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EVALUATING AND BENCHMARKING THE PERFORMANCE OF URBAN IRRIGATION

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ABSTRACT

The question as to whether or not turf landscape plantings should be irrigated is only a relatively recent one. The development of our urban environments has been on the assumption that water for irrigation is available. That time has now passed and all water used in urban areas is or will be subjected to critical review.

The performance of turf and landscape irrigation systems is generally not well appreciated in quantitative terms. Performance benchmarking is a powerful tool in identifying opportunities for improvement in irrigation techniques and practices. To achieve effective performance benchmarking, it is essential to have performance indicators that are appropriate, clearly described and clearly defined. Currently a range of indicators is used and the determination of the indicator value also can vary.

Irrigation performance indicators need to allow evaluation of the total water consumption over a nominated period (for example, the irrigation season) and the evaluation of the efficiency of application of the irrigation system.

This paper identifies several key performance indicators for turf and landscape areas including the Irrigation Index (Ii) and Distribution Uniformity (DU) coefficient as appropriate measures for urban irrigation. Experiences in performance evaluation of sports turf, parks and garden areas in Australia are presented.

KEYWORDS

Performance benchmarking, irrigation efficiency, Irrigation Index, Distribution Uniformity, Crop Factor, urban irrigation

1 INTRODUCTION

Increasingly those who have responsibility for urban water use will be required to demonstrate that current irrigation practices are at an acceptable standard and that strategies are in place to achieve ongoing improvement.

Urban irrigation is highly visible. Examples of poor irrigation practice can be very damaging to the reputation and credibility of responsible irrigation managers. The ability to demonstrate existing high irrigation standards and the pursuit of high efficiency is very important. The turf and landscape industries can improve water use efficiently significantly.

There is broad agreement that irrigation efficiency gains of more than 30% can be achieved in many urban areas. In order to achieve these gains, it is necessary to evaluate the irrigation performance so that deficiencies can be identified.

Most urban organisations responsible for irrigated open space have some form of open space reporting of water consumption. However the value of this information to the broader industry and the community is often of limited value. Not only does the information lack transferability, but there are often other key aspects of water management performance that have not been reported.

The evaluation of how well irrigation water is used should be a core responsibility for all involved in urban irrigation.

2 PERFORMANCE BENCHMARKING OF URBAN IRRIGATION

2.1 BENCHMARKING ELEMENTS

Performance benchmarking has been demonstrated to be a powerful tool in agriculture, production horticulture and viticulture. The urban irrigation sector now needs to catch up to the standards of water management reporting that have been achieved in these other sectors of the irrigation industry.

The major elements of performance benchmarking are:

(1) Quantitative measurement of performance
(2) Comparison with best practice in industry – identifying gaps in performance
(3) Identify strategies to improve performance
(4) Foster a culture of ongoing improvement
(5) Demonstration and reporting of irrigation performance level

2.2 KEY PERFORMANCE INDICATORS

The assessment of the performance of an irrigation system should provide the manager or operator with a numerical or quantitative measure that will allow the effectiveness and efficiency of irrigation to be evaluated and referenced to an industry standard or benchmark.

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 irrigation season. Potentially there are many performance indicators, however there are two key indicators for urban irrigation. One type evaluates the effectiveness of application of the irrigation system and the other evaluates how well the system was managed, over a designated period, for example a month, year or irrigation season. The latter indicator assesses performance in terms the amount of water applied compared to the amount that should have been used.

2.3 EFFICIENCY

Within the water industries the "efficiency" term is extensively used as it potentially allows a ready assessment of performance. It is, however, a term that can mean and describe many different things. Regardless of the particular definition used, the overall aim is to achieve high efficiency or minimum wastage in urban irrigation.

The major factors that contribute to high urban irrigation efficiency are:

High quality irrigation system design

Installation of system in accordance with quality standards

High standard maintenance of system hardware/equipment

Precision management and operation (scheduling) of irrigation system

In the Irrigation Association (USA) publication, *Landscape Irrigation Scheduling and Water Management* (McCabe, 2003a), the ways in which an efficient irrigation system reduces waste of water is outlined. They are:

- Not irrigating preceding, during and following a significant rain event
- Irrigating only at night or early morning when evaporation and wind speed are lowest
- Adjusting the irrigation schedule to compensate for current weather conditions
- Basing the irrigation schedule on actual plant water requirements and the current amount of water in the root zone

Defining irrigation efficiency can be difficult. There are a multitude of definitions and terms in use. The term "Water Use Efficiency" (WUE), which is now very popular within urban water management, has tended to be used both as a generic term to describe how well water is managed and also as a performance indicator.

As a performance indicator, the Water Use Efficiency term is commonly used to describe the relationship between water (input) and agriculture product (output), for example, kg/ML (Fairweather et al, 2002).

The WUE term, as a performance indicator term, is not suited to turf and landscape situations, as there is not a readily measurable yield or output from the vegetation or "crop". There are no kilograms of fruit or litres of wine that can be used as a reference on which to evaluate performance. The WUE term should be reserved as a generic label for the study of water management, as proposed by Aquatech Consulting (2003), and defined indices be used to describe specific aspects of performance under the WUE framework or umbrella.

The sources of inefficiency in urban irrigation systems can be grouped according to two broad categories.

(1) Some of the water applied by the irrigation to the area does not reach the root zone and/or is distributed unevenly. This category is generally referred to as the Application Efficiency.

and

(2) Some water is lost as a result of inappropriate operation of the irrigation system. Excess or insufficient water can be applied. This category is generally referred to as Water Management Efficiency or Scheduling Efficiency.

There are three key efficiency terms that are relevant to turf and landscape irrigation.

They are:

(1) Overall Irrigation Efficiency
(2) Scheduling Efficiency or Water Management Efficiency
(3) Application Efficiency or Field Efficiency

The Overall Irrigation Efficiency (McCabe, 2003a) encompasses all losses that occur between the supply of water to the site and the actual water used by the plants. It is sometimes referred to as Irrigation Efficiency.

3 URBAN VEGETATION WATER REQUIREMENTS

3.1 ESTIMATION TECHNIQUES

The estimation of the water requirements of turf and landscapes is very important for several reasons including water budgeting, scheduling, costing and performance evaluation. There is a range of techniques employed to estimate plant water demand including those that use measured evaporation pan data and those that use calculated reference crop evapotranspiration rates.

A generalised equation for the determination of plant water demand is:

Plant Water Demand (mm) = Factor x Reference Evaporation (mm)

The multiplier factor needs to be defined for each type of evaporation reference that is used to estimate the plant water demand.

When the multiplier factor is used, in conjunction with evaporation pan data, it is called a Crop Factor and when it is used, in conjunction with a reference crop evapotranspiration, it is called a Crop Coefficient.

The Plant Water Demand term is equivalent to the Evapotranspiration rate (ETc) of the vegetation.

3.2 CROP FACTORS AND CROP COEFFICIENTS

The use of two terms as the multiplier factor, Crop Coefficient and Crop Factor, in the estimation of water requirements can be confusing. The following two expressions define the terms.

(1) ETc = Crop Coefficient (Kc) x Reference Evapotranspiration (ETo)

(2) ETc = Crop Factor (CF) x Pan Evaporation (Epan)

ETc - Crop evapotranspiration rate

ETo – Rate of evapotranspiration from an extensive surface of cool-season grass cover of uniform height of 12 cm, actively growing, completely shading the ground and not short of water.

Epan – Class A Evaporation pan reading

The rate of water evaporation (mm per day) from an evaporation pan is higher than the evaporation rate from a high water use reference grass. This means that the value of the multiplier, in each of the above equations, must be different in order that similar crop water use estimate values are determined. The Pan Coefficient (Skewes, 2002) is used to estimate a value of Crop Coefficient equivalent to a corresponding Crop Factor. Crop Factor (CF) values are lower, typically in the range of 20%, than Crop Coefficient (Kc) values.

The techniques that are available to determine crop water requirements are outlined by Skewes (2002) for agricultural crops. The estimation and determination of irrigation water requirements have been presented by Connellan (2002).

The following expression is used in the Landscape Irrigation Auditing Program (Kah and Walker, 1996) to estimate landscape water requirements:

Plant Water Requirement (PWR) = Landscape Coefficient (K_L) x ETo

The value of the Landscape Coefficient is determined using three separate components: Species Factor (K_S), Density Factor (K_D) and a Microclimate Factor (K_{MC}).

The estimation of the water requirements of individual landscape plantings can be found in the *Guide to Estimating Irrigation Water Needs of Landscape Plantings in California* (Costello and Jones, 2000).

3.3 VEGETATION PERFORMANCE LEVELS

The irrigation of urban landscapes is carried out for a variety of reasons. In some cases it is for plant establishment and in other cases to ensure survival. In most situations it is to achieve enhanced growth of the vegetation. The outcome from the application of the irrigation water will vary according to the amount applied and the conditions. Lush vegetation will generally require greater applications of water.

Defining the required level of performance of an irrigated area is an essential part of water management planning. Assignment of appropriate Crop Factor values for desired levels of performance is critical.

In water management planning projects involving irrigated turf in Melbourne, carried out by the author, three classifications or levels of performance, based on Handreck and Black (2001), have been used.

The three levels of performance for turf are:

1. Premium, Lush
2. Medium, Strong growth
3. Low maintenance, Just acceptable

Table 1. Turf and shrub Crop Factor values for various performance levels

Performance Level	Turf - Warm Season	Turf – Cool Season	Shrubs – General
Premium, Lush	0.70	0.90	0.80
Medium, Strong Growth	0.55	0.80	0.60
Low Maintenance, Just acceptable	0.40	0.70	0.40

The performance level approach, used by the City of Salisbury (Charlton, 2003) is based on the Irrigation Scheduling Visual Standard (ISVS). The ISVS, which has five levels of performance, is used to adjust the Crop Factor value. For example, an A Grade Sports area would be allocated a Crop Factor value of 0.5 for warm season grasses and a medium quality (B Grade) Passive recreation area would be allocated a Crop Factor of 0.2.

4 EVALUATING IRRIGATION SYSTEMS

4.1 UNIFORMITY

The achievement of high efficiency with sprinkler irrigation systems is dependent on a high degree of uniformity of application. It is not possible to achieve high efficiency with sprinklers that have poor uniformity. If a system with poor uniformity is operated for a set period of time, some areas will be under watered. This results in low efficiency due as some parts of the soil root volume do not receive the programmed amount of water. If the irrigation system is operated so that the under watered areas receive adequate water, then some areas will be over watered, and water is wasted.

In the case of microirrigation systems, high efficiency is dependent on each plant receiving the designated amount of water. If there is a large variation in discharge in emitters, then water is wasted due to the fact that some plants are under watered and some are over watered. Drip systems require a high degree of evenness in the amount of water delivered by each emitter in order to achieve high efficiency.

4.2 DISTRIBUTION UNIFORMITY

A measure of uniformity for turf and landscape is the Distribution Uniformity (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.

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.

M_{25} - average of lowest 25% of readings

The industry standard is that turf irrigation systems should have a minimum DU of 75%.

Whilst this one value of DU (75%) is generally quoted for all turf irrigation purposes, the Distribution Uniformity coefficient has potential application in a number of different ways.

The following is a guide;

New irrigation systems:	DU should be >85%	
Existing systems:	If DU < 75%	System should be repaired
Existing systems:	If DU < 60%	System should be replaced.

A lower value of Distribution Uniformity (DU >65%) should be used for spray systems as the performance of these applicators or heads is not to the same standard as sprinklers (Connellan, 2004).

4.3 PRECIPITATION RATE

The rate at which water is applied to irrigated areas is significant for two reasons. The first is that 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 second role of the system precipitation rate is to allow the determination of the correct depth of water to be applied as part of the scheduling of the irrigation.

It is the responsibility of the system designer to select a system precipitation rate appropriate to the soil type and site.

The precipitation rate of an irrigation system can be calculated theoretically or measured in the field. The field 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 measurement is a standard part of an irrigation audit.

4.4 SCHEDULING COEFFICIENT

The Scheduling Coefficient term is used both in the design of irrigation systems and in the management of systems. It is is both a uniformity coefficient and is used to provide a time adjustment factor to ensure that the dry or under watered areas receive an adequate depth of application.

As a system design parameter it allows sprinklers to be selected so that there is a high degree of overall uniformity (eg. DU > 85%) and there is a narrow range in application depths. The latter performance criteria is achieved by using the Scheduling Coefficient.

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

There are several Scheduling Coefficient terms. The Center of Irrigation, Fresno, (Zoldoske et al, 1994) states that the Scheduling Coefficient is calculated using lowest readings for a contiguous area (1%, 2% or 5%). In the auditing of irrigation systems, the DU is usually calculated using lowest 25% of can readings ($DU_{25\%}$ or DU_{LQ}).

It is increasingly common for new irrigation systems to be designed to achieve an

$SC_{5\%}$ of 1.3 or less.

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

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

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

It is recommended in MaCabe (2003b) that the Run Time Multiplier (RTM) be used to adjust the irrigation duration to account for non-uniformity. This multiplier can be determined using several SC values as the basis for the calculation. Whilst it is common to use DU_{LQ}, the *Turf and Landscape Irrigation Best Management Practices (Draft)* (McCabe, 2003b) recommends that the RTM be calculated with DU_{LH} , which uses the lowest 50% of readings. A consequence of using DU_{LH} is that the time adjustment is less than if DU_{LQ} is used. In an audit test example where the DU_{LQ} was 83.3%, the corresponding DU_{LH} was 87.3% which results in a RTM of 1.15 rather than 1.20. This approach results in adding only 15% to the scheduled run time rather than 20%.

An industry standard for $SC_{25\%}$ is that, it should be less than 1.3

There needs to be caution when using SC to adjust the run time, as very large adjustments can be suggested if the uniformity of the system is only fair. In reality, it would be recommended that the irrigation be corrected, rather than to increase the run time to try and overcome the problem of under watering.

5 URBAN IRRIGATION WATER CONSUMPTION

5.1 REPORTING PERFORMANCE

The urban irrigation industry has tended to use either a simple gross volume of water consumption or “savings” as measures of water consumption performance. Whilst these are helpful within the enterprise and do allow limited comparison with other similar enterprises (similar soils, vegetation, climate, vegetation, conditions etc), they do not fulfill the primary purpose of benchmarking. Performance indicators should allow comparison across the industry and with other enterprises.

5.2 THE IRRIGATION INDEX

The seasonal irrigation water consumption performance can be represented by the Irrigation Index (Ii), which compares the depth of water actually <u>applied</u> to the estimated depth of water <u>required</u> 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:

$$\text{Irrigation Index (Ii)} = \frac{\text{Water Applied to Site}}{\text{Estimated Water Required}}$$

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.

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

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.

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 contributed through rainfall (Re).

Net Water Requirement (IWR) = (ETc – Re) (mm)

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 (Re). 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. An important characteristic of shallow rooted turf is the limited ability to capture rainfall. Also, significant amounts of water can be stored on leaf surfaces and in thatch, which can contribute to the losses

It is reasonable to assume that Re to be 50% for many turf and landscape situations, if daily analysis of rainfall and soil moisture is not possible. The values of average effective rainfall have been determined by the USDA Soil Conservation Service (McCabe, 2003b) to be from 42% to 49% for shallow (150mm) rooted crops. For deeper crops (300 mm), the effective rainfall increases to 48% to 57%.

The sprinkler irrigation system, due to inefficiencies, needs to apply more water than the estimated water requirement (IWR). 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 irrigation system efficiency, which takes into account these losses, can range from very low values up to the vicinity of 90%. Achievable or minimum acceptable system efficiency, such as 75%, can be selected to provide a reference performance standard for turf sprinkler systems.

$$\text{Estimated Water Required } (W_R) = \frac{\text{Net Water Requirement (IWR)}}{\text{Irrigation System Efficiency}} \quad \text{mm}$$

5.3 IRRIGATION INDEX EXAMPLES

An example of a water consumption report is presented in Table 2. The total water consumption shows a reduction in 2003/2004 to 17.250 ML from 21.860 ML in 2002/2003 (21% reduction).

Table 2. Water consumption report example – Sporting ovals

WATER CONSUMPTION REPORT		
Sporting Complex: 4 Ovals and surrounds Total area: 6.0 Hectares Turf: Warm season grass		
	Season 2002/2003	Season 2003/2004
Turf Performance Level	Premium, Lush	Premium, Lush
Crop Factor	0.5	0.5
Water Consumption	21.864 ML	17.250 Ml
Water Depth	364 mm	288 mm
Evaporation (Epan)	850 mm	770 mm
Rainfall	320 mm	370 mm
Irrigation Efficiency	80%	80%
Irrigation Index (Ii)	1.10	1.15

The determination of the depth of water applied is a useful in analysing water consumption. This relates more closely to the irrigation management of the site, as application depths can be more effectively compared. In the case outlined in Table 2, the applied depth was 364 mm compared to 288 mm. Further analysis of the data shows that depth of water applied in 2003/2004 was greater than the amount that should have been applied under optimum conditions. In fact, this analysis shows that the irrigation management performance has declined over the two years as the Irrigation Index has increased from 1.10 to 1.15.

The improvement in water management is clearly demonstrated by the experiences of the Royal Botanic Gardens, Melbourne, where the Irrigation Index values were reduced from 3.5 in 1995-1996 to around 1.0 in 1999-2000 (Symes, 2000). This demonstrated a high level of irrigation performance has been maintained in recent years (2002-2003). (Refer to *Irrigation Management Plan (Reviewed 2004)*, Royal Botanic Gardens, Melbourne, Website http://www.rbg.vic.gov.au/about/water)

In a study carried out by Keig (1994), on ten irrigated sports fields in Melbourne, it was found that Ii values ranged up to 2.75. The actual maximum applied depth of water was 275% of the depth that was considered appropriate for that season.

6 SUMMARY

Performance benchmarking should be strongly encouraged for all irrigated turf and landscape areas as a strategy to improve water use efficiency. The awareness of the benefits of the evaluation of turf and landscape water management practices and the auditing of urban irrigation systems needs to be greatly increased.

As a minimum requirement all urban irrigated areas should be evaluated in terms of uniformity and the depth of water applied over the irrigation season.

Some key activities are the collection of accurate water consumption data, installation of dedicated irrigation water meters and adoption of auditing programs for all irrigation systems. Initially auditing should be directed at selected key sites to gain a representative view. The evaluation process will need to be an ongoing part of the management of turf and landscape assets.

Benchmarking the performance of turf and landscape irrigation systems will become an important part of urban environmental management in the future. Importantly performance reporting also provides the opportunity for the irrigation industry to showcase the good irrigation practices that do exist in environmental horticulture.

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