surface or subsurface)

Drip irrigation is likely to be the most suitable form of irrigation for use with recycled water for two important reasons. Firstly, it limits contact of the recycled water with the plant, workers and general public. Secondly, it provides the best control over the application of irrigation water. It leads to reduced environmental impacts (i.e. no irrigation runoff, little rainfall runoff and little drainage past the root zone, if well managed).

Drip is a technologically advanced method of irrigation that can apply water evenly to plants across a landscape. To achieve this water is pumped around the paddock in pipes to emitter points that are at the plant root zone. Irrigation is closely matched to the plant water use on a daily (or sub-daily) basis. Characteristics of drip systems that help achieve this are:

- Water is applied frequently at low application rates. Drip irrigation can apply water only at low rates (e.g. 5–10 mm/hr). This means that drip systems are operated frequently and are run for long sets. These features are a constraint to irrigation in that large soil water deficits cannot be replaced quickly.
- Water is applied uniformly to all plants.
- Water is applied directly to the plant root zone.

Drip emitters have passages as small as 0.25 mm in diameter and as such are extremely vulnerable to blockage. The greatest source of non uniformity in a drip system is due to emitter clogging. Recycled water is generally nutrient rich, which encourages algae growth that can lead to dripper clogging. Dripper design should consider: passage width; passage depth; passage area; passage length; anti-suck back features; filtration area; and filter location. When installing drippers ensure that have been designed appropriately so they will be suitable for the type of recycled water that will be used.

A good filtration system with sound system maintenance should minimise the risk of dripper clogging in most situations (Table 20). The best filters are media filters which are pressurised tanks filled with silica sand or crushed granite. The size and number of tanks depends upon the system flow rate and the cleanliness of the water. The filters are kept clean by back flushing. This operation can require large amounts of water compared to screen or disk filters, and a suitable disposal site for this water needs to be found as it will be high in nutrients.

Media filters also need to be chlorinated to control biological activity that may clog them. Media filters are generally considered to be the best all-round filtration device but they are considerably more expensive than screen or disk filters and also take up much more space. Table 20 shows the risks of drippers clogging related to several water quality parameters.

Apart from fertilisers other chemicals need to be applied through the system to keep the laterals and emitters clean. There is also the possibility of applying herbicides, fungicides and nematicides through the system. Soil or water ameliorants can also be applied through a drip system. Some dripper lines include the use of root-inhibiting chemicals (herbicides) to prevent root intrusion. Irrigation with recycled water higher in nutrients might attract roots and drip lines should be monitored and maintained appropriately. Blockages caused by algae or microorganisms can be managed by dosing with chlorine or algaecides. Blockages from chemical precipitation can be managed with nitric or phosphoric acid. In some areas (e.g. Northern Western Australia) white ants may damage drip tape and the use of pesticides may be required to prevent white ant access.

**Table 20** Water quality parameter relative to the potential for drip emitter clogging.

| Water quality parameter | Symbol | Unit | Impact rating for risk of clogging emitters | | |
|---|---|---|---|---|---|
| | | | Insignificant | Minor | Moderate to high |
| Total suspended solids (include algae) | TSS | mg/L | <50 | 50–100 | >100 |
| pH | pH | | <7 | 7-8 | >8 |
| Total dissolved salts | TDS | mg/L | <500 | 500-2000 | >2000 |
| Manganese | Mn | mg/L | <0.1 | 0.1–0.5 | >1.5 |
| Total iron | Fe | mg/L | <0.2 | 0.2–1.5 | >1.5 |
| Hydrogen sulphide | $H_2S$ | mg/L | <0.2 | 0.2–1.5 | >1.5 |
| Bacterial number | Count/100ml | | <10,000 | 10,000–50,000 | >50,000 |

Source: Asano et al. 2007, p 1068

Chemical injection is a fundamental part of drip irrigation as fertiliser is required. Nutrient distribution under a drip system depends upon the wetting pattern, soil type and rate at which the recycled water and any fertiliser are applied.

## Groundwater: perched and rising water tables

### Impacts of perched and rising water tables

Irrigation can lead to perched and rising water tables, associated with increasing soil salinity and waterlogging. This can have negative impacts on native vegetation in the same way as for other plant species. Perched and rising saline water tables can also discharge into freshwater systems, which can be particularly sensitive to increases in salinity. For example, some water-plants and insects are damaged or killed at salinities as low as 1000 mg/L or 1.7 dS/m.

Rising water tables can occur when native, perennial, deep-rooted vegetation is cleared and replaced with shallow-rooted plants (Figure 14). Perennial, deep-rooted plants use deep groundwater throughout the year, while annual plants generally only remove water from the upper soil layers during plant growth; which is usually for about 4–6 months of the year. This situation can be aggravated by over-irrigating, which allows even more water to move down to the water table.

## How can perched and rising water tables be managed?

To use water accumulating in the groundwater table, retain native vegetation where possible, or plant deep-rooted perennial vegetation (such as trees). Species that are native to the area are likely to be suited to the environmental conditions and will provide habitat for native animals, which may play a role in managing horticultural pests.

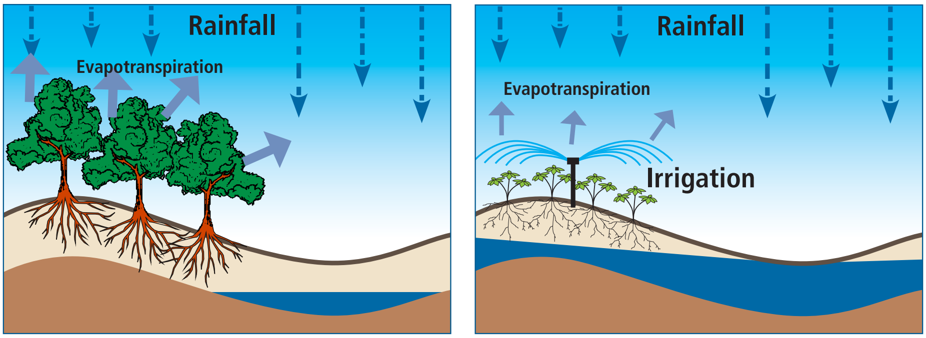


**Figure 14** Formation of rising water tables following change of land use.

Best irrigation practices should also be adopted (Section 4.9, p 50) and use only as much water as is required by the plant, plus a leaching fraction to reduce soil salinity if necessary. Using more water than this is wasteful and can lead to rising and perched water tables, causing problems for both horticulture and the environment.

### Perched water tables

Perched water tables generally occur when water moving down through soil becomes trapped by an impervious layer of clay or rock close to the surface rather than draining down to the local groundwater table (Figure 15). This is more likely to occur when large amounts of irrigation water are being applied.

Perched water tables' also occur when a relatively coarse mineral material underlies a finer textured material (e.g. gravel under clay or gravel under sand). Water will only normally move into the underlying coarse-textured materials under the force of gravity when this overcomes the surface tension of water in the overlying materials. This usually means that the moisture content of the overlying layer has to be saturated (greater head of water) before any water will move into the material below. Equilibrium is reached where some water will always remain in the fine material ('perched') above the coarse material - unless removed by evapotranspiration. In application, this may pose salinity problems for turf where the perched water table phenomenon is deliberately applied in media construction to provide water storage for turf to access. Without leaching salinity levels could also be a problem for these types of application.

### Groundwater

Rising groundwater tables occur when the amount of water moving down through the soil, to the local groundwater table, is continually greater than the removal of water (naturally or by human activity) from that groundwater. This leads to an accumulation of water in the soil, bringing the water table closer to the surface and creating a raised water table (Figure 14). If the water table gets too close to the surface (<approx. 2m) then water and salts from the water table rise to the soil surface though capillary action. The water brought to the surface evaporates and the salts are left in the surface soil. This process is the opposite of leaching. If further irrigation or rainfall does not leach these salts back down the soil profile, they can accumulate and cause the soil to become saline and/or sodic.

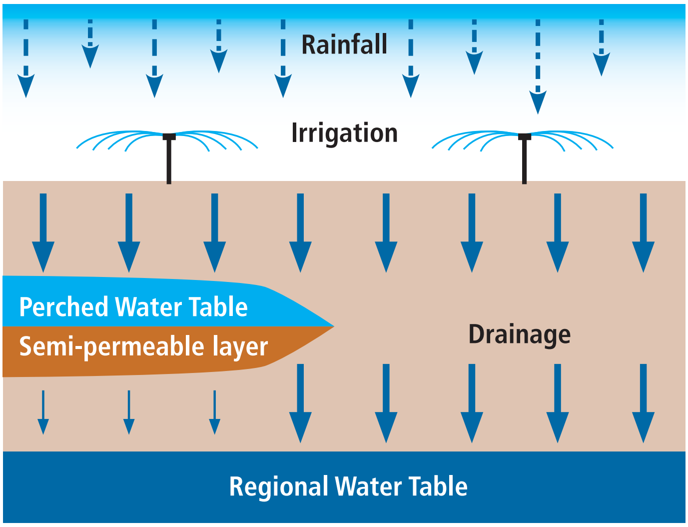


**Figure 15** Formation of perched water table.

# 4.10 Algae management

## Algal Blooms

Algal blooms are dense congregations of algae that can form over lakes, dams or streams. Factors that foster algal bloom formation and growth include:

- Temperature
- Light
- pH
- The availability of nutrients
- Lack of competition from other micro-organisms
- The absence of predators.

Any water containing sufficient nutrients (N and P particularly) will potential form algal blooms if other conditions are conducive. Long periods of dry stable warm weather provide favourable conditions for algal growth.

## Potential Problems

Algal blooms can cause major problems for the natural ecosystems including fish mortalities, and can interrupt water supply for towns and cities and limit recreational activities. These problems are mostly caused by blooms of cyanobacteria (commonly called 'blue-green' algae) which often produce toxins which are harmful to human and animal health. Species in Australia which are commonly found to be toxic are *Microcystis* and *Anabaena*.

Algae that flourish in secondary treatment lagoons and winter storages may pose a risk to the adequate treatment and distribution of recycled water during bloom events. Generally, algae applied to turf via recycled water will not affect animal health provided the appropriate withholding periods are implemented and animals are allowed access after turf has dried. There is, however, a greater risk to animal health associated with drinking recycled water containing blue-green algae.

## Managing algae growth

The best method for management of algae is to limit their growth by manipulating the factors discussed above that influence their growth. For example, restrict light, introduce predators or minimise storage time. Different algae may also live in different depths of the water storage. If this is the case, adjustment of water intake can minimise algae intake into the irrigation system. If a toxic bloom is identified it is very difficult to remove the toxins.

## Algae Assessment

It is preferable to examine live samples for taxonomic identification of algae. If this is not possible storage of specimens can be preserved in a solution of 70% alcohol, 25% water and 5% glycerol. With storage, many features such as colour or the presence of flagella may be lost or changed making them more difficult to discern.

## Additional information on algae

Has your dam got a blue-green algae problem? (Thomas and Martinelli 1999)

Minimising algae growth in farm dams. (Cummings 2002)

www.dpi.vic.gov.au/dpi/nreninf.nsf/childdocs (then click on Landcare/waterquality).
www.health.vic.gov.au/environment/water/bluegreenalgae.htm (CRC for WQT 2004)

# Monitoring Programs




In Victoria, all monitoring, reporting and auditing procedures and programs for recycled water use should be documented in the Environmental Improvement Plan (EIP). Audit programs for schemes that use greater than 1 ML per day should comply with the principles in *ISO 14010's Guidelines for Environmental Auditing* or equivalent. The proponent of the reuse scheme should ensure that an appropriately qualified independent auditor or internal expert undertakes the audit (EPA Victoria 2003). See section 8 and 9 of the Victorian Guidelines (EPA Victoria 2003) and Section 7.1, p 72.

## 5.1 General principles

Monitoring can be undertaken for a range of purposes. The principal types of monitoring are:

1. Baseline monitoring (i.e. 'where are we now?')
2. Validation monitoring (i.e. 'will it work?')
3. Operational monitoring (i.e. 'is it working now?')
4. Verification monitoring (i.e. 'did it work?').

The main functions of each of these types of monitoring are given in Table 21 below.

**Table 21** Purpose of main types of monitoring.

| Type of monitoring | Main functions |
|---|---|
| Baseline | Gather information that will underpin the risk assessment process and provide a basis for assessing potential impacts of recycled water on the environment |
| Validation | Obtain evidence that the elements of the recycled water quality management plan will achieve performance requirements |
| Operational | Conduct a planned sequence of observations or measurements of control parameters to assess whether a preventive measure is operating within design specifications and is under control |
| Verification | Apply methods, procedures, tests and other evaluations, in addition to those used in operational monitoring, to determine compliance with the recycled water quality management plan, and to determine whether the plan needs to be modified |

Monitoring may also form part of the surveillance undertaken as a statutory requirement under license or approval from a regulatory authority. In the context of recycled water quality management, good monitoring programs should:

1. Have clearly defined objectives of monitoring, set within the context of the recycled water management plan.
2. Be carefully designed, to ensure that the stated monitoring objectives will be met.
3. Make clear what data will be gathered, how it will be obtained and how results will be used.
4. Use sampling and analytical techniques that are reliable and sufficiently sensitive.
5. Include analysis and reporting of data, to provide valuable information on the operation of the recycled water system.
6. Be developed in conjunction with stakeholders such as users and regulators or authorities responsible for auditing the performance of the recycled water system.

The range of parameters and the frequency of testing included in monitoring programs will depend on the size of the scheme and the potential exposure associated with the end use. For example, monitoring programs for large urban sewage treatment plants providing recycled water for dual reticulation or unrestricted municipal irrigation will be far more extensive than those for rural sewage treatment plants providing recycled water for drip irrigation of grape vines.

A practical and pragmatic approach needs to be adopted in designing monitoring programs.

# 5.2 Baseline monitoring

Baseline monitoring is undertaken before establishing recycled water systems, whereas validation, operational and verification monitoring are undertaken when establishing and running a recycled water system. These latter forms of monitoring are common to risk management systems, such as the hazard analysis critical control point (HACCP) approach. For more information see Section 5 of the Australian Guidelines for Water Recycling (NRMMC and EPHC 2006) and the Victorian Guidelines (EPA Victoria 2003). The sampling protocol and analysis methods used in the baseline should be maintained in the verification monitoring program (see Sections 5.3, 5.4 and 5.5).

Monitoring for health and environmental risks follow a similar framework. However, much of the pathogen monitoring is limited to the operation of the wastewater treatment facility and the operation of the water reclamation system. In contrast, much of the environmental monitoring is focused on specific high risks that have been identified in the environmental pathways and endpoints (e.g. organisms, soils, water bodies, air). Two major factors which influence environmental monitoring requirements are the size of the recycled water scheme and the level of risk being managed.

# 5.3 Recycled water supply monitoring

For all recycled water schemes, the frequency of sampling and monitoring required is relative to the level of risk identified in the maximal risk assessment (i.e. the risk assessment before preventive measures are put into place) and the confidence in a specific preventive measure used to reduce the risk to acceptable levels (e.g. low).

For example, validation of preventive measures can give a level of confidence in the preventive measure and assist in developing the initial monitoring program. Verification monitoring could then improve confidence with the preventive measures used, allowing the initial monitoring program's frequency to be reduced.

Double or multiple preventive measures can also increase the confidence that the specific risk controlled will remain low, minimising the monitoring program. Alternately, if a critical limit is exceeded or target criteria are continually exceeded for relevant environmental indicators, the sample frequency may need to be increased to monitor the associated risks more closely or additional preventative measure applied.

## 5.4 Soil monitoring

Soil quality should be monitored for recycled water schemes to ensure that there are no adverse impacts on soil structure and quality. Generally, a soil-monitoring program for major schemes should:

1. Specify the parameters to be monitored and their frequencies. Soils should be analysed at least every two to three years (including initial baseline monitoring) for pH, electrical conductivity, exchangeable cations, total N, P, K, total cation concentration and sodium adsorption ratio (SAR) or exchangeable sodium percentage (ESP) to determine ongoing changes of key hazards.

2. Seek evidence of heavy metal concentrations in soil if the recycled water contains significant heavy metals.

3. Monitor standard soil fertility parameters according to the plant specific fertiliser management practices and desired growth. Major soil layers should be identified for each sample site, detailing soil texture, structure, cracking, colour, moisture, rocks and stones, and other biological features. The parameters specified above may be varied based on advice from an appropriately qualified agricultural consultant or soil scientist. Soil moisture should be monitored regularly to determine irrigation scheduling rates.

4. Specify the sampling locations. The number and location of sampling locations will depend on the distribution of soil types on the land. If there is little variation, three to five sites (which can be composites) may be sufficient for five to ten hectares. More sites will be required for complex land systems. Personnel with expertise in soil science should be consulted to assist in developing a soil-monitoring program appropriate to the risks the scheme poses and the sensitivities of the site.

A timetable for soil monitoring is ideal.

*Field staff should usually assess irrigation areas when in the field*

Field staff should be trained to visually assess the irrigated area in their day to day work in the field. They should look out for changes in soil as outlined in Table 22.

**Table 22** Visual symptoms that may be observed in soil irrigated with recycled water.

| Look for | Possible cause | Management options |
|---|---|---|
| Pools of water not infiltrating into the soil | Sodicity | Test soil and apply calcium amendment if required |
| Erosion from excess irrigation causing surface runoff | Poor irrigation uniformity or scheduling or sodicity (see above) | Check uniformity of irrigation system and adjust if required. Check scheduling and timing of irrigation. Check soil sodicity |
| Salt scaulds | Excessive salts applied with recycled water or groundwater levels high | Check salinity of recycled water is appropriate for your intended use and check groundwater levels are deeper than 2 m |
| Bare soil from death or poor growth of grass/plants | Salinity, sodicity or boron toxicity | Check plants sensitivity compared with soil analysis |
| Soil water holding capacity restricted (i.e. requires water more regularly) | Sodicity leading to degradation of soil structure | Assess soil sodicity (ESP or SAR) and determine if calcium or organic amendment should be applied |

# 5.5 Plant monitoring

The easiest and most effective monitoring for landscapes and turf is visual assessment by an experienced eye. If things look wrong then they probably are, and plant analysis or soil tests will help determin the problem and lead to actions that can be taken to overcome problems. If visual symptoms are identified a leaf analysis may help identify the problem and consequently, how to manage it.

Common visual symptoms that may be observed in plants grown with recycled water are summarised in Table 23.

**Table 23** Visual symptoms that may be observed in plants grown with recycled water.

| Look for | Possible cause | Management options |
|---|---|---|
| Margins of the oldest leaves yellow and then turn to dark brown or black, spots may develop near veins. | Boron toxicity | Check recycled water concentrations of boron. Adjust as required or plant boron tolerant plants. |
| Stunted growth, leaves smaller and thicker, more succulent darker green. For woody plants leaf margins often turn yellow, then brown/black as they die. | Salinity | Check salt sensitivity of plant and compare with recycled water salinity and soil salinity. Increase leaching fraction if soil salinity too high. |
| Leaf burn at the tip of older leaves which progresses back into the leaf blade, premature senescence (seasonal wilting of leaves and flowers), bronzing and defoliation. | Chloride toxicity | Leach soil if high in chloride. Check water chloride levels, dilute if required. |
| Low wear tolerance of grass. | Potassium supply for plant inadequate | Apply potassium fertiliser at required rates. |
| Lanky, succulent, weak plants that are susceptible to diseases, do not tolerate dry conditions and easily fall over. Wear tolerance may be affected. | Excess nitrogen | Check nitrogen concentration in recycled water and soil. Modify fertilisation program or dilute recycled water if another water source is available. |
| Grey, rust or black discolouration of the margins of old leaves, the younger foliage yellows through iron deficiencies. Plants not so sensitive have a dull colour appearance and/or reduced growth. | Phosphorus toxicity | Check phosphorus concentrations in recycled water and soil. Modify phosphorus applications if required. |
| Root growth impaired. | Sodicity – leading to degradation of soil structure | Assess soil sodicity (ESP or SAR) and determine if calcium or organic amendment should be applied. |

For addition information see Appendix Section 7.10, p 113 and Section 7.11, p 114.

# 5.6 Water resources

Any nearby water resources (ground or surface waters) should be monitored if there is a risk of contamination from the irrigation of recycled water. As a general rule, the lower the risk the less frequent the sampling required (NRMMC and EPHC 2006). See Chapter 8 of the Victorian Guidelines (EPA Victoria 2003).

## 5.7 Quality control and quality assurance

Quality assurance (QA) and quality control (QC) procedures are essential components of all phases of the monitoring program. They anticipate and help to avoid likely errors and problems, and ensure that data collected are of a known quality.

Quality assurance is the implementation of checks on the success of the quality control; it includes managerial activities, staff training, data validation, and audits of laboratory and data analysis and management.

## 5.8 Data analysis and interpretation

Assessment of the environment must be based on a statistically valid sampling program, and monitoring requirements need to be:

1. Tailored to the scale of the reuse scheme.
2. Mindful of the intended end uses of the recycled water.
3. Developed with the relevant regulators or authorities that will be responsible for auditing the environmental performance of the reuse scheme.
4. Frequency adjusted, in accordance with performance (e.g. if target or trigger values identified in the risk assessment are exceeded, sampling frequency should be increased; if trigger values are not exceeded, it should be decreased).
5. Reported and have information disseminated.

Reporting procedures will often relate to the activities of both the recycled water supplier and user, and will require them to:

1. Provide arrangements for the submission of performance reports to authorities, users and the community.
2. Identify, as early as possible, acute or chronic health and environmental impacts.
3. Identify incidents of non-compliance with guidelines, and ensure that the appropriate people and agencies are notified, and that incident response strategies are effective.
4. If required, alter management or monitoring practices to ensure the best protection available for the health of the community and the environment.

Reporting requirements are usually annual, but may vary depending on scheme-specific criteria. Typical best-practice management for reporting will require:

1. A list or register of users of recycled water.
2. Regular inspections and maintenance of treatment, reticulation and reuse facilities or farms and recording of details.
3. Monitoring data specific to preventive measures and environmental protection (analysis undertaken and flows recorded).
4. Demonstrated ongoing compliance with the objectives of the guidelines or management plans developed from the guidelines.

5. Identification of areas of management or practice that may be improved (i.e. recommend additional preventative measures if required).

6. Suppliers making reports available for users on a regular basis.

7. Modification to sampling and analysis undertaken as part of management plans, or preventive measures, due to results not complying with trigger levels or reference points.

## 5.9 Review process

Reviewing the monitoring and reporting program is an important element to ensure that the program remains effective and 'on track' to meet the stated objectives. The review process and its response should be outlined, and regular independent audits of the program should be conducted by appropriately qualified personnel.

# Further Information




# 6.1 Websites

California Irrigation Management Information System (CIMIS).
www.cimis.water.ca.gov/cimis/infoEtoCropCo.jsp

Irrigating with recycled water.
www.recycledwater.com.au

Cummings D (2002) 'Minimising algal growth in farm dams.' State of Victoria, Department of Natural Resources and Environment 2002, LC0079, Melbourne.
www.dpi.vic.gov.au/DPI/nreninf.nsf/childdocs/-49A21C225110DAB74A2568B30004DB83-9DB564B1D158B03BCA256BC700835FFC-C7D48D071C2F58834A256DEA00294C5B-8C02B879A41DBA01CA256BCF000AD4F8?open

Irrigation Association of Australia.
www.irrigation.org.au/standards.html#qi_stds_04

WRF (2007) Managing Salinity of Recycled Water or Landscape Irrigation [CD ROM]. WateReuse Foundation, Alexandria, VA, USA.
www.salinitymanagement.org

Your guide to good garden watering.
www.irrigation.org.au/download/standards/Home%20Gardener%20FINAL%20web.pdf

# 6.2 Text books

Carrow RN, Duncan RR (1998) 'Salt affected turf grass sites - Assessment and management.' (Ann Arbor Press: Chelsea Michigan, USA)

Handreck K, Black N (2001) 'Growing media for ornamental plants and turf'. (New South Wales University Press, Kensington)

Asano T, Burton FL, Laeverenz HL, Tsuchihashi R, Tchobanoglous G (2007) 'Water Reuse. Issues, Technologies and Applications.' (McGraw Hill.: New York, USA)

Stevens D (2006) 'Growing Crops with Reclaimed Wastewater.' (CSIRO Publishing: Melbourne)

Myers BJ, Bond WJ, Benyon RG, Falkiner RA, Polglase PJ, Smith CJ, Snow VO (1999) 'Sustainable Effluent-Irrigated Plantations: An Australian Guideline.' (CSIRO Forestry and Forest Products: Canberra)

# 6.3 Guidelines

See Section 7.1, p 72.

# Appendix

# 7.1 Recycled Water Guidelines

## Victorian Recycled Water Guidelines

There are three Victorian guidelines (EPA Victoria 1991; 2003; 2005) relevant for the reclamation of water from sewage effluent in Victoria:

- EPA Victoria (2003) 'Use of reclaimed water. Guidelines for environmental management.' EPA Victoria, Southbank, Victoria 3006, Australia .
- EPA Victoria (2005) 'Guidelines for Environmental Management: Dual pipe water recycling schemes - Health and environmental risk management.' EPA Victoria, Melbourne, Australia.
- EPA Victoria. (1991) 'Guidelines for wastewater irrigation. Publication no 168.' 168, EPA Victoria, Melbourne.

See www.epa.vic.gov.au/publications for any new guidelines.

These guidelines refer to recycled water as Class A, B, C or D; depending on the level of treatment. Class A has the highest level of treatment (EPA Victoria 2003). In Victoria, sewage treatment plants processing greater than 5 kL per day of sewage are subject to works approvals and licensing by EPA Victoria (EPA Victoria 2003; Stevens 2006 ). Under the *Environment Protection (Scheduled Premises and Exemptions) Regulations 1996*, an exemption from these statutory processes is provided for effluent reuse schemes that meet the requirements specified in the Victorian guideline (EPA Victoria 2003). The Australian Guidelines for Water Recycling (AGWR) should also be considered (see below).

The AGWR provide a framework for the management of recycled water, sets performance objectives, establishes the obligations of suppliers and users of recycled water, and suggests best practice measures for treatment, quality, site selection, application, site management, and monitoring and reporting in order to meet the performance.

Environment Improvement Plans (EIP) form a critical component of the exemption process. EIPs need to demonstrate that the performance objectives of the guideline can be complied with by detailing the procedures and practices that will be implemented to manage risk and ensure sustainability.

Suppliers and users of recycled water must ensure that:

1. All reuse schemes have an appropriate EIP.
2. For Class A recycled water schemes, approval from EPA Victoria and the Department of Human Services (DHS) is required
3. For all non Class A schemes involving greater than 1 ML per day of recycled water or industrial process waters, approval from EPA or an appointed auditor is required.
4. Endorsement from the Department of Primary Industries is also required for water with significant quantities of animal effluent (EPA Victoria 2003).
5. Reuse schemes that use more than 1 ML per day should be annually audited to verify compliance with these Guidelines.
6. Reuse schemes that use less than 1 ML per day must be audited at least every three years (EPA Victoria, 2003).

All monitoring, reporting and auditing procedures and programs should be documented in the EIP. Audit programs for schemes that use greater than 1 ML per day should comply with the principles in *ISO 14010's Guidelines for Environmental Auditing*. The proponent of the reuse scheme should ensure that an appropriately qualified independent auditor or internal expert undertakes the audit (EPA Victoria 2003).

# Australian Guidelines for Water Recycling

The new Australian Guidelines for Water Recycling (AGWR) have recently set the standard for managing risks posed to human health and the environment in Australia (NRMMC and EPHC 2006). They do not supersede Victorian State Guidelines (EPA Victoria 2003), however, it would be considered best practice to use the framework and information in the AGWR within the context of the Victoria Guidelines.

There are two components of the AGWR that should be considered:

**1. The Australian Guidelines for Water Recycling**

Full reference: NRMMC, EPHC (2006) 'Australian Guidelines for Water Recycling. Managing Health and Environmental Risks. Phase 1. National Water Quality Management Strategy 21.' Natural Resource Management Ministerial Council. Environment Protection and Heritage Council Australian Health Ministers' Conference, Canberra, Australia.

See www.ephc.gov.au/ephc/water_recycling.html

**2. National Chemical Reference Guide - Standards in the Australian Environment**

This website provides information analysed to derive safe concentration values that should be achieved in order to protect ecosystems and human health in Australia.

See www.deh.gov.au/chemicals-guide

### Key parameters of AGWR

The framework for management of recycled water quality and use given in Australian Guidelines for Water Recycling (NRMMC and EPHC 2006) is based on, and follows the same principles as the framework used in the 2004 *Australian Drinking Water Guidelines* (NHMRC and NRMMC 2004).

The framework describes a generic process for developing and implementing preventive risk management systems for recycled water use. Such systems can be applied to all combinations of water source and end use, including applications not specifically addressed in this document, such as stormwater recycling and use of recycled water to augment drinking water sources. The aim is to provide a measurable and ongoing assurance that performance requirements are met and that, as far as possible, faults are detected before recycled water is supplied, discharged or applied, so that corrective actions can be implemented proactively.

### Recycled water - "Fit-for-purpose"

One of the major differences between Victorian State guidelines and the Australian Guideline for Water Recycling is the concept of identifying and producing recycled water of a quality that is **'fit-for-purpose'** from a pathogen and chemical hazard perspective. To be consistent with this approach, these guidelines do not include a classification system for recycled water like in the Victorian State Guidelines (refer to Section 1). A principal reason for this decision is that classification systems can limit flexibility and implies some water qualities are better than others.

The framework in the Australian guidelines also relates specifically to the quality of the recycled water, ensuring any hazards to human health or the environment (including the horticultural system) do not pose a significant risk (i.e. the level of risk is low and acceptable). That is, the recycled water is fit for the intended use from an environmental and human health perspective. The commonly used Class A, B C, D system in Australia often did not relate specifically to recycled water and impacts on the environment, but was historically used from a pathogens and human health perspective. The fit-for-purpose classification overcomes the misunderstandings of the Class terminology and ensures that the environment, agronomic and human health perspectives are considered when developing and using recycled water.

## 7.2 Plumbing requirements

Recommendations from the Victorian 'Recycled Water Plumbing Guide 2005' (PIC 2005) are summarised below. We recommend you also download the guide.

See www.pic.vic.gov.au

### General

- All plumbing work must be carried out by a licensed plumber.
- A "Compliance Certificate" must be submitted to the consumer upon completion of all work.
- On the Compliance Certificate Item 5 "cold water" and Item 91 "recycled water" must be circled.

### Recycled water mains

- All underground recycled water mains piping must be purple in colour or be wrapped in purple coloured plastic sleeve.
- All recycled water stand-pipes and fire hydrants must be purple in colour and be marked "recycled water".

### Meter assemblies

- Recycled water meter assemblies must be purple in colour (Figure 16), fitted above ground in an accessible position as close as possible to the relevant property boundary and adjacent to the drinking water meter.
- A dual check valve is required on the outlet of every drinking water meter assembly and must be visible, accessible and fitted in the horizontal section of the meter assembly.

**Figure 16** Recycled water meter assembly with purple to identify it contains recycled water.

## Inside the property

- All external tap outlets on the drinking water service shall be fitted with hose connection vacuum breakers.
- All hose taps must have removable handles to prevent unauthorized use.
- "DO NOT DRINK" signs must be displayed above all external recycled water outlets.
- All pipe work inside a property must be approved for use with recycled water as per page 9 of the 'Recycled Water Plumbing Guide 2005'.
- All buried pipe must have identification tape installed on top of the recycled water pipe running longitudinally and fastened to the pipe at 3 metre intervals.
- The warning tape must be at least 75 mm wide and state "Warning: Recycled Water – Do not drink" continually along its length and coloured in accordance with clause 9.5.4 AS/NZS 3500.1:2003 (AS/NZS 2003) (Figure 17).
- All other installation requirements of AS/NZS 3500.1:2003 (AS/NZS 2003) Section 3 and 5 installation of cold water services also apply.


**Figure 17** Example of warning tape laid above buried pipe that reticulate recycled water. Tape meets Aust standard being a minimum of 75mm wide and stating "Recycled water" and "Do not drink".

## 7.3 Classes of recycled water

**Table 24** Victorian classifications of recycled water and permitted uses.

| Class | Overview of recycling process | Permitted Uses (Fit-for-purpose) |
|---|---|---|
| A | This is the highest quality of recycled water and is achieved after a tertiary treatment process combined with pathogen removal. Class A recycled water is classified as safe for use on irrigation for food plants - including those eaten raw. Indicative objectives: < 10 E.coli org/100 mL, Turbidity < 2 NTU, < 10 / 5 mg/L BOD / SS, pH 6 – 9.5 and 1 mg/L $Cl_2$ residual (or equivalent disinfection). In addition to this the guidelines for dual pipe recycled water scheme indicate that 7-log removal of viruses and 6-log removal of protozoa with helminth control if required (EPA Vic 2005, Table 5.1) | •residential garden watering<br>•closed system toilet flushing<br>•process/cooling water for industry<br>•fire protection stores and reticulation systems<br>•irrigation of municipal parks and sports grounds<br>•water for contained wetlands or ornamental ponds<br>• food plants that are consumed raw all of the uses listed for classes B, C and D |
| B | A secondary treatment process, combined with some pathogen reduction is used to produce Class B recycled water. Indicative objectives: <100 E.coli org/100 mL, pH 6 – 9.5, < 20 / 30 mg/L BOD / SS and Helminth control required for cattle grazing | • irrigation of dairy cattle grazing fodder<br>• livestock drinking water (not including pigs)<br>• wash down water for dairy sheds and stockyards (not including milking equipment)<br>• urban (non-potable) uses with restricted public access<br>• closed industrial systems<br>• all of the uses listed for classes C and D |
| C | A secondary treatment process combined with minor pathogen reduction is used to produce Class C recycled water. Indicative objectives: <1000 E.coli org/100 mL, pH 6 – 9.5, < 20 / 30 mg/L BOD / SS and Helminth control required for cattle grazing | •cooked/processed human food plants<br>•selected (raw/unprocessed) plants not directly exposed to recycled water (e.g. apples)<br>•grazing/ fodder for cattle, sheep, horses, goats etc.<br>•grazing for dairy cattle (subject to a five day withholding period after irrigation)<br>•urban (non-potable) uses with restricted public access<br>•closed industrial systems<br>•all of the uses listed for Class D |
| D | A secondary treatment process is used to produce water of this quality. Indicative objectives:<br><10000 E.coli org/100 mL, pH 6 – 9.5 and < 20 / 30 mg/L BOD / SS | •non food plants such as woodlots, turf growing and flowers |

Source: EPA Victoria 2003, p 20

# 7.4 Components found in recycled water

**Table 25** Typical concentrations of components found in recycled water.

| Parameter | Symbol | Median | Units |
|---|---|---|---|
| Total nitrogen | $N_{tot}$ | 15.2 | mg/L |
| Ammonium | $NH_4$ | 8.4 | mg/L |
| Total phosphorus | $P_{tot}$ | 5.9 | mg/L |
| pH | | 7.9 | pH |
| Total dissolved salts | TDS | 675 | mg/L |
| Electrical conductivity | EC | 1.3 | dS/m |
| Sodium adsorption ratio | SAR | 6 | $(mmolc/L)^{0.5}$ |
| Sodium | Na | 181 | mg/L |
| Calcium | Ca | 35 | mg/L |
| Magnesium | Mg | 19 | mg/L |
| Chloride | Cl | 135 | mg/L |
| Aluminium | Al | 227 | µg/L |
| Arsenic | As | 1.9 | µg/L |
| Boron | B | 289 | µg/L |
| Cadmium | Cd | 0.3 | µg/L |
| Chromium | Cr | 9.4 | µg/L |
| Cobalt | Co | 0.7 | µg/L |
| Copper | Cu | 23.5 | µg/L |
| Iron | Fe | 722 | µg/L |
| Lead | Pb | 5.4 | µg/L |
| Manganese | Mn | 35.2 | µg/L |
| Mercury | Hg | 0.1 | µg/L |
| Molybdenum | Mo | 9.8 | µg/L |
| Nickel | Ni | 7.0 | µg/L |
| Silver | Ag | 2.6 | µg/L |
| Zinc | Zn | 48 | µg/L |

Source: modified from NRMMC and EPHC 2006. For water recycled from sewage effluent in Australia. Therefore recycled water would be on average similar, but affected by the type of reclamation treatment and any evaporation in storage or reticulation.

# 7.5 How salinity impacts on plant available water

In the absence of salinity, as a soil becomes drier, water becomes harder to extract from around the soil particles as it clings more and more tightly to them (this is called the matric potential effect). In saline soils there is the added complexity that as salt concentration increases as the soil dries then the plant's ability to "suck" water from the soil is further reduced (this is known as the osmotic effect or potential; Anderson *et al*. 2007).

Fresh water is attracted to saline water or towards salts in the soil or plant roots. Water is taken up by plants in this way, as it is attracted to concentrated solutions of salts and sugars inside plant roots – hence there is a pressure gradient from the soil into the plant root.

This pressure is called osmotic pressure. High concentrations of salts in soil water lower this pressure gradient between the soil and plant root, slowing the movement of water into roots (Figure 18). Eventually, if the concentration of salts in the soil water becomes high enough, water ceases to flow into the root regardless of the amount of soil water. In some cases even though the soil may appear to be "wet" in saline soil the plant cannot access this water.

*In saline soil, irrigation will need to be scheduled more often to ensure sufficient plant available water*

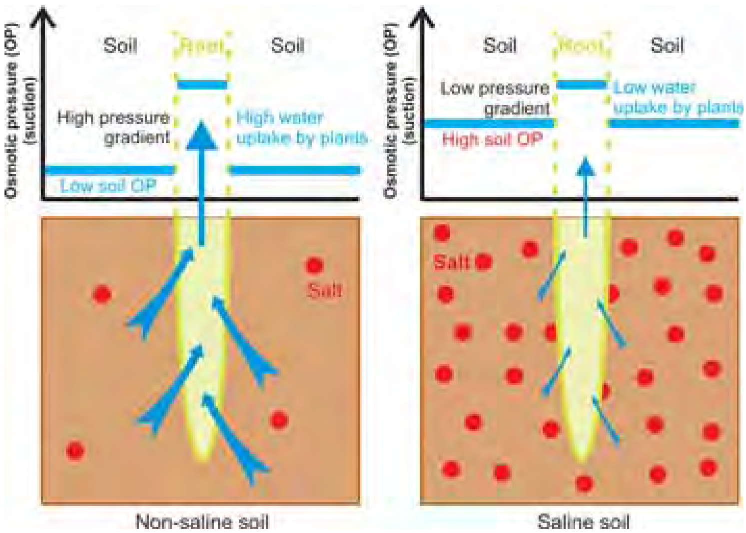


**Figure 18** Relative water uptake by plants in saline and non-saline soils. OP = osmotic pressure. Source: Anderson *et al*. 2007.

# 7.6 Sensitivity of plants to sodium, chloride and salinity

## Salt tolerance of trees, shrubs, and ground covers

**Table 26** Tolerance of selected landscape tree species to salt spray and to soil salinity.

| Common name | Botanical name | Tolerance to salt spray(1) | Tolerance to soil salinity(2) |
|---|---|---|---|
| Trees | | | |
| *Aleppo Pine* | *Pinus halepensis Mill.* | moderate | moderate |
| Almond | *Prunus duclis D.A.Webb.* | sensitive | sensitive |
| Almond-leaved Pear | *Pyrus spinosa Forssk.* | moderate | moderate |
| American Persimmon | *Diospyros virginiana L.* | sensitive | sensitive |
| Apricot | *Prunus armeniaca L.* | sensitive | sensitive |
| Avacado | *Persea americana Mill.* | moderate | moderate |
| Banana | *Musa acuminata Colla.* | sensitive | sensitive |
| Black Sapote | *Diospyros digyna L.* | moderate | moderate |
| Blackthorn | *Prunus spinosa L.* | tolerant | moderate |
| Cape Plumbago | *Plumbago auriculata Lam.* | tolerant | moderate |
| Carambola, Starfruit | *Averrhoa carambola L.* | moderate | moderate |
| Carolina Laurel Cherry | *Prunus caroliniana Ait.* | moderate | sensitive |
| Chinese Elm | *Ulmus parvifolia Jacq.* | moderate | moderate |
| Chinese Hackberry | *Celtis sinensis Pers.* | sensitive | sensitive |
| Chinese Pistache | *Pistachia chinensis Bunge.* | sensitive | sensitive |
| Chinese Tallow Tree | *Sapium sebiferum Roxb.* | highly tolerant | tolerant |
| Coast Live Oak | *Quercus agrifolia Nee* | tolerant | tolerant |
| Coast Redwood | *Cupressus sempervirens L.* | moderate | moderate |
| Var. Aptos Blue | *Sequoia sempervirens Endl.* | sensitive | sensitive |
| Coast Redwood | *Diospyros virginiana L.* | sensitive | sensitive |
| Var. Los Altos | *Sequoia sempervirens Endl.* | moderate | moderate |
| Cork Oak | *Quercus suber L.* | moderate | moderate |
| Cornelian Cherry | *Cornus mas L.* | sensitive | sensitive |
| Crab Apple | *Malus sylvestris Mill.* | sensitive | sensitive |
| Crape Myrtle | *Lagerstoemia indica L.* | sensitive | sensitive |
| Deodar Cedar | *Cedrus deodara D. Don* | moderate | moderate |
| Drake Elm | *Ulmus parvifolia Drake* | moderate | moderate |
| Edible Fig | *Ficus carica L.* | tolerant | tolerant |
| Florida Slash Pine | *Pinus elliotti Engelm.* | moderate | moderate |
| Forsythia | *Forsythia intermedia Zabel* | tolerant | tolerant |
| Frangipani | *Plumaria spp. L.* | tolerant | tolerant |
| Ginkgo | *Ginkgo biloba L.* | sensitive | sensitive |
| Golden Marguerite | *Euryops pectinatus* | sensitive | sensitive |
| Goldenrain Tree | *Koelreuteria paniculata Laxm.* | moderate | moderate |
| Grapefruit | *Citrus paradisi Macf.* | sensitive | sensitive |

| Common name | Botanical name | Tolerance to salt spray[(1)] | Tolerance to soil salinity[(2)] |
|---|---|---|---|
| Guava | *Psidium guajava L.* | sensitive | sensitive |
| Guayule | *Parthenium argentatum Gray.* | highly tolerant | highly tolerant |
| Italian Cypress | *Cupressus sempervirens L.* | moderate | moderate |
| Jacaranda | *Jacaranda mimosifolia D. Don.* | sensitive | sensitive |
| Japanese Black Pine | *Pinus thunbergii Parl.* | moderate | moderate |
| Japanese Privet | *Ligustrum japonicum Thunb.* | moderate | moderate |
| Laurel Oak | *Quercus laurifolia Michux* | sensitive | sensitive |
| Lemon | *Citrus limon L.* | sensitive | sensitive |
| Lemon Bottlebrush | *Callistemon citrinus Curtis.* | tolerant | moderate |
| Live Oak | *Quercus virginiana Mill.* | highly tolerant | tolerant |
| Loquat | *Eriobotrya japonica Lindl.* | moderate | moderate |
| Lychee | *Litchi chinensis Sonn.* | sensitive | sensitive |
| Mango | *Mangifera indica L.* | sensitive | sensitive |
| Mexican Stone Pine | *Pinus cembroides Zucc.* | highly tolerant | tolerant |
| Norfolk Island Pine | *Araucaria heterophylla (Salisb.)* | highly tolerant | tolerant |
| Olive | *Olea europaea L.* | sensitive | sensitive |
| Orange | *Citrus sinensis Osbeck.* | sensitive | sensitive |
| Orchid Tree | *Bauhinia purpurea L.* | sensitive | moderate |
| Oriental Arbor-Vitae | *Platycladus orientalis Franco* | moderate | moderate |
| Peach | *Prunus persica Batsch* | sensitive | sensitive |
| Pear | *Pyrus communis L.* | sensitive | sensitive |
| Pecan | *Carya illinoinensis Koch.* | moderate | moderate |
| Pomegranate | *Punica granatum L.* | moderate | moderate |
| Raywood Ash | *Fraxinus oxycarpa Bieb. Ex Willd.* | moderate | moderate |
| Red Maple | *Acer rubrum L.* | sensitive | sensitive |
| Rockspray or Little-leaf Cotoneaster | *Cotoneaster microphyllus Lindl.* | tolerant | moderate |
| Rose Apple | *Syzgium jambos Alston* | sensitive | sensitive |
| Sand Pine | *Pinus clausa Vasey* | highly tolerant | tolerant |
| Sapodilla | *Manilkara zapota* | tolerant | tolerant |
| Schefflera, Umbrella Tree | *Schefflera actinophylla Harms* | moderate | moderate |
| Sea Grape | *Coccoloba uvifera L.* | highly tolerant | tolerant |
| Silk Oak | *Grevillea robusta Cunn.* | highly tolerant | tolerant |
| Silk Tree | *Albizia julibrissin Durazz.* | sensitive | sensitive |
| Skyroket Juniper | *Juniperus virginiana L.* | highly tolerant | tolerant |
| Southern Magnolia | *Mangnolia grandiflora L.* | sensitive | sensitive |
| Southern Red Cedar | *Juniperus silicicola Bail.* | highly tolerant | tolerant |
| Sweet Gum | *Liquidambar styraciflua L.* | sensitive | sensitive |
| Sycamore Maple | *Acer pseudoplatanus L.* | sensitive | sensitive |
| Tangerine | *Citrus reticulata  Blanco.* | sensitive | sensitive |

| Common name | Botanical name | Tolerance to salt spray(1) | Tolerance to soil salinity(2) |
|---|---|---|---|
| | | Palm | |
| Areca Palm | *Chrysalidocarpus lutescens Wendl.* | moderate | moderate |
| Cabbage Palmetto | *Sabal palmetto Lodd.* | tolerant | tolerant |
| Canary Island Date | *Phoenix canariensis Chabaud.* | moderate | moderate |
| Date Palmetto | *Phoenix dactylifera L.* | tolerant | tolerant |
| European Fan Palm | *Chamaerops humilis L.* | tolerant | tolerant |
| Fishtail Palm | *Caryota mitis Lour.* | moderate | moderate |
| Lady Palm | *Rhapis excelsa Henry* | moderate | moderate |
| Paurotis Palm | *Acoelorrhaphe wrightii Becc.* | moderate | moderate |
| Pindo Palm | *Butia capitata Becc.* | tolerant | tolerant |
| Ponytail Palm (not a true palm) | *Nolina recurvata Hemsle* | moderate | moderate |
| Pygmy Date Palm | *Phoenix roebelinii O'Brien.* | moderate | moderate |
| Queen Palm | *Syagrus romanzoffiana L.* | moderate | moderate |
| Saw Palm | *Serenoa repens Small* | tolerant | tolerant |
| Senegal Date Palm | *Phoenix reclinata Jacq.* | moderate | moderate |
| Washingtonia Palm | *Washingtonia robusta Wendl.* | tolerant | tolerant |

Source: Tanji *et al*. 2007 -
Data in the table adapted from Wu L. and Dodge L. 2005 Special Report for the Elvenia J. Slosson Endowment Fund (in press).

(1): Tolerances to salt spray are defined by the degree of salt stress symptoms developed in the leaves of the plants and the salt concentrations in the irrigation water as follows:

Highly tolerant: No apparent salt stress symptoms may be observed when the plants are irrigated with water containing 600 mg/L sodium and 900 mg/L chloride and having an ECi of 2.1 dS/m .

Tolerant: No apparent salt stress symptoms may be observed when the plants are irrigated with water containing 200 mg/L sodium and 400 mg/L chloride.

Moderate: Less than 10% symptoms may be observed when the plants are irrigated with water containing 200 mg/L sodium and 400 mg/L chloride and having an ECi of 0.9 dS/m.

Sensitive: More than 20% of the leaves may develop symptoms when the plants are irrigated with water containing 200 mg/L sodium and 400 mg/L chloride and having an ECi of 0.6 dS/m.

(2): The definitions of soil salinity tolerance are:

Highly tolerant: Permissible soil ECe greater than 6 dS/m,
Tolerant: Permissible soil ECe greater then 4 and less than 6 dS/m,
Moderate: Permissible soil ECe greater than 2 and less than 4 dS/m,
Sensitive: Permissible soil ECe less than 2 dS/m.

**Table 27** Tolerance of landscape shrub species to salt spray and to soil salinity.

| Common name | Botanical name | Tolerance to salt spray(1) | Tolerance to soil salinity(2) |
|---|---|---|---|
| Abelia 'Edward Goucher' | *Abelia grandiflora Rehd.* | sensitive | sensitive |
| African Bush Daisy | *Gamolepis chrysanthemoides DC.* | highly tolerant | tolerant |
| Bamboo | *Bambusa sp. Schreb.* | moderate | moderate |
| Bird of Paradise | *Strelitzia reginae Bankses Dryander* | moderate | moderate |
| Blue Blossom | *Ceanothus thyrsiflorus Esch.* | tolerant | moderate |
| Bottle Brush | *Callistemon rigidus R. Br.* | moderate | moderate |
| Butterfly Bush | *Buddleja davidii Franch.* | sensitive | sensitive |
| California Holly Grape | *Mahonia pinnata Fedde* | sensitive | sensitive |
| Camellia | *Camellia japonica L.* | sensitive | sensitive |
| Canna Lily | *Cannax generalis Bailey.* | moderate | moderate |
| Cape Jasmine, Gardenia | *Gardenia augusta Merrill* | moderate | moderate |

| Common name | Botanical name | Tolerance to salt spray(1) | Tolerance to soil salinity(2) |
|---|---|---|---|
| Cape Plumbago | *Plumbago auriculata am.* | tolerant | tolerant |
| Century Plant | *Agave americana L.* | highly tolerant | tolerant |
| Chinese Holly | *Ilex cornuta Burford* | moderate | moderate |
| Coast Red Elderberry | *Sambucus callicarpa Greene* | tolerant | moderate |
| Copper Leaf | *Acalypha wilkesiana Muell.* | sensitive | sensitive |
| Coral Plant | *Jatropha multifida L.* | sensitive | moderate |
| Cornelian Cherry | *Cornus mas L.* | sensitive | sensitive |
| Croton | *Codiaeum variegatum Blume.* | sensitive | sensitive |
| Crown of thorns | *Euphorbia milii Ch. Des Moulins* | highly tolerant | highly tolerant |
| Dracaena | *Dracaena deremensis Engler.* | moderate | moderate |
| Dwarf Shefflera | *Schefflera arboricola L.* | moderate | moderate |
| Dwarf Yaupon Holly | *Ilex vomitoria Nana* | highly tolerant | tolerant |
| Escallonia | *Escallonia rubra Pers.* | tolerant | moderate |
| Firecracker Plant | *Russelia equisetiformis Schlecht & Cham.* | moderate | moderate |
| Golden Shrub Daisy | *Euryops pectinatus L.* | tolerant | moderate |
| Guayule | *Parthenium argentatum Gray.* | highly tolerant | highly tolerant |
| Heavenly Bamboo | *Nandina domestica Thunb.* | sensitive | sensitive |
| Heliconia | *Heliconia sp.* | moderate | moderate |
| Hybrid Forsythia | *Forsythia intermedia Zabel* | moderate | moderate |
| Hydrangea | *Hydrangea macrophylla Ser.* | tolerant | moderate |
| Indian Hawthorn | *Raphiolepis indica Lindl.* | highly tolerant | tolerant |
| Ixora | *Ixora coccinea L.* | sensitive | sensitive |
| Japanese Boxwood | *Buxus microphylla Mull. Arg.* | tolerant | moderate |
| Japanese Photinia | *Photinia glabra Maxim.* | sensitive | sensitive |
| Jasmine | *Jasminum polyanthum Franch.* | moderate | moderate |
| Lantana | *Lantana camara L.* | highly tolerant | tolerant |
| Mock Orange | *Pittosporum tobra Aiton* | highly tolerant | tolerant |
| Natal Plum | *Carissa macrocarpa A. DC.* | highly tolerant | tolerant |
| Oleander | *Nerium oleander L.* | highly tolerant | tolerant |
| Opuntia Cactus | *Opuntia sp. Miller* | moderate | tolerant |
| Orange Cestrum | *Cestrum aurantiacum Lindl.* | moderate | moderate |
| Orange Jessamine | *Murraya paniculata L.* | sensitive | sensitive |
| Oregon Grape | *Mahonia aquifolium Nutt.* | sensitive | sensitive |
| Papaya | *Carica papaya L.* | moderate | moderate |
| Pentas, Egyptian star-cluster | *Pentas lanceolata Deflers* | sensitive | sensitive |
| Photinia | *Photinia fraseri Dtress* | sensitive | sensitive |
| Poinsetta | *Euphorbia pulcherrima Willd.* | sensitive | sensitive |
| Powder Puff Tree | *Calliandra haematocephala Hassk.* | sensitive | sensitive |
| Prostrate Acacia | *Acacia redolens Maslin.* | tolerant | tolerant |
| Pyrenees Cotoneaster | *Cotoneaster congestus Baker* | sensitive | sensitive |
| Red Firethorn | *Pyracantha coccinea Roem.* | moderate | moderate |
| Rockspray Cotoneaster | *Cotoneaster microphylla Lindl.* | moderate | sensitive |

| Common name | Botanical name | Tolerance to salt spray(1) | Tolerance to soil salinity(2) |
|---|---|---|---|
| Rose | *Rosa sp. L.* | sensitive | sensitive |
| Rose of China, Garden Hibiscus | *Hibiscus rosa L.* | moderate | moderate |
| Sandankwa Viburnum | *Viburnum suspensum Lindl.* | moderate | moderate |
| Shrimp Plant | *Justicia brandegeana Wassh.* | sensitive | sensitive |
| Silverthorn, Silverberry | *Elaeugnus pungens Thunb.* | highly tolerant | tolerant |
| Spanish Bayonet | *Yucca aloifolia L.* | highly tolerant | highly tolerant |
| Surinam Cherry | *Eugenia unifora L.* | sensitive | sensitive |
| Sweet Viburnum | *Viburnum odoratissimum Ker.* | moderate | moderate |
| True Myrtle | *Myrtus communis L.* | tolerant | tolerant |
| Vine Hill Manzanita | *Arctostaphylos densiflora M.S.Bac* | tolerant | tolerant |
| Wax Myrtle | *Myrica cerifera L.* | highly tolerant | tolerant |
| Yaupon Holly | *Ilex vomitoria Ait.* | tolerant | tolerant |
| Yew Pine | *Podocarpus macrophyllus D. Don* | sensitive | sensitive |

Source: Tanji *et al*. 2007

Data in the table adapted from Wu L. and Dodge L. 2005 Special Report for the Elvenia J. Slosson Endowment Fund (in press).

(1): Tolerances to salt spray are defined by the degree of salt stress symptoms developed in the leaves of the plants and the salt concentrations in the irrigation water as follows:

Highly tolerant: No apparent salt stress symptoms may be observed when the plants are irrigated with water containing 600 mg/L sodium and 900 mg/L chloride and having an ECi of 2.1 dS/m .

Tolerant: No apparent salt stress symptoms may be observed when the plants are irrigated with water containing 200 mg/L sodium and 400 mg/L chloride.

Moderate: Less than 10% symptoms may be observed when the plants are irrigated with water containing 200 mg/L sodium and 400 mg/L chloride and having an ECi of 0.9 dS/m.

Sensitive: More than 20% of the leaves may develop symptoms when the plants are irrigated with water containing 200 mg/L sodium and 400 mg/L chloride and having an ECi of 0.6 dS/m.

(2): The definitions of soil salinity tolerance are:

Highly tolerant: Permissible soil ECe greater than 6 dS/m,

Tolerant: Permissible soil ECe greater then 4 and less than 6 dS/m,

Moderate: Permissible soil ECe greater than 2 and less than 4 dS/m,

Sensitive: Permissible soil ECe less than 2 dS/m.

**Table 28** Tolerance of various landscape ground covers and vine species to salt spray and to soil salinity.

| Common name | Botanical name | Tolerance to salt spray(1) | Tolerance to soil salinity(2) |
|---|---|---|---|
| Ground cover | | | |
| African Iris | *Dietes spp. Salisb. ex Klatt.* | moderate | moderate |
| Aloe | *Aloe vera Burm. f.* | highly tolerant | tolerant |
| Bromeliads | *Bromeliaceae sp. L.* | moderate | moderate |
| Caladium | *Caladium sp. Vent.* | sensitive | sensitive |
| Carpet Bugle | *Ajuga repens* | sensitive | sensitive |
| Chinese Juniper | *Juniperus chinensis L.* | moderate | moderate |
| Coontie | *Zamia integrifolia L. f.* | highly tolerant | tolerant |
| Creeping Fig | *Ficus pumila L.* | highly tolerant | tolerant |
| Creeping Juniper | *Juniperus horizontalis Moench.* | highly tolerant | tolerant |
| Daylily | *Hemerocallis sp. L.* | moderate | moderate |
| False Heather | *Cuphea hyssopifolia Kunth.* | moderate | tolerant |

| Common name | Botanical name | Tolerance to salt spray[1] | Tolerance to soil salinity[2] |
|---|---|---|---|
| Hottentot Fig | *Carpobrotus edulis L. Bolus.* | highly tolerant | tolerant |
| Iceplant | *Malephora crocea Schwantes.* | highly tolerant | highly tolerant |
| Iris | *Iris hexagona Walter* | moderate | moderate |
| Japanese Garden Juniper | *Juniperus procumbens Siebild ex Endl.* | moderate | moderate |
| Joyweed | *Alternanthera ficoidea R. Br.* | moderate | moderate |
| Kalanchoe | *Kalanchoe sp. Adans.* | moderate | moderate |
| Lady Fern | *Athyrium filix-femina Rith.* | sensitive | sensitive |
| Lilyturf (Liriope) | *Liriope muscari L. H. Bail.* | moderate | moderate |
| Lynne's Vine Hill Manzanita | *Arctostaphylos densiflora 'Lynne' M.S.Back.* | moderate | moderate |
| Maidenhair Fern | *Adiantum sp. L.* | moderate | moderate |
| Mealycup Sage | *Salvia farinacea Benth.* | sensitive | sensitive |
| Natal Plum | *Carissa macrocarpa A. DC.* | highly tolerant | tolerant |
| Peperomia | *Peperomia obtusifolia Dietr.* | sensitive | sensitive |
| Periwinkle | *Catharanthus roseus G. Donf.* | tolerant | moderate |
| Purple Iceplant | *Lampranthus productus N. E. Br.* | highly tolerant | highly tolerant |
| Purple Queen | *Tradescantia pallida Hunt.* | highly tolerant | tolerant |
| Purslane (Rose Moss) | *Portulaca grandiflora Hook.* | moderate | sensitive |
| Red Apple Iceplant | *Aptenia cordifolia N. E. Br.* | tolerant | tolerant |
| Rosea Iceplant | *Drosanthemum hispidum Schwantes.* | highly tolerant | highly tolerant |
| Rosemary | *Rosmarinus officinalis L.* | moderate | moderate |
| Shore Juniper | *Juniperus conferta Parl.* | tolerant | tolerant |
| Society Garlic | *Tulbaghia violacea Harvey* | moderate | moderate |
| Spider Plant | *Chlorophytum comosum Jacq.* | moderate | moderate |
| Sword Fern | *Nephrolepis exaltata Schott.* | highly tolerant | tolerant |
| Tiger Flower | *Tigridia pavonia Ker Gawler* | tolerant | moderate |
| Umbrella Sedge | *Cyperus alternifolius L.* | moderate | moderate |
| Verbena | *Verbena sp. L.* | sensitive | sensitive |
| White Iceplant | *Delosperma 'Alba' N. E.* | highly tolerant | highly tolerant |
| Vine | | | |
| Algerian Ivy | *Hedera canariensis Willd.* | highly tolerant | tolerant |
| Allamanda | *Allamanda cathartica L.* | tolerant | tolerant |
| Bleeding Heart Vine | *Clerodendrum thomsoniae Balf. f.* | sensitive | sensitive |
| Bougainvillea | *Bougainvillea glabra Choisy* | highly tolerant | tolerant |
| Cape Honeysuckle | *Tecomaria capensis Spach.* | tolerant | tolerant |
| Coral Vine | *Antigonon leptopus Hookery* | sensitive | moderate |
| Creeping Fig | *Ficus pumila L.* | highly tolerant | tolerant |
| English Ivy | *Hedera helix L.* | moderate | moderate |
| Mealycup Sedge | *Salvia farinacea Benth.* | sensitive | sensitive |
| Night Blooming Cereus | *Hylocereus undatus Britton & Rose* | moderate | moderate |
| Passion Flower | *Passiflora incanata L.* | sensitive | sensitive |

| Common name | Botanical name | Tolerance to salt spray(1) | Tolerance to soil salinity(2) |
|---|---|---|---|
| Philodendron | *Philodendron williamsii Hook.* | moderate | moderate |
| Pothos | *Epipremnum sp. Schott.* | moderate | moderate |
| Purple Allamanda | *Allamanda blanchetii A. DC.* | moderate | moderate |
| Railroad Vine | *Ipomoea pescaprae R. Br.* | highly tolerant | tolerant |
| Seafoam Morning Glory | *Ipomoea stolonifera Gmel.* | highly tolerant | tolerant |
| Star Jasmine | *Trachelospermum jasminoides Lem.* | tolerant | tolerant |
| Trumpet Creeper | *Campsis radicans Seem.* | sensitive | sensitive |
| Umbrella Sedge | *Cyperus altenifolius L.* | moderate | moderate |
| Violet Trumpet Vine | *Clytostoma callistegioides Miers ex Bur.* | sensitive | sensitive |

Source: Tanji *et al*. 2007

Data in the table adapted from Wu L. and Dodge L. 2005 Special Report for the Elvenia J. Slosson Endowment Fund (in press).

(1): Tolerances to salt spray are defined by the degree of salt stress symptoms developed in the leaves of the plants and the salt concentrations in the irrigation water as follows:

Highly tolerant: No apparent salt stress symptoms may be observed when the plants are irrigated with water containing 600 mg/L sodium and 900 mg/L chloride and having an ECi of 2.1 dS/m .

Tolerant: No apparent salt stress symptoms may be observed when the plants are irrigated with water containing 200 mg/L sodium and 400 mg/L chloride.

Moderate: Less than 10% symptoms may be observed when the plants are irrigated with water containing 200 mg/L sodium and 400 mg/L chloride and having an ECi of 0.9 dS/m.

Sensitive: More than 20% of the leaves may develop symptoms when the plants are irrigated with water containing 200 mg/L sodium and 400 mg/L chloride and having an ECi of 0.6 dS/m.

(2):The definitions of soil salinity tolerance are:

Highly tolerant: Permissible soil ECe greater than 6 dS/m,

Tolerant: Permissible soil ECe greater then 4 and less than 6 dS/m,

Moderate: Permissible soil ECe greater than 2 and less than 4 dS/m,

Sensitive: Permissible soil ECe less than 2 dS/m.

## Salt tolerance of flowers

**Table 29** Salt tolerance of selected landscape flower crops.

| Common name | Botanical name | Salt tolerance* | Reference(s) |
|---|---|---|---|
| Ageratum | *Ageratum houstonianum* | moderately sensitive | Devitt and Morris, 1987 |
| Amaryllis | *Hippeastrum hybridum* | very sensitive | Shillo *et al*., 2002; Sonneveld and Voogt, 1983 |
| Anthurium | *Anthurium andreanum* | very sensitive | Sonneveld and Voogt, 1983 |
| Apple Cactus | *Cereus peruviana* | moderately sensitive | Costello *et al*., 2003 |
| Arabian Star Flower | *Ornithogalum arabicum* | very sensitive | Shillo *et al*., 2002 |
| Asiatic Hybrid Lily | *Lilium spp.* | sensitive | Sonneveld, 1988 |
| Azalea | *Rhododendron hybrids* | moderately sensitive | Cabrera, 2003 |
| Azalea | *Rhododendron obtusum* | sensitive | Pearson, 1949; Lunt *et al*., 1957 |
| Baby's Breath | *Gyposphila paniculata* | moderately tolerant*** | Shillo *et al*., 2002 |
| Begonia | *Begonia bunchii* | sensitive | Pearson, 1949 |
| Begonia | *Begonia ricinifolia* | sensitive | Pearson, 1949 |
| Bird of Paradise | *Strelitzia reginae* | very sensitive | Farnham *et al*., 1985 |

| Common name | Botanical name | Salt tolerance* | Reference(s) |
|---|---|---|---|
| Blue Throatwort | *Trachelium caeruleum* | sensitive | Shillo *et al*., 2002 |
| Bouvardia | *Bouvardia longiflora* | moderately sensitive | Sonneveld *et al*., 1999 |
| California Poppy | *Eschscholzia californica* | moderately tolerant*** | Glattstein, 1989 |
| Camellia | *Camellia japonica* | sensitive | Pearson, 1949 |
| Carnation | *Dianthus caryophyllus* | moderately tolerant | Baas *et al*., 1995 |
| Carnation | *Dianthus chinensis* | moderately tolerant | Devitt and Morris, 1987 |
| Chief Celosia | *Celosia argenta cristata* | tolerant | Carter *et al*., 2005 |
| China Aster | *Callistephus chinensis* | moderately sensitive | Kohl *et al*., 1957 |
| China Aster | *Callistephus chinensis* | moderately tolerant | Sonneveld *et al*., 1999 |
| Clematis | *Clematis orientalis* | very tolerant | Krupenikov, 1946 |
| Coleus | *Coleus blumei* | tolerant | Zurayk *et al*., 1993 |
| Coreopsis | *Coreopsis grandiflora* | moderately sensitive*** | Glattstein, 1989 |
| Cosmos | *Cosmos bipinnatus* | very sensitive | Devitt and Morris, 1987 |
| Crested Coxcomb | *Celosia argenta cristata* | moderately sensitive | Devitt and Morris, 1987 |
| Croton | *Codiaeum punctatus* | moderately tolerant | Farnham *et al*., 1985 |
| Cucumber Leaf | *Helianthus debilis* | very tolerant | Costello *et al*., 2003 |
| Cushion Bush | *Calocephalus brownii* | moderately sensitive | Costello *et al*., 2003 |
| Cyclamen | *Cyclamen persicum* | sensitive | Bik, 1980 |
| Dusty Miller | *Artemesia stelleran* | moderately sensitive *** | Glattstein, 1989 |
| Felicia | *Felicia amelloides* | sensitive | Farnham *et al*., 1985; Skimina, 1980 |
| Fuchsia | *Fuchsia hybrida* | very sensitive | Pearson, 1949 |
| Gardenia | *Gardenia augusta* | sensitive | Lunt *et al*., 1957 |
| Gazania | *Gazania aurantiacum* | moderately tolerant | Costello *et al*., 2003 |
| Geranium | *Pelargonium x hortorum* | sensitive | Kofranek *et al*., 1958 |
| Geranium | *Pelargonium domesticum* | tolerant | Zurayk *et al*., 1993 |
| Gerbera Daisy | *Gerbera jamesonii* | moderately sensitive | Sonneveld and Voogt, 1983; Baas *et al*., 1995; Savvas *et al*., 2002 |
| Giant Turf Lily | *Ophiopogon jaburan* | moderately sensitive | Skimina, 1980 |
| Gladiola | *Gladiolus spp.* | sensitive | Kofranek *et al*., 1957 |
| Globe Amaranth | *Gomphrena globosa* | moderately sensitive | Kang and van Iersel, 2002 |
| Golden Marguerite | *Euryops pectinatus* | sensitive | Wu *et al*., 1999 |
| Hibiscus | *Hibiscus rosa-sinensis* | sensitive | Bernstein *et al*., 1972 |
| Impatiens | *Impatiens x hawkeri* | sensitive | Todd and Reed, 1988 |
| Inca lily, Peruvian lily | *Alstroemeria hybrids* | very sensitive | Sonneveld, 1988 |
| Ivy Geranium | *Pelargonium peltatum* | moderately tolerant | Costello *et al*., 2003 |
| Jade Plant | *Crassula ovata* | moderately sensitive | Skimina, 1980 |

| Common name | Botanical name | Salt tolerance* | Reference(s) |
|---|---|---|---|
| Japanese Limonium | *Limonium spp.* | very tolerant | Shillo *et al.*, 2002 |
| Kalanchoe | *Kalanchoe spp.* | moderately tolerant | Costello *et al.*, 2003 |
| Kochia | *Kochia childsii* | tolerant | Monk and Peterson, 1961 |
| Larkspur | *Consolida ambigua* | sensitive | Arnold *et al.*, 2003 |
| Lily of the Nile | *Agapanthus orientalis* | sensitive | Skimina, 1980 |
| Lisianthus | *Eustoma grandiforum* | moderately sensitive | Shillo *et al.*, 2002 |
| Love-Lies-Bleeding | *Amaranthus tricolor* | tolerant** | Aronson, 1989 |
| Marigold | *Tagetes erecta* | moderately tolerant | West *et al.*, 1980 |
| Marigold | *Tagetes patula* | moderately tolerant | Devitt and Morris, 1987 |
| Mexican Evening Primrose | *Oenthera speciosa* | moderately tolerant | Costello *et al.*, 2003 |
| Moss Rose | *Portulaca grandiflora* | very tolerant | Devitt and Morris, 1987 |
| Mum | *Chrysanthemum morifolium* | moderately tolerant | Kofranek *et al.*, 1953; Pearson, 1949 |
| Myrtle | *Vinca minor* | sensitive | Farnham *et al.*, 1985 |
| Nasturtium | *Tropaeolum majus* | moderately sensitive*** | Glattstein, 1989 |
| Orchid | *Cymbidium spp.* | very sensitive | de Kreij and van den Berg, 1990 |
| Orchid | *Phalaenopsis hybrid* | very sensitive | Wang, 1998 |
| Oriental Hybrid Lily | *Lilium spp.* | sensitive | Sonneveld and Voogt, 1983 |
| Ornamental Cabbage | *Brassica oleracea* | sensitive** | Maas and Grattan, 1999 |
| Ornamental Kale | *Brassica oleracea* | sensitive** | Shannon *et al.*, 2000 |
| Pansy | *Viola x wittrockiana* | sensitive | Arnold *et al.*, 2003 |
| Paperwhite Narcissus | *Narcissus tazetta* | sensitive | Arnold *et al.*, 2003 |
| Periwinkle | *Vinca major* | moderately tolerant | Costello *et al.*, 2003 |
| Petunia | *Petunia hybrida* | tolerant | Devitt and Morris, 1987 |
| Pinks | *Dianthus barbatus* | moderately sensitive | Monk and Peterson, 1961 |
| Poinsettia 'Barbara Ecke' | *Euphorbia pulcherrima* | very sensitive | Kofranek *et al.*, 1956 |
| Poinsettia 'Red Sails' | *Euphorbia pulcherrima* | sensitive | Cox, 1991 |
| Pot Marigold | *Calendula officinalis* | moderately tolerant | Chaparzadeh *et al.*, 2003 |
| Protea | *Protea obtusifolia* | moderately tolerant | Rodrigues-Perez *et al.*, 2000 |
| Pygmy Torch | *Amaranthus hypochondriacus* | tolerant | Aronson, 1989 |
| Rex Begonia | *Begonia Rex-cultorum* | very sensitive | Pearson, 1949 |
| Rose | *Rosa x hybrida* | sensitive | Cabrera and Perdomo, 2003; Fernández Falcón *et al.*, 1986 |
| Saff Flower | *Carathamus tinctorius* | moderately tolerant** | Beke and Volkmer, 1994 |
| Sea Lavender | *Limonium latifolium* | very tolerant | Aronson, 1989 |
| Snapdragon | *Antirrhinum majus* | moderately sensitive | Carter *et al.*, 2005 |

| Common name | Botanical name | Salt tolerance* | Reference(s) |
|---|---|---|---|
| Spiderlily | *Hymenocallis keyensis* | moderately tolerant | Costello *et al.*, 2003 |
| St. Bernard's Lily | *Chlorophytum comosum* | tolerant | Zurayk *et al.*, 1993 |
| Starfish Flower | *Stapelia gigantea* | moderately tolerant | Costello *et al.*, 2003 |
| Statice | *Limonium perezii* | sensitive | Farnham *et al.*, 1985 |
| Statice | *Limonium perezii* | very tolerant | Grieve *et al.*, 2005; Carter *et al.*, 2005 |
| Statice | *Limonium sinuatum* | very tolerant | Grieve et al., 2005; Carter *et al.*, 2005 |
| Stock | *Matthiola incana* | very tolerant | Lunt et al., 1964; Wigdor *et al.*, 1958 |
| Sunflower | *Helianthus annuus* | moderately tolerant | Ashraf and O'Leary, 1995 |
| Sweet Alyssum | *Lobularia maritima* | moderately tolerant | Monk and Peterson, 1961 |
| Sweet Pea | *Lathyrus japonica* | moderately tolerant | Costello *et al.*, 2003 |
| Treasure Flower | *Gazania spp.* | very tolerant | Perry, 1989 |
| Vinca | *Catharanthus roseus* | sensitive | Arnold *et al.*, 2003; Huang and Cox, 1988 |
| Zinnia | *Zinnia elegans* | moderately sensitive | Devitt and Morris, 1987 |

Source: Tanji *et al*. 2007

* Criteria for assigning salt tolerance: not more than 50% reduction in growth, no visually-observable foliar burn, and maximum permissible ECe (dS/m) as follows:

< 2 very sensitive

2–3 sensitive

3–4 moderately sensitive

4–5 moderately tolerant

5–6 tolerant

> 6 very tolerant

** Based on salt tolerance classification of related agronomic or horticultural species or variety

*** Only qualitative data are available

**Table 30** Varietal differences in salt tolerance for selected cut-flower crops.

| Common name | Variety | Threshold ECe (dS/m) | Slope (%) | Reference |
|---|---|---|---|---|
| Carnation | Adefie | 1.1 | 2.1 | Sonneveld *et al.*, 1999 |
| | Beauty | 4.3 | 3.9 | Sonneveld *et al.*, 1999 |
| | Princess White | 5.0 | — | Devitt and Morris, 1987 |
| | Scania | 1.2 | 6.9 | Sonneveld and Voogt,1987 |
| | Nora Barlo | 1.2 | 5.5 | Sonneveld and Voogt,1987 |
| Chrysanthemum | Indianapolis White | 2.4 | — | Rutland,1972 |
| | Spider | > 0.8 | 6.8 | Sonneveld and Voogt, 1987 |
| | Horim | > 0.8 | 12.1 | Sonneveld and Voogt, 1987 |
| | Maghi* | > 8.0 | — | Rahi and Datta, 2000 |
| | Basantika* | > 8.0 | — | Rahi and Datta, 2000 |
| | Bronze Kramer | 6.0 | 9.0 | Kofranek *et al.*, 1953 |
| | Albatross | 2.0 | — | Lunt *et al.*, 1962 |
| Gerbera | Beauty | 1.5 | 9.8 | Sonneveld *et al.*, 1999 |
| | Mandarine | < 0.6 | 5.1** | Sonneveld and Voogt, 1983 |
| | Fabiola | < 0.6 | 6.5** | Sonneveld and Voogt, 1983 |
| Rose | Baccara | 1.0 | 10 | Yaron *et al.*,1969 |

| Common name | Variety | Threshold ECe (dS/m) | Slope (%) | Reference |
|---|---|---|---|---|
| | Grenoble | 2.1 | 20 | Bernstein *et al*.,1972 |
| | Forever yours | 1.8 | — | Hughes and Hanan,1978 |
| | Sonia | 1.0 | 10 | Zeroni and Gale,1989 |
| | Europa | 2.1 | 5.3 | Sonneveld *et al*.,1999 |
| | Madelon | 4.8*** | 2.0 | Baas and Berg,1999 |
| | Kardinal | 2.2 | 20 | Wahome *et al*.,2000 |
| | Bridal Pink | 5.4**** | — | Cabrera, 2001 |

Source:Tanji *et al*. 2007

* Plants grown from cuttings subjected to mutagenesis by gamma irradiation resulted in more salt tolerant genotypes

** Based on weight of peduncle

*** Recirculating irrigation system

**** Electrical conductivity (EC) of leachate

# Sensitivity of turf species to salinity

**Table 31** Relative soil salinity tolerance thresholds of turf grasses to salinity in soil extract (ECe) and estimates for irrigation water (ECi).

| Common name | Species | ECe | | | ECi | | | |
|---|---|---|---|---|---|---|---|---|
| | | At 80% growth | At 50% growth | Source | 25% LF (e.g. sand)[a] | 20% LF (e.g. sandy loam)[a] | 17% LF (e.g. loam)[a] | 12% LF (e.g. light clay)[a] |
| Alkaligrass | *Punccinella ssp* | 6–12, 8.5[b] | 20–30 | z | 8.5 | 7.3 | 6.3 | 4.8 |
| Annual bluegrass | *Poa annua* | 0–3, 1.5[b] | – | z | 1.5 | 1.3 | 1.1 | 0.8 |
| Annual ryegrass | *Lolium multiflorum* | | 4 | w | 1.7 | 1.5 | 1.2 | 1.0 |
| Aussiblue | *Digitaria didactyla* | 1–2.8 | 4–8.5 | x | 1.6 | 1.4 | 1.2 | 0.9 |
| Bahiagrass | *Paspalum notatum* | | 3 | w | 1.3 | 1.1 | 0.9 | 0.7 |
| Bermuda grass (couch grass) | *Cynodon species* | | 18 | w | 7.6 | 6.6 | 5.6 | 4.3 |
| Bermuda grass, hybrids | *Cynodon species* | 0–10, 3.7[b] | 11–33 | z | 3.7 | 3.2 | 2.7 | 2.1 |
| Blue grama | *Bouteloua gracilis* | 2–10, 5.2[b] | – | z | 5.2 | 4.5 | 3.8 | 2.9 |
| Buffalo grass | *Buchloe dactyloides* | | 8 | w | 3.4 | 2.9 | 2.5 | 1.9 |
| Buffalo grass | *Buchloe dactyloides* | 0–10, 5.3[b] | 13 | z | 5.3 | 4.6 | 3.9 | 3.0 |
| Carpetgrass | *Axonopus species* | 0–1, 1.5[b] | 4 | w, z | 1.5 | 1.3 | 1.1 | 0.8 |
| Cavalier | *Zoysia matrella* | 4 | 14 | x | 4.0 | 3.4 | 2.9 | 2.2 |
| Centipede-grass | *Eremochloa ophiuroides* | 0–3, 1.5[b] | 8–9 | z | 1.5 | 1.3 | 1.1 | 0.8 |

| Common name | Species | ECe | | | ECi | | | |
|---|---|---|---|---|---|---|---|---|
| | | At 80% growth | At 50% growth | Source | 25% LF (e.g. sand)[a] | 20% LF (e.g. sandy loam)[a] | 17% LF (e.g. loam)[a] | 12% LF (e.g. light clay)[a] |
| Chewings fescue | *Festuca rubra commutata* | | 4 | w | 1.7 | 1.5 | 1.2 | 1.0 |
| Colonial bentgrass | *Agrostris tenuis* | 0–3, 1.5[b] | 3 | w, z | 1.5 | 1.3 | 1.1 | 0.8 |
| Conquest | *Cynodon dactylon* | 8 | 18 | x | 8.0 | 6.9 | 5.9 | 4.5 |
| Creeping bentgrass | *Agrostis palustris* | 0–10, 3.7[b] | 8–12 | w, z | 3.7 | 3.2 | 2.7 | 2.1 |
| Creeping red fescue | *Festuca ruba L. spp ruba* | 3–6, 4.5[b] | 8–12 | z | 4.5 | 3.9 | 3.3 | 2.5 |
| CT-2 | *Cynodon dactylon* | 7 | 16 | x | 7.0 | 6.0 | 5.1 | 3.9 |
| Diamond | *Zoysia matrella* | 5 | 21 | x | 5.0 | 4.3 | 3.7 | 2.8 |
| Fairway wheatgrass | *Agropyron cristatum* | 6–10, 8[b] | | z | 8.0 | 6.9 | 5.9 | 4.5 |
| G1 | *Zoysia matrella* | 13 | 24 | x | 13.0 | 11.2 | 9.6 | 7.3 |
| Gladstone | *Sporobulus virginicus* | 22 | 30 | x | 22.0 | 19.0 | 16.2 | 12.4 |
| Hard fescue | *Festuca longifolia* | 3–6, 4.5[b] | 4 | w, z | 4.5 | 3.9 | 3.3 | 2.5 |
| Hatfield | *Cynodon dactylon* | 8 | 18 | x | 8.0 | 6.9 | 5.9 | 4.5 |
| Hybrid Zoysia grass | *Zoysia spp* | 0–11, 2.4[b] | 16 | z | 2.4 | 2.1 | 1.8 | 1.3 |
| JT1 | *Cynodon dactylon* | 11 | 20 | x | 11.0 | 9.5 | 8.1 | 6.2 |
| Kentucky bluegrass | *Poa pratensis* | 0–6, 3.0[b] | 3–30 | z | 3.0 | 2.6 | 2.2 | 1.7 |
| Kikuyu | *Pennisetum clandestinum* | 6–10, 8.0[b] | – | z | 8.0 | 6.9 | 5.9 | 4.5 |
| Legend | *Cynodon dactylon* | 7 | 17 | x | 7.0 | 6.0 | 5.1 | 3.9 |
| Lemon alkali grass | *Puccinellia lemmoni* | | 30 | w | 12.7 | 11.0 | 9.3 | 7.1 |
| Manila grass | *Zoysia matrella* | | 30 | w | 12.7 | 11.0 | 9.3 | 7.1 |
| Mascarene grass | *Zoysia tenuifolia* | | 30 | w | 12.7 | 11.0 | 9.3 | 7.1 |
| Meadow fescue | *Festuca elatior* | | 4 | w | 1.7 | 1.5 | 1.2 | 1.0 |
| Mountain Green | *Cynodon dactylon* | 9 | 17 | x | 9.0 | 7.8 | 6.6 | 5.1 |
| Nuttall alkali grass | *Puccinellia airoides* | | 30 | w | 12.7 | 11.0 | 9.3 | 7.1 |
| NyPa Turf | *Distichlis spicata* | 12 | 27 | x | 12.0 | 10.3 | 8.8 | 6.7 |
| Oz-E-Green | *Cynodon dactylon* | 7 | 22 | x | 7.0 | 6.0 | 5.1 | 3.9 |

| Common name | Species | ECe | | | ECi | | | |
|---|---|---|---|---|---|---|---|---|
| | | At 80% growth | At 50% growth | Source | 25% LF (e.g. sand)[a] | 20% LF (e.g. sandy loam)[a] | 17% LF (e.g. loam)[a] | 12% LF (e.g. light clay)[a] |
| Palmetto | *Stentoaphrum secundatum* | 16 | 18 | x | 16.0 | 13.8 | 11.8 | 9.0 |
| Perennial ryegrass | *Lolium perenne* | 3–10, 6.5[b] | 8–10 | z | 6.8 | 5.9 | 5.0 | 3.8 |
| Plateau | *Cynodon dactylon* | 4 | 14 | x | 4.0 | 3.4 | 2.9 | 2.2 |
| RB1 | *Sporobulus virginicus* | 19 | 37 | x | 19.0 | 16.4 | 14.0 | 10.7 |
| Riley's Super Sport | *Cynodon dactylon* | 9 | 18.5 | x | 9.0 | 7.8 | 6.6 | 5.1 |
| Rottnest | *Sporobulus virginicus* | 3 | 12 | x | 3.0 | 2.6 | 2.2 | 1.7 |
| Rough bluegrass | *Poa trivialis* | 0–3, 1.5[b] | 4 | w, z | 1.5 | 1.3 | 1.1 | 0.8 |
| Royal | *Zoysia matrella* | 5 | 23 | x | 5.0 | 4.3 | 3.7 | 2.8 |
| Royal Cape II | *Cynodon dactylon* | 7 | 15.5 | x | 7.0 | 6.0 | 5.1 | 3.9 |
| Saltene | *Paspalum vaginatum* | 24 | 31 | x | 24.0 | 20.7 | 17.6 | 13.5 |
| Saltgrass | *Distichlis sppstricta* | 6–10, 8.0[b]> | >40 | w, z | 8.0 | 6.9 | 5.9 | 4.5 |
| Saphire | *Stentoaphrum secundatum* | 10.5 | 16 | x | 10.5 | 9.1 | 7.7 | 5.9 |
| Sea Isle 1 | *Paspalum vaginatum* | 4 | 13 | x | 1.0 | 0.9 | 0.7 | 0.6 |
| Sea Isle 2000 | *Paspalum vaginatum* | 11–24 | 25–30 | x | 17.5 | 15.1 | 12.9 | 9.8 |
| Seashore paspalum (salt water couch) | *Paspalum vaginatum* | 0–20, 8.6[b] | *30–31* | w, z | 8.6 | 7.4 | 6.3 | 4.8 |
| Shademaster | *Stentoaphrum secundatum* | 16.5 | 19 | x | 16.5 | 14.2 | 12.1 | 9.3 |
| Sheep fescue | *Festuca ovina* | | 4 | w | 1.7 | 1.5 | 1.2 | 1.0 |
| Sir James | *Stentoaphrum secundatum* | 5 | 19 | x | 5.0 | 4.3 | 3.7 | 2.8 |
| Sir Walter | *Stentoaphrum secundatum* | 3 | 16 | x | 3.0 | 2.6 | 2.2 | 1.7 |
| Slender creep. Red fescue | *Festuca rura L. trichophylla* | 3–10, 6.3[b] | 8–12 | z | 6.3 | 5.4 | 4.6 | 3.5 |
| St Augustine-grass | *Stentoaphrum secundatum* | 0–18, 6.5[b] | 29 | z | 6.5 | 5.6 | 4.8 | 3.7 |
| ST-26 | *Stentoaphrum secundatum* | 3 | 16 | x | 3.0 | 2.6 | 2.2 | 1.7 |
| ST-85 | *Stentoaphrum secundatum* | 5 | 21 | x | 5.0 | 4.3 | 3.7 | 2.8 |
| ST-91 | *Stentoaphrum secundatum* | 3 | 9 | x | 3.0 | 2.6 | 2.2 | 1.7 |
| Tall fescue | *Festuca arundinacea* | 5–10, 6.5[b] | 8–12 | w, z | 6.5 | 5.6 | 4.8 | 3.7 |

| Common name | Species | ECe At 80% growth | ECe At 50% growth | ECe Source | ECi 25% LF (e.g. sand)[a] | ECi 20% LF (e.g. sandy loam)[a] | ECi 17% LF (e.g. loam)[a] | ECi 12% LF (e.g. light clay)[a] |
|---|---|---|---|---|---|---|---|---|
| TifBlair | *Eremochloa ophiuroides* | 1–1.5 | 3–4 | x | 1.3 | 1.1 | 0.9 | 0.7 |
| Velvet | *Stentoaphrum secundatum* | 3 | 10.5 | x | 3.0 | 2.6 | 2.2 | 1.7 |
| Velvet bentgrass | *Agrostris canina* | | 3 | w | 1.3 | 1.1 | 0.9 | 0.7 |
| Velvetene | *Paspalum vaginatum* | 14 | 40 | x | 14.0 | 12.1 | 10.3 | 7.9 |
| Weeping alkali grass | *Puccinellia distans* | | 30 | w | 12.7 | 11.0 | 9.3 | 7.1 |
| Western wheatgrass | *Agropyron smithii* | 6–10, 8[b] | 12–16 | z | 8.0 | 6.9 | 5.9 | 4.5 |
| Windsor Green | *Cynodon dactylon* | 11 | 19 | x | 11.0 | 9.5 | 8.1 | 6.2 |
| Winter Gem | *Cynodon dactylon* | 9 | 18 | x | 9.0 | 7.8 | 6.6 | 5.1 |
| Wintergreen | *Cynodon dactylon* | 4 | 13 | x | 4.0 | 3.4 | 2.9 | 2.2 |
| Zorro | *Zoysia matrella* | 9 | 20 | x | 9.0 | 7.8 | 6.6 | 5.1 |

EC = electrical conductivity in dS/m; ECe = electrical conductivity of a soil paste extract; ECi = electrical conductivity of irrigation water; LF = leaching fraction.

Note: Values in this table are indicative only; salt tolerance of all plants will vary depending on a range of factors, such as soil type, drainage, climate and turf maturity.

[a] ECi has been estimated from average or mid-range ECe 80% growth, assuming limited rainfall and the specified LF, using equation 9 from Ayers and Westcot (1985). Where no ECe 80% growth was reported but average ratio (0.42) of 50%:80% growth for species was reported, this was used to estimate the ECi.

[b] Average root salinity tolerance (ECe dS/m)

Sources: w = Marcum (1999); x = Loch *et al* (in press). ECe values where quoted as ECi. Growth threshold was assumed to be 80% growth; z = Carrow and Duncan (1998)

**Table 32** California turfgrass species tolerate varying levels of soil salinity. Grasses listed here are grouped by their tolerance to soil salinity (expressed as the Electrical Conductivity of soil paste extract, ECe).

| Sensitive (<3 dSm$^{-1}$) | Moderately Sensitive (3 to 6 dSm$^{-1}$) | Moderately Sensitive (6 to 10 dSm$^{-1}$) | Tolerant (>10 dSm$^{-1}$) |
|---|---|---|---|
| Annual bluegrassess *(Poa Annua)* | Annual ryegrass *(Lolium moltiflorum)* | Course-leaf zoysiagrasses *(Japanica type)* | Alkaligrass *(Puccinellia spp.)* |
| Colonial bentgrass *(Agrostis tenuis)* | Buffalograss *(Buchloe dactyloides)* | Perennial ryegrass *(Lolium perenne)* | Bermudagrasses *(Cynodon spp.)* |
| Hard fescue *(Festuca longifolia)* | Creeping bentgrass *(Agrostis palustris)* | Tall fescue *(Festuca arundinacea)* | Fineleaf zoysiagrasses *(Matrella type)* |
| Kentucky bluegrass *(Poa pratensis)* | Slender, creeping red, and Chewings fescues *(Festuca rubra)* | | Saltgrass *(Distichlis spp.)* |
| Rough bluegrass *(Poa trivialis)* | | | Seashore paspalum *(Paspalum vaginatum)* |
| | | | St. Augustinegrass *(Stenotaphurm secundatum)* |

Source: Tanji *et al*. 2007

# Sensitivity of native (California) plants to salinity

**Table 33** Salt Tolerance of Selected California Native Trees, Shrubs, and Ground Covers*.

| Common name | Botanical name | type | Native range | Salt tolerance |
|---|---|---|---|---|
| Apache Plume | *Fallugia paradoxa* | shrub | Texas west to California; Colorado to Mexico | fair |
| Ash | *Fraxinus species* | tree | Texas to California, Colorado and Utah south to Mexico | fair to poor |
| Bigleaf Sage | *Artemesia tridentata* | shrub | Dakotas, Rockies, Sierra Nevada, and Cascades; predominant in Great Basin region | low to moderate |
| Blanketflower | *Gaillardia species* | ground cover | Throughout North America | good |
| Blue Flax | *Linum lewisii* | ground cover | Alaska east to Saskatchewan and south to Kansas, Texas, New Mexico, Arizona, California | fair to poor |
| Blue Grama | *Bouteloua gracilis* | ground cover | Wisconsin to Alberta, Canada; Missouri, Texas, southern California, New Mexico | fair |
| Broom Baccharis | *Baccharis emoryii* | shrub | Texas, New Mexico, Arizona, California, Nevada, Utah, Colorado | good |
| Bush Penstemon | *Penstemon ambiguus* | ground cover | Kansas, Colorado, Utah, Texas west to California | fair |
| Chamisa (Rabbitbrush) | *Chrysothamnus nauseosus* | shrub | Western Canada south to California, Texas, northern Mexico | moderate |
| Cliffrose | *Cowania mexicana* | shrub | Southern Colorado west to southeastern California, Mexico | fair |
| Cottonwood | *Populus fremontii and subspecies* | tree | Nevada, Southwestern Utah, northern California, Arizona, New Mexico | fair |
| Creeping Mahonia | *Berberis repens* | ground cover | Texas, New Mexico, Arizona, California; north to Nebraska and British Columbia | very poor |
| Desert Willow (Flor de Mimbres) | *Chilopsis linearis* | tree | Central Texas west to California, northern Mexico | very good |
| Dwarf Coyotebush | *Baccharis pilularis* | ground cover | California coast—Sonoma to Monterey Counties | undocumented; coastal native origin suggests tolerance fair or better |
| Fernbush | *Chamaebatieria millefolium* | shrub | Idaho south to New Mexico, Arizona, California | fair |
| Fourwing Saltbush (Chamiso) | *Atriplex canescens* | shrub | New Mexico north to South Dakota and west to California | excellent |
| Littleleaf Sumac (Lemita) | *Rhus microphylla* | shrub | Washington to Missouri, California east to Texas | fair |
| Quaking Aspen | *Populus tremuloides* | tree | Alaska east to Labrador, south to Virginia; Rocky Mountains south to New Mexico and Arizona | poor |
| Russian Olive | *Elaeagnus angustifolia 'King Red'* | tree | Southern Europe and southwestern Asia. Naturalized in western U.S. | excellent |
| Threeleaf Sumac (Lemita) | *Rhus trilobata* | shrub | Washington to Missouri, California east to Texas | poor to moderate |
| Winterfat | *Ceratoides lanata* | shrub | Canada south to Mexico, Rocky Mountains west to Pacific Coast | fair |

Source: Tanji *et al*. 2007
*Adapted from Phillips (1987).

**Table 34** Salt-tolerant Trees and Shrubs for Coastal Southern California*.

| Common name | Botanical name | Type of plant | Tolerant to saltwater spray? | Tolerant to saline soil? |
|---|---|---|---|---|
| Aleppo Pine | *Pinus halepensis* | tree | no | yes |
| Australian Tea Tree | *Leptospermum laevigatum* | small tree | yes | no |
| Beefwood | *Casuarina species* | tree | no | yes |
| Bird of Paradise Bush | *Caesalpinia gilliesii* | shrub or small tree | yes | no |
| Black Tea Tree | *Melaleuca styphelioides* | tree | yes | no |
| Blackwood Acacia | *Acacia melanoxylon* | shrub | yes | no |
| Bottlebrush | *Callistemon species* | shrub or small tree | yes | yes |
| Brazilian Pepper | *Schinus terebinthifolius* | tree | no | yes |
| California Encelia | *Encelia californica* | shrub | yes | no |
| Catalina Cherry | *Prunus lyonii* | shrub or tree | yes | no |
| Chinese Jujube | *Zizyphus jujuba* | small tree | no | yes |
| Coral Gum | *Eucalyptus torquata* | tree | yes | yes |
| Desert Gum | *Eucalyptus rudis* | tree | no | yes |
| Dwarf Chaparral Broom | *Baccharis pilularis* | shrub | yes | no |
| Italian Jasmine | *Jasminum humile* | shrub | yes | no |
| Italian Stone Pine | *Pinus pinea* | tree | yes | no |
| Lemonade Berry | *Rhus integrifolia* | shrub | yes | no |
| Little Sur Manzanita | *Arctostaphylos edmundsii* | shrub | yes | no |
| Myoporum | *Myoporum laetum* | shrub or tree | no | yes |
| New Zealand Christmas tree | *Metrosideros tomentosus* | tree or large shrub | yes | yes |
| Oleander | *Nerium oleander* | shrub | no | yes |
| Pink Melaleuca | *Melaleuca nesophila* | tree or large shrub | yes | yes |
| Pittosporum | *Pittosporum crassifolium* | shrub | yes | yes |
| Plume Albizia | *Albizia lophantha* | tree | yes | no |
| Red Gum | *Eucalyptus camaldulensis* | tree | no | yes |
| Russian Olive | *Elaeagnus angustifolia* | small tree | no | yes |
| Saltbush | *Atriplex species* | shrub | yes | yes |
| Sandhill Sage | *Artemisia pycnocephala* | shrub | no | yes |
| Silverberry | *Elaeagnus pungens* | shrub | yes | no |
| St. Catherine's Lace | *Eriogonum giganteum* | shrub | yes | no |
| Sweet Hakea | *Hakea suaveolens* | shrub | yes | no |
| Sydney Golden Wattle | *Acacia longifolia* | shrub | yes | no |
| Tamarisk | *Tamarix species* | tree | no | yes |
| Torrey Pine | *Pinus torreyana* | tree | yes | no |

| Common name | Botanical name | Type of plant | Tolerant to saltwater spray? | Tolerant to saline soil? |
|---|---|---|---|---|
| Tree Mallow | *Lavatera assurgentiflora* | shrub | yes | yes |
| Willow Pittosporum | *Pittosporum phillyraeoides* | shrub | yes | yes |

Source: Tanji *et al.* 2007

* All these plants survive well in the climate zones of the Los Angeles and San Diego areas.

## Spray resistance to sodium and chloride

**Table 35** Spray Resistance to sodium and chloride: Ground Covers, Shrubs,Tree Seedlings and Garden Foods.

| Common name | Scientific name | Tolerance |
|---|---|---|
| **Flowering Annuals and Perennials** | | |
| Tea rose | *Rosa sp. Hybrid Tea* | S |
| Lily of the nile | *Agapanthus africanus* | S |
| Crape myrtle | *Lagerstroemia indica* | S |
| Gazania | *Gazania sp.* | MS |
| Texas sage | *Leucophyllum frutescens* | MS |
| Lady Banks Rose | *Rosa banksiae* | MT |
| Trailing lantana | *Lantana montevidensis* | MT |
| Verbena | *Verbena sp.* | MT |
| Sunflower | *Helianthus sp.* | T |
| **Vines and Ground Covers** | | |
| Vinca | *Vinca major* | S |
| Grape | *Vitus sp.* | S |
| Japanese honeysuckle | *Lonicera japonica* | MS |
| Liriope | *Liriope muscari* | MS |
| Star jasmine | *Trachelospermum jasminoides* | MS |
| Asian jasmine | *Trachelospermum asiaticum* | MS |
| Carolina jasmine | *Gelsemium sempervirens* | MS |
| English ivy | *Hedera helix* | MT |
| Strawberry | *Fragaria sp.* | T |
| **Shrubs** | | |
| Nandina | *Nandina domestica* | S |
| Photinia, "Red Tip" | *Photinia fraseri* | S |
| Pyracantha | *Pyracantha fortuneana* | MS |
| Dwarf rosemary | *Rosmarinus officinalis* | MS |
| Wild Lilac | *Ceanothus thyrsiflorus* | MS |
| Yaupon holly | *Ilex vomitoria* | MT |
| Euonymous | *Euonymus japonica* | MT |
| Indian hawthorne | *Raphiolepis indica* | MT |
| Buffalo juniper | *Juniperus sabina Buffalo'* | MT |
| Cotoneaster | *Cotoneaster buxifolius* | MT |
| Japanese boxwood | *Buxus micropylla* | T |
| Oleander | *Nerium oleander* | T |

| Common name | Scientific name | Tolerance |
|---|---|---|
| **Tree Seedlings** | | |
| Pistachie 'UCB-3' | *Pistacia spp.* | S |
| Plum | *Prunus domestica* | S |
| Apricot | *Prunus americana* | S |
| Mexican buckeye | *Ungnadia speciosa* | S |
| Chinese pistache | *Pistachia chinensis* | S |
| Sweet gum | *Liquidambar styraciflua* | S |
| Wax-leaf Ligustrum | *Ligustrum japonicum* | MS |
| Afghan pine | *Pinus eldarica* | MT |
| Mexican stone pine | *Pinus cembroides* | T |
| **Garden foods** | | |
| Almond | | S |
| Apricot | | S |
| Citrus | | S |
| Plum | | S |
| Grape | | S |
| Pepper | | MS |
| Potato | | MS |
| Tomato | | MS |
| Cucmber | | MT |
| Sunflower | | T |

Source: Miyamoto *et al*. 2004, Garden foods: ANZECC and ARMCANZ 2000 and Maas 1990

S: Sensitive (< 1 dS/m-1, Na and Cl < 150 ppm), MS: moderately sensitive (1 – 2 dS/m-1, Na < 280 ppm, Cl < 360 ppm), MT: moderately tolerant (2 – 3 dS/m-1, Na < 425 ppm, Cl < 590 ppm), and T:tolerant (> 3 dS/m-1).

**Table 36** Spray resistance to sodium and chloride tolerance of mature trees.

| Common name | Scientific name | Comment |
|---|---|---|
| Highly Sensitive: (Significant Damage at 150 to 200 ppm of Na and Cl) | | |
| Pecans | *Carya illinoensis* | Tip then margin burn |
| Cottonwood | *Populus fremontii* | Margin burn then defoliation |
| Sycamore | *Platanous acerifolia* | Margin then entire leafburn |
| Western Soapberry | *Sapindus drummondii* | Tip-burn |
| Sensitive (Severe damage at 350 ppm of Na or Cl) | | |
| Silverberry | *Elaeagnus pungens* | Margin burn and defoliation |
| Pomegranate | *Punica granatum* | Margin burn and defoliation |
| Honey Locust | *Gleditsia triacanthos* | Tipburn, then defoliation |
| Black Locust | *Robina pseudoacacia* | Tipburn, then defoliation |
| Chinese Pistache | *Pistacia chinensis* | Tipburn, then defoliation |
| Shumard Red Oak | *Quercus shumardii* | Tipburn, then defoliation |
| Bur Oak | *Quercus macrocarpa* | Tipburn, then defoliation |
| White Mulberry | *Morus alba* | Margin burn then defoliation |
| Poplar | *Populus sp.* | Margin burn then defoliation |
| Mimosa | *Acacia baileyana* | Tipburn then defoliation |
| Arizona Cypress | *Cupressus arizonica* | Defoliation |
| Oriental Arborvitae | *Thuja orientalis* | Defoliation |

| Common name | Scientific name | Comment |
|---|---|---|
| Osage Orange | *Maclura pomifera* | Defoliation |
| Ornamental Pears | *Pyrus communis* | Defoliation |
| Arizona, Ash | *Fraxinus velutina* | Tipburn then defoliation |
| Moderately Sensitive (Recognizable damage at 350 ppm of Na or Cl) | | |
| Raywood Ash | *Fraxinus angustifolia* | Tipburn, then defoliation |
| Globe Willow | *Salix matsudana 'umbraculifera'* | Tipburn then defoliation |
| Corkscrew Willow | *Salix matsudana 'tortuosa'* | Tipburn then defoliation |
| Weeping Willow | *Salix babylonica* | Tipburn then defoliation |
| Japanese Pagoda Tree | *Sophora japonica* | Tipburn then defoliation |
| Live Oak | *Quercus virginiana* | Tipburn, then defoliation |
| Chittamwood | *Bumelia lanuginosa* | Tipburn, then defoliation |
| Texas Vitex | *Vitex agnus-castus* | Tipburn, then defoliation |
| Moderately Tolerant (Slight or occasional damage at 350 ppm of Na or Cl) | | |
| European Olive | *Olea europaea* | Tipburn |
| Desert Willow | *Chilopsis linearis* | Tipburn |
| Holly Oak | *Quercus ilex* | Slight to no injury |
| Alligator Juniper | *Juniperus deppeana pachyphlaea* | Slight to no injury |
| Juniper | *Juniperus chinensis* | Slight to no injury |
| Rocky Mt. Juniper | *Juniperus scopulorum* | Slight to no injury |
| Honey Mesquite | *Prosopis grandulosa* | Slight to no injury |
| Tolerant (No damage at 350 ppm of Na or Cl) | | |
| Italian Cypress | *Cupressus sempervirens* | No injury |
| Hollywood Juniper | *Juniperus chinensis 'Torulosa'* | No injury |
| Dwarf Pittosporum | *Pittosporum tobia, compacta* | No injury |
| Oleander | *Nerium oleander* | No injury |
| Ligustrum | *Ligustrum japonica* | No injury |
| Euonyomus | *Euonyomus japonica* | No injury |
| Japanese Black Pine | *Pinus thunbergiana* | No injury |
| Afghan Pine | *Pinus eldarica* | No injury |
| Aleppo Pine | *Pinus halepensis* | No injury |
| Italian Stone Pine | *Pinus pinea* | No injury |

Source: Miyamoto *et al.* 2004

# 7.7 Sensitivity of plants to boron

## Boron tolerance of flowers

**Table 37** Boron tolerance limits for cut flowers.

| Sensitivity to Boron | Species | | Threshold (g/m³) |
|---|---|---|---|
| | Common name | Botanical name | |
| Sensitive | Geranium | *Pelargonium x hortorum* | 0.5–1.0 |
| | Violet | *Viola odorata* | 0.5–1.0 |
| | Pansy | *Viola tricolor* | 0.5–1.0 |
| | Zinnia | *Zinnia elegans* | 0.5–1.0 |
| | Larkspur | *Delphium sp.* | 0.5–1.0 |
| Moderately Sensitive | China Aster | *Callistephus officinalis* | 1.0–2.0 |
| | Gardenia | *Gardenia sp.* | 1.0–2.0 |
| | Gladiola | *Gladiolus sp.* | 1.0–2.0 |
| | Marigold | *Calendula officinalis* | 1.0–2.0 |
| | Poinsettia | *Euphorbia pulcherrima* | 1.0–2.0 |
| Moderately tolerant | Carnation | *Dianthus carophyllus* | 2.0–4.0 |
| | Sweet Pea | *Lathyrus odoratus* | 2.0–4.0 |

Source: Tanji *et al*. 2007

## Boron tolerance of shrubs

**Table 38** Boron injury to leaves, and growth reduction, in 25 species of shrub*.

| Sensitivity to boron | Species | | Boron level** | Observed response | Growth reduction |
|---|---|---|---|---|---|
| | Common name | Botanical name | | | |
| Tolerant | Natal plum | *Carissa grandiflora (E.H. Mey.) A. DC. cv. Tuttlei)* | Low | No injury | 0% |
| | | | High | No injury | 0% |
| | Indian hawthorn | *Raphiolepis indica (l.) Lindl. cv. Enchantress* | Low | No injury | 0% |
| | | | High | No injury | 0% |
| | Chinese hibiscus | *Hibiscus rosa-sinesis L.* | Low | No injury | 0% |
| | | | High | Slight premature leaf drop | 0% |
| | Oleander | *Nerium oleander L.* | Low | No injury | 21% |
| | | | High | Narrow (1 to 2 mm) marginal chlorosis; slight tip burn | 24% |
| | Japanese boxwood | *Buxus microphylla Siebold and Zucc. var japonica (Mull. Arg.)* | Low | No injury | 0% |
| | | | High | General marginal chlorosis with necrotic older leaves | 0% |
| | Bottlebrush | *Callistemon citrinus (Curtis) Stapf* | Low | Slight marginal coloration similar to HB | 0% |
| | | | High | Marginal anthocyanin coloration (5 mm from leaf tip) progressed inward in semicircle pattern toward midrib; marginal and tip necrosis developed as leaves matured | 0% |
| | Cenisa | *Leucophylum frutescens (Berland.) I.M. Johnst. cv. Compactum* | Low | No injury | 15% |
| | | | High | Older leaves dropped prematurely | 24% |
| | Blue dracaena | *Cordyline indivisa (G. Forst) Steud.* | Low | Tip burn, 5 to 7 cm (1973); 10 to 13 cm (1975) | 0% |
| | | | High | Tip burn, 7 to 10 cm (1973); 18 to 22 cm (1975) | 0% |

| Sensitivity to boron | Species | | Boron level** | Observed response | Growth reduction |
|---|---|---|---|---|---|
| | Common name | Botanical name | | | |
| Semi-tolerant | Brush cherry | *Syzgium paniculatum Gaertn.* | Low | Slight anthocyanin spotting oldest leaves | 0% |
| | | | High | Moderate anthocyanin spotting; oldest leaves dropped prematurely; general appearance chlorotic | 11% |
| | Southern yew | *Podocarpus macrophyllus (Thunb.) D. Don var. Maki Endl* | Low | Slight tip burn with narrow chlorotic band between burn and remainder of leaf | 0% |
| | | | High | Moderate to severe tip burn (1 cm) with narrow chlorotic area like LB; leaves on lower 3/4 plant exhibited burn | 8% |
| | Oriental arbivitae | *Platycladus orientalis (L.) Franco* | Low | Slight chlorosis to necrosis on tips older leaves | 27% |
| | | | High | Severe necrosis older leaves; only outside perimeter of plant was still green | 30% |
| | Rosemary | *Rosemarius officinalis C* | Low | Tip necrosis older leaves | 20% |
| | | | High | Tip necrosis all leaves | 51% |
| | Glossy abelia | *Abelia X grandiflora (Andre) Rehd.* | Low | Bronzing and tip burn older leaves | 56% |
| | | | High | Bronzing all leaves; slight leaf drop | 70% |
| Sensitive | Yellow sage | *Lantana camara L.* | Low | Tip and marginal leaf burn intermediate and older leaves; some hastened leaf drop | 14% |
| | | | High | Moderate to severe leaf burn all leaves; severe leaf drop | 82% |
| | Juniper | *Juniperus chinensis L. cv. Armstrongii* | Low | Moderate tip burn older leaves | 20% |
| | | | High | Severe tip burn all leaves, except perimeter of new leaves; center leaves of plant dead | 47% |
| | Chinese holly | *Ilex cornuta Lindl. and Paxt. cv. Burfordii* | Low | Some marginal burn and interveinal chlorosis | 17% |
| | | | High | Tip and marginal burn all leaves; premature leaf drop | 88% |
| | Japanese pittosporum | *Pittosporum tobira* | Low | Margin burn and tip burn distal half older leaves; premature leaf drop | 50% |
| | | | High | Premature leaf drop all leaves, except very youngest; young leaves chlorotic with moderate to severe marginal and tip burn; small rosettes young leaves at branch tips | 50% |
| | Spindle tree | *Euonymus japonica Thunb. cv. Grandiflora* | Low | Slight tip burn; slight leaf drop | 4% |
| | | | High | Severe chlorosis and tip burn all leaves; severe leaf drop | 100% |

| Sensitivity to boron | Species | | Boron level** | Observed response | Growth reduction |
|---|---|---|---|---|---|
| | Common name | Botanical name | | | |
| Sensitive | Pineapple guava | *Feijoa sellowiana O. Berg* | Low | Slight tip burn 1st year; moderate leaf drop, moderate tip, and marginal burn 1974 and 1975 | 13% |
| | | | High | Severe leaf drop; all leaves showed severe tip and marginal burn; youngest leaves also chlorotic | 35% |
| | Wax-leaf privet | *Ligustrum japonicum Thunb.* | Low | No apparent injury symptoms, except reduced growth | 17% |
| | | | High | Terminal 1/2 to 2/3 of branches dead; necrotic spotting older leaves; nearly completely defoliated | 100% |
| | Laurustinus | *Viburnum tinus L. cv. Robustum* | Low | Marginal and tip burn intermediate and older leaves; moderate leaf drop | 0% |
| | | | High | Severe tip and marginal burn all leaves, except very youngest | 100% |
| | Thorny elaeagnus | *Elaegnus pungens Tnunb. cv. Fruitlandii* | Low | Older leaves interveinal and marginal chlorosis on distal half of leaf | 11% |
| | | | High | Severe chlorosis with marginal necrosis; severe leaf drop nearly all, but youngest, leaves; remaining leaves hypnonastic | 70% |
| | Xylosma | *Xylosma congestum (Lout.) Merrill* | Low | Older leaves anthocynanin mottling and tip burn; more severe by mid-summer; severe leaf drop older leaves | 23% |
| | | | High | Many branches dead; anthocyanin mottling and severe tip burn all leaves; nearly complete leaf drop | 100% |
| | Photinia | *Photinia X Fraseri Dress* | Low | Marginal and tip burn older leaves | 0% |
| | | | High | Severe leaf burn; severe leaf drop; stem tips dead; death mid-1974 | 100% |
| | Oregon grape | *Mahonia aquifolium (Pursh) Nutt.* | Low | Tip necrosis young leaves; severe leaf drop older leaves | 50% |
| | | | High | Severe leaf drop, except very youngest; severe burn older and intermediate leaves; tip burn young leaves; barely survived 1st year (1973). | 100% |

Source: Tanji *et al.* 2007

* Excerpted from Francois and Clark (1979).

** Boron concentrations were 2.5 mg/L for low concentration and 7.5 mg/L for high concentration. Control plants were treated with 0.5 mg/L boron.

# Boron tolerance of ornamentals

**Table 39** Boron tolerance limits for ornamentals*.

| Sensitivity to boron | Species** | | Threshold (g/m$^3$) |
|---|---|---|---|
| | Common name | Botanical name | |
| Very sensitive | Oregon grape | *Mahonia aquifolium* | < 0.5 |
| | Photinia | *Photinia X Fraseri* | < 0.5 |
| | Xylosma | *Xylosma congestum* | < 0.5 |
| | Thorny elaeagnus | *Elaegnus pungens* | < 0.5 |
| | Laurustinus | *Viburnum tinus* | < 0.5 |
| | Wax-leaf privet | *Ligustrum japonicum* | < 0.5 |
| | Pineapple guava | *Feijoa sellowiana* | < 0.5 |
| | Spindle tree | *Euonymus japonica* | < 0.5 |
| | Japanese pittosporum | *Pittosporum tobira* | < 0.5 |
| | Chinese holly | *Ilex cornuta* | < 0.5 |
| | Juniper | *Juniperus chinensis* | < 0.5 |
| | Yellow sage | *Lantana camara* | < 0.5 |
| | American elm | *Ulmas americana* | < 0.5 |
| Sensitive | Zinnia | *Zinnia elegans* | 0.5–1.0 |
| | Pansy | *Viola tricolor* | 0.5–1.0 |
| | Violet | *V. adorata* | 0.5–1.0 |
| | Larkspur | *Delphinium sp.* | 0.5–1.0 |
| | Glossy abelia | *Abelia X grandiflora* | 0.5–1.0 |
| | Rosemary | *Rosemarius officinalis* | 0.5–1.0 |
| | Oriental arbivitae | *Platycladus orientalis* | 0.5–1.0 |
| | Geranium | *Pelargonium X hortorum* | 0.5–1.0 |
| Moderately sensitive | Gladiolus | *Gladiolus sp.* | 1.0–2.0 |
| | Marigold | *Calendula officinalis* | 1.0–2.0 |
| | Poinsettia | *Euphlorba pulcherrieucs* | 1.0–2.0 |
| | China aster | *Callistephus chinensis* | 1.0–2.0 |
| | Gardenia | *Gardenia sp.* | 1.0–2.0 |
| | Southern yew | *Podocarpus macrophyllus* | 1.0–2.0 |
| | Brush cherry | *Syzgium paniculatum* | 1.0–2.0 |
| | Blue dracaena | *Cordyline indivisa* | 1.0–2.0 |
| | Cenisa | *Leucophylum frutescens* | 1.0–2.0 |
| Moderately tolerant | Bottlebrush | *Callistemon citrinus* | 2.0–4.0 |
| | California poppy | *Eschscholzia californica* | 2.0–4.0 |
| | Japanese boxwood | *Buxus microphylla* | 2.0–4.0 |
| | Oleander | *Nerium oleander L.* | 2.0–4.0 |
| | Chinese hibiscus: | *Hibiscus rosa-sinesis* | 2.0–4.0 |
| | Sweet pea | *Larkyrus odorarus* | 2.0–4.0 |
| | Carnation | *Dianthus caryophyllus* | 2.0–4.0 |
| Tolerant | Indian hawthorn | *Raphiolepis indica* | 6.0–8.0 |
| | Natal plum | *Carissa grandiflora* | 6.0–8.0 |
| | Oxalis | *Oxalis bouiei* | 6.0–8.0 |

Source: Tanji *et al*. 2007
* After Maas, 1984
** Species listed in order of increasing tolerance, based on appearance as well as growth

## Boron tolerance of commercial crops

**Table 40** Maximum boron concentrations in irrigation or soil water tolerated by a variety of plants, without reduction in yields.

| Tolerance | Boron in irrigation or soil water (mg/L) | Plant |
|---|---|---|
| Very intolerant | < 0.5 | Blackberry, lemon, avocado, grapefruit |
| Intolerant | 0.5-1.0 | Peach, cherry, plum, grape, onion, garlic, sweet potato, sunflower, mung bean, sesame, lupin, strawberry, Jerusalem artichoke, kidney bean, lima bean, snap bean, peanut |
| Moderately intolerant | 1.0-2.0 | Broccoli, capsicum, pea, carrot, radish, potato, cucumber, lettuce, olive, pumpkin, radish |
| Moderately tolerant | 2.0-4.0 | Kentucky blue grass, cabbage, turnip, corn, artichoke, mustard, sweet clover, squash, musk melon, cauliflower |
| Tolerant | 4.0-6.0 | Tomato, alfalfa, parsley, red beet, sugar-beet |
| Very tolerant | 6.0-15.0 | Most grasses, asparagus, celery |

Source: ANZECC and ARMCANZ 2000; Keren and Bingham 1985; Carrow and Duncan 1998.

# 7.8 Estimating leaching requirements

Leaching requirements are often needed to manage salts applied with recycled water. There are several methods for calculating the leaching requirement for a specific water salinity to maintain soil salinity at acceptable levels for the desired plant growth. The methods below give an indication of a leaching requirement (LR) for two types of irrigation (Figure 19):

1. Conventional irrigation (LRc), where the soil is allowed to dry out significantly between irrigations (Similar to the method of Ayers and Westcot 1985).
2. High frequency irrigation (LRf), where there is limited drying out of the root zone between irrigations.

All methods of determining leaching requirements are estimates and should be checked by measuring actual soil salinity levels and modifying leaching requirements (LR) accordingly.

An example of calculations to estimate leaching requirements is:

You wish to grow a turf plant *Festuca ruba* L. spp ruba (Creeping red fescueum). The plants ECe threshold where 80% growth is acceptable by the user is estimated to be 3 dS/m at a worse case scenario. The recycled water salinity is an ECi of 1.5 dS/m. Then:

$$\begin{aligned} Fc &= ECe\ threshold/ECi \\ &= 3/1.5 \\ &= 2 \end{aligned}$$

Where Fc = concentration factor
ECi = irrigation water electrical conductivity

Using Figure 19, an Fc of 2 is equivalent to a 3% (high frequency irrigation; LRf) or 9.5% (conventional irrigation; LRc).

The average root zone salinity is impacted by soil water depletion between irrigation. If all other parameters remain constant and a LR is applied, high frequency irrigation leads to a higher average integrated plant available water (lower integrated rootzone salinity) as the period between wetting and drying is less and the extremes of drying less. In addtion the more saline the soil or water the higher the osmotic potential and the less plant available water. Therefore the plant available water will be lower under conventional irrigation (Rhoades and Loveday, 1990) and average root zone salinity higher.

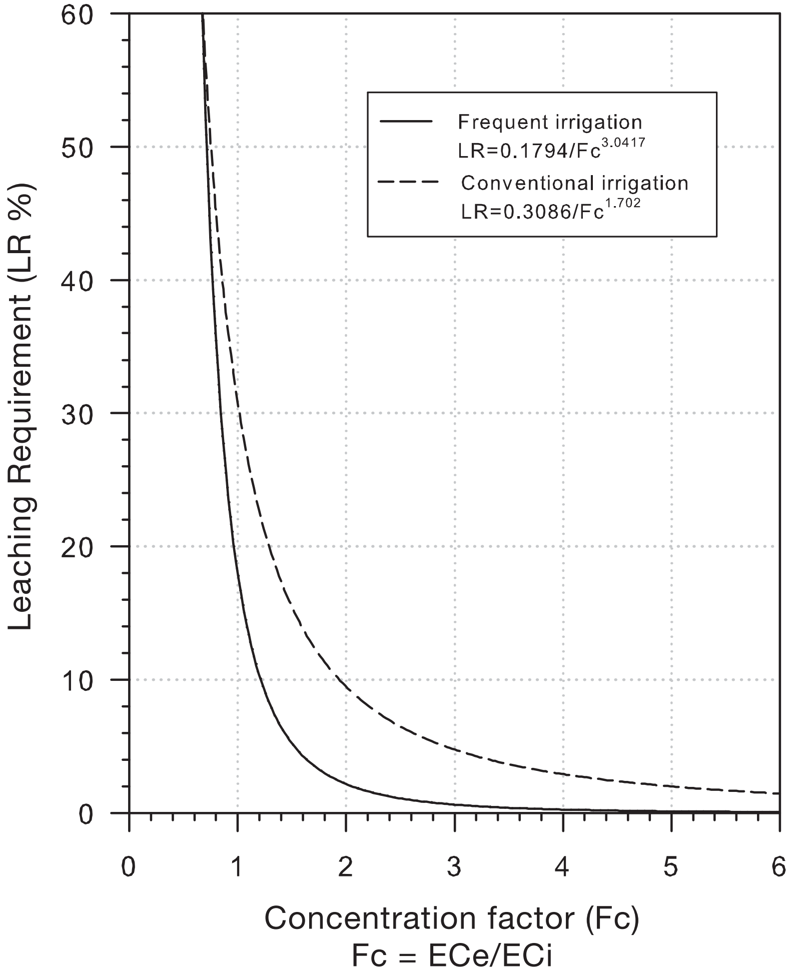


**Figure 19** Leaching requirement determined by using a permissible root zone factor for concentration of salts (Fc). Modified from Rhoades and Loveday 1990.

If rainfall was also considered, then the ECi could be adjusted with a flow weighted average ECi which includes rainfall (ECrf). The effectiveness of rainfall for leaching should be used with caution and checked for specific situation.

**Equation 8** Flow weighted electrical conductivity of total water applied.

$$ECirf = \frac{ECi \times DepthIrrigation\,(mm)}{TotalWater\ (mm)} + \frac{ECrf \times DepthRF\,(mm)}{TotalWater\ (mm)}$$

Where:

Total water = Irrigation (mm) + rainfall (mm)
RF = rainfall
ECi = electrical conductivity of irrigation water (recycled water) (dS/m)
ECrf = electrical conductivity of rainfall (~0.03dS/m)
ECrfi = Flow weighted electrical conductivity of rainfall and irrigation water applied

A targeted approach to the application of the leaching requirement can add to its effectiveness. Applying leaching requirements during the wet season will provide the following benefits:

1. Low evapotranspiration, which reduces losses to the atmosphere, maximising downward leaching.

2. Improved leaching, as generally the soil profile will have a higher soil water content.

3. Water applied through rainfall and irrigation will have a lower average salinity, improving leaching effectiveness by decreasing soil salinity on the rootzone.

An important consideration to the application of leaching requirements is the off-site impacts associated with the application of irrigation water that is greater than plant requirement. While sustainable irrigation requires an appropriate leaching fraction, this leaching fraction can have off-farm implications, including:

1. A contribution to ground watertables. (Depending on the depth to watertable/aquifer). Can the regional hydrology handle this extra water input? Will watertables rise, leading to increased salinisation of soils on a regional scale?

2. Any movement of water out of the root zone of plants will lead to the movement of nutrients. This movement of nutrients can lead to the eutrophication of ground and terrestrial waters.

The calculation of leaching fractions often assumes that there are no barriers in the soil profile that could potentially impede water movement, creating perched watertables (p 57). These barriers could include sodic clay, sheet limestone (calcrete), or compacted soil layers. These should generally be identified in the preliminary soil survey conducted prior to scheme development.

The impact of leaching fraction (LF), given an irrigation water salinity (ECi), on soil salinity can also be estimated using Figure 20. This figure can also be used to estimate a leaching requirement (LR). For example, if the plants ECe threshold where 80% growth is acceptable by the user is estimated to be 3 dS/m at a worse case scenario. The recycled water salinity is an ECi of 1.5 dS/m; a LF of approximately 9% (similar to LRc above) would be required to maintain soil salinity (ECe) at an average of 3 dS/m.

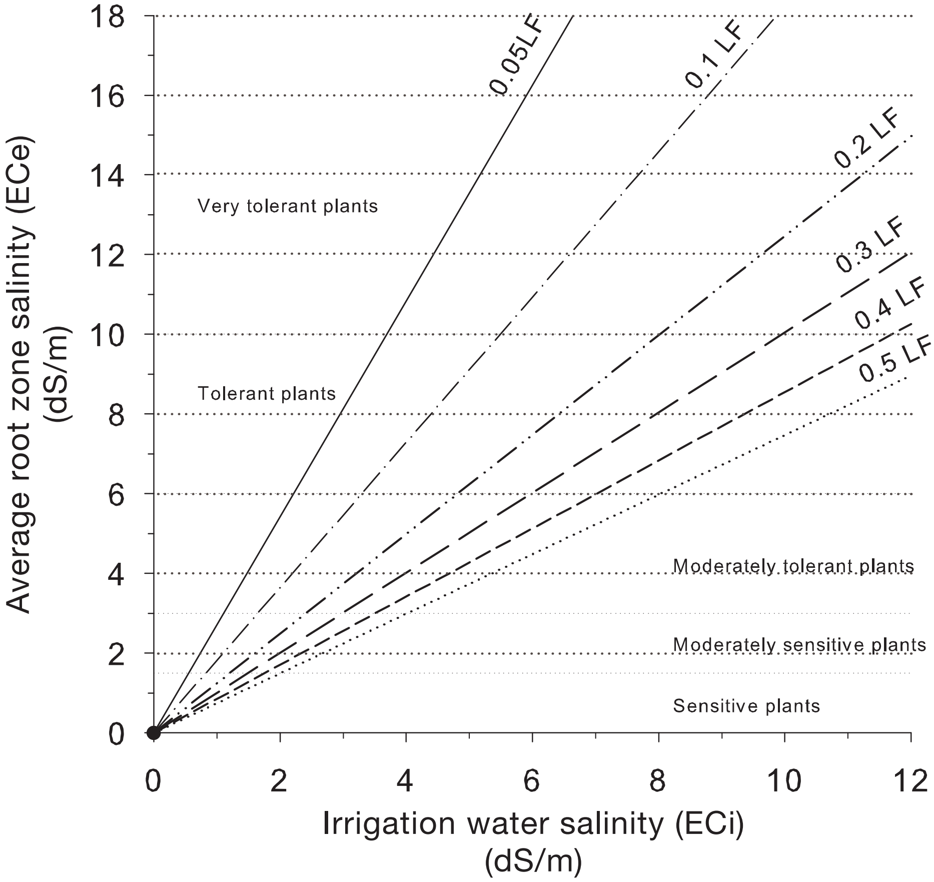


**Figure 20** Relationship between average root zone salinity (ECe) and electrical conductivity of irrigation water (ECi), as a function of leaching fraction (LF) and plant salt tolerance.
Source: adapted from Rhoades *et al*. 1992

# 7.9 Sensitivity of plants to phosphorus

## Phosphorus sensitivity of Australian native plants

**Table 41** Relative phosphorus (P) sensitivity of a range of Australian native plants (Score 1 = tolerant to Score 7 = sensitive).

| Genus | Species | Genus | Species |
|---|---|---|---|
| **Score 1** | **Plants healthy across P addition range, with no growth without P to the greatest growth with highest P addition** | | |
| *Abutilon* | *indicum, leucopetalum, oxycarpum* | *Kunzea* | *ambigua, baxteri, ericifolia, pomifera, teretifolius* |
| *Acacia* | *amblyphylla, ampliceps, aphanoclada, bivenosa, brachystachya, calcigera, chrysella, colletioides, delibrata, dentifera, dictyoneura, elata, estrophiolata, extensa, floribunda, gracilifolia, graffiana, gregorii, guinetii, hakeoides, harveyi, holosericea, horridula, howittii, inaequilatera, iodomorpha, jibberdingensis, juncifolia, lanigera, lasiocalyx, lasiocarpa, leiophylla, leptocarpa, linophylla, littorea, longifolia, meissneri, microbotrya, o'shanessii, oncinophylla, oxycedrus, paraneura, pendula, polybotrya, prainii, pulchella, quadrimarginea, quornensis, ramulosa, retinoides, rigens, rostellifera, rotundifolia, sclerophylla, sclerosperma, stenophylla, subcaerulea, subtessaragona, tetragonophylla, translucens, tysonii, venulosa, verniciflua, verticillata, wiseana* | *Labichea* | *lanceolata* |
| *Agonis* | *flexuosa, grandiflora, juniperina, marginata* | *Lamarchea* | *hakeifolia* |
| *Allocasuarina* | *corniculata, decaisneana, dielsiana, huegeliana, lehmanniana, meulleriana, pusilla, scleroclada, striata, verticillata* | *Lambertia* | *propinqua* |
| *Alternanthera* | *nodiflora* | *Lasiopetalum* | *baueri* |
| *Alyogyne* | *cuneiformis, hakeifolia* | *Lavatera* | *plebia* |
| *Anigozanthos* | *bicolor, humilis, manglesii* | *Lawrencia* | *densiflora, glomerata, repens, spicata, virid-grisea* |
| *Aotus* | *ericoides* | *Leptospermum* | *continentale, coriaceum, flavescens, juniperinum, laevigatum, lanigerum, myrsinoides* |
| *Atriplex* | *acutibracta, amnicola, leptocarpa, lindleyi, nummularia, rhagodioides, semibaccata, stipitata, suberecta, undulata* | *Linum* | *marginale* |

| Genus | Species | Genus | Species |
|---|---|---|---|
| *Banksia* | *audax, elderana, laevigata, lanata, littoralis, menziesii, petiolaris, speciosa* | *Lobelia* | *heterophylla, tenuior* |
| *Beaufortia* | *micrantha, orbifolia* | *Lotus* | *australis, cruentus* |
| *Beyeria* | *lechenaultii* | *Lysiphyllum* | *cunninghamii* |
| *Billardiera* | *cymosa* | *Maireana* | *brevifolia, sedifolia* |
| *Bonamia* | *rosea* | *Melaleuca* | *acerosa, acuminata, armillaris, brevifolia, cardiophylla, citrina, cliffortioides, coccinea, concreta, cordata, cucullata, cuticularis, decussata, densa, depressa, diosmifolia, dissitiflora, elliptica, ericifolia, filifolia, fulgens, gibbosa, glaberrima, globifera, glomerata, halmaturorum, hamulosa, huegelii, holosericea, hypericifolia, incana, lanceolata, lateralis, lateriflora, lateritia, laxiflora, leiocarpa, leucadendra, microphylla, nesophylla, pentagona, pulchella, radula, rhaphiophylla, sheathiana, spathulata, spicigera, squamea, squarrosa, steedmanii, striata, stypheloides, suberosa, subfalcata, thymoides, thyoides, trichophylla, uncinata, undulata, urceolaris, viminea, viridiflora, wilsonii* |
| *Boronia* | *denticulata* | *Mirbelia* | *spinosa* |
| *Bossiaea* | *ericocarpa, foliosa, heterophylla, pulchella, rhombifolia* | *Myoporum* | *acuminatum* |
| *Brachychiton* | *acerifolius, diversifolia* | *Myriocephalus* | *stuartii* |
| *Brachysema* | *aphyllum, lanceolatum, latifolium* | *Neptunia* | *monosperma* |
| *Callistemon* | *brachyandrus, citrinus, glaucus, phoenicius, pinifolius, pungens, rigidus, rugulosus, sieberi, speciosus, viminalis* | *Olearia* | *teretifolia* |
| *Callitris* | *columnellaris, preissii* | *Orthrosanthus* | *multifrorus* |
| *Calocephalus* | *brownii, citreus* | *Oxylobium* | *atropurpurea, cuneatum, lanceolatum, racemosum* |
| *Calothamnus* | *asper, chrysantherus, quadrifidus, sanguineus, tuberosus, validus, villosus* | *Pandorea* | *pandorana* |
| *Canavalia* | *papuana* | *Pavonia* | *hastata* |
| *Casuarina* | *cristata, glauca* | *Petalostylis* | *labicheoides, millefolium* |

| Genus | Species | Genus | Species |
|---|---|---|---|
| *Chorizema* | *cordatum, dicksonii, diversifolium, ilicifolium* | *Petrophile* | *canescens, carduacea, diversifolia, heterofolia, longifolia, serruriae* |
| *Conostylis* | *aculeata, candicans* | *Phymatocarpus* | *porphyrocephalus* |
| *Convolvulus* | *erubescens, remotus* | *Pittosporum* | *phylliraeiodes* |
| *Crotalaria* | *retusa, novae-hollandiae* | *Plantago* | *varia* |
| *Daviesia* | *benthamii, corymbosa, flexuosa, latifolia, longifolia* | *Podolepis* | *rugata* |
| *Diplolaena* | *grandiflora* | *Psoralea* | *cinerea, martinii, plumosa* |
| *Diplopeltis* | *eriocarpa* | *Pultenaea* | *reticulata* |
| *Dodonaea* | *aperta, ceratocarpa, hackettiana, inaequifolia, lobulata, microzyga, ptarmicifolia, stenozyga, viscosa* | *Radyera* | *farragei* |
| *Dryandra* | *baxteri, ferruginea, fraseri, nobilis, serratuloides, sessilis, shuttlworthiana, stuposa* | *Regelia* | *ciliata* |
| *Enchylaena* | *tomentosa* | *Rhagodia* | *candolleana, crassifolia, parabolica, preissii, spinescens* |
| *Eremaea* | *ebracteata, pauciflora* | *Samolus* | *junceus* |
| *Gastrolobium* | *spinosum* | *Senna* | *artemisioides, helmsii, odorata, pleurocarpa, venusta* |
| *Goodenia* | *stapfiana* | *Sesbania* | *cannabina, simpliciuscula* |
| *Goodia* | *lotifolia* | *Sida* | *calyxhymenia, rholenae* |
| *Gossypium* | *sturtianum* | *Solanum* | *linearifolium, simile, symonii* |
| *Grevillea* | *crithmifolia, robusta* | *Stylidium* | *adnatum* |
| *Hakea* | *arborescens, brooksiana, commutata, coriacea, dactyloides, eriantha, falcata, macraeana, nodosa, suaveolens, verrucosa, vittata* | *Swainsona* | *canescens, colutoides, formosus, tephrotricha, villosa* |
| *Hannafordia* | *quadrivalvis* | *Templetonia* | *egena, sulcata* |
| *Hardenbergia* | *comptoniana* | *Thomasia* | *petalocalyx* |
| *Hibiscus* | *farragei* | *Thryptomene* | *australis* |
| *Hovea* | *crispa, trisperma* | *Velleia* | *cycnopotamica, panduriformis, trinervis* |
| *Hypocalymma* | *angustifolium* | *Villarsia* | *capitata* |
| *Indigofera* | *australis* | *Viminaria* | *juncea* |
| *Isopogon* | *ceratophyllus* | *Wahlenbergia* | *preissii* |
| *Isotropis* | *atropurpurea, divergens* | *Waitzia* | *acuminata* |
| *Jacksonia* | *sternbergiana* | *Xanthorrhoea* | *quadrangulata, semiplana* |
| *Kennedia* | *beckxiana, eximea, prorepens, rubicunda, stirlingii* | *Zygophyllum* | *aurantiacum* |
| *Keraudrenia* | *hermanniifolia* | | |

| Genus | Species | Genus | Species |
|---|---|---|---|
| **Score 2** | **Plants healthy across P addition range, but with some growth without phosphorus<br>Greatest growth was with highest P addition** | | |
| *Acacia* | *complanata, cuthbertsonii, fasciculifera, pyrifolia, validinevia, viscidula* | *Flindersia* | *australis* |
| *Actinostrobus* | *pyramidalis* | *Hakea* | *cycloptera, gibbosa, muelleriana* |
| *Banksia* | *ashbyi, brownii, caleyi, lemanniana, nutans, occidentalis, pilostylis, prionotes, pulchella, repens, violacea* | *Isopogon* | *dubius* |
| *Dodonaea* | *hexandra* | *Platylobium* | *obtusangulum* |
| *Dryandra* | *arborea, carduacea, formosa, obtusa* | | |
| **Score 3** | **All plants healthy, with some growth without P<br>Largest plants with second highest P rate, no P toxicity evident** | | |
| *Abutilon* | *lepidum* | *Gastrolobium* | *bilobum* |
| *Acacia* | *amoena, blakelyi, deanei, difformis, dodonaeifolia, eremaea, exocarpoides, fauntleroyi, hemignosta, leptospermoides, maitlandii, megalantha, monticola, murrayana, neriifolia, orthocarpa, oxyclada, pachyacra, parramattensis, pellita, perangusta, pruinocarpa, pubicosta, pyrifolia, rubida, semilunata, siculiformis, torulosa, trachycarpa, triptera, uncinata, vestita, wildenowiana, xanthina, xylocarpa* | *Gomphrena* | *affinis* |
| *Allocasuarina* | *campestris, lehmanniana* | *Hakea* | *adnata, baxteri, cristata, epiglottis, ferruginea, flabellifolia, platysperma, sericea, stenophylla* |
| *Alternanthera* | *nana* | *Jacksonia* | *sericea* |
| *Amaranthus* | *pallidiflorus* | *Kennedia* | *coccinea* |
| *Anigozanthos* | *viridis* | *Lotus* | *cruentus* |
| *Banksia* | *aemula, candolleana, coccinea, leptophylla, marginata, robur* | *Melochia* | *pyramidata* |
| *Bossiaea* | *ensata, scolopendria* | *Mirbelia* | *dilatata, ramulosa* |
| *Canavalia* | *maritima* | *Oxylobium* | *capitatum, ellipticum, parviflorum* |
| *Casuarina* | *obesa* | *Patersonia* | *occidentalis* |
| *Crotalaria* | *cunninghamii* | *Petrophile* | *fastigiata* |
| *Daviesia* | *acicularis, decurrens, physodes, revoluta, rhombifolia, teretifolia, umbellata* | *Santalum* | *acuminatum* |

| Genus | Species | Genus | Species |
|---|---|---|---|
| *Dillwynia* | *brunioides, dillwynioides* | *Senna* | *luerssenii, oligophylla, planitiicola* |
| *Dryandra* | *calophylla, carduacea, carlenoides, mucronulata, polycephala, quercifolia, tenuiifolia, vestita* | | |
| **Score 4** | **Slight toxicity at highest P rate, largest plants in second highest P rate** | | |
| *Abrus* | *precatorius* | *Gossypium* | *robinsonii* |
| *Acacia* | *chincillensis, declinata, erinacea, glaucoptera, havilandii, iteaphylla, lineata, longispinea, lysiphloia, melliodora, merinthopora, papyricarpa, paradoxa, patagiata, rhodophloia, saligna, sessilispica, sibina, stereophylla, subcaerulea, terminalis, triptycha, uncinella, williamsonii* | *Grevillea* | *biternata, pterosperma* |
| *Adansonia* | *gregorii* | *Hakea* | *brachyptera, crassifolia, leucoptera, oleifolia, orthorrhyncha, petiolaris, rostrata, salicifolia* |
| *Banksia* | *attenuata, burdettii, ericifolia, integrifolia, laricina, media, oblonga, tricuspis, ornata, media* | *Isopogon* | *anethifolius* |
| *Bossiaea* | *aquifolium, webbii* | *Leptospermum* | *laevigatum* |
| *Brachysema* | *aphyllum* | *Melaleuca* | *eleutherostachya, leptospermioides, leucodendron* |
| *Calothamnus* | *pinifolius, rupestris* | *Olearia* | *floribunda* |
| *Conospermum* | *taxifolium* | *Plantago* | *drummondii* |
| *Crotalaria* | *cunninghamii, verrucosa* | *Psoralea* | *badocana, lachnostachys* |
| *Darwinia* | *diosmoides* | *Pultenaea* | *dasyphylla* |
| *Daviesia* | *angulata, cordata, divaricata, horrida* | *Senna* | *pruinosa* |
| *Diplopeltis* | *huegelii* | *Sesbania* | *erubescens* |
| *Dryandra* | *pulchella* | *Sollya* | *heterophylla* |
| *Gastrolobium* | *laytonii* | *Sphaerolobium* | *fornicatum* |
| *Goodenia* | *corynocarpa, redacta* | *Swainsona* | *decurrens* |
| *Tephrosia* | *flammea* | | |

| Genus | Species | Genus | Species |
|---|---|---|---|
| **Score 5** | **Severe P toxicity at highest P rate, some toxicity at second highest rate** | | |
| *Acacia* | *ancistrocarpa, citrinoviridis, dawsonii, denticulosa, dictyopyhleba, fauntleroyi, fragilis, gillii, granitica, hilliana, imbricata, latipes, leioderma, lycopodifolia, mollifolia, nodiflora, pachycarpa, phlebopetala, pilligaensis, pinguifolia, pruinosa, pubifolia, pustula, quadrisulcata, retivenia, rossei, rupicola, saliciformis, shirleyi, signata, stricta, tenuissima, tetragonocarpa, trachyphloia, urophylla, wanyu* | *Gomphrena* | *canescens* |
| *Amaranthus* | *mitchellii* | *Gossypium* | *australe* |
| *Banksia* | *aculeata, canei, cunninghamii, grandis, victoriae* | *Hakea* | *corymbosa, costata, eyreana, minyma, nitida, undulata* |
| *Bossiaea* | *preissii* | *Indigofera* | *boviperda, colutea, georgei, hirsuta* |
| *Calothamnus* | *affinis, blepharospermus* | *Isopogon* | *alicornis* |
| *Daviesia* | *incrassata, mimosioides, polyphylla, wyattiana* | *Jacksonia* | *floribunda* |
| *Dodonaea* | *caespitosa, microzyga, petiolaris, viscosa sspspathulata* | *Pultenaea* | *capitata* |
| *Dryandra* | *ashbyi, cuneata, falcata, foliosissima, nivea, pteridifolia* | *Sida* | *corrugata* |
| *Gastrolobium* | *spinosum var grandiflorum* | *Stylidium* | *scandens* |
| *Glycirrhiza* | *acanthocarpa* | *Thespesia* | *populneoides* |
| *Gompholobium* | *marginatum, tomentosum* | | |
| **Score 6** | **Considerable P toxicity at highest two P rates, best plants were at the two lowest P rates, plants were smaller without P** | | |
| *Acacia* | *alata, anaticeps, aphylla, aspera, auriculiformis, boormanii, cochlearis, cultriformis, drepanocarpa, dunnii, gilbertii, gladiiformis, hemiteles, hilliana, kempeana, ligustrina, minutifolia, multispicata, nervosa, neurophylla, nitidula, notabilis, rhigiophylla, sessilis, siculiformis, spectabilis, unifissilis, victoriae, wattsiana, wilhemiana* | *Hardenbergia* | *violacea* |
| *Achyranthes* | *aspera* | *Hibiscus* | *meraukensis* |
| *Actinostrobus* | *arenarius* | *Isopogon* | *axillaris, formosus* |
| *Agonis* | *acutivalvis, obtusissima* | *Jacksonia* | *furcellata, lehmannii* |
| *Alyogyne* | *huegelii* | *Kennedia* | *prostrata* |

| Genus | Species | Genus | Species |
|---|---|---|---|
| *Banksia* | *attenuata, baueri, baxteri, benthamiana, blechnifolia, hookeriana, incana, lemanniana, leptophylla, oblongifolia, paludosa, quercifolia, scabrella, sceptrum, seminuda, telmatiaea* | *Lysiphyllum* | *calycina, gilvum, sparsiflora* |
| *Bossiaea* | *laidlawiana, linophylla* | *Nitraria* | *billardierei* |
| *Brachichiton* | *diversifolius* | *Olearia* | *pimeleiodes* |
| *Burtonia* | *polyzyga, scabra* | *Oxylobium* | *reticulatum* |
| *Daviesia* | *leptophylla, ulicifolia* | *Petrophile* | *drummmondii, ericifolia* |
| *Dichrostachys* | *spicata* | *Porana* | *sericea* |
| *Dodonaea* | *obulata, peduncularis, physocarpa* | *Senna* | *notabilis* |
| *Dryandra* | *armata, comosa, hewardiana* | *Sida* | *cardiophylla, echinocarpa* |
| *Gompholobium* | *latifolium* | *Swainsona* | *cyclocarpa* |
| *Gomphrena* | *cunninghamii, fusiformis* | *Templetonia* | *retusa* |
| *Grevillea* | *banksii, thelemanniana* | *Tephrosia* | *coriacea* |
| *Hakea* | *brownii, cinerea, decurrens, erecta, gilbertii, incrassata, lasianthoides, marginata, obtusa, pandanicarpa, prostrata, pycnoneura, scoparia* | *Xylomelum* | *angustifolium* |
| **Score 7** | **Plants without P in the mix were the only ones that grew well** | | |
| *Acacia* | *polystachya* | *Petrophile* | *sessilis* |
| *Bossiaea* | *dentata* | | |

Source: Handreck 1997

**Table 42** Phosphorus-sensitive Australian native plants.

| Phosphorus-sensitive Australian native plants |
|---|
| *Acacia baileyana, A. iteaphylla, A. obtusata, A. suaveolens, A. verticillata* |
| *Banksia aemula, B. ericiflia, B. longifolia, B. robur* |
| *Beaufortia squarrosa* |
| *Boronia megastigmata* |
| *Callistemon citrinus* |
| *Grevillia aquifolium, G. glabella, G . 'Poorinda firebird'* |
| *Hakea laurina* |
| *Pultenaea pedunculata* |
| *Telopea speciosissima* |

Source: Leake 1996

## Phosphorous sensitivity of South African Proteaceaes

**Table 43** Phosphorus sensitivity of some South African Proteaceae.

| Sensitivity | Proteaceae |
|---|---|
| Highly sensitive | *Protea compata, P. harmeri, P. nerifolia, Leucadendron uliginosum, L. salcifolium, Leucospermum cordifolium* |
| Moderately sensitive | *Protea cyanoides, P. longifolia, P. coronata, Leucadendron coniferum, Dryandra formosa* |
| Slightly sensitive | *Protea eximia, P. speciosa, P. grandiceps, P. macrocephala, P. punctata, Leucadendron linifolium, L. orientale, L. rubrum, L. elimense, L. teratifolium, L. strobilinium, Serruria florida, Aulax pinifolia* |
| Tolerant | *Protea repens, P. roupelliaea, P. mundii, P. nana, P. obtusifolia, P. longifolia, Leucadendron salignum, L. procerum, L. gandogeri* |

Source: Leake 1996

# 7.10 Turf grasses and lawns – Symptom, diagnosis and solutions

| Symptom or Condition | Diagnosis | Potential Solution |
|---|---|---|
| Tip burning, bluish-green leaves | Excess salinity in water and/or soil | Increase leaching fraction and/or replace with more salt tolerant turf, blend with less saline water |
| Extensive vegetative desiccation | Insufficient irrigation | Increase duration and/or rate of water application |
| Localised dry and wet spots | Nonuniform irrigation patterns | Improve uniformity of application |
| | Surface soil compaction | Carry out soil core aeration, add organic matter such as compost |
| | Subsoil impermeable layers | Improve drainage with installation of subsurface drainage |
| | Water repellant sand-based turf | Add wetting agents and clay colloids like zeolites |
| Difficulties in seed germination and early seedling growth | Excessive salinity in water and/or soils | Select and plant more salt tolerant turf, blend saline water with less saline water or conduct reclamation leaching before seeding |
| Spotty bare spots with salt crust | Excessive salinity in soils | Conduct localized leaching to remove salts |
| Spotty bare spots with no salt crust | Excessive sodicity in soils | Add calcium amendments to soil and/or water (e.g. gypsum) |
| Bare spots with dispersed organic matter | Excessive RSC in water | Inject acids to source water, add calcium amendment to soil or water |
| Uniform yellowing and senescence of older leaves | Nitrogen deficiency | Apply N fertilisers, improve drainage, aerate to relieve compaction |

| Symptom or Condition | Diagnosis | Potential Solution |
|---|---|---|
| Uniform chlorosis of younger and older leaves, leaf tips necrotic, stunted growth | Sulfur deficiency | Rare, but resembles N deficiency symptoms. Apply S containing fertiliser. |
| Yellowing of younger leaves and new leaves white or necrotic in severe cases | Iron deficiency | Add acid forming materials to calcareous soils, apply iron chelate or other iron fertilisers |
| Dark green discoloration of older leaves | Phosphorus deficiency | Apply P fertiliser appropriately broadcasting or by injection into water supply, P will tend to precipitate in calcareous soils and high bicarbonate waters |
| Drooping of leaves, chlorosis and leaf rolling | Potassium deficiency | Broadcast K fertiliser, incorporate into ground as much as possible |
| New leaves chlorotic, deformed, and stunted or necrotic | Calcium deficiency | Rare in alkaline and neutral soils |
| Interveinal chlorosis of older leaves or necrosis of older leaves | Magnesium deficiency | Rare in alkaline and neutral soils |

Source: Tanji *et al.* 2007

## 7.11 Trees and shrubs – Symptom, diagnosis and solutions

| Symptom or Condition | Diagnosis | Potential Solution |
|---|---|---|
| Stunted growth, chlorosis, leaf tip burn, marginal burn, defoliation, death | Excess salinity in soil and/or water | Leach soil, increase leaching fraction, select more salt tolerant plants, correct drainage problem, blend with less saline water |
| Stunted growth, chlorosis, necrosis, black salt crust on soil surface, water ponding | Excess sodicity in soil and/or water | Add gypsum, acid or acid forming materials to soil or water and leach |
| Stunted growth, chlorosis, necrosis, white salt crust on soil surface | Excess salts and sodicity | Leach salts, add gypsum, acid or acid forming materials |
| Stunted growth, necrosis of leaf tips and margins, bronzing, leaf drop | Excess chloride in water and/or soil | Leach or increase leaching fraction, correct drainage problem, reduce foliar wetting, select more chloride tolerant plants |
| Yellowing of leaf tip, necrosis of leaf margins and between veins | Excess boron in water and/or soils and/or soils | Avoid foliar wetting, leach soil, select boron tolerant plants |
| Mottled and interveinal chlorosis leaves, burning of growing tips | Excess sodium in water and/or soil | Avoid foliar wetting, leach soils, plant more sodium tolerant plants, inject acid into water, apply gypsum to soil |
| Yellowing foliage and leaf drop,, damage to buds, limbs and shoots, root crown diseases | Excess irrigation and/or poor drainage | Decrease irrigation, improve drainage and aeration |
| Excessive growth and succulent tissue, dark green foliar margins | Excess N fertilisation | Decrease N fertilisation |

| Symptom or Condition | Diagnosis | Potential Solution |
|---|---|---|
| Uniform yellowing of leaves, light green coloring, yellowish and short needles in conifers | Nitrogen deficiency | Apply N fertiliser, nutrient deficiency in woody plants are usually not caused by deficiency of soil nutrients except for container plants. Sometimes N deficiency confused with symptoms caused by restricted root growth |
| Bronzing of lower leaves with purple or brown spots, dieback of needles in conifers | Phosphorus deficiency | Add P fertiliser. P deficiency in woody plants is normally rare, symptoms may look like herbicide damage |
| Leaf spotting and sparse leaf growth, older leaves yellow, marginal necrosis along leaflets, necrosis at needle tips in conifers | Potassium deficiency | Apply K fertiliser, K deficiency is rare among conifers and broadleaf species but occurs in palms and fruit and nut trees, P deficiency may resemble leaf spot damage from sucking insects and certain pre-emergence herbicides |
| New foliage yellowish and undersized with green veins, causes curling and burning in palms, stunted and chlorotic needle tips in conifers | Iron and/or manganese deficiency | Noted especially in acid loving plants grown in calcareous soils, lower soil pH with acidic amendments, apply iron chelate, improve drainage and aeration |
| Uniformly yellow and stunted new growth may turn purplish and die, small leaves, branches and needles extremely stunted, and die back of terminals in conifers | Zinc deficiency | Apply zinc chelates or zinc sulfate, may be confused with systemic herbicide (glyphosate) damage |
| Yellowing of leaves, premature leaf drop, wilting, stunted growth | Poor aeration or soil aeration deficit | Improve drainage, reduce excess irrigation, conduct appropriate site preparation before planting |
| Dieback of youngest foliage, damage to lower leaves and canopy dieback, dieback of limbs. Rapid onset of foliar symptoms | Low temperature injury | Select more cold tolerant trees and shrubs. Protect sensitive plants during periods of low temperature |
| Leaf discoloration and necrosis, damage to bark and trunk | Sunburn or scalding damage | Select more tolerant plants, shade plants, irrigate adequately |
| Trees appears to be under water deficit, leaf necrosis and leaf drop,tattering of leaves, fewer leaves on windward side | Wind damage | Select wind tolerant species, provide wind breaks |
| Leaves or needles turn yellow to brown, foliage die back, stippling or specking of leaves | Air pollution injury | Select trees more tolerant to ozone, sulfur dioxide, etc |

Source: Tanji *et al*. 2007

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