IRRIGATION MANAGEMENT IN TURFGRASS

A CASE STUDY FROM WESTERN AUSTRALIA DEMONSTRATING THE AGRONOMIC, ECONOMIC AND ENVIRONMENTAL BENEFITS

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INTRODUCTION

The Perth metropolitan region has over 13,500 ha of turfgrass irrigated from groundwater reserves (del Marco 1990). The majority of turf is grown on highly permeable sandy soils. Careful management is therefore required to achieve an acceptable balance between maintaining turf quality, reducing water use and minimising water and nutrient loss beyond the rootzone.

In response to the paucity of locally applicable information on turf water and nutrient management, the “Turf Irrigation and Nutrient Study” (TINS) was initiated in 1990. Its objectives were to provide a better understanding of water and nutrient use in turfgrass grown on sandy soils. Stage 1 of the project identified that overwatering was common on sands of the coastal plain and recommended that improved irrigation scheduling practices be developed as a major component of improved water and nutrient application strategies (TINS stage 1 Report, 1990).

Stage II of the TINS project aimed to provide an improved understanding of turfgrass water requirements and develop better water management strategies for turfgrass on sandy soils. This paper summaries some of the results from the irrigation research component of this project.

One of the difficulties encountered in conducting irrigation research on sandy soils is in measuring rates of water movement through the profile. Conventional methods used for this type of research (such as neutron probe) are very labor intensive and are incapable of detecting changes in the soil moisture content within the small time intervals necessary to fully describe water movement patterns throughout the profile. Frequent, simultaneous monitoring at a number of profile depths and for a prolonged period is required to provide a full understanding of water movement patterns. Recent advances in technology have seen a range of soil moisture sensors and monitoring systems come on to the market. Agriculture Western Australia has carried out a critical appraisal of a range of soil moisture sensors (Aylmore et.al. 1994,), and is using the EnviroSCAN Soil Moisture Monitoring System for its water/nutrient management work with horticultural crops.

MATERIALS AND METHODS

The EnviroSCAN system utilises capacitance sensors that measure the complex dielectric constant of the soil- water medium. As change in soil dielectric properties is attributable almost exclusively to change in water content measured changes in soil dielectric properties can be interpreted by the system as changes in volumetric soil water content to 0.1% accuracy (Buss, 1993.) Sensors are mounted one above another on a probe, which is installed within a vertical PVC access tube in the ground at representative monitoring sites. Subsurface probes have been developed for use in turfgrasss applications. Probes are networked via buried cables to a central logging facility enabling continuous monitoring of soil water data at different sites as frequently as every minute. Data can be downloaded via cable to a portable computer on site, or remotely via radio frequency to the office computer off-site.

The software for data collection and analysis is particularly user friendly enabling rapid and versatile graphic display of data recorded at multiple depths. Visual interpretation of data to determine soil

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water dynamics is straightforward and intuitive requiring only basic computing skills.

The site chosen for the study was a recently established (18 months old) Wintergreen couch turf on a low intensity use sports reserve situated in the northern suburbs of the Perth metropolitan region. The soil was a deep sand of the Karrakatta series and is well above the water table. The turfgrass was irrigated with Hunter 130 sprinklers (nozzle 9) on an 18m equilateral triangle spacing, using an automatic control system. Groundwater was pumped to the surface using a Grunfos SP 45/15 submersible pump.

Two irrigation regimes were open in operation at this site between 17 February 1995 and 1 May 1995:

- **Current Practice** – Turf was irrigated using the practice currently adopted by the local council. This comprised daily irrigations of 40 minutes duration (approximately 42mm water per week) throughout the summer irrigation period. This irrigation strategy is in operation for over 500 hectares of turfgrass managed by this council.

- **Managed** – Irrigation commenced when soil moisture levels in the rootzone (0-50cm) declined to a level known to induce mild drought stress in the turf. Sufficient water was applied at each irrigation to return soil moisture levels in this zone to around “field capacity”. Soil irrigated under this treatment was thus maintained within moisture content limits which we will refer to as: *The refill point* defined as the moisture content at which mild drought stress first becomes apparent and *field capacity* defined in this case as the moisture content at which water movement beyond the root zone drops to an acceptably low rate. These limits determined empirically for each treatment during an observation period prior to commencement of the trial in which visual assessment of turfgrass performance were related to EnviroSCAN readings.

Irrigation events averaged approximately 70 minutes duration under the managed regime compared to 40 minutes per event under current practice regime with water application rates the same for both treatments.

The EnviroSCAN was set to record soil moisture content continuously at 10-minute intervals. Two probes (10m apart) monitored the current practice site and two probes (10m apart) monitored the managed site. All probes were subsurface with sensors located at 10, 20, 30, 40 and 50 cms. The system was in place between September 1994 through to February 1996. The current practice regime was programmed via the on site controller. In the strategically managed regime irrigation events were initiated manually after inspection of soil moisture profiles down loaded from the EnvrioSCAN system.

RESULTS AND DISCUSSION

The EnviroSCAN software allows inspection of data for up to one year in a single view. The Excel spreadsheet format used to prepare the following figures permits display of data from only 4000 recording events. Thus the data chosen to illustrate soil moisture dynamics of the two irrigation systems comes predominantly from a 4 week period between 1st March 1995 and 28th March 1995.

Throughout this period the current practice regime required 19 irrigation events; a total of 760 minutes pumping (19 events @ 40 mins/event). Had normal irrigation practice not been interrupted by two pump breakdowns total pumping time would have been 1,150 minutes. In the same period only 7 irrigation events were required on the managed regime; a total of 500 minutes pumping.

Figure 1 shows the volumetric water content of soil under the current practice regime between 1st March 1995 and 28th March 1995. Water content is expressed as depth of water within the rootzone (nominated at 0-50cm). Figure 2 shows the volumetric water content of soil under the managed regime for the same period.

The Field capacity (32mm) and refill points (15mm) shown on both figures indicate desirable upper and lower soil moisture contents respectively. Comparison of figures 1 and 2 clearly shows that while current irrigation practice maintained soil moisture content above field capacity for much more of the period, managed irrigation was able to maintain soil moisture contents within the desired limits for the whole period. Note that the final watering event shown in these figures was due to heavy rainfall, the only significant precipitation recorded within the monitoring period.

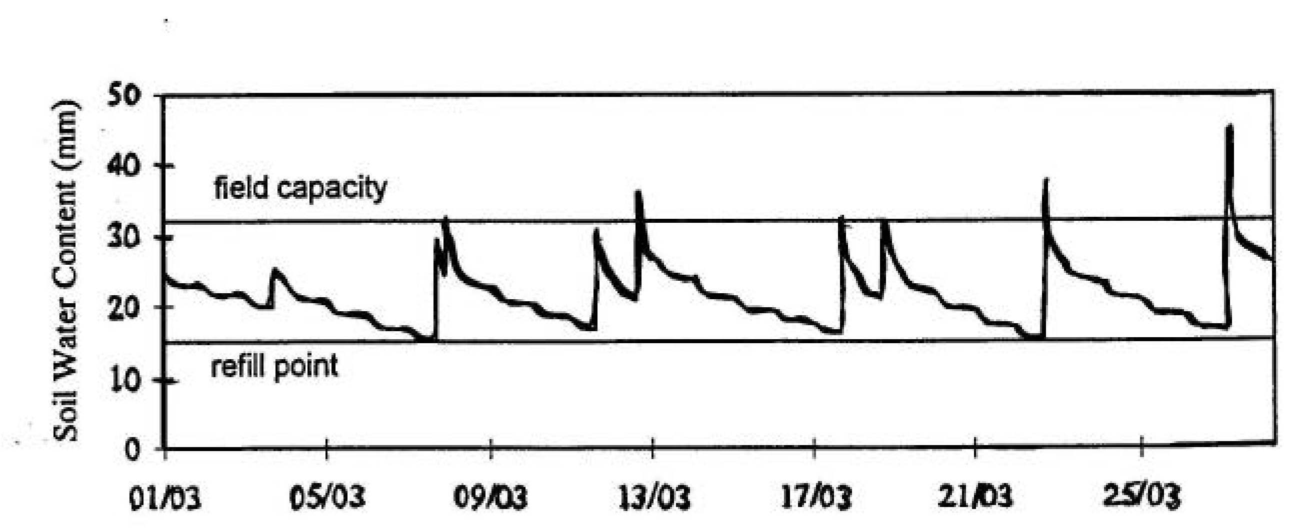
The ability to strategically delay or modify irrigation events in anticipation of rainfall enhances the water use efficiency advantage achieved under the managed regime. Dry soil has the capacity to accept and store (as plant available water) rainfall which would drain rapidly through an initially moist soil.

Figure 1:
SOIL MOISTURE REGIME IN THE ROOTZONE OF TURFGRASS UNDER CURRENT PRACTICE REGIME

Current Practice Summed Over Rootzone

Figure 2:
SOIL MOISTURE REGIME IN THE ROOTZONE OF TURFGRASS UNDER MANAGED IRRIGATION

Managed Regime Summed Over Rootzone



A more detailed picture of soil water dynamics the rootzone is revealed in figures 3 and 4. Figure 3 shows the volumetric soil moisture content at mean depths of 10, 20, 30, 40 and 50 cm between 1st March 1995 and 28th March 1995 for turf irrigated under current practice. Figure 4 shows the equivalent data set for turf under the managed regime. In contrast to the managed site where moisture content at 50cm remained low and essentially constant, soil under current practice was maintained at higher moisture contents throughout the profile and shows evidence of significant drainage beyond 50cm.

Figure 3:
SOIL MOISTURE REGIME AT FIVE DEPTHS IN THE ROOTZONE OF TURFGRASS UNDER CURRENT PRACTICE REGIME

Current Practice Individual Sensor Readings

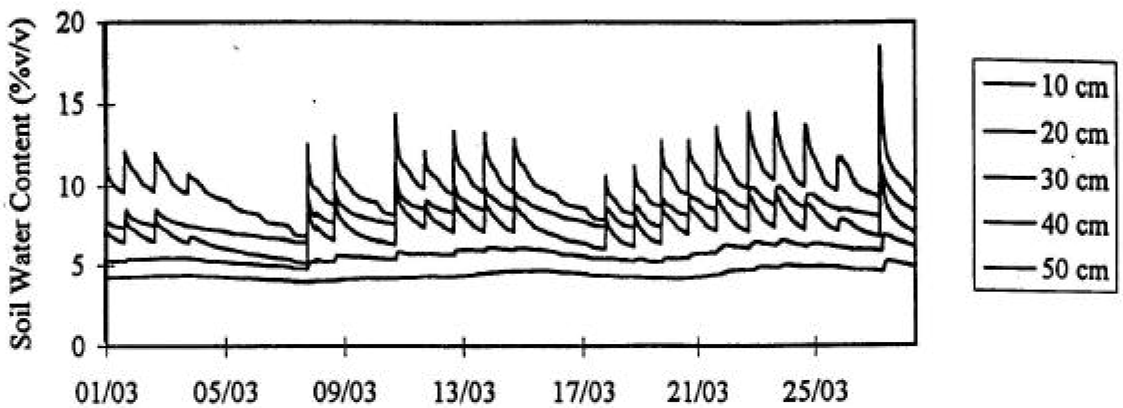
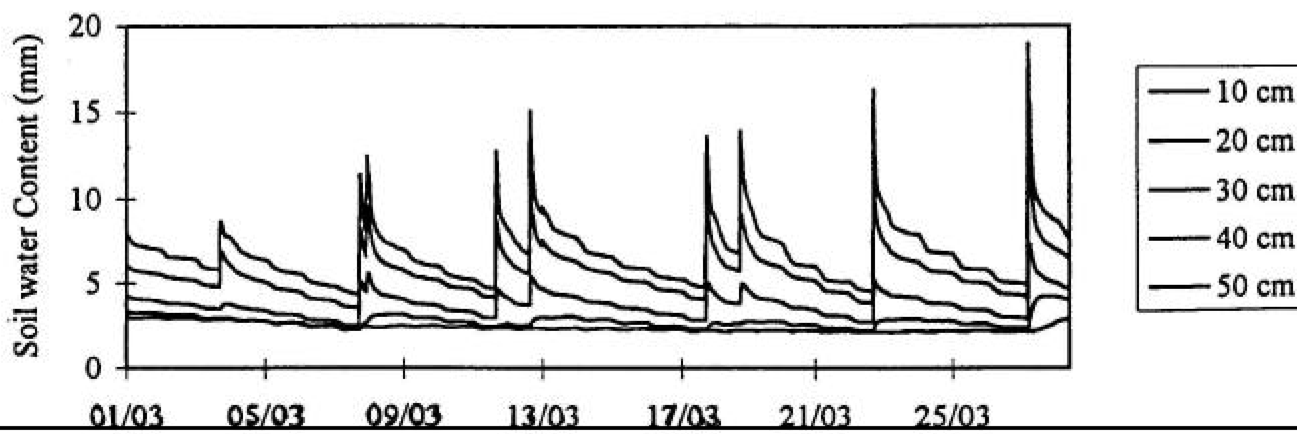


Figure 4:
SOIL MOISTURE REGIME AT FIVE DEPTHS IN THE ROOTZONE OF TURFGRASS UNDER CURRENT PRACTICE REGIME

Managed Moisture Regime At Five Depths In The Rootzone Of Turfgrass Under Managed Regime



From these measurements we can conclude that implementing the managed irrigation practice minimised water drainage beyond the zone of greatest root activity, minimised the opportunity for nutrient leaching and reduced irrigation requirement for maintenance of adequate turf condition by over 60%.

One of the advantages of reduced irrigation frequently lies in promoting more uniform exploitation of the soil moisture reserves by plant roots, effectively increasing the root accessible volume of the soil water reservoir. Figure 5 presents water use data for a six day period following a rainfall event (18mm in 3 days) in managed turf. Bars indicate water usage from each of 5 depths (10,20,30,40,and 50cm) for each day of the drying cycle. Data for the managed regime are presented in Table 1 for total daily water use, pan evaporation and water use as a percentage of pan evaporation.

Figure 5:
DAILY WATER EXTRACTION FROM FIVE SOIL DEPTHS FROM 31ST MARCH TO 5TH APRIL 1995

Soil Water Extraction (mm/day) with depth- Managed Regime

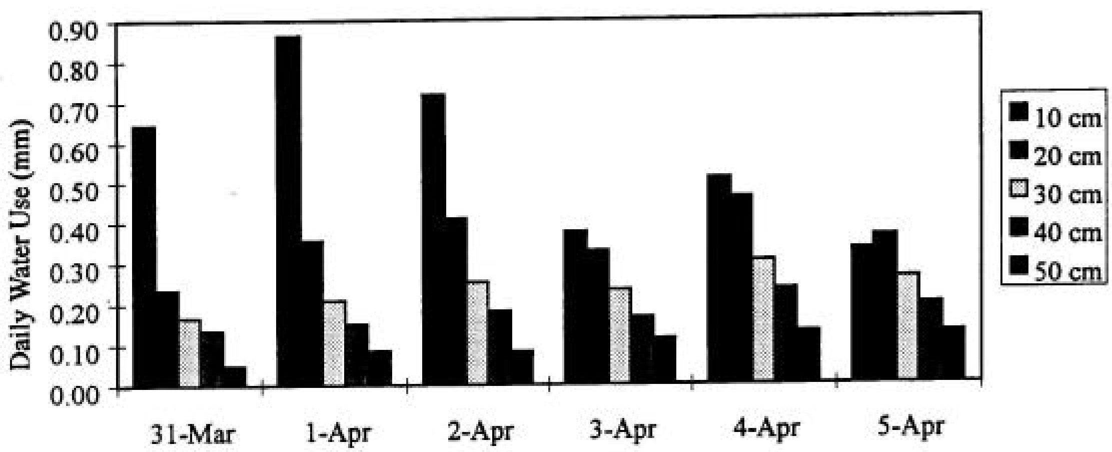


Table 1 WATER LOSS AND EVAPORATION DATA- MANAGED REGIME[1]

	31-Mar	1- Apr	2-Apr	3-Apr	4-Apr	5-Apr
Water Used (mm)	1.2	1.7	1.6	1.2	1.6	1.3
Pan Evaporation(mm)	5.0	6.4	6.8	4.2	12.2	6.0
% Pan Evaporation	24.5	25.9	24.1	28.8	13.4	21.4

1 **31st March to 5th April 1995**

Daily water use varies in response to evaporative demand and soil moisture status, it is clear however that the proportion of daily water requirements met from the upper part of the profile is decreasing and from lower in the profile is increasing with the duration of drying.

Similar findings have been reported elsewhere in the literature, for the example Garrot & Mancino (1994) working on couch turf in Arizona found that after irrigation, water use increased in the top 30cm of soil and decreased at the lower depths. As the top 30cm of soil dried, soil water from 30-60 cm and 60-90 cm deep regions of the profile contributed a progressively greater proportion of total turf water use.

The frequent continuous monitoring of soil water content afforded by the EnviroSCAN system is of great assistance to turf managers in scheduling irrigations to meet plant requirements as they vary with management practice and environmental (mainly evaporative) conditions. With frequent monitoring and an adequate set of criteria on which to base irrigation decisions, the turf manager no longer needs to play safe with frequent irrigations which promote greater evaporative loss during the water application, luxury water consumption by turf and potential for through drainage. The EnviroSCAN system takes the risk out of implementing more adventurous regimes.

Regulation deficit irrigation (RDI) is becoming standard practice with many crops in horticulture so as to manipulate plant growth process (Goodwin, 1995). Table 2 presents a comparison of clippings dry matter harvested on both current practice and managed regimes for the 69 day period from 21 February 1995 to 1 May 1995. The results demonstrate that vegetative growth was significantly reduced (by 73%) under the managed regime. Provided turf quality is not adversely affected, reduced vegetative growth reduces the need for mowing throughout the irrigation period. It has been demonstrated that Deficit irrigation can be used to reduce turfgrass growth rate, (cell elongation) which will reduce the requirement for extra capital investment tied up in the expensive mowing equipment and a reduction in labor, fuel and maintenance costs without affecting turfgrass appearance.

TABLE 2 COMPARISON OF VEGETIVE GROWTH[2] TWO IRRIGATION REGIMES

	Current	Managed
Sample 1	13.8	2.6
Sample 2	6.8	2.0
Sample 3	7.8	3.2
Mean[3]	9.5	2.6

2 21 February 1995 to 1st May 1995 (69 days)
3 Dry matter of clippings
Whole field has been mown 2 weeks earlier
Yields were determined by mowing 10m strips with a 50cm walk behind reel mower

The results from the comparison between the Current Practice and Managed regimes showed that the Managed regime lead to significant savings in both water and energy costs (Tables 3, 4, 5 & 6). The information provided by the EnviroSCAN soil moisture monitoring system enabled the scheduling to be more closely matched to the plant requirements. The savings in water and energy were due to being able to reduce drainage below the rootzone and reduced luxury water consumption.

TABLE 3:
COMPARISON OF TWO IRRIGATION REGIMES[4]

	Current	Managed	% Reduction
Number of Irrigations	58	11	81
Total Run Time (mins)	2320	870	63
Quantity Irrigation (mm)	387	145	63
Total Epan (mm)	508	508	-
% of Epan	76	29	-

4 **21 February 1995 to 1st May (69 Days)**

TABLE 4:
COMPARISON OF TWO IRRIGATION REGIMES OVER AN IRRIGATION SEASON[5]

	Current	Managed	Saving
Pump Cost (hr)	$2.26	$2.26	-
Application rate (mm/hr/ha)	3.96	3.96	-
Quantity Irrigation (mm)	1382	518	864
Pump hrs (hr/ha)	349	131	218
Pump costs ($/ha)	789	296	493

5 **Calculation based on 220 day season**

TABLE 5:
WATER SAVINGS ACHIEVED OVER THE IRRIGATION SEASON[6]

Water Applied	Current	Managed	Saving
Megalitres/ha	13.82	5.18	8.64
Megalitres/ 100 ha	1382	518	864
Megalitres/500 ha	6910	2590	4320

6 **Calculation based on 220 day season**

TABLE 6:
POWER SAVINGS ACHIEVED OVER THE IRRIGATION SEASON[7]

Power usage	Current	Managed	Saving
$/ ha	789	296	493
$/ 100 ha	78800	29600	49300
$/ 500 ha	394000	148000	246500

7 **Calculation based on 220 day season**

During this period there has been over a 60% reduction in water use between the current site and the managed site with no adverse effects on turf quality detectable. These savings in irrigations will have enormous impact in terms of water savings and hence fertiliser and as well as economic benefits due to a reduction in pumping and therefore energy costs. For local council with 500 ha of irrigated turfgrass area, this can be costed out into dollars and megalitres saved- real measurable benefits. Over a season this equates to $246,000 in energy costs saved and over 4,320 megalitre saved per annum per council who are irrigating 500 hectares. The return on investment on capital purchase of the EnviroSCAN soil moisture monitoring system can be assessed on the savings achieved.

A local council irrigating turfgrass can be divided into management units based on the grouping of turfgrass areas which have similar characteristics (for example location, soil type, turfgrass species, age and usage). Therefore there would be a number of sports fields or parks grouped into one management unit with these similar characteristics. Each management unit would require a separate irrigation regime so as to meet the site specific requirements.

The capital cost to monitor a management unit with the EnvrioSCAN Soil Moisture Monitoring System is approximately $20,000.00. Based on the energy cost savings alone, the return on investment over a 5 year period is 408% or 4 times the investment made.

TABLE 7:
RETURN ON INVESTMENT FOR 100 HA AND 500 HA OF TURFGRASS AREA[8]

Area (ha)	Management Units	Capital Cost $	Capital Cost $/per annum	Saving $/per annum	Return on Investment %
100	3	60000	12000	49000	408
500	15	300000	60000	245000	408

8 Amortised over a 5-year period

Using meteorological data to determine plant-water requirements is the main method used by irrigation managers in the turf industry to schedule irrigations. This is based on the fact that atmospheric conditions dictate to a large degree the rate of soil-water loss by evaporation and transpiration. The pitfall of this method is that it is a global, indirect, single point estimation of turfgrass water use and not site specific, nor a direct and continuous measurement of the soil dynamics and changes that occur rapidly in the sandy soil profile.

Until recently, the measurement of soil moisture by soil sensors to schedule irrigations has been met with mixed results by the West Australian turf industry. This has been due to the poor reliability of product, inadequate installation and diagnostic procedures, no local technical support, poor training of the irrigation operators who interpret the data collected and no ongoing agronomic support. The EnviroSCAN has proven to be reliable in this trial (550 days) with no down time due to product failure. (Five days of logging were missed due to an external power supply problem). Local technical support provided no more than 6-12 hour turnaround time when any issues arose and ongoing agronomic support and operator training was provided throughout the trial period.

SUMMARY

In the past 15 years, irrigation management in Australia has targeted and achieved a range of management objectives that have lead to significant commercial gains and environmental benefits (Moller & Buss, 1994).

Guesswork in irrigation management is costing the turf industry unnecessary financial losses and the undesirable impact on sensitive groundwater sources, waterways and estuaries. This paper has defined a water management system which is available to the turfgrass industry to provide an efficient, cost effective management system of water resources for irrigation in a sustainable way. In conclusion, the challenge for the turf industry is to embrace new methods of irrigation management. How long can we afford to go on guessing using traditional irrigation methods, when the results from this irrigation research have demonstrated the following:

- **Maintenance of turfgrass quality using less water:** The turfgrass grown under the managed regime maintained the appropriate turfgrass cover and strength for the purpose that it was intended for. It has been demonstrated that deficit irrigation can be used to conserve water by up to 63% without significantly effecting the quality of the turfgrass surface

- **Regulate turfgrass growth processes (controlling vegetative growth):** The turfgrass grown under the managed regime showed a 73% reduction of vegetative growth which was desirable in terms of reducing the number of mowings required throughout the irrigation period. It has been demonstrated that Deficit irrigation can be used to reduce turfgrass growth rate, which will reduce the requirement for extra capital investment tied up in expensive mowing equipment and a reduction in labour, fuel and maintenance costs associated with mowing.
- **Save water, fertiliser and reduce irrigation input costs:** Irrigation amount and frequency was tailored on a regular basis to meet the turfgrass development needs, evaporative demand and ensure that a deficit was available to harvest rainfall inputs when required. The ability to analyse each separate level allowed the placement of the wetting front of each irrigation to a targeted depth preventing overwatering and leaching of fertiliser below the bottom of the effective rootzone of the turfgrass. Significant savings have been demonstrated in water and thus fertiliser input costs. Over the duration of the trial the managed regime achieved 63% savings in water and energy.
- **Optimise the use of a limited water supply:** Pressures are increasing with competing uses within the community for a finite water resource. Better utilisation of existing water resources will ensure that meeting demand for future water resource needs can be managed in a sustainable manner.
- **Minimise ground water, waterways and estuary pollution:** The turf industry is a significant water user in the Perth metropolitan area. The sandy soil of the Swan Coastal Plains increases the potential problems of leaching water and nutrients. The correct placement of water and fertiliser through continuous soil water monitoring and irrigation scheduling will minimise leaching into deeper soil layers below the rootzone and into groundwater sources waterways and estuaries.
- **Return on Investment:** It has been demonstrated based on the energy savings alone, using continuous soil water monitoring and irrigation scheduling of turfgrass, the return on investment over a 5 year period on the capital cost of the EnviroSCAN Soil Moisture Monitoring System is significant at 408% or 4 times the investment made. A higher return of investment will be achieved if the cost savings for the purchase of water, and a reduction in purchase of expensive mowing equipment, reduced labour, fuel and maintenance costs for mowing and reduced fertiliser input costs were included in the assessment process.

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EnviroSCAN Case Study in Cotton

Introduction
Cotton is currently Australia's fifth largest crop and its estimated export worth is now AUD$1.6 billion (ABARE, 2000).

Tony and Sally Quigley, recipients of the 1999 Australian Cotton Grower of the Year Award, own and manage an irrigated cotton farm of 350Ha in Trangie, New South Wales.

In New South Wales there is an estimated 298 400Ha of cotton being farmed on irrigated land, with an average yield of 1.7t/Ha. (ABARE, 2000). The Quigleys have traditionally produced yields higher than the average, but still felt that they could continue to increase yields with better control of their cropping process. A total farm management system was introduced, with an EnviroSCAN® to continuously monitor soil moisture levels playing an integral role in further improving farm management. Over the first three years of using data from the EnviroSCAN to schedule irrigation events a 20% increase in yields was reported as well as water and labour savings.

EnviroSCAN's Positive Influence on Farm Management Practices
"As a key component of our total farming system, Sentek's EnviroSCAN has helped us to fine tune our irrigation and farming practices, allowing us to save water, reduce labour and increase yields", Tony said.

A lack of accurate, continuous data from previous irrigation methods prompted Tony to change to EnviroSCAN. "In the past, I used a neutron probe, but this only gave me a snapshot of how my crops were using water" Tony said.

The continuous monitoring of multiple depths at multiple sites providing instant water management information has enabled Tony to significantly reduce irrigation related expenses and improve crop yields.

EnviroSCAN has allowed the Quigleys to reduce the number of irrigations they make per season by knowing exactly when the crop needs water. By setting his EnviroSCAN to monitor crop water usage each hour, Tony discovered he could irrigate just as the crop reaches moisture stress, reducing the number of irrigations per season from eight to six, which in turn reduced the number of waterlogging events each season.

How the Quigleys use EnviroSCAN
The Quigley's EnviroSCAN monitors soil moisture levels on an hourly basis. The data is then downloaded as frequently as once a day depending on the weather and how close the crop is to needing irrigation. The easy to read graphs tell the Quigleys exactly when the crop is nearing moisture stress requiring an irrigation. The graphs also help Tony determine how much water is needed to keep the crop in the zone of "optimal" soil moisture for as long as possible. Also, as cotton is three times more sensitive to waterlogging than any other stress, a key benefit for Tony has been the ability to reduce the number of days the crop spent in waterlogged conditions.

EnviroSCAN's Accuracy
Tony's farming consultant regularly cross checks his neutron probe data with Tony's EnviroSCAN data to validate the data from the neutron probe. The EnviroSCAN's accuracy, as reported by many leading commercial, research and agricultural groups (see Appendix A), allows Tony's farming consultant to obtain a more accurate picture of district trends in water use.

Increased Profits achieved by the Quigleys
The Quigleys have significantly increased profits as a result of their farm management system, in

which irrigation management with an EnviroSCAN system plays a crucial part. Direct achievements contributing to their increased profits have included:

- ✓ Increased Yield – The Quigleys have increased yields from an average of 8 bales/Ha a season to an average of 9.8 bales/ha over the last three seasons - an increase of over 20%!
- ✓ By using data from EnviroSCAN to schedule irrigation events, the number of waterlogging events for the cotton crop have been significantly reduced. "This allows more days for the crop to grow during the season, allowing it to produce greater yields" Tony said.
- ✓ The use of EnviroSCAN has also enabled Tony to extend the growing season by seven to ten days.
- ✓ At $454/bale in the 99/00 season, over 350Ha of cotton farming, that equates to an increase in revenue of $286,020. (ABARE, 2000)
- ✓ Water Savings – Water savings of 1.5ML/Ha over 350 hectares have resulted in a total reduction in water use of over 525 ML/season. At $10.50/ML, a total saving of over $5,512.50 has been realised each season just in water savings.
- ✓ "EnviroSCAN has reduced our water use from around 9 ML/Ha to 7.5 ML/Ha.
- ✓ Water use efficiency has also gone from 0.9 bales/ML to 1.3 bales/ML of total water use" states Tony. This was achieved by a reduction in the number of irrigation events. EnviroSCAN data showed that Tony had been irrigating more often than necessary in previous seasons.
- ✓ Labour Savings – Tony has been able to reduce his labour input into irrigation related matters by 35 to 70 hours per season. EnviroSCAN has enabled Tony to review the exact soil moisture content at different levels, from many different sites scattered across the property in one convenient location. This eliminates the need to check soil moisture levels manually. Also, a reduction in the number of irrigations means that labour input associated with an irrigation event have been reduced.

Return on Investment Within the First Season

The Quigleys' investment in an EnviroSCAN for their cotton property was returned within the first season through water cost savings alone. Increased yields and reduced labour inputs were an additional bonus for the Quigleys. This is presented below:

Table 1. Water Savings

Water Applied	Before EnviroSCAN	After EnviroSCAN	Savings
ML/Ha	9	7.5	1.5
Total ML at Quigley's	3150	2625	525
Total Water Cost	$33,075	$27,562.50	$5,512.50

Table 2. Yield Results

Yield Increase	Before EnviroSCAN	After EnviroSCAN	Yield Increase
Bales/Ha	8.0	9.8	1.8
Total Bales at Quigley's	2 800	3430	630
Total Value in $	$1,271,200	$1,557,220	$286,020

(Assuming 1999/2000 average of $454/bale)

Conclusion

The Quigley's investment in EnviroSCAN has contributed significantly to their success in relation to return, water savings and increased yield, highlighted by the figures below:

- ✓ Over 20% increase in yield
- ✓ Growing season extended by 7-10 days
- ✓ Increase in revenue of $286,020
- ✓ A 525ML reduction in water use – saving $5,512.50
- ✓ Saving of 35-70 hours a season in irrigation related matters

- ✓ An increase of 0.4bales/ML of water applied

Based on these results, Tony believes that "EnviroSCAN is miles ahead because it delivers a continuous picture of soil moisture – in simple terms the crop is showing me how to grow itself".

The Quigleys are now planning to expand their EnviroSCAN system to monitor another group of fields with a heavier soil type and different field history. Telemetry options available with EnviroSCAN which enable remote downloading of data utilising a radio, phone or modem may also prove useful for another farm owned by the Quigleys which is 25km away. This technology will enable the Quigleys to make irrigation management decisions for this second farm without having to leave the office.

Overall, the use of EnviroSCAN has become an integral part of the award winning farm management strategy devised and successfully executed by the Quigleys. The associated increase in returns and reductions in water use and labour have ensured the effort the Quigleys have contributed has been returned several times over.

Reference List

Australian Bureau of Agricultural and Resource Economics (ABARE) ***The Australian Cottongrower Cotton Year Book*, 2000**

Appendix A

For further information on the accuracy of EnviroSCAN, please refer to the following published articles:

Fares, A &Alva, AK ***Evaluation of capacitance probes for optimal irrigation of citrus through soil moisture monitoring in an entisol profile*** **Florida Ag. Experiment Station J Series No. R06105 (1999)**

Mead, RM & Ayars, JE *Evaluating the Influence of Soil Texture, Bulk Density and Soil Water Salinity on a Capacitance Probe Calibration* Paper presented at ASAE Summer Meeting (1995)

Morgan et al. *Field Calibration of a Capacitance Water Content Probe in Fine Sand Soils* Soil Sci. Soc. Am. J 63:987-989 (1999)

Paltineanu, IC & Starr, JL, *Real-time Soil Water Dynamics Using Multisensor Capacitance Probes: Laboratory Calibration* Soil Sci. Soc. Am. J 61:1576-15-85 (1997)

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