

Efficient Irrigation:
A Reference Manual for Turf and Landscape

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**EFFICIENT IRRIGATION:
A REFERENCE MANUAL FOR TURF AND LANDSCAPE**

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Table of Contents

1. Water Management Issues	2
2. Good Irrigation Practice	4
2.1 Principles of Good Irrigation	4
2.2 Correct depth of application	
2.3 Correct timing of irrigation	7
2.4 Uniform application	11
2.5 Avoiding wastage	12
3. Evaluating Irrigation Performance	13
3.1 Justification	13
3.2 Which performance indicators	13
3.3 Precipitation rate	13
3.4 Uniformity coefficients	15
3.5 Irrigation management indicator	17
3.6 Summary list of key performance indicators	19
4. Auditing Of Irrigation Systems	20
4.1 Benefits of an audit	20
4.2 Preparing for an audit	20
4.3 Carrying out an audit	22
4.4 Analysing audit results	23
5. Strategies To Improve Irrigation Efficiency	25
5.1 Reduce plant water demand	25
5.2 Maximise irrigation application efficiency	26
5.3 Precise control of irrigation	27
5.4 Adopt new technologies	27
5.5 Operator skills	28
6. References	29
7. Appendices	30
7.1 Guide to soil water properties	30
7.2 Irrigation system application efficiencies	30
7.3 Crop Factor values	30
7.4 Evaporation pan data	31
7.5 Guide to sprinkler spacing along laterals	31

1. WATER MANAGEMENT ISSUES

Water Management Plan

The era of unlimited high quality water available for irrigation has passed in Australia. There is pressure to ensure that water used for irrigation in urban landscapes is not wasted and is used in an environmentally responsible manner.

There is increasing pressure on Australian urban water users to develop sustainable water management practices. The increasing consumption in turf and landscape areas, the dependence on potable water, inefficient irrigation practices and the relatively low use of recycled or greywater for irrigation are some of the issues that need to be addressed.

Organisations which have responsibility for irrigated areas should develop site water management plans that allow all issues to be considered and incorporated into future decision making processes. Consideration should be given to achieving compliance with Environmental Management Standard AS/NZS ISO 14001:1996.

It is recommended that organisations develop a water management plan for each irrigated site to provide a sound foundation on which future irrigation decisions can be made.

Irrigation managers must consider a breadth of issues when they are making irrigation decisions. These include environmental, horticultural, economic, personnel and community issues.

The site water management plan should include:

- Accurate plan of the site including the irrigation system
- Water supply characteristics, amount, flow rates, quality
- Horticultural assessment - estimated water requirements
- Water restrictions - implications for site
- Strategies to cope with drought
- Soil types, properties and root zone depths
- Irrigation schedule
- System performance targets
- Water quality issues
- Water cost
- Impact on environment of irrigation practices
- Staff skills and training
- Strategies to adopt new technologies
- Regular evaluation of system management and efficiency
- Maintenance procedures
- Documentation of repairs

The site water management plan should form part of other related management plans of the organisation including the environmental and horticultural/landscape management plans.

Quality Information

Irrigation represents a large part of the water used within the urban areas. The competent management of water should be based on high quality information.

An accurate record of the system layout ("as built" plan), the site and the plantings should be obtained or prepared. The location of features such as the sprinklers/sprays, mainlines, submains, laterals, valves, water supply points and controller should be clearly and accurately located on the plan. The make, model, size of components (sprinklers, valves etc) should also be recorded.

Irrigation Efficiency

The pursuit of irrigation efficiency should be the highest priority for all urban organisations responsible for irrigated areas. There are several key requirements that need to be successfully accomplished in order to ensure that irrigation is efficient.

Core requirements for irrigation efficiency:

1. High quality irrigation system design
2. Installation of system in accordance with quality design
3. High standard maintenance of system hardware/equipment
4. Precision management and control (scheduling) of irrigation system

Major sources of inefficiency and wastage

Unfortunately there are many examples of situations in which water is being wasted through poor water management practices. These include:

1. Amount of water applied in excess of plant needs
2. Non uniform application of water
3. Precipitation rate higher than soil infiltration rate
4. Faulty or malfunctioning equipment
5. Operating in windy conditions
6. Runoff
7. Overspray from misdirected sprinklers and sprays

There are many other potential equipment, design and system management factors that can also contribute to irrigation inefficiencies and water wastage.

The purpose of this manual is to provide irrigation managers with the knowledge to achieve high efficiency of water use in turf and landscape areas.

2. GOOD IRRIGATION PRACTICE

2.1 PRINCIPLES OF GOOD IRRIGATION

The following are the four key principles that need to be implemented to ensure that the irrigation of turf and landscape areas is efficient:

- (1) Amount of water applied is appropriate to plant and soil
- (2) Timing of water application to suit plant and weather
- (3) Water is applied uniformly and effectively
- (4) Water is applied to the plant root zone without wastage through runoff, deep drainage, ineffective coverage and other sources.

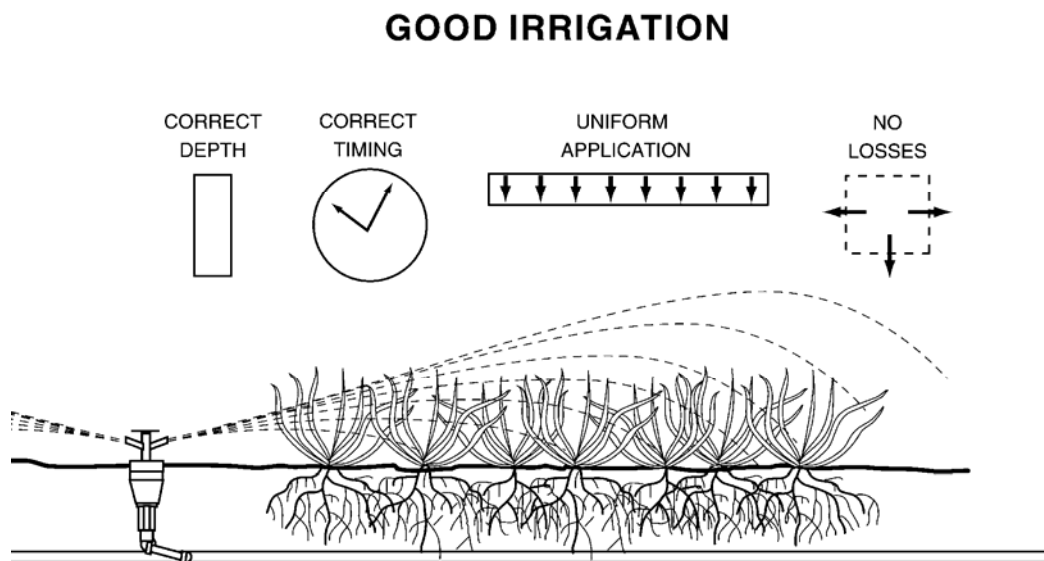


Figure 1 : The four key principles of good irrigation practice

In summary good irrigation is the efficient application of the right amount of water at the right time in the right place.

2.2 CORRECT DEPTH OF APPLICATION

Precision irrigation is based on the application of the correct amount of water to the soil. Whilst the term "amount" is commonly used, a more appropriate term is the

"depth" of water. Rainfall is measured and described in millimetres (mm). Irrigation should also be described in mm. In both cases it is the depth of water that is important.

The principles of good irrigation require that water not be wasted. A primary requirement of good irrigation is that the depth of water applied by the irrigation system should be appropriate to the water storage available in the plant root zone. If it is greater than the capacity of the soil storage, then water will be wasted. The first step is to determine the soil water storage capacity of the soil.

Plant Available Water (PAW)

The depth of water that is in the root zone and is available for use by the plants is referred to as the Plant Available Water (PAW). PAW is dependent on the depth of the water absorbing roots in the soil (called the Root Zone Depth (D)) and the Available Water Holding Capacity (W) of the soil.

Root Zone Depth

The depth to which plants extend their root system is a key characteristic of plants that are grown using irrigation. Plants with deep root systems have access to greater water reservoirs. The range in depths is extensive and is dependent not only on the plant species but also soil type, degree of compaction and watering regime. Root systems tend to develop to greater depths in soils, which are more open, such as sands. In heavier and compacted soils root depths are generally shallower.

Available Water Holding Capacity (AW)

Soils vary in their ability to hold water. Water is stored within the pore spaces between particles. There is a huge variation in particle sizes and particle distribution within the different soil types.

The volume of water that can be stored in soil typically ranges from around 6% to 20% of total soil volume. This is generally expressed in terms of mm of water per 1000 mm (or mm/m) of soil. A sandy loam for example has an Available water holding capacity (AW) of 110 mm per 1000 mm of soil. Full details for various soil types and AW values are presented in Appendix 7.1.

Determining Stored Water

The depth of water that can be stored in the soil and be available to the plants is the foundation of good irrigation. It is determined in the following way:

PAW = Root zone depth (D) mm x Available water holding capacity (AW) mm/h

Example - PAW:

Kikuyu grass growing in sandy loam soil

Root zone depth (D): 150 mm

Available water holding capacity (AW): 110 mm per 1000 mm

(Refer to Appendix 7.1 Guide to soil properties.)

$$\text{PAW} = 150 \text{ mm} \times (110 / 1000) = 16.5 \text{ mm}$$

PAW is used to determine the depth of irrigation that should be applied. In this case 16.5 mm is the maximum that can be applied to a dry soil.

In order to calculate the desired Irrigation Depth, there are two aspects that need to be considered the Refill Point and the System Application Efficiency.

Refill Point

The PAW represents the total water storage capacity available to the plant when the soil is at Field Capacity. The management of the irrigation system requires soil moisture level be maintained between "full" and "empty". At the "full" level soil is at Field Capacity. If it is "empty" it is at Wilting Point. If irrigation is applied so that the "full" level is exceeded then water will be wasted either through deep drainage or runoff. If the soil moisture is allowed to be depleted to Wilting Point, then plant stress and damage will occur.

Good irrigation is about managing the soil moisture level so that the plant is maintained in the desired condition. In some cases a degree of water stress may be acceptable. The point at which the soil storage is replenished is the Refill Point (RP). This is a key irrigation management decision. How much water should be depleted prior to initiating a new irrigation event?

In some cases the soil storage is maintained close to "full". This is often the case with drip irrigated crops that require readily available continuous water. Allowable depletion under these situations is low. It may only be in the vicinity of 20% which means that soil water is close to field capacity and the plant continually has access to readily available water. On the other hand, there are many situations in which soil water storage is allowed to be depleted so that the majority of the soil storage is removed prior to irrigation. Plants will experience some stress under these conditions. As a general guide it is common practice for turf and landscape irrigation systems to be managed with 50% depletion.

System Application Efficiency

The delivery of water to the plant root zone by the irrigation system is not 100% efficient. Water can be lost due to runoff, drainage below the root zone, poor

uniformity, wind drift and evaporation. The irrigation "application efficiency" takes these into account. A guide to the application efficiencies for various irrigation methods is presented in Appendix 7.2.

Irrigation Depth

The irrigation system needs to apply a depth of water to both refill the soil storage and allow for the inefficiency of the irrigation method.

$$\text{Irrigation depth (mm)} = \frac{\text{Percentage Allowable Depletion (\%)} \times \text{PAW}}{\text{Application efficiency (\%)}}$$

Note: Efficiency is expressed as a decimal ie. 80% = 0.80.

Example - Irrigation depth:

Turf:	kikuyu in sandy loam
Irrigation:	Pop-up sprinklers
P A W:	16.5 mm
Percentage allowable depletion:	50%
Allowable depletion depth:	8.3 mm
Application efficiency:	75%
Irrigation depth:	11.0 mm ($= \frac{0.5 \times 16.5}{0.75}$)

In this situation the irrigation system will need to apply 11 mm to ensure that 8.3 mm is delivered to the turf root zone.

2.3 TIMING OF IRRIGATION

The timing of irrigation needs to meet the changing water demands of the plant and the moisture level of the soil.

The key factors to consider are:

- (1) Water use characteristics of the plant
- (2) Climate conditions
- (3) Soil moisture level and soil water storage

Transpiration and Evapotranspiration

The process of water evaporating from plant material is called transpiration. Water loss from a plant is mainly, but not exclusively, from the leaves. Water also

evaporates from the soil. The total water loss from an area of vegetation, including plants and soil, is referred to as Evapotranspiration. It is designated by the letter ET. Evapotranspiration is commonly expressed as millimetres per day.

There are numerous factors influencing ET rate. The major ones are:

- a. Plant species
- b. Stage of growth
- c. Weather - evaporative demand
- d. Available water in soil
- e. Water quality

What Climate Factors Influence Evaporation Rate?

The main driving force of plant water use is the evaporative demand or the evaporation potential of the atmosphere around the plant foliage. The following climatic factors directly influence the level of evaporative demand and hence the plant water use rate.

1. Solar radiation - provides energy for evaporation
2. Air temperature
3. Relative humidity - indicates dryness of the air
4. Wind speed - increases water use rate

Techniques For Estimating Water Use

To achieve good irrigation management it is necessary to know the rate of plant water use. The techniques available include assessment of the plant, the soil and the weather.

A very crude technique is to visually observe the conditions of the plant and recognise if it is stressed. The use of instruments allows more precise estimates to be made. One technique is to measure leaf temperature and determine the degree of water stress.

Soil moisture measurements can also be used. The most accurate and reliable method of measuring soil moisture is to take a soil sample, weigh it, dry it and then weigh it again. This provides an accurate measure of the amount of water in the soil. This is called the gravimetric method. It is however labour intensive and time consuming.

A wide range of instruments is available to monitor and measure the actual level and changes in soil moisture level. Soil moisture sensors can be broadly grouped according to those that measure the water content (mass or volume) and those, such as tensiometers that measure water tension. Careful consideration needs to be given to the characteristics and needs of the site prior to the selection of a soil moisture sensor.

A common technique to estimate plant water requirements using climate data is by measurement of evaporation or by calculating evaporation from the climate parameters. The actual evaporation rate (Epan) is available from the Bureau of Meteorology or from a local (site specific) weather station. There are various techniques and mathematical expressions that can be used to estimate plant water use. The Crop Factor Method is the only one described in detail in this manual.

The Crop Factor Method

The water used by a particular crop or plant, measured in mm depth of water, can be determined using the following expression:

$$\text{Evapotranspiration (ETc)} = \text{Crop Factor (F)} \times \text{Daily Evaporation (Epan)}$$

ETc - evapotranspiration by a particular crop/ plant (mm)

F - Crop Factor. The proportion of water used by the crop/plant compared to the water evaporated from a Class A pan.

Epan - depth of water evaporated from the Class A evaporation pan (mm)

The values of Crop Factor typically range from 0.2 to 0.8. A crop Factor of 1.0 would represent a plant that uses water at the same rate as water evaporates from the open water surface of the evaporation pan. In practice plants use water at a rate less than this. In some extreme cases it is only 20% (or $F = 0.2$) of this rate.

Details of Crop Factor values are presented in Appendix 7.3

An alternative technique to estimate ETc is to use the Reference Evapotranspiration rate of crop (ETo). This value is calculated using climate parameters that influence the plant water use rate. Details of this method, including Penman and Monteith expressions, are presented in FAO Irrigation and Drainage Publication No. 24 (Doorenbos and Pruitt, 1977). ETc is calculated using a Crop Coefficient (Kc) value. These estimations are considered more accurate if local weather data are available.

Example - Plant Water Use

Turf:	kikuyu
Crop Factor (F) :	0.5 (Refer to Appendix 7.3)
Evaporation:	8 mm per day (Reading from Class A pan)
ET _C :	4 mm per day

Irrigation Interval

The time between irrigation events is the Irrigation Interval. If the storage is large or plant water use is low then there will be longer irrigation intervals. The water extraction rate (due to evapotranspiration) is extremely variable and is strongly dependent on the weather conditions.

$$\text{Irrigation Interval (Ti)} = \frac{\text{Allowable Depletion Depth}}{\text{ETc}}$$

Example - Irrigation Interval

Determine the interval between irrigations for a turf area assuming that the area experiences an evaporation rate (Epan) of 8 mm per day for several days.

Turf: kikuyu

ETc: 4 mm per day (refer previous example)

Allowable depletion: 8.3 mm (refer previous example)

$$\text{Ti} = \frac{8.3}{4} = 2.1 \text{ days}$$

Irrigation is generally commenced at a similar time each time of the day. The irrigation interval needs to fit in with this format rather than irrigate at different times of the day. In the example above the irrigation interval would be every 2 days rather than attempting to accommodate a 2.1 day interval.

Determining Volume Of Water To Be Applied

Whilst irrigation management can be discussed in terms of the depth of water, it is often necessary to determine the volume of water for applications such system design, water resource availability and costing.

$$\begin{aligned} \text{Volume} &= \text{Area} \times \text{Depth} \\ \text{Volume (Litres)} &= \text{Area (m}^2\text{)} \times \text{Depth (mm)} \end{aligned}$$

Note that when m² are multiplied by mm, the resulting volume is in litres.

Example - Volume of water

Determine the volume of water required by the irrigation system to apply 11 mm to a sports oval of 1.2 Hectares.

Site: sports oval
Turf: kikuyu

Area:	12,000 m ²	(1.2 Hectares)
Soil:	sandy loam	
Irrigation depth:	11 mm	
Irrigation volume:	132,000 litres	(= 11 x 12,000)

In this situation the irrigation system needs to deliver 132,000 litres per irrigation.

2.4 UNIFORM APPLICATION

A fundamental requirement of any irrigation system is that it be designed to apply water efficiently and effectively and that it be maintained to ensure ongoing high standard performance. Uniformity of application is essential for sprinkler and spray irrigation systems. If sprinkler systems are not uniform then wastage will occur. It is common to observe dry areas within irrigation patterns. Poor uniformity is generally the cause of this condition.

Sprinkler irrigation systems are deceptive in terms of the application of water. They can appear to be very even in application because a lot of water is being distributed over a relatively confined area. In fact, every sprinkler irrigation systems exhibit some degree of unevenness. Some are particularly poor.

The potential reasons for this lack of evenness include:

- a. Sprinklers and sprays spaced too far apart
- b. Poor sprinkler precipitation distribution profile
- c. Unfavourable environmental operating conditions - wind
- d. Incorrect operating pressure
- e. Incorrect nozzle size
- f. Poor pipe and valve sizing - excessive pressure and flow variation in system
- g. Sprinkler head or equipment not functioning effectively.

Strategies For Achieving High Uniformity Of Sprinkler And Spray Systems

The starting point for high uniformity is good design. Qualified irrigation specialists should be engaged to design irrigation systems. There is considerable amount of skill and irrigation expertise required to evaluate the requirements of a site and develop an irrigation design that will meet the needs of the site and deliver water uniformly and efficiently.

The selection of sprinkler heads, operating pressure, nozzle combinations and spacings are critical to the achievement of uniform application. Excessive spacing of sprinklers directly contributes to poor uniformity. Independent irrigation test centres and manufacturers have uniformity results available for particular sprinkler models, nozzle combinations, operating conditions and spacings. A brief summary guide to sprinkler spacings is presented in Appendix 7.5

Irrigation systems need to be continually monitored and evaluated to assess the uniformity, effectiveness and quality of management. Carrying out an audit is another strategy that can be used to achieve a high uniformity.

2.5 AVOIDING WASTAGE

In addition to developing water efficient strategies, such as correct irrigation depth, correct timing and uniformity, irrigation managers need to be aware of other ways in which water can be wasted. These include:

- Runoff - design or management problem
- Wind - droplet evaporation losses and distorted wetting pattern
- Misdirected sprays and sprinklers
- Incorrect operating pressure
- Obstructed distribution for sprinkler and sprays
- Blocked nozzles

A more comprehensive listing of the potential sources of inefficiency are outlined in Section 5.

3. EVALUATING IRRIGATION PERFORMANCE

3.1 JUSTIFICATION

The performance and management of irrigation systems should be checked on a regular basis. It is important to know the operating characteristics of the system and also to determine if the actual performance meets the required industry standards and benchmarks.

Many factors contribute to the performance of an irrigation system. These include design, equipment selection, equipment functioning, installation, maintenance and management issues. Systems are sensitive to the correct functioning of many items of equipment. Failure of an individual valve or sprinkler can adversely affect the system performance. Ongoing evaluation is therefore critical.

3.2 WHICH PERFORMANCE INDICATORS?

In the case of sprinkler irrigation systems, it is important to consider both the operating effectiveness of the system at any point in time and the management of the irrigation over a longer period, for example, the whole irrigation season. There are broadly two categories of performance indicators. One category evaluates the effectiveness of application or the uniformity of the system and the other evaluates how well the system was managed in terms the amount of water applied compared to the amount that should have been used.

The two key performance readings that an irrigation audit will provide are (1) the average precipitation rate and (2) the evenness or uniformity of the application. Both are essential information for the quality management of an irrigation system.

3.3 PRECIPITATION RATE

The rate at which water is applied to irrigated areas is significant for two reasons. The first is water should be applied without wastage and in particular without runoff. To achieve this the irrigation system should be designed so that the precipitation rate is less than the soil infiltration rate. The other role of system precipitation rate is to allow the depth of water that is to be applied to be determined.

The precipitation rate (rate of water falling on to the ground), is expressed in millimetres (depth) per hour.

It is the responsibility of the system designer to select a precipitation rate appropriate to the soil type and site. This requires identification of soil type, surface conditions and soil infiltration properties. Outlet equipment (eg. sprinkler nozzles) should be selected so that the sprinklers or sprays will apply water to match the design precipitation rate. The design precipitation rate must be less than soil infiltration rate. An audit test will tell you the actual precipitation rate being achieved in the field

under typical operating conditions. It provides a check for new systems and accurate information on the precipitation performance for existing systems.

The precipitation rate of an irrigation system can be determined by calculating it using the design details or by measuring it in the field.

Calculating Theoretical Precipitation Rate

The key information required to calculate the theoretical rate is the dimensions of the sprinkler layout and the performance of the sprinklers or spray heads.

$$\text{Theoretical/ Calculated PR (mm/h)} = \frac{\text{Outlet flow rate}}{\text{Wetted Area}}$$

$$\text{Precipitation rate PR} = \frac{q \times 60}{S \times L} \text{ mm/h}$$

q - flow rate from one outlet (sprinkler or spray) (L/min)

S - spacing between outlets along lateral (m)

L - perpendicular spacing between laterals (m)

Calculating Actual Precipitation Rate

The precipitation rate of a sprinkler or spray irrigation system can be obtained by positioning a number of cans within the wetted area. The system needs to be operated for long enough to ensure that a measurable volume of water is delivered into the cans. This may take 20 minutes or longer.

The calculation of the system precipitation rate requires that the average depth of application be determined. Generally the water in each can is measured in millilitres (mL). If a round can is used, then the depth of water can be determined by dividing the volume of water by the area of the top of the can. To calculate the average precipitation rate, it is necessary to determine the average depth of water using the readings from all the cans. The average precipitation rate is then calculated taking into account the duration of the test.

The following expression allows the precipitation rate to be directly calculated from the can readings.

$$\text{Actual Precipitation Rate (PR)} = \frac{V_{\text{avg}} \times 60,000}{T \times A_c} \text{ mm/h}$$

V_{avg} - average volume in test cans (mL)

T - test run time in minutes

A_c - area of can in mm^2

3.4 UNIFORMITY COEFFICIENTS

Uniformity

The general aim of an irrigation system is to deliver uniform and accurate amounts of water to the plant root zone. The effectiveness of turf sprinkler systems is dependent on applying water uniformly. In the case of drip systems for landscape plantings, the effectiveness is dependent on delivery of precise and known volumes from the emitter.

Individual sprinklers and sprays do not apply water uniformly along the radius. Overlap of sprinkler distributions is therefore required to achieve uniformity. Tests that provide a measure of the variation in application depths are therefore valuable in assessing performance. Whilst several uniformity coefficients have been developed, the Distribution Uniformity (DU) is generally accepted as being appropriate for turf and landscape sprinkler and spray irrigation systems.

Distribution Uniformity Coefficient

The preferred measure of uniformity for turf and landscape is the DU which compares the average of the lowest 25% of test can readings to the average of all readings. A DU of 100% would indicate that the application was perfectly even. In practice, this does not happen. It is generally accepted that sprinkler systems for turf should have a minimum DU of 75%.

The value of Distribution Uniformity coefficient is calculated using the following expression:

$$DU (\%) = \frac{M_{25}}{M} \times 100$$

where:

M - average value of all catch can readings.

M₂₅ - average of lowest 25% of readings

Christiansen Coefficient of Uniformity

Whilst the Distribution Uniformity Coefficient is generally recommended for turf. The Christiansen Coefficient of Uniformity (Cu) is also widely used in the broader irrigation industry. The Cu value is calculated by determining how much variation (if any) there is for each can reading from the average reading. The total variation from the average is calculated by adding up any difference, whether it is above or below the average value. This total variation is used to determine the non-uniformity of the application.

$$C_u = \left(1 - \frac{\sum Md}{M \times n} \right) \times 100 \quad \%$$

M - average value of all can readings

$\sum Md$ - total of variation of each reading from the average

n - number of can readings

A C_u value of 100% would represent a perfectly uniform or even application of water. The industry standard suggests that C_u be greater than 84%. Due to the method of calculation of C_u , it will always have a higher value of uniformity than DU for the same set of readings. It is therefore important to specify which particular uniformity coefficient is being used.

Scheduling Coefficient (SC)

In order to ensure that all parts of the irrigated area receive an adequate depth of water, it is recommended that the sprinkler run times are increased to allow for unevenness in the application. The Scheduling Coefficient is used to provide a time adjustment factor to ensure that the dry or underwatered areas receive an adequate depth of application.

$$\text{Scheduling Coefficient (SC)} = \frac{\text{Average of all can readings}}{\text{Selected can/s readings (Dry area)}}$$

There are several versions of SC. In some cases, the test can with the absolute lowest reading is used or 1%, 5% etc. In other cases a group, for example the lowest 25%, of can readings are used. If a single can reading is used, then the value of SC will be higher than if a group value is used.

The SC based on the lowest 25% ($SC_{25\%}$) can be found if DU has already been determined.

$$SC_{25\%} = \frac{1}{DU}$$

Eg. If DU is 75%, then $SC_{25\%} = (1/0.75) = 1.33$

There are other Scheduling Coefficient terms in use. It is important to clarify which SC term is being used for each situation. An efficient irrigation system should aim to achieve a scheduling coefficient less than 1.3.

3.5 IRRIGATION MANAGEMENT INDICATOR

An appropriate seasonal irrigation performance indicator is the Irrigation Index (Ii) which compares the depth of water actually applied to the estimated depth of water

required over the complete irrigation season. This simple measure provides the manager with a visible, readily understood measure of how well or how efficiently the system is performing and how the performance compares with other sites. An irrigated area, that is being well managed, would have an Irrigation Index value of 1.0 or less. If the Ii value is greater than 1.0, it would suggest that there is some wastage of water.

The Irrigation Index (Ii) can be defined in the following way:

$$\text{Irrigation Index (Ii)} = \frac{\text{Water Applied to site (W}_A\text{)}}{\text{Estimated Water Required (W}_R\text{)}}$$

Determining Water Applied (W_A)

The amount applied, expressed in millimetres, can readily be determined from total irrigation water consumption at the site and the size of the area being irrigated.

$$\text{Water applied (W}_A\text{)} = \frac{\text{Volume of water supplied to site (Litres)}}{\text{Irrigated area (m}^2\text{)}} \quad \text{mm}$$

Note: One litre is equal to a depth of one millimetre (mm) spread over an area of one square metre.

It is important to keep records of meter readings not only at the start and end of the irrigation season but also on a regular basis throughout the season. This assists with the monitoring of the site, the equipment and irrigation scheduling.

Seasonal Water Required (W_R)

The amount of water that needs to be deposited, by the irrigation system, in the root zone to satisfy plant growth is the net difference between the plant water use (ET) and the amount supplied through rainfall (Peff).

$$\text{Net Water Requirement (NWR)} = (\text{ETc} - \text{Peff}) \quad (\text{mm})$$

The accuracy of this technique is dependent upon the frequency of calculating the Net Irrigation Requirement. This can be done on a daily, weekly or monthly basis.

The proportion of rainfall that is actually used by plants, after all rainfall losses have been taken into account, is referred to as Effective Rainfall (Peff). It is difficult to accurately determine without a full and detailed analysis. It can, however, be estimated by taking into account some of the factors that will influence it.

These include:

1. Rainfall in excess of the amount that can be stored in the root zone will be wasted due to deep drainage.
2. Rainfall intensities greater than the soil infiltration rate will result in some runoff.
3. Very light rainfall amounts may not result in a net addition of water to the root zone. It is likely to be lost by evaporation from vegetation and the soil surface. Rainfall less than 2 mm can be ignored as it is regarded as non effective.

The estimation of Effective Rainfall should take into account the total amount of water that can actually be stored in the soil root zone, as rainfall in excess of this capacity will be wasted. Shallow rooted turfgrasses, growing in lighter soils, will have a storage capacity in the range of 10 mm to 20 mm. Deeper rooting species may have a storage capacity in the vicinity of 20 mm to 30 mm in light soils. A characteristic of shallow rooted turf is the limited ability to capture rainfall.

It is reasonable to assume 50% of all rainfall is Effective. It should however be noted that this is an estimate and more detailed analysis will result in more accurate determinations of the actual amount of rainfall that is beneficial or effective.

The sprinkler irrigation system, due to inefficiencies, needs to apply more water than the estimated water requirement (NWR). Some water is lost due to wind and evaporation, some may drain below the root zone and there is always some unevenness in the application. The system efficiency (Ns), which takes into account these losses, can range from very low values up to the vicinity of 90%. An achievable or minimum acceptable system efficiency, such as 75%, can be selected to provide a reference performance standard for turf sprinkler systems.

$$\text{Estimated Irrigation Water Required (W}_A\text{)} = \frac{\text{Net Water Requirement (NWR)}}{\text{System Application Efficiency (Ns)}} \text{ mm}$$

The determination of the Irrigation Index can be carried out using a relatively limited amount of data and the application of simple analysis techniques. As well as providing useful information on current performance, it provides the basis for benchmarking your irrigation against other sites and industry standards. In a study by Keig (1994), of sporting ovals in Melbourne, the value of Irrigation Index was determined to be in excess of 2.0 for two ovals. This represents a total water use of 200% of the water that should have been used on those sites. There are plenty of opportunities for water conservation at these sites.

3.6 SUMMARY LIST OF KEY PERFORMANCE INDICATORS

The following is a list of the performance indicators that could be used to evaluate irrigation performance. All irrigation managers should be aware of at least the first two, Precipitation rate and Du, if they are to be competent water managers.

System precipitation rate - PR (mm per hour)

A measure of the average rate of water reaching the soil surface within the test area. This should be less than soil infiltration rate to avoid runoff.

Distribution Uniformity - DU (Should be greater than 75%)

A measure of the evenness of application of water application by sprinkler systems using a can test. This coefficient takes into account the average of the lowest 25% of readings obtained from test cans and compares this value to the average of all readings.

Christiansen Uniformity - Cu (Should be greater than 84%)

A measure of the evenness of application of water application by sprinkler systems. This coefficient takes into account the amount of variation in test can readings both above and below the average value of all can readings. It is in more common use in agriculture.

Scheduling Coefficient - SC ($SC_{25\%}$ should be less than 1.3)

A measure of the range of depths of water applied by the irrigation system within the test area. Provides a basis for adjusting irrigation run times to allow for underwatered areas.

Irrigation Index - Ii (Should not be greater than 1.0)

Ratio of the depth of water applied at a site compared to the depth of water that has been estimated to be required.

4. AUDITING OF IRRIGATION SYSTEMS

4.1 BENEFITS OF AN AUDIT

Carrying out an audit on an irrigation system, new or old, can be a very extremely valuable investment. The information gained can be directly used to improve the performance of the system and provide the basis for the ongoing efficient management of the irrigation at the site. It provides information valuable to the system owner, the irrigation company and the water supply organisation.

The potential benefits of an audit are:

1. Potential water savings and cost savings
2. Nutrient savings and reduced release of nutrients to environments
3. Higher quality turf and landscape plantings eg. more uniform turf surfaces
4. Savings in time and labour
5. Improved management of a valuable resource

In summary, an audit will provide information on the following:

1. Identify faulty equipment
2. Current operating efficiency and uniformity of the system
3. Identify any weaknesses in system
4. Establish key system performance parameters
pressure, flow rate, precipitation rate
5. Provide basis for developing an irrigation schedule for the site
How much to apply, when to apply.

4.2 PREPARING FOR AN AUDIT

Background Information

Conducting an audit of an irrigation system requires establishing an accurate record of the system, the site and the vegetation. The foundation to building a quality irrigation management program is a detailed plan, which not only includes records of locations of important features, but also reference to accurate details of equipment. The make, model, size of components (sprinklers, valves etc) should be recorded.

Details of the water supply and control equipment are particularly important - pump or water meter, controller, master valves, etc. It is also critical that details of control programs, for each control station, be noted so that recommendations can be made on the appropriate run times of the system as tested, to meet the needs of the vegetation at the particular site.

The soil water properties for each irrigated zone need to be determined. The key properties are infiltration rate and available water holding capacity. Identifying the soil type allows these properties to be obtained from a reference table (Appendix 7.1). There are also techniques available, using instruments, to measure infiltration rate in the field.

Site Test Conditions - Weather and Hydraulics

An audit should be carried out under conditions, which provide a fair representation of the normal performance of the system. The climate conditions, in particular wind, should be within acceptable limits during the test. A maximum wind speed of 10 kph can be used as a guide.

The system pressure should be checked to see that the equipment to be tested is operating within design conditions. Shreuder valves (car tyre valves) can be installed at strategic points around the system to facilitate the taking of pressure readings. A pitot tube gauge (small diameter tube inserted into water stream) can be used to check nozzle pressures. When using this method, it is important to note that the nozzle pressure will be higher than the inlet (base) pressure to the sprinkler head. Irrigation systems are most commonly designed on inlet pressure and so this difference needs to be taken into account when analysing a system.

Preliminary Check Of System

The system should be operated prior to the actual audit to check the functioning of the various components. This stage of the audit process is sometimes referred to as the "walk through". Often problems that directly affect the performance of the system will be observed. For example, a sprinkler head may be damaged, blocked or not rising to the full operating position. These problems should be fixed prior to the audit test. It does not make sense to evaluate the performance of an irrigation system that has readily fixable problems.

Some of the problems that might be identified during the "walk through" include:

- Malfunctioning valves
- Sunken sprinkler heads
- Incorrect or non-rotation of sprinkler heads
- Tilted heads
- Plugged nozzles
- Broken casings and missing parts
- Distorted spray distribution
- Incorrect nozzles installed
- Leaking pipes, valves, fittings, equipment, broken seals
- Incorrect operating pressure - high, low

Any problems observed should be identified according to position on the ground and controller station. This information should be recorded and noted on the plan as part of a maintenance record of the irrigation system.

Not all problems will be able to be fixed prior to the test. The audit may indicate system deficiencies (problems) such as incorrect sprinkler spacing or low operating pressures that may involve major works or design changes.

4.3 CARRYING OUT AN AUDIT

Audit Test Equipment

The following equipment is required to carry out an irrigation audit.

Catch cans - 20 to 30 containers – Customised collection cans, that allow direct reading of the depth of water, are available from Irrigation Australia Ltd.

Measuring flask (mL) (If required)

Funnel

Bucket and tubing - to measure sprinkler flow rate

Pressure gauge and pitot tube

Stopwatch

Measuring tape

Recording sheet for can readings

Full details on conducting audits are presented in the Irrigation Efficiency Course (IEC) (Commenced in 2007) conducted by the Irrigation Australia Ltd. (IAL). This course replaces the Certified Landscape Irrigation Course. Details available from: IAL, P O Box 1804, Hornsby, NSW. Website: www.irrigation.org.au

Setting Out The Cans

To carry out a test, it is advisable to use at least 20 cans to obtain a fair representation of the system performance. The cans should be laid out in a grid pattern. It is helpful to allocate each can a position number so the location of each particular reading can be readily identified. The test will generally require an operation time in excess of twenty minutes to ensure that a reasonable amount of water has been deposited in the cans. Cans should not be placed too close to sprinkler and spray heads. They should be positioned so that they can readily collect the water falling on that particular area.

Pressure Testing

An accurate pressure gauge is an extremely valuable tool for the evaluation and monitoring of irrigation systems. Pressure is the heart rate of the irrigation system. Part of the audit test will involve checking the actual sprinkler operating pressure and

pressure variation throughout the system. Some of the key information that can be provided through pressure measurements include:

- (1) Checking the outlets (sprinklers and sprays) are operating at correct (optimum) pressure.
- (2) The pressure variation along the lateral Is it acceptable?
- (3) The pressure variation between stations and outlets in different parts of the system.
- (4) The amount of pressure loss due to friction in the system.
- (5) The pressure loss across valves, filters and special fittings.

4.4 ANALYSING AUDIT RESULTS

The two key performance readings that an audit will provide are (1) the evenness or uniformity of the application and (2) the average precipitation rate.

It is important to note the position of each can and take care in recording the volume. If there are irregularities in the application, then the particular areas can be identified.

Precipitation Rate Results

The precipitation rate is used to check that the system has been correctly designed. The actual precipitation rate should be less than the soil infiltration rate. If the precipitation rate is too high it will generally be apparent through runoff or ponding during the test. There are not a lot of options available to change an existing irrigation system. It may be possible to change nozzle combinations or even the sprinkler or spray heads but this would need to be checked with the product manufacturers or system designer.

If the precipitation rate is too high an alternative approach is to apply the required depth in several small amounts rather than one continuous application. The controller is required to initiate multiple starts for each irrigation station. For example, to apply 9 mm it may be applied in three lots of 3 mm each irrigation event separated by a period of one hour. This allows the 9 mm to be applied over three hours rather than being applied in one application.

Uniformity Results

The first step is to compare the measured uniformity values with the industry standards - DU greater than 75% and Cu greater than 84%. If the values are significantly lower, then possible causes should be investigated.

Low uniformity values may be due to either a poorly designed system or a system not performing up to standard. A check of the sprinkler or spray performance and measurement of the sprinkler spacings will provide details necessary to ascertain if

there are flaws in the basic design. The wetted diameter of sprinklers should be checked to see that they meet the required spacing guidelines for high uniformity. (Appendix 7.5).

If the system is shown to meet basic design guidelines and it has low uniformity value then other aspects should be assessed. Each sprinkler and spray should be checked for pressure, flow rate and distribution. Individual readings within the test area should be reviewed. A pattern of low or high readings may indicate specific problems within the system.

Developing An Irrigation Schedule

An important part of an irrigation audit is for the system manager to determine of the depth of water that should be applied and the recommended timing. A considerable amount of information is required about each part of the site, vegetation characteristics and soil properties in order to determine the irrigation schedule.

To accommodate the changing ETC there are two approaches to the scheduling of irrigation systems. Irrigation systems should be designed to handle the worst case scenario in terms of plant water demands. If water demand is low, then irrigation can be carried out with longer irrigation intervals or less water can be applied. The application of design irrigation depth at longer intervals (or less frequent irrigation) has the advantage the whole root zone will be watered and shallow rooting will not be encouraged.

A recommended irrigation depth should be determined for each irrigation zone. Turf with relatively short root zone depths will have different requirements than shrubs, which will tend to have deeper root systems and may have different soil types and properties.

The recommended run time for each station to achieve the desired application will be part of the scheduling information. The run time for an irrigation station is dependent on the depth to be applied and the precipitation rate of the system.

$$\text{Run Time} = \frac{\text{Irrigation Depth (mm)} \times 60 \text{ min}}{\text{Precipitation Rate (PR) (mm/h)}}$$

Example - Irrigation Run Time

Site:	sports oval
Turf:	kikuyu
Irrigation Depth:	8.3 mm
Precipitation Rate:	12 mm/h (This is an assumed value but it can be calculated - Refer to Section 3.3)

$$\text{Run Time} = \frac{8.3 \times 60}{12} = 41.5 \text{ min}$$

5. STRATEGIES FOR WATER CONSERVATION

5.1 REDUCE PLANT WATER DEMAND

A. Plant selection

The rate at which plants use water is dependent on many factors including plant species. There is potential to reduce water requirements by selecting plants that achieve the desired performance yet require less water. Species selection within the turf family is an area for significant potential savings. For example cool season grasses typically use 30% more water than warm season grasses. Details of the differences in water use rate can be obtained from the Crop Factor Table in Appendix 7.3

B. Site landscape design

There are sometimes opportunities to reduce water demand by replacing vegetation (turf and landscape plants) with impervious surfaces such as paving. The shape of the area to be irrigated can also affect the efficiency of irrigation. Narrow lawn areas, for example, are difficult to effectively irrigate using sprinklers or sprays.

C. Plant cultural practices

The manner in which plants are managed influences the water requirement. Frequent, close mowing of grass results in a higher demand for water than higher, less frequent mowing. Also, high fertiliser rates encourage higher demand for water.

Regular aeration and dethatching of grass is recommended. Aeration assists with water penetration and dethatching minimises water absorbed by the thatch and subsequently lost or wasted.

D. Root zone depth

Maximising the potential water storage in the soil should be a key water management strategy. This is particularly important for shallow plants such as grass. Encouraging deeper root systems is strongly recommended. Deep infrequent irrigations are advised rather than shallow infrequent applications. The deep watering ensures water reaches the lower parts of the root system. Allowing the root zone to dry out encourages root development in the lower part of the root system.

E. Mulching

The application of mulch is a very effective water conservation strategy. Water loss from the soil is eliminated and weed growth, which also wastes water, can be greatly restricted.

F. Soil amendments

Some soils exhibit water repulsion or hydrophobic properties. Various chemical treatments are available to improve wettability and infiltration properties of these soils.

5.2 MAXIMISE IRRIGATION APPLICATION EFFICIENCY

A. High uniformity

It is not possible to achieve efficient application of water with sprinkler and spray systems if the application of water is not uniform. The achievement of high uniformity should be a high priority for new systems and existing systems.

B. Optimise hydraulic operating conditions for outlets

There are numerous reasons why operating conditions, including pressure and flow rate, may not be optimum. The system design may be deficient, incorrect equipment may be installed or there may be equipment (eg. valves) malfunctioning or not correctly adjusted. The use of a pressure gauge to check an irrigation system is a very valuable asset.

C. Correct outlet selection

Irrigation outlet needs to be matched to the situation. Performance characteristics including coverage, operating pressure, flow rate, droplet size, stream trajectory, blockage risk may all need to be considered. The use of microsprays in mulched areas is an example of poor outlet selection. Much of the applied water may be absorbed by the mulch. Drippers positioned under the mulch would be a better selection in many situations.

D. Effective outlet coverage

The wetting of paths, hardsurfaces and roadways is a common example of water wastage. Care should be taken to ensure that part circle sprinklers and sprays are correctly adjusted.

E. Effective functioning of equipment

Irrigation systems require regular maintenance. They are systems made up of many vulnerable parts. Pop-up irrigation systems are a particular issue. Sprinkler heads may not lift to the required operating position or they may become stuck in the high position and be subsequently damaged by mowers and machinery. The correct functioning of valves also needs to be constantly monitored to ensure that flow and pressure is correct.

F. Low head drainage

Some water can be wasted following shut down of a sprinkler or spray line as water will drain to the lowest part of the pipe system. Incorporation of low head shut down valves in sprinkler and spray heads eliminates this source of wastage.

5.3 PRECISE CONTROL OF IRRIGATION

A. Match irrigation to plant water demand

The rates at which plants use water and hence require watering vary according to the weather conditions. It is therefore important to time irrigation to match the demand. This approach requires constant monitoring of the weather conditions so that specific plant water needs and soil moisture levels can be determined and the irrigation system operated to satisfy the demand.

B. Correct depth of irrigation

Precision irrigation is based on knowing the appropriate depth of water that should be applied so that the soil moisture level is maintained within the desired range. Overwatering which results in overfilling of the soil water storage and drainage below the root zone is a common source of wastage of water. Detailed knowledge of the site including root zone depth and soil properties is essential in determining the correct depth. Also knowledge of the precipitation rate of the irrigation system is required to determine the appropriate operating time (run time) of the system.

C. Hydrozones

The grouping of plants into areas of similar water requirements allows the irrigation system to be designed and managed so that the desired depth of water can be applied. In areas of mixed plantings, including trees in turf areas, it is necessary to divide up the control of the irrigation system so that the area close to the trees is separately controlled. If it is not then there is the risk that the irrigation system will be operated to achieve satisfactory water around the tree and so the lawn areas will be overwatered.

5.4 ADOPT NEW TECHNOLOGIES

A. Weather stations

An accurate estimation of the evaporation close to the site being irrigated is an extremely valuable irrigation management aid.

B. Soil moisture sensors

Obtaining feedback on the moisture level in the soil assists in the control of the irrigation. Soil moisture sensors also provide valuable information on water movement through the soil and the water use characteristics of the plant.

C. Smart controllers

Irrigation controllers have developed beyond the stage of being sophisticated electrical switch boxes. They can now provide detailed information about the operation of the irrigation system, both electrically and hydraulically. The programming and processing capabilities of today's controllers means that all watering and equipment options can be accommodated.

D. Alternative method of irrigation - Subsurface drip

Whilst pop-up sprinklers may be logical for large turf areas there are many instances in landscape situations where alternative irrigation methods such as subsurface drip could be used.

5.5 OPERATOR SKILLS

The competent management and maintenance of an irrigation system requires a reasonable level of skill and expertise. Organisations should continually pursue opportunities to advance the skills of staff involved in irrigation. In addition to educational institutions providing training, many irrigation companies provide a good range of training opportunities for staff.

6. REFERENCES

- Anon (1996) *Landscape Irrigation Auditor Training Manual (Australian Version)*, 2nd Edition March 1996, The Irrigation Association, USA.
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- Handreck, K. A. and Black, N. D. (2001) *Growing media for ornamental plants and turf*, 3rd Edition, New South Wales University Press, Kensington, Australia.
- Keig, S. (1994) *Water use efficiency - Evaluation of selected sports grounds*, 1994 Horticultural Project Report, Victorian College of Agriculture and Horticulture, Burnley Campus, University of Melbourne.

7. APPENDICES

Appendix 7.1 - Guide To Soil Properties

Soil Type	Available Water (AW)	Infiltration Rate (i)
	mm/m	mm/h
Sand	60	>20
Fine sand	90	15 - 20
Sandy loam	110	10 - 18
Loam	170	10 - 15
Silt loam	170	8 - 12
Clay loam	165	5 - 10
Clay	140	1 - 5

Appendix 7.2 - Irrigation System Application Efficiencies (Ns)

Drip	80% to 95%
Sprinkler	70% to 80%
Spray	60% to 70%
Surface/flooding	50% to 70%

Appendix 7.3 - Crop Factor Values

PLANT	Crop Factor (F) Range	
	Low	High
Trees	0.3	0.8
Shrubs	0.3	0.7
Ground Covers	0.3	0.6
Vegetables	0.4	0.9
Turf - Cool season	0.65	0.85
eg. Bentgrass, Bluegrass		
Tall Fescue, Ryegrass		
Moderate growth, just acceptable	0.65	0.70
Strong growth	0.70	0.75
Vigorous growth	0.80	0.85
Turf - Warm season	0.25	0.7
eg. Buffalo, Couch,		
Kikuyu, Zoysia		
Moderate growth, just acceptable	0.25	0.40
Strong growth	0.45	0.55
Vigorous growth	0.55	0.70

Guide to Crop Factor (F) values for various turf conditions. (Adapted from Handreck and Black, 2001).

Appendix 7.4 - Evaporation Pan Data - Mean daily (mm per day)

LOCATION	Summer (January)	Autumn (April)	Winter (July)	Spring (October)	Annual
Adelaide	8.7	4.3	1.9	5.5	1898
Brisbane	7.4	4.4	3.0	6.5	1960
Canberra	7.0	2.7	1.2	4.0	1375
Darwin	6.7	7.1	7.3	8.6	2696
Hobart	4.9	2.1	0.9	3.1	994
Melbourne	6.1	2.8	1.3	3.8	1268
Perth	8.1	4.0	2.0	5.0	1764
Sydney	7.0	4.1	2.7	5.7	1788

Appendix 7.5 - Guide To Sprinkler Spacings Along Lateral

Wind Speed	Square Pattern	Triangular Pattern
0 to 5 kph	55%	60%
6 to 12 kph	50%	55%
13 to 20 kph	45%	50%

NB. Sprinkler spacings are expressed as percentage of the wetted diameter of the sprinkler.