WAA001

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Sugar Research and Development Corporation

Project:	WAA001
Title:	Water Table Monitoring in the Ord River Valley
Duration:	July 1995-June 1999
Organization:	Agriculture Western Australia
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Summary:

Monitoring of groundwater levels has been undertaken in the Ord River Irrigation Area using a network of bores established on farms throughout the Stage 1 area. These bores, many of which were installed as part of this project, complement a network previously established off farm. They have been monitored on a regular basis and changes in levels have been examined in relation to a range of factors including irrigation and crop management practices, rainfall and irrigation infrastructure management, to allow causal relationships to be established and hence potential management strategies to be developed. Monitoring has been assisted through the equipping of many bores with water depth probes and loggers to automatically record changes in levels over extended periods of time.

A range of options for management of rising groundwater in the Ord has been identified and a number of these have subsequently been assessed and demonstrated to be feasible in the area. They include the use of dewatering to lower groundwater levels and the use of alternative irrigation practices to improve the efficiency of water application. Requirements for drip irrigation and improving surface irrigation management have also been examined. This process has included the assessment of soil moisture monitoring equipment, including the EnviroSCAN, to investigate the deep drainage component of irrigation, contributing to groundwater accessions. The EnviroSCAN has also been shown to be effective in irrigation scheduling of sugar cane.

Since involvement of stakeholders and extension of project findings have been considered critical for the successful implementation of findings and achievement of project outcomes, significant effort has been placed in this process. Project review and planning have been undertaken through workshops with growers, and results made available through seminars, reports and newsletters. Best management practices developed through this and related projects will be implemented in association with a Land and Water Management Plan currently being developed for the ORIA.

This project is linked to the SRDC project CR22, 'Best practice irrigation management to maximize profitability and ensure sustainability in the Ord Sugar Industry'.

Systems developed to manage rising groundwater and to support sustainable cropping systems in the Ord Stage 1 area will also be directly relevant to the proposed Stage 2 development of the ORIA. The proposal is for a further 40,000 hectares of land to be developed, with the majority of this area for sugar cane production.

Background:

Piezometers were first installed in the Ord River Irrigation Area (ORIA) by the Public Works Department in 1964 to monitor groundwater levels on the Ivanhoe Plain. Additional piezometers were installed in 1978 and 1983. All were located close to either supply channels or drains. With one exception, the most frequent monitoring of these piezometers was three times per year.

Water level data obtained to September 1986 were reviewed by McGowan (1987) and to 1990 by Laws (1991). McGowan (1987) concluded that the hydrological conditions on the Ivanhoe Plain were changing in response to irrigation that had taken place since 1964. Laws (1991) found that water levels were rising at between 20 and 50cm per year over most of the area with groundwater at less than 3m from the surface in one localized area.

Because all the data used in the reviews came from bores adjacent to the supply and drainage system, there was a tendency to attribute the rising water levels to leakage from the channels and drains. In 1991 the Department of Agriculture (now Agriculture Western Australia) installed piezometers at six sites on farm properties away from the main supply and drainage systems.

In 1994 hydrographs from the piezometer network were examined and the rates of water level rise extracted. This showed an area of some 1360 ha where groundwater was rising in excess of 50 cm per year. Groundwater was rising at between 40 and 50 cm per year over an additional area of 900 ha and at greater than 20 cm per year over much of the remainder.

The piezometers installed by the Department of Agriculture showed rates of rise between 40 and 80 cm per year. As these were well away from the supply and drainage system they indicated that water level rises were not solely due to channel or drain leakage. They also indicated that the long term responses observed in the other bores were indicative of the situation under the entire plain and not just the land adjacent to the supply and drainage system.

By 1990, it was estimated that groundwater levels were within 3m of the surface over an area of 120 ha. This had increased to 620 ha by 1994. Hydrographs developed from monitoring data, while valuable in determining long term trends in water levels, provided no insight into the process whereby water was accessing the groundwater system. Equipping monitoring bores with water depth probes and loggers could begin to provide that insight.

There was also a large area where groundwater conductivities were greater than 300 mS/m in 1990 (Laws 1991). At these levels of conductivity, serious salt accumulations could be expected in the root zone if the water table reached within 1.5 to 2 m of the surface with Na and Cl the dominant ions in the groundwater (McGowan 1983). Irrigation practice would then have to incorporate a leaching fraction that could further exacerbate the rise in water levels unless there was adequate drainage.

By the early 1990's it was becoming evident that groundwater levels were not stabilizing and that if they continued to rise unchecked that serious land degradation could occur through waterlogging and salinity. If this eventuated, it would result in reduced crop yields and a restricted range of crops that could be grown.

This project addresses the issue of rising groundwater by developing an understanding of the processes and causes for rising groundwater in the Ord valley and by consideration and development of appropriate management options. This is fundamental to the development of economically and environmentally sustainable irrigation farming and sugar cane production in the ORIA.

Objectives:

1. To establish with grower support 40 on-farm monitoring bores on the Ivanhoe and Packsaddle plains of the Ord River Irrigation Area (ORIA).
2. To record groundwater level changes and relate these to the site stratigraphy, irrigation practices, rainfall, crop type and the irrigation infrastructure management.
3. To identify and test appropriate irrigation and cropping practice options for economically sustainable cropping in the ORIA.
4. To promote the adoption of appropriate management practices for economically, sustainable cropping in the ORIA.

Problem/Research need:

Sugar cane has recently been introduced to the ORIA as a commercial crop and is now a major industry in the irrigation area. Sugar cane would ultimately be affected by a continued rise in groundwater which if left unchecked could lead to problems with waterlogging and salinity with consequent reduction in yield and loss of the land resource.

Land degradation would also impact on the new sugar industry. The industry, now producing over an area of 4000ha and with potential for significant expansion in both the Stage 1 and Stage 2 areas of the ORIA, is a significant contributor to the economy of the area, with a current value of over $17 million. The industry could also itself exacerbate the situation with rising groundwater. With a requirement for irrigation throughout the entire year, and application of more than double the water used for most other crops, sugar cane could potentially contribute significantly to rising groundwater if managed inappropriately.

Sugar cane is also moderately sensitive to salinity although with varietal differences evident. Yield depressions of 10% and 25% at water conductivities of 300 and 500 mS/m respectively have been reported for NCo varieties (Bernstein et al 1966).

This project addresses these issues by examining the processes implicated with rising groundwater to allow identification and development of appropriate management strategies and by educating stakeholders in requirements for sustainable development of irrigated agriculture throughout the ORIA. A key component of the project is the involvement of growers throughout the development and implementation phases, to ensure acceptance and successful implementation of findings.

Methodology

Preliminary data on groundwater levels in the ORIA:

A network of piezometers was installed by the Public Works Department (now Water and Rivers Commission), commencing in 1964, to monitor groundwater levels throughout the ORIA. Forty-seven additional monitoring bores were installed by Agriculture Western Australia prior to 1995, at sites on farm, away from existing supply and drainage infrastructure. They were monitored by manually recording depths around three times per year. These data were used together with longer term data from the Water and Rivers Commission wells to review the groundwater status at that time. A report published by the Water and Rivers Commission in 1996 presented groundwater levels throughout the ORIA, changes in groundwater levels and risk maps predicting groundwater levels into the future if current trends in rates of rise continued.

Bore installation:

An additional 17 monitoring bores were installed in late 1996. These were sited in areas requiring further monitoring based on results obtained from analysis of data from existing bores. Monitoring bores were installed at two sites in a network adjacent to production bores to monitor pumping tests. Other bores were installed on a newly developed farm in the area. Wells were drilled to bedrock (15-25m) and cased with 50mm PVC pipe, slotted for 3m at the base. They were backfilled with coarse sand and sealed towards the surface with bentonite to prevent seapage from the surface. These bores were equipped with depth level sensors and loggers.

Many of these and previously installed bores were buried to a depth of 20-30cm below the surface to prevent mechanical damage to the structure, since some were located on farm roadways and others in cropped areas. Burying bores allowed normal use of farm machinery over the site. A metal plate was placed under ground over the bore and a metal detector used to locate the site when monitoring was required.

Coordinates for all bores have been determined by GPS to aid in mapping of bore locations.

Equipping of monitoring bores for logging changes in groundwater levels:

Fourteen monitoring bores were equipped with Wesdata dataloggers attached to 2m water level sensors, during 1995. These were calibrated prior to installation, set to monitor changes in groundwater levels at six hourly intervals and downloaded at three monthly intervals. Equipment is serviced or replaced at each downloading to minimize data loss through failure. Sensor probes are routinely raised as water levels increase. An additional ten Dataflow 392 dataloggers and 2m or 3m water level sensors were calibrated and installed in 1996 and a further 16 in 1997. There are currently 40 bores equipped with depth probes and loggers to automatically record changes in groundwater levels.

Equipping bores to automatically record changes in groundwater depths has significantly increased the amount of data available and has allowed interpretation of results with respect to processes involved with rising groundwater and causal relationships.

Monitoring of groundwater levels:

Agriculture Western Australia is currently monitoring 64 observation wells, over 11 farms throughout the ORIA, for changes in groundwater levels. Most are accessed at three monthly intervals when levels are recorded manually and loggers downloaded. Some wells located in the centre of sugar cane crops are accessed less frequently due to difficulty in physically entering the crop. These wells are equipped with loggers and water depth sensors. Data obtained from wells are entered into a data base. Reports generated from the data base are provided to growers participating in the monitoring program, at six monthly intervals and to others on an annual basis.

Knowledge of groundwater levels and changing trends is important in understanding processes contributing to changes as well as the extent to which, and the rate at which changes in management practices are required.

Monitoring of management practices:

Intensive monitoring of the management practices associated with irrigation and irrigation infrastructure was carried out between July 1995 and June 1997 at sites surrounding 51 groundwater monitoring bores. The presence of water in on farm or off farm channels and drains was recorded as were dates of irrigation and rainfall. Cropping practices such as pre-irrigations, crop type and planting and harvesting dates were also recorded. Bore logs were also used to assess site stratigraphy.

Monitoring deep drainage:

An EnviroSCAN system was purchased in March 1996. It has been assessed for identifying deep drainage from irrigation or rainfall, below the root zone into the groundwater system. The system consists of a series of sensors located on probes, to monitor soil moisture at varying depths down the profile. Measurements are continuously recorded using a data logger connected by cable to probes installed throughout a crop.

The system was installed at three locations on Cununurra clay soils between 1996 and 1999. Measurements in each location were taken at three sites within the crop with one probe installed at each site. Each probe had eight sensors located at depths of 20, 40, 60, 80, 100, 120, 160 and 200cm below the ground surface. The EnviroSCAN equipment was calibrated at each location at which it was used for measurement of volumetric soil moisture content. It was initially installed on Block 68 in 1996 on an area with shallow groundwater, planted to a pumpkin crop, with each probe adjacent to a groundwater monitoring bore. The soil moisture levels were continuously monitored over a three month period and results assessed.

The EnviroSCAN system was relocated to a first ratoon crop of sugar cane on Block 55, later in 1996. The soil moisture level in this crop was monitored continuously until harvest in September 1997. After harvest, cultivation and fertiliser application, the system was re-installed in this same crop and changes in soil moisture further monitored until harvest in August 1998.

The EnviroSCAN system was then relocated to another cane crop, planted on Block 27 in May 1999, and soil moisture levels monitored from August 1999.

Identifying potential options for groundwater management:

A report has been prepared identifying innovative and practical technologies applicable to water management in the ORIA. The report was researched and compiled by the Kimberley Development Commission in collaboration with Agriculture Western Australia. It focuses on techniques to improve irrigation resource management and efficiency, including the control of rising groundwater. Information in the report was obtained from a range of sources including industry and scientific.

Testing and demonstration of groundwater management options:

i) Dewatering

Short term test

Two groundwater pumping sites were established to determine the feasibility of dewatering for management of rising groundwater. One site was located on the Ivanhoe Plain (Block55) and the other on the Packsaddle Plain (KL 384) of the ORIA. Production bores were established in areas with shallow groundwater, underlain by gravel aquifers likely to be suitable for pumping, with access to power for pumping and with drainage for removal of pumped water. A network of monitoring bores was established around each production bore to record changes in groundwater levels as a result of pumping. Initially, a short-term (eight hour) air lift pump test was conducted to determine aquifer parameters and soil drainage effects. The results of this test were analysed and reported by the Water and Rivers Commission.

Long term test

As results of the short term pump test indicated that pumping the underlying gravel aquifer could vertically drain the overlying silts, a long term test was then conducted to determine the area which could be influenced by pumping. Production bores were equipped with electric pumps designed to run continuously and to remove almost the entire water yield of the bores (1.5ML and 1.8ML per day for the Ivanhoe and Packsaddle bores respectively). They were set at a depth of 12m below the static groundwater level. Piping was installed to remove the pumped water to nearby irrigation supply channels for disposal through drainage or through conjunctive use. The pumps were run for a total of 115 days. Changes in groundwater levels were monitored hourly in nearby bores using water depth sensors and loggers. After 115 days the pumps were turned off for 20 days to assess the recovery of groundwater levels.

Demonstration sites

Following the long term testing, the two pump test sites were sign posted to advertise their purpose and pumped intermittently as demonstration sites. Many opportunities were used to demonstrate and explain the system to growers, industry and the community.

ii) Drip irrigation

Drip irrigation has been tested and monitored on a range of crops on a number of commercial farms throughout the ORIA.

Bananas

Drip irrigation was compared with micro sprinkler irrigation for a plant crop of Cavendish bananas grown on Ord Sandy Loam (levee type soil) between July 1996 and April 1997. Two hectares were assessed with drip irrigation and compared with an adjacent area of sprinkler irrigated crop. Two *Netafim* tapes were laid on the surface for each planted row of bananas or a single line of *Wingfield Challenger* micro sprinklers for each two rows. A similar volume of water (3.5mm/hr) and quantity of fertilizer was applied through both systems. Irrigation was scheduled using accumulative pan evaporation deficit.

Beans

T-Tape was assessed on green bean crops grown on Cununurra clay soil on Block 30 during the 1998 and 1999 dry seasons. A single tape was installed at 5cm depth between each two rows of beans planted on 1.8m beds. Fertilizer was applied through the system. EnviroSCAN equipment was used to assist in scheduling irrigation and in determining the quantity of water required. Advantages of trickle and furrow irrigation were compared at the demonstration site.

Sugar cane

In May 1998 drip irrigation laterals were installed by burying to a depth of 20cm on a 7ha area of Cununurra clay on Block 102 before planting to sugar cane. An area alongside was planted and irrigated using the traditional furrow irrigation method. The system was only used for a short period during 1998 due to blockages of the filtering system. The system has been operational on the ratoon crop throughout 1999 since overcoming this initial problem. Comparison of cane yield and sugar levels is planned for the next harvest in 2000. The scheduling of irrigation is based on accumulative pan evaporation deficit using a crop factor of between 0.8 and 1.0.

iii) Improved surface (furrow) irrigation

Water balance studies were commenced in 1996 to investigate water application efficiencies for furrow irrigation on Cununurra clay soils and to provide information required for modeling optimum furrow irrigation practices using *SIRMOD* (Walker 1993). Sugar cane crop water use was also assessed at one site. Work is continuing on development of SIRMOD for modeling water application efficiency and for determining optimum irrigation practices, through SRDC project CR022.

Tail water losses by individual furrow measurements:

Tail water losses were examined by measuring flows in furrows of sugar cane crops at the lower end of the furrow. Each half of the trial area was irrigated for a different duration to assess tail water losses associated with varying inundation periods at irrigation. Five bays of sugar cane were examined in this way.

Block	Bay Length (m)	Inundation (hr)
B45	580	18/25
B51	490	16/24
B54	350	20/23
B68	1000	24/30
B86	430	12/24

Measurements were taken in 4 adjacent furrows for each treatment and results averaged. *Great Lakes* flow meters were calibrated and installed at the upper and lower ends of each furrow and logged during irrigation to collect flow data. Treatments within each bay were irrigated at similar soil moisture deficits.

Tail water losses by whole bay measurements:

An irrigation block was set up in 1995 (Block 68) to determine water balance at a whole bay level. An automatically recording rainfall gauge was installed and water movement onto the block was measured and recorded through a Dethridge wheel and data logger. Water movement off the block was initially measured and recorded using a Dopler meter and data logger which were later replaced with a Crump weir and float well with data logger, to improve accuracy of measurements.

Tail water flows were recorded for a pumpkin crop in 1996 and for a sugar cane crop in 1997 and 1998.

Soil moisture measurements were also taken during 1996. An EnviroSCAN system was installed at 3 sites to a depth of 2m and soil moisture continuously monitored to assess deep drainage.

Tail water losses and crop water use:

Measurements of furrow tail water losses and crop water use were obtained for a sugar cane crop on Block 27. Measurements of tail water loss were taken at a number of irrigations and crop water use estimated from change in soil moisture between irrigations. Deep drainage was also assessed by observing for increase in soil moisture below the root zone following irrigation.

Block	Date	Bay Length (m)	Inundation (hr)
B27	17.08.99	300	18
B27	31.08.99	300	12
B27	14.09.99	300	12
B27	28.09.99	300	24
B27	12.10.99	300	18

Eight furrows were used for flow measurements and neutron moisture meter (NMM) access tubes were used to investigate soil moisture extraction across the soil profile in addition to down the profile, to determine crop water use. Four access tubes were installed at each of six sites, with two sites at both the upper and lower ends of the furrow and two towards the centre. At each site, four tubes were installed within the 90cm distance between centre of bed and centre of furrow (11, 34, 56, and 79cm from the centre of the bed). Gravimetric soil moisture and bulk density samples were also used for surface soil moisture measurements in the top 15cm to complement the deeper NMM measurements. Gravimetric measurements have been found to be more accurate for surface measurements and critical, given the extent of surface soil moisture use by the crop. Changes in soil moisture were used to determine crop water use and to assess for drainage below the root zone. *Great Lakes* meters were used to obtain flow data.

Water advance rate, furrow profile and water depth in the furrow during irrigation were also measured for use in developing *SIRMOD* for modeling optimum irrigation requirements. Advance rates and furrow depth were recorded using small resistor type instruments positioned along the furrow and connected to a data logger. Changes in resistance were recorded as water reached the resistor and increased in depth.

iv) *Irrigation scheduling and water application requirements*

Preliminary irrigation scheduling and water application requirements have been developed for sugar cane grown in the Ord using information from a range of sources including earlier work in the Ord (Sherrard, 1991) and work undertaken through this project. Work is continuing to further refine these requirements while concurrently examining requirements for groundwater management.

Research on irrigation requirements of sugar cane is also linked to the SRDC project CR22 'Best practice irrigation management to maximize profitability and ensure sustainability in the Ord Sugar Industry'.

Data from water balance studies undertaken are now being used to identifying appropriate irrigation practices, through modeling with SIRMOD, to improve water application efficiency and minimize deep drainage. SIRMOD is being used to identify optimum furrow length and duration of inundation at irrigation. EnviroSCAN equipment has also been used to identify events where excessive irrigation has resulted in deep drainage. Trials have also been undertaken to examine the effect on cane productivity of extended periods of drying off prior to harvest.

Continuing work includes an irrigation trial commenced during 1998 to refine optimum scheduling requirements. Treatment plots were irrigated at 60, 120 and 180mm pan evaporation. This trial is continuing during 1999/00 to examine crop response to a range of soil moisture deficits at irrigation.

The relationship between rate of stalk elongation, soil moisture deficit and crop productivity is also currently being examined as a scheduling technique as developed by the BSES for the Eastern States cane industry.

Information transfer:

Project findings have been reported to stakeholders to encourage change where required through implementation of best management practice. This has been achieved in a number of ways, through extension activities, reports and publications.

Groundwater monitoring data reports have been produced for presentation to growers and the wider community. Reports have been prepared on de-watering as a groundwater management option. A review of work on sugar cane is held with Ord cane growers twice annually. These activities are used to update growers on current findings associated with irrigation and groundwater management. Findings are also promoted through other sugar cane extension activities undertaken by an officer appointed in early 1999 through the SRDC funded project CR022.

Information and project findings on groundwater monitoring and management have also been provided to stakeholders through activities undertaken by a Steering Committee currently involved in the development of a Land and Water Management Plan for the ORIA. This work is part funded by the Natural Heritage Trust.

Results:

Preliminary data on groundwater levels in the ORIA:

A report was published (Yesertener, 1997) providing information on groundwater levels throughout the ORIA recorded up to 1996, on changes in groundwater levels and with risk maps predicting groundwater levels into the future.

Groundwater levels prior to the commencement of irrigation in 1964 were around 16-17m below ground level over much of the Ivanhoe Plain of the ORIA. Infiltration from irrigation channels and irrigation practices has since caused rising water levels to the extent that by 1996 groundwater was within 1.5 m of the surface in a few localized areas. It is likely that prior to 1965 the Ord River recharged the aquifer while during the period since, this has been reversed with the aquifer recharging the Ord River.

In the southern half of the lvanhoe Plain groundwater flow appeared to continue to be dominated by leakage from the main supply channel, through the area, with groundwater levels generally stable or rising slightly. In contrast, in the northern half of the Plain, the level was less influenced by the channel and more by irrigation practices and possible leakage from drains. Most of the plain showed groundwater levels rising in excess of 0.25m/year with rates in some areas greater than 0.60m/year for the period between April 1995 and April 1996. Over most of the north-eastern area, data indicated that water levels were rising in excess of 0.40m/year.

By 1996, an area of almost 750 ha had groundwater within 1.5m of the surface. It was predicted that an area of almost 2150 ha would be similarly affected by 2000 if groundwater continued to rise at similar rates (Figure 1). By 2020, an even larger area of the northern lvanhoe Plain would be affected by high groundwater levels and require remediation.

Groundwater salinity levels in the southern half of the Ivanhoe Plain were generally low (EC of less than 500 µS/cm) and higher in the northern half although declining as a result of aquifer recharge from irrigation.

On the Packsaddle Plain, depth to groundwater in the monitored bores ranged from 2-9m with indications of recharge from both irrigation and irrigation infrastructure. Projection of groundwater level trends to 1996 indicated that an area of 125 ha would have groundwater within 1.5 m of the surface by the year 2005 (Figure 1).

Bore installation and equipping for logging changes in groundwater levels:
Locations of bores monitored as part of this project are presented in Figure 2 and Appendix 1. Figure 2 shows the broad distribution of bores throughout the developed Irrigation Area (Stage 1) with bores installed earlier generally located adjacent channel or drainage infrastructure and more recently installed bores generally away from infrastructure on farm cropping bays. The irrigated area covers approximately 12,000 ha with the Ivanhoe Plain to the north and the Packsaddle Plain to the south. Included are 17 monitoring bores installed in late 1996 in areas requiring further monitoring based on results obtained from analysis of data from bores installed earlier. Monitoring bores were installed at two sites in a network adjacent to production bores to monitor pumping tests. Other bores were installed on a newly developed farm as part of a process to ensure that groundwater levels are monitored from the commencement of irrigation.

Appendix 1 lists bores monitored, GPS coordinates and those equipped with water depth sensors and loggers for automatic recording of changes in groundwater levels. This equipment has allowed continuous collection of data and from bores located within crops which are at times inaccessible. There are currently 40 bores equipped with depth sensors and loggers.

Equipping bores to automatically record changes in groundwater depths has significantly increased the amount of data available which has allowed interpretation of results with respect to processes involved with rising groundwater.

Monitoring of groundwater levels and management practices:
Agriculture Western Australia is now monitoring 64 observation bores, over 11 farms throughout the ORIA, for changes in groundwater levels. These bores and their locations are listed in Appendix 1. Most are accessed at three monthly intervals when levels are recorded manually and loggers downloaded to provide more detailed information on changes occurring in levels throughout the three month period. Data obtained from wells are entered into a database.

Table 1 provides information on current levels and changes in levels over a five year period to November 1999. Only those bores installed prior to November 1994 have been included in these results. Significant rises have occurred over this period, averaging 30cm/year for the bores listed and ranging from 3-64cm/year. Groundwater levels were within or close to 1.5m of the surface in two locations monitored. At these shallow depths, levels tend to fluctuate significantly with irrigation or rainfall events and shallower levels than those recorded occurred at various times throughout 1999. Groundwater salinity levels tend to be lower in shallower areas due to dilution from low salinity groundwater accessions. To date, no adverse affects on crop production have

Figure 1. Critical Groundwater Level Projections. Areas predicted to have groundwater within 1.5m of the surface, and yearsby which this would occur, if rates of rise occuring to 1996 continued (Yesertener, 1997).

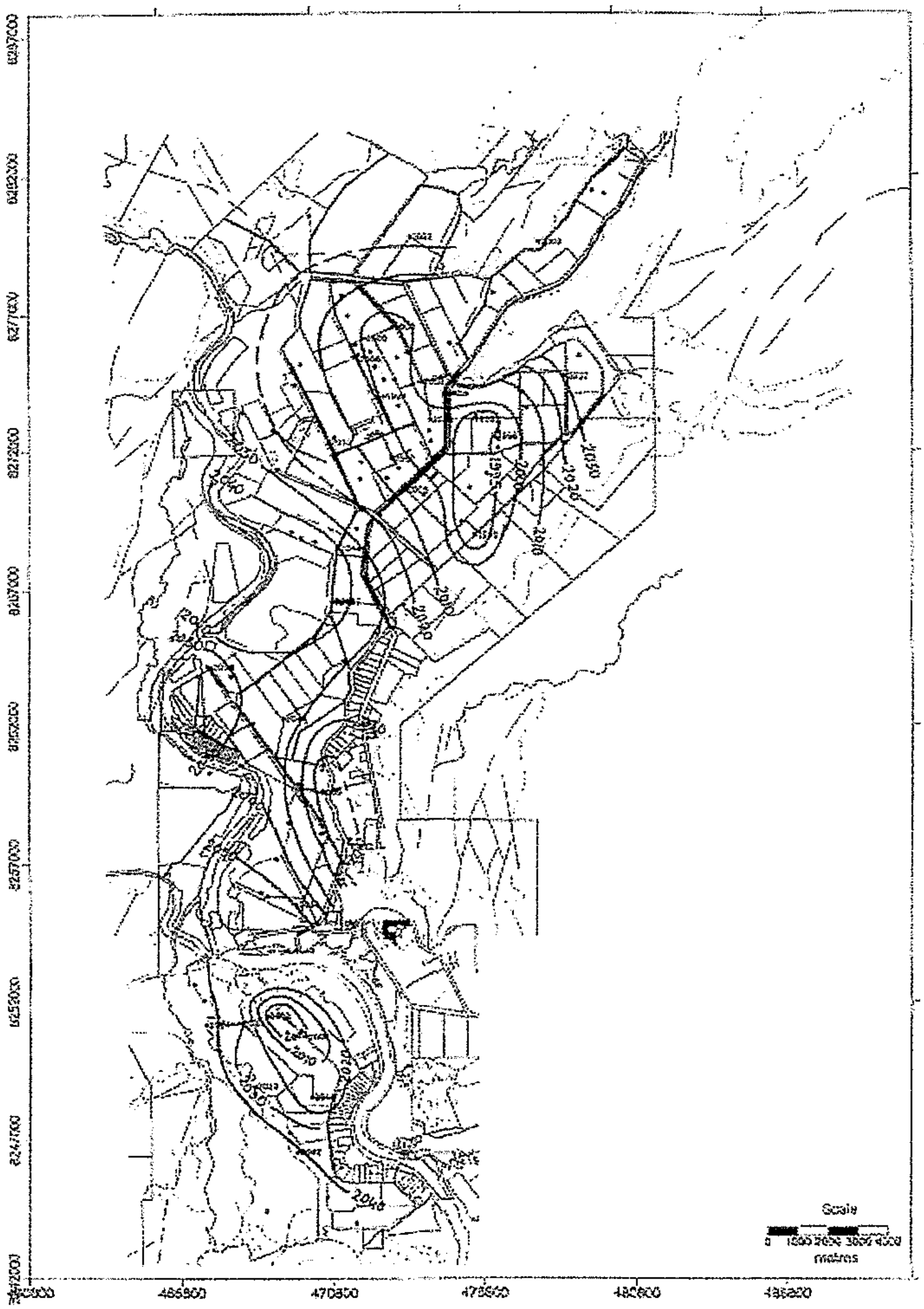
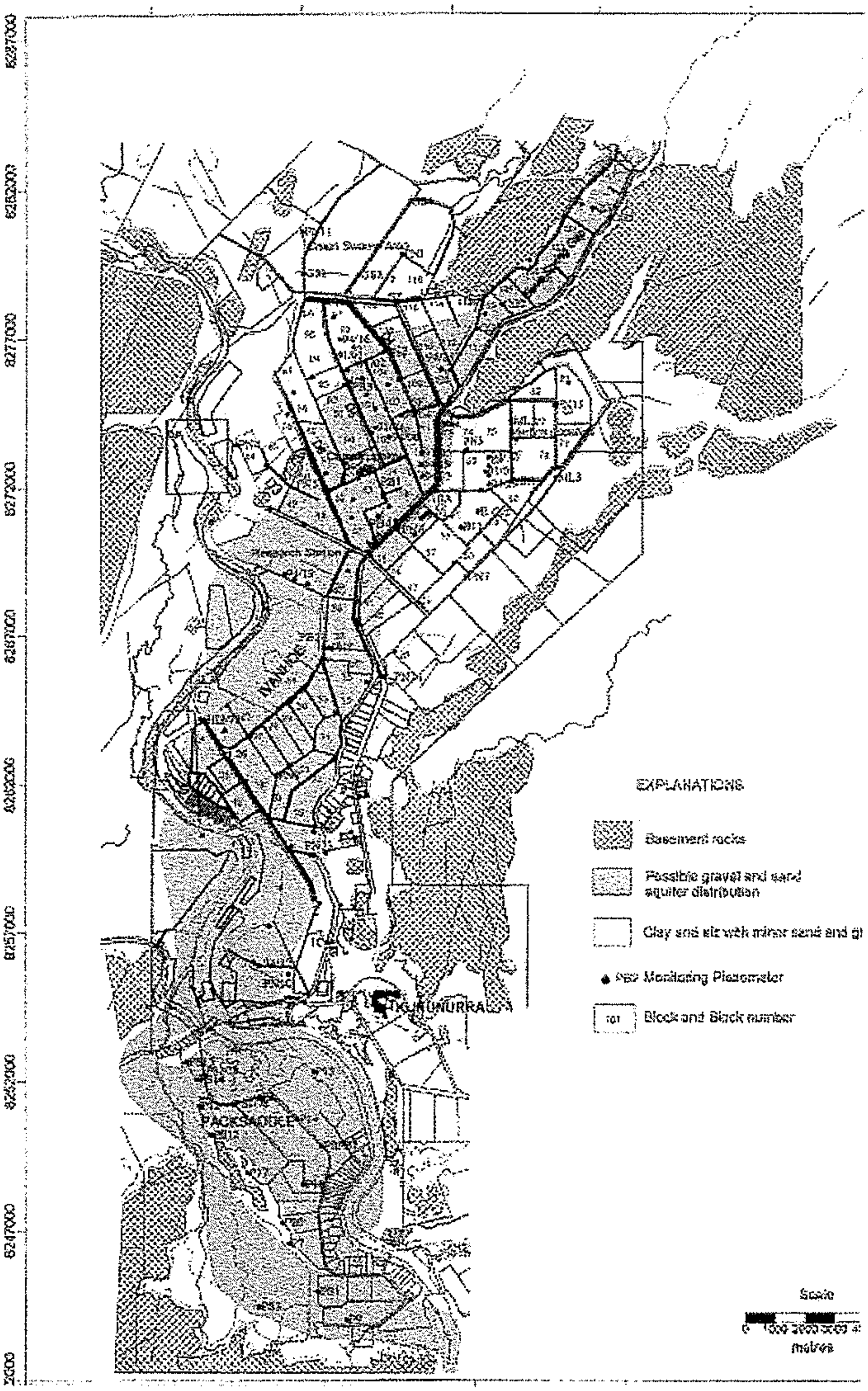


Figure 2. Monitoring Bore Locations in the Ord River Irrigation Area



been observed although areas with shallow groundwater are increasing as predicted in the 1997 report by Yesertener.

More detailed information on changes in levels is provided in Figures 3-6. This information, together with information on irrigation management practices around these bores has assisted in development of an understanding of the processes involved with and hence management strategies required for rising groundwater.

Figure 3 shows groundwater levels over a three year period with a continuous rising trend. With limited wet season irrigation in the Ord, it is clear that both wet season rainfall and dry season irrigation have contributed to rising groundwater. Significant rises occurring through some wet seasons have been associated with falls through the following dry season with subsurface drainage to surrounding areas with deeper groundwater, resulting in continuous rises in these surrounding areas (Figure 6). Previously, with native vegetation and the absence of dry season irrigation, wet season rainfall resulted in groundwater levels in equilibrium at 16-17m below the surface. Improved wet season surface drainage and use of rainfall by wet season or perennial crops such as sugar cane will assist in limiting wet season groundwater accessions.

A more consistent rising trend is associated with dry season irrigation. This is evident in Figure 3, in seasons when the rising trend is not confounded by groundwater drainage from significant accessions occurring during the previous wet season.

Figures 4 and 5 show changes in levels at two sites through the 1997 dry season. Figure 4 also shows rises correlating with irrigation events. This is not as evident in Figure 5, showings changes at a nearby site and indicating the variability in responsiveness to irrigation between these sites, as a result of variation in infiltration or permeability characteristics. Bore logs, providing information on sub-surface stratigraphy, indicate that variation in permeability is related to changes in lower profile texture which is not evident in surface soil.

The fall in groundwater level towards the end of the dry season shown in Figures 4 and 5, as the area of crop under irrigation declines, is common in areas of shallower groundwater. Lateral sub-surface drainage occurs from these areas to areas with deeper groundwater, increasing levels in those areas throughout the season.

These and other results obtained indicate the variation in infiltration or permeability over the area as well as the influence that irrigation practices in one area have on adjacent areas. The results also show both wet season rainfall and dry season irrigation resulting in rising groundwater.

Table 1. Groundwater Levels and Rates of Rise in the ORIA

Bore Number	Current Level November 1999	Average Annual Rate of Rise (m) (1994-1999)
91/01	3.38	0.27
91/02	3.40	0.28
91/06	2.84	0.22
91/07	1.53	0.30
91/08	1.58	0.34
94/01	3.47	0.46
94/02	3.05	0.35
94/03	2.86	0.15
94/04	3.55	0.20
94/06	3.55	0.33
94/08	2.91	0.29
94/09	3.01	0.27
94/10	3.09	0.26
94/11	4.22	0.43
94/12	3.74	0.41
94/13	2.55	0.19
94/14	7.83	0.38
94/17	3.79	0.19
94/18	5.46	0.28
94/22	3.75	0.31
94/23	3.58	0.32
94/24	2.72	0.22
94/25	3.34	0.23
94/26	6.99	0.45
94/27	4.94	0.52
94/28	2.83	0.17
94/29	1.56	0.20
94/30	1.55	0.25
94/31	1.95	0.33
94/32	2.91	0.15
94/33	1.01	0.64
94/34	2.61	0.30
94/35	2.45	0.27
94/36	2.33	0.27
94/37	6.55	0.39
94/40	6.91	0.60
94/41	3.21	0.11
94/42	5.39	0.03
PN12	4.56	0.26
PN12	4.61	0.26
PN2	2.42	0.30
PN2	2.59	0.23
Average		**0.30**

Figure 3. Seasonal effects on groundwater levels in the ORIA (Bore 94-23)

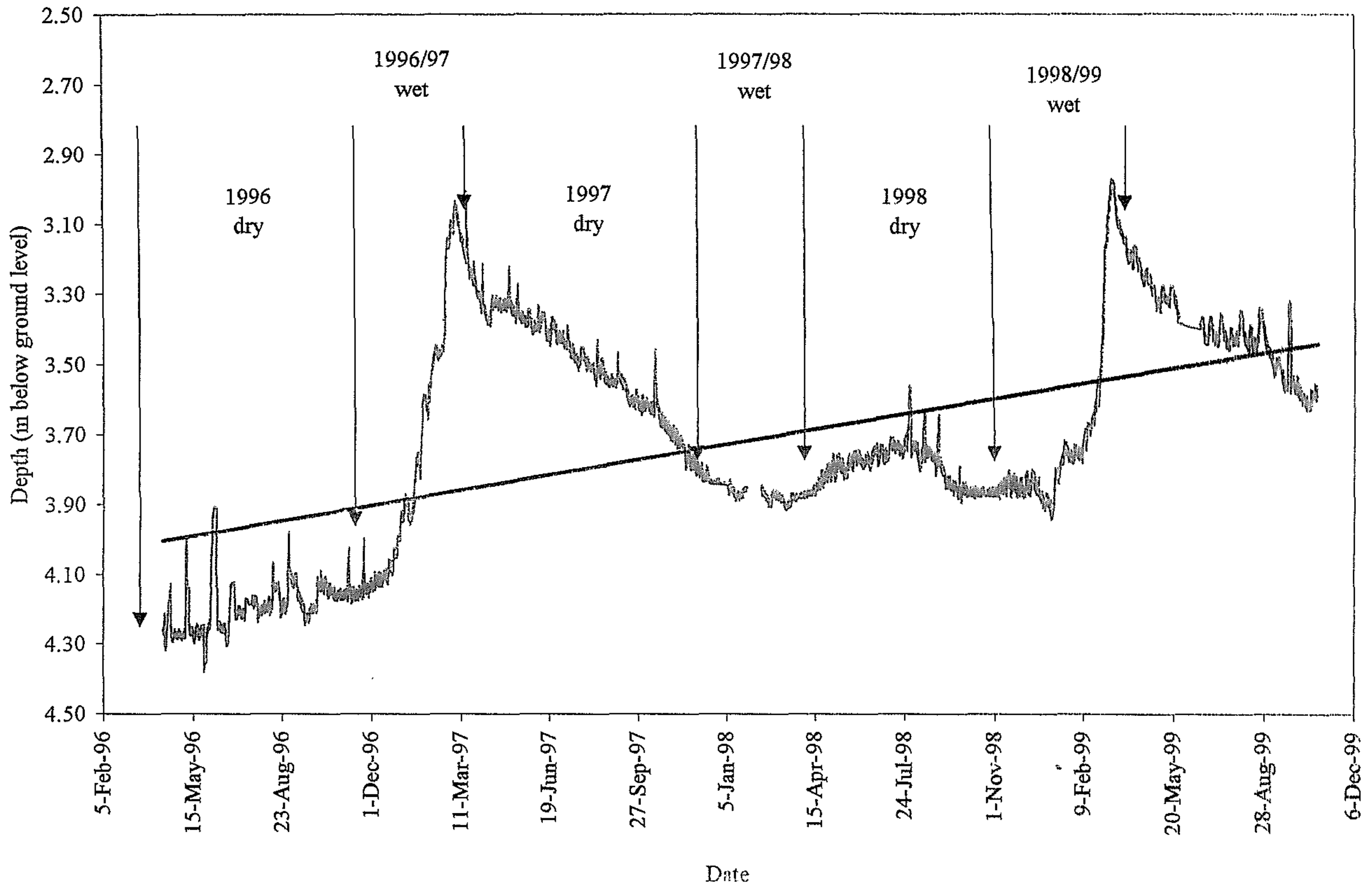


Figure 4. Changes in groundwater levels with dry season irrigation showing the effect of individual irrigation events (bore 94-02).

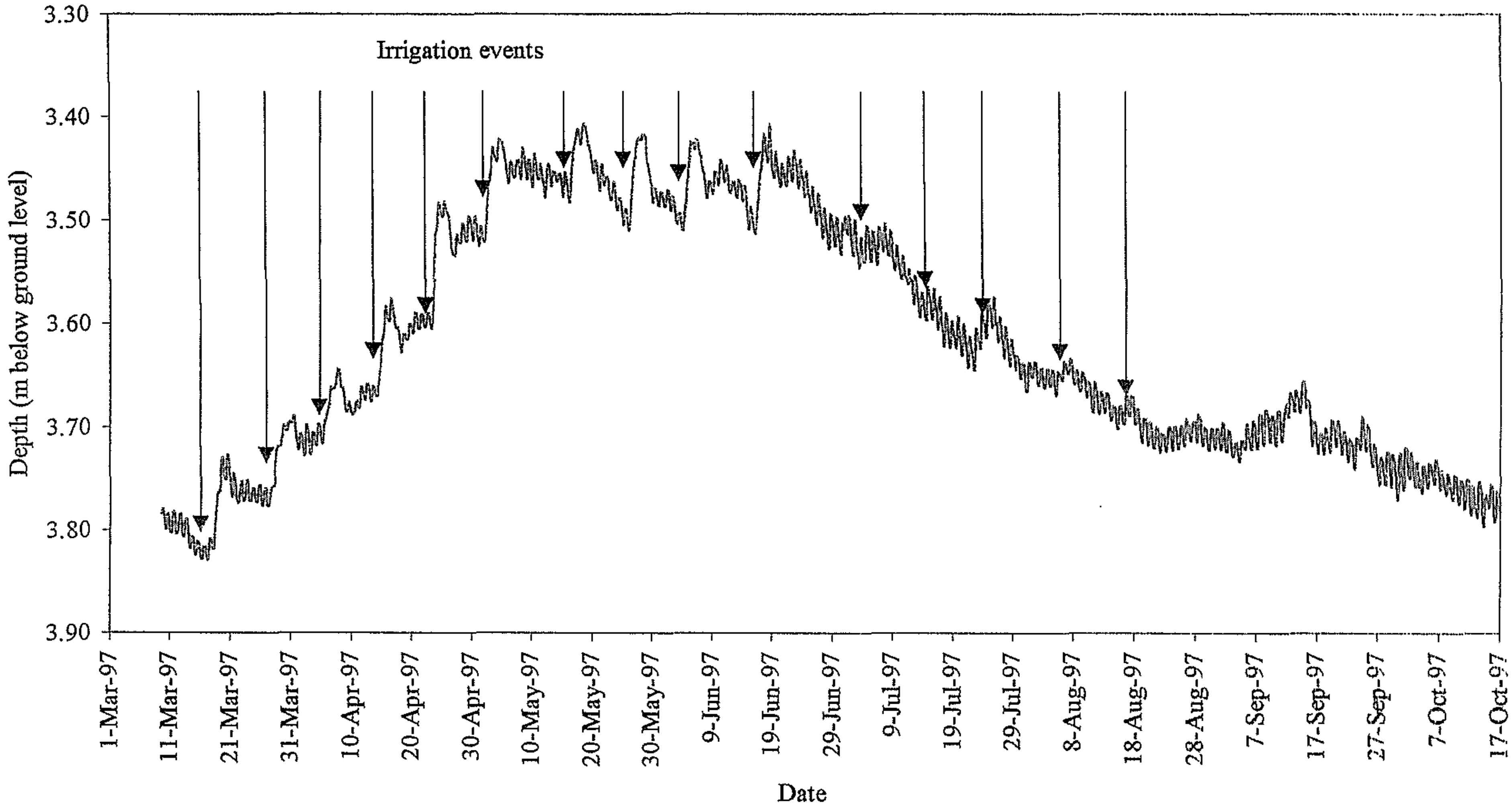


Figure 5. Changes in groundwater levels with dry season irrigation showing minimal response to individual irrigation events (bore 94-04).

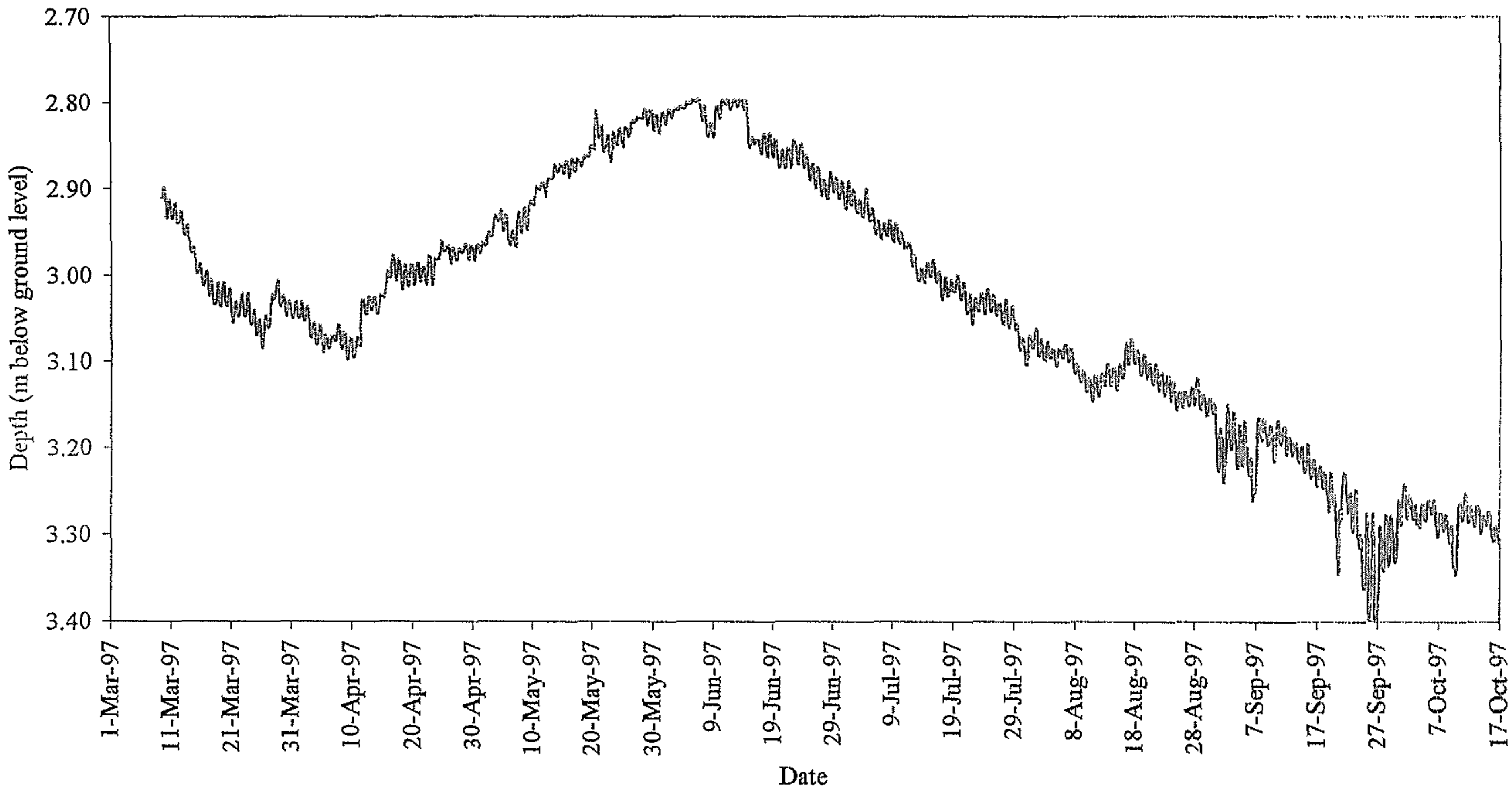
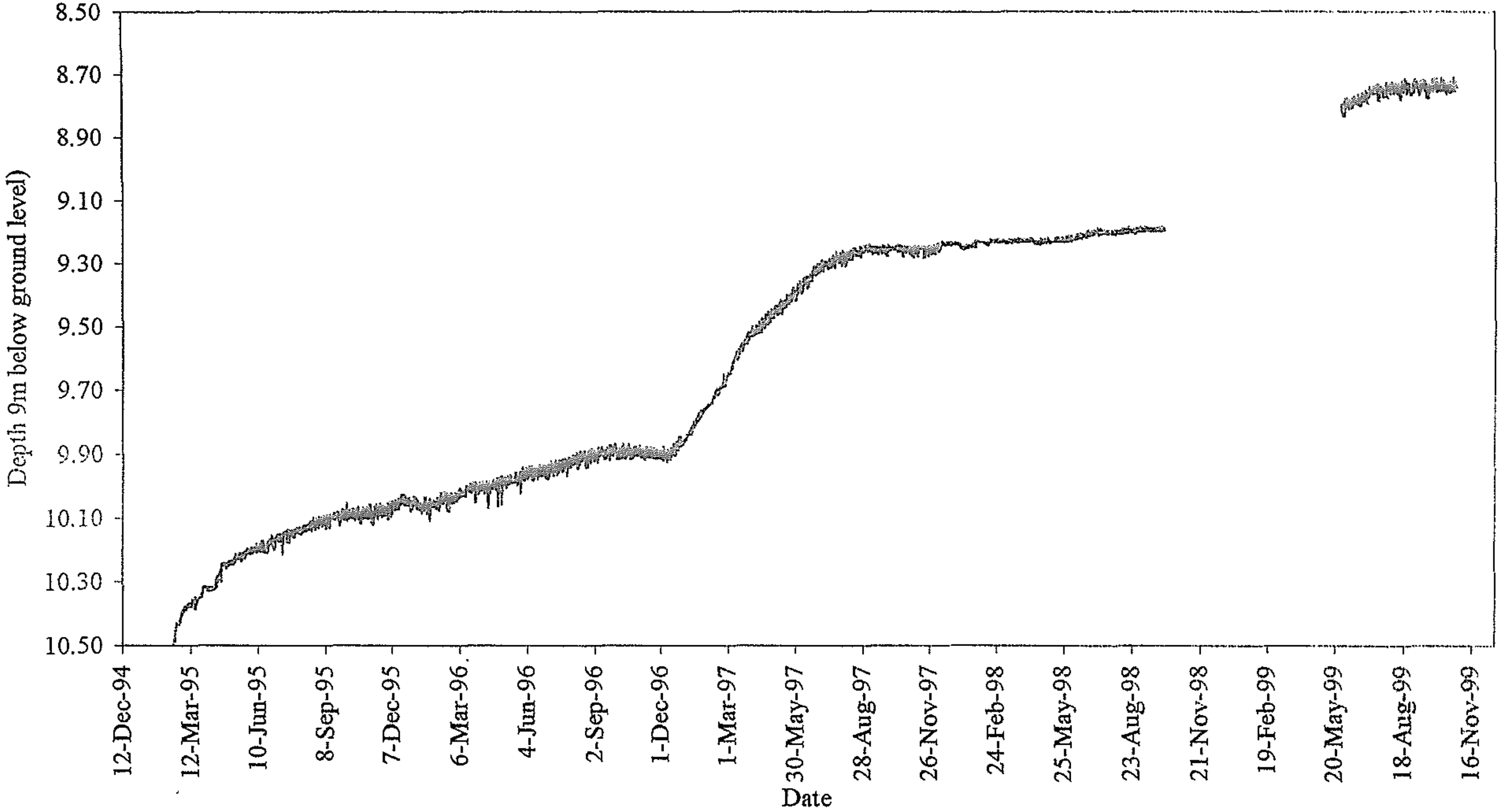


Figure 6. Changing levels at a site with deeper groundwater (Bore 94-20). The level continues to rise regardless of rising and falling trends in shallower bores, indicating lateral drainage from adjacent shallower areas.



Monitoring deep drainage:

Figures 7a and 7b show the change in soil moisture at two sites on Block 68 during 1996 following a number of irrigations of a pumpkin crop. Both figures show gradual drying of the profile at 20cm depth as a result of crop water use. Figure 7a also shows drainage at a depth of 80cm with a rapid increase in soil moisture at irrigation followed by a rapid decrease but without further drying through crop water use. Only a small change is shown at 120cm depth which is likely due to masking of change by the proximity to groundwater and near-saturation of the profile at 120cm depth. Figure 7b shows only minimal drainage at 80cm and none at 120cm. Results are also likely to be confounded at this site where groundwater was shallower. The rapid rise in groundwater level at these sites following installation of the EnviroSCAN equipment limited the usefulness of results obtained. The EnviroSCAN system was moved to another location to further examine the potential for identifying deep drainage.

Figure 8 shows change in soil moisture through the 1996/97 wet season and with early 1997 dry season irrigation, for a ratoon 1 sugar cane crop on Block 55. Groundwater was at approximately 4-5m from the surface. Changes in soil moisture levels, reflecting crop water use, occurred to 160cm depth, during November and December 1996. The soil profile was then fully wetted (field capacity) to 200cm depth as a result of rainfall between December and March and remained at close to that level until later in the 1997 dry season when frequency of irrigation was reduced and the lower soil profile commenced drying. Irrigation of the fully wetted profile during the 1997 dry season resulted in deep drainage to a depth of at least 200cm, potentially resulting in groundwater accessions.

The EnviroSCAN system has clearly been able to demonstrate deep drainage below the root zone during irrigation and from rainfall events and therefore has potential as a tool for groundwater management.

Identifying potential options for groundwater management:

A report, 'Best Practice in Irrigated Agriculture. 1998', has been prepared identifying innovative and practical technologies applicable to water management in the ORIA. It focuses on techniques to improve irrigation resource management and efficiency, including the control of rising groundwater.

Techniques identified include soil permeability mapping for locating areas with high infiltration rates, groundwater pumping to maintain lower groundwater levels with conjunctive use of pumped water, irrigation management, sub-surface drainage and tree cropping.

Testing and demonstration of groundwater management options:

i) Dewatering

Results from the dewatering testing have shown that this method is likely to be very effective in managing rising groundwater over a significant part of the Ord Stage 1 area. Results are presented in two reports (O'Boy, 1997 and O'Boy, 1998).

Figure 7a. Change in soil moisture level, showing deep drainage, under a pumpkin crop on Block 68 during the 1996 dry season. The site was located close to bore number 94/31. Increased soil moisture levels are associated with irrigation. Groundwater levels recorded nearby fluctuated between 180cm and 220cm below ground level. Soil moisture levels were measured using EnviroSCAN equipment.

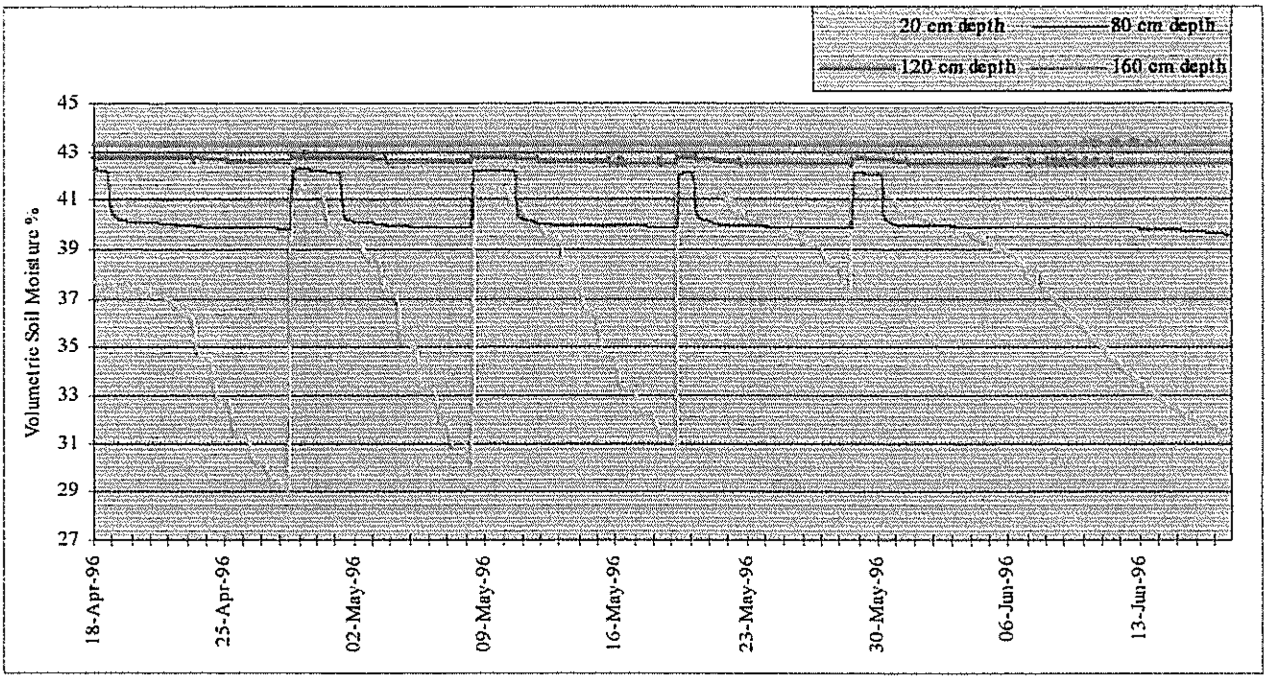


Figure 7b. Change in soil moisture level, showing minimal deep drainage, under a pumpkin crop on Block 68 during the 1996 dry season. The site was located close to bore number 94/30. Increased soil moisture levels are associated with irrigation. Groundwater levels recorded nearby fluctuated between 100cm and 150cm below ground level. Soil moisture levels were measured using EnviroSCAN equipment.

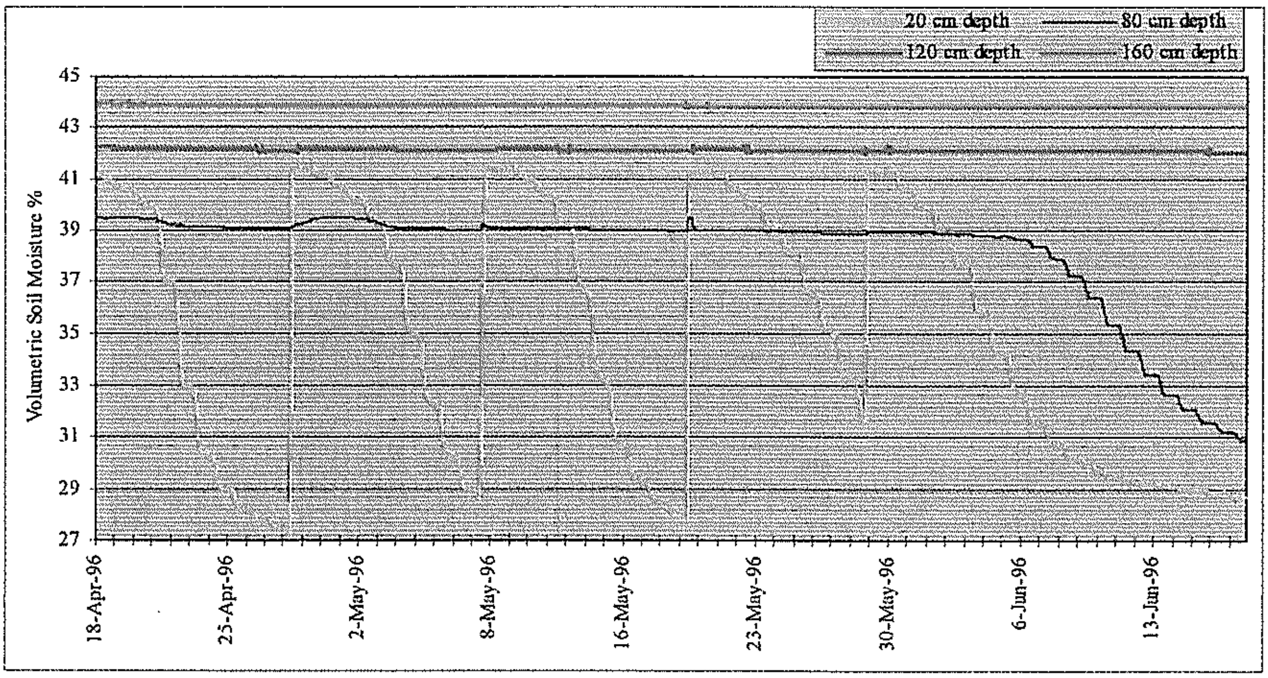
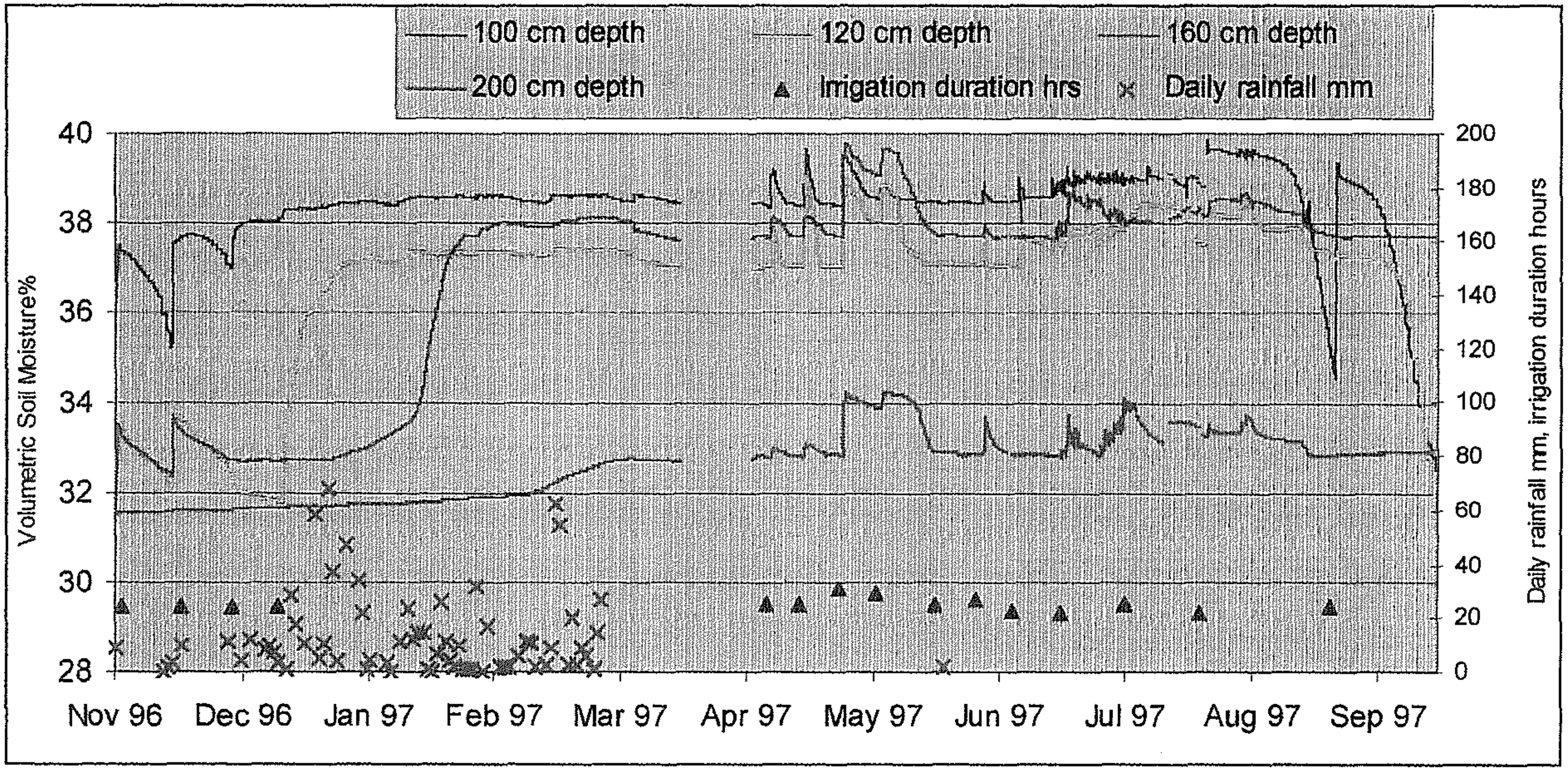


Figure 8. Changes in soil moisture levels under a ratoon 1 sugar cane crop on Block 55. Soil moisture levels were measured using EnviroSCAN equipment. The EnviroSCAN traces show wetting of the profile during the 1996/97 wet season and deep drainage associated with irrigation during the 1997 dry season.



The results from the short term pumping test on the Ivanhoe Plain indicated that the underlying gravel aquifer could vertically drain the overlying soil. This was confirmed by the long term testing where significant drawdown was measured at distances of up to 630m from the production bore and with effects projected to go beyond 1000m.

Results from the Packsaddle bore site were complicated by the presence of two gravel aquifers. However, pumping caused drawdown in both aquifers with drainage from the overlying soils into the upper aquifer. The drawdown was extrapolated to extend to a maximum distance of 1500m.

Results indicate that continuous pumping of bores on the Ivanhoe Plain at about 4000 kL/day could effectively hold groundwater levels steady at a distance of up to about 1000m. Bores on Packsaddle would probably only need to be pumped intermittently at a similar rate to achieve a similar result. This management strategy, with four bores on critical areas on Ivanhoe and two on Packsaddle could effectively control groundwater over approximately two-thirds of the Ord Stage 1 area.

ii) Drip irrigation

Drip irrigation has the potential to reduce groundwater accessions and significantly improve the efficiency of water application. However, the system can be more costly than furrow irrigation and the advantages need to be assessed and demonstrated. The following results indicate potential advantages in using drip irrigation for a range of crops grown in the Ord, while further evaluation will be required to determine the cost effectiveness of this method as a groundwater management option.

Bananas

A comparison of micro-sprinkler versus drip irrigation of bananas resulted in significantly heavier bunches (28 kg) with micro-sprinkler than with drip (22kg) when irrigated with the respective systems from planting to harvest (Kesavan, 1999). However, the young banana plants grew well under drip irrigation as there was less weed competition and the soil temperature remained warmer in the cooler months.

Sprinkler irrigation resulted in taller, later bunching plants and the use of sprinklers improved growing conditions in warmer weather later in the year by increasing humidity and reducing temperature. Sprinklers were also more effective in fully wetting the ground surface and preventing plant water stress in warmer weather.

Results from this work indicate that a combination of the two irrigation methods is most likely to be effective with drip irrigation during plant establishment during cooler weather, followed by sprinkler irrigation as the crop develops and temperatures increase. This system is now in use on a significant area of bananas in the Ord.

Beans

Drip tape has been assessed for use in irrigation of green beans on Cununurra clay soils. A significant advantage with drip compared with furrow irrigation is in the ability to access the cropped area at all times for timely pesticide application and harvesting operations.

The main problem encountered has been in adjusting water application to optimum requirements. The bean crop requires some stress to induce and prolong flowering to maximize yields. Further work is required to develop appropriate irrigation scheduling techniques for beans grown on clay soils in the Ord, using drip irrigation.

Sugar cane

Yield results are not yet available for the demonstration area of drip irrigation on sugar cane. There will however be other advantages compared with furrow irrigation, in improved water application efficiency through minimization of deep drainage and tail water losses. Economic analysis will be required to assess the potential for drip irrigation, particularly in areas where highly permeable soils are resulting in significant groundwater accessions with rising groundwater.

Rockmelons

Drip irrigation has also been assessed on rockmelon crops grown in the Ord and while no significant areas are yet irrigated with drip on the Cununurra clay soils, smaller areas grown on Cockatoo sands have been successfully irrigated with drip for a number of years. Results from the limited assessment of drip with rockmelons on clay soils have been encouraging. Both fruit quality and size have been shown to be superior when compared with flood irrigation. In one trial, marketable yield was increased from 1370 to 1830 trays /ha using drip. There is also the potential to improve management of flowering, water logging, fertiliser application and weed and insect pests and to effectively manage irrigation during harvest to allow improved access, which is more difficult with furrow irrigation.

Further economic analysis is required to assess the usefulness of drip irrigation as a groundwater management option, and should be considered particularly in areas where dewatering is not feasible.

iii) Improved surface (furrow) irrigation

Initial water balance studies examined the variation in tail water losses for sugar cane crops in the Ord with varying duration of irrigation, representing current irrigation practice. Results are presented in Table 2. Percentage runoff varied significantly between blocks (11-71%) for the sites examined with high levels indicating significant potential for improvement. While some Blocks showed significant increase in runoff with minimal increase in duration of irrigation, others showed a similar percentage runoff with increased duration (Blocks 45 and 51), indicating increased infiltration of the soil profile with increased duration and potentially increased deep drainage.

Table 2. Measurements of furrow inflow and outflow and runoff as a percentage of water applied for five blocks of sugar cane with varying duration of irrigation.

Block	Treatment	Inflow	Outflow/Runoff	
		ML/Ha	ML/Ha	%
45	580m / 18hrs	0.89	0.45	50
	580m / 25hrs	1.22	0.60	49
51	490m / 16hrs	0.75	0.36	48
	490m / 24hrs	1.21	0.60	49
54	350m / 20hrs	1.27	0.22	17
	350m / 23hrs	1.39	0.46	33
68	1000m / 24hrs	1.08	0.12	11
	1000m / 30hrs	1.25	0.32	26
86	430m / 12hrs	0.71	0.41	58
	430m / 24hrs	1.51	1.07	71

Additional studies were undertaken to measure water applied through irrigation and rainfall and to measure tail water runoff over an entire season, from ratooning to the following harvest, for a sugar cane crop on Block 68 (Table 3). Figure 9 graphically represents the data presented in Table 3 showing irrigation and rainfall events and runoff for the 12 month period. Runoff from irrigation, from rainfall and where irrigation and rainfall coincided was in all situations close to 30% of water applied when averaged for the season. While a total of 20.3 ML/ha (irrigation plus rainfall) remained on the bay, it is unknown what quantity of this contributed to groundwater through deep infiltration below the root zone. It is also likely that the crop was able to access the shallow groundwater in this area, reducing the requirement for irrigation.

Further work was undertaken to obtain information for use in development and validation of SIRMOD for modeling optimum irrigation requirements. This was obtained for Block 27 on an area underlain by deeper groundwater which would not confound the results obtained (Table 4). Water advance rate, furrow profile and water depth in the furrow during irrigation were measured. Modeling will predict application efficiency, runoff and deep drainage for a range of management strategies including variation in run length, duration of inundation at irrigation, water applied and gradient of irrigated area.

Results in Table 4 show the relationship between duration of inundation at irrigation, soil moisture and runoff. Crop water use was found to be relatively constant at 7-8mm/day following canopy closure in mid September. No deep drainage was observed on Block 27 using soil moisture monitoring equipment.

Table 3. Measurements of water on and off a 90 hectare sugar cane crop on Block 68 from irrigation and rainfall for the period August 1998 to July 1999.

Date	Inflow ML/ha	Rainfall ML/ha	Tailwater ML/ha	% Runoff
5-Aug-98	1.52		0.51	33.5
24-Aug-98	1.05		0.30	28.3
4-Sep-98	0.91		0.38	41.7
13-Sep-98	1.25		0.29	23.3
21-Sep-98	0.84	0.10	0.33	34.6
29-Sep-98	1.27		0.37	29.0
3-Oct-98	0.75		0.29	39.0
10-Oct-98	0.74		0.16	21.6
20-Oct-98		0.14	0.00	0.0
25-Oct-98	1.05	0.10	0.21	18.2
31-Oct-98		0.03	0.00	0.0
2-Nov-98	0.77	0.24	0.24	23.7
7-Nov-98		0.23	0.00	0.0
17-Nov-98	0.97	0.03	0.26	26.3
25-Nov-98	1.06	0.09	0.43	37.5
2-Dec-98		0.03	0.00	0.0
5-Dec-98	0.80		0.26	32.2
10-Dec-98		0.86	0.30	34.9
17-Dec-99		0.27	0.01	3.7
22-Dec-99		0.22	0.01	4.5
28-Dec-98		0.28	0.04	14.3
1 Jan to 31 Jan 99		3.91	1.03	19.7
1 Feb to 28 Feb 99		2.68	0.79	23.2
1 Mar to 31 Mar 99		2.20	1.02	51.5
3-Apr-99	1.56	0.42	0.59	21.0
10-Apr-99		0.17	0.00	0.0
23-Apr-99	0.78		0.15	19.8
6-May-99	0.67		0.21	30.7
20-May-99	0.93		0.30	32.4
2-Jun-99	0.71		0.26	37.1
All Irrigations	**10.57**		**3.22**	**30.5**
Irrigations with rainfall	**6.25**	**0.98**	**2.06**	**33.0**
Rainfall		**11.02**	**3.20**	**29.0**
Total	**16.82**	**12.00**	**8.48**	**29.4**

Figure 9. Irrigation and rainfall events are shown together with associated runoff from a ratoon 1 sugar cane crop grown on Cununurra clay on Block 68 during 1998/99.

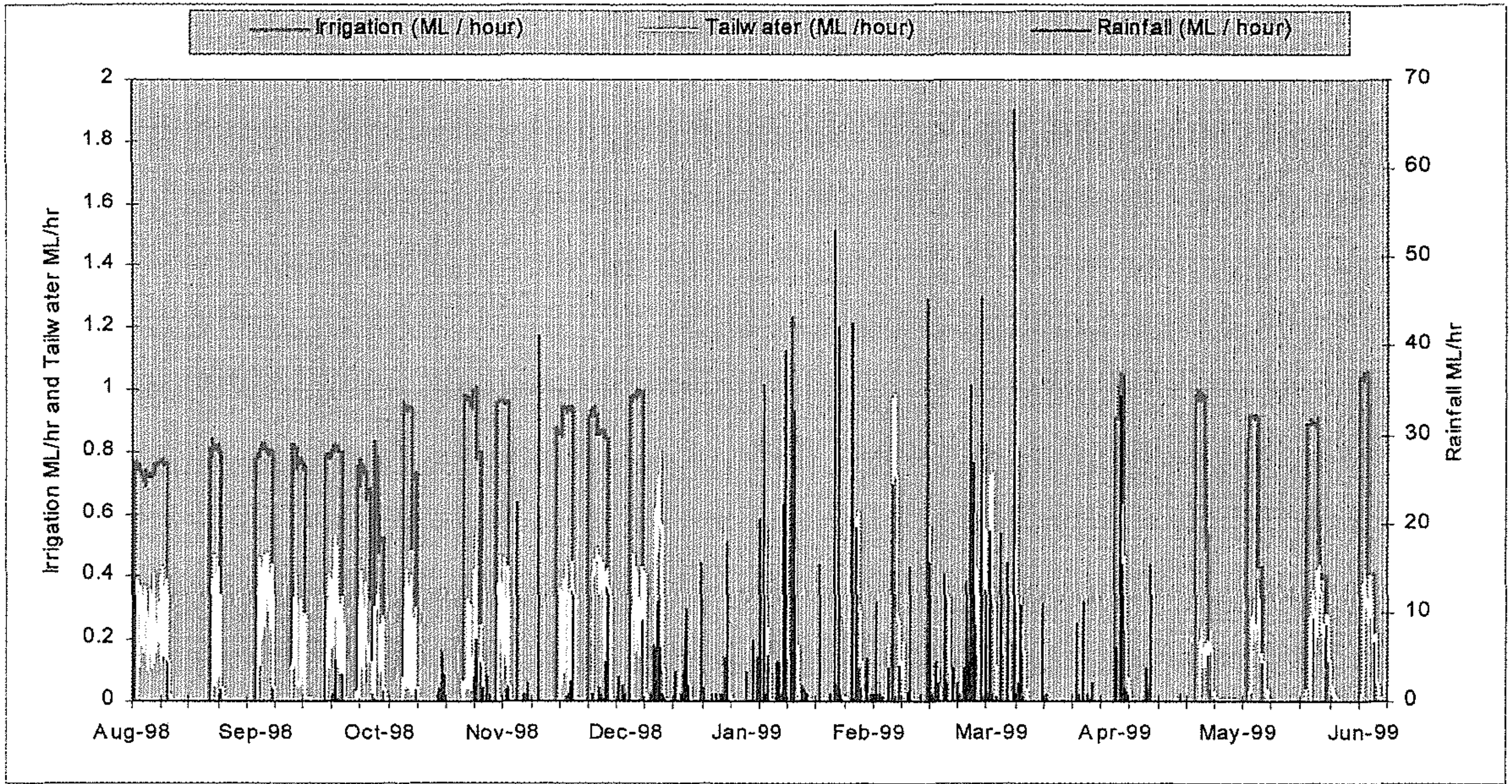


Table 4. Water balance components for a sugar cane plant crop grown on Cununurra clay on Block 27 using furrow irrigation.

Block 27			Soil moisture at irrigation	Inflow	Runoff		Crop water use during previous irrigation cycle	
Irrigation date	Days since last irrigation	Irrigation duration	mm/2m depth	ML/ha	ML/ha	% of inflow	mm/day	Crop Factor *
17/08/99	34	18 hours	743	1.34	0.24	18	3.2	0.5
31/08/99	14	12 hours	761	0.79	0.19	24	6.2	0.9
14/09/99	14	12 hours	726	0.71	0.04	5	7.0	1.0
28/09/99	14	24 hours	741	1.47	0.45	31	7.4	1.0
12/10/99	14	18 hours	730	1.15	0.35	31	7.3	1.0

* Estimated from daily water use and evaporation.

iv) Irrigation scheduling and water application requirements

In addition to influencing crop growth, irrigation scheduling will also influence efficiency of water application and needs to be considered as part of the water management strategy for groundwater management. Scheduling is influenced by the rate of crop water use and the soil moisture deficit at which the crop should be irrigated.

SIRMOD is being developed to determine the optimum requirements for run length and duration of irrigation using current soil moisture deficits. As the optimum deficit at irrigation is refined, SIRMOD will be adjusted to redefine optimum run length and duration. Work is underway through SRDC project CR22 to define the optimum soil moisture deficit at irrigation by examining the relationship between irrigation at varying soil moisture deficits and crop response (cane and sugar yield).

Agriculture Western Australia is also examining the relationship between soil moisture levels and rate of stalk elongation for sugar cane. A similar procedure has been developed by the BSES for irrigation scheduling of sugar cane. Initial results in the Ord indicate fastest growth rates at high soil moisture levels in the surface 60-80cm and following full canopy cover, although rates fluctuate significantly during periods of rainfall and once the crop lodges later in the season. It is likely that scheduling based on an optimum soil moisture deficit determined following full canopy development will be appropriate for the first half of the season, to optimize vegetative growth, with a modified value for later in the season to optimize sugar production. Further refinement may be required to manage growth to minimize lodging as lodging is likely to adversely affect both cane and sugar production.

While it may be possible to relate soil moisture deficit to pan evaporation with a full standing canopy, this will be difficult with lodged crops due to dependence of crop factor on canopy light interception. Hence, for scheduling, it may be necessary to rely on soil moisture measurements to determine soil moisture deficit instead of pan evaporation and crop factors.

Current indications are that sugar cane in the Ord should be irrigated at a soil moisture deficit of approximately 48mm early in the season to achieve maximum cane growth rate, followed by a higher and currently undefined deficit later in the season to promote sugar production. The deficit of 48mm is based on soil moisture extraction predominantly from the surface 80cm of Cununurra clay soil with available water holding capacity of 96mm and readily available water of 50% of this value or 48mm. The challenge in scheduling to this deficit will be in the required frequency and in applying water efficiently with observed daily rates of water use as high as 7-8mm/day requiring irrigation at 6-7 day intervals.

Scheduling will be improved through consideration of factors influencing both crop production and efficient application and with economic analysis of information to ensure the development of an economic and sustainable production system.

Information transfer:

Project findings have been reported to stakeholders to encourage change where required through implementation of best management practice. This has been achieved in a number of ways.

Groundwater monitoring data reports have been presented to growers participating in the program, at six monthly intervals. Data have also been presented at annual public meetings held at Kununurra in March 1996, April 1997, March 1998 and March 1999. A report on groundwater levels published by the Water and Rivers Commission (Yesertner, 1997) was discussed at the 1996 seminar and a report on rising groundwater at the 1998 seminar (Sherrard, 1998).

Information on dewatering, improving water application efficiency at irrigation and on irrigation scheduling has also been provided to growers at the annual workshops and at other industry specific meetings. Reports on dewatering have been published by O'Boy (1997, 1998) and Robinson (1998). A review of work underway on sugar cane has been presented to cane growers at meetings held twice annually. Related findings are now also promoted through sugar cane extension activities undertaken by an officer appointed in early 1999 through the SRDC funded project CR022, 'Best practice irrigation management to maximize profitability and ensure sustainability in the Ord sugar industry.'

Information and project findings on groundwater monitoring and management have also been provided to stakeholders by the Steering Committee currently involved in the development of a Land and Water Management Plan for the ORIA. A newsletter published at two monthly intervals is used to inform the community on land and water management issues in the ORIA. The Land and Water Management Plan will also be used as a means for implementing best practice groundwater management.

Use of sites on growers properties for trial work and demonstrating findings on requirements for groundwater management has been effective in transferring information to growers and in promoting adoption of improved practices.

A crop log survey was undertaken during 1996/97 as part of SRDC project CR022. Detailed information was obtained on irrigation practices used at the time and opportunities for improving efficiency of water application identified. Discussion of results has been effective in raising awareness of groundwater management issues. A further survey is currently underway to assess any changes in management practices since that time.

Discussion:

Establishment of on-farm monitoring bores in the Ord River Irrigation Area:
A network of groundwater monitoring bores has been successfully set up on farms across the ORIA to complement a network previously installed adjacent channel and drainage infrastructure. Forty of these bores have been installed with water depth probes and loggers to continuously monitor changes in groundwater levels. Installation of bores on farms has been advantageous in increasing awareness and understanding of groundwater issues amongst stakeholders in the Ord with growers involved in their installation and taking an increased interest in results obtained on groundwater levels. Previously, results obtained from bores off farm, indicating rising groundwater, were considered by many to be influenced largely by adjacent irrigation infrastructure and not resulting from on farm activities. This attitude has changed and many growers are now involved in processes examining ways of managing rising groundwater. Information provided by the Water Corporation, Western Australia indicates that approximately 75 percent of groundwater accessions are now from on farm irrigation activities.

Groundwater level changes, causal relationships and effects:
Data on groundwater levels already available at the commencement of the project were discussed in a report reviewing groundwater conditions at that time (Yesertner, 1997). The review not only provided information on rates of groundwater rise but also on risk mapping assessment by predicting groundwater levels into the future and when levels would reach critical depths should management practices remain unaltered with existing rates of rise continuing. This work confirmed earlier predictions that management of rising groundwater would be essential to prevent longer term land degradation in the ORIA. This information also provided an insight into areas where management was most likely to be critical and influenced future work in the project in locating new monitoring bores and in targeting areas requiring early management with identification of alternative management practices.

Detailed data on groundwater levels and changes in levels were collected from monitoring bores installed with logging equipment. This information, together with information collected on management practices and rainfall within the vicinity of the bores and on bore site stratigraphy allowed the identification of causal relationships between these factors and rising groundwater. Irrigation and rainfall events were found to have an immediate effect on groundwater levels in some locations but not others nearby, indicating localized areas with higher infiltration rates or permeability. This has resulted in groundwater mounds in some locations where the groundwater has reached to within 1-2m of the surface. Options for management of rising groundwater have been examined.

Concern with rising groundwater is due to potential for land degradation, initially from waterlogging and in the longer term from salinity and sodicity. Work undertaken in other cane growing areas already subject to waterlogging, salinity and sodicity as a result of rising groundwater has provided information on sugar cane response to these factors and has heightened awareness of the need to prevent this from occurring in the Ord. Varietal differences have been found to occur in response to both waterlogging and salinity.

While sugar cane is better adapted to waterlogging than many crop species due to its origins in the wet tropics, waterlogging has been shown to reduce Commercial Cane Sugar (CCS) levels as the crop uses increased carbohydrate reserves to fuel the root system under these conditions. Although the crop doesn't usually suffer nitrogen deficiency, due to its ability to use ammonia formed under waterlogged conditions, other nutrient imbalances are likely to occur. Potential yield losses of 0.5 tonne of cane per day with groundwater within 0.5m of the surface have been estimated in Queensland.

Sugar cane is regarded as moderately sensitive to salinity. Ratoon cane appears more sensitive to salinity than sugar cane plant crops and increasing salinity has been shown to increase juice ash content, resulting in reduced sugar recovery in the milling process and reduced sugar quality (Kingston and McMahon, 1990). Yield depressions of 10% and 25% at water conductivities of 300 and 500 mS/m respectively have been reported for N.Co- varieties (Bernstein et al 1966). While areas of groundwater greater than 300 mS/m exist in the Ord, these areas also tend to currently be associated with deeper groundwater.

Trial work at Mackay in Queensland has shown yield losses of 20% with soil exchangeable sodium percentage (ESP) of 15 and increasing to total crop failure at an ESP of 66 (Kingston and McMahon, 1990). Sodicity does not currently affect Ord Irrigation Area soils with exchangeable sodium percentages in the root zone generally well below threshold levels, although levels greater than 15% do occur deeper in the profile in some areas. Leaching of soil can overcome sodicity in some circumstances although this needs to be weighed up against increased risk of rising groundwater.

The establishment and monitoring of the groundwater monitoring bore network has been crucial in raising awareness of rising groundwater in the Ord and in providing information required for identifying and developing appropriate management strategies. Continued monitoring will be required to assess progress in managing rising groundwater.

Economically sustainable groundwater management options:

A range of options has been identified with potential for successful adoption in the Ord for management of rising groundwater. These are discussed in a report prepared by the Kimberley Development Commission (Best Practice in Irrigated Agriculture, 1998). A number of these options have been assessed and have been found suitable for use in the ORIA. Further work will be required to assess additional options and to determine those most economically feasible for the Ord.

Dewatering has been shown to be effective as a groundwater management tool for the Ord. Results indicate that continuous pumping of bores on the Ivanhoe Plain at about 4000 kL/day could effectively hold groundwater levels steady at a distance of up to about 1000m. Bores on Packsaddle would probably only need to be pumped intermittently at a similar rate to achieve a similar result. This management strategy, with four bores on critical areas on Ivanhoe and two on Packsaddle could effectively control groundwater over approximately two-thirds of the Ord Stage 1 area. In addition, cost estimates for dewatering indicate that this option is likely to be economically viable. Implementation of this option is likely to be required in the near future as groundwater levels continue to rise.

Improved surface irrigation practices have also been shown to be an effective management tool for rising groundwater in the Ord. Water balance studies on cane crops in the area have identified opportunities for improving water application efficiency with reduction in tail water losses. Modeling, using SIRMOD, with data obtained from these studies is currently being used to identify optimum practices for surface irrigation. Preliminary results from modeling with SIRMOD have identified opportunities for improving water application efficiency by varying run length and duration of inundation at irrigation.

As information on optimum soil moisture deficit at irrigation is further refined for sugar cane in the Ord, this will be used with SIRMOD to improve modeling predictions for optimizing irrigation practices. Current estimate of optimum soil moisture deficit at irrigation for cane in the Ord (48mm) has been determined based on information currently available from the Ord and other areas. Work underway to refine this value includes an irrigation trial to examine the relationship between soil moisture deficit at irrigation and cane and sugar yield as well as work examining the relationship between stalk elongation rate and soil moisture deficit. This work will assist in developing better information for managing crops to optimize both crop water and groundwater management practices.

Soil moisture monitoring equipment has been used to assess deep drainage and in water balance studies to determine crop water use. This equipment will be useful in scheduling irrigation of cane to more accurately maintain optimum soil moisture levels. This could be particularly important in crops where soil moisture extraction varies and where it would otherwise be difficult to predict soil moisture deficits and the correct time at which to irrigate. The ability to monitor for deep drainage would be an additional benefit of monitoring soil moisture levels.

Other work has examined the potential for use of drip irrigation and has identified a number of advantages, usually specific to various crops. While use of drip irrigation is currently limited in the Ord, there is now a good level of experience in use of this method which would facilitate its use over a larger area should it be required for limiting groundwater accessions from irrigation in localized areas. Already it is a requirement on some more recently developed areas of the Ord to minimize the potential for leaching of applied chemicals and nutrients into the groundwater and river systems.

Identification of localized areas with increased permeability will be important in locating areas requiring a higher level of management to minimize groundwater accessions. While this work has not yet been undertaken a study to determine the feasibility of this technique has commenced. The study will initially concentrate on areas where dewatering options are limited. However, in addition to examining surface soil infiltration characteristics, the study will also examine lower profile permeability and the potential for lateral movement of groundwater, to also determine the feasibility of localized dewatering with low yield bores.

Promoting the adoption of appropriate management practices for economically, sustainable cropping in the ORIA:

Project findings have been promoted largely through the ORIA Land and Water Management Planning process, through activities undertaken by the Ord Sugar Industry Extension Agronomist and through other workshops and publications.

The community has been educated on the issue of rising groundwater and the implications of failing to manage this issue through seminars and workshops leading to the development of a community Steering Committee now involved in developing the Land and Water Management Plan. The Plan was initiated with the objective of managing groundwater and water quality for the sustainable development of irrigated cropping in the Ord. A high level of community and farmer involvement in and support has been achieved for this work. The Plan will facilitate the implementation of best practice groundwater management in the Ord.

Community and industry involvement in the planning and development of work associated with groundwater management has been a key component of this project and ensures that findings are both practical and supported by growers. Use of sites on growers properties for trial work and for demonstrating findings on requirements for groundwater management has been effective in transferring information to growers and in promoting adoption of improved practices.

Promotion of findings by the recently appointed Ord Sugar Industry Extension Agronomist has also been successful through integration of groundwater and irrigation management requirements with other production and broader sugar cane industry requirements.

Implications/Recommendations:

This project has addressed a number of issues relating to improving groundwater management in the ORIA as well as identifying areas where additional improvements could be made.

- Continued monitoring of groundwater levels will be critical for managing rising groundwater in the Ord. Monitoring should be used as an educational activity with grower involvement to ensure understanding of the need for groundwater management. Monitoring will also be required to determine how effective management strategies have been and where modification to strategies is required.

- Installation and operation of dewatering bores will be required as groundwater levels continue to rise. While it is proposed that a total of six bores will be required, only a limited number of these will be required initially. While it is likely that dewatering will prove to be the most economical option for much of the area, minimizing groundwater accessions through alternative management practices could reduce the number of bores required. Specifications for these bores and sites and costs for installation and operation have already been determined. Responsibility for installation and operation of the bores is being addressed through the Land and Water Management Plan.

- Permeability mapping will be required. Mapping will identify areas with high surface infiltration rates allowing alternative management practices to be implemented over these areas, hence reducing groundwater accessions. Permeability mapping should also be investigated to examine lower profile permeability and the potential for lateral movement of groundwater, to determine the feasibility of localized dewatering with low yield bores.

- Best practice irrigation management requirements for sugar cane production in the Ord should be further developed and include requirements for groundwater management. Current recommendations will be improved through refinement of the value for optimum soil moisture deficit at irrigation and by optimizing irrigation practices for minimizing deep drainage and tail water losses. This is currently being addressed through work underway in association with the SRDC funded project CR022. An irrigation trial is underway to refine the soil moisture deficit while further modeling is planned using SIRMOD to better define optimum irrigation practices for improving water use efficiency.

- Other options for improving groundwater management should be examined when appropriate. For example, if groundwater levels reach sufficiently close to the surface, an alternative management option could be the use of mole drainage for some crops on some areas of the Ord. However, while groundwater is at current levels, it is logistically impractical to assess this technique.

- Further economic assessment will be required to determine the most appropriate combination of management options for groundwater management across the ORIA. In addition to addressing groundwater management requirements, analysis will also need to address requirements for irrigation management. Sufficient detail will be required on costs and benefits of each option for adequate comparison to be made.

- Continued promotion of findings and implementation of best practice will be required. This should be addressed in a number of ways. The ORIA Land and Water Management plan will be used to promote best management practice and is the basis for its implementation. While the Plan is expected to be completed by December 2000, its development and implementation will be an on-going process to ensure promotion and implementation of continual improvement in best practice. Other extension activities will also be required. These should be addressed for the Ord Sugar Cane Industry by the Ord Sugar Industry Extension Agronomist.

Intellectual Property:

No issues to be addressed other than the Final Report itself.

Information Development:

No issues to be addressed.

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Appendix 1. ORIA Groundwater Monitoring Bore Locations

Bore No.	Block No.	Easting	Northing	Monitored
91/01S	100	471807.982	8276121.646	Manually
91/02D	100	471810.926	8276123.346	Manually
91/03S	102	472425.522	8273980.916	Lost
91/04D	102	472423.677	8273979.718	Lost
91/07	68	476120.44	8272512.71	Manually
91/08	68	476120.7	8272509.72	Manually
91-5/6D	69	473988.207	8273113.387	not monitored
91-5/6S	69	473986.59	8273112.862	Data Logger
94/01	46	472543.969	8271009.738	Data Logger
94/02	55	472909.729	8271369.137	Data Logger
94/03	69	474006.175	8272353.367	Data Logger
94/04	70	473313.163	8274398.682	Data Logger
94/06	102	472911.047	8273646.49	Data Logger
94/07	101	472796.461	8274605.079	Lost
94/08	101	472437.816	8274607.724	Manually
94/09	100	472153.121	8275084.517	Manually
94/10	100	472000.398	8275623.773	Manually
94/11	47	471656.52	8270979.133	Manually
94/12	52	471688.665	8271586.423	Manually
94/13	104	473216.073	8275600.281	Manually
94/14	87	469710.852	8275174.826	Manually
94/16	95	471255.599	8276939.344	Lost
94/17	96	471053.955	8277701.223	Logger data available
94/18	93	470326.479	8275693.296	Manually
94/19	FWI	469406.751	8269088.663	Data Logger
94/20	FWI	469731.257	8268903.825	Data Logger
94/21	FWI	470168.822	8268745.624	Data Logger
94/22	93	471410.559	8275416.362	Data Logger
94/23	100	471587.689	8275521.431	Data Logger
94/24	103	472869.24	8275408.301	Data Logger
94/25	109	474641.635	8275936.298	Data Logger
94/26	83	468950.187	8271318.148	Manually
94/27	51	470797.485	8272476.227	Data Logger
94/28	69	473950.156	8272729.31	Data Logger
94/29	68	476232.206	8272091.028	Data Logger
94/30	68	476230.238	8272390.485	Data Logger
94/31	68	476228.429	8272689.927	Data Logger
94/32	68	476226.327	8272989.832	Data Logger
94/33	56	473987.17	8270948.948	Data Logger
94/34	56	474056.945	8271020.289	Data Logger
94/35	56	474126.501	8271091.431	Data Logger
94/36	56	474196.137	8271162.762	Data Logger
94/37	39	471538.854	8269186.457	Data Logger
94/39	34	469524.357	8264910.075	Manually
94/40	loc. 649	467417.925	8263775.442	Manually
94/41	13	470389.808	8258114.119	Data Logger

94/42	5	468612.846	8255869.069	**Manually**
95/01	79	**749000***	**8277000***	**Data Logger**
96/01	55	**473000***	**8271500***	**Manually**
96/02	55	**473000***	**8271500***	**Manually**
96/03	55	**473000***	**8271500***	**Data Logger**
96/04	82	**478240***	**8275800***	**Dry**
96/05	80	**478860***	**8274720***	**Data Logger**
96/06	79	**478860***	**8273600***	**Data Logger**
ML6	81	478901.65	827491.25	**Data Logger**
PB4	55	473115.68	8270873.9	**Data Logger**
PB4M1	55	473115.68	8270873.9	**Data Logger**
PB4M2	55	473105.62	8270891.48	**Data Logger**
PB4M3	55	473093.94	8270918.89	**Data Logger**
PB4M4	55	473068.7	8270983.22	**Data Logger**
PN12	97	470812.33	8278200.75	**Manually**
PN12	97	470812.33	8278200.75	**Manually**
PN2	99	472734.79	8276534.16	**Manually**
PN2	99	472729.09	8276526.86	**Manually**
PSPB1	loc. 384	470679.83	8249819.52	**Data Logger**
PSPB1M1	loc. 384	470666.2	8249805.3	**Data Logger**
PSPB1M2	loc. 384	470645.41	8249783.63	**Data Logger**
PSPB1M3	loc. 384	470597.24	8249733.58	**Data Logger**
PSPB1M4	loc. 384	470666	8249834	**Data Logger**
PN6D	27	473159.21	827057.38	**Data Logger**

*** estimated**