SECTION TWO

Water Management

Contents

SECTION 2:
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KEY CONCEPTS

- The availability of a good-quality and regular water supply is essential in maintaining high-quality turf surfaces.
- Possibly the single greatest threat to the management of golf courses is the lack of water and the increasing salinity of water supplied.
- As the demand for potable water increases, golf courses will potentially have to use lower-grade water supplies which are high in salts, sodium, nutrients and other contaminants.
- With the increased use of lower-quality water supplies, more intensive management will be required using various water treatment and soil remediation techniques.
- Reclaimed wastewater is an underused resource that can provide a good-quality water source for golf courses.

- Common source water indicators for turf include:
  - total soluble salts (salinity)
  - sodium
  - sodium adsorption ratio (SAR)
  - chloride
  - carbonate
  - bicarbonate
  - boron
  - pH

- Additional reclaimed water indicators include:
  - nutrients (phosphorus, nitrogen and potassium)
  - human pathogens (indicated by thermotolerant coliforms)
  - other contaminants (e.g. trace metal, pesticides)

Before initiating a reuse system it is important to have an understanding of the site conditions, including:
  - geology and soils
  - topography
  - proximity to ground and surface water
  - climate, rainfall, runoff and evaporation conditions
  - irrigation requirements
  - vegetation types.

- High-salinity water can be managed through modified irrigation and soil management practices and the selection of salt-tolerant grasses.

2.1 INTRODUCTION

Water is essential for sustaining and maintaining the quality of life that we are used to in Australia. For most Australians in urban environments, water arrives at the turn of a tap, clean and free of disease. Water is often taken for granted and very little concern is shown for the economic, environmental and social costs associated with its supply.

Under the *Protection of the Environment Operations Act 1997* (POEO) it is an offence to pollute waters (Section 120). It is also an offence to cause or permit water pollution.

'Waters' means the whole or any part of:

- any river, stream, lake, lagoon, swamp, wetlands, unconfined surface water, natural or artificial watercourse, dam or tidal waters (including the sea); or
- any water stored in artificial works, any water in water mains, water pipes or water channels, or any underground or artesian water.

Under POEO it is an offence to willfully or negligently cause a substance to leak, spill or otherwise escape in a manner that harms or is likely to harm the environment. Heavy penalties apply, including up to $1 million for a corporation and $250 000 and 7 years gaol for an individual.

Australia is a dry continent and our water resources are essentially finite. It is fortunate that we are able to supplement our surface catchment areas with millions of litres of subterranean water that has been stored over millions of years.

The major pressures on our waterways have been described as:

- excessive surface and groundwater abstractions;
- loss of riparian vegetation;
- loss of wetlands;
- altered flow regimes resulting from dam and barrage construction and water abstraction;
- increased sediment, nutrient, salt and contaminant (e.g. pesticide) inputs from agricultural and urban developments;
- introduced, translocated and nuisance species;
- hazardous industrial and mining waste discharge; and
- river modification.

Australia is a country that is often subjected to severe drought, which places increasing pressure on the available water. It is necessary to carefully prioritise where water is to be used, whether in households, agriculture, irrigating turf or industry. Acknowledging that the available water is finite, there is a need to utilise alternative sources.

The maintenance of a high-quality turf relies on having access to a constant water source that is of moderate to good quality. The time is approaching where high-quality potable (drinking) water will not be available for turf areas and lower-quality water higher in salts and other contaminants will have to be used. As a consequence of droughts, the cost of potable water and the lack of potable water available for irrigating turf, many golf courses have been forced to use alternative water sources such as reclaimed wastewater and saline bore water. This has increased the emphasis on research toward environmental stress-resistant and water-efficient turfgrasses (Kenna and Horts 1993).

In the long term, to be ecologically and economically sustainable golf courses will have to:

- make do with lower-quality water sources;
- alter management practices;
- treat the water and soils to offset the detrimental effects of salts, bicarbonates and nutrients;
- introduce more water-efficient and salt-tolerant turfgrass species;
- have a greater knowledge of water quality and its impact on soils and plants;
- undergo increased soil, water and plant monitoring; and
- use improved irrigation practices.

2.2 WATER QUALITY CRITERIA

The quality of a water supply is judged by the amount of dissolved and suspended materials present (VIRASC 1980). High quality is generally associated with low amounts of these materials; however, in practice quality must always be considered in relation to the intended use. ANZECC and ARMCANZ (2000) provide guidelines for assessing the quality of water so that it is safe and optimal for irrigation.

Key source water indicators for turf (Harivandi 1997) include the following:

- Salinity – measures the presence of soluable salts in or on soils or in waters. High salinity levels in soils can result in reduced plant productivity.
- Sodium (Na) – contributes to soil salinity and sodicity, and has the potential to result in foliar injury when present in spray irrigation.
- Sodicity or sodium adsorption ratio (Na, Ca, Mg) – to assess potential soil structural or permeability problems.
- Chloride (Cl) – risks relate to foliar injury from spray irrigation, and increased chloride and cadmium uptake by plants.
- Bicarbonate (HCO_3) and carbonate (CO_3) – elevated levels can adversely affect soil structure, crop foliage or irrigation equipment.
- Boron – essential for turf growth but high levels can be toxic.
- pH – indicates potential impacts of acidity or alkalinity of irrigation water (very high or low soil pH affects the availability of nutrients and other elements to plants; is used to assess the potential affects of other parameters at various pH levels; is one surrogate measure of effluent treatment efficiency; and is used to assess potential for corrosion and fouling of irrigation systems).

Additional key reclaimed water indicators include the following:

- Nutrients (phosphorus, nitrogen and potassium) for plant requirements and surface and groundwater protection against nutrient enrichment.
- Human pathogens (indicated by thermotolerant coliforms) for public health protection.

Monitoring a sub-set of the above indicators and any additional risk factors may be required for assessing potential impacts on surface and ground waters (e.g. BOD, thermotolerant coliforms, plant-available nutrients) and additional indicators in soils or plants for sound agronomic practice (e.g. turf grass nutrient status) or potential groundwater pollution (e.g. phosphorus sorption capacity, nitrates).

Key indicators from above are addressed in relation to turf management in the following sections.

2.2.1 Salinity

The soluble salt level is a key indicator of the quality of bore, dam, recycled, or runoff water used for irrigation. High-salinity water causes an increase in soil salts and as soil salinity increases it becomes more difficult for plants to extract water from the soil. This is due to an increase in the osmotic pressure of the soil water, that is the salts 'hold' the water so strongly that plants cannot remove it and therefore appear to be under drought stress even when adequate moisture is present.

Table 2.1 outlines the different classes for irrigation water based on the soluble salt content. As a general rule, salts exceeding 1000 mg/L (about 1.5 dS/m) severely limit water use on turf; however, this is dependent on grass species and variety, soil type, thatch level and irrigation and soil management.

Salt-tolerant grasses growing on well-drained soils that are readily leached of salts can be irrigated with saline water with up to 2000 mg/L (about 3 dS/m) total salts. Excessive and frequent applications of water are required so that leaching occurs and the soil is prevented from drying out excessively.

ANZECC and ARMCANZ (2000) provides useful guidance on managing saline water used for irrigation. See: http://www.ea.gov.au/water/quality/nwqms/index.html#quality

2.2.2 Sodium

High concentrations of sodium, relative to calcium and magnesium, in irrigation water can adversely affect plant growth and soil structure and can lead to reduced permeability, aeration, infiltration, leaching and soil workability. The degree to which soil dispersion occurs is also dependent on the soil's clay content and mineralogy, pH, Ca/Mg ratio, EC, organic matter content and the presence of iron and aluminium oxides (ANZECC and ARMCANZ 2000). The most commonly used method to evaluate the potential for saline irrigation water to cause soil problems is to calculate the sodium adsorption ratio. Soil sodicity refers to the amount of exchangeable sodium cations relative to other cations in the soil and is expressed in terms of exchangeable sodium percentage (ESP).

Australian soil scientists have concluded that soils with an ESP of greater than 5 are at risk of showing the adverse structural impacts associated with sodicity. Effluent with an SAR of greater than 6 is likely to raise ESP in non sodic soils, whereas effluent with a SAR of less than 3 may lower ESP in sodic soils. Prior to irrigating with saline water it may be beneficial to determine the existing ESP in the soil and conduct ongoing soil monitoring of ESP where SAR of irrigation water is elevated.

The sodium adsorption ratio (SAR) is defined by the equation:

$$SAR = Na^{+} / \sqrt{} [(Ca^{++} + Mg^{+}) / 2]$$

where Na, Ca and Mg represent the concentrations in milli-equivalents per litre of the respective ions. Tables 2.2 and 2.3 show the sodium hazard based on SAR and related to clay type.

On some clay soils or soils with a low Cation Exchange Capacity (CEC), an SAR greater than 6-8 gives cause for concern and efforts have to be made to minimise the breakdown in soil structure. On sandy soils where permeability is less of a problem, the cation exchange sites become saturated with Na at the expense of Ca, K and Mg and sodium is taken up by the plant in preference to these other cations. Sodium accumulation in the plant can then reach toxic concentrations, resulting in a loss of turf vigour, low recovery potential, lower tolerance to heat stress, reduced tolerance to pests and diseases, and potential death of sodium-sensitive plant species. Fortunately, most turfgrass species have moderate to good tolerance to sodium and while there may be a reduction in vigour, death of the plant is unlikely.

Calcium must be applied to counteract the effects of high-sodium waters, most often in the form of gypsum ($CaSO_4$). Gypsum can be applied directly to the turf, or it can be applied through the irrigation system. In situations where the sodium content of the water is very high and there is a need to apply large amounts of gypsum, regular small applications applied through the irrigation system are more convenient and effective than large, irregular applications to the turf.

2.2.3 Bicarbonate and carbonate

Permeability problems are also related to the carbonate (CO_3) and bicarbonate (HCO_3) content in the irrigation water and this is not considered in the SAR calculation. When drying of the soil occurs, part of the CO_3 and HCO_3 precipitates as Ca-$MgCO_3$, therefore removing Ca and Mg from the soil water and increasing the relative proportion of sodium. The presence of high concentrations of CO_3 and HCO_3 can cause nutritional disturbances, such as reducing the availability of calcium and the uptake of iron. The effect of CO_3-HCO_3 on soil permeability can be calculated by the Residual Sodium Carbonate (RSC) method or by using a modified SAR equation (adjusted SAR) (Carrow and Duncan 1998). The adjusted SAR includes the influence of carbonate and bicarbonate ions and their effects on calcium and magnesium. Calculating the RSC is the most convenient method of determining the bicarbonate/carbonate hazard, which is as follows:

$$RSC = (CO_3) + (HCO_3) – (Ca + Mg)$$

where CO_3, HCO_3, Ca and Mg are in milli-equivalents per litre (meq/L).
Table 2.4 lists the potential problems associated with bicarbonate and carbonate.

High-bicarbonate waters can be treated by acidification of the irrigation water to remove the excess bicarbonate (Carrow et al. 2000). Acid treatment systems available in Australia inject acid into the irrigation mainline, the quantity of acid being determined by the volume of water applied and the pH.

CASE STUDY: Acid Injection

At one Australian golf course an acid injection system was installed four years ago. The acid injection system provided several advantages:

- no mains water was required
- fungicide usage was reduced
- greens retained complete turf cover
- golfer satisfaction increased.

The costs and benefits are as follows:

- acid injection unit $35,000
- acid (annual cost) $20,000
- savings in mains water $40,000
- savings in fungicides $5,000 (approx.)
- payback period 1.4–2 years

2.2.4 Chloride

Sodium and chloride are the most damaging ions, chloride being particularly toxic (see table 2.5). Plants accumulate chloride to the exclusion of calcium, magnesium and potassium, causing nutritional disturbances. In addition to being taken up by the plant, chloride will cause direct injury to the plant as water dries on the leaf, particularly if irrigation is undertaken during the heat of the day. However, there is significant variation in plant tolerance to chloride, enabling the selection of more tolerant plants to be used under saline conditions. Table 2.5 shows the levels of various ions that can be associated with soluble salts and their acceptable levels.

Table 2.1: Salinity class of irrigation waters

Salinity hazard class	Comments	EC_{iw} (dS/cm)
Low	Low salinity hazard, no detrimental effects on plants or soil build-up are expected.	<0.75
Medium	Sensitive plants may show salt stress, moderate leaching prevents soil salt accumulation.	0.75–1.5
High	Salinity will adversely affect most plants. Requires selection of salt-tolerant plants, careful irrigation, good drainage and leaching.	1.5–3
Very high	Generally unacceptable except for very salt-tolerant plants, excellent drainage, frequent leaching and intensive management.	>3

Table 2.2: Sodium hazard of irrigation waters

Sodium hazard classification	SAR or adj SAR*	Comments
Low	<10	Can be used on most soils without structure deterioration. Salt-sensitive plants may be affected.
Medium	10–18	Appreciable Na hazard on fine-textured soils with high CEC. Best used on coarse-textured soils with good drainage.
High	1826	Harmful levels of Na accumulation on most soils. Will require intensive management—amendments, drainage and leaching.
Very high	>26	Generally not suitable for irrigation. Requires intensive management.

***Use SAR when HCO_3 is < 120 mg/L and CO_3 is < 15 mg/L.**
Use adj SAR when HCO_3 and CO_3 are higher.

Table 2.3: Sodium hazard of irrigation waters based on clay type classification*

Sodium hazard classification	SAR or adj SAR*	Clay type	Comments on Na hazard
None	<6 <8 <16	Montmorillonite Illite Kaolinite	Generally no Na hazard unless EC_w is very low
Possible	6–9 8–16 16–24	Montmorillonite Illite Kaolinite	Possible problem unless a Ca source and some leaching are used
Probable	>9 >16 >24	Montmorillonite Illite Kaolinite	Requires intensive corrective measures to use

** Ayers and Westcot (1985)*

Table 2.4: Sodium hazard (permeability) of irrigation water based on residual sodium carbonate

RSC value (meq/L)	Na hazard
<0 (i.e. negative)	None. Ca and Mg will not be precipitated as carbonates from irrigation water; they remain active to prevent Na accumulation on CEC sites.
0–1.25 Low.	Some removal of Ca and Mg from irrigation water.
1.25–2.50 Medium.	Appreciable removal of Ca and Mg from irrigation water.
>2.50 High.	High. All or most of Ca and Mg removed as carbonate precipitates leaving Na to accumulate. How rapidly Na build-up occurs depends on Na content of the water.

Tables 2.1, 2.2 and 2.4 adapted from: Carrow and Duncan *(1998)*

Table 2.5: Specific ion toxicity

Parameter	No problems	Increasing problems	Severe problems
Chloride			
Foliar absorption (mg/L)	<106	>106	
Root absorption (mg/L)	<142	142–355	>355
Sodium			
Foliar absorption (mg/L)	<69	>69	
Root absorption (SAR)	<3	3–9	>9
Boron	<1	1–2	>2

Reference: Ayers and Westcot *1976*

2.3 RECLAIMED WASTEWATER

KEY CONCEPTS

- Effluent is an excellent source of water if it is of satisfactory quality for the intended purpose.
- The salts, nutrients etc. in effluent can be beneficial, but in excess they pose a significant environmental risk.
- Reuse of effluent must be sustainable in the long term. Excessive concentrations of nutrients, salts, heavy metals and other contaminants can cause rapid and severe deterioration of soils, turf quality and water bodies.
- With careful planning, good understanding of the interactions between effluent and the site, good water and nutrient management and an appropriate monitoring program, effluent can be a useful resource that saves fresh water and reduces fertiliser use.

Reclaimed wastewater, which is primarily treated sewage effluent, is increasingly being used to irrigate turf. A number of detailed reports (Lang et al. 1977; GHD 1977; NSW Task Force on Reclaimed Water 1982) have investigated and described the feasibility of reusing treated sewage effluent. A Department of Resources and Energy report (1983) stated that in Australia the total amount of treated sewage was about 1300 gigalitres/annum, of which 56 gigalitres/annum (4.4%) is reused in irrigation. Treated wastewater is an important water resource for irrigation purposes and in the future it may be the only source of supplemental water available for turf culture.

In regions serviced by Sydney Water, annual usage of recycled water has settled at an average of approximately 27 megalitres per day over the past four years. Recycling within sewage treatment plants (STPs) accounted for 89% of all recycling, irrigation for 10% and industrial recycling for 1%. The present level is about 2% of daily water consumption (Sydney Water 2001).

As demands on our water supplies for domestic consumption increase, less water becomes available for irrigation purposes. However, the increase in urban development brings not only a greater demand for potable waters but also generation of more wastewater. The treatment of this wastewater and its disposal have become significant environmental issues. In particular, the disposal or reuse of wastewater must be done in an ecologically sustainable manner. Wastewater can contain a range of contaminants including salts, nutrients, heavy metals, viruses and bacteria that can limit the reuse options. The use of wastewater that has a heavy contaminant load can have implications for human health, cause soil degradation and result in uncontrolled discharge of pollutants to surface and groundwaters. The other important component of the sustainability equation is maintaining the playing quality of the turf area.

The reuse of wastewater will, in the future, be an integral part of ecologically sustainable development and integrated catchment management philosophies concerning water quality. There is now strong encouragement to reuse treated wastewater for irrigation purposes in order to protect the quality of surface waters.

In most states, environment protection policies demand that wastewater no longer be discharged to surface waters and that it be reused. The general philosophy and, in some cases, legislation demand there be no discharge of wastewater to waterways by early in the new millennium. As a consequence, numerous reuse schemes are being established around Australia to use wastewater for turf irrigation.

The reuse of wastewater has a strong community appeal and it seems to be the right thing to do. However, if a reuse scheme is to be sustainable for a long period—and most authorities define this as at least 50 years—then much investigation is required before the scheme is implemented. Once the scheme is implemented, it must then be monitored by the water authority, environmental regulators and the golf course to ensure that it is sustainable and does not present an environmental or public health risk

2.3.1 Guidelines for the reuse of reclaimed wastewater

Most of the state authorities responsible for the reuse of wastewater, such as the NSW Department of Environment and Climate Change (DECC) and the various state health authorities, have in conjunction with Departments of Agriculture and water authorities produced guidelines for wastewater reuse. While State guidelines vary, the underlying philosophies are similar and most use the ANZECC and ARMCANZ (2000) water quality guidelines and for sewerage effluent, the ANZECC, ARMCANZ and NHMRC (2000): *Guidelines for sewerage systems – use of reclaimed water* as their base documents. In NSW, the reuse of treated wastewater is covered in the *Draft Environmental Guidelines for Industry – The Utilisation of Treated Effluent by Irrigation* (NSW DECC 1995). The following information provides a general overview of this document from a turf management perspective.

2.3.2 NSW guidelines for use of effluent by irrigation

The DECC's Draft Environmental Guideline *The Utilisation of Treated Effluent by Irrigation* (NSW DECC 1995), is the principal reference and should always be consulted for detailed guidance on irrigating effluent.

The DECC guideline is educational and advisory in nature and can be described as outcome- or performance-based, encouraging best management practices. This means that the guideline describes environmental outcomes (which may be required by legislation or government policy) and provides information on some of the acceptable approaches that may be used to achieve those outcomes. This gives the user the flexibility to develop other approaches specific to their site that meet the environmental outcomes described in the guideline. The guideline is not a mandatory or regulatory tool but is designed to assist the user to achieve a sustainable effluent irrigation scheme. The topics that the guideline includes are described below.

Scope of the guidelines

The guideline provides information for planners, designers, installers and operators of effluent irrigation systems, with the aims of:

- encouraging the beneficial use of effluents and providing guidance as to how this might be accomplished in an ecologically sustainable manner;
- providing guidance for the planning, design, operation and monitoring of effluent irrigation systems in order to minimise risks to public health, the environment and agricultural resources; and
- outlining the statutory requirements that may be needed for an effluent irrigation system in NSW.

The document is an environmental guideline, it is not a design and operations manual. Technical and scientific problems associated with the use of effluent can be complex and often require the integrated efforts of several disciplines in science and engineering. Accordingly, designers and operators might need to seek advice from specialist consultants and from government authorities such as NSW Agriculture, the Department of Planning, NSW Health and Workcover NSW.

Environmental performance objectives

The DECC has established the following environmental performance objectives for using effluent by irrigation.

Resource use: *Potential resources in effluent, such as water, plant nutrients and organic matter, should be identified, and agronomic systems developed and implemented for their effective use.*

Prevention of public health risks: *The effluent irrigation scheme should be sited, designed, constructed and operated so as not to compromise public health. In this regard, special consideration should be given to the provision of barriers that prevent human exposure to pathogens and contaminants.*

Protection of surface waters: *Effluent irrigation systems should be located, designed, constructed and operated so that surface waters do not become contaminated by any flow from irrigation areas, including effluent, rainfall run-off, contaminated sub-surface flows or contaminated groundwater.*

Protection of groundwater: *Effluent irrigation areas and systems should be located, designed, constructed and operated so that the current or future beneficial uses of groundwater do not diminish as a result of contamination by the effluent or run-off from the irrigation scheme or changing water tables.*

Protection of lands: *An effluent irrigation system should be ecologically sustainable. In particular, it should maintain or improve the capacity of the land to grow plants, and should result in no deterioration of land quality through soil structure degradation, salinisation, waterlogging, chemical contamination or soil erosion.*

Community amenity: *The effluent irrigation system should be located, designed, constructed and operated to avoid unreasonable interference with any commercial activity or the comfortable enjoyment of life and property off-site, and where possible to add to the amenity. In this regard, special consideration should be given to odour, dust, insects and noise.*

Protection of plant and animal health: *Design and management of effluent irrigation systems should not compromise the health and productivity of plants, domestic animals, wildlife and the aquatic ecosystem. Risk management procedures should avoid or manage the impacts of pathogenic micro-organisms, biologically active chemicals, nutrients and oxygen depleting substances.*

Planning and approvals

Users of effluent irrigation may have specific statutory obligations under health, environmental, agricultural and/or food legislation in NSW and these may be a condition of land development. In addition, wastewater treatment plant owners, operators and end-users may be liable under common law and under the *Trade Practices Act* for the use of effluent that causes harm. Proposals for an effluent irrigation system should be discussed at the early planning stage with the relevant regulatory or advisory authorities which may include the local council, NSW DECC, NSW Health, NSW Agriculture, Department of Planning and the WorkCover NSW.

Environment Protection Licences

Specific activities and premises are required to be licensed under the *Protection of the Environment Operations Act 1997* (the POEO Act); however, an environment protection licence is not likely to be required for effluent irrigation schemes operating in accordance with the DECC guideline.

Scheduled activities

Schedule 1 of the POEO Act is the 'Schedule of EPA-licensed activities.' A licence is always required for Scheduled activities. Whenever effluent irrigation is ancillary to a Scheduled activity, the licence associated with the scheduled activity may also include conditions relating to the effluent irrigation.

Under the POEO Act, DECC is the relevant authority for an activity whenever:

- the activity is listed on Schedule 1 of the POEO Act;
- a licence to control water pollution from the activity has been granted; or
- a public authority is carrying out the activity or is occupying the premises where the activity occurs.

Effluent irrigation is not specifically listed on Schedule 1, therefore it does not generally have to be licensed.

Non-scheduled activities

Non-scheduled activities are any activities other than those listed in the 'Schedule of EPA-licensed activities.' The POEO Act does not generally require non-scheduled activities, which includes effluent irrigation, to be licensed. Operators of effluent irrigation schemes should be able to manage their effluent to avoid pollution of water.

Golf courses

Golf course construction and operation is a non-scheduled activity and therefore does not generally require an environment protection licence. The local council will be the appropriate regulatory authority for golf courses.

Site assessment

Where reclaimed water is to be used as a source of irrigation water it is very important that a detailed analysis and site investigation are undertaken as part of the planning process. Site assessments for golf courses must look in detail at all greens, tees and fairways, soil types and all other areas to be irrigated with effluent.

ESSENTIAL SITE ASSESSMENT CRITERIA

- Soil types and soil limitations for irrigation of effluent (including phosphorus sorption capacity, exchangeable sodium percentage, soil salinity, depth to seasonal high water table, depth to bedrock or hardpan, saturated hydraulic conductivity; available water capacity, soil pH (CaCl2), effective cation exchange capacity, emerson aggregate test).
- Limiting site characteristics (including drainage, climate, proximity and sensitivity of ground and surface waters, topography, geology of the site; proximity to dwellings or other sensitive receptors, flooding potential).
- Grass species.
- Irrigation requirements and methods.
- Nutrient loads.
- Ability of the site to cope with extra demands because of the effluent, e.g. extra growth, runoff containment.
- Proximity to dwellings.

Reclaimed water treatment

Effluent may include water from industrial sources, stormwater runoff and sewage. The quality of the effluent depends on its source and level of treatment. For reclaimed water from sewerage systems, effluent quality also depends on the catchment and industries serviced. Treatment must be such that it protects the beneficial uses of soil, ground and surface waters from polluted runoff and protects public health from toxicants and micro-organisms.

A priority performance objective for effluent reuse is protection of human health. In general, the better the treatment and the greater the disinfection, the fewer micro-organisms there will be and therefore there are fewer restrictions to site access and management. For example, tertiary or advanced treatment of sewerage wastewater will produce an effluent that is very low in biological oxygen demand (BOD), suspended solids (SS), coliform bacteria and viruses and the wastewater can be used for food crops or aquaculture with fewer controls on human access to the irrigated area.

For irrigation of reclaimed water from sewerage systems, public health requirements are based on national *Guidelines for Sewage Systems — Reclaimed Water* (ARMCANZ, ANZECC & NHMRC 2000). This national guideline outlines general treatment, disinfection and irrigation requirements, however, in NSW the NSW DECC or NSW Health may adopt more stringent requirements on a site-specific basis.

NSW Health should be consulted in regard to the level of treatment of effluent to be achieved when public health could be at risk through contact with irrigated effluent.

Golf courses

For golf courses, the relevant end-use category in the national sewerage reclaimed water guidelines is: 'URBAN (NON POTABLE) — Municipal with either controlled or uncontrolled public access'.

Nutrients, salts and heavy metals are recognised as important constituents of wastewater and must be accounted for in determining the sustainability of a reuse site.

Reclaimed water quality for irrigating turf

The quality of irrigation waters has already been outlined in Section 2.2. The DECC effluent irrigation guideline provides a detailed description of the key constituents of reclaimed wastewater and how effluent quality should be considered in the design and operation of an irrigation system. Summary information on key effluent constituents with emphasis on turf irrigation is provided below.

- **Nitrogen:** In wastewater nitrogen levels can be very high and the main impact of this will be on grass growth. Every time the turf is irrigated it is fertilised with a soluble source of nitrogen that is readily taken up by the plant. Uncontrolled and lush growth can occur, resulting in a soft, thatchy and disease-prone turf. Nitrogen that enters waterways can also stimulate growth of nuisance plants and weeds and algae.

- **Phosphorus:** Phosphorus is another important element and applications in excess of what the soil can absorb and the vegetation will take up can be leached into ground and surface waters. Excess phosphorus in waterways is a prime cause of algae growth.

- **Heavy metals:** Heavy metals such as zinc, iron, copper, nickel, lead, chromium and cadmium occur in recycled water. Iron, zinc and copper are essential for healthy turf but in excessive amounts these elements are toxic. Heavy metals in recycled water can be a problem where the main source of effluent is of industrial origin; however, recycled water that is mainly of domestic origin has a low heavy metal input and is unlikely to be toxic to turf. The ANZECC and ARMCANZ (2000) guidelines for irrigation water quality and Harivandi et al. (1997) have published comprehensive lists of heavy metals and the recommended concentrations.

- **Boron:** Boron occurs naturally in some soils and groundwater as well as in recycled water. Boron is used in detergents and soaps and most treated effluent contains 0.5–1.0 mg/L of boron. Boron is essential to turf growth but levels greater than 2.0 mg/L can be toxic. The effects of boron depend on plant species tolerance and soil conditions. Well-drained soils that are readily leached generally do not accumulate boron because it is a mobile element and is easily leached through the soil. In general, recycled water of domestic origin does not contain toxic levels of boron.

- **Human pathogens:** When dealing with treated wastewater, health considerations must be taken into account. Wastewaters (such as those from sewerage systems) can contain a wide variety of potentially infectious microorganisms. Thermotolerant coliforms are the most commonly used indicator of pathogens.

All states have public health requirements governing the microbiological quality and use of recycled water. These requirements are generally based on the ANZECC, ARMCANZ and NHMRC (2000) reclaimed water guidelines and are designed to provide assistance to authorities, users and the general public.

- **Other contaminants:** Wastewater used for turf irrigation can come from a range of sources and knowledge of what takes place at the source will provide an indication of possible toxic elements, for example:
  - citrus processing — various oils and acids;
  - sewerage treatment — e.g. agricultural and industrial chemicals;
  - petroleum processing — hydrocarbon residues; and
  - wool scouring — sodium and bicarbonate.

Design considerations

The design of an effluent irrigation scheme needs to take into consideration a range of factors including: site limitations, plant selection, volumes of water and levels of pollutants in effluent, irrigation methods and scheduling, land area available for irrigation, storage requirements of effluent; stormwater runoff controls, and buffer distances to sensitive receptors such as waterways.

Water and nutrient budgets

When planning and designing a scheme to use reclaimed wastewater or where it is already in use, it is very important to estimate the annual water requirements and nutrient load as this will have a significant effect on the fertiliser program, soil management and the health and quality of the turf. The calculation of the irrigation requirement is detailed in section 2.6.

The nutrient content is an important economic as well as environmental consideration (Harivandi et al. 1997). Even if the concentration of nutrients is relatively low, because they are applied on a regular basis, the nutrients are efficiently used by the turfgrass.

CALCULATING NITROGEN LOADINGS

Average total nitrogen in the wastewater	= 30 mg/L (0.00003 kg/L)
Evapotranspiration (ET) per irrigation season	= 350 mm
Volume of water applied per 100 m² per season	= 35 000 L
Total nitrogen applied per 100 m² per season	= 35 000 L × 0.00003 kg
Total nitrogen applied per 110 m² per season	= 1.05 kg/100 m²

If the annual nitrogen requirement is 3kg/100m², then the reclaimed wastewater will provide about 30% of the annual requirement.

CALCULATING PHOSPHORUS LOADINGS

Average total phosphorus in the wastewater	= 5–10 mg/L (0.000005–0.00001 kg/L)
Evapotranspiration (ET) per irrigation season	= 350 mm
Volume of water applied per 100 m² per season	= 35 000 L
Total phosphorus applied per 100 m² per season	= 35 000 L × 0.000005 kg (0.00001 kg)
Total phosphorus applied per 100 m² per season	= 0.175–0.35 kg/100 m².

If the annual phosphorus requirement is 0.5–0.8 kg/100 m², then the reclaimed wastewater will provide up to 70% of the annual requirement.

The above examples are for a relatively low ET requirement. If the water demand or usage were 1200 mm (120 000 L), then the nitrogen load would be 3.6 kg/100 m² and the phosphorus 0.6–1.2 kg/100 m². In this scenario, the annual nitrogen requirement is provided by the wastewater, as is all of the phosphorus.

The above examples assume that the irrigation season is over the full 12 months; however, this is not the case in all areas of New South Wales where the climate is more seasonal, with periods when no supplementary water is required. It is important to realise that there is little or no carryover of nitrogen in sandy soils and while the applied nitrogen meets the annual requirements it may in fact be applied over a shorter time period. This can result in excessive, soft growth.

In assessing the suitability of wastewater for irrigating turf, long-term analytical data is required, as the quality of wastewater can change during the year: e.g. in summer the salts often increase. Monthly water quality data, over several years, will give a good indication of the possible changes. Unfortunately, many wastewater treatment plants, in particular those in rural areas, often only have minimal information available.

Essential data required for assessing reclaimed water quality:

pH	Electrical conductivity
Calcium	Magnesium
NH_3-N	Total phosphorus
NO_2-N	Boron
NO_3-N	Potassium
Bicarbonate	Heavy metals
Sodium	Chloride

2.3.3 Site evaluation and monitoring

In evaluating the feasibility of using wastewater, it is important to determine whether or not the system can cope with the potential nutrient and salt loads and whether a long-term, sustainable turf system can be maintained.

There is no point in establishing a recycling system because it seems like a good thing to do if in the long term it is going to result in site degradation. *The Utilisation of Treated Effluent by Irrigation (NSW DECC 2004)* describes the procedure for establishing reclaimed water irrigation system.

Procedure for establishing an effluent irrigation system

The following is a suggested checklist of procedures to be followed when setting up an effluent irrigation system:

Planning:

- Discuss the proposal with the relevant DECC regional office and other appropriate authorities.
- Assess effluent quality .

Site selection:

- Select an appropriate site and conduct site assessment
- Any site assessment must look in detail at all greens, tees and fairways and determine the following conditions

ESSENTIAL SITE ASSESSMENT CRITERIA

- Soil types
- Drainage
- Phosphorus retention
- Proximity and quality of ground and surface waters
- Topography
- Geology of the site
- Irrigation requirements
- Nutrient loads
- Ability of the site to cope with extra demands because of the wastewater e.g. extra growth, runoff containment
- Proximity to dwellings

Design:

- Determine the water balance for the irrigation system
- Establish the minimum land area requirements based on limiting loading rates (hydraulic, nutrient, organic and salt)
- Calculate the minimum wet weather storage capacity requirements for the irrigation system
- Define the operational processes to be used in effluent irrigation and management

Statutory approvals:

- Comply with the requirements of the local council, NSW Health, DECC and other authorities in the planning and design stages where appropriate

Installation:

- Install system in accordance with the conditions of Pollution Control Approval
- Once construction is completed, forward a Certificate of Compliance to the DECC indicating that installation has been in accordance with the conditions of approval

Operation and maintenance:

- Operate the system in accordance with best management practices.

On-going monitoring

An annual review of the management plan and monitoring results may be required as a condition of licence and this may be in the form of an annual Environmental Management Report. These procedures enable the operator and the DECC to assess the on-going performance of the irrigation scheme.

Sampling may be required on the following:

- Soils (surface and subsoils down to 2 m) from the irrigation areas;
- Effluent
- Groundwaters and surface waters
- Crops/plants

The samples may need to be analysed for the following constituents, where appropriate:

- Soils: Structure, profile features, cation exchange capacity, electrical conductivity, N and P (total and available), P sorption capacity, organic matter, chloride, and pH.
- Wastewater, and water samples: BOD, N and P (Total and Available), salinity indicators (electrical conductivity, Na, Ca, K, Mg and SAR), exchangeable cations, chloride, chemical contaminants, and TDS.
- Additionally, the water table height should be measured.

Sampling may be necessary where some trace contaminants had previously been identified in the system. Plant analysis also provides the opportunity to fine tune the nutrient budget since it provides quite precise information on nutrient uptake by the vegetation. The frequency of sampling would vary according to the parameter being measured.

Once the site assessment is completed and a reuse program implemented, it is then necessary to initiate a monitoring program. The site assessment will identify key areas that can be used as indicators and include monitoring.

KEY MONITORING POINTS FOR GOLF COURSES

- Surface and groundwater
- Each of the major soil types
- Representative greens, tees and fairways

The monitoring will include water and soil analysis; water use; weather data and records of any significant changes in turf conditions (e.g. pests, weeds and disease, soft growth etc).

Table 2.6: Soil monitoring on wastewater reuse sites*

Parameters	Frequency
pH, EC and salinity, sodium, calcium, magnesium, available phosphorus, total phosphorus, potassium	End of first irrigation season and immediately prior to the next season. A total of 4 samplings over the first 2 years and annually thereafter
Copper, iron, manganese and zinc	Once a year

**Note: Also refer to NSW DECC guidelines for use of effluent by irrigation.*

Table 2.7: Surface water, watertable and bore water monitoring on wastewater reuse

Parameters	Frequency
pH, EC, salinity, bicarbonate, carbonate, sodium, calcium, magnesium, chloride, total phosphorus, total nitrogen, TKN, nitrate and nitrite	6-monthly pre- and post-irrigation season

**Note: Also refer to NSW DECC guidelines for use of effluent by irrigation.*

Where reclaimed water is to be used as a source of irrigation water it is very important that a detailed analysis and site investigation are undertaken as part of the planning process. The following is a basic checklist of tasks that need to be undertaken.

Table 2.8: Checklist for reclaimed water reuse on turf

Task	Done
1. Make contact with the supplier of the reclaimed water (eg. sewerage authority, local council and sewage treatment plant).	
2. Make early contact with the appropriate regulatory agencies (in particular the local council, DECC, NSW Health, the Department of Planning) for approval and other key agencies for advisory information (NSW Agriculture).	
3. Obtain detailed analyses data of the reclaimed water source (long-term data required.	
Data required: • pH and EC	
• Nitrogen	
• Phosphorus	
• Potassium	
• Sodium	
• Calcium	
• Magnesium	
• Sodium Adsorption Ratio	
• Carbonate	
• Bicarbonate	
• Chloride • [+ Cl_2 residual or equivalent pathogen reduction, when required, eg uncontrolled public access]	
• Sulfate	
• Boron	
• Heavy metals and other contaminants (depends on water source)	
• **Biological parameters** - Biological oxygen demand (BOD) - Thermotolerant coliforms - Suspended solids (SS)	
4. Undertake detailed site assessment. The interactions between effluent quality and site/soil characteristics should be considered	
5. Determine uses and restrictions based on analysis of soil and wastewater	
6. Undertake detailed site assessment	
7. Prepare an environmental management plan.	
8. Undertake cost analysis of project including:	
• upgrade to irrigation and water supply system	
• on-site water storage	
• on-site water treatment (e.g. acid or gypsum injection)	
• increased maintenance costs including: - mowing - use of growth retardants - modified working hours - soil amendments (e.g. gypsum) - increased turf renovations	

2.4 TURFGRASS TOLERANCE TO SALINITY

The future for irrigating turf may rely on the use of moderate- to high-salinity water and, in order to ensure that the turf system is sustainable, will rely on the use of salt-tolerant grasses and an improved knowledge of the effects of salinity on turfgrasses.

High levels of soluble salts in the turf rootzone are detrimental to most turfgrasses. Excess soluble salts can affect growth by osmotic inhibition of water uptake (physiological drought) by the specific ions (Harivandi et al. 1992). Salinity affects different species in different ways and the effects can vary according to the age of the plant: salinity effects are generally greater at germination and planting (when vegetative material is used) than in the mature plant. Salinity tolerance in turfgrasses is related to the plants' ability to reduce NaCl uptake.

A number of studies to investigate salt tolerance in turfgrasses and the mechanisms affecting salt tolerance have been undertaken. Younger et al. (1967) observed significant variation in the salt tolerance of creeping bentgrass (*Agrostis* spp.) varieties. The main effect of high salinity was the reduction in top growth; the old variety 'Seaside' had the highest salt tolerance and 'Penncross' the lowest. It was noted that 'Seaside' had high variation between individual plants and Engelke (pers. comm.) has selected new varieties (e.g. 'Mariner') with improved salt tolerance and turf quality based on this variation. McCarty and Dudeck (1993) reported that when germinating bentgrasses in high-salt solutions, 'Streaker' red top and 'Seaside' creeping bentgrass were the most salt-tolerant. 'Kingston' velvet, 'Exeter' colonial and 'Highland' colonial had intermediate tolerance while 'Pennlinks', 'Penncross' and 'Penneagle' creeping bentgrass were the most salt-sensitive. Marcum (2000) has studied the salt tolerance in the modern bentgrass varieties. He tested 35 bentgrass cultivars, with increasing salinity concentrations from 1 decisiemans/metre/day up to 8 decisiemans/metre/day at which time data was collected. The most salt tolerant cultivars were Mariner, Seaside II, Grand Prix, Seaside, 18th Green and Century. The least tolerant cultivars suffered complete death after ten weeks exposure and they included Avalon (velvet bent) Ambrosia (colonial bent) as well as Regent, Putter, Penncross and Penn G-6.

Dudeck and Peacock (1993) carried out a study on warm season grasses and demonstrated that 'Emerald' zoysiagrass (*Zoysia* spp.), FSP-3 Seashore paspalum (*Paspalum distichum*) and 'Tifway' couchgrass (*Cynodon dactylon × C. transvaalensis*) were the most salt-tolerant. 'Floralawn' St Augustinegrass (*Stenotaphrum secundatum*), 'Tifway II' couchgrass (*Cynodon dactylon × C. transvaalensis*) and 'FSP-1' Seashore paspalum had intermediate salt tolerance while Centipedegrass (*Eremochloa ophiuroides*) and Bahiagrass (*Paspalum notatum*) were very salt-sensitive. Dudeck and Peacock (1993) also demonstrated that as salinity increased, plant K levels decrease and to a lesser degree there is a decrease in Ca, Mg and P.

Duncan and Carrow (2000) have demonstrated that some selections of Seashore paspalum can tolerate undiluted seawater under the correct management regimes. Seawater has an EC of 54 dS/m (34 560 mg/L) and these new salt-tolerant varieties provide an opportunity to use very brackish sources of water though a high level of management is required.

Salinity effects on turfgrass growth have been summarised by Harivandi et. al. (1992) as:

- reduced water uptake due to osmotic stress;
- reduced nutrient uptake — for example, K may be depressed by absorption of Na;
- root biomass may increase to improve water-absorbing ability; and
- Na and Cl reduce growth by interfering with photosynthesis.

Harivandi et al. (1992) have also listed the common turfgrasses and their estimated salt tolerance (Table 2.9).

2.5 MANAGING HIGH SALINITY WATER

ANZECC and ARMCANZ (2000) Vol. 3 Primary Industries, provides guidance on water quality for irrigation. The future management of golf courses may be dependent on the use of lower-quality and higher-salinity water. While the use of salt-tolerant plant species and varieties may increase the viability of using high-salinity water, it is also essential that the golf course manager has a good understanding of complete soil/turf/drainage system to ensure long-term sustainability.

If water of high salinity is the only available water supply, several management techniques can be used to minimise salt damage. These are described below:

- Establish salt-tolerant species and varieties of turfgrasses. Establishment will most likely have to be done using a freshwater source
- Construct the greens and tees using high drainage rate sands that meet the USGA specification (1993) for greens construction and include a subsoil drainage system to ensure that leaching of salts occurs.
- Ensure that irrigations are sufficient to leach salts out of the rootzone and prevent accumulation but do not leach pollutants into groundwater. The amount of water required for leaching, when rainfall is not sufficient for leaching, can be calculated:

$$\text{Leaching requirement} = \frac{EC_{iw}}{EC_{dw}}$$

  where EC_{iw} is the electrical conductivity of the irrigation water and EC_{dw} is the electrical conductivity of the drainage water (VIRASC 1980). One method of calculating the leaching requirement is to assume that the concentration of the drainage water is the same as that of the saturation extract (EC_e) at the bottom of the rootzone. An appropriate value can be chosen from table 2.4 and then the calculation made.

For example, if Creeping bentgrass (*Agrostis stolonifera*) has an EC_e of 3 - 6 dS/m and the irrigation water is 2 dS/m (say, 1400 mg/L) the leaching requirement is 33 - 66%. That is, the amount of irrigation required is 33 - 66% greater than if low salinity water is used.

The DNRQ (1997) has produced a water facts sheet (DNRQ97089) on salinity that includes the salt tolerance of a wide range of ornamentals that are useful for non-turf and landscaped areas.

- To avoid short-term high salt concentrations, do not allow excessive drying out of the soil.
- Maintain adequate soil permeability through subsoil aeration and thatch control.
- Irrigate at night to avoid salt burn.
- Irrigate with freshwater whenever possible to aid leaching.
- Conduct soil analysis to monitor soil soluble salt and cation levels. Adjust as required, e.g. apply gypsum to counteract Na accumulation.
- Maintain adequate nutrient levels including K, Ca, Mg and P.
- Construct on sandy soils whenever possible.
- Install subsoil drainage into low-lying and poorly drained areas that are likely to accumulate salts.

Table 2.9: Estimated salt tolerance of common turfgrasses (Harivandi et al. 1992)

Cool-season turfgrass		**Warm-season turfgrass**	
Name	**Rating***	**Name**	**Rating***
Alkaligrass (*Puccinellia* spp.)	T	Bahiagrass (*Paspalum notatum* Fluegge)	MS
Annual bluegrass (*Poa annua* L.)	S	Burmudagrass (*Cynodon* spp.)	T
Annual ryegrass (*Lolium multiflorum* Lam.)	MS	Blue grama (*Boutleoua gracilia* (H.B.K) Lag. ex. steud.)	MT
Chewings fescue (*Festuca rubra* L. spp. *commutata* Gaud.)	MS	Buffalograss (*Buchlon dactyloides)* (Nutt.) Engelms.]	MT
Colonial bentgrass (*Agrostis tenuis* Sibth)	S	Centipedegrass (Eremochla ophiuroides) (Munro) Hackell]	S
Creeping bentgrass (*Agrostis palustris* Huds)	MS	Seashore paspalum (*Paspalum vaginatum* Swartz.)	T
Creeping bentgrass cv. Seaside	MT	St Augustinegrass [(*Stenotaphruum secundatam* (Walter) Kruntze]	T
Creeping red fescue (*Festuca rubra* L spp. *Rubra*)	MT	Zoysiagrass (*Zoysia* spp.)	MT
Fairway wheatgrass [*Agropyron cristatum* (L.) Gaertn.]	MS		
Hard fescue (*Festuca longifolia* Thuill.)	MT		
Kentucky bluegrass (*Poa pratensis* L.)	MS		
Perennial ryegrass (*Loloium perenne* L.)	S		
Rough bluegrass *(*Poa trivialis *L.)*	S		
Slender creeping red fescue cv. Dawson (*Festuca rubra* L. spp. *trichophylla*)	MT		
Tall Fescue (*Festuca arundinacea* Schreb.)	MT		
Western wheatgrass (*Agropyon smithii* Rydb.)	MT		

**The rating reflects the general difficulty in establishment and maintenance at various salinity levels. It in no way indicates that a grass will not tolerate higher levels with good growing conditions and optimum care. The ratings are based on soil salt levels (EC_e) of: Sensitive (S) = <3 dS/m, Moderately Sensitive (MS) = 3–6 dS/m, Moderately Tolerant (MT) = 6–10 dS/m, Tolerant (T) = >10 dS/m.*

2.6 IMPROVING IRRIGATION EFFICIENCY

Water is a valuable resource that is shared with the entire community and therefore must be managed responsibly and used efficiently. Irrigation is a considerable cost on all golf courses, whether it is the direct cost of the water supply or the cost of pumping it. Irrigation systems can be inefficient for several reasons.

Factors affecting irrigation efficiency include:

- poor sprinkler uniformity;
- leaks (e.g. from valves, pipework, sprinklers);
- inadequate operating pressure;
- malfunctioning valves;
- sunken sprinkler heads;
- incorrect nozzles;
- incorrect rotation of sprinkler heads; and
- inadequate control system

These all contribute to the ineffective application of water and uneven watering. As a result, the system will be operated to pick up dry areas, which in turn will result in the overwatering of other areas. This not only wastes water, it also results in a turf of uneven health and quality as a playing surface.

The performance and management of the irrigation system must be evaluated on a regular basis (Connellan 2000). This includes both the performance of the irrigation system (i.e. the mechanics of the system and how uniformly water is applied) and how well the system was managed over the irrigation season (i.e. the amount of water applied compared to the amount that should have been used).

2.6.1 Irrigation management indicator

The quantitative measure of how much water is applied versus the demand can be used both as a post-mortem of the water use for the previous season and as a prediction of the expected water use for the season ahead. The irrigation index is a seasonal performance indicator that can be used to compare the amount of water actually used versus the estimated quantity required (Connellan 2000). It is expressed as follows:

$$\text{Irrigation Index (I)} = \frac{\text{Water applied to site}}{\text{Estimated water required}}$$

The amount of water applied can be easily determined from total water consumption at the site and the size of the area being irrigated. To assist in this process, regular meter readings should be taken. Modern pumping and control equipment will also provide this information.

The estimation of water required or plant water use is the estimation of the amount of water that should have been used by the site over a particular period or season and is somewhat more involved; however, the basic information is readily available.

Plant water use or evapotranspiration (ET) can be calculated using local climatic data and, in particular, evaporation from an A-pan evaporimeter.

$$\text{Plant water use (ET) in mm} = \text{Epan} \times \text{Crop Factor (CF)}$$

The value of CF will vary depending on the turf type, available soil water, management practices and, most importantly, the quality of turf required. In the following examples, crop factors of 50%, 60% and 70% have been used for couchgrass (Cynodon spp.). A higher CF is used for putting greens than for fairways, where the CF could be as low as 30%.

Rainfall needs to be factored into the water requirement equation and, most importantly, the amount of rainfall actually used or available to the plant, i.e. the effective rainfall. The effective rainfall is that proportion of the rainfall that is used by the plants after all the rainfall losses have been taken into account. The main factors to consider are:

- Rainfall in excess of soil storage capacity is lost through drainage beyond the rootzone.
- Rainfall intensities greater than the infiltration rate of the soil will result in some runoff.
- Very small amounts of rainfall will add very little water to the rootzone due to losses by evaporation from the turf surface. Rainfall of less than 2 mm can be ignored.

The irrigation requirement to satisfy plant requirements can then be expressed by:

$$\text{Net Irrigation Requirement (IR) in mm} = \text{ET} - \text{Effective Rainfall}$$

Due to inefficiencies, the sprinkler system needs to apply more water than the estimated irrigation requirement (IR). Some water is lost due to wind drift and evaporation, some may drain below the rootzone and there is always unevenness in application. The system efficiency, which accounts for the losses, can range from 50% to 90%, with a minimum acceptable efficiency of 80%. The water required can then be calculated as follows:

$$\text{Water required in mm} = \frac{\text{Net Irrigation Requirement (IR)}}{\text{System Efficiency (use 75\% as a minimum)}}$$

The Bureau of Meteorology has an excellent website (www.bom.gov.au) where climatic averages are available for various locations. This information can provide a very good preseason predictive model. Appendix 1 provides example tables of rainfall and evaporation for various New South Wales locations.

As an end-of-season assessment of irrigation efficiency or on a month-by-month assessment, the irrigation index should be calculated and ideally will be about 1.0.

2.6.2 Sprinkler uniformity performance

It is not possible to achieve efficient irrigation if the water is not applied uniformly. The 'catch can' test is used to determine sprinkler uniformity. Cans are placed at regular sprinkler intervals within the sprinkler pattern and the system is then run for sufficient time to ensure that a measurable amount of water is collected (figure 2.1). The preferred measure of uniformity for turf is DU (Connellan 1997).

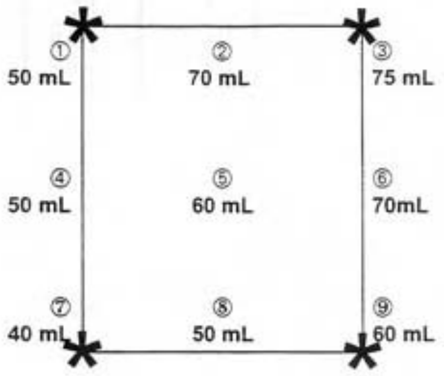
The DU places emphasis on areas of turf that receive low amounts of water and is calculated by comparing the average of the lowest 25% of can readings to the overall average. The equation is as follows:

$$DU\ (\%) = \frac{\text{Lowest 25\% of readings}}{\text{Average of all readings}} \times 100$$

A DU greater than 85% is considered acceptable for turf sprinkler systems. The can test not only provides information on system uniformity, it also gives a precipitation rate in millimetres/hour. Too often, irrigation is scheduled on run times in minutes, rather than the amount of water applied.

Figure 2.2: 'Catch can' test layout IRRIGATION CHECKLIST

AN EXAMPLE: **Calculation of Distribution Efficiency for an Irrigation Zone**



① Catch Can
✳ Sprinkler Head
50 mL - Volume of Water Collected in Catch Can

Number of Catch Cans	=	9
25% of Catch Cans	=	9 x .25
	=	2.25 (say 2)
Average Water Collection in Lowest 25% of Catch Cans	=	(40+50)/2
	=	45 mL
Overall Average Water Collection	=	(40+50+50+50+60+60+70+70+75)/9
	=	58.3 mL

$$D.U. = \frac{45}{58.3} = 0.77$$

Since D.U. is less than 0.85, it is concluded that the system isn't operating efficiently.

IRRIGATION CHECKLIST

Irrigation is a relatively complex task, with numerous factors affecting the efficiency of water use. The following is an example of a checklist that could be developed to provide a quick guide to some of the tasks that need consideration.

Task	Result	Date
1. Check water quality for key constituents:		
pH		
electrical conductivity (EC)		
sodium		
calcium		
magnesium		
sodium adsorption ratio		
carbonate		
bicarbonate		
chloride		
2. Undertake irrigation audit	**YES / NO**	
3. Update water, salt and nutrient balances based on monitoring data		
4. Calculate irrigation efficiency	**Ii =**	
5. Check sprinkler distribution on representative:		
greens	**DU =**	
tees	**DU =**	
fairways	**DU =**	
6. Collect monthly weather data:		
evaporation		
rainfall		
maximum temperature		
humidity		
7. Check controller operation—pre-season		
8. Check pump operation—pre-season		
9. Record monthly water consumption		

2.6.3 Irrigation control

An efficient irrigation system is one that has been competently designed, incorporates quality hardware, is installed correctly and is managed according to plant water needs and soil conditions. The crucial link between the irrigation hardware and the achievement of efficient water use is effective control (Connellan 1995).

The requirements of an automatic irrigation controller have been described by Peasley (1992) and are summarised below.

i. Basic requirements

- To operate reliably when required and to complete the planned schedule completely without fault.
- To apply the correct depth of water to the irrigation area during every scheduled irrigation and throughout every irrigation season.
- To apply the correct depth of water at the correct rate to suit the soil infiltration rate and the crop requirement.
- To be easy to operate.

ii. More sophisticated requirements

- To apply the correct depth of water to the irrigation area as efficiently as possible by optimising:
  - the plant/moisture synergy that causes healthy growth;
  - the design of practical watering schedules;
  - uniformity of application;
  - water consumption;
  - construction costs;
  - energy costs;
  - labour costs; and
  - maintenance costs.

- To provide specialised functions for specific management tasks such as:
  - scheduling based on moisture monitoring;
  - scheduling based on weather station monitoring;
  - multiple repeat cycle or pulse irrigation;
  - historical record keeping and statistical analyses;
  - pump control;
  - filter flushing;
  - volume metering;
  - heat stress suppression;
  - runoff control;
  - groundwater monitoring;
  - soil electrical conductivity (salinity) monitoring;
  - frost control by temperature monitoring;
  - fertigation metering; and
  - burst pipe isolation.

On golf courses, the irrigation control system is typically a Master/Satellite local network control system that features a central computer, controlling a multitude of satellites by various methods of communication — two-wire cable, radio, microwave etc. These systems can be interfaced with soil moisture sensors, weather stations, pumping plants etc.

In terms of the controller satisfying the requirements of the golf course it must have the following characteristics (in order of importance):

- reliability
- durability
- ease of programming

- sensor inputs
- flexibility
- program performance
- monitoring
- recording capability
- alarm facility
- remote communication.

Quality irrigation systems that aim to achieve efficient water use should incorporate some form of feedback into the control process (Connellan 1995). Two basic approaches can be taken: (i) use of soil moisture sensors, and (ii) use of predictive plant water use models.

2.6.4 Soil moisture sensors

Turfgrasses obtain their water needs from the soil and it makes sense to monitor the changing soil moisture status as a method of irrigation scheduling. Soil moisture sensors that are accurate and reliable can provide real-time information on the soil moisture status. They are particularly useful in providing feedback on the effectiveness of an irrigation or rainfall event and at what point the dry-down cycle is as a means of determining when the next irrigation is likely to be necessary. Soil moisture sensors also have the capacity to provide additional information such as soil nutrient status (by EC) and soil temperature. Trials carried out by Krieg (1994) demonstrated that using soil moisture sensors could reduce water use by up to 50% compared to irrigating by observation/experience.

Different types of soil moisture monitoring devices use different methods of determining soil moisture content. These include gypsum or porous ceramic blocks and tensiometers, neutron probes, capacitance probes and heat pulse soil moisture sensors.

Independent trials undertaken by the Australian Irrigation Technology Centre (AITC) tested the performance of twelve different environmental devices at various sites around Australia (AITC 1996). They included rain switches, evaporimeters and soil moisture sensors. The trial demonstrated a wide range of performance and the importance of the correct installation of this equipment. Two products, a small plastic evaporimeter ('Aquamiser') and a differential dehydration tension type soil sensor ('Watermatic'), demonstrated good performance.

In Western Australia, nine types of sensors were evaluated for use on irrigated horticultural crops on sandy soils (Luke et al. 1994). Of the sensors evaluated, the 'Watermatic', 'Hydroprobe', 'Enviroscan' and 'Loktronic' performed reliably, in accordance with the manufacturers' instructions. Moller et al. (1996) demonstrated the effectiveness of using the 'Enviroscan' for scheduling irrigation with up to a 60% reduction in the requirement for irrigation on warm season grass sportsfields. In the trials undertaken, they also detailed the potential cost-effectiveness of adopting a managed irrigation regime (table 2.10)

Table 2.10: Return on investment for 100 and 500 hectares of turfgrass, amortized over 5 years (Moller et al. 1996)

Area (ha)	Management units	Capital cost ($)	Capital cost ($/annum)	Saving ($/annum)	Return on investment (%)
100	3	60,000	12,000	49,000	408
500	15	300,000	60,000	245,000	408

The use of 'Watermatic' sensors has also demonstrated considerable savings in fertiliser by minimising leaching losses on sandy soils. Neylan and Robinson (1995) reported that with irrigation control by observation an application of soluble fertiliser was leached out of the rootzone within 5 days of application, whereas under sensor control the fertiliser lasted up to 25 days.

The key requirements for soil moisture sensors (Connellan 1995) are that they:

- operate effectively in a wide range of soil types;
- respond accurately and rapidly to changing soil moisture conditions;
- have simple calibration;
- operate in confined rootzones;
- are easily installed and provide a good soil/sensor interface;
- have output signals that are compatible with irrigation controllers and/or computers;
- are electrically and electronically sound and reliable;
- have long-term wetting and drying reliability;
- are of robust construction; and
- have minimum ongoing maintenance requirements.

The efficiency of irrigation management on golf courses in New South Wales is unknown, though many golf courses have the equipment to provide a high level of water use efficiency.

2.6.5 Control prediction models using weather stations

The use of predictive models to calculate plant water use has been described in section 2.6.1; however, with the introduction of on-site weather stations, localised predictive models can be used to schedule irrigation. The main advantage of the on-site weather station is the climate data will be more site-specific than Bureau of Meteorology data, which is likely to be from a more remote location.

The accuracy of this technique is dependent on the quality of the mathematical expression used to calculate the evapotranspiration rate (ET) and the quality of the climatic data used in the calculations. Generally, the accuracy will increase with the number of parameters measured, the frequency of the readings and the accuracy of the readings.

2.6.6 Pumping

The most significant advance in irrigation pumping technology for golf courses has been the introduction of the variable frequency drive (VFD) (Brockway 1997). In the USA, VFD systems represent 80% of the pump stations sold to golf courses. VFD stations vary pump speed to meet flow demands, whereas with the fixed speed system the pump operates at a fixed speed and a pressure-reducing valve constantly opens and closes to maintain a constant irrigation pressure as the flow changes. It is common for fixed speed booster pumps to operate at 20–50 PSI more pressure than is required.

The VFD station uses a pressure transducer to relay pressure information back to the VFD. As the flow demand increases, output pressure decreases. The VFD senses this and increases motor speed to increase pressure. Brockway (1997) provides a cost analysis of the VFD system, described below:

- **Initial cost:** VFD booster systems typically cost 20–35% more than a comparable fixed speed system.
- **Operating cost:** VFD systems generally reduce electricity costs by 20–50%.
- **Maintenance costs:** Over the life of the pump system, the maintenance cost of a VFD station should be less than that of a fixed speed station. However, a poorly maintained system can be very expensive to repair.
- **Smoothness of operation:** A VFD system will be much softer on the piping system. The gradual 'ramping up' to speed and continual speed modulation minimise water hammer and pressure surges.
- **Complexity:** Basic VFD controls are simpler than those of fixed speed stations. VFD stations are simpler to calibrate, although the electronics can be quite sophisticated.
- **Susceptibility to lightning and power surges:** High-quality surge protection devices have been developed that protect VFDs in the golf industry.
- **Headache factor:** VFD systems overall absorb less maintenance and repair time than a comparable fixed speed system.

Overall, the operational goal of a pump station manufacturer is to 'build a pump station that reliably and efficiently sequences pumps to provide variable flow rates at a constant discharge pressure. Pumping systems should eliminate air and offer sufficient alarms and shutdowns to protect the integrity of both the pump station and irrigation system'.

CASE STUDY: Pump replacement benefits

In the eco-efficiency survey at Horton Park Golf Course it was recommended that a review and upgrade of the pumping system be undertaken. It was proposed to install four 5 kw pumps to replace the existing 21 kw pump so there was greater flexibility in operation, depending on the water demand. For this particular site it was estimated that there would be a power saving of 29 200 kwh.

• Cost of multistage pump	$22,000
• Cost of a standard pump	$12,000
• Power saving (29 200 kw/h @ 7.348 c/kwh)	$2,145
• Payback period	4.6 years

Other than the power savings, there is less wear and tear on the pumps, irrigation pipework and sprinklers.

2.6.7 Water audits

An irrigation audit is a critical first step in improving irrigation efficiency. The irrigation audit determines the overall condition and effectiveness of the irrigation equipment and its operation.

Some of the problems that may be identified in undertaking an audit include:

- poor sprinkler uniformity;
- leaks (e.g. valves, pipework, sprinklers);
- inadequate operating pressure;
- malfunctioning valves;
- sunken sprinkler heads;
- incorrect nozzles;
- incorrect rotation of sprinkler heads,
- inadequate control system;
- broken casings and missing parts;
- distorted spray distribution;
- broken seals; and
- tilted irrigation heads.

The Irrigation Association of Australia (IAA) offer a Water Audit training course designed for hands-on operators that provides them with the skills to evaluate turf irrigation systems.

IRRIGATION ASSOCIATION OF AUSTRALIA (IIA) – WATER AUDIT TRAINING COURSE OBJECTIVES

- Turf water requirements and irrigation needs
- Development of appropriate irrigation control and scheduling programs
- Understanding the performance of irrigation systems
- Inspecting and assessing irrigation system hardware
- Irrigation performance evaluation. Testing an irrigation system
- Analysing irrigation system test results
- Developing strategies and formulating recommendations to improve the performance of irrigation systems.

Undertaking an irrigation system audit and documenting the findings benchmarks the current condition of the system and allows decisions to be made on what needs to be done to improve the operational efficiency. This then allows appropriate budget allocations to be made.

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LONG TERM MONTHLY EVAPORATION AND RAINFALL DATA
SYDNEY AIRPORT AMO Latitude: 33.94 S Longitude: 151.17 E

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
EVAPORATION (mm)	220	182	164	123	87	78	84	115	141	177	195	229	1794
RAINFALL (mm)	100	111	122	106	98	123	69	81	62	73	82	75	1102
E-R (mm)	120	71	43	17	-11	-46	14	34	79	104	113	155	692.1
ET-50%(mm)	60	36	21	8	-6	-23	7	17	39	52	57	77	346.1
ET-60%(mm)	72	43	26	10	-7	-27	9	20	47	62	68	93	415
ET-70%(mm)	84	50	30	12	-8	-32	10	24	55	73	79	108	484
ET-80%(mm)	96	57	34	13	-9	-36	12	27	63	83	90	124	554

LONG TERM MONTHLY EVAPORATION AND RAINFALL DATA
CANBERRA AIRPORT Latitude: 35.30 S Longitude: 149.20 E

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
EVAPORATION (mm)	251	202	171	108	66	50	53	78	111	158	192	251	1689
RAINFALL (mm)	62	54	53	50	49	40	42	47	53	66	65	53	631
E-R (mm)	190	148	118	59	17	10	11	30	58	93	128	198	1059
ET-50%(mm)	95	74	59	29	9	5	5	15	29	46	64	99	529
ET-60%(mm)	114	89	71	35	10	6	6	18	35	56	77	119	635
ET-70%(mm)	133	104	83	41	12	7	7	21	41	65	89	139	741
ET-80%(mm)	152	118	94	47	14	8	9	24	47	74	102	158	847

LONG TERM MONTHLY EVAPORATION AND RAINFALL DATA
COFFS HARBOUR MO Latitude: 30.31 S Longitude: 153.11 E

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
EVAPORATION (mm)	202	165	161	126	90	81	84	112	144	174	189	202	1728
RAINFALL (mm)	185	211	248	183	171	118	77	79	63	90	133	151	1708
E-R (mm)	17	-46	-87	-57	-81	-38	6	33	81	84	57	51	20
ET-50%(mm)	9	-23	-43	-29	-41	-19	3	16	41	42	28	25	10
ET-60%(mm)	10	-27	-52	-34	-49	-23	4	20	49	50	34	30	12
ET-70%(mm)	12	-32	-61	-40	-57	-26	4	23	57	59	40	36	14
ET-80%(mm)	14	-37	-69	-46	-65	-30	5	26	65	67	45	41	16

LONG TERM MONTHLY EVAPORATION AND RAINFALL DATA
ORANGE AGRICULTURAL INSTITUTE Latitude: 33.32 S Longitude: 149.08 E

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
EVAPORATION (mm)	217	179	155	96	60	40	47	65	90	130	162	217	1458
RAINFALL (mm)	93	70	58	55	77	69	94	103	83	93	75	79	949
E-R (mm)	124	109	97	41	-17	-29	-47	-38	7	37	87	138	510
ET-50%(mm)	62	55	49	20	-8	-15	-24	-19	4	19	44	69	255
ET-60%(mm)	75	65	58	24	-10	-17	-28	-23	4	22	52	83	306
ET-70%(mm)	87	76	68	28	-12	-20	-33	-26	5	26	61	97	357
ET-80%(mm)	99	87	78	33	-13	-23	-38	-30	6	30	70	110	408

LONG TERM MONTHLY EVAPORATION AND RAINFALL DATA
WAGGA WAGGA AGRICULTURAL INSTITUTE Latitude: 35.05 S Longitude: 147.34 E

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
EVAPORATION (mm)	304	246	211	120	60	43	40	62	93	146	207	304	1836
RAINFALL (mm)	40	42	41	43	44	50	46	51	45	55	42	42	540
E-R (mm)	264	204	170	77	16	-6	-6	11	48	91	165	262	1297
ET-50%(mm)	132	102	85	39	8	-3	-3	6	24	45	82	131	648
ET-60%(mm)	159	123	102	46	10	-4	-3	7	29	54	99	157	778
ET-70%(mm)	185	143	119	54	11	-4	-4	8	34	63	115	184	908
ET-80%(mm)	211	163	136	62	13	-5	-5	9	38	72	132	210	1037

LONG TERM MONTHLY EVAPORATION AND RAINFALL DATA
WELLINGTON RESEARCH CENTRE Latitude: 32.50 S Longitude: 148.97 E

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
EVAPORATION (mm)	267	216	192	126	75	53	53	74	102	155	204	267	1783
RAINFALL (mm)	66	59	52	44	49	40	47	49	45	64	57	51	625
E-R (mm)	200	157	140	82	26	13	6	25	57	91	147	216	1158
ET-50%(mm)	100	78	70	41	13	6	3	13	28	45	73	108	579
ET-60%(mm)	120	94	84	49	15	8	3	15	34	54	88	130	695
ET-70%(mm)	140	110	98	57	18	9	4	18	40	63	103	151	810
ET-80%(mm)	160	125	112	65	21	10	4	20	45	72	117	173	926

LONG TERM MONTHLY EVAPORATION AND RAINFALL DATA
WILLIAMTOWN RAAF Latitude: 32.79 S Longitude: 151.83 E

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
EVAPORATION (mm)	211	174	149	114	78	78	81	109	138	171	189	226	1716
RAINFALL (mm)	104	118	123	101	110	123	73	80	59	76	80	81	1127
E-R (mm)	107	56	26	13	-32	-45	8	29	79	94	109	145	589
ET-50%(mm)	53	28	13	7	-16	-23	4	14	40	47	55	73	295
ET-60%(mm)	64	34	15	8	-19	-27	5	17	48	57	66	87	353
ET-70%(mm)	75	39	18	9	-22	-32	5	20	56	66	76	102	412
ET-80%(mm)	85	45	20	11	-25	-36	6	23	63	75	87	116	471

Period in which evapotranspiration exceeds rainfall and irrigation is likely to be required.