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Technical Report

A water balance study for lucerne seed production resourced by an underground aquifer.

A Report for the Rural Industries Research and Development Corporation

by *James De Barro*

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Foreword

Irrigated lucerne seed production in the Keith region of the Upper South East of South Australia is resourced by underground aquifers. The South Australian Government through its Department of Water, Land and Biodiversity Conservation is changing the licensing system from an area based system with no cap on the quantity of water pumped to a metered licensing system with allocated permissible pumping volumes. Irrigated lucerne seed producers currently have no quantified understanding of the water balance of their production methods and consequently there is no data to support their claim for a fair and equitable licence conversion.

The research was designed to develop a methodology suitable for quantifying the water balance for both check bank guided flood irrigation and centre pivot irrigation. A method was developed to measure the water pumped, losses to evaporation and drainage as well as lucerne water use. Conducted over three irrigation seasons the project provided excellent data for irrigators to use as supporting evidence through the licence conversion process.

This report includes rationale for the research, methodology outline and the summarised data collected from the project. The results are presented in a format that can be used both by irrigators, the irrigation industry, as well as the Department of Water, Land and Biodiversity Conservation as part of the licence conversion process.

This project is funded by De Barro Agricultural Consulting and industry revenue that is matched by funds provided by the Federal Government.

This report is an addition to RIRDC's diverse range of over 900 research publications, forms part of our Pasture Seeds R&D program, which aims to facilitate the growth of a profitable and sustainable pasture seeds industry based on a reputation for the reliable supply, domestically and internationally, of a range of pasture species.

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About the author

James De Barro owns and manages De Barro Agricultural Consulting James has an honours degree in Agricultural Science and a Graduate Diploma of Business and was awarded a Churchill Fellowship in 2000. James resides in Keith in South Australia and specialises in consulting to lucerne seed producers and industry regarding all facets of seed production in dryland and irrigated systems. James is responsible for the ongoing research focus of the business that finances several projects.

Nothing in life is to be feared. It is only to be understood.

Madame Curie

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Executive Summary

Felix qui potuit rerum cognoscere causas
(lucky is he who has been able to understand the causes of things)

Of all the research that could be undertaken at this point of time in the history of irrigated lucerne seed production in the upper south east of South Australia this research project is the most important and most timely. With the impending changes to irrigation licences posing questions over the sustainability of irrigation practices and the aquifer, the research serves both immediate and longer term requirements for improved understanding of the current irrigation systems used.

Since the commencement of irrigated lucerne seed production in the Keith region, no recorded attempt has been made to quantify or qualify the irrigation systems used. Such information is the foundation data required for assessing the systems' efficiency and any areas of likely improvement as well as the impact of irrigation on the quality and quantity of the aquifer.

The aim of the research was to determine what happens to the water pumped from the aquifer for the purpose of lucerne seed production. The research methodology used is simple and repeatable. The methodology for this indicative type of research project amalgamates the use of several commercially available instruments into an excellent process for quantifying lucerne water balance. The methods used were so successful that they have become the model for the South Australian Department of Water, Land and Biodiversity Conservation Volumetric Conversion Project for the entire South East region of South Australia.

Additionally the research methodology can be used for extended irrigation efficiency studies that could result in improvements in irrigation delivery and crop yield. Whilst the project was not aimed to investigate irrigation efficiency, it did by design, assess the efficiency of irrigation delivery. The following general observations were made from the findings.

The research showed that, specifically for lucerne seed production, a fixed centre pivot in good working order that was irrigated according to crop water requirements and active root depth was 36.4% more efficient than the most efficient flood irrigated lucerne seed crop and about 70% more efficient than the worst performed flood irrigation.

Provided water quality is not in excess of 3000 ppm total dissolved salts a conventional centre pivot or lateral flow could be an alternative to flood irrigating lucerne seed crops. Compromises to this include capitalising the conversion of irrigation delivery and environmental factors such as tree removal. Modifications to centre pivots such as drop tubes could present opportunities for their use with water of significantly higher salinities.

The efficiency of a shiftable, shared centre pivot declines significantly compared to a fixed system due to compromises in irrigation timing.

Flood irrigation efficiency is expressed as a high percentage of pumped water that is used by the crop. This depends largely on the flow rate of the water pumped, sealing properties of the delivery channel and the irrigation bay slope and soil type. The configuration of bay size/slope in relation to the flow rate impacted on the eventual percentage of pumped water used by the crop. The research found that between 25% and 59% of the pumped water is used by the lucerne seed crop, the remainder mostly lost through drainage and only minimal losses due to evaporation. The findings indicate that there is substantial room for improvement in the efficiency of flood irrigated lucerne seed production.

Hay production from flood irrigation and pivot irrigation required nearly twice as much water to be pumped which is directly related to the increased number of required irrigations. In the case of the

flood irrigated crop the percentage of pumped water used by the lucerne for hay production was no different than the seed crop the previous year. Since the same percentage of pumped water is required by lucerne in hay and seed production, hay production is not necessarily any less or more efficient but by virtue of the number of irrigations requires significantly more water than seed production.

Aside from developing a method for evaluating irrigation efficiency, the research achieved its aim of determining the water balance for irrigated lucerne seed production. The benefits of this research are that the results will support irrigator's requests for defined water quantities in the licence conversion process. The conversion process should not be a system to reduce or increase licence allocations but rather a process of simply converting the current licence format into another, more useful format. Any changes to allocations must be on the basis of confirmed knowledge of aquifer sustainability – particularly in respect of salinity and recharge.

The research determined that for flood irrigation in the defined region an irrigator requires between 7 and 14 ML of water for every hectare irrigated for lucerne seed production. The quantity required depends on both the existing infrastructure of the irrigated area and environment being irrigated. There are many factors influencing the quantity required, including soil type, channel design, pump flow rate, bay size and slope. Some factors, such as soil type and possibly slope, can not be altered but bay size, channel design, delivery system and flow rate may be modified to improve efficiency and hence reduce the quantity of water required per hectare of seed producing area.

The defined quantity of water required by the irrigated lucerne seed producer to continue their current practice is now established. The conversion of licences should be relatively straight forward, at least on the mathematical level. The contentious issue will arise if and when the conversion process results in cuts to the volumes required to maintain the current status quo, especially if the cuts are not based on quantified and qualified reasoning.

1. Introduction

1.1 Lucerne seed industry

1.1.1 General overview

The Australian lucerne seed industry produces in excess of 5,000 tonne of seed per financial year of which over 90% is produced in South Australia. Over 8,000 ha of irrigated seed production occurs in the Upper South East of South Australia and at least 85% of Australia's total lucerne seed production is produced in the Project's research region, Keith, South Australia. The export value of lucerne seed exceeds $A 13.5 million, a value which is steadily increasing. The increasing value of lucerne seed to the Australian pasture seed industry defines it as a commodity that requires research designed to maintain and improve yields and grower returns. As an intensive high input crop there is a requirement for sustainable practices that are acceptable with the environmental issues impacting on primary production in today's world.

1.1.2 Research area

Lucerne seed production in the research region is the district's key crop. By virtue of the naturally saline ground water, lucerne is the most reliable perennial crop as it persists and provides profitable seed yields for the region's irrigators, and in particular, border check flood irrigators. The irrigation of lucerne for seed production adds significant economic and social stability for the communities concerned.

1.2 Water resource issues

1.2.1 Licencing system

Across most of the South East of South Australia a ground water resource exists in the form of unconfined and confined aquifers. The South East of South Australia is divided into regional Prescribed Wells Areas and the common source of flood irrigation water for lucerne seed production is in the Tatiara Prescribed Wells Region. Salinity in this area ranges from 2000 to in excess of 7000 mg/l and is the water source central to the conducted research. In 1984 the Tatiara region (incorporating the Keith area) was prescribed due to concerns of increasing water salinity. The development of an area based volumetric water allocation system based on estimated crop water requirements was instituted in 1988. The ground water allocation plan was an Irrigation Equivalent System where the allowable area of any irrigated crop to be grown was relative to the water use of a "standard area and type" of pasture referred to as the 'reference crop'. This system operates on an estimation of the water use of the crop to be grown and is currently in use across the Upper South East of South Australia. The licence provides *no limit* on the volume of water than can be pumped from the aquifer to irrigate lucerne for seed production but only specifies the area upon which any volume of irrigation can be applied.

Historically land in South Australia has been divided into Hundreds for the purposes of simplifying government management. Within the Tatiara Prescribed Wells Area the Hundred of Stirling is Australia's biggest lucerne seed production area and as a result is a highly concentrated area of border check flood irrigation. In 1997 detailed crop area ratios were created in the Hundred of Stirling as a result of proactive irrigators concerned that water withdrawal was greater than the annual recharge of the aquifer system which was associated with a noted rise in water salinity. Allocation reductions were instituted and new crop area ratios created to allow producers to best use their reduced allocation for their production practices. This was the first exhibited licence change, organised by irrigators and State Government water resource representatives, that was directly in response to the notion of the importance of water quantities pumped and the impact this has on the ground water system.

1.2.2 Water resource management framework

The Water Resource Act 1997 was created to permit specific water resource management where deemed necessary, with the aim of sustainability of the water resource. The Tatiara Prescribed Wells Area is one of five management areas in the South East where the Act required a water allocation plan to be created. A State Government Select Committee Report on Water Allocations in the South East was released in August 1999 and created the framework for the South East Catchment Water Management Board (SEWCMB), which was formed under the Act, to be empowered in consultation with the community to produce water allocation plans to replace existing water allocation policies. The Tatiara Prescribed Wells Area and the Tintinara/Coonalpyn Prescribed Wells Area constitute the designated area of research although the research will have bearing on lucerne seed production in the Padthaway Prescribed Area. Along with the SECWMB, the State Government Department of Water, Land and Biodiversity Conservation (DWLBC) is undertaking the research and community consultation aspect of the water allocation licence changes in accordance to the revised water allocation plans.

1.2.3 Licence conversion

The water allocation licence changes will convert the current area based licences to volumetric licences. Such licences will provide the irrigator with a set volume of water that will be permitted to be pumped from the aquifer in any given year. Consequently the irrigator will not be restricted in the area irrigated.

2. Objectives

2.1 Research aims

2.1.1 Purpose of research

The development of a new water allocation licence system to replace the current irrigation equivalent system is complex and emotive. Environmental, social, economic and agricultural factors need to be well researched and considered so a fair and equitable system of conversion can be created. Such a conversion needs to be based on solid quantified data collected through appropriate research. The research needs to determine what quantities are currently required by irrigators to maintain their current status quo. Unless the research determines significant sustainability issues and can provide solutions to the problems, any reductions in licences should not be part of the conversion process. The conversion process should simply change the type of licence without any major changes to current irrigation practices.

The irrigated lucerne seed producer’s ability to irrigate provides an opportunity to produce an income that otherwise would not be possible or obtain yields above that of a dryland system. The right to irrigate comes with inherited responsibilities to use the resource in an efficient and ecologically sustainable manner. Such responsibility is under increasing political and social scrutiny as the demand for the resource increases. Present day and future lucerne seed irrigators need to be seen by all sections of the community to be actively researching a solution to efficient and effective water use thereby justifying existing demand for irrigation in a sustainable system. The research will provide benchmark information upon which to develop improvements in efficiency whilst at least maintaining production and will be evidence to relevant government authorities and communities of irrigators consciousness of the importance of developing management systems that permit profitable yet ecologically sustainable irrigation water use.

The irrigators require their own independent research to collect data that can be used to support their interests in the conversion process. They need to be an active participant in the research so as to achieve a fair and equitable result.

The underground water system has been exposing symptoms of fragility such as increasing salinity and decline in water table depth for over a decade. The creation of an accurate knowledge base would allow for refined allocation of the underground water for flood irrigation of lucerne seed hence an immediate advance in sustainable and efficient water use. This in turn assists in securing the availability of the quantity and quality of the water resource for the future.

3. Methodology

3.1 Development of the methodology

At the time of development of the concept of this research project in 1999 there existed no specific literature in the world pertaining to a method for collecting the required data and using it to calculate a water balance for irrigated production (border check and centre spray pivot) resourced by an underground aquifer. The topic of determining a water balance had not been specifically addressed until this time but the 'raw understanding' of the impact of the water balance was accepted. This raw understanding was used to develop the Irrigation Equivalent (IE) licencing system[1], yet the Department of Agriculture recognised in 1988 when the system was introduced that specific research into this area was required because of the "significance and magnitude of agriculture in the South East of the State"[1]. Such suggested research was determining available moisture in the root zone and developing more reliable estimations of crop water use which would be used to refine the crop coefficients and hence the accuracy of the IE system[1]. In 1997 when the IE system in the Hundred of Stirling within the Tatiara Prescribed Wells Area was modified there was still uncertainty regarding the soil water root zone storage and the crop coefficients used were those developed in 1988[2]. Certainly no action had been taken by the South Australian Government to conduct the suggested research or even to undertake a water balance to quantifiably understand the irrigation requirements of irrigated lucerne, but rather it was content to permit the irrigation licencing system to exist on a basis of assumed knowledge.

In 1999 when the lucerne irrigators in the Tatiara Presecribed Wells Area sensed changes to the irrigation licencing system, together with rumours of licence reductions, this research project began to evolve. The aim of a water balance project was to account for the water that was pumped for the purpose of irrigating lucerne seed crops. Such a method would need to measure the volume of water pumped, losses of water in the delivery channel, lucerne crop use and drainage of water (if any) back into the aquifer. A search of international and national research revealed that no specific water balance methodology for what was required existed and it became apparent that the method would need to be developed. Assistance with particular aspects of the methodology could be gathered from discussions with researchers working in specific areas of irrigation research or commercial irrigation water delivery, and who, through the period of research and thereafter have published their research that was in progress at the time of methodology development. Some of the aspects of the methodology were well known to the author through commercial irrigation research experience and no extra information was needed.

The method was developed through 1999 and 2000 and initially implemented in the 2000/01 irrigation season. Assessment of the data was conducted in 2001 and a repeatable method for calculating the water balance was developed. The water balance calculation is a simple equation but requires many small calculations from the collected data, a process that is laborious and technical.

The following sections individually outline the rationale behind the methods used to collect specific required data and an example of the calculating process is provided.

3.2 Research plan

The research undertook a water audit by measuring water pumped from the aquifer, lucerne seed crop water use, evaporative losses from the irrigation channel and flood bay, soil water storage and the percentage of water return back to the aquifer beyond the lucerne root zone. The data would test the underlying assumptions of crop water use upon which the crop area ratio system is based. The research would also create necessary benchmark data for use in further research aimed at improving the efficiency of irrigation systems using the underground water resource.

3.3 Site selection

Five field trials were created in established Hunter River lucerne seed crops in the Keith region of South Australia. Four of the trial sites were situated on soil types typical of border check flood irrigation in the Tatiara Prescribed Wells area. A fifth site was established under a centre pivot to assist in refining lucerne water use data. This site was located in the Tintinara Coonalpyn Prescribed Wells Area. The lucerne seed crops had a uniform plant density of 20 or more plants /m^2.

3.4 Research Tools

Collection of relevant data for the research was achieved with the following equipment:

3.4.1 Water metering

The use of flow meters to measure the flow rate of pumped irrigation water and the total flow of water was, in 1999, a foreign concept to irrigators in the research area. The licence system is independent of the volume pumped and permits growers to pump as much as they want, whenever they want to. It was necessary to determine what type of metering device would suit the 10-12 inch outlet pipes of flow rates estimated to be 450,000 litres/hour. There existed the need to measure both the flow of water from the pump as well as the flow into the irrigation bay of a border check irrigation system. There are various systems for metering water from a pump as well as through an open flow channel and to measure the flow rate and volume applied it was necessary to calculate the velocity of water passing through an irrigation gate, the sectional area through which water was passing and the depth of water through the gate opening.

In 1999/00 Wes Douglas, Goulburn-Murray Water, was conducting research funded by Land and Water Resources Research and Development Corporation into benchmarking the distribution efficiency of an irrigation supply system[3]. At this time Goulburn-Murray Water was replacing their Dethridge wheel meter technology with logging meter technology manufactured by MACE. Douglas' research and the experiences of others in research and commercial supply monitoring systems such as Measurement Engineering Australia stated that meters such as the Dethridge wheel and the Starflow[R] meter were unsuitable due to the mechanism of water delivery into the irrigation channel and the irrigation bay, cost of establishing the metered site, reliability of engineering a reliable structure in which to measure flow, ease of corrupting recorded data, inconvenience of moving meters from site to site as well as accuracy. Even in 2004 there is still private (and to a lesser degree public) research into accurately measuring water flow into the irrigation bay and there is still no readily available commercial device.

In 2000 there were very few logging flow meters commercially available. Goulburn-Murray Water was using MACE Agriflo meters as they were simple to install, could log all required flow and total volume data and were simple to download to a computer. For this research the ability to shift meters from pump to pump for each irrigation presented a cost saving to the project's budget as compared to installing a fixed meter at each site. Consequently each flood irrigation pump was modified to fit a MACE 2 inch insert type ultrasonic flow meter. The meter was characterised for the specific pipe and flow rates of each site and it was simple to shift the meter from site to site at irrigation time and download the specific pump specification to the meter for data recording. The flow rate in the period of irrigating the research bay was recorded and averaged for the irrigation season (Tables 7-11).

3.4.2 Irrigation timing

It was necessary to determine a method for accurately knowing how long an irrigation bay was irrigated that did not involve relying on the irrigator to record these times. Barry Swann from the NSW Department of Agriculture (pers. Comm.) advised the author about using Dataflow Systems 392 depth loggers. These loggers were used to record the commencement and completion of each irrigation event by placing a depth logger at the irrigation outlet gate to the bay. The calibrated logger recorded the depth of the water moving out from the channel through the irrigation gate and the time of irrigation was a function of the depth of the water passing over it when the gate was opened and closed.

3.4.3 Channel drainage

The pondage test is considered a worldwide standard method for quantifying channel seepage and, whilst there are several methods available, they all have compromises (Akbar and Khan[4]). Pondage tests are applied in non flow situations where normal flow conditions are not met (Rohwer[5]) but compared to inflow-outflow, point measurement and electromagnetic instrumentation techniques (Akbar and Khan[4]), and coupled with the relative nature of the research and the comparatively deep water table in relation to the channel, such tests were a simple and cost effective method for assessing drainage. Thus the pondage test was selected to estimate channel drainage (seepage) in this project.

The Dataflow Systems 392 depth loggers were placed down the length of the channel.
All the channel irrigation gates were closed and the channel was filled to the irrigation level and the rate of water surface level decline was measured at peak fill when head pressure for seepage was maximised. The depth logger data was downloaded, exported into a spreadsheet and graphed. The depth at peak fill after the water level had settled across the length of the channel after the pump was turned off was determined and the rate of water decline was calculated for the first few hours afterwards when the channel head pressure was greatest for seepage and would be representative of the seepage losses through the irrigation season. The rate of water loss (mm/hour) was calculated for each position along the channel and averaged.

3.4.4 Soil moisture recording

There are several commercial tools for recording soil moisture. Such tools are neutron probes, gypsum blocks, capacitance type sensors and reflectometers. The author commercially uses neutron probes and two types of capacitance sensors which are suitable for the research sites. Gypsum blocks are not suitable for the saline water used for irrigation and installation of reflectometers are too problematic. Neutron probe and capacitance devices such as Gopher[R] and Diviner[R] are manually used and hence there is a need to visit the site to take readings. The optimal data set for ascertaining crop water use vs. drainage involves taking many readings at close intervals of time. This was deemed too time consuming and the high frequency of site visits could create a potential site compaction problem. A continuous recording device was therefore preferred and due to the author's experience the Agrilink C-probe[R] was selected to record soil moisture to a depth of 1.5 m. The continuous recording by the C-probe enabled specific assessment of the precise depth the lucerne actively used soil moisture for crop production. In addition the C-probe permitted determination of drainage from all depths. The C-probes were also used to schedule the timing of each irrigation for every site through the duration of the project.

The flood sites had three soil moisture monitoring sites per bay and there was one soil moisture monitoring site in the centre pivot. The soil moisture sensors were located directly in and below the root zone of the lucerne. The C-probes were calibrated in comparison to a neutron probe moisture meter and a bulk density assessment of soil to determine volumetric soil moisture content. Such a calibration procedure provided reliable data to calculate lucerne water use and determine the crop's active root zone and the root zone storage capacity. Analysis of the soil moisture records was painstaking but served to provide reliance on the estimated crop water use determined by using the weather station/modified Penman Monteith calculation of potential evapotranspiration in conjunction with lucerne crop factors derived from significant years of experience in managing irrigated lucerne seed crops. In future research it is not recommended to allocate significant time to a site specific calibration and a soil moisture data analysis. Concise determination of crop use factors from a thorough crop understanding is a more practical process in what is a complex area of research with potential for too many assumptions and instrument installation created biases (e.g. preferential drainage patterns through soil structures damaged when installing in ground soil moisture recording devices. Such tools are excellent for irrigation scheduling but create conjecture for water use studies).

3.4.5 Monitoring wells

The use of monitoring wells on two of the flood sites was to permit the monitoring of the groundwater in response to pumping, irrigation events and annual rainfall. The wells were not used specifically in the water balance calculation but were used to confirm the return of irrigation water to the aquifer in the process of border check irrigation as well as the time frame in which this occurred. In addition they provided an understanding of how rainfall contributed to the aquifer's recharge both in situ as well as via run away holes throughout the irrigation district.

The wells were situated in the middle of the research bay and were constructed to the same depth as the irrigation bore supplying the irrigation water. Each well had a continuously recording water level sensor installed.

3.4.6 Weather stations

Two Adcon weather stations were installed within the research area. Temperature, relative humidity, solar radiation, leaf wetness and wind speed were continuously recorded by data loggers to provide data for determining potential evapotranspiration (ETo) which was used in crop water use and evaporation calculations. Each site had a rainfall gauge that automatically recorded local rainfall quantities. All the recorded data was relayed via telemetry to a computer system in the research organisation premises. The computer software presented the individual logger data as well as a calculated ETo. Data was recorded by the loggers for every 15 minute period. The Adcon weather stations operated within the same telemetry network as the C-probes.

3.4.7 Evaporative losses

Channel surface evaporative loss was measured at each irrigation and from the flood bay surface prior to the crop canopy developing using the evapotranspiration data calculated from the weather data. The method for calculating evaporative losses was as follows. The surface area of the channel (when full) and bay was calculated. The period of time that the research bay was irrigated was recorded by the Dataflow loggers. The evapotranspiration (ETo) off the channel surface during the bay irrigation period was calculated as the relative percentage of the ETo during that period. If the irrigation was conducted at night the ETo was extremely low. Similarly the evapotranspiration off the bay surface was calculated over the time period water remained on the soil surface during the irrigation and including the time the soil surface was super saturated after the water had visibly drained from the surface. The bay ETo was calculated only for the irrigations when there was no crop canopy over the ground. Dataflow loggers were placed down the bay to record the period of time irrigation water lay on the soil surface.

3.5 Deep drainage

Drainage of applied irrigation water through the soil profile back into the ground water is a difficult measurement to determine with absolute accuracy. Any installation of equipment vertically into the soil profile for the purpose of measuring drainage, by virtue of the installation procedure, will compromise the draining passage of water. To date this has been the standard means of installing drainage metering devices. Ideally it would be more appropriate to excavate horizontally into the soil profile at the depth of interest and measure moisture draining from above but this is inappropriate and impractical for the research sites. The monitoring wells record a rapid rise in the groundwater following flood irrigation and a slow steady rise in the non irrigation season. Dryland drainage as observed in caves underground is a slow and constant process, often not visually influenced by periods of wet or drier weather. Changes in water table levels are more influenced by recharge from runaway holes than they are from localised drainage through the soil profile – at least this appears to be the case in the research area. Consequently, after examining differing methods of attempting to measure drainage beyond the root zone of lucerne seed crops, the research project decided to use an interpolative approach.

3.6 Water balance calculation

The monitoring wells established the relationship between flood irrigation and drainage to the ground water table from where the water was pumped. Additionally it established a link between pumping and the draw down of the ground water towards the pump. The time of a ground water response to the localised flood irrigation event varied depending on the dryness of the root zone and varied between 6 and 12 hours. With this relationship proven a simple mathematical approach was possible.

Given the research project involved only 5 sites its findings would be relative rather than absolute. Consequently a mathematical approach using the best data possible would provide the best and only available guide to the water balance. The approach was based on concentrating efforts to measure as accurately as possible the water pumped, the losses from the channel due to drainage and evaporation, the evaporative losses from the irrigated area, the crop water use and the residual water stored in the active root zone. Detailed analysis of the soil moisture records in combination with estimated crop water requirements between full and refill points to grow a commercial lucerne seed crop allowed estimation of the readily available water, crop water needs and any residual soil moisture left in the root zone prior to each irrigation and at the point of harvest. By calculating all these factors and accepting that below the irrigated lucerne root zone the soil would always be saturated, it was possible to estimate the drainage volume.

A = water pumped
B = channel drainage
C = evaporative losses from channel surface and bay surface (or pivot application)
D = lucerne seed crop or hay crop use
E = residual water stored in root zone throughout irrigation season
F = drainage to groundwater

F= A- (B+C+D+E)

Although the drainage portion was calculated, the rate of drainage could not. The monitoring wells indicate the frequency of recharge and compared with the soil moisture monitoring records through the years, indicated that drainage never ceases. Rather the recharge from runaway holes only increases the rate at which ground water rises above the ‘background” drainage rate and the rate at which an irrigation created zone of depression recedes.

3.7 Example of water balance calculation

The following example of the process of the water balance calculation is from the data collected for site 1 in season 2000/01.

Table 6a presents the dates and times of the three irrigations for that season. Table 7 provides the average pump flow rate for the season.

Raw Data:

Average irrigation time = 726 minutes
Average flow rate = 7.86 KL/min
Total water pumped (per ha) = 10.7 ML
Irrigation channel surface area when full = 180m^2
Irrigation bay area = 1.6 ha
Channel drainage loss = 0.295mm/min
ETo during bay irrigation period 1 on 11/12/00 = 6.5 mm (taken from weather station data)
ETo during channel use time for irrigations 1-3 = 7.0 mm (taken from weather station data)

Channel loss calculation:
0.000295 x 180 = 0.053 m^3/min
0.053 x 726 = 38.49 m^3/726 min = 38.49 m^3/1.6 ha
38.49/1.6 = 24 m^3/ha = 0.024 ML/ha
0.024 x 3 (irrigations) = **0.072 ML/ha**

Bay evaporative loss calculation: 0.0065 m x 16000 m^2 = 104 m^3/1.6 ha
104/1.6 = 65 m^3/ha = **0.065 ML/ha**

Channel evaporative loss calculation: 0.007 x 180 m^2 = 1.26 m^3/1.6 ha
1.26/1.6 = 0.788 m^3/ha = **0.0008 ML/ha**

Irrigation bay delivery calculation: 10.7 - 0.072 – 0.0008 = **10.627 ML/ha**

Crop production calendar and water use calculation:
Table 1 presents the growing period for site 1 in 2000/01 season. The following table divides the growing period into crop development stages based on growth data collected through the seed production period. The ETo is taken directly from the ETo calculation (modified Penman Monteith) from the computer software (AgWise platform) based on the weather station data. The ETo is divied into the time periods relevant to the crop growth stages. The crop coefficients (Kc) have been developed and used by the author for commercial irrigation scheduling for many years. The ETc is the ETo x Kc.

Table 1: Estimated ETc using crop coefficients

Days of growth	**Crop stage**	**ETo (mm)**	**Kc**	**ETc (mm)**
1-7 (start 12/12/00)	Initial growth	49.3	0.3	14.79
8-21	Vegetative production	74.1	0.7	51.87
22-32	Budding-early flower	78.7	0.9	70.83
33-52	80% flower-80% post flower	117.9	0.9	106.11
53-60	80% post – post flower	54.3	0.9	48.87
61-87	Post-50% ripe	146.7	0.5	73.35
88-106 (harvest 27/3/01)	50% ripe-Harvest	63.8	0.2	12.76
			Total ETc	**378.58**

Crop water use zone determination:
Assessment of the C-probe data indicated the depth from which the crop was using soil moisture for crop production. The visible status of the crop confirmed the active root zone depth and once the available moisture to this depth was sufficiently depleted, the crop stressed indicating that below this depth the crop did not or could not use the moisture for crop production. Moisture at this depth is more likely used by the tap root for survivorship rather than production.

At site 1 the active root zone depth was 0-80 cm and the readily available moisture was estimated to be 130 mm. The data indicated that the readily available moisture could be as much as 170 mm but by forcing the crop to extract this volume of water from the root zone placed the crop at significant risk. Consequently, in an irrigation scheduling process aimed at separating irrigations far enough to avoid excess vegetative production before flowering and commencement of seed set, a depletion of 130 mm post irrigation is suitable. The readily available moisture volume was calculated using the results of a bulk density assessment and comparison with data from a calibrated neutron probe. The C-probe default data is in simple units expressing changes of capacitance in the soil at sensor sites and the changes in soil moisture are unit changes which are not expressed in volumetric soil moisture percentages or any other quantification but only plain number changes. The conversion factors of the C-probe crop use data for site 1 is listed in table 2. Between each irrigation event the change in soil moisture through the root zone detected by the C-probe was assessed and the proportion of crop water use and drainage at each depth was estimated (at least until drainage became negligible from the active root zone). This enabled determination of the active root zone capacity as well as the crop water use between irrigations. This is outlined in table 3. This matched well with the crop factor ETc data. This approach to calculating the ETc is very time consuming and does involve some educated judgements. Given its proximity to the ETc calculated using the modified Penman Monteith model it is suggested that this is the simplest method of estimating crop water use provided accurate crop coefficients and crop calendars are used.

Table 2: Conversion of C-probe data for site 1.

Sensor depth (cm) *	**Bulk density/Neutron probe: Full point (mm)**	**Bulk density/Neutron probe: Refill point (mm)**	**Water storage (mm): Full point-refill point**	**Total number of C-probe units attributed to crop use**	**Calibrated C-probe unit (mm)**
10	17.0	4.5	12.5	8.0	1.56
20	17.0	5.7	11.3	8.0	1.41
30	24.5	8.4	16.1	7.0	2.3
40	32.4	15.8	16.6	10.0	1.67
80	38.9	22.7	16.2	18.7	0.86
0-80 cm total estimated water holding capacity (mm)			**130**		

* Water storage for depths 50, 60 & 70 cm estimated from bulk density assessment and examination of C-probe 80 cm sensor data.

Table 3: Raw ETc calculation.

Between Irrigations:	**Days between irrigations**	**Crop use (mm)***	**ML/ha**
1-2	21	62.95	0.63
2-3	29	170.03	1.70
Post irrigation 3	56 (after final irrigation to harvest)	138.43	1.38
		Total ETc (raw)	**3.71**

* The value of the total amount of converted C-probe units between irrigations apportioned to crop use from 2 days post irrigation.

The first irrigation at the time of seed crop closure added 170 mm. Between irrigation 1 and 2 the crop used approximately 60 mm, hence the second irrigation replaced the 60 mm with the remainder drained below the active root zone. Between irrigation 2 and 3 the crop used 170 mm and irrigation 3 added 170 mm of which approximately 138 mm was used until harvest. Consequently the root zone storage required for the irrigation season was approximately 410 mm or 4.1 ML/ha. (Approximately 42 mm was stored in the active root zone after harvest but provided for minimal regrowth as it was deep in the profile rather than in the top 30 cm where moisture is needed for immediate fresh growth post harvest).

Water balance calculation:

Total drainage calculation: 10.627 - 4.100 = 6.527 ML/ha (irrigation bay drainage)
6.527 + 0.072 (channel drainage) = 6.599 ML/ha

Drainage calculation: 6.599/10.7 (Total pumped) = 61.7%

Evaporation calculation: (0.065 + 0.0008)/10.7 = 0.6%

Crop use calculation: 3.71/10.7 = 34.7%

Root zone storage: 100.0% - (61.7+0.6+34.7) = 3.0%

4. Results

4.1 Lucerne production

In the 2000/01 and 2001/02 all the crops at each site were irrigated for seed production, commencing in early-mid December and being harvested in the late March to mid April period. In 2002/03 one flood paddock (Site 1, Table 2) and the centre pivot paddock (Site 5, Table 2) were irrigated for hay production with the other three flood sites being irrigated for seed production.

4.2 Soil types and water quality

Table 4 presents the soil type of each irrigation site and the salinity of water used for irrigating.

Table 4: Research site soil type and irrigation water quality.

Site	Soil Type	Water Salinity (ppm)
1	Sand (0-2m); Clay/limestone(2-9m); Sand/Limestone/Marl (9-16m)	3000
2	Sandy loam & limestone (0-0.8m); Limestone/marl (0.8-15m)	7500
3	Loamy sand & limestone (0-1.2m); Limestone/marl (1.2-15m)	4150
4	Loamy sand & limestone (0-1.2m); Limestone/marl (1.2-15m)	5300
5	Sandy loam (0-1m); sand and limestone(1-20m)	2500

Site 1 (flood): Brimbago – E140°457', S36°274'. Site 2 (flood): Keith west - E140°306', S36°123'.
Site 3 (flood): Keith south - E140°361', S36°161' Site 4 (flood): Mt Monster - E140°314', S36°194'
Site 5 (pivot): Coombe - E140°258', S35°982'

From Table 1, sites 2, 3 and 4 have similar soil types typical of a significant majority of flood irrigation land in the Hundred of Stirling in the Tatiara Prescribed Wells Area. Site 1 is representative of another area of significant flood irrigation in the Tatiara Prescribed Wells Area. Site 5 is located in the Tintinara Coonalpyn Prescribed Wells Area and is representative of significant areas of pivot irrigation, particularly in the Hundred of Archibald.

The water storage capacity of soils typical of the irrigation area varies depending on soil type. Sites 2, 3 and 4 hold about 75-80 mm in the active root zone when at full point. Site 5 being deeper sand holds 95 mm and site 1 holds 130 mm. This factor dictates the number and frequency of irrigations through the seed production period.

4.3 Weather and crop growing period

Table 5 presents the temperature, relative humidity and rainfall through the irrigation periods for each site over each year of the project.

Table 5: Temperature, relative humidity and rainfall through the irrigation periods for each site over each year of the project.

	Site	Temperature (°C) Min.	Max.	Avg.	Relative Humidity (%) Min.	Max.	Avg.	Rainfall (mm)	Production Period (days)
2000/01	1	1.5	40.1	20.9	8.7	99.4	54.8	35.0	106
	2	1.8	40.4	20.8	8.7	99.3	56.3	40.2	112
	3	0.7	41.5	20.1	8.7	99.4	54.8	30.8	106
	4	1.5	40.1	21.0	8.7	99.4	53.4	35.0	106
	5	-0.8	43.5	21.5	5.4	100.0	56.9	24.6	88
	Site	**Temperature (°C) Min.**	**Max.**	**Avg.**	**Relative Humidity (%) Min.**	**Max.**	**Avg.**	**Rainfall (mm)**	**Production Period (days)**
	1	0.3	37.2	17.0	11.4	99.2	62.1	48.6	128
	2	-0.4	38.5	16.8	11.4	99.2	62.8	60.2	132

2001/02	3	-1.8	37.7	16.7	11.4	99.2	62.6	53.6	136
	4	0.0	37.2	17.1	11.4	98.4	61.9	48.4	128
	5	-3.5	38.4	16.8	12.9	100.0	69.3	31.4	120
2002/03	**Site**	**Temperature (^oC)**			**Relative Humidity (%)**			**Rainfall (mm)**	**Production Period (days)**
		Min.	**Max.**	**Avg.**	**Min.**	**Max.**	**Avg.**		
	1	-1.1	41.4	16.8	9.3	99.5	62.4	133.6	182
	2	1.6	41.4	19.0	9.3	97.5	58.6	70.3	113
	3	2.4	41.4	18.9	9.3	97.5	57.9	88.6	114
	4	2.8	41.4	19.2	9.3	97.5	58.3	77.8	105
	5	0.4	44.3	19.2	9.8	100.0	61.3	121.2	129

From Table 2 it is evident that the growing period of lucerne for seed production is relatively constant between crops grown on varying soil types with differing water qualities in any given year. Prevailing weather is relatively consistent across the irrigation area with the length of production apparently driven by subtle variations in temperature from year to year, given that day length is significantly consistent.

Irrigation times

Tables 6a-e present the irrigation dates and times for each site in each season.

Table 6a:

Site 1	**00/01**	**00/01**	**01/02**	**01/02**	**02/03**	**02/03**
Irrigation	Date	Time	Date	Time	Date	Time
1	11/12/00	13:50-23:30	14/12/01	01:00-10:35	26/09/02	18:30-01:55
2	1/1/01	20:00-08:39	2/1/02	10:40-19:35	1/11/02	02:15-08:35
3	30/1/01	08:30-22:30	2/2/02	17:15-24:00	18/12/02	17:15-**
4			27/2/02	20:10-03:15	29/12/02	17:50-01:15
5					17/1/03	23:15-06:00
6					4/2/03	02:30-08:30
7					9/3/03	05:15-13:30
					18/4/03*	08:35-22:45

* two bays opened at once hence double area irrigated

** power failure caused excessive and abnormal irrigation length. Average irrigation time was used in assessment.

Table 6b:

Site 1	**00/01**	**00/01**	**01/02**	**01/02**	**02/03**	**02/03**
Irrigation	Date	Time	Date	Time	Date	Time
1	17/12/00	11:20-16:40	30/11/01	15:55-22:50	14/12/02	19:15-23:40
2	11/1/01	21:10-01:40	20/12/01	18:05-23:05	30/12/02	17:15-20:50
3	24/1/01	07:55-12:30	11/1/02	23:12-04:07	13/1/03	03:45-07:45
4	4/2/01	17:00-21:20	1/2/02	09:45-15:20	22/1/03	22:40-06:50
5	19/2/01	15:15-19:35	15/2/02	15:55-21:10	07/2/03	12:15-16:25

Table 6c:

Site 1	**00/01**	**00/01**	**01/02**	**01/02**	**02/03**	**02/03**
Irrigation	Date	Time	Date	Time	Date	Time
1	11/12/00	07:05-10:30	3/12/01	08:20-11:30	02/12/02	08:20-12:00
2	1/1/01	08:14-11:34	20/12/01	07:40-11:35	16/12/02	16:50-20:20
3	13/1/01	14:15-17:35	8/1/02	07:15-11:00	27/12/02	07:30-10:15
4	25/1/01	06:35-09:50	21/1/02	07:05-11:00	8/1/03	08:55-12:20
5	6/2/01	06:40-10:10	5/2/02	08:00-11:55	19/1/03	07:00-10:50
6	18/2/01	07:40-11:50	19/2/02	07:50-12:00	29/1/03	18:30-23:55
7			4/3/02	06:35-10:25	11/2/03	10:20-13:50

Table 6d:

Site 1	**00/01**	**00/01**	**01/02**	**01/02**	**02/03**	**02/03**
Irrigation	Date	Time	Date	Time	Date	Time
1	5/12/00	12:10-14:50	10/12/01	20:15-23:25	12/12/02	15:30-17:50
2	23/12/00	08:25-10:35	30/12/01	20:35-00:10	27/12/02	21:20-00:20
3	8/1/01	12:05-15:00	18/1/02	16:55-20:30	12/01/03	15:40-18:40
4	20/1/01	17:10-20:25	2/2/02	11:10-13:50	26/1/03	21:55-01:15
5	3/2/01	16:10-20:15	20/2/02	18:30-21:05	14/2/03	23:30-02:50

Table 6e:

Site 5	**00/01**	**00/01**	**01/02**	**01/02**	**02/03**	**02/03***
Irrigation	Date	Application	Date	Application	Date	Application
1	19/12/00-25/12/00	1.38 ML/ha	6/12/01-12/12/01	1.14 ML/ha	21/11/02 - 25/11/02	2.038 ML/ha
2	14/1/01-16/1/01	0.63 ML/ha	31/12/01 -3/1/02	0.65 ML/ha 13 mm rain	7/12/02-13/12/02	
3	31/1/01-3/2/01	0.63 ML/ha	20/1/02-23/1/02	0.65 ML/ha 11 mm rain	4/12/02 (rain)	4.8 mm
4	12/2/01 (rain)	4.8 mm	5/2/02-11/2/02	1.14 ML/ha	30/12/02 (rain)	32 mm
5	16/3/01 (rain)	33.8 mm			11/1/03-14/1/03	2.33 ML/ha
6					19/1/03-21/1/03	
7					30/1/03 (rain)	9.4 mm
8					9/2/03-12/2/03	2.33 ML/ha
9					1/3/03-4/3/03	
10					16/2/03 (rain)	20.8 mm
11					19/3/03	1.0 ML/ha**

* Three irrigated hay cuts: 27/12/02 (3.4 t/ha); 1/2/03 (2.5 t/ha); 7/3/03 (1.8 t/ha).
** One irrigation for stock feed.

4.4 Water balance results

The data collected from all the instrumentation was analysed in various appropriate calculations used to compute the information required. Tables 7-11 present the water balance results for each site for each year of the project.

Table 7: SITE 1

	00/01	**01/02**	**02/03**
Average pump flow rate	0.471 ML/hr	0.733 ML/hr	0.666 ML/hr
Volume pumped	10.7 ML/ha	13.913 ML/ha	24.15 ML/ha
Channel drainage (@ peak flow)	0.072 ML/ha	0.664 ML/ha	1.22 ML/ha
Evaporative losses (bay)	0.065 ML/ha	0.028 ML/ha	0.191ML/ha
Evaporative losses (channel)	0.0008 ML/ha	0.006 ML/ha	0.0223 ML/ha
Volume delivered onto bay	10.627 ML/ha	13.243 ML/ha	22.91 ML/ha
Feeder root depth storage	4.10 ML/ha	4.60 ML/ha	6.72 ML/ha
Drainage	6.599 ML/ha	9.272 ML/ha	17.217 ML/ha
Estimated crop use (raw data)	3.71 ML/ha	3.52 ML/ha	6.08 ML/ha
Residual water stored	0.39 ML/ha	1.08 ML/ha	0.64 ML/ha
ETc (crop use factors)	3.79 ML/ha	3.63 ML/ha	5.08 ML/ha
% pumped water return to aquifer	61.7%	66.6%	71.3%
% pumped water used by crop	34.7%	32.9%	25.2%
% evaporative losses	0.6%	0.3%	0.9%
% pumped water stored in soil throughout crop production period	3.0%	0.2%	2.6%
Irrigations	3	4	8 (all hay)
Clean seed yield (kg/ha)	662	604	N/A

(Rainfall influence is incorporated in the crop water use assessment)

Table 8: SITE 2

	00/01	01/02	02/03
Average pump flow rate	0.8 ML/hr	0.839 ML/hr	0.736 ML/hr
Volume pumped	8.022 ML/ha	10.10 ML/ha	7.89 ML/ha
Channel drainage	0.265 ML/ha	0.32 ML/ha	0.265 ML/ha
Evaporative losses (bay)	0.025 ML/ha	0.05 ML/ha	0.06 ML/ha
Evaporative losses (channel)	0.013 ML/ha	0.014 ML/ha	0.015 ML/ha
Volume delivered onto bay	7.744 ML/ha	9.766 ML/ha	7.61 ML/ha
Feeder root depth storage	4.00 ML/ha	4.00 ML/ha	4.00 ML/ha
Drainage	3.984 ML/ha	6.036 ML/ha	3.815 ML/ha
Estimated crop use (raw data)	3.69 ML/ha	3.62 ML/ha	3.60 ML/ha
Residual water stored	0.31 ML/ha	0.38 ML/ha	0.40 ML/ha
ETc (crop use factors)	3.65 ML/ha	3.68 ML/ha	3.76 ML/ha
% pumped water return to aquifer	49.7%	59.8%	48.4%
% pumped water used by crop	46.0%	35.8%	45.6%
% evaporative losses	0.5%	0.6%	1.0%
% pumped water stored in soil throughout crop production period	3.8%	3.8%	5.0%
Irrigations	5	5	5
Clean seed yield (kg/ha)	440	410	365 (seedling)

(Rainfall influence is incorporated in the crop water use assessment)
02/03 was a different field site in an adjacent seed crop. This crop was furrow irrigated. Using the same pump and channel.

Table 9: SITE 3

	00/01	01/02	02/03
Average pump flow rate	0.766 ML/hr	0.737 ML/hr	0.590 ML/hr
Volume pumped	6.965 ML/ha	8.504 ML/ha	7.348 ML/ha
Channel drainage	0.534 ML/ha	0.679 ML/ha	0.665 ML/ha
Evaporative losses (bay)	0.015 ML/ha	0.015 ML/ha	0.06 ML/ha
Evaporative losses (channel)	0.003 ML/ha	0.002 ML/ha	0.007 ML/ha
Volume delivered onto bay	6.428 ML/ha	7.823 ML/ha	6.676 ML/ha
Feeder root depth storage	4.80 ML/ha	5.60 ML/ha	5.60 ML/ha
Drainage	2.144 ML/ha	2.902 ML/ha	1.741 ML/ha
Estimated crop use (raw data)	4.09 ML/ha	4.06 ML/ha	3.98 ML/ha
Residual water stored	0.71 ML/ha	1.54 ML/ha	1.62 ML/ha
ETc (crop use factors)	3.97 ML/ha	3.99 ML/ha	4.04 ML/ha
% pumped water return to aquifer	30.8%	34.1%	23.7%
% pumped water used by crop	58.7%	47.8%	54.2%
% evaporative losses	0.3%	0.2%	0.9%
% pumped water stored in soil throughout crop production period	10.2%	17.9%	21.2%
Irrigations	6	7	7
Clean seed yield (kg/ha)	680	714	550

(Rainfall influence is incorporated in the crop water use assessment)

Table 10: SITE 4

	00/01	01/02	02/03
Average pump flow rate	0.406 ML/hr	0.385 ML/hr	0.479 ML/hr
Volume pumped	9.061 ML/ha	9.497 ML/ha	10.855 ML/ha
Channel drainage	0.42 ML/ha	0.455 ML/ha	0.42 ML/ha
Evaporative losses (bay)	0.02 ML/ha	1.0×10^{-4}ML/ha	0.051 ML/ha
Evaporative losses (channel)	0.013 ML/ha	0.003 ML/ha	0.016 ML/ha
Volume delivered onto bay	8.628 ML/ha	9.039 ML/ha	10.419 ML/ha
Feeder root depth storage	4.25 ML/ha	4.25 ML/ha	4.25 ML/ha
Drainage	4.778 ML/ha	5.244 ML/ha	6.522 ML/ha
Estimated crop use (raw data)	3.85 ML/ha	3.71 ML/ha	3.80ML/ha
Residual water stored	0.40 ML/ha	0.54 ML/ha	0.45 ML/ha
ETc (crop use factors)	3.85 ML/ha	3.71 ML/ha	3.59 ML/ha
% pumped water return to aquifer	52.7%	55.2%	60.1%
% pumped water used by crop	42.5%	39.1%	35.0%
% evaporative losses	0.4%	3.1×10^{-4}%	0.6%
% pumped water stored in soil throughout crop production period	4.4%	5.699%	4.3%
Irrigations	5	5	5
Clean seed yield (kg/ha)	608	621	556

(Rainfall influence is incorporated in the crop water use assessment)

Table 11: SITE 5

	00/01[a]	01/02[a]	02/03[b]
Average pump flow rate	0.386 ML	0.386 ML	0.182 ML/hr
Volume pumped	2.70 ML/	3.75 ML/	6.698 ML/ha
Rain	0.246 ML/ha	0.314 ML/ha	1.21 ML/ha
Evaporative losses	0.162 ML/ha	0.193 ML/ha	0.139 ML/ha
Volume delivered	2.786 ML/ha	3.871 ML/ha	6.559 ML/ha
Feeder root depth storage	3.00 ML/ha	3.90 ML/ha	4.20 ML/ha
Drainage	0.0 ML/ha	0.0 ML/ha	2.35 ML/ha
Estimated crop use (raw data)	3.29 ML/ha	3.56 ML/ha	3.50 ML/ha
Residual water stored	0.00 ML/ha	0.311 ML/ha	0.70 ML/ha
Etc (crop use factors)	3.29ML/ha	3.41ML/ha	3.49 ML/ha
% delivered water return to aquifer	undetectable	undetectable	35.1%
% delivered water used by crop	100.0%	92.0%	52.3%
% evaporative losses	5.5%	5.1%	2.1%
% delivered water stored in soil throughout crop production period	0.0%	8.0%	10.5%
Irrigations	3	4	6
Clean seed yield (kg/ha)	450	550	N/A

a: centre pivot rated as 95% efficient with no run off. **b**: centre pivot rated as 87% efficient with no run off.
00/01 & 00/02 used a new permanent centre pivot dedicated to the irrigated seed crop and irrigation was applied to supply crop needs in consideration of rainfall. Rainfall is included in the volume applied.
02/03 was a shared old centre pivot with another lucerne hay crop and irrigation was applied irrespective of rainfall but based on logistics. Rainfall is not included in the volume applied.

The water balance results indicate that under typical prevailing weather during the irrigation season evaporative losses in flood irrigation are minimal and while they were significantly greater under the centre pivot system, they were still comparatively minor compared to crop water use and drainage.

The detailed, time consuming and more costly assessment of crop water use from the soil moisture data compared closely with the estimated data using the modified Penman Monteith equation together with the crop factors specified for varying stages of lucerne seed production. The need for volumetric analysis of soil moisture holding capacity to calibrate the soil moisture sensors is a complex process made more onerous in the stony soil types in the research area. Of more importance is the development of accurate crop factors for manipulation of the ET data. This permits greater scope for the application of the water balance calculation as it eradicates the volumetric analysis. In the context of this relative type of research, increased site evaluation is of more value than slightly more accuracy across reduced sites. Consequently in future research, use of estimated crop water use using the crop factors would be adequate.

5. Implications for irrigators

The results highlight the impacts of some of the basic management processes used in irrigation of lucerne seed crops. Seed yields were generally consistent with the 02/03 season yields being reduced due to seasonal influences. For seed production crops the water use (using specific lucerne seed production crop use factors) across the district, on varying soil types and with varying water salinity were very similar, ranging from 3.29 – 4.09 ML/ha. Water use was consistent from season to season for each seed crop but the percentage of water used by the crop varied in relation to the volume pumped. The volume pumped per season, whilst being a function of the number of total irrigations, also varies significantly irrespective of whether the numbers of irrigations from year to year vary or not. This has an immediate impact on the efficiency of the irrigation system, where efficiency can be expressed as the percentage of pumped water actually used by the crop. For example in site 4 in 00/01, 42.5% of the pumped water was used by the crop and in 02/03, 35% was used by the crop yet the total number of irrigations were the same and the total crop production period varied by only one day. The factors of significance impacting on volume pumped was the time taken to irrigate the field and the pump flow rate. In general the flow rate varied due to the volume of water in the aquifer, type of pump used (i.e. centrifugal or turbine) and, in the case of diesel motor driven pumps, the motor revolutions/minute. For site 4 in 02/03 the flow rate was 17% higher than 00/01 yet the average time taken to irrigate the bay differed only by one minute. Consequently 17% more water was applied but did not increase the rate of irrigation (i.e. reduce irrigation time/ha) only increasing the drainage component as the active root zone could not store the extra water applied per irrigation. The other factor of interest is that either the grower did not cease irrigating the bay early enough or, and more likely, the 17% extra water did not increase the head of pressure to increase the rate of flow down the bay in excess of the infiltration rate through the soil before the water reached the bay end. An implication of this result is that increasing the flow rate does not necessarily result in reduced irrigation time and improved irrigation efficiency. This example is further highlighted at site 2 between seasons 00/01 and 01/02 and seasons 01/02 and 02/03. In addition at site 1 in 00/01 there was only one pump available and three irrigations were applied resulting in crop water use of 34.7% of water pumped. In 01/02 an additional pump was added to the system which reduced irrigation time by 2.8 hours/ha by increasing the volume applied by 29%. However these changes did not improve the percentage of pumped water used by the crop as one more irrigation was applied, more water was drained through the feeder root zone and more water loss occurred through the additional irrigation channel.

Consequently, an implication of the research for the irrigators is that increasing flow rates does not necessarily equate to improved irrigation efficiency. Soil type, bay size and slope have significant bearing on the percentage of pumped water used by the crop. In addition, such as with site 2, where from season 00/01 to 01/02 pump flow rate increased by 5.0% yet average irrigation time increased by approximately 0.5 hour/ha and the percentage of pumped water used by the crop reduced by 10%, the main factor was the timing of irrigation changes – i.e. the irrigation bays were over irrigated. Such results indicate that irrigation practice has an immediate impact on irrigation efficiency.

The percentage of pumped water stored in the soil throughout the crop production period is a cumulative measurement of the soil water quantity within the feeder root zone (being part of the estimated readily available water quantity) remaining in the active root zone immediately prior to each irrigation. In addition, it includes the estimation of soil moisture remaining in the active root zone after the final irrigation and at the time of harvest. In sites 1,2 and 4 when a final irrigation was applied 8 weeks before harvest the crop used a significant proportion of the stored water and a residual less than 10% is not enough for any substantial regrowth after harvest. In site 3 when the final irrigation was applied 6-7 weeks before harvest the stored water percentage increased above 10% and fresh lucerne regrowth is evident after harvest. The number of flood irrigations for seed production is static from one season to the next. An increase in irrigations is associated with a cooler season rather than a hotter season as the crop takes longer to mature and there is uncertainty as to whether there will be enough moisture in the soil for optimum seed fill. In hotter seasons the crops mature quickly and the extra irrigation is often unwarranted. When an extra final irrigation is applied the residual water storage tends to increase. Consequently in site 3 there exists an opportunity for the irrigator to slightly increase the time between irrigations 5 and 6 which may permit the omission of irrigation 7 and hence improve efficiency. Provided the crop is not unduly water stressed the efficiency of an irrigation system and the reduction in drainage can be improved by strategic timing of irrigation to reduce the stored content prior to irrigation thereby maximising each irrigation's impact on replenishing the root zone rather than having increased drainage.

Channel drainage is directly related to the material used for channel construction, with leaking irrigation gates contributing in a minor way to water loss. Channels constructed of marly rubble seal well in comparison to channels made with stoney rubble and inadequate sealing of the channel floor. Irrigating 50 hectares of lucerne seed using a marly rubble channel such as site 2 would lose approximately 3.0 ML through channel drainage whereas site 1 with stony rubble material forming a channel would lose 8.3 ML through channel drainage. Evaporative losses are very small relative to channel seepage losses and improvements in irrigation efficiency could be gained by alterations to the delivery channel, specifically the associated drainage component.

In 00/01 and 01/02 site 5 was a fixed centre pivot seed crop that could be irrigated as the crop required. Irrigation was applied to the feeder root depth with negligible quantities passing below this level. Irrigations were often at night or in calmer daytime weather so as to improve application efficiency by reducing evaporative losses. In 00/01 the crop was under irrigated and was forced into a water deficit after the final irrigation. Consequently in the water balance calculation all of the pumped water (excepting evaporation losses) was used by the crop with no storage. The irrigation management was refined in 01/02. The increased seed yield in 01/02 was directly influenced by more applied irrigation compared to 00/01. The pivot site enabled a refined assessment of crop water use as delivery of specific quantities of irrigation to the crop supplied the lucerne seed crop requirement thereby minimising drainage and storage. These results confirm the reliability of crop water use estimates, using weather data and crop coefficients, as well as the drainage components in the flood irrigated research sites.

Site 5 was shifted in 02/03 to an older centre pivot shared between two irrigated paddocks – a situation common in irrigated pivot production. Both pivots were lucerne hay crops. Consequently the hay crop was irrigated before and after hay cuts and when the pivot was not in use by the other crop. This was, on occasions, in periods of rainfall or cooler weather when the hay crop did not necessarily require irrigation due to available soil moisture in the feeder root zone. It is evident that in this situation the efficiency of the pivot irrigation system was significantly less than the seed crop of preceding seasons. However the crop used more than 50% of the applied irrigation. It is reasonable to assume that the water use efficiency of seed crops irrigated in a shared pivot system would also be significantly different from the fixed pivot data and are more likely to be similar to the hay crop data – especially as the water use figures are comparable. Irrigators involved with these systems could improve efficiency by having a sufficient time difference between the hay or seed crops to minimize irrigating when not required by the crop.

In site 1 the hay crop in 02/03 used nearly 73% more water than the seed crop on the same paddock in the preceding season, and required 73% more water to be pumped. However the percentage used by the crop or stored in the feeder root zone differed only by 7.1%. Consequently, in this case, the water use efficiency was not greatly different between the seed and hay crops.

The water balance research provides an understanding of the baseline data from which improvements in irrigation efficiency can be derived. The results are of considerable benefit to the irrigator in the licence conversion process, but beyond this the greater strength is in a system of measuring the water balance and any improvements to the efficiency of irrigation delivery and crop water use.

6. Implications for policy makers

The research sites represent a significant proportion of the irrigated lucerne seed production area which the irrigation licence conversion process effects and the research has determined that for the flood irrigated sites a delivery component, i.e. the percentage of water pumped that is lost in the process of delivering water to the crop, is very small. For example in site 2 in the 02/03 season the delivery component was 0.9% of the volume pumped. Additionally the losses attributed to evaporation are also very small and at the same site the losses in 02/03 were 1.0%. Consequently the significant majority of water pumped is used by the crop, stored in the root zone for use after harvest or drained at an undetermined rate back to the aquifer.

In the conversion of the licence system it could be considered that the volume granted per hectare of irrigation currently irrigated for lucerne seed production be 120 – 150% the root depth storage. Alternatively, and possibly easier to calculate, the volume granted could be 200% of the ETc. For example, if it is accepted that a lucerne seed crop uses 4.0 ML/ha, the licence should be 12.00 ML/ha. From this quantity, and on the basis of the research over three consecutive seasons, 10 of the 11 flood irrigated seed crops would be unaffected by the licence conversion. This would successfully have the volumetric conversion process not significantly influence current irrigation operations, production base, economic status of the irrigated lucerne seed production industry and regional economic structure.

Desmier and Schrale (1988) based the current irrigation equivalent (I.E) licence system on estimated lucerne seed crop water use (ETc) requirements that exceed those calculated in this research. Their estimate of lucerne seed crop water use for the months of December to March exceeded 5.0 ML/ha whereas the research calculates water use in the range of 3.5-4.0 ML/ha. One of the assumptions of the IE scheme is that the root zone of lucerne was 500 mm deep and plant available moisture in this zone ranged from 35-70 mm depending on soil type. This research has determined the active root zone available moisture to vary between 80-120 mm and that root zone depth varies from 400-1200 mm depending on the soil type. The research's findings impact on the technical accuracy of the IE scheme i.e. lucerne does not use as much water as the IE scheme estimates hence the assigned equivalent should be higher. A key factor in the inaccuracy of the IE scheme are the crop coefficients used in the conversion of ETo to ETc. The research has fine tuned the variation of the crop coefficients through the seed crop production phase. A correction of the IE schemes inaccuracy could result in an increased irrigated lucerne area. However this is not necessarily advocated due to declining ground water levels and water quality in some areas. The impacts of irrigation on the unconfined aquifer and its quality are evident and the inaccuracy of the IE scheme in respect to lucerne seed production has probably had a positive effect on aquifer sustainability.

The IE scheme assessed lucerne seed and the reference crop across an entire calendar year in determining the ETc and hence the IE conversion. This may have been appropriate in 1988 when the scheme was introduced but it appears to have inaccuracies. It is more appropriate to focus on the irrigated period for the calculations given that under current practices in 2004, the management and production off a lucerne seed crop pasture (potential seed crop) in the months of May-November/December (or when lucerne seed crops are initially irrigated) is totally rain fed. It appears more appropriate to focus on the lucerne crop (and reference crop) water use and irrigation requirements for production through the irrigated period and make the distinction between rain and irrigation contribution. As mentioned earlier the estimation of lucerne seed crop water use by the IE scheme is inaccurate and it appears appropriate to use research such as utilised in this project to determine the volumes required to permit continuance of the current irrigation practices rather than attempt to convert from the existing scheme per se.

The licence conversion process should not, unless an existing irrigation system is very inefficient, reduce the current volumes pumped and area irrigated for lucerne seed production in the region. The process of modifying licence volumes in the context of aquifer management e.g. groundwater salinity management, should be a separate process based on different and more specific research.

7. Recommendations

On the basis of the research results the following recommendations and comments are made to the lucerne irrigators of the upper south east of South Australia, the Australian lucerne seed Industry, Rural Industries Research and Development Corporation (RIRDC), the Department of Water, Land and Biodiversity Conservation (DWLBC) and the South East Catchment Water Management Board (SECWMB).

1) Proceed with the Volumetric Conversion Project throughout the upper and lower south east of South Australia utilising this research and its methodologies.

2) The research is critical in a fair conversion of licences from the current IE system to a quantified water volume (volumetric) licence. The research is indicative of the irrigated lucerne seed production region but there are likely to be those whose irrigation systems will be better or worse than the efficiencies recorded. The aim of the licence changing process is to fairly convert based on quantified evidence from across the irrigation region.

3) The conversion process is not an opportunity to reduce or increase water licence allocations, but it is a starting point for obtaining the baseline understanding of irrigation efficiency. The water balance research determines what happens to pumped irrigation water and, in turn, defines areas where water use efficiency can be improved.

4) Any form of conversion from the existing scheme, for the benefit of the ground water system, would need to be done from its current form and not a revised and more technically accurate form. The conversion could be as simple as: 1 reference crop unit = 1.2 lucerne seed units = 1 ha of irrigated lucerne seed = 12.00 ML/ha (or a similar figure)

5) Irrigators must use the results of the research and investigate their own irrigation systems to understand their water balance and where improvements in efficiency can be made. This will be paramount once licences become volumetric and there is defined water quantities available for irrigation as well as the option to trade water in excess of their own crop's requirements.

6) To encourage efficiency improvements by irrigators coupled with any necessary reductions in licenced volumes on the basis of quantified research, an irrigators specific reductions could be placed in trust and can be redeemed for own use (e.g. trading/ farm use) if they meet (in a forecast time) milestone efficiency improvements such as reduced pumped volumes per irrigated area.

7) Dedicated research must take place in the area of quantifying the impact of the water balance system on water quality and hence the sustainability of the resource. Such work has commenced and is critical if significant changes to water allocations are to be required.

8) Research should be conducted into quantifying how much pumped irrigation water is pumped again in the same irrigation season, and the impact this has on the water quality. In addition there are licensing issues if a percentage of the water is pumped on more than one occasion. This is all part of a fair and sustainable licensing system.

9) This type of research should be well promoted to the irrigation communities of Australia.

8. Communications strategy

The completed research report will be disseminated to DWLBC, SECWMB, Hundred of Stirling Water Resources Group, Tintinara-Coonalpyn Irrigators and the South East Natural Resources Consultative Committee (SENRCC).

The irrigators will have the research findings disseminated via local press/media as well as via the Volumetric Conversion Project community consultation process. Information will also be released at any appropriate field day and conferences.

9. References

1. *Desmier, R.E. & Schrale G. (1988):* Estimations of water requirements for irrigated crops in the Tatiara Proclaimed Region. Dept. of Ag. SA. Tech. Rep. No. 127.

2. *Schrale, G. & Ciganovic, C. (1997):* Crop Area ratios of the lucerne growing practices – Hundred of Stirling. PIRSA. Tech. Rep. No. 257.

3. *Douglas, W. (in progress):* Benchmarking the distribution efficiency of an irrigation supply system.

4. *Akbar, S. and Khan, S. (2003):* Methodologies for quantifying on-farm channel and drain interactions with regional groundwater dynamics. To be published.