Report for the South East Natural Resource Management Board

Irrigation Efficiency Project

Surface Irrigation Project

A study of surface irrigation system performance in the South East of South Australia

Definitions

Following Walker (1989), the term 'surface irrigation' refers to a category of irrigation systems in which water is distributed at the field level via a free surface, overland flow regime. Surface irrigation methods are further divided according to system configuration and management requirements. The surface irrigation method most common in the South East of South Australia is border check, in which a field is divided into sloping borders, or 'bays', as illustrated below.

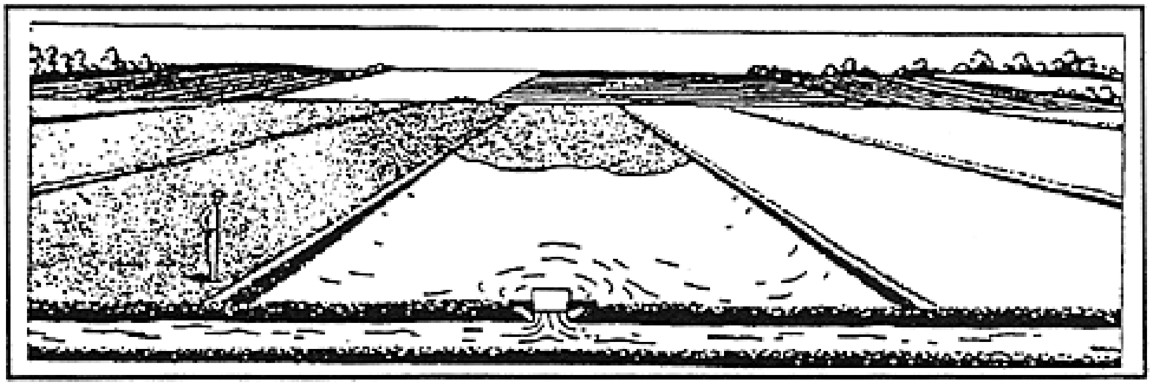


Figure 1: Typical configuration of border check irrigation systems. *From Walker (1989)*

Water is commonly delivered to the upper end of the field via earthen channel or subsurface pipe and enters the bay through outlets that may be: Cuts into the wall of the supply channel, siphons over the wall of the supply channel, gates or pipes through the wall of the supply channel or riser valves on subsurface pipelines. Dykes or tail-drains may be installed at the lower end of the field in order to minimise runoff or capture tail-water, however open-ended bays are more common in the South East.

Border check irrigation systems are most suited to soils with moderately low to moderately high infiltration rates. Uniformity of infiltration across the bay is important as variations reduce efficiency and result in non-uniform water application. There should be no cross slope so that water spreads evenly as it flows down the length of the bay.

A surface irrigation event composes of the four phases outlined below (Walker, 1989) and illustrated graphically in Figure 2.

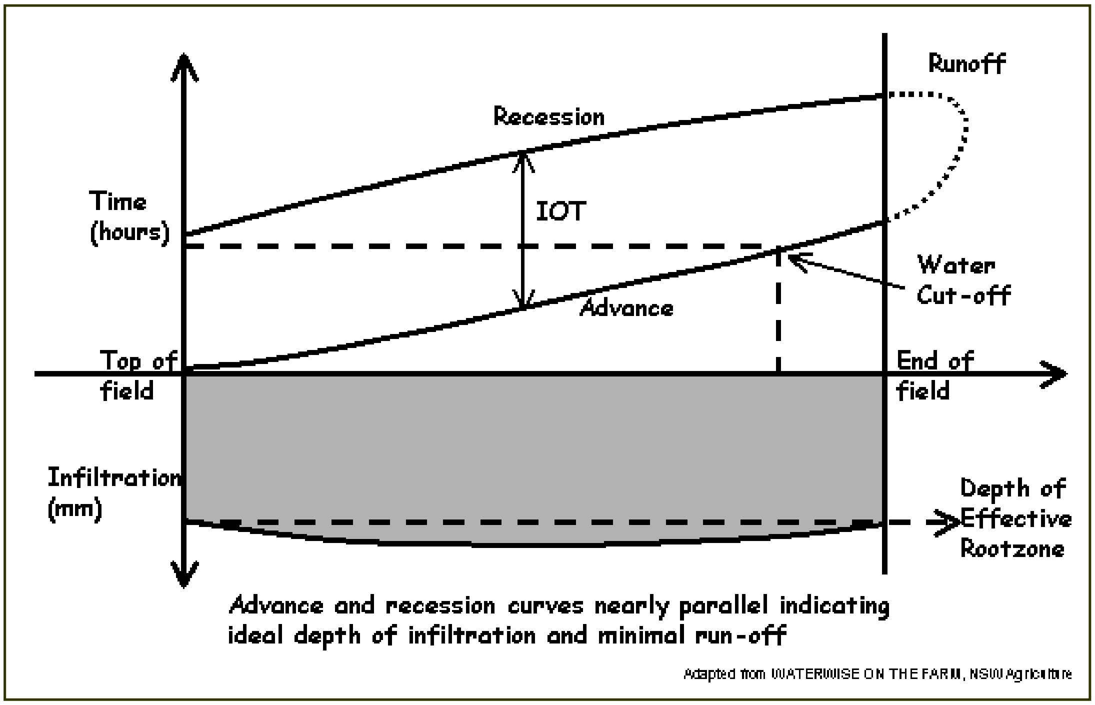
Advance: When irrigation is applied to the field, water *advances* across the surface until it covers the entire area. Under border check irrigation, water will directly wet the entire surface as the whole bay area is designed as the flow path.

Ponding: Before inflow is cut-off, irrigation water either runs off the end of the field or begins to pond on the surface. This is called the *ponding* or *wetting* phase and describes the volume of water stored on the soil surface for infiltration.

The volume of water on the soil begins to decline following cut-off, either draining as run-off or infiltrating into the soil; therefore drainage is considered in *vertical* and *horizontal* phases.

Depletion (*vertical* drainage): The depletion phase is the period in which depth of water at the upstream end falls to zero.

Recession (*horizontal* drainage): The recession phase begins at the point of depletion and continues until the surface is drained.



Adapted from WATERWISE ON THE FARM, NSW Agriculture

Figure 2: Time-space trajectory of water during a surface irrigation showing advance and recession phases, infiltration opportunity time (IOT) and infiltration.

The advance and recession curves illustrate the trajectories of the leading and receding edges of the surface flows and the period defined between these two curves at any distance is the time water is on the surface and therefore infiltrating into the soil. This is otherwise described as the infiltration opportunity time (IOT). To apply the correct depth of water across the field, advance and recession curves should be parallel and separated by a distance (time) equal to the required opportunity time (Raine and Smith, 2005).

Seven key variables determine the design and subsequent performance of surface irrigation systems. These elements are summarised below (adapted from Raine and Smith, 2005).

Soil Infiltration Characteristic: The dominant factor in determining the efficiency and uniformity of surface irrigation applications. The infiltration characteristic controls the rate of advance and recession, whereby high infiltration results in slow advance and rapid recession.

Inflow Rate: An important variable in the surface irrigation process and second only to infiltration, inflow affects advance but has little impact on the rate of recession. Provided all other factors are held constant, increasing the rate of inflow yields more rapid advance.

Infiltration and Inflow are considered first-order variables as the rate of advance depends almost entirely on the difference between the rate of discharge onto the field and the accumulating infiltration into the soil (Walker, 1989). Second-order variables include:

Surface Roughness: The surface of the irrigation bay provides a resistance to water flow. The degree of resistance is a function of the roughness of the soil surface and the amount of vegetation that projects through the flow. For a given inflow, increasing surface roughness results in a greater depth of flow and lower velocity; however very large changes in roughness are required to cause a significant change in the rate of advance or recession.

Field Slope: The longitudinal slope of the field influences both advance and recession, whereby increasing slope increases the rate of both. But the degree to which modifying field slope increases advance is defined by attributes of infiltration and inflow; whereby a large change of slope is required to counter high soil infiltration. It is of greater importance to achieve uniform longitudinal slope and minimal cross-slope to ensure even coverage.

Length of Field: Field length has a significant bearing on surface irrigation performance although it does not affect the form of advance and recession curves. It is typically more difficult to achieve high distribution uniformity in longer fields and higher inflow rates are required to maintain a sufficiently fast advance rate. Maximum application efficiency is more likely achieved in shorter fields.

Time to Cut-off: The period for which water discharges into the field. A key management variable, time to cut-off has a direct impact on depth of application, uniformity, efficiency and losses to deep percolation and run-off.

Depth of Application - Z_{req}: The desired depth of application may be fixed (i.e. the depth of irrigation required to achieve field capacity) or viewed as a management variable – Z_{req} is viewed as the maximum amount to be applied and that the actual amount applied in irrigation may be reduced if the result is improved application efficiency. Such management decisions are only possible where irrigation can be applied with precision.

In many situations time to cut-off, inflow and Z_{req} (to some degree) are the only factors that can be varied prior to or during individual irrigation events. Other variables are either beyond the control of the irrigator (soil infiltration and surface roughness) or fixed at the design stage (field length and slope).

Variable	Impact on advance	Impact on performance	Variable type	Comments
Soil infiltration characteristic	***	***	Fixed	High infiltration soil – slow advance & rapid recession
Inflow rate	***	***	Design & Management	High flow rate – fast advance rate, increased tailwater runoff
Surface roughness	*	*	Fixed	Rough surface – slower advance
Field slope	*	*	Design	Steep slope – rapid advance & recession
Length of field	-	**	Design	High efficiency & uniformity difficult on long fields
Time to cut-off	-	***	Management	Determines opportunity time & deep percolation
Desired depth of application	-	**	Management	Higher applications more efficient

From: Raine, S. R. and Smith, R. J. (2005). Simulation modelling for surface irrigation evaluation. Training in using SIRMOD and InfiltV5. National Centre for Engineering in Agriculture Publication 1000008/4, USQ, Toowoomba

Executive Summary

Surface irrigation methods are old and widely practised. Nevertheless surface irrigation is complex, requiring careful design and management to achieve high efficiencies. This is significant as the ability of an irrigation system to deliver water efficiently and uniformly is a major factor in the agronomic and economic viability of a production system.

Surface irrigation system assessments were conducted from 2006 to 2008 at sites that represent common production systems and soil types in the South East. Results suggest that surface irrigation systems operate below desired performance levels; with great variation from property to property and between individual applications. Typical application efficiency of single irrigation events ranges from 15% to 65%, whilst the average for each site is approximately 20% to 55%.

The primary disadvantage common to all sites is the volume of water 'lost' as deep percolation below the rootzone – tail-water losses are less significant in comparison. Such losses may have a negative impact on groundwater and are likely to limit productivity and flexibility when operating within the confines of a volumetric allocation. Deep percolation is a result of excessive intake opportunity time, which is itself related to the time required for water to advance from the upper end to the lower end of a bay. If excess irrigation water does not drain from the rootzone and saturated soil conditions exist for several days, plant health and productivity will suffer.

A review of literature suggests that for many situations it is possible to design and operate surface irrigation systems that will deliver at least 70% application efficiency. Although it is difficult to develop site specific recommendations without at least some in-field experimentation, such findings provide a useful target for systems in the South East. The key is to develop the skills and methods that enable the optimum design to be found for each system.

Variables that determine surface irrigation performance are: the soil infiltration characteristic, surface roughness, longitudinal slope, field length, inflow, time to cut-off and the desired depth of application. Unique site characteristics promote the need to perform in-field experimentation in order to find an optimum system design. Conversion to another irrigation method must be considered in circumstances where prevailing conditions are not conducive to high efficiency using border check.

Historically, labour and cost constraints have been of primary consideration when designing an irrigation system. For example, irrigated fields are often designed within existing fence lines without proper consideration of variation in soil characteristics. As is common in other regions, system operation has been based around a desired 'shift' time (i.e. 12 or 24 hours) to accommodate desired labour input or availability. In order to achieve better performance, it is necessary to place greater emphasis on soil conditions and crop water requirements.

Water delivery and control structures vary in specification, quality of design and standard of maintenance. Pipe and riser delivery systems appear to be best practice but, due mainly to cost, have not been adopted widely. The primary benefits of installing pipes in place of earthen channels include: gains in labour and time efficiency, ease of use, better utilisation of available area and reduced distribution losses (however distribution losses are typically far less significant than potential losses to deep drainage).

Results show that precise irrigation depth is difficult to achieve at all sites. That is, actual depth applied (mm) relative to that required (mm). Simulation and modelling analysis using SIRMOD II indicates that reducing bay length is the simplest method for improving irrigation precision and reducing variability. For example, decreasing bay length from 535m to 250m at site #5 would decrease the average volume of irrigation water applied from 1.061 to 0.633 ML/ha/irrigation and increase average application efficiency from 38.5% to 64.2%.

Field surveys revealed that at six of the nine sites slope in the advance direction changes two or three times along the bay. Although earthworks have been conducted at all sites, the quality of the finished surface is sometimes poor and the capacity to achieve an even rootzone is often limited by shallow soils. Theory dictates that the degree of slope in the advance direction has only a minor effect on the rate of advance; but a uniform surface gradient is important for irrigation recession, uniformity and surface drainage. Results at site #7a show that if significant increases in slope can be obtained (increasing gradient from 0.12% to 0.17%), meaningful improvement in system performance can follow. The conclusion drawn from this experience is that longitudinal slope at sites with moderate to high soil infiltration should be as steep as can be obtained. In practice this is more readily achieved in shorter fields.

Increasing inflow is commonly recommended as a means to reduce advance time; however this measure may have little effect on both uniformity and subsurface drainage (Hanson and Ayars, 2003). Evidence suggests that whilst not necessarily reducing the volume of water pumped, increasing inflow improves system capacity and is associated with better productivity and management flexibility. Installation of a second pump at site #1b reduced the time required to complete an irrigation cycle, thus enabling the manager to apply a closer-to-optimal irrigation schedule. Anecdotal evidence suggests that benefits include higher Lucerne seed yield and reduced labour burden.

Automated irrigation control is utilised at sites #1 (a + b) and #4, but is of limited benefit to irrigation performance. Rather, the advantage of adopting this equipment is realised in reduced labour input and improved lifestyle – eliminating the need to manually open and close inlets at 3:00 am. The timer-controlled bay gates employed are of different designs; however both require the operator to estimate likely start and finish times, in which the accuracy may vary considerably. As such, these are considered semi-automatic irrigation controls. To achieve greater benefits from automation these components must be integrated into the system design and operate on real-time water management information.

Irrigation scheduling amongst site managers is largely based on operator experience with little to no application of soil water monitoring tools or other aids. Furthermore, the opportunity for irrigation scheduling can be limited by the time required to irrigate. This is common across many irrigation districts in Australia. Evidence from field sites in the South East (DWLBC) shows that surface irrigators tend to run crops and pasture (unintentionally) into moisture deficit for significant periods of time. There are many reasons as to why this might occur; however the result is increased plant stress and reduced productivity.

Adoption of soil water monitoring tools and improved scheduling is also likely to yield more consistent irrigation application. Soil moisture status prior to irrigation influences performance and therefore attention to antecedent moisture content is required. It has been shown that higher antecedent moisture levels generally result in lower initial infiltration rates (Furman et al, 2006). No system can deliver acceptable application efficiency if soils (cracking soils in particular) are allowed to become too dry.

Greater emphasis on purpose of irrigation and strategy is required for most production systems, for productivity will suffer if: scheduling is ad-hoc, the target area is not determined prior to the irrigation season or is beyond the capacity of the system and production goals are not defined.

Areas for Further Study

- Due to case study sites operating as businesses there has been limited scope to study significant system modification without risking some productive loss. Further in-field experimentation is required with allowance for a trial and error approach to define best practice, for:

    - A relationship between antecedent moisture content and irrigation performance has been identified; now techniques and tools for the determination of optimum irrigation scheduling strategies need to be developed. This may assist the implementation of automatic irrigation control components.

    - Whilst INFILT has been shown to be the most accurate and reliable method for determining infiltration parameters (Khatri and Smith, 2005) and SIRMOD has been shown to accurately simulate a wide variety of irrigation events, when investigating alternative management strategies it is important to consider the relationship between these models. Parameters derived in INFILT refer to site and event specific field conditions (Furman et al, 2006) and may not be appropriate for use in SIRMOD when making large modifications to other factors – particularly inflow.

    - The development of specific rules for the management of surface irrigation is compromised by the substantial variation in the infiltration characteristics of soils across field and throughout the irrigation season. The multidimensional effect of field and management parameters on performance requires a design approach that demonstrates these interactions and includes the effect of infiltration variability (Raine et al, 1997).

    - Raine and Smith (1996) observed that "a major obstacle to the adoption of new technologies is recognition by the farmer of the benefits associated with implementation. It requires that the full impact of adopting alternative practices is assessed prior to large scale implementation." This implies that in addition to field experimentation, cost-benefit analyses need to be conducted to evaluate any proposed alternative irrigation strategies.

- More sophisticated irrigation management regimes should be trialled to determine suitability to soils in the South East. Surge flow irrigation in particular is thought to offer better irrigation performance and increased flexibility for existing systems on a range of soils. Advocates of surge irrigation identify advantages in three broad categories:

    - For a given inflow, the irrigation advance rate under surge flow is comparable to, if not faster than, the rate achieved for continuous flow. However uniformity during the advance phase is improved as a smaller volume of water is required to achieve the same rate of advance.

    - Deep percolation and tail-water losses can be reduced and application efficiencies improved using proper automated management. Hanson et al (1994) reported that almost 30-40% less water may be required compared to continuous-flow irrigation for complete advance across the field on some soils.

    - Surge irrigation provides an inexpensive means of automating, managing and accurately controlling irrigation whilst reducing demands on labour.

  Essentially a method of applying water to the field in a series of intermittent surges, rather than a continuous stream, surge flow management comprises an *advance* phase and a *cutback* phase. The purpose of alternate filling and emptying of the field is to quickly lower soil infiltration, reduce percolation depth and smooth the soil surface. These changes in soil condition enable more efficient water use in the cutback phase. Following is an example of how surge flow might work in the field.

1) Cycle time, the time for one complete on/off cycle, in the advance phase is relatively long – typically more than 30 minutes. As such water is in the field for 30 minutes, out for 30 minutes and then returned for 30 minutes. This process is repeated until water reaches the end of the bay. During this phase inflow must not return until all of the water from the previous surge has disappeared, otherwise the full benefits will not be realised.

2) Cycle time in the cutback phase is shortened and water will be in the bay at all times until the end of irrigation. The cutback phase ensures that the average flow rate is approximately half that of a conventional continuous application.

The intensive inflow management required for surface irrigation is the reason for recommending system automation and therefore in-field trials of automated management tools should be pursued.

- Unique and variable site characteristics require greater collection and dissemination of information to more effectively aid the design process. This has been well described by North (2007) as follows:

- Hydraulic data to support the design process, including:
    - › Roughness coefficients for within channels, drains and bays.
    - › Characteristic soil hydraulic properties.
    - › Performance characteristics of *new* design elements

- Data to support an economic analysis of alternative irrigation designs and to show the full costs and benefits of each alternative, including:
    - › Agronomic data.
    - › Expected improvements in returns to water, land, labour and capital and the timeline for return on investment. Experience has shown that opting for cheaper cost options at initiation may compromise ongoing performance of the design.

- A ‘one size fits all’ approach is not likely to be successful and should be discouraged.

Introduction

Surface irrigation uses approximately 42% of the water used for irrigation in the South East and is the second most popular irrigation type by area. Surface irrigation systems are utilised throughout the South East to grow a wide range of crop types and are generally the dominant system type in areas of poor water quality - particularly in areas of high salinity. Surface irrigated crops in the upper South East include lucerne seed (approximately 70% of the irrigated lucerne seed area), clover seed and cereal crops, whereas pasture and summer fodder crops are more common in the lower South East. Approximately 30% of the farm gate value from irrigated agriculture in the South East is generated by lucerne seed and pasture-based enterprises; a poor return (in $/ML) relative to other crop and system types.

Project objectives

In 2003, the South East Natural Resources Management Board (SENRMB) initiated the *Irrigation Efficiency Project* for the improvement of irrigation efficiency and management in the South East of SA.

The surface irrigation component of the Irrigation Efficiency Project was tasked with the following objectives:

- Identify technical and management issues limiting production, profitability and irrigation efficiency associated with surface irrigation on broad area pasture and field crops in the South east of South Australia.
- Identify those limiting issues that are likely to provide greatest improvement or financial return.
- Compile known solutions, technologies and management practices to address the limitations.
- Identify the issues requiring new research.
- Work with project partners and selected irrigators to develop best practice case study field sites, with a view in subsequent years to utilise information from the sites for training programs and promoting best practice to the broader irrigation community.
- Provide support to the Steering Committee for the SENRMB's Irrigation Efficiency Project.
- Develop a comprehensive irrigation curriculum, manuals and workshops that incorporate findings from field investigations, issues identified during the introductory workshop series, soils, optimum system design and scheduling strategies for the main irrigation systems used in the SE.

Methodology

Case study sites

Data was collected from single bays at seven case study sites located across the South East (see Appendix). Six sites were chosen initially, representing major crop and soil types under surface irrigation, with two special interest sites added during the course of the project. Normal irrigator practices were followed at each site so that evaluations would be representative of ‘real world’ performance.

Review of tools and models for evaluating border system performance

The IRRIMATE suite of tools

Irrimate^{TM} is the commercial name within Australia given to a package for surface irrigation evaluation and optimisation. The package consists of hardware for in-field measurement and software to translate field measurements into objective performance figures.

Hardware components of the Irrimate^{TM} package include a flume gauge, calibrated meter and set of data-loggers. These items enable measurement of such irrigation parameters as instantaneous inflow rate, total volume of water applied and advance rate along the bay or furrow.

The software components of the Irrimate^{TM} package are as follows:

Infilt

As described by developers of the software (National Centre for Engineering in Agriculture, University of Southern Queensland, 1999):

Infilt is a tool designed to calculate the Kostiakov-Lewis infiltration parameters (described further in *Irrigation Evaluation* below) by solving the inverse problem through calibration using measured advance data. Infilt employs a volume balance model using optimisation to minimise the error between the predicted and measured advance. This method differs from others in that only advance data and inflow rates are required. The average cross sectional area of the furrow and the final infiltration rate are treated as fitted parameters and need not be measured – although the quality of results is improved when using more comprehensive input data.

SIRMOD II

The following description for SIRMOD is taken from Raine and Walker (date unknown):
SIRMOD is an irrigation model that simulates the hydraulics of surface irrigation (border, basin and furrow) at the field scale. The principle role of SIRMOD is the evaluation of alternative field layouts (field length and slope) and management practices (application rate and cut-off time). Originally developed for research and education, SIRMOD has been used successfully at Utah State University and the University of Southern Queensland since 1987. The ability of SIRMOD to accurately assess furrow and border system performance has been well established and confirmed under Australian conditions.

Irrigation Evaluation

The methodology applied for assessing irrigation performance follows that described by Smith et al (2005) in previous surface irrigation experimentation. The method is as follows:

Soil infiltration characteristics for each event are expressed in terms of the modified Kostiakov equation:

$$I = kt^{a} + f_{0}t$$

Where I is the cumulative depth of infiltration (expressed as a volume per unit length of furrow or bay), t the infiltration opportunity time, f_0 the steady state or final infiltration rate for the soil and k and a are fitted (dimensionless) parameters.

For each irrigation the parameters a, k and f_0 were determined from irrigation advance data using the program INFILT. These parameters along with the physical characteristics of the bay were then used in the surface irrigation simulation model SIRMOD to reproduce each irrigation event as observed and measured. Calibration of the model for each event was achieved by adjusting the hydraulic resistance term (Manning n) until the simulated advance matched as near as possible to the measured advance. Once modelled successfully, SIRMOD could be used to explore a range of strategies aimed at improving application efficiency (Smith et al, 2005).

Soil Water Monitoring

Irrigation scheduling and assessment of soil moisture at case study sites is largely based on operator experience with tools for measuring soil water installed only at Site #5. In order to properly determine moisture content a variety of soil water monitoring devices were installed, a summary of which is presented in the Appendix (Appendix Table 1). Sets of equipment were installed at one and two-thirds bay length in an attempt to capture reasonably representative soil sections and monitor changes in irrigation performance through the field.

Table 1: Summary of soil water monitoring equipment employed at case study sites.

Site	Device Installed	Description	Field Position (distance along bay)	Depth of Profile Measured (cm)	Data Range
#1a	*Sentek* EnviroSCAN	Multi-sensor capacitance (Frequency Domain Reflectometry) probe, measuring soil water volume, connected to a data logger.	1/3 and 2/3	20-80	Nov 2005 - Present
#1b	*Sentek* EnviroSCAN	As above, however alternative equipment installed due to failure of device.	1/3 and 2/3	20-80	Nov 2005 - Jan 2007
	SM200 + TBug	Measures volumetric soil water content, connected to a TBug data logging unit.	1/3 and 2/3	20, 40, 70, 110	Jul 2007 - Present
#3	GB Lite (Watermark) + Gbug	Measuring soil moisture tension, GB Lites have an operating range of 10 > 200 kPa in all soil types. Connected to a Gbug data logging unit.	1/3 and 2/3	20, 40, 60, 100	Nov 2005 - Present
	SM200 + TBug	Measures volumetric soil water content, connected to a TBug data logging unit.	1/3 and 1/2	10, 20, 30, 50	Jul 2007 - Present
	Agrilink C-Probe	Capacitance probe measuring soil water volume, data logged via telemetry and accessed on the internet.	1/3 and 2/3	10, 30, 50, 100	Jun 2003 - Feb 2006
#4	*Agrilink* C-Probe	Capacitance probe measuring soil water volume, data logged via telemetry and accessed on the internet.	1/3 and 2/3	10, 30, 50, 100	Jul 2003 - Mar 2006
#5	*Agrilink* C-Probe	Capacitance probe measuring soil water volume, data logged via telemetry and accessed on the internet.	1/3 and 2/3	10, 50, 100	Dec 2006 - Apr 2006
#6	GB Lite (Watermark) + Gbug	Measuring soil moisture tension, GB Lites have an operating range of 10 > 200 kPa in all soil types. Connected to a Gbug data logging unit.	1/3 and 2/3	20, 40, 60, 100	Nov 2005 - Dec 2007
	GB Heavy + Gbug	Measuring soil moisture tension in clay or loam soils, GB Heavy operates in a range of 50 - 500 kPa. Connected to a Gbug data logging unit.	1/3 and 2/3	20, 40, 60, 100	Nov 2005 - Dec 2007
	Agrilink C-Probe	Capacitance probe measuring soil water volume, data logged via telemetry and accessed on the internet.	1/3 and 2/3	10, 30, 50, 100	Aug 2003 - Mar 2006
#7	No Device Installed				
#8	No Device Installed				

Note: All devices installed as part of the Surface Irrigation Project except 'Agrilink C-Probe' devices, which were installed as part of the Field Irrigation System Trial (FIST) conducted by the Department of Water, Land and Biodiversity Conservation.

Table 2: Summary of Irrigation Evaluations for Case Study Sites 2005-08.

Site	Evaluation	Field Length (m)	Bay Width (m)	Irrig. Area (ha)	Q_o (l/sec/m)	Cut-off (mins)	E_a (%)	E_r (%)	DU (%)	Abs DU (%)	App. Rate (ML/ha)	Inflow (m^3/m)	Outflow (m^3/m)	Infilt (m^3/m)	Error (%)
#1a	15/12/2005	385	22.5	0.866	4.346	300	39.37	100	77.51	64.33	2.031	78.2	4.2	72.8	1.55
	12/1/2006	385	22.5	0.866	6.259	270	30.38	100	70.21	48.95	2.634	101.4	1	100.4	0.01
	6/12/2006	385	22.5	0.866	5.322	341	27.88	98.53	54.33	6.31	2.821	108.6	0	108.6	-0.01
	20/12/2006	385	22.5	0.866	4.122	345	32.25	89.08	38.8	26.23	2.210	85.1	0	85	0.04
	2/2/2007	385	22.5	0.866	5.1	344	26.87	91.61	41.6	14.16	2.735	105.3	0	105.3	-0.06
	13/11/2007	385	22.5	0.866	4.6958	355	30.89	100	60.73	36.59	2.590	99.7	1.2	97.1	1.39
	15/1/2008	385	22.5	0.866	5.12	369	27.85	100	60.86	34.79	2.873	110.6	0.8	109	0.71
#1b	17/12/2005	435	22.5	0.979	3.53	715	21.71	93.82	43.61	5.9	3.457	150.4	0	151.5	-0.73
	17/1/2006	435	22.5	0.979	6.786	334	24.21	94.59	47.86	2.16	3.126	136	0	135.9	0.05
	18/12/2006	435	22.5	0.979	6.79	290	24.93	84.63	38.5	5.76	2.715	118.1	0	119.5	-1.15
	16/1/2007	435	22.5	0.979	6.83	308	25.22	91.46	43.12	1.17	2.901	126.2	0	126	0.17
	14/11/2007	435	22.5	0.979	7.59	365	19.32	93.11	42.7	1.98	3.811	165.8	0	166	-0.15
	14/1/2008	435	22.5	0.979	7.285	425	16.9	91.27	37.66	3.58	4.271	185.8	0	186.9	-0.61
#3	10/02/2006	435	29.5	1.283	1.135	695	55.15	100	93.61	83.14	1.088	47.3	7.3	39.6	0.91
	31/03/2008	435	29.5	1.283	1.433	570	53.26	100	99.33	91.86	1.127	49	11.1	37.4	1.14
#4	2/4/2007	465	20	0.930	4.979	159	48.95	100	90.62	82.23	1.022	47.5	5.9	41.3	0.54
	12/10/2007	300	20	0.600	3.8	410	16.05	100	73.66	54.68	3.117	93.5	3	90.5	-0.07
	16/11/2007	300	20	0.600	6.8596	311	11.76	100	77.25	62.9	4.253	127.6	4.1	123.5	0.01
	20/3/2008	335	20	0.670	4.0011	302	22.96	99.36	64.54	12.57	2.164	72.5	0	72.5	0.03
#5	13/2/2006	535	29	1.552	1.328	580	46.31	100	88.8	81.37	0.864	46.2	9.2	36.8	0.47
	22/3/2006	535	29	1.552	1.334	646	41.45	100	79.49	64.26	0.964	51.6	3.3	48.2	0.3
	27/11/2007	535	29	1.552	1.46	680	35.93	100	93	87.32	1.114	59.6	7.6	51.6	0.46
	11/2/2008	535	29	1.552	1.0398	1117	30.25	98.34	58.17	1.26	1.301	69.6	0	69.2	0.46
#6	3/1/2007	600	25	1.500	3.068	830	23.56	100	74.03	60.73	2.547	152.8	3.4	149.4	-0.05
	5/2/2007	520	25	1.300	3.655	921	15.45	100	66.27	44.97	3.885	202	1	198.9	1.02
	28/10/2007	500	25	1.250	3.3233	724	20.71	99.55	59.13	4.83	2.884	144.2	0	135.6	5.99
#7a	9/1/2007	487	29.5	1.437	4.67	271	38.62	100	89.28	76.96	1.554	75.7	0.8	74.5	0.5
	7/2/2007	487	29.5	1.437	4.322	183	61.57	100	99.49	97.58	0.975	47.5	6.1	40.4	1.84
	8/1/2008	487	29.5	1.437	4.19	186	62.49	100	87.87	74.48	0.961	46.8	1.1	45.1	1.18
	19/2/2008	487	29.5	1.437	4.45	203	54.45	100	98.89	96.27	1.103	53.7	4.3	48.5	1.62
#7b	9/1/2007	487	29.5	1.437	4.67	416	25.19	100	85.47	75.42	2.382	116	9.6	106.1	0.25
	7/2/2007	487	29.5	1.437	4.322	324	34.78	100	79.56	63.73	1.725	84	4.8	78.8	0.43
	8/1/2008	487	29.5	1.437	4.19	340	34.29	100	84.63	73.01	1.749	85.2	6.5	78.4	0.35
	19/2/2008	487	29.5	1.437	4.45	329	31.61	100	92.21	86.49	1.793	87.3	15.4	71.6	0.39
#8	25/11/2007	370	38	1.406	2.301	324	57.9	100	88.36	79.93	1.208	44.7	2.2	42.1	0.89
	19/1/2008	240	38	0.912	2.06	285	27.35	100	70.8	51.95	1.463	35.1	0.7	33.9	1.53

Note: Only evaluations returning meaningful data are listed. Observations from other irrigation events are not included here but may be referred to elsewhere.