DEVELOPING WATER MANAGEMENT STRATEGY FOR COMPLEX LANDSCAPES

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ABSTRACT

Empirical analysis of evapotranspiration (ET_o) and crop coefficients (K_c) is readily available for plant monocultures such as many agricultural crops and ornamental turf. However, these constitute relative homogeneous plant communities and soil environments. Evapotranspiration (ET_o) rates of plants and subsequent water consumption in highly diverse urban landscapes are inadequately understood, particularly when considered in the context of water scarcity from increasing population demand, reform and climate change impacts.

Precision scheduling of irrigation in garden beds, comprising mixed plantings, requires knowledge of not only the water requirements of the plantings, but also the soil water behaviour. The root systems of different species are spread over varying depths and soil properties can change down the profile. Additionally ground treatments such as mulch, significantly influence the way in which water, rainfall and irrigation enter the soil.

A trial has been established at the RBG Melbourne to gain an understanding of the water movement (infiltration, extraction and drainage) in complex landscapes, and to examine the influence of hydrophobic conditions on soil water holding capacity and infiltration, to gauge the effectiveness of irrigation and rainfall on the soil water balance. Central to the trial are permanently installed, multiple sensor capacitance probes (EnviroSCAN$^{®}$). The sensors are linked to a web based site accessible, in real time, to the research partners.

Current anecdotal landscape coefficients (ET_L) are reviewed against the research undertaken within the Royal Botanic Gardens Melbourne. Adaptive water management strategies are proposed for enhancing irrigation scheduling practices in complex, multi-tiered urban landscape vegetation types. Evapotranspiration rates are quantified by analysing data from an automatic weather station, soil moisture sensing technology, and assessments of plant performance.

Proposed is a novel stress indicator called the Evapotranspiration Stress Index (ETSI) and is based on measurements of volumetric soil moisture and ET_o data.

It is expected that the research outcomes will be defined to further inform the improvement of irrigation scheduling in urban landscapes and public open space.

INTRODUCTION

Complex Landscapes – Nature, Role, and Benefits

Complex urban landscapes present distinctive challenges for effective irrigation strategies to improve water use efficiency. The vegetation characteristics of these sites include multi-layered canopy tiers with plant forms such as trees, shrubs, perennial herbs and grasses occupying the same canopy silhouette, and competing for water and nutrients in the same soil profiles. Compounding this diversity is significant microclimate and edaphic spatial variation, even at the sub-metre area basis.

At the macro level, these landscapes often cover many hectares which in turn, can increase the potential diversity for management. Aesthetically, these sites often appear with dynamic relationships between void and mass. Large lawn areas provide the void spaces, interspersed with ornamental shrubberies and trees either as individual specimens or as arboretum elements comprising the mass. Pending the maturity of the landscape, much of the planting can be compared to woodland or forest in appearance.

Plant and habitat assortment in peri-urban and urban environments provides multiple niches for fauna to survive, even proximate to and within cities and towns. There are significant opportunities for visitors to learn about plant adaptations and relate their importance to our environmental and social wellbeing, notwithstanding recreational benefits. For horticultural industries, complex landscapes provide spaces to demonstrate adaptive management practices and improve knowledge of plant cultivation.

The picturesque, heritage, landscape of Royal Botanic Gardens Melbourne (RBG Melbourne) is one example of landscape complexity of over 38 hectares of managed land. There are over 50,000 individual plants represented from over 10,000 taxa including rare and endangered species in the living collections. These come from a variety of habitats and geographical locations around the world, and are grown over an inner-city site of varying topography and aspect. RBG Melbourne curates a greater level of plant diversity than what is found naturally within the State of Victoria where over 3,500 taxa have been recorded (Ross and Walsh 2003).

Visitation trends for the Gardens have been rising under a regime of increasingly stringent water restrictions. In 2006-07, about 1.4 million visitors were counted - up from about 1.2 million in 2005-06. During peak summer conditions, increases in patronage of 20-30% have also been noted.

Irrigation Challenges and Management of Complex Landscapes

As custodians of a heritage landscape and cognisant of the need for water conservation, the Royal Botanic Gardens seeks to sustain healthy plants and living collections with the minimum water consumption possible. Irrigation is aimed at supplementing rainfall to achieve moderate rather than lush rates of plant growth. Allowable depletion rates of 50%-75% of Readily Available Water (10-300 kPa suction) are applied to provide some level of water stress, rather than maintaining high levels of soil moisture. This reduces water demand by significantly reducing evapotranspiration rates (Mark Skewes pers. comm. 22 June 2005). Other strategies that were applied included professional development; adoption of current infrastructure and technology; improvement of application efficiency; development of performance management indicators; public reporting for accountability in water consumption, and reduction in water demand through plant selection.

Judgement of irrigation scheduling by horticultural employees from an assessment of plant health is one approach that remains highly valued by the Royal Botanic Gardens, except that this is potentially open to a range of subjective and variable management practices. Since 1994-95, the RBG irrigation scheduling approach incorporated more objective estimations of plant water loss using Class A pan evaporation data (Epan) and crop factors (CF) (Connellan and Symes 2006) to derive two generic scheduling regimes for gardens and turf areas. Since 1998, the installation of an Automatic Weather Station (AWS) provided ET_o estimates [modified Penman-Monteith algorithm (FAO 1990)] which were used to calculate landscape evapotranspiration (Costello and Jones 2000).

Generic values for evapotranspiration were applied relatively effectively across the plant diversity of the landscape. However, advances in staff expertise, irrigation control software; and the imperative to lift water use efficiency to a higher level, required greater precision. In 2006, a differential irrigation scheduling framework was developed based on management policy, qualitative assessments of landscape priorities and microclimates, edaphic variation and required plant performance.

Due to the existing water restrictions regime, a pertinent factor in the assessments was the requirement to achieve greater water savings whilst ensuring landscape survival. Despite this, some plant losses and detrimental impacts to tree health resulted from the 2006-07 experience that was attributed to lack of water. It was judged that continuing this irrigation regime over the longer term would result in further accumulated stress and deaths of many of the significant plant specimens. In late 2007, the ET_L rates were revised to ensure the continued health of the landscape whilst seeking to maintain efficient water management.

Other challenges of managing irrigation in complex landscapes include interception of precipitation by vegetation canopies and plant debris. Some studies on canopy interception of mature trees have found rates of 10-40% of the annual rainfall caught and evaporated from the canopy (Lull 1966; Tate 1996; Xiao et al. 2000) without ever reaching the ground layer. Technical trials in RBG Melbourne indicated about 4-8 mm of rainfall from a single precipitation event could be intercepted and prevented from reaching the soil surface by tree and shrub canopies. It was found that trees with smaller leaves and dense, fine-textured canopies such as Conifers and Melaleucas intercepted the most rainfall, while trees with large leaves such as the Moreton Bay Fig (*Ficus macrophylla*) and those with vertically orientated foliage such as *Eucalyptus* spp. intercepted the least (Symes and Connellan 2004). Highly significant interception is possible in multi-tiered urban vegetation canopies. For example, preliminary research from a Monash University Honours project (*Rainfall partitioning and soil repellency in the Royal Botanical Gardens of Melbourne, Victoria, Australia*) indicated an average 82 % canopy interception of a single 10 mm rainfall event (Alison Cull pers.com. 6 March 2008) within the Australian Forest Walk.

One of the other emerging concerns for the Gardens is the proliferation of hydrophobic (water repellent) soil conditions across the landscape. Predisposing factors may include a dominance of organic sandy loams, deficit irrigation practices, and significantly lower annual rainfall over the last ten years. This may be more a problem of perception, as a greater water management focus has increased the level of observation and monitoring of soil moisture levels over this time also. It is possible that hydrophobic soils may have been as widespread and present in urban landscapes such as the Gardens for many years prior. Nevertheless, the current necessity to improve water use efficiency is focusing attention towards enhancing soil moisture holding performance. Landscape trials are being developed in RBG Melbourne to investigate environmentally sustainable techniques to remediate soil water repellency. It is currently understood that water can preferentially flow (Kramers et. al. 2005) through water repellent soil layers to accumulate further down the soil profile. This has also been found in many areas of the Gardens as soil sampling across the landscape indicates high water repellency typically in the top 100 mm of the soil profile - with improved spatial wetting below. In effect, the management of irrigation scheduling with hydrophobic soils may need to reconsider the wetted soil depth paradigm on the basis that the available soil water reservoir is not from the surface to the bottom of the effective rooting depth, but rather it is identified as the effective rooting depth below the water repellent layer – in some cases this may be below 100 mm from the soil surface.

Empirical analysis of urban landscape evapotranspiration is one of the most significant challenges presented, particularly when compensating for the high levels of plant, soil and microclimate diversity that occur. Limited development of this understanding is incongruous with the emphasis on best practice water management. In RBG Melbourne, landscape coefficients (K_L) have been applied - originally based on some existing literature on crop factors (Handreck and Black 2001), and since 1998, on crop and landscape coefficients (Costello and Jones 2000). Adaptive management based on observations of plant performance has largely been the driver for fine-tuning of these coefficients. Soil moisture sensing technology was applied in a limited fashion to help correlate the irrigation scheduling models that were used, but required expansion across the landscape to provide more meaningful comparisons.

Complex Landscapes Water Management

Development of Garden Bed Irrigation Schedules

Evolution of irrigation scheduling in urban landscapes has progressed from time-based programming which was often irrespective of weather conditions and plant performance, to a more sophisticated application of a greater spread of inputs such as climatic data, evapotranspiration estimation methodologies, soil moisture sensing, and increasing anecdotal knowledge of plant performance. Furthermore, a greater emphasis on water use efficiency and the insecurity of water supply presented by greater regulation and restrictions has increased priority setting of water allocation within respective landscapes. This preferential irrigation is usually based on the perceived values or expectations of quality given to different areas or components of the landscape. The setting of subjective quality standards in urban horticulture has generally been a vexing and contentious dilemma, let alone linking these standards to irrigation scheduling for various landscape performance levels.

There are various methodologies for estimating plant evapotranspiration (ET_c). Two terms that are often used are Crop Factors (CF) and Crop Coefficients (K_c) (Connellan and Symes 2006).

a) ET_c = Crop Coefficient (K_c) x Reference Evapotranspiration (ET_o)

b) ET_c = Crop Factor (CF) x Pan Evaporation (Epan)

These are plant specific expressions. However, complex landscapes are characterised by diverse vegetation with multiple root systems and canopy tiers coexisting within the same square metre of garden bed. In these situations, it is recommended that an improved approach is to apply a 'landscape evapotranspiration' formula to obtain a mean estimation of evapotranspiration across the hydro-zone. Costello and Jones (2000) outline a method that incorporates reference evapotranspiration (ET_o), a landscape coefficient (K_L), plant species factor (k_s), microclimate factor (k_{mc}) and vegetation density factor (k_d) to estimate Landscape Evapotranspiration (ET_L) and is summarised below:

c) $ET_L = K_L (k_s \times k_{mc} \times k_d) \times ET_o$

This methodology does not include landscape management prerogatives such as water resource scarcity. Deriving levels of desired landscape performance (Connellan and Symes 2006) are a contemporary issue and are described further.

Assigning levels of quality or priorities help complete the development of the irrigation schedule. Another way to consider quality ranking in this context is through the amount of water stress that is allowed for particular landscape areas. For instance, areas that were managed in a lush fashion would normally be subjected to only very low levels of water stress (unless waterlogged), while areas not irrigated at all would be subject to very high stress (unless adapted to local climate) (Connellan and Symes 2006). The Royal Botanic Gardens has linked its irrigation scheduling to priority levels (see Table 1 for current RBG 2007-08 landscape coefficient classification). This has resulted in an improved water distribution to the relevant irrigation zones without significantly increasing overall consumption for the relative climatic conditions.

Table 1 - RBG Melbourne Landscape Coefficient Classification

Landscape Coefficient

Landscape Priority	Rank	K_L	K_L	K_L
	High X	0.4	0.5	0.6
	High	0.4	0.5	0.5
	Medium	0.3	0.4	0.4
	Low	0.2	0.3	0.3
		Low	*Medium*	*High*
		Scheduling Requirement		

Examples of High Scheduling Requirement

Median January Water Requirement (mm)	RBG Landscape Zones
102	Fern Gully, Australian Forest Walk, Southern Chinese Collection
82	General Living Collections
62	General Landscape
41	General Landscape (low priority/demand)

Soil Moisture Sensors in Scheduling

Knowledge of the soil moisture content of the soil and the response of plants to soil moisture conditions is essential for precision scheduling of irrigation. The soil moisture level is typically determined using a predictive technique through ET estimation and conducting a soil water balance. Soil moisture sensing allows the actual value of soil moisture to be an input into the scheduling decision making process. The incorporation of soil moisture sensing in the control process as feedback makes this a true “closed loop” type of control.

Access to soil moisture data significantly expands knowledge of plant and soil water behaviour. Identification of the time the soil moisture levels reaches a set-point value, to initiate irrigation, is only one application of the technology.

The nature of the soil moisture data that can be obtained determines how it can be used. The number, location and precision of sensors and frequency of readings are all important. Whilst a single sensor, positioned within the root zone and monitored on a daily basis, provides valuable information, the installation of multiple sensors greatly expands the knowledge base. The installation of multiple sensors at selected positions down the soil profile allows soil moisture in the different soil zones to be monitored and changes between zones to be analysed. Continuous monitoring of sensors with access through the internet, in real time, provides the opportunity for enhanced analysis of the plant soil system.

Portable probes provide for assessment of variations in plant water use (ET_C) rates across the various hydro-zones of the landscape.

Graphical presentation of soil moisture data allows not only absolute values to be read but also the changes in soil moisture conditions to be readily interpreted.

The nature of the information available from a range of soil moisture data groups is presented.

(A) Data group – Soil moisture at specific depths (refer to Figures 1-4)

Information provided: Refill point, Occurrence of stress and Size of soil water reservoir

(B) Data group – Changes in soil moisture level - Depletion

Information provided: Plant water use (ET_C) and Drainage

(C) Data group – Changes in soil moisture - Addition

Information provided: Rainfall contribution and Irrigation contribution

Examples of how soil moisture data can be used to provide a better understanding of aspects of the water management of complex landscapes are presented.

(a) Identification of active root zones

Through comparison of water extraction rates, as reflected by a decrease in soil moisture, from different layers in the root system, it is possible to gain an appreciation of the absolute rate of extraction for a layer and to identify which parts of the root system are active relative to other layers. Analysis of extraction from different layers allows the role of different root zones to be identified.

(b) Estimate of the Crop Coefficient (K_c) value

Monitoring the extraction of soil moisture over defined time periods, for example a day, week, month, allows the amount of water used by the plant to be compared to the potential evapotranspiration rate for the same period. Access to concurrent weather data is required. The proportion of the water used by the plant to the reference evapotranspiration (ET_o) rate for the same period is a guide to the Crop Coefficient value.

It should be noted that only the vegetation represented by the soil volume with the soil moisture sensor can be used in this type of analysis.

(c) Influence of water logged conditions on plant growth

Ideal conditions for plant growth and water uptake include access to water, nutrients and oxygen. Following irrigation, heavy rainfall events and under poor drainage conditions soil pore spaces are full of water and oxygen is displaced. Continuous monitoring of soil moisture levels, following these events and saturated conditions, analysis of the rate of soil moisture depletion (if any) provides an insight into the reduced plant extraction rate compared to non saturated (e.g., Field Capacity) rates.

(d) Effectiveness of irrigation

The aim of irrigation is to deliver water into the root zone at high efficiency. Monitoring of soil moisture, particularly in the surface soil layers, readily shows the entry of water into the soil and down the soil profile. Through measurement of irrigation application a water balance can be carried out to evaluate the efficiency of application. In some cases hydrophobic soil conditions may be identified.

(e) Effectiveness of rainfall

Knowledge of the contribution of rainfall to soil moisture reservoir is essential in achieving high water use efficiency. Monitoring of surface soil layers show how much rainfall is beneficial. The contribution or otherwise of small rainfall events, for example 2 to 4 mm, can be evaluated and also high intensity events, where significant losses may occur.

(f) Drainage characteristics of the soil

Understanding the movement of water down the soil profile, through the monitoring of increasing soil moisture levels, in particular soil layers, over time, is valuable in appreciating the water behaviour of the soil over the whole root zone depth. Low drainage rate soils and potential drainage losses below the plant root zone can be detected.

Adaptive Management Practice

A current lack of scientific study of ornamental plant water use highlights the need for adaptive management in irrigation scheduling. This may be defined as a cyclic process through obtaining the relevant baseline information (soil hydraulic characteristics, plant type, climate information); setting initial targets (evapotranspiration estimations and levels of performance); implementation (scheduling); monitoring results (measuring soil moisture/water balance and observing plant health). As a continuous improvement system, the cycle begins again with periodic updating of baseline information, revision of targets, and so on.

Complex Landscape Soil Moisture Sensor Project

Trial Design

In May 2007, the Royal Botanic Gardens Melbourne, Sentek Pty Ltd and the University of Melbourne formally commenced a partnership project to study landscape and plant water use over an initial 12 months. One of the main outcomes of the project was to develop more quantifiable rates of landscape water use in complex plantings. Central to the project are permanently installed, multiple sensor capacitance probes. The sensors are linked to a web-based site accessible in real time to the research partners. In attempting to determine the best method for irrigating zones that contain a wide variety of mixed vegetation, (i.e. a combination of ground covers, herbaceous plants, shrubs, and trees), four distinct "zones" within the Gardens were selected for monitoring using capacitance probes to compare the soil moisture trends with modified Penman-Monteith ET_o measurements (Automatic Weather Station), and irrigation scheduling practices (refer to Table 2).

Sandy and loamy soil types are included across the trial sites. However, while there are subsets of these soil types, the hydraulic characteristics of these soils were considered to be all very similar in the effective root-zones across the Gardens. The Royal Botanic Gardens soil survey (Van Rees et al. 1993) indicates typical Readily Available (RAW) water contents of about 47 mm per 200 mm depth for all the main soil types: Loamy Gradational, Sandy Yellow Duplex and Loamy Yellow Duplex.

Table 2 -Trial Site Characterisation

Bed	Probe Designation	Aspect	Soil Type	Vegetation Type
Rose Species Collection	RBG1A	Fully exposed to sun and windy conditions, no overhead canopy.	Deep Loamy	Single woody, deciduous vegetation strata. Chosen as the monocultural reference site to other locations.
Viburnum Bed	RBG2A RBG5A	North-easterly, full sun until late afternoon; less exposure to northerly winds than Triangle Bed, overhead tree canopy.	Deep Loamy	Multi-tiered vegetation strata comprising high density of woody shrubs and perennials with large deciduous mature trees.
Triangle Bed	RBG3A	Northerly, full sun, some exposure to northerly winds..	Deep Loamy	Multi-tiered vegetation strata comprising medium-high density of woody shrubs and perennials with small tree overhead canopy.
Herbarium Bed	RBG4A	Northerly exposed to high sun and infrared radiation, some protection from northerly winds by garden plantings about 50 metres away, partial overhead canopy from background large mature trees.	Deep Sandy	Multi-tiered vegetation strata comprising medium density of mixed mesophytic and xerophytic 'fashionable' planting in foreground, also dominated by woody shrub planting and mature tree root extraction from back of bed. Site also chosen to determine the influence of tree roots on water use.

It was acknowledged in the trial design that due to the vegetation diversity and density that it would be very difficult to obtain complete coverage from a minimum of 4 sprinkler heads for most of the trial sites. Improvements to sprinkler coverage were only to be undertaken if it was part of a normal maintenance practice for that particular situation.

Primarily, the trial focus was determining the higher expected landscape evapotranspiration rates in the landscape, and then ultimately using this data to manage the expected lower water use sites. Subsequently, the areas were selected on the criteria of microclimates with northerly aspects, high sun and wind exposure, dominated by medium to high density woody plantings. The RBG Species Rose collection site was chosen as a reference site that is typical of many common ornamental monocultures.

MATERIALS AND METHODS

Capacitance Soil Moisture Probes

The Sentek probes contain capacitance sensors, which use differences in the dielectric properties of soil and water to derive a measure of the Volumetric Water Content (VWC) in the soil. This is calculated from electrical signals from the probe, which are related to a standard curve based on a reference sandy loam organic soil (Paltineanu, 1997). No site–specific soil calibration has yet been performed for the trial sites.

Five Sentek probe systems were installed in 4 separate garden beds at the Royal Botanic Gardens Melbourne. The sites chosen were: Species Rose Garden (RBG1A), Viburnum Bed (RBG2A, RBG5A), Triangle Bed (RBG3A) and Herbarium Bed RBG4A). Four probes used the same type of sensors, but the hardware differed slightly in functionality: 3 were EnviroSCAN Plus® systems with remote telemetry downloading their data to a web site; one was an EnviroSCAN Solo® unit and another was an RT6 unit. The latter 2 units were required to be downloaded manually, but their data was displayed on the same web page for easy viewing by any of the collaborators and RBG employees generally.

Climatic Data and Evapotranspiration

Weather data was collected on-site by a Vaisala Automatic Weather Station (AWS) which included a modified Penman-Monteith algorithm [(Food and Agriculture Organisation of the United Nations (FAO) (1990)] in the software to calculate reference evapotranspiration and a tipping bucket rain gauge (0.2mm tips). The ETo and rainfall data was incorporated into the analysis via IrriMAX® software. To measure and confirm the actual and effective rainfall for each trial site, five catch cans were installed in a circle 15 cm away from each soil moisture sensor to avoid interfering with water infiltration. One 'control' catch-can was placed as proximate and in an open area as possible for each trial site to compare any rainfall variation with the AWS.

Indicator Plants and Bed Performance

A digital image record was maintained of the trial sites including the condition of specific indicator plants. Images were captured on a routine basis, and as a response to soil moisture condition as indicated by the sensor readings.

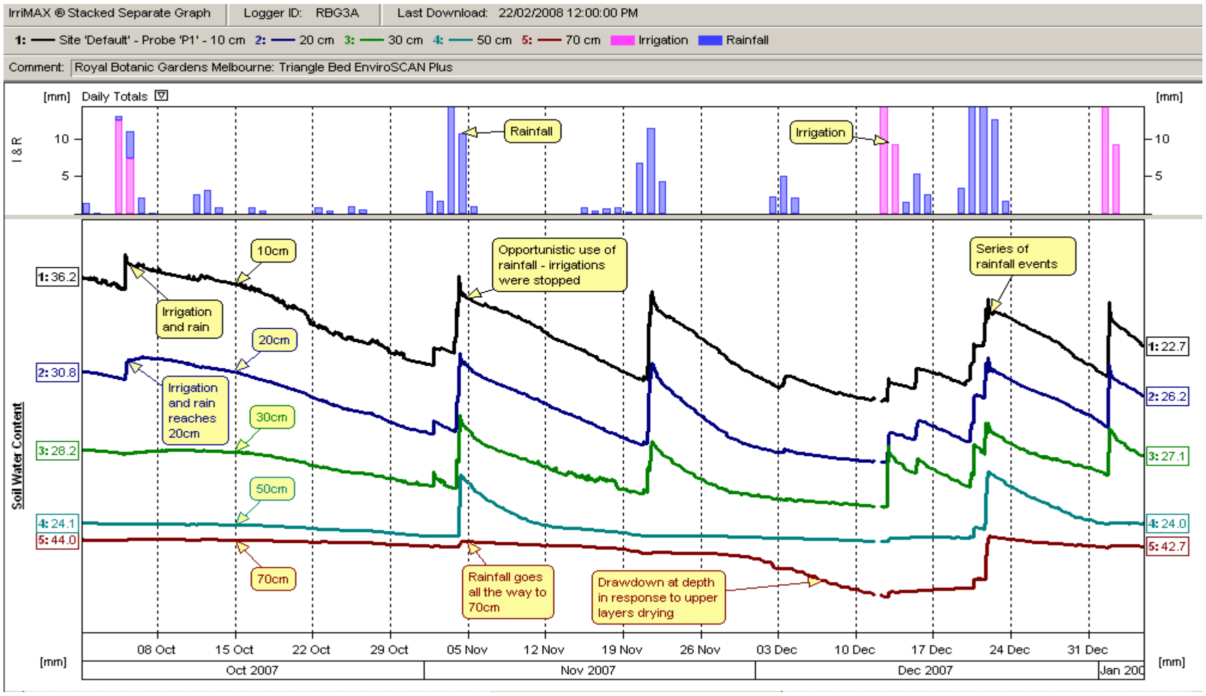
RESULTS and DISCUSSION

Separate level and summed soil moisture graphs provide a detailed view of the changing water status throughout the profile that is being monitored.

The graphs in Figures 1, 2 and 3 show the soil water contents at each individual sensor depth being monitored within the profile. Each coloured line represents one 10cm depth layer within the profile. The lines are arranged in depth order, with the shallowest on top, and the deepest at the bottom of the graph. Every graph line is displayed at the same scale.

Figure 4 shows the sum of water content, measured by varying sensors, and is determined in a profile as the sum of soil water content of these sensors over time. In other words, this graph takes the water contents from all the different layers being monitored within the profile and sums them together, to show the total water storage and movement within the whole profile.

Units on the Y-axis represent Total Soil Water Content in millimeters for the selected profile. Units on the X-axis represent time in hours, days or months."



IrriMAX ® Stacked Separate Graph | Logger ID: RBG3A | Last Download: 22/02/2008 12:00:00 PM

1: — Site 'Default' - Probe 'P1' - 10 cm 2: — 20 cm 3: — 30 cm 4: — 50 cm 5: — 70 cm Irrigation Rainfall

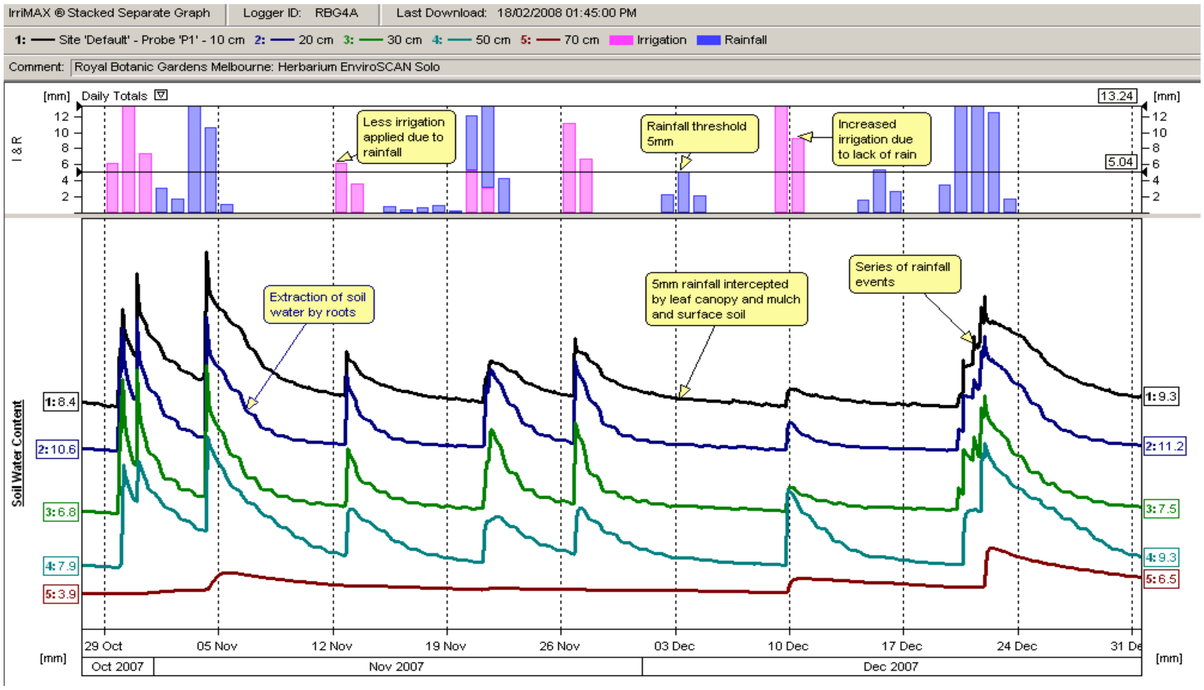
Comment: Royal Botanic Gardens Melbourne: Triangle Bed EnviroSCAN Plus

Figure 1

Triangle Bed - RBG3A, Stacked Separate Level Graph

Figure 1 shows a typical stacked level graph from the probe in the Triangle Bed. The tracings have been separated for clarity of use, and show the Volumetric Water Content at 10, 20, 30, 50 and 70cm depth levels in the major pane. In this way, it can be seen that a series of rainfall events on 4 November 2007 infiltrated to a depth of 70cm. Because of the rain, irrigations were temporarily ceased. Drying of the upper profile over the next few weeks then caused the plants to activate deeper root systems to maintain water status.

In the minor pane are displayed the irrigation and rainfall events recorded during the same time-span.



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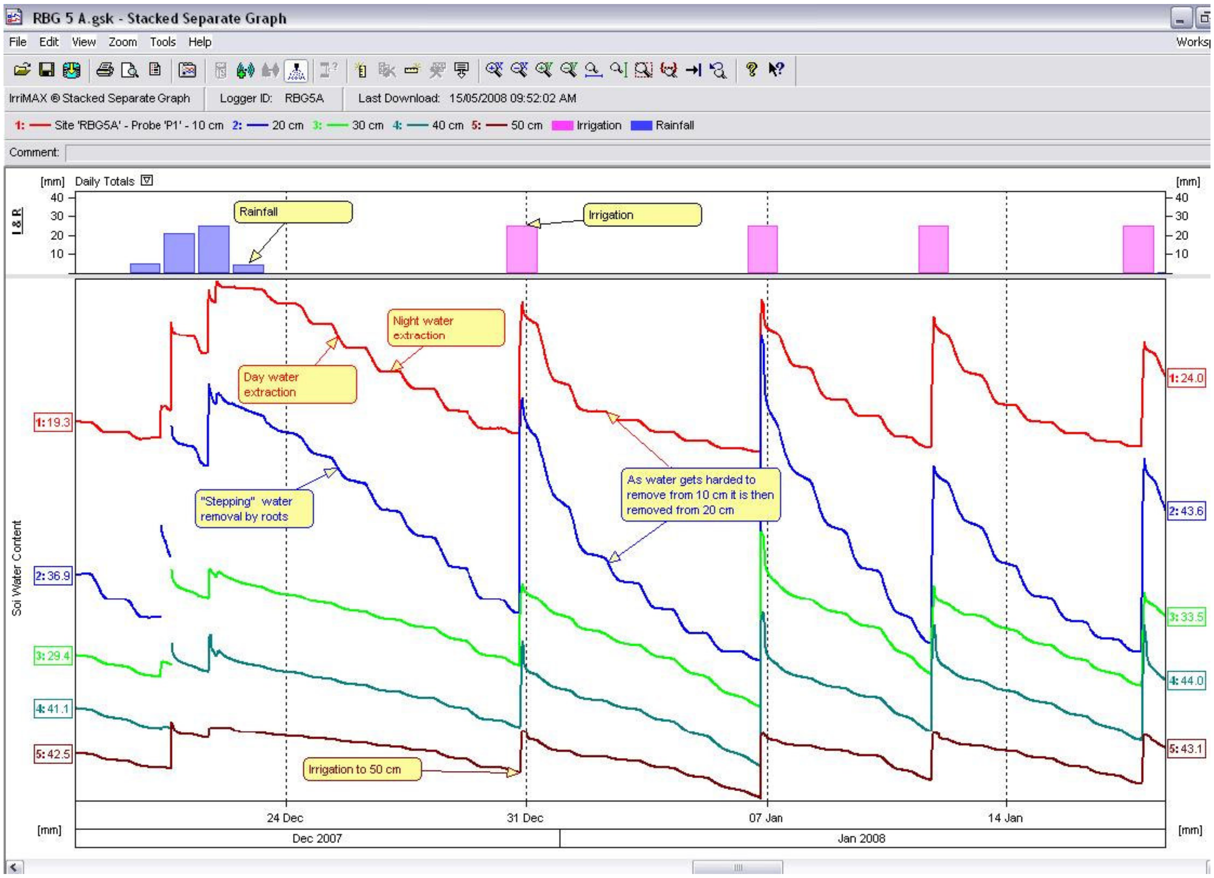
1: — Site 'Default' - Probe 'P1' - 10 cm 2: — 20 cm 3: — 30 cm 4: — 50 cm 5: — 70 cm Irrigation Rainfall

Comment: Royal Botanic Gardens Melbourne: Herbarium EnviroSCAN Solo

Figure 2 Herbarium Bed - RBG4A, Stacked Separate Level Graph

Figure 2 shows the Volumetric Water Content trace from the Herbarium Bed. It shows a typical example of the “stepping” that occurs due to the different amounts of water extracted by the plant and natural drainage during the day as compared to the night. It also shows that there is a clearly defined Rainfall Threshold below which no water is detected in the top 10cm of the soil. This gives an indication of the relative losses due to canopy and mulch interception. The top pane also shows the irrigation management interventions made in response to the rainfall events.



Night water extraction

Day water extraction

"Stepping" water removal by roots

As water gets harded to remove from 10 cm it is then removed from 20 cm

Irrigation to 50 cm

Figure 3
Viburnum Bed - RBG5A, Stacked SeparateLevel Graph

Figure 3 shows the typical “stepping” trace of water as it is extracted by the plant roots. During the day, the plant loses water which it has gained from the soil through transpiration from its leaves. During the night, transpiration essentially gives way to respiration, and most water losses from the soil are due to drainage. As data is monitored in real time by soil moisture sensors (every 15 minutes in this case), it is possible to visualize these small changes as a “step” in water status. Also demonstrated here is the plant’s ability to remove water from greater depth as it becomes difficult to remove from the surface layers. Plants vary in their ability to do this, and these results are complicated that in a mixed bed planting, the root density profile is also complex.

Garden Bed Soil Water Management

The soil moisture data recorded throughout the trial period provided an insight into the water balance of garden beds. Soil moisture readings illustrate the nature and relative importance of the processes involved in water entry, storage, extraction and drainage in these complex plant/soil systems. Positioning of the soil moisture sensors is critical to achieving accurate and representative data. Some of the factors include consideration of the prevailing microclimate, edaphic conditions, vegetation palette and dominant root extraction.

In many mature urban landscapes, trees will dominate the landscape evapotranspiration rates even if some distance away. It is understood that non-confined root proliferation of many trees and woody plants can potentially extend to 2-3 times the canopy diameter (Harris 1992). The extent of this tree root domination was also observed and monitored through moisture extraction at depth. For instance, the RBG1A trial site in the Species Roses Collection was dominated by root extraction of mature trees surrounding the location. This ‘Root Halo’ highlights the importance of site selection, and suggests more attention to specific irrigation control through greater hydro-zoning, although on the large landscape scale, this would dramatically add to the complexity and maintenance costs of irrigation systems. Alternatively, one solution may be to provide specific irrigation to particular trees through sub-surface or sub-mulch irrigation systems in an attempt to reduce root extraction beyond the canopy silhouette.

High vegetation density impacts on the effective coverage and uniformity of above ground irrigation systems. In particular, an average 30% to 88% of scheduled irrigation applied was measured proximate to the soil moisture probes. Poor sprinkler layout can exacerbate inefficient water delivery and RBG2A was found to be a key example. Some obviously needed remedial work resulted in improvements from 30% to 50%. Many of the garden bed irrigation designs in RBG Melbourne rely on matching required precipitation from adjacent turf hydro-zones. This overlap was found to supply insufficient water in some cases – often compounded by vegetation impediment of the sprinkler stream.

It is recommended to avoid prevailing extremes of soil moisture content for sensor placement by catch-can testing for irrigation uniformity and precipitation rates. However, soil moisture probes also assist in detecting and alerting irrigation managers to anomalies from 'normal' irrigation cycles such as those caused by faulty sprinklers, station malfunctions, pressure variations, etc. This was demonstrated through the differing extent of wetting patterns through the soil profile from standard scheduling events.

Rainfall interception by upper tier vegetation canopies and mulch layers was also a pertinent factor for all the trial sites. Typically, rainfall only appeared effective in increasing soil moisture content if individual amounts were over 4-5 mm as measured by the RBG Automatic Weather Station (AWS). From May 2007 to February 2008, average canopy interception of total rainfall over the probe sites ranged typically from 22-45% compared to AWS data. The variation of rainfall effectiveness for respective events and sites was monitored and readily observed through soil moisture sensing. This reinforces the importance of applying an 'effective rainfall' factor in irrigation scheduling methodology.

Frequency of scheduling was readily informed by tracking soil moisture trends concurrently with irrigation schedules. Throughout the partnership project period, the trials highlighted the diversity of soil water loss and plant uptake across the landscape. In some cases, usual irrigation scheduling was paused to prevent overwatering after viewing soil moisture trends for those sites, particularly in cooler months and or dominated with deciduous vegetation extraction. The value of hydro-zone specific irrigation design and scheduling is highlighted, along with the feedback provided by the soil moisture probes to 'close the loop' in irrigation control.

Evapotranspiration Stress Index (ETSI)

Plants are considered to be under moisture stress if the availability of soil moisture is less than the potential evaporative demand of the plant. Severe stress occurs when evaporative demand is high (high air temperature, high vapour pressure deficit) and the soil moisture is low or "dry". If soil moisture is readily available under these demanding conditions, the plant, if healthy, will transpire readily. The ratio of the reference evapotranspiration rate (ET_o) to the actual amount of water extracted (used) by the plant provides a measure of the availability of water or, as proposed with this index, the level of moisture stress. The ratio, referred to as the Evapotranspiration Stress Index (ETSI), and is defined as: $ETSI =(ET_o /DWU)$.

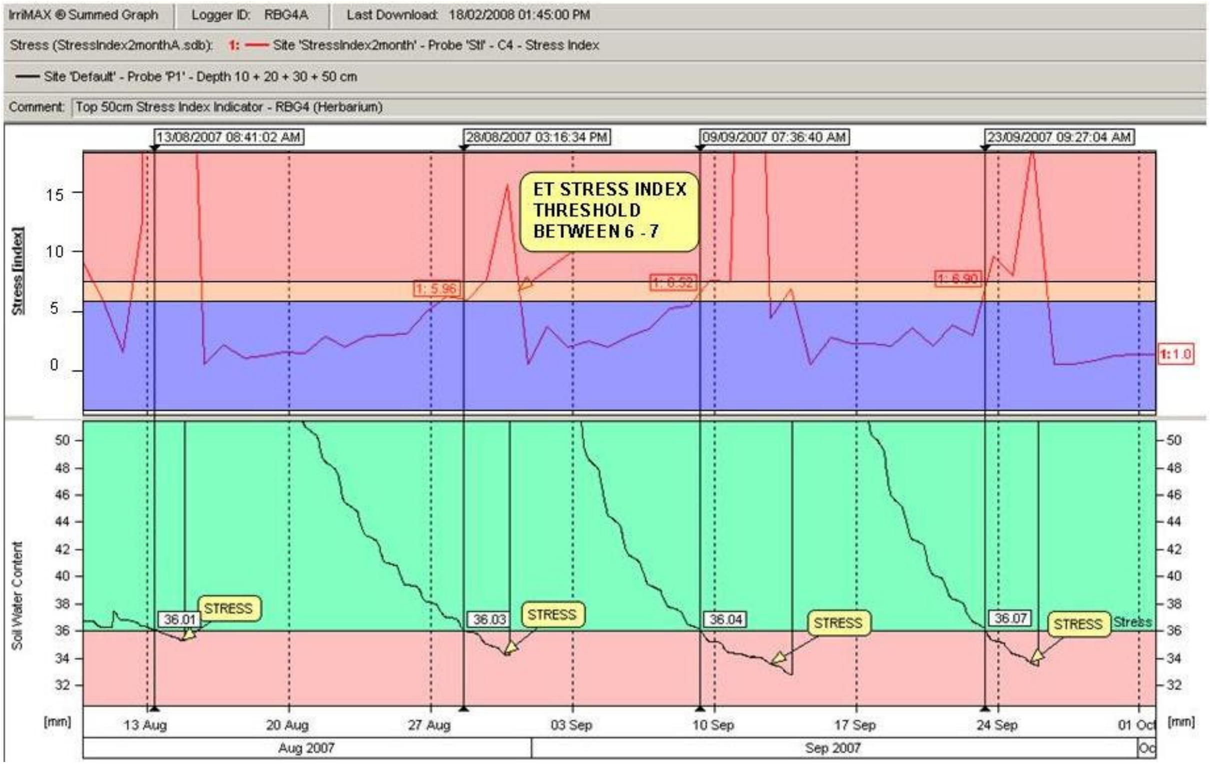
Daily Water Use (DWU) is the amount of water used by the plant in a day. It is calculated by subtracting the volumetric water content at the end of the day (VMC_F) from the volumetric water content at the start of the day (VMC_S). A correction was made for drainage during the day by the water loss observed during the previous night. The volumetric soil water content can be readily obtained using soil moisture sensors that measure water content. Daily ET_o values are also required. These values are readily available from local or on-site weather stations.

The ETSI value reflects the reduced extraction or decreased stepping down of soil moisture on a daily basis. If the rate of decrease is reducing and there is ongoing significant evaporative demand, then plant stress will be increasing. Reduced rate of decrease may be due to reduced evaporative demand, for example, cloudy cool days. If the ratio is high, the plant is considered to be severely stressed. If it is close to, or in the range of 1.0, then is considered that water is available to the plant and it is not exhibiting stress.

The ETSI allows the plant soil water system to be monitored in detail. The traditional approach is to assume to a soil water depletion amount to identify a refill point for irrigation. In the ETSI approach the soil water conditions, including degree of plant stress, can be continuously monitored.

There will be various categories of plant response to the amount of stress experienced by the plants. Ideally the ETSI will be linked to observed plant stress. The actual stress experienced by the plants will depend on the species. Some species, such as perennial herbs, will readily show visible signs of stress. Woody species would tolerate higher levels of soil moisture depletion prior to showing signs of stress.

It is proposed to identify a range of stress categories to be used in conjunction with ETSI values as a decision making tool for irrigation managers. This can inform the optimum time to irrigate against pre-determined levels of 'allowable' soil moisture depletion.



IrriMAX ® Summed Graph | Logger ID: RBG4A | Last Download: 18/02/2008 01:45:00 PM

Stress (StressIndex2monthA.sdb): 1: — Site 'StressIndex2month' - Probe 'StI' - C4 - Stress Index

— Site 'Default' - Probe 'P1' - Depth 10 + 20 + 30 + 50 cm

Comment: Top 50cm Stress Index Indicator - RBG4 (Herbarium)

Figure 4
Herbarium Bed, RBG Melbourne - RBG4A, ETSI

Figure 4 shows the ETSI calculated for a series of stress points experienced by the plants in the Herbarium garden bed. As the soil dries, the plant uses more energy to extract less water per day, and the plant is stressed (shown by line entering the red section). This slow-down in soil water extraction is routinely used to identify the point of 'Onset of Stress' (Ref: http://www.sentek.com.au/home/default.asp - Data Interpretation Manual). The longer the plant is extracting water under these conditions, the greater is the stress. This is reflected in the top pane as a sharp rise in the ETSI at these times. An ETSI threshold can be clearly seen at between 6 and 7.

Future Developments

Calibration

This study has been based on relative soil water dynamics calculated on a standard default calibration equation for an organic sandy loam soil. To develop the ET Stress Index (ETSI) further, site specific calibration for the trial sites will be required to more precisely relate ET_o to absolute Daily Water Use (DWU). Moreover, it is expected that this calibration will provide more accurate information to quantify landscape coefficients (KL) and derive landscape evapotranspiration (ETL) values. These values could be used to compare the accuracy and or relevance of the ‘Landscape Evapotranspiration Formula’ methodology to Australian conditions as described by Costello and Jones (2000).

Practical application of ETSI

As the ETSI is proposed as a practical day-to-day irrigation management tool it still requires more fine-tuning and testing to validate this approach. As a second stage of the research project in 2008-09, it is planned to assign certain stress thresholds to selected garden beds in the Royal Botanic Gardens Melbourne. Expert horticultural observation and soil moisture data would be used to monitor stress symptoms of selected indicator plants within these hydro-zones. It is expected that a range of ETSI values could then be correlated with the visual symptoms and developed for effective irrigation management of complex urban landscapes.

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