Field Testing of Controlled Drainage, and Verification of the WaSim Simulation Model

(KAR Project 7133)

C L Abbott
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Report OD/TN 102
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HR Wallingford

DFID Department For International Development

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Date ...26 Feb 2001...

Executive Summary

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Introduction

Irrigated agriculture currently uses about two thirds of all water abstracted from rivers and underground aquifers in developing countries, and in many areas available water resources are nearly or fully utilised. If irrigated food production is to increase, irrigated agriculture must use water more efficiently, while maintaining the income and livelihoods of poor rural communities, and sustaining the quality of water and soil resources.

Controlled drainage

Controlled drainage is a promising agricultural technique with the following potential benefits:

- Yield increases (particularly in watershort seasons).
- Water and energy savings.
- Water quality benefits – increased soil salt leaching efficiencies and reduced transport of agrochemicals to river systems.

The technique is likely to be beneficial in many arid and semi-arid regions of the world, where water tables are high. Potential areas of application include Egypt, Pakistan and India.

Controlled drainage involves an extension of on-farm water management to include management of drainage flows. Farmers control the amount of water leaving the land in the drainage system, using a weir or blocking device to control drainage flows. As controlled drainage is relatively new there are many theoretical and practical issues to be addressed before it can be applied in semi-arid regions. The technique involves maintaining high watertables in the soil profile for extended periods of time (using "On/Off" gated devices or weir control), and management is required to ensure that crop growth is not affected by anaerobic conditions. Also to prevent accumulation of solutes (particularly salts) in the root zone it is necessary to maintain leaching processes.

Executive Summary continued

Aims of the Fieldwork

This report describes findings from the fieldwork stage of a project to develop integrated irrigation and drainage management methods incorporating controlled drainage. Fieldwork was carried out over 2 crop seasons in the Western Nile Delta, Egypt. The project is being carried out by the Water Management Department of HR Wallingford in collaboration with the Drainage Research Institute of the National Water Research Centre, Egypt, (DRI).

The aims of the fieldwork were:

- To test controlled drainage on small-scale field plots and compare with conventional drainage.

- To test a prototype controlled drainage device in the field.

- To test the suitability of the WaSim model for simulation of controlled drainage strategies and comparison with conventional strategies, by testing with the field data.

Fieldwork results

Two crop seasons were studied at the field site. Maize was grown from June 1999 to October 1999, and wheat from November 1999 to May 2000. Conventional irrigation and drainage management was compared to controlled drainage using weir devices positioned in the access manholes, and by controlling water depth in the main outfall drain. The field site was instrumented to enable irrigation water use, drainage flows, soil moisture and salinity, watertable depth and crop response to be compared on the two plots.

The overall conclusions from the fieldwork were:

- The prototype controlled drainage device was simple to construct from locally available materials, and install in the sub-surface drainage system. The device worked well for both crop seasons, allowing drainflow when the watertable was above the designated depth, and preventing it when it was below. The device was unfortunately rather expensive to make, but design simplifications and production on a larger scale would bring unit costs down, making it more attractive to small farmers in the developing world.

- The application of controlled drainage to the study plots significantly reduced drainflow during the maize and wheat seasons.

- Watertable depths (and soil water contents) were generally maintained at a higher level under controlled drainage, although high lateral seepage at the site meant that soil water was free to enter and leave the plots depending on watertable depths in the surrounding area and the main drain.

- When the technique is applied to larger areas, or on less permeable soils, the impacts of lateral seepage will be reduced or cease.

Executive Summary continued

- Crop yields were not reduced by controlled drainage, in fact small increases in yield were recorded.

- Over the course of the study (one year) the average soil salinity levels decreased slightly on both plots. Maintenance of acceptable soil salinity levels over time is one requirement for longterm sustainability of farming techniques.

- Although the fieldwork gave an indication of the impacts and benefits of controlled drainage, application to larger areas with farmer management is necessary to fully quantify and demonstrate the benefits.

Testing of WaSim Simulation Model using the Field Data

The WaSim simulation model was tested against project field data collected over 2 crop seasons of conventional irrigation and drainage management, and controlled drainage management.

Five key parameters were compared on a daily and seasonal basis, and it was generally concluded that WaSim gave adequate agreement with the field data. The model thus constitutes an acceptable representation of processes occurring in the field, and the potential impacts and benefits of controlled drainage compared to conventional practice.

Although the extent of the testing was limited to 2 crop seasons at the field site, it is concluded that the WaSim model is an acceptable tool to develop and compare conventional and controlled drainage strategies for different situations.

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1. INTRODUCTION

1.1 The Project

This Technical Note is an output from the DFID Knowledge and Research Contract R7133 – Integrated Irrigation and Drainage to Save Water. The project is being implemented by HR Wallingford in collaboration with the Drainage Research Institute of the National Water Research Centre, Egypt.

The research aims to develop integrated irrigation and drainage management strategies incorporating controlled drainage, to save water, and protect soil and water resources in semi-arid regions. At the farm level the introduction of controlled drainage has the potential to improve the livelihoods of farmers by reducing water application costs and maintaining agricultural production in water short years. The planned project outputs are:

- A predictive tool to assess water saving, resource protection and crop production under controlled drainage.
- Practical guidelines for integrated irrigation and drainage incorporating controlled drainage.
- Guidelines for uptake and dissemination of controlled drainage.
- Report on the potential for controlled drainage outside Egypt.

The project is being carried out in two stages. The activities comprising the first stage were a literature review, an investigation of the potential and constraints to the introduction of controlled drainage in the Nile Delta in Egypt, and the initial development of a tool to predict the impacts of controlled drainage. The results of these activities are presented in the phase 1 report OD/TN96.

Activities for the second stage include fieldwork in the Nile Delta, Egypt, further development of the predictive tool and development of practical guidelines for the controlled drainage technique.

This report presents data and results from the fieldwork component of the project, carried out at the WMRI (Water Management Research Institute of the National Water Research Centre, Egypt) Mariut Experimental Farm in the western Nile Delta, Egypt between May 1999 and May 2000. Field data are used to assess the use of the WaSim water balance model to simulate conventional and controlled drainage strategies.

2. EXPERIMENTAL SITE AND METHODOLOGY

2.1 Aims of the fieldwork

The phase 1 project report (Abbott et al, 1999) included an introduction to controlled drainage techniques and discussion of potential benefits. The aims of the fieldwork were:

- To test controlled drainage on small-scale field plots and compare with conventional drainage.
- To test a prototype controlled drainage device in the field.
- To test the suitability of the WaSim model for simulation of controlled drainage strategies and comparison with conventional strategies, by testing with the field data.

2.2 Experimental Site

The fieldwork was carried out at the Mariut experimental station, located just off the Cairo-Alexandria Desert Road, about 35km south of Alexandria (see figure 1). The site is situated within a traditional farming area, composed of small family-run farms. Farmers use traditional Egyptian farming methods including surface irrigation in furrows and basins, and subsurface drainage is common. Farming operations including weeding and surface soil cultivation are carried out mostly by hand. The area receives irrigation water from Abo-Khalifa canal, which is moderately saline with an EC_w of about 2-3 dS/m.

As in other parts of the Delta, there are two main growing seasons per year. The winter season runs from about October to May and the summer season runs from April/May until October. The most common winter crops in the area are wheat, broad beans, barley and berseem. Maize, cotton and sunflower are the most common summer crops with some rice also grown. These crops are grown both for subsistence, and sale to the local markets and those in Alexandria, on the Mediterranean coast.

Situated on the western fringes of the Nile Delta, precipitation is low and usually occurs only in the winter months (October to January). Soils in the area are predominantly light in composition.

2.3 Study Field Layout

Two plots were established at the experimental site, each approximately 100m by 100m, separated by a drainage collector – see figure 2. The plots were irrigated via a small concrete channel with gates to enable the area to be surface irrigated with minimum distribution losses. The area is served by a horizontal subsurface piped drainage system, consisting of 255mm diameter PVC collector pipes and 72mm diameter PVC laterals. Concrete access manholes (diameter 1m) are positioned along the collector pipe where the laterals intercept the collector. The laterals are installed at a depth of approximately 1.2m and a spacing of 31 to 35m. The drainage system discharges into an open drain at the lower end of the site.

2.4 Soil type

Textural analysis was carried out on soil samples from across the site, down to a depth of 1.8m. Results are shown in appendix 1. The soil varied quite a lot around the site from sandy silt loam to clay loam. Hydraulic conductivity was determined by the Auger Hole Method, with a value of 2m/day obtained. Dry bulk density of the soil was determined as $1.60 g/cm^3$.

2.5 Monitoring programme

Two crop seasons were studied at the field site. Maize was grown from June 1999 to October 1999, and wheat from November 1999 to May 2000. The treatments were conventional irrigation and drainage operation, compared to controlled drainage using weir devices positioned in the access manholes, and controlled drainage by controlling water depth in the main outfall drain. The fieldsite was instrumented in May 1999 to enable irrigation water use, drainage flows, watertable depth, moisture content and crop response to be compared on the two plots.

The parameters measured were:

Evapotranspiration and rainfall:

Daily meteorological data were obtained from a nearby automatic weather station, providing the information necessary to calculate daily reference crop evapotranspiration (ET_o). Potential crop evapotranspiration (PET) was estimated from ET_o using daily FAO crop factors. A manual raingauge was also installed at the study site to measure daily rainfall.

Irrigation water application:

Irrigation water application was measured using the global water probe, a current meter designed for low flow rates.

Drainflow:

Drainflow was measured from each lateral drain using a stopwatch and bucket (vol 7.35l). The catchment area for each lateral was estimated and total drainflow for each plot calculated. Several sets of measurements were taken during periods of drainflow and daily discharge was estimated. As it was not possible to measure drainflow on a continuous basis, measured drainflow was only considered an estimate of actual drainflow.

Irrigation and drainage water salinity:

A handheld electrical conductivity meter was used to measure salt content of irrigation and drainage water.

Salinity is given by:

$TDS = 44.84 + (633 \times EC_w)$

TDS is total dissolved salts in parts per million (ppm) and EC_w is electrical conductivity in deci Siemens per metre (dS/m).

Depth to watertable:

Sixteen piezometers were installed in each plot (total of 32) down to a depth of 2m. The depth to the watertable was then measured at each point on a daily basis, and average values calculated for mid-drain position across each plot.

Soil moisture and soil water potential:

Two profiles of tensiometers were installed (see figure 2) in the plots. Installation depths were 20cm, 30cm, 45cm, 80cm, 120cm and 180cm. The tensiometers measured total and matric potential of water in the soil profile on a daily basis at different depths. The total potential values were used to indicate direction of water movement in the soil profile and the matric potential values were used to give a measure of soil wetness. Gravimetric soil moisture was determined on soil samples of known matric potential and the pF curve developed – see appendix 2.

Soil salinity content:

Soil salinity profiles were determined on both plots at the start and end of each crop season. This was done by soil sampling and laboratory analysis.

2.6 Development and testing of controlled drainage device

The fieldwork component of the project afforded the opportunity to develop and test a prototype controlled drainage device, suitable for use by farmers. Specifications for the device were developed following consultation with farmers, engineers and the project team. The developed specifications were:

- The device should be simple, cheap and easily manufactured from locally available materials.
- It should be straightforward for farmers to fit and operate the device.

- The device should prevent drainflow to the sub-surface drainage system when the watertable in the field is below a specified depth, and allow drainflow when the watertable is above this depth.

- It should be possible to vary the specified depth during the crop season if required.

The designed device was constructed from 90mm PVC pipe, commonly available across the developing world. The design is shown in figure 3. The device is fitted onto the end of each field lateral pipe where it meets the collector pipe. Access is straightforward as these subsurface drainage systems have many access manholes at these points. Farmers can thus fit and maintain the devices themselves. Different lengths of vertical pipe allow the device to control drainage at varying watertable depths, either during or between crop seasons.

The cost of the prototype device (materials and construction) was 140LE, which is about £25. This is expensive, as several devices would be needed by each farmer. Design simplifications or use of other materials would reduce the cost. Also if the devices were made in bulk the unit price would reduce considerably. In areas where controlled drainage could be applied to the sub-collector (rather than lateral drain), one device could serve many farmers, which also reduces the cost considerably.

3. RESULTS AND DISCUSSION

The fieldwork ran from May 1999 to May 2000, during which time a summer crop of maize and a winter crop of wheat were grown on the two study plots. The maize crop was planted on 10/6/99 and harvested on 9/10/99. Winter wheat was planted on 20/11/99 and harvested on 5/5/00.

3.1 Irrigation and Drainage Management Strategies Studied

The management strategies applied to each crop in each plot are summarised in the table below:

Table 1 Irrigation and Drainage Management Strategies Applied to the Field Plots.

Plot	Crop	Irrigation and Drainage Management	
		Irrigation	Drainage
A	Maize	Conventional	Conventional
B	Maize	As above	Controlled drainage with manhole weir at 0.6-0.7m depth
A	Wheat	Conventional	Conventional
B	Wheat	10% reduction in irrigation application	Controlled drainage with manhole weir at 0.6-0.7m depth, and weir in outfall drain

3.2 Maize Season

The maize crop was planted on 10/6/99 and harvested on 9/10/99. Eight irrigations were applied to each plot. These are detailed in Table 2.

The average salinity of applied water was 2.95dS/m. As shown in Table 2 the plots received virtually the same of amount of irrigation water over the crop season, with small differences for individual irrigations. However drainflow was very different between the plots. This is shown in Figure 4.

Table 2 Irrigation Applications during the Maize Season.

date	Irrigation water salinity ECw dS/m	Amount applied (mm)	
		Conventional Plot	**Controlled Drainage Plot**
10/06/99	2.3	82.5	81.5
19/06/99	2.5	57.8	58
30/06/99	2.8	82	81.6
19/07/99	3.1	68.7	65.3
8/08/99	3.7	112.8	112.6
25/08/99	3.0	105.2	111.3
11/09/99	2.95	113.9	115.2
27/09/99	3.2	114.3	109.1
9/10/99	Harvest		
Total		737.2	734.6

Total drainflow for the maize season was as below:

Table 3 Drainflow for the Maize Season.

Treatment	Conventional Plot	Controlled Drainage Plot
Total Drainflow (mm)	287	46

As expected, with the controlled drainage plot there was significantly reduced outflow from the drains. We would expect this reduced drain outflow to impact the watertable depth in the controlled drainage plot, compared to the conventional plot.

Figure 5 shows the watertable depths (average of mid-drain positions) for the two plots for the maize season. The irrigation application dates have been marked on[1]. The rise in water table due to irrigation is evident. (Note: watertable rise shows there was clearly an additional irrigation event after the end of the season on about October 16th but it was not recorded.) It is evident from the figure that the watertable was always higher on the controlled drainage plot, particularly following irrigation events. Recession of the watertable was rapid on both plots. For the conventional plot this was caused by water leaving the soil profile through the drains. This was initially the case for the controlled drainage plot but drainflow ceased when the watertable went below 0.7m depth. As well as crop water abstraction on both plots, it was concluded that water was leaving the soil profile on the controlled plot via lateral seepage towards the main drain at the bottom end of the plots. The extent of the lateral seepage was estimated for both plots using a daily waterbalance (see appendix 3). The seasonal total lateral seepage for each plot is shown in the table below:

Table 4 Estimated Lateral Seepage for the Maize Season.

Treatment	Conventional Plot	Controlled Drainage Plot
Total lateral seepage* (mm)	+172	-118

* positive value indicates flow is into the plot, negative value indicates flow is out of the plot.

It was estimated (from the water balance calculation) that 118mm water left the controlled drainage plot via lateral seepage. On the conventional plot it was estimated that there was a net inflow of water by lateral seepage (from surrounding agricultural areas) of 172mm over the season.

[1] Irrigation dates were the same for the conventional and controlled drainage plots. Amounts differed slightly so the figure shows the amounts applied to the conventional plot.

Figure 6 shows the mid-drain watertable depth and drainflow data together. On the conventional plot the drains are at approximately 1.2m and it was observed that in general that when the mid-drain watertable was below drain depth there was no drainflow.

On the controlled drainage plot drainflow ceased at a much shallower depth, estimated at a mid-drain watertable depth of just over 0.5m.

The calculated crop yield (samples taken on 4/10/99) from the two plots was comparable –7.1 tonnes/hectare for the conventional plot and 7.4 tonnes/hectare for the controlled drainage plot. Average yields in this area are about 5.6 tonnes/hectare (DRI, 1997). Yields on both plots exceeded the local average yield (by 26 and 32%), indicating that yields were not adversely affected on either plot. The yield was greater on the controlled drainage plot by 4%, which is not considered a significant increase. Figure 7 shows this result.

The soil salinity was determined at the start and end of the crop season. Results for the maize season are shown in figure 8 and indicate a notable reduction in average soil salinity on both plots – 16% on the conventional plot and 38% on the controlled drainage plot. Soil salinity is an important factor in long-term sustainability of farming methods.

3.3 Main conclusions from the maize season

These are summarised below:

- Drainflow was reduced on the controlled drainage plot. The primary aim of the controlled drainage technique is to save water by reducing drainage losses from agricultural land. The controlled drainage device succeeded in reducing drainflow as intended.
- Watertable depths through the season were a bit higher on the controlled drainage plot compared to the conventional plot, but were not as high as expected. This was due to water loss from the controlled drainage plot via lateral seepage. If the technique was applied to a larger area, or on a less permeable soil, the water table would remain higher throughout the crop season under controlled drainage.
- Soil salinity was reduced on both plots during the maize season.
- Maize yields were comparable for the two plots, and were higher than the local recorded average. This indicates no detrimental effects were experienced by the crop on either plot. The crop yield on the controlled drainage plot was 4% higher than on the conventional plot.
- Although drainflow was significantly reduced under controlled drainage, there was no real water saving during the maize season due to lateral seepage losses from the plot. With application to larger plots (or less permeable soil), lateral seepage losses will be minimised and drainflow water savings will remain in the soil profile. This water will be available for crop development, thus reducing irrigation requirements and representing real water savings to the farmer.

3.4 Wheat Season

The winter wheat crop was planted on 20/11/99 and harvested on 5/5/00. Some adjustments were made to the experimental approach for the second season. First of all, less irrigation water was applied to the controlled drainage plot, to see if reductions in drainflow could be translated into savings in irrigation water applied. Secondly, in addition to the controlled drainage devices installed in the sub-surface drainage system (set at 0.6-0.7m depth) on the controlled drainage plot, a weir was also introduced into the main drain. This was installed upstream of the drainage outfall on the conventional plot (see figure 2), and downstream of the drainage outfall on the controlled drainage plot. The difference in water level in the drain upstream and downstream of the weir was approximately 30cm.

There were seven irrigations applied to each plot. Irrigation dates, salinities and amounts are detailed in the table below:

Table 5 Irrigation Applications during the Wheat Season.

date	Irrigation water salinity ECw dS/m	Amount applied (mm)	
		Conventional Plot	Controlled Drainage Plot
20/11/99	2.7	75	75
8/12/99	2.6	85.8	78.4
26/12/99	2.6	64.6	58.5
13/01/00	3.8	39.8	35.4
16/02/00	2.5	86.7	77
4/03/00	3.2	79.6	70.8
21/03/00	3.1	83.7	74.6
5/05/00	Harvest		
Total		515.2	469.7

Except for the first irrigation, less water was applied to the controlled drainage plot on each occasion. Over the season the conventional plot thus received approximately 10% more irrigation water than the controlled drainage plot. There was also some rainfall during the season. This is detailed in appendix 4 and came to a seasonal total of 116.2mm.

Drainflow from the plots was again very different. Daily recorded drainflow from the plots is shown in figure 9 and summarised in the table below:

Table 6 Drainflow for the Wheat Season.

Treatment	Conventional Plot	Controlled Drainage Plot
Total Drainflow (mm)	753	290

Drainflow was far greater on the controlled drainage plot than on the conventional plot. In fact for the wheat season the drainflow total on the controlled drainage plot was greater than the sum of irrigation and rainfall entering the plot. This was due to lateral seepage INTO the plot from the surrounding area, leaving the plot via the subsurface drainage system. The magnitude of lateral seepage was estimated using a water balance calculation (see appendix 5) and the results summarised in the table below:

Table 7 Estimated Lateral Seepage for the Wheat Season.

Treatment	Conventional Plot	Controlled Drainage Plot
Lateral Seepage* (mm)	479	77

* positive value indicates flow is into the plot, negative value indicates flow is out of the plot.

This indicates that over the wheat season, there was a net flow of water INTO both plots from the surrounding areas and/or main drain, which was far greater on the conventional plot (due to the lower watertable depths throughout the season).

Figure 10 shows the watertable depths (average of mid-drain positions) for the two plots for the wheat season. The irrigation applications[2] and rainfall events have been marked on. There are two immediate observations:

[2] Irrigation dates were the same for the conventional and controlled drainage plots. Amounts applied differed (by about 10%) so the figure shows the amounts applied to the conventional plot.

- Throughout the winter wheat season the watertable on both plots was consistently higher (about 20cm) than during the summer maize season. This is explained by a seasonal rise in the local groundwater level during the winter and subsequent rise in waterlevel in the main drain over the winter season. The effect of this is to maintain watertables in the plots at a higher level.
- It is evident from figure 10 that the watertable was always higher on the controlled drainage plot, by 10-40cm. This was mainly due to the introduction of the weir in the main drain, and raised upstream water level, which raised watertable levels on the controlled drainage plot. The controlled drainage devices installed in the subsurface drainage system were judged to have less effect on watertable depths. The devices reduced drainflow, but due to small plot size and high soil conductivity, lateral seepage meant that the watertable on the controlled drainage plot was able to move up and down freely.

Figure 11 shows the mid-drain watertable depth and drainflow data together. On the conventional plot the drains are at approximately 1.2m depth. During the wheat season the watertable was always above about 1.1m and drainflow was recorded every day.

On the controlled drainage plot there was much less drainflow due to the presence of the controlled drainage weir device. The devices were set at a depth of 0.6-0.7m below the ground surface (and should thus only allow drainflow when the watertable is above this depth) which (as shown in figure 11) agrees with the data. Some strange points were recorded (see figure) which usually occurred on the day of irrigation when the watertable depth was recorded before irrigation, and the drainflow occurred after irrigation and after the watertable had risen.

Soil salinity levels were determined on both plots at the start and end of the wheat season. Salinity profiles are shown in figure 12. Average soil salinity increased on both plots during the season, by 7% on the conventional plot and 27% on the controlled drainage plot. However final soil salinity levels on both plots were lower than initial levels at the start of the maize season, indicating that both approaches are sustainable on an annual basis.

The wheat crop yields from the two plots showed some difference. For the conventional drainage plot the yield was 6.7 tonnes/hectare and for the controlled drainage plot it was 7.3 tonnes/hectare. Average wheat yields in the area are about 5.3 tonnes/hectare (DRI, 1997), indicating that wheat yield in neither plot was detrimentally affected. The yield was greater on the controlled drainage plot by 9%. Figure 13 shows the results.

3.5 Main conclusions from the wheat season

These are summarised below:

- Drainflow was again less on the controlled drainage plot, due to the controlled drainage device at 0.6-0.7m depth.
- Watertable depths were higher on the two plots than during the maize season. This was due to a seasonal rise in local groundwater and main drain waterlevel during the winter wheat season.
- Watertable depth through the season was higher on the controlled drainage plot, due to the application of controlled drainage. It was observed that the introduction of a weir in the main drain maintained higher watertable levels more effectively than the use of the controlled drainage devices in the subsurface drainage system. On larger plots, where lateral seepage is not significant, both methods should work equally well.
- There was significant lateral seepage INTO the plots from the surrounding area, over the course of the season. The use of larger plots or implementation in areas with heavier soils would reduce or obviate this effect.

- Although average soil salinity levels increased on both plots during the wheat season, they decreased from initial levels at the start of the maize season. This indicates that the controlled drainage strategy tested is sustainable (from soil salinity perspective) on an annual basis.
- Wheat yields on both plots were higher than the reported local average yields, indicating no adverse crop effects on either plot.
- The wheat yield was 9% higher on the controlled drainage plot, where 9% less irrigation water was applied.
- An irrigation water saving was achieved on the controlled drainage plot during the wheat season without decreased crop yield, although lateral seepage again made quantitative deductions difficult.

3.6 Overall conclusions from the field work

- The prototype controlled drainage device was simple to construct from locally available materials and install in the sub-surface drainage system. The device worked well for both crop seasons, allowing drainflow when the watertable was above the designated depth, and preventing it when it was below. The device was unfortunately rather expensive to make, but design simplifications and mass production would reduce costs considerably.
- The application of controlled drainage to the study plots significantly reduced drainflow during the maize and wheat seasons.
- Watertable depths were generally maintained at a higher level under controlled drainage, although high lateral seepage at the site meant that soil water was free to enter and leave the plots according to watertable depths in the surrounding area and the main drain.
- When the technique is applied to larger areas, or on less permeable soils, the impacts of lateral seepage will be reduced or cease.
- Crop yields were not reduced by controlled drainage, in fact small increases in yield were recorded.
- Over the course of the study (one year) the average soil salinity levels decreased slightly on both plots. Maintenance of acceptable soil salinity levels over time is one requirement for longterm sustainability of farming techniques.
- Although the fieldwork was able to give an indication of the impacts and benefits of controlled drainage, application to larger areas with farmer management is necessary to fully quantify and demonstrate the benefits.

4. TESTING THE SIMULATION MODEL WaSim USING THE FIELD DATA

4.1 Introduction

The simulation model WaSim was developed by HRWallingford and Cranfield University with DFID funding. It is a computer-based package for the teaching and demonstration of issues involved in irrigation, drainage and salinity. The model allows simulation of the soil/water/salinity relationships in response to different management strategies and environmental scenarios.

The WaSim model was further developed (as part of this project) to simulate controlled drainage using weirs (situated in open drain or sub-surface drainage system), and “on/off” devices such as flap gates, and to assess the impacts on the soil water and salt balance, water table depths, drainflow and crop response. Details of algorithms used are included in appendix 6.

The field data collected during the work at Mariut Experimental Station allow the model to be tested to see if it gives reasonable predictions of soil, water, salt and crop response, and is thus suitable as a tool to design different controlled drainage strategies for different situations.

4.2 The WaSim Model

The WaSim model carries out a one-dimensional daily soil water balance. It aims to simulate the soil water storage and rates of input (infiltration) and output (evapotranspiration and drainage) of water in response to climate, irrigation and seepage (where relevant). The upper boundary is the soil surface and the lower boundary is the impermeable layer. Water is stored between these two boundaries in five stores (layers):

0. the surface (0-0.15m) layer,
1. the active root zone (0.15m – root depth),
2. the unsaturated layer below the root zone (root depth – water table),
3. the saturated layer above drain depth (water table – drain depth),
4. the saturated layer below drain depth (drain depth – impermeable layer).

The inputs of water are from net rainfall, net irrigation and lateral seepage. Net irrigation and rainfall are defined as the gross amounts, less interception losses and surface runoff.

The outputs from the soil profile are:

1. Open water evaporation which occurs only if there is ponding on the soil surface.
2. Soil evaporation.
3. Plant transpiration.
4. Capillary rise from the groundwater.
5. Drainflow occurs from the surface layers when the water table is above drain depth.

For full details the reader is referred to the WaSim technical and user manuals.

4.3 Setting up the WaSim Model for the Field Site

Data from the fieldwork were used to set up input files for soil, drainage system, climate, crops, irrigation schedules and initial conditions at the site.

These are described below:

4.3.1 Soil definition

The required parameters, values adopted and source are shown in the table below:

Table 8 WaSim Soil Input Data Adopted for the Field Site.

Soil Parameter	Value adopted	Source
Soil saturation moisture content (volumetric)	48%	PF curve developed at the site (see appendix 2)
Field capacity moisture content (vol)	33%	‘’
Permanent wilting point moisture content (vol)	26%	‘’
Saturated paste moisture content (vol)	88%	Lab results
Saturated hydraulic conductivity	2m/day	Field tests
Drainage coefficient Tau	0.51	Default value based on hydraulic conductivity measured at site
Curve number	89	‘’
Leaching efficiency	90%	Default value

4.3.2 Drainage System Design

The required drainage system parameters, values adopted and source are shown in the table below:

Table 9 WaSim Drainage System Input Data Adopted for the Field Site.

Drainage Parameter	Value adopted	Source
Depth	1.2m	Installation depth
Diameter	0.08m	Measured
Spacing	33m	Average of measured spacings
Depth to impermeable layer	10m	Local knowledge

4.3.3 Climate Data

WaSim requires daily rainfall and reference evapotranspiration (ETo) data. Rainfall was measured directly at the site, and reference evapotranspiration was calculated from the meteorological data collected nearby on a daily basis. The file runs from 1st Jan 1999 to 31st May 2000. The data file is included in appendix 7.

4.3.4 Crop Data

Crop data used for the maize and wheat season are shown below:

Table 10 WaSim Crop Input Data Adopted for the Field Site.

Crop Parameter	Value adopted for maize	Value adopted for wheat	Source
Crop Cover Development			
Planting date	10 June	20 November	FAO guidelines
Emergence date	10 June	20 November	‘ ’
20% cover	5 July	16 December	‘ ’
Full cover	13 August	15 January	‘ ’
Maturity	20 September	20 March	‘ ’
Harvest	10 October	5 May	‘ ’
Max root date	28 August	9 April	‘ ’
Cover			
Max cover	95%	100%	Field observation
Mulch cover	0%	0%	‘ ’
Crop coeff at full cover	114%	105%	FAO guidelines
Roots			
Planting depth	0.1m	0.1m	Default value
Max root depth	1m	0.9m	FAO guidelines
Ponding			
Max ponding depth	20cm	20cm	Field observation
Kc for ponding	1.0	1.0	FAO guidelines
Transpiration Factors			
p-fraction	0.55	0.55	FAO guidelines
Yield response	1.25	1.0	DRI, 1997
Salinity threshold	3 dS/m	6 dS/m	FAO guidelines and DRI, 1993
Slope	10%/dS/m	7.1%/dS/m	

4.3.5 Irrigation Data

Irrigation dates, amounts and salinities from tables 2 and 5 were used in the WaSim irrigation input screens.

4.3.6 Initial Conditions Data

Initial conditions including start and finish dates for simulation, initial soil moisture content and watertable depth, and initial soil salinity levels were specified for each crop season from the field data, and are shown below:

Table 11 WaSim Initial Conditions Input Data Adopted for the Field Site.

MAIZE SIMULATION – Conventional Plot : 9 June 1999 – 10 October 1999			
Initial Conditions	Depth (m)	Moisture Content	Salinity (dS/m)
Topsoil	0.15	0.36	2.86
Unsat. Zone	0.67	0.35	4.13
Sat. zone above drains	1.2	0.48	3.60
Sat. zone below drains	10	0.48	2.48

MAIZE SIMULATION – Controlled Drainage Plot : 9 June 1999 – 10 October 1999			
Initial Conditions	Depth (m)	Moisture Content	Salinity (dS/m)
Topsoil	0.15	0.36	2.86
Unsat. Zone	1.0	0.38	4.00
Sat. zone above drains	1.2	0.48	2.48
Sat. zone below drains	10	0.48	2.48

WHEAT SIMULATION – Conventional Plot : 8 November 1999 – 5 May 1999			
Initial Conditions	Depth (m)	Moisture Content	Salinity (dS/m)
Topsoil	0.15	0.34	3.15
Unsat. Zone	0.89	0.36	3.12
Sat. zone above drains	1.05	0.48	3.10
Sat. zone below drains	10	0.48	3.10

WHEAT SIMULATION – Controlled Drainage Plot:8 November 1999 – 5 May 1999			
Initial Conditions	Depth (m)	Moisture Content	Salinity (dS/m)
Topsoil	0.15	0.35	2.26
Unsat. Zone	0.74	0.38	2.26
Sat. zone above drains	1.05	0.48	2.31
Sat. zone below drains	10	0.48	2.34

4.3.7 Irrigation and Drainage Management

The 2 crop seasons were simulated under conventional irrigation and drainage management, and with controlled drainage management.

4.3.8 Other Input Data

Analysis of the field data demonstrated that lateral seepage was a major process at the site and must therefore be included in the simulation modelling. Lateral seepage was estimated on a daily basis from the waterbalance (see appendix 3 and 5), but differences in timings of measurements and uncertainties in daily values meant a daily estimate of lateral seepage gave unrealistic values. For this reason the magnitude of seasonal lateral seepage (both in and out of the plots) was calculated in each case, and converted into a mean daily lateral seepage for each crop season, and used as an input to the WaSim model. The values are shown below:

Table 12 Daily Estimated Average Lateral Seepage Rates for the Plots.

Lateral Seepage mm/day	Conventional Plot	Controlled Drainage Plot
Maize Season	+1.4*	-1.0
Wheat Season	+2.9	+0.5

* positive value indicates flow is into the plot, negative value indicates flow is out of the plot.

4.4 Simulation Results

4.4.1 General Comments

Simulations were undertaken for the two plots over the two crop seasons, using the input data described above. Comparisons were made with the field data based on the following parameters:

- Predicted crop water use.
- Mid-drain watertable depth throughout the crop season.
- Watertable depth at end of season.
- Drainflow – seasonal total and throughout the season.
- Soil salinity at end of season.
- Crop effects – reduction in crop yield.

For the predicted crop water use, WaSim computes the potential evapotranspiration on a daily basis, then reduces this amount according to predicted levels of stress experienced by the crop due to excess soil water, soil water shortage and soil salt content. It was observed in early simulations that WaSim predicted large amounts of excess water stress, drastically reducing the predicted crop water use and hence final crop yield. This disagreed with the field data which recorded excellent crop yields in all cases and thus very little (if any) crop stress at any time. For this reason all subsequent simulations were carried out without reducing evapotranspiration due to excess water (there is an option in WaSim that allows this to be turned off).

4.5 Conventional Drainage Simulation Results

Daily simulations were carried out for the maize and wheat season under conventional management using the input data described.

The results for the seasonal parameter comparisons are shown in table below:

Table 13 Comparison of WaSim Simulation Results for Conventional Management with the Field Data.

	MAIZE SEASON		WHEAT SEASON	
	Field Data	WaSim Prediction	Field Data	WaSim Prediction
Total crop water use mm	569	520	358	364
Total drainflow mm	287	438	754	824
Average soil salinity at end of season dS/m	3.1	3.6	3.3	2.0
Water table depth at end of season m	0.99	1.11	0.98	0.94
Seasonal relative crop transpiration %	No yield reduction	93.4	No yield reduction	100

The daily predicted crop water use under conventional management for the field site and for WaSim are shown in figure 14. The general agreement is good, with some discrepancies at the start and end of each season. The seasonal totals are in good agreement (within 9% for the maize crop and 2% for the wheat crop).

Figure 15 shows the model predictions for mid-drain watertable depth together with the results from the field. For both seasons the WaSim watertable generally goes up and down following the same pattern as the field data, except for occasions at the end of each season when there were irrigations but the amount was not measured. WaSim predicts the watertable does not rise so high after irrigations as it did with the fieldwork for the maize season, but the fit is better for the wheat season. The end of season watertable depths are comparable in both cases.

The daily drainflows are shown in figure 16. WaSim and the field data generally go up and down together although WaSim is less peaky, but WaSim predicts considerably more drainflow than was recorded in the field. This may be explained by under-estimation of drainflow in the field due to the crude measurement approach but this is not clear.

In general, the field data and WaSim were in good agreement for the predicted crop water use, water table depths and overall yield effects. The agreement was also good for the maize season for the end of season soil salinity, but was not so good for predicted drainflow over the season. It is concluded that WaSim gives adequate agreement with the field data for conventional irrigation and drainage practice.

4.6 Controlled Drainage Simulation Results

Daily simulations were carried out for the maize and wheat season under controlled drainage using the input data described. For both seasons the weir depth was set in WaSim at 0.7m.

Seasonal comparisons of main parameters are shown in table below, for the controlled drainage plot.

Table 14 Comparison of WaSim Simulation Results for Controlled Drainage with the Field Data.

	MAIZE SEASON		WHEAT SEASON	
	Field Data	WaSim Prediction	Field Data	WaSim Prediction
Total crop water use mm	569	547	358	392
Total drainflow mm	46	34	290	317
Average soil salinity at end of season dS/m	2.3	5.7	2.9	2.6
Water table depth at end of season m	0.92	0.9	0.84	0.89
Seasonal relative crop transpiration %	No yield reduction	94	No yield reduction	100

The WaSim and fieldwork values for predicted daily crop water use are shown in figure 17. The agreement is good for both seasons, with similar seasonal totals (within 10%) predicted.

Figure 18 shows the model predictions for mid-drain watertable depth together with the results from the field. For both seasons the WaSim watertable broadly goes up and down following the field data. The fit is better for the wheat season. The end of season watertable depths predicted by WaSim are in excellent agreement with the field results.

For the maize season WaSim gives excellent agreement with the field data for total crop water use, total drainflow, end of season water table depth and crop yield. Average soil salinity at the end of the season was over-estimated.

For the wheat season WaSim gives good agreement for total crop water use and total drainflow. WaSim under-estimates the end of season soil salinity. Agreement is good for end of season water table depth, and the crop yield.

Daily drainflows from WaSim and the field data are compared in figure 19. Seasonal totals and daily values are in quite good agreement although WaSim over-estimates the drainflow for the wheat season.

It is thus concluded that WaSim gives acceptable agreement with the field data for controlled drainage management.

4.7 Overall conclusions from WaSim Testing

The WaSim simulation model was tested against project field data collected over 2 crop seasons of conventional irrigation and drainage management, and controlled drainage management.

Five key parameters were compared on a daily and seasonal basis, and it was generally concluded that WaSim gave adequate agreement with field data. The model thus constitutes an acceptable representation of processes occurring in the field, and the potential impacts and benefits of controlled drainage compared to conventional practice.

Although the extent of the testing was limited to 2 crop seasons at the field site, it is concluded that the WaSim model is an acceptable tool to develop and compare conventional and controlled drainage strategies for different situations.

5. ACKNOWLEDGEMENTS

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Figures

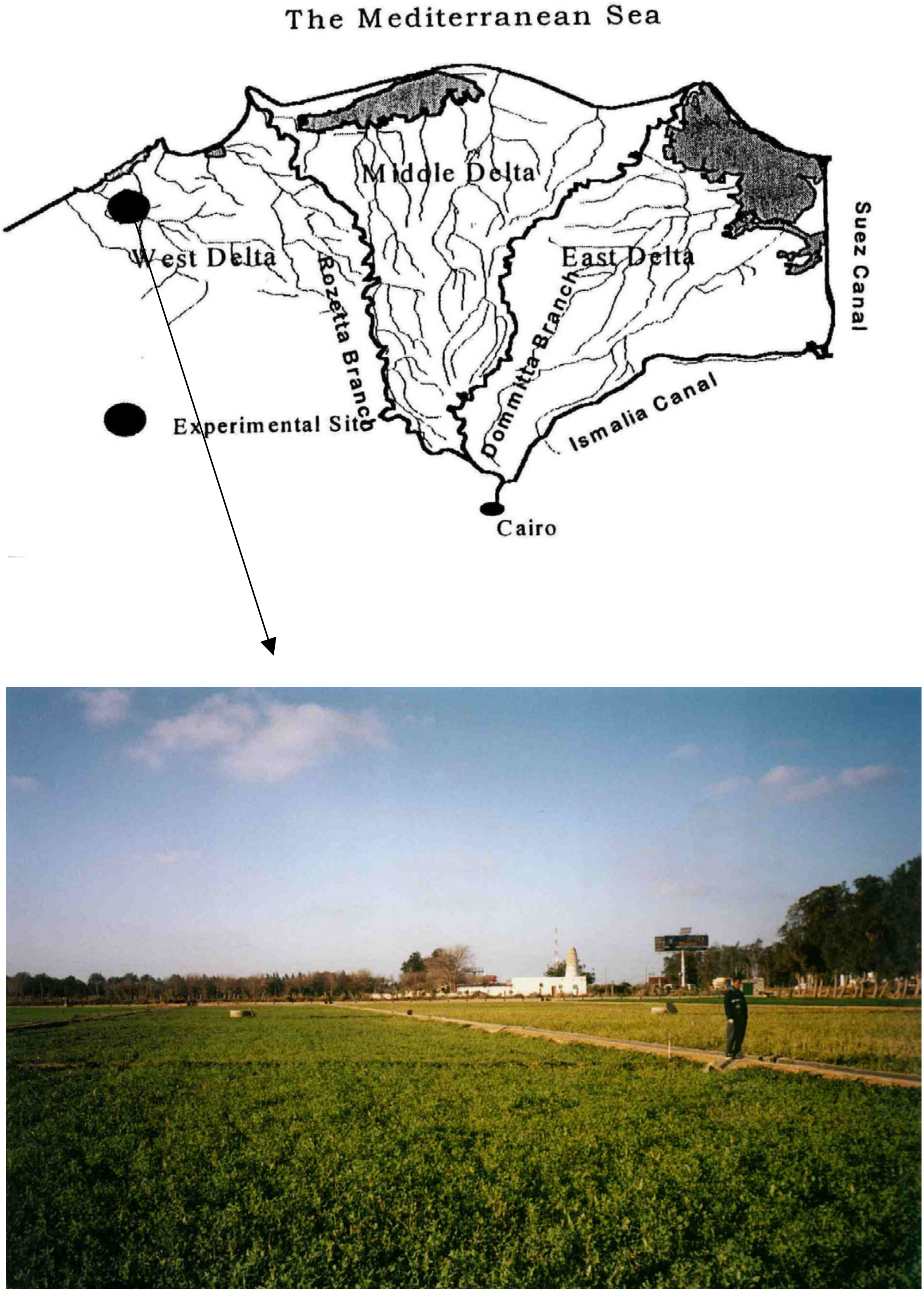


Figure 1 Location of the Mariut field site

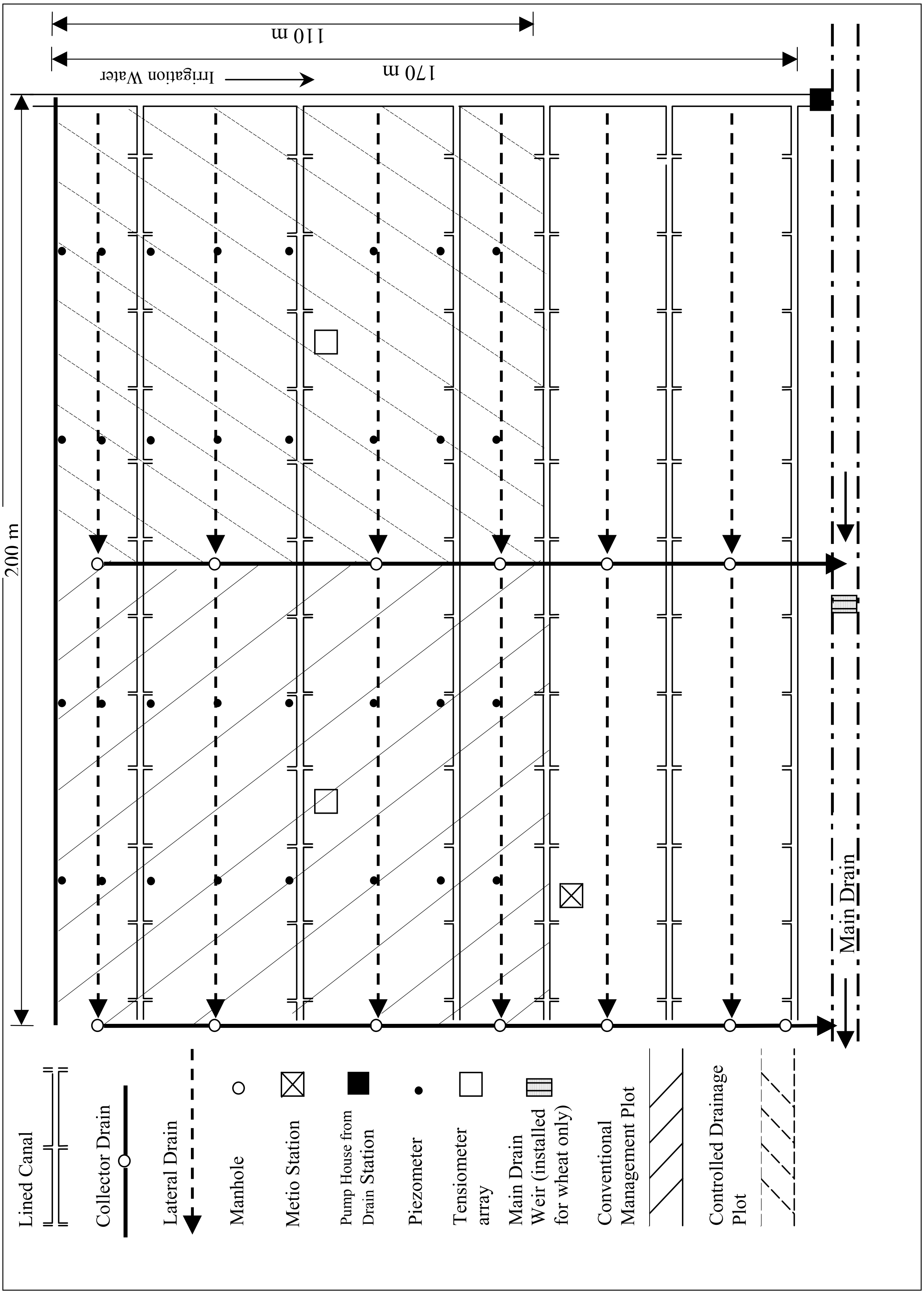


Figure 2 Mariut field site showing irrigation and drainage layout for the plots, and instrumentation installed

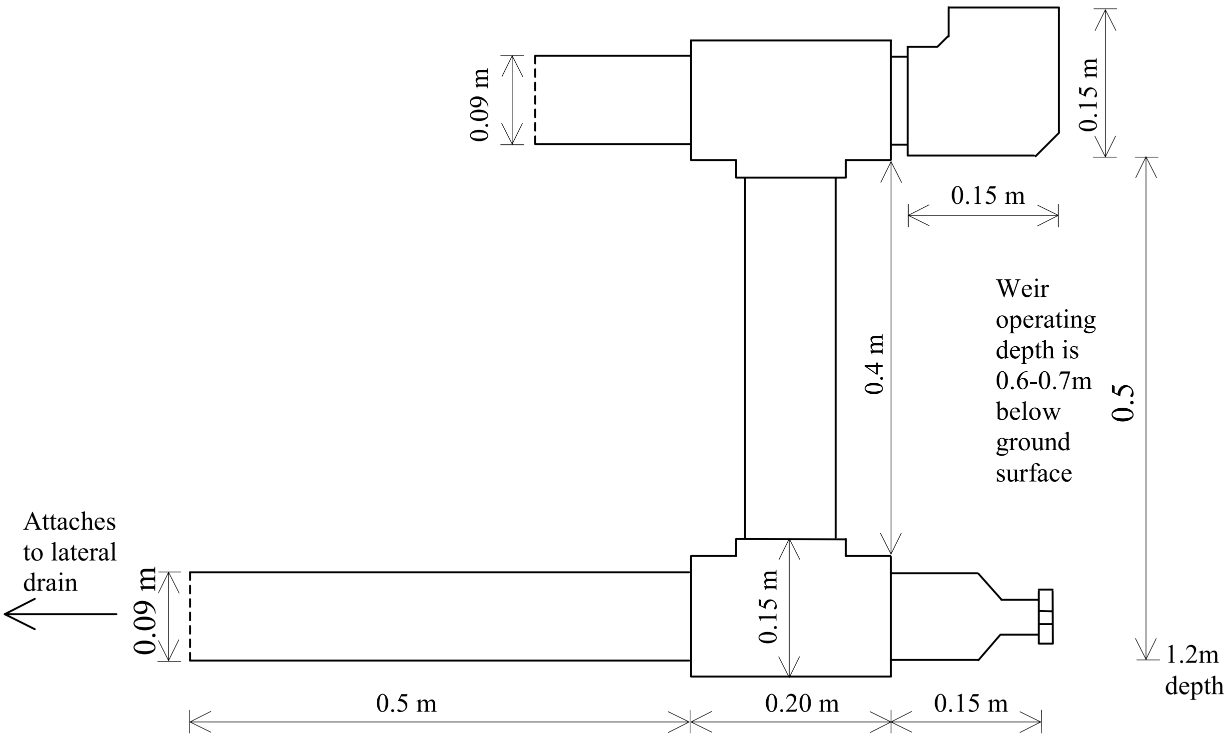


Figure 3 Prototype controlled drainage device, showing design details and location in subsurface drainage access manhole.

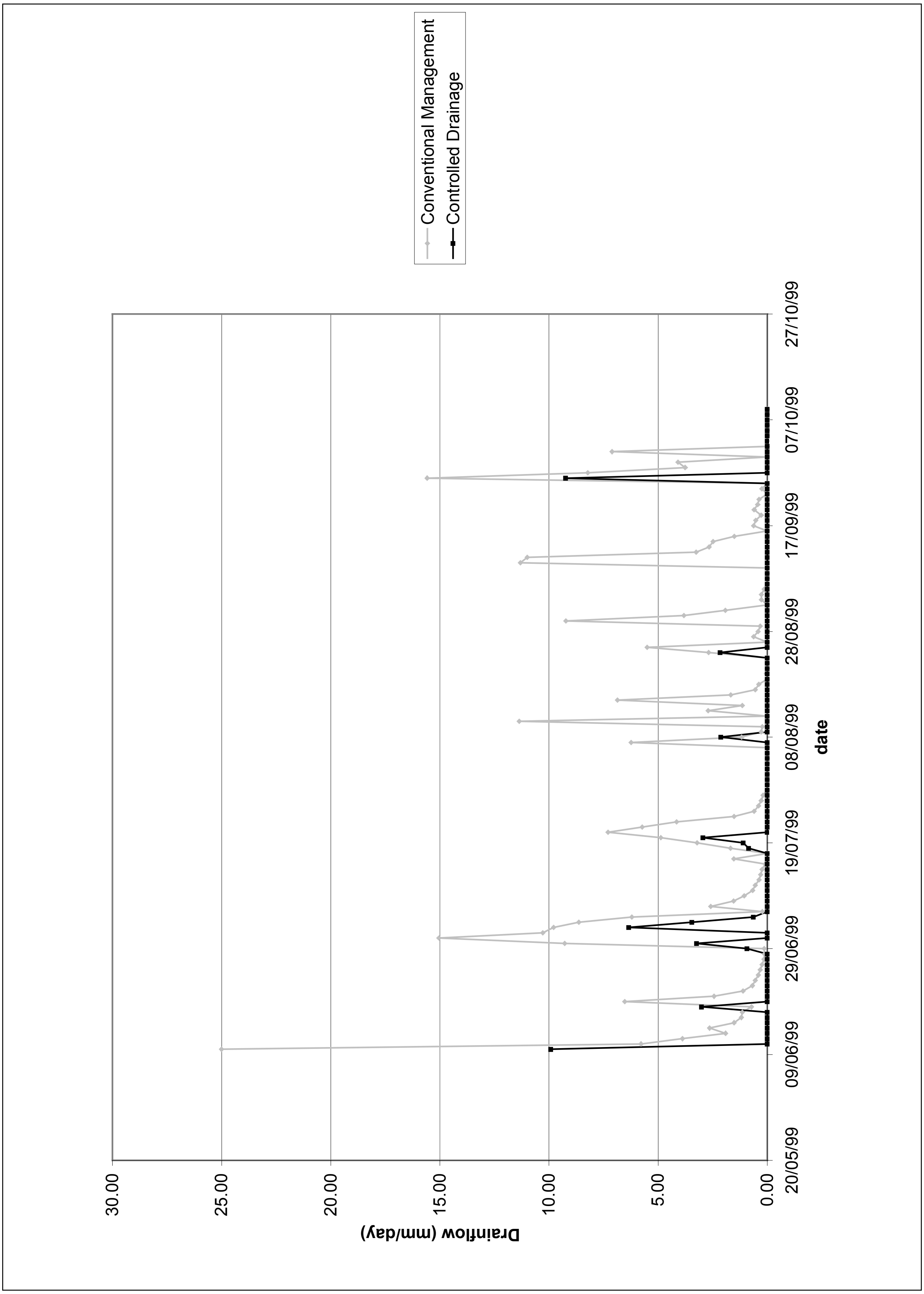


Figure 4 **Daily drainflow during the maize season.**

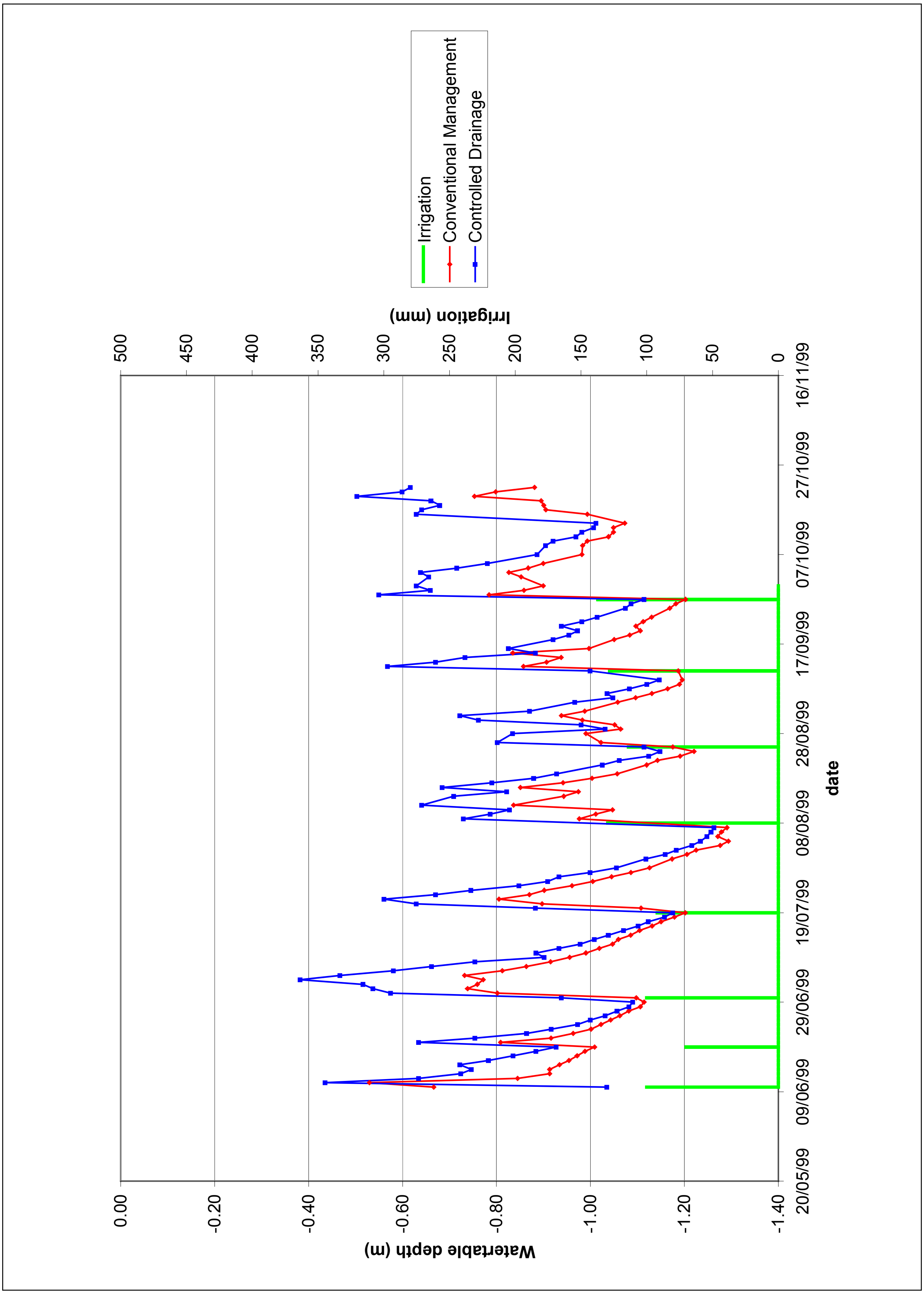


Figure 5 **Daily mid-drain watertable depths during the maize season, with irrigation events indicated.**

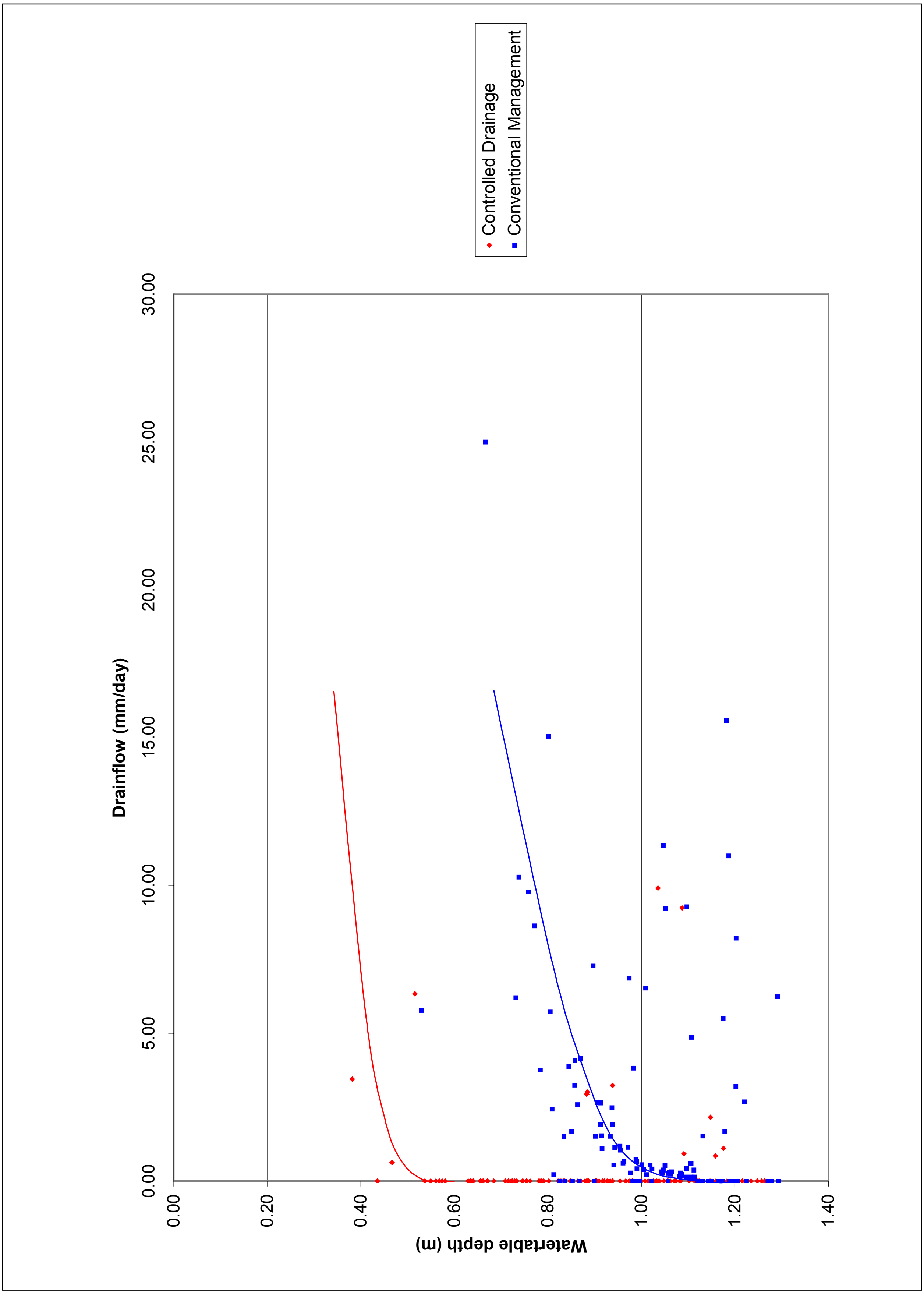


Figure 6 Daily mid-drain watertable depth and drainflow data for the maize season, showing effective drain depths for the two plots.

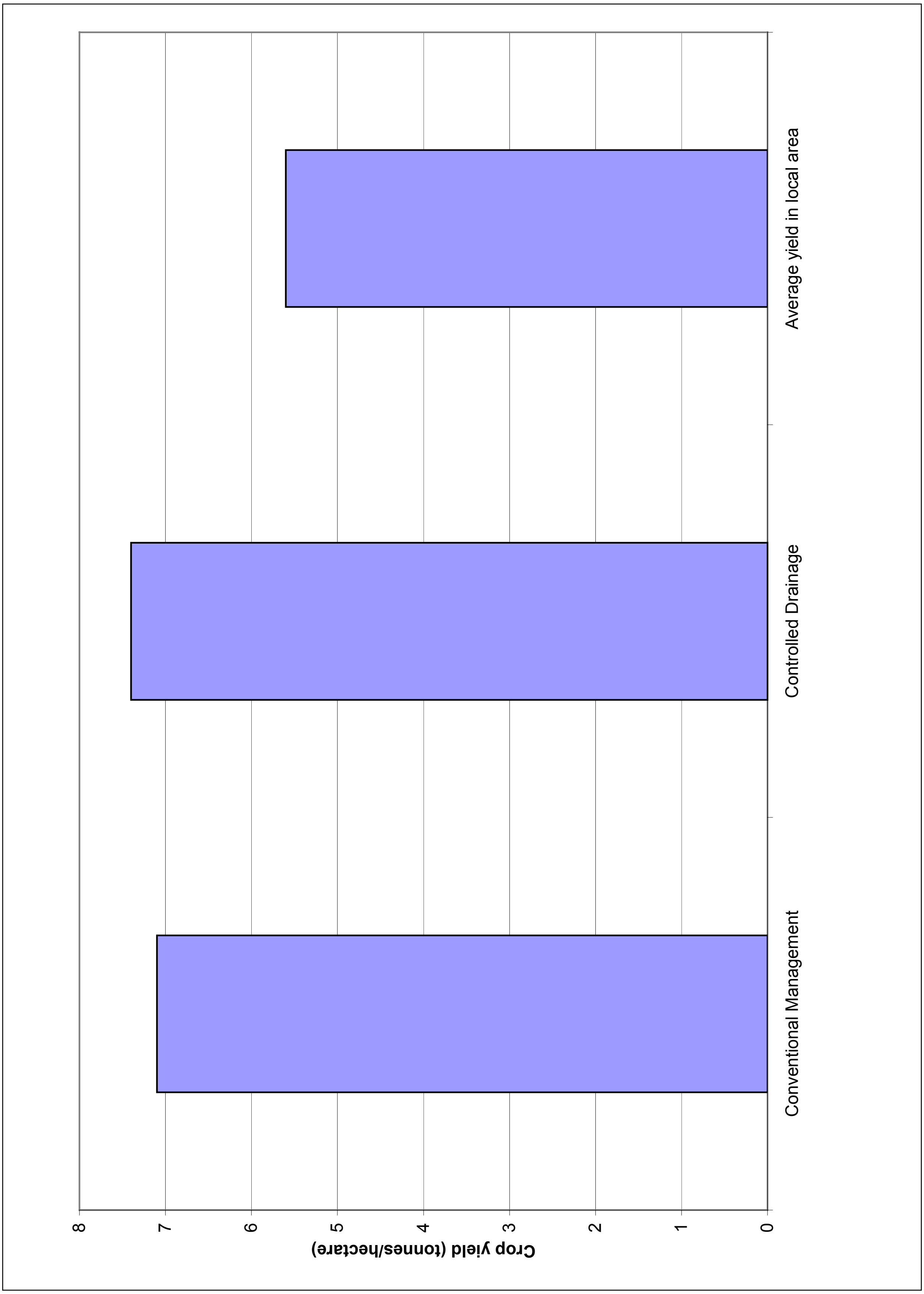


Figure 7 **Maize crop yields from the field site, together with an average yield figure from the local area.**

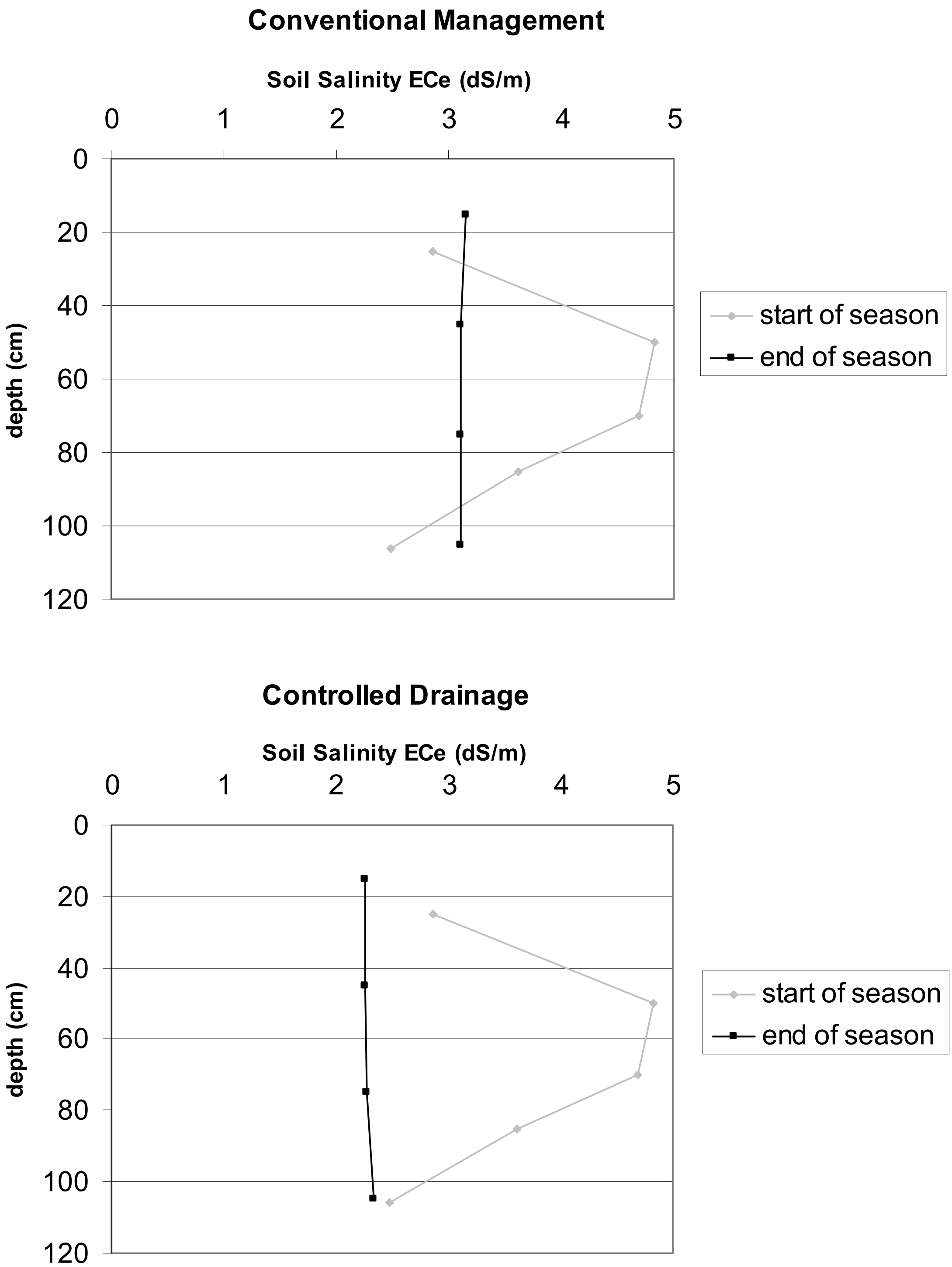


Figure 8 Soil salinity levels at the start and end of the maize season.

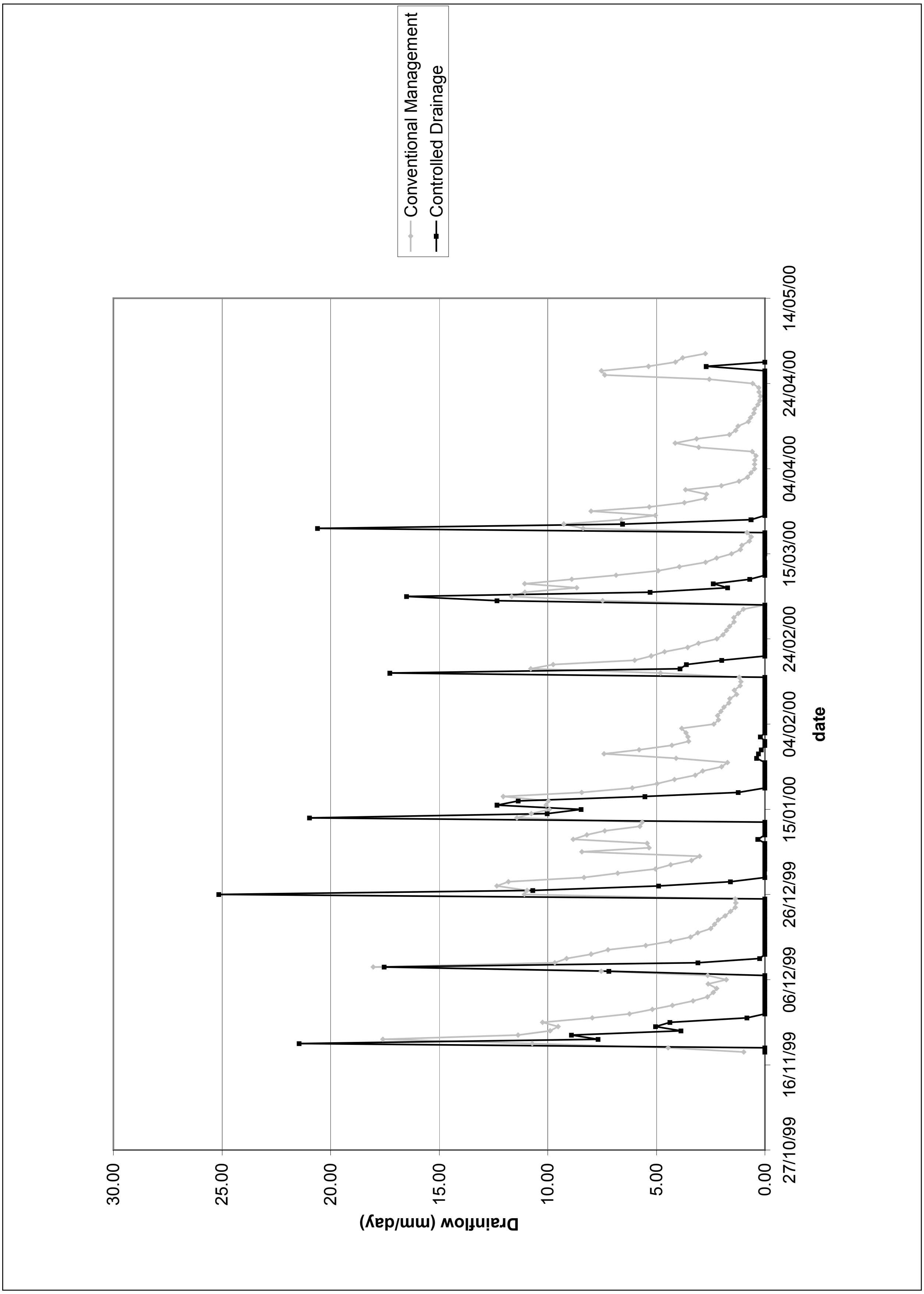


Figure 9 Daily drainflow during the wheat season.

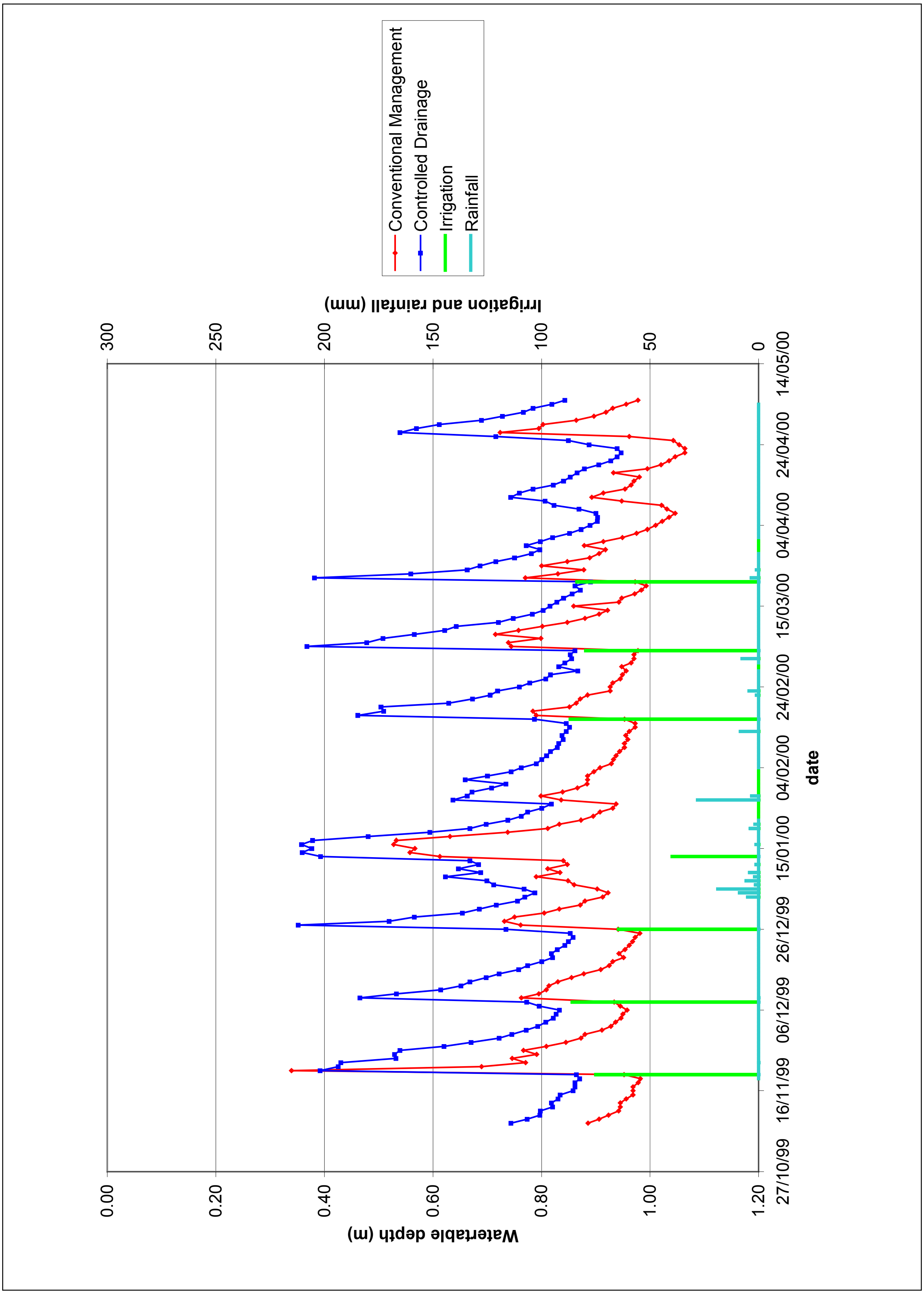


Figure 10 **Daily mid-drain watertable depths during the wheat season, with irrigation and rain events indicated.**

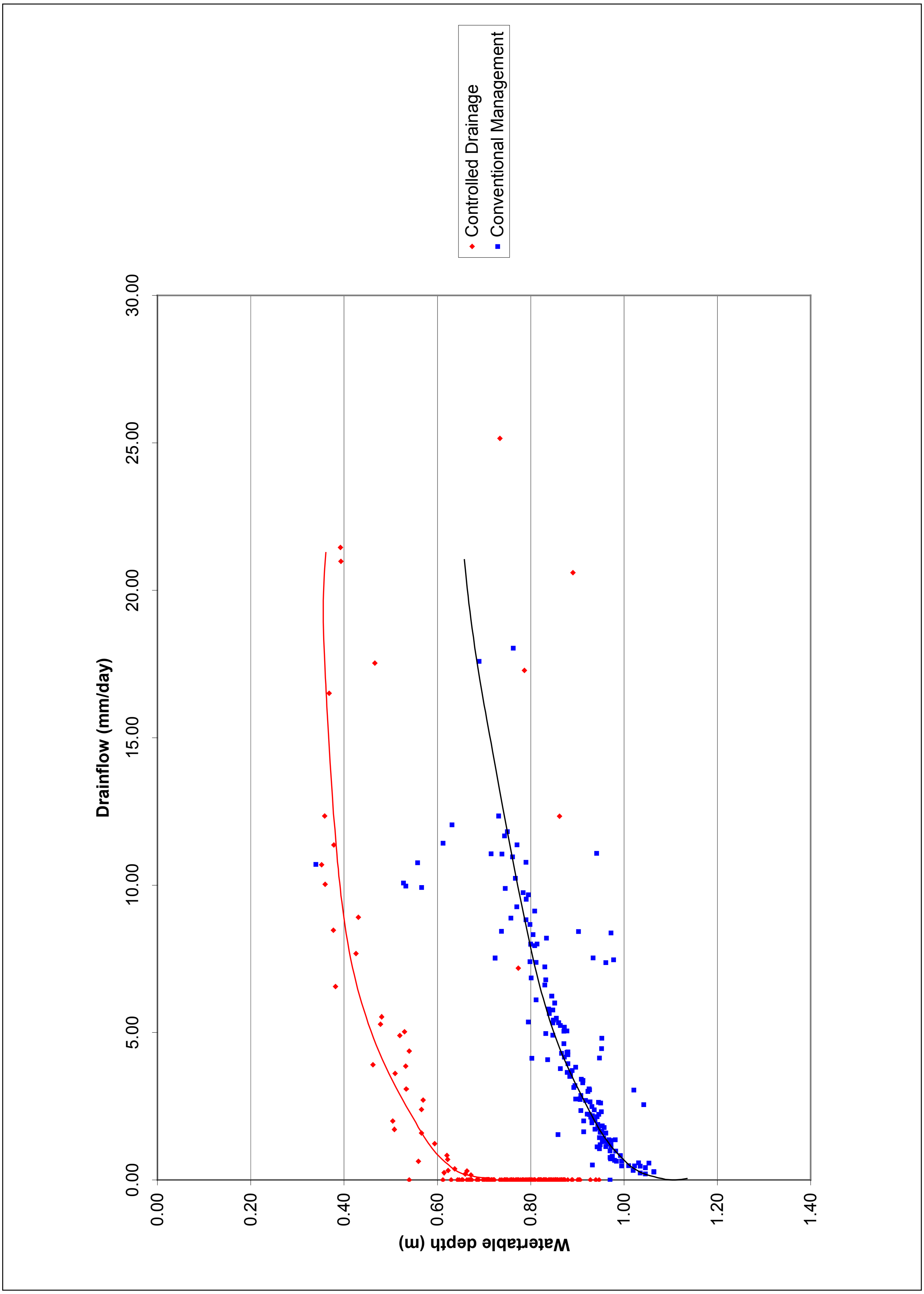


Figure 11 Daily mid-drain watertable depth and drainflow data for the wheat season, showing effective drain depths for the two plots.

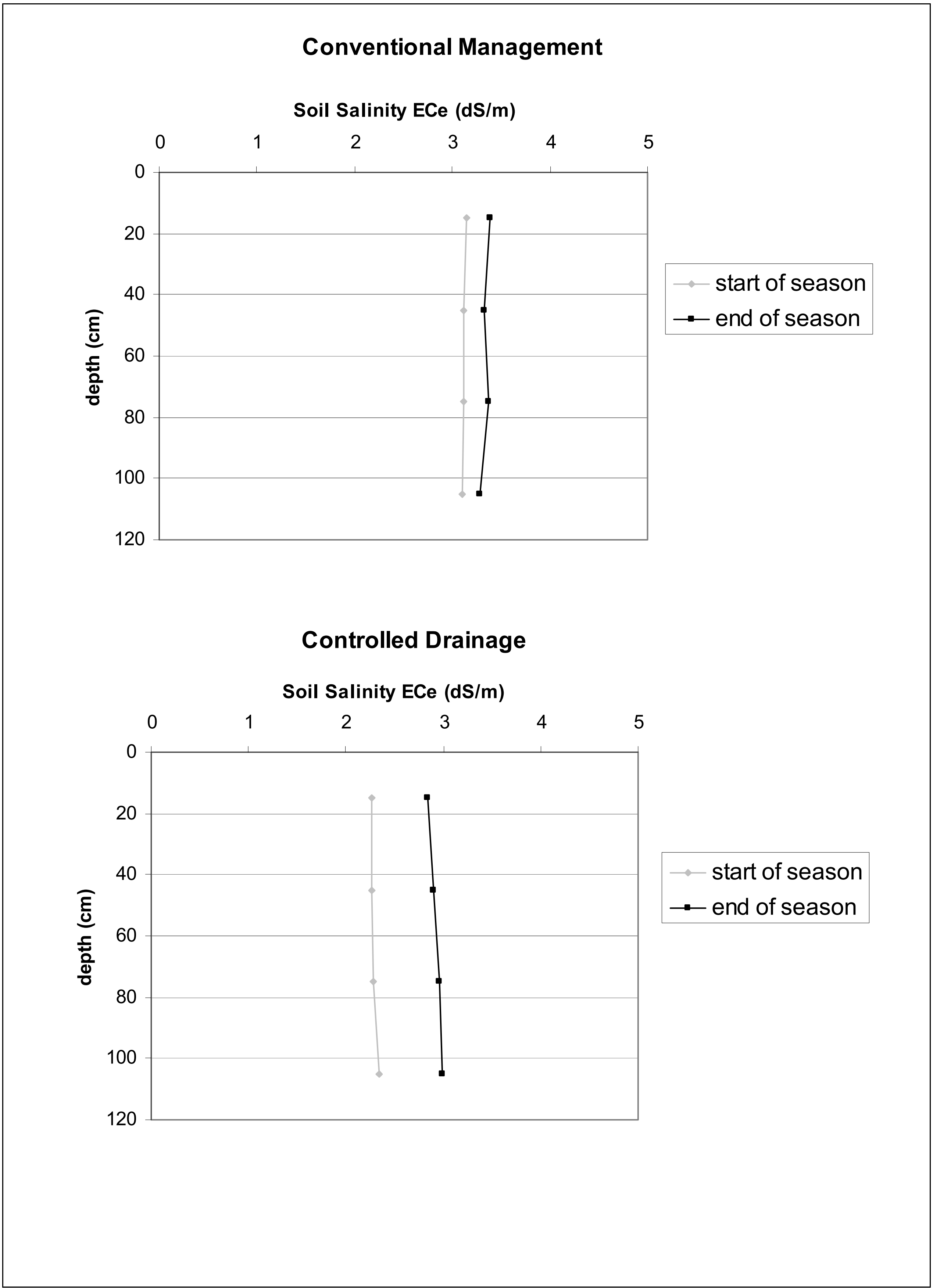


Figure 12 Soil salinity levels at the start and end of the wheat season.

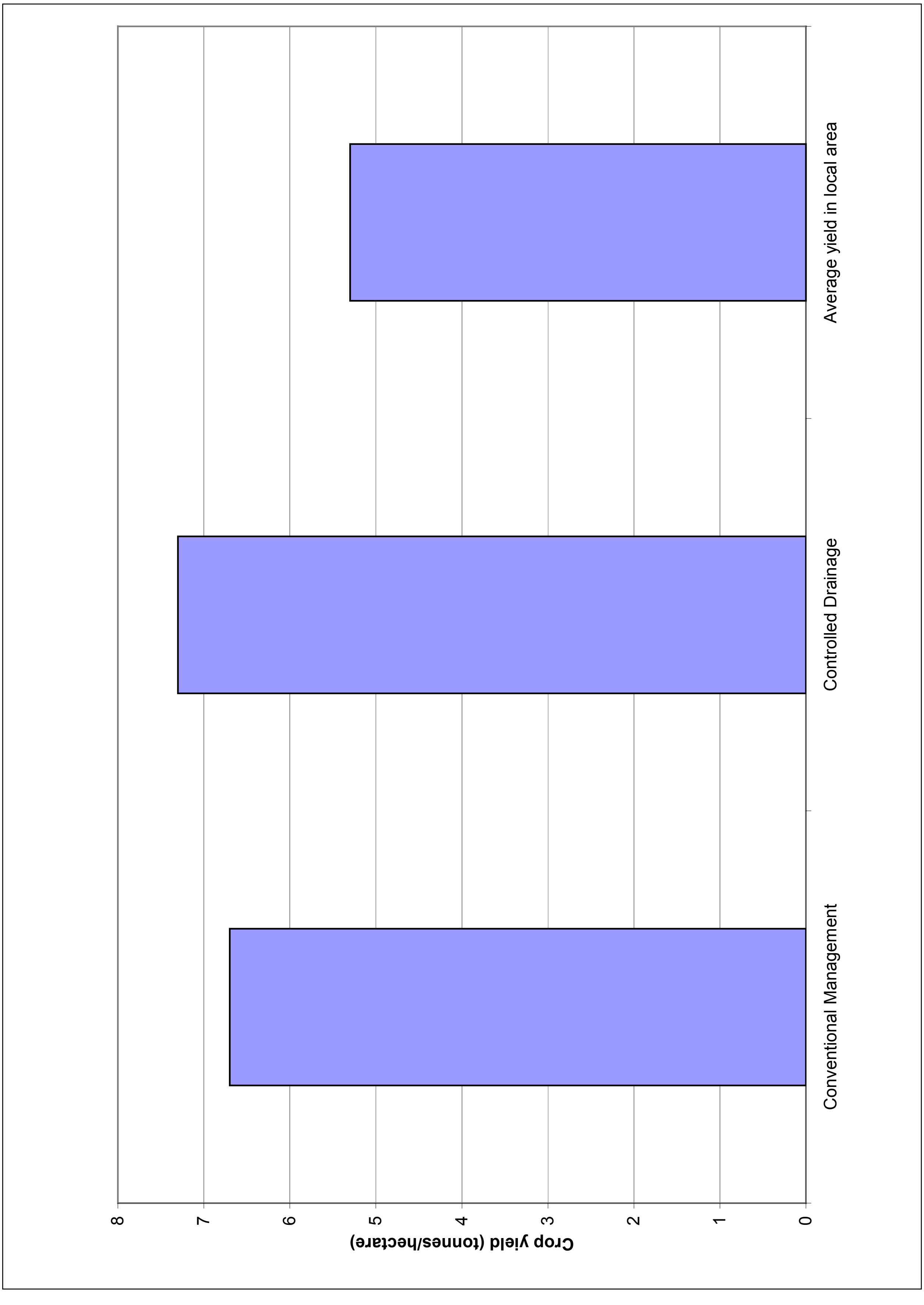


Figure 13 Wheat crop yields from the field site, together with an average yield figure from the local area.

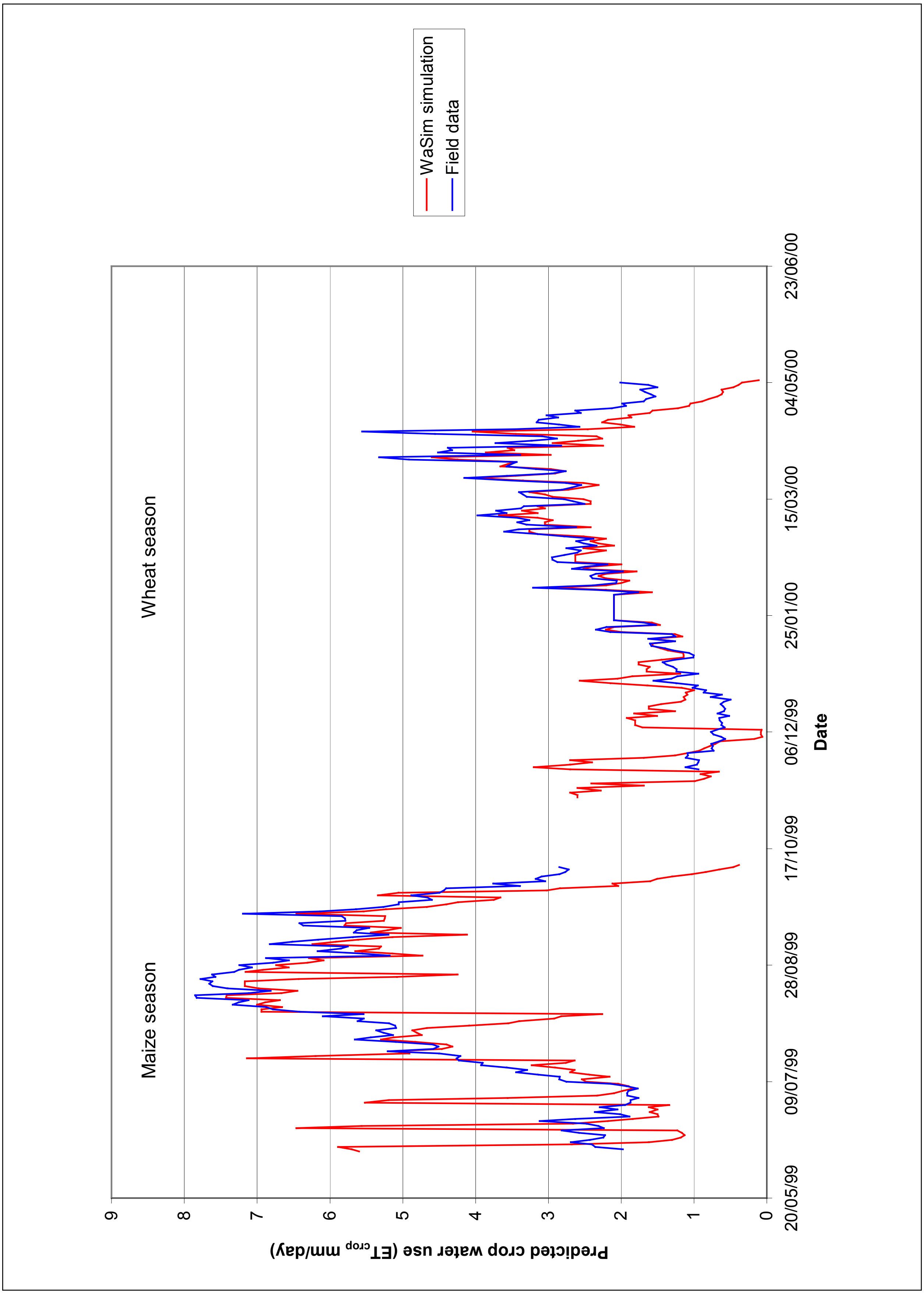


Figure 14 Daily predicted crop water use under conventional management for the field site and for the WaSim simulation.

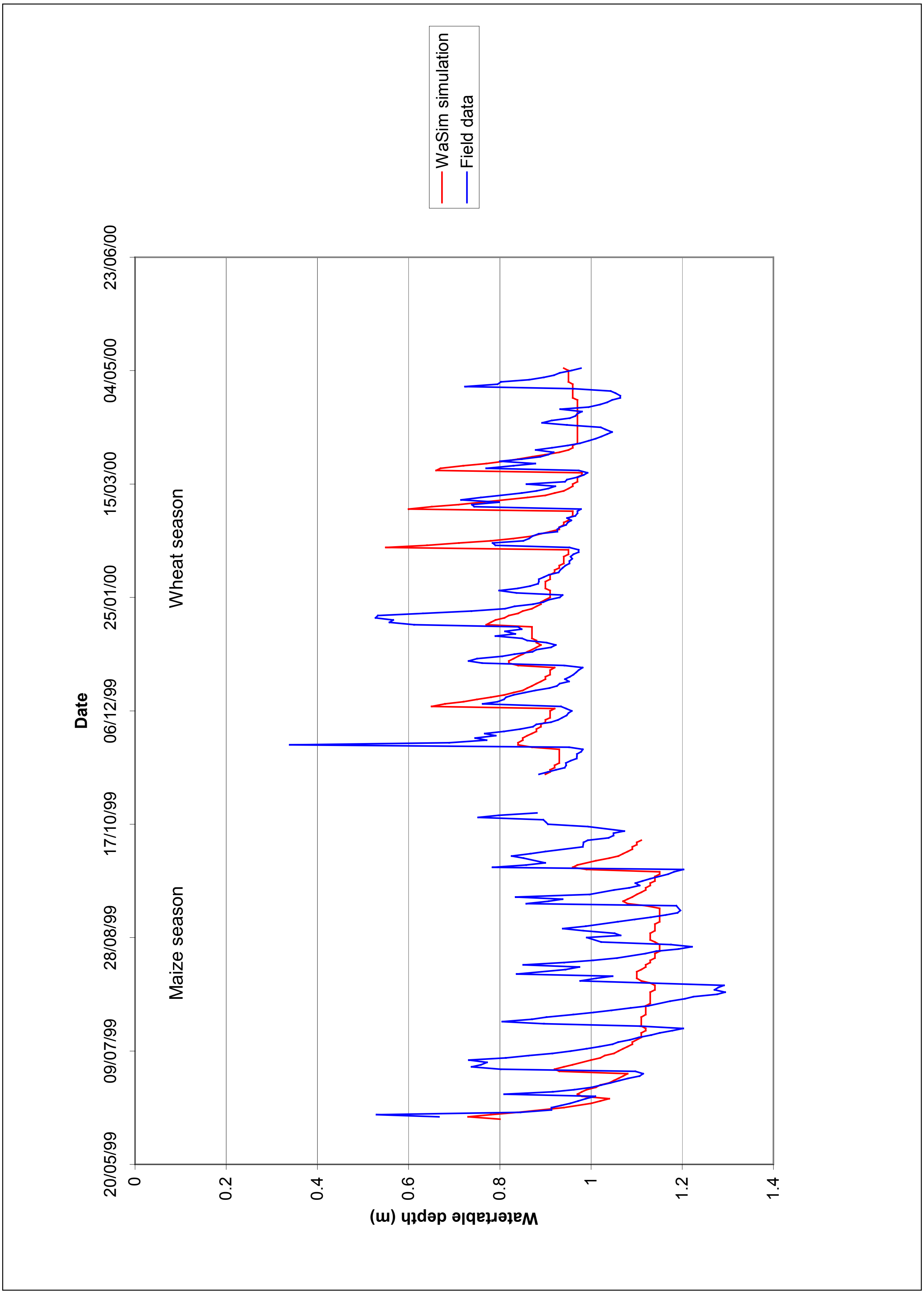


Figure 15 Daily mid-drain watertable depth data for conventional management at the field site and predicted by the WaSim simulation.

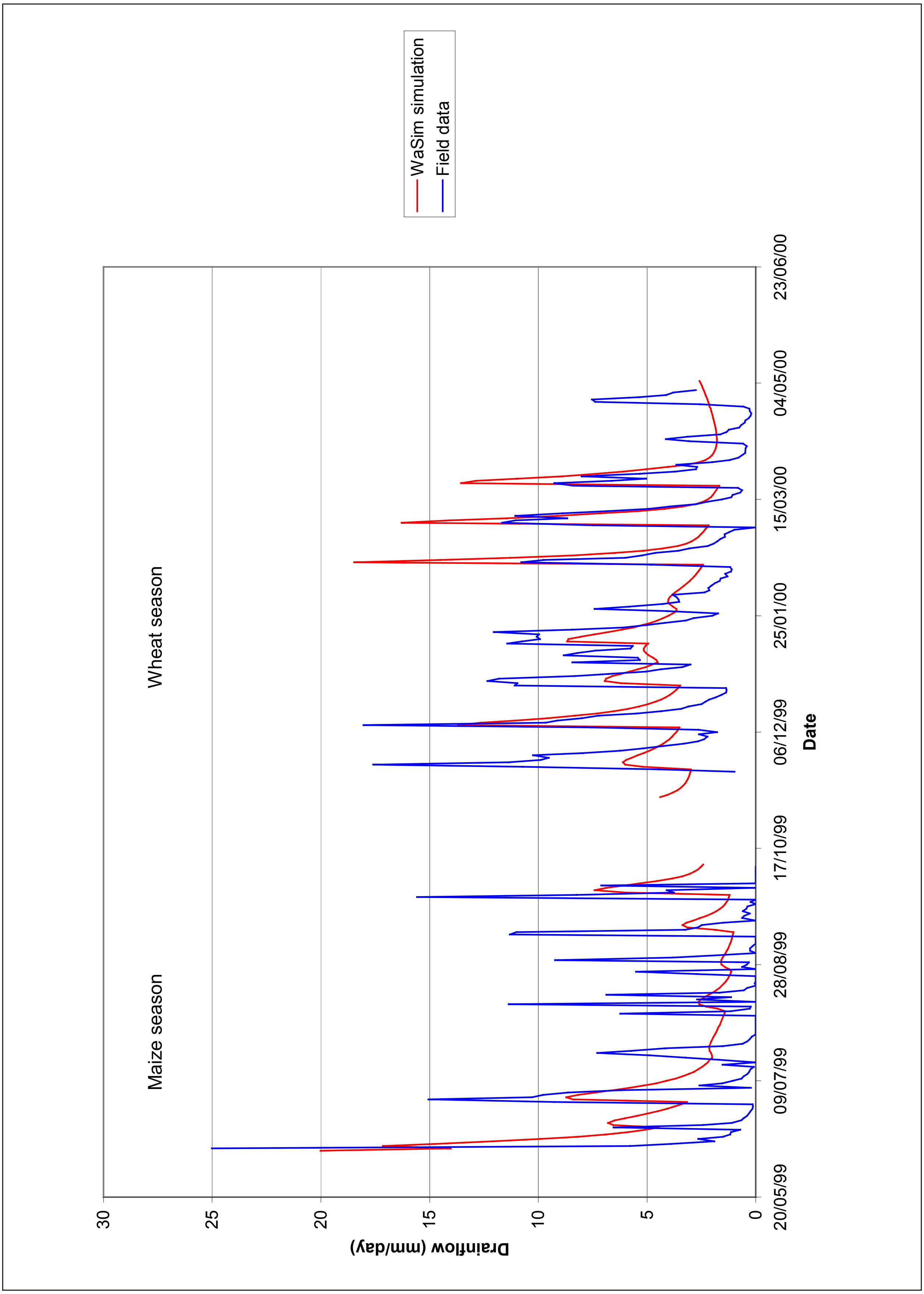


Figure 16 Daily drainflow data for conventional management at the field site and predicted by the WaSim simulation.

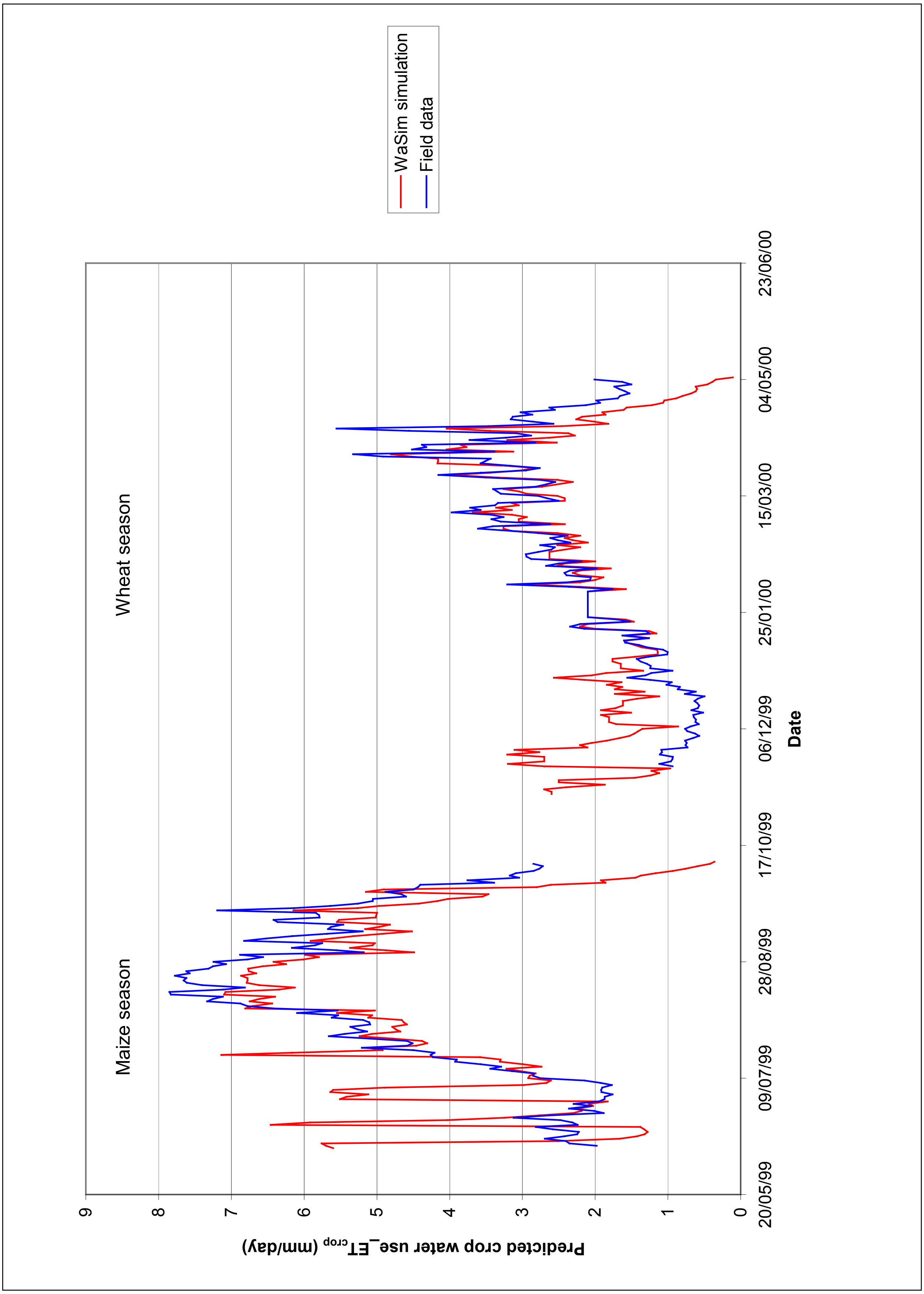


Figure 17 Daily predicted crop water use under controlled drainage for the field site and for the WaSim simulation.

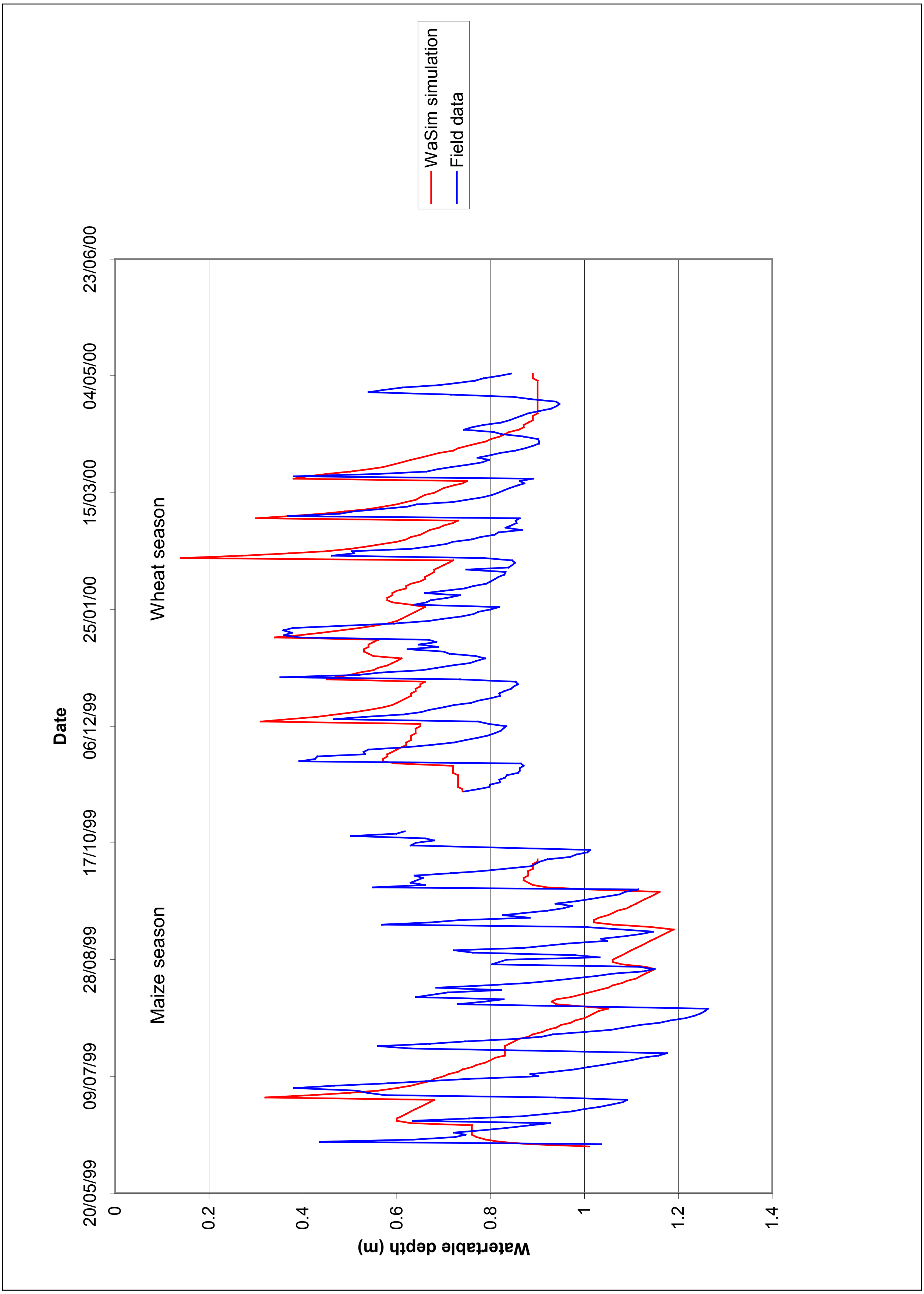


Figure 18 Daily mid-drain watertable depth data for controlled drainage at the field site and predicted by the WaSim simulation.

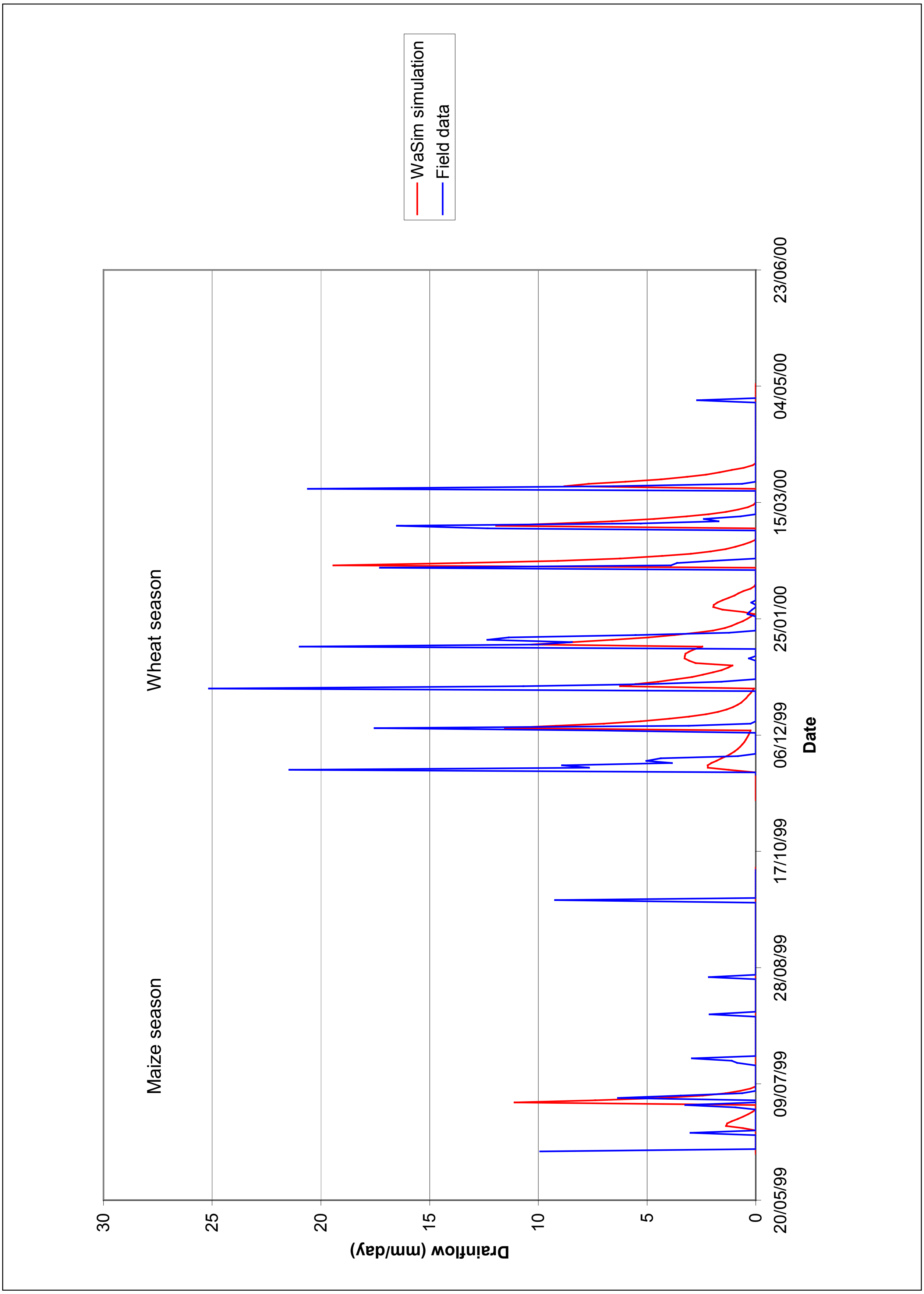


Figure 19 Daily drainflow data for controlled drainage at the field site and predicted by the WaSim simulation.

Appendices

Appendix 1

Soil Textural Analysis

Appendix 1 Soil Textural Analysis.

Table A summarises the soil textural analysis from the field site in the Western Nile Delta. Soil samples were taken from 13 locations around the site, and 6 depths in each case to cover the soil profile from the surface down to 1.8m. Analysis is divided into % of the main soil classes sand, silt and clay, with an assessment of the soil textural class also given.

Table A Soil Textural Analysis from the Field Site.

Sample No	Depth	Clay %	Silt %	Sand %	(Soil Texture)
1	0 - 30	16.6	40.1	50	Sandy silt loam
1	30 - 60	32.2	30.3	37.5	Clay loam
1	60 - 90	35.5	33.1	31.4	Clay loam
1	90-120	32.2	27.1	40.7	Clay loam
1	120-150	25.9	20.6	53.5	Sandy clay loam
1	150-180	25.9	20.6	53.5	Sandy clay loam
2	0 - 30	32.2	27.1	40.7	Clay loam
2	30 - 60	38.6	30	31.4	Clay
2	60 - 90	37	31.6	31.4	Clay
2	90-120	32.2	30.3	37.5	Clay loam
2	120-150	30.6	31.9	37.5	Clay loam
2	150-180	32.2	30.3	37.5	Clay loam
3	0 - 30	32.2	23.6	44.2	Clay loam
3	30 - 60	35.5	30.2	34.3	Clay
3	60 - 90	32.7	38.7	29.1	Clay loam
3	90-120	29.1	27.4	43.5	Clay loam
3	120-150	29.5	29.8	40.7	Clay loam
3	150-180	26.3	31.3	42.4	Clay loam
4	0 - 30	23.1	17	59.9	Sandy clay loam
4	30 - 60	29.5	36.2	34.3	Clay loam
4	60 - 90	29.5	25	45.5	Clay loam
4	90-120	23.7	14.9	61.4	Sandy clay loam
4	120-150	23.7	27.8	48.5	Clay loam
4	150-180	33.01	24.5	42.4	Clay loam
5	0 - 30	31.6	31.2	36.2	Clay loam
5	30 - 60	36.4	30.7	32.9	Clay
5	60 - 90	36.1	30.7	33.2	Clay
5	90-120	18.7	22.8	58.5	Sandy clay loam
5	120-150	36.1	27.5	36.5	Clay
5	150-180	29.8	27.5	42.7	Clay loam
6	0 - 30	20.3	25.9	53.8	Sandy clay loam
6	30 - 60	42.6	30.6	26.9	Clay
6	60 - 90	26.7	36.8	36.5	Clay loam
6	90-120	32.8	21.4	45.8	Clay loam
6	120-150	32.8	27.5	39.7	Clay loam
6	150-180	29.8	30.5	39.7	Clay loam
8	0 - 30	23.7	33.9	42.4	Clay loam
8	30 - 60	27	43.1	29.9	Clay loam
8	60 - 90	27	32.3	40.7	Clay loam
8	90-120	27	22.7	50.3	Clay loam
8	120-150	19	35.2	45.5	Clay loam
8	150-180	22	32.5	45.5	Clay loam
9	0 - 30	15.8	44.8	39.4	Sandy silt loam
9	30 - 60	30	33.8	36.2	Clay loam
9	60 - 90	36.4	33.7	29.9	Clay

Sample No	Depth	Clay %	Silt %	Sand %	(Soil Texture)
9	90-120	30	37.1	32.9	Clay loam
9	120-150	23.7	33.9	42.4	Clay loam
9	150-180	20.6	33.9	45.5	Clay loam
10	0 - 30	20.6	37	42.4	Clay loam
10	30 - 60	23.7	46.4	29.9	Clay loam
10	60 - 90	35.2	33.8	31	Clay
10	90-120	22.4	21.3	56.3	Sandy clay loam
10	120-150	33.5	28.3	37.2	Clay loam
10	150-180	31.9	45.1	23	Clay loam
11	0 - 30	31.9	37.1	31	Clay loam
11	30 - 60	41.5	26	32.5	Clay
11	60 - 90	38.3	38.7	13	Clay
11	90-120	35.2	33.8	31	Clay
11	120-150	35.2	30.8	34	Clay
11	150-180	31.9	24.3	43.8	Clay loam
12	0 - 30	31.9	34.1	34	Clay loam
12	30 - 60	35.2	26	28.8	Clay
12	60 - 90	31.9	21.2	46.9	Clay loam
12	90-120	31.9	27.9	40.2	Clay loam
12	120-150	32.2	30.6	37.2	Clay loam
12	150-180	25.9	29	45.1	Clay loam
13	0 - 30	29.1	30.7	40.2	Clay loam
13	30 - 60	33.8	32.2	34	Clay loam
13	60 - 90	32.2	36.8	31	Clay loam
13	90-120	24.3	35.7	50	Clay loam
13	120-150	25.9	33.9	40.2	Clay loam
13	150-180	22.4	30.7	46.9	Clay loam

Appendix 2

pF Curve Developed at the Field Site.

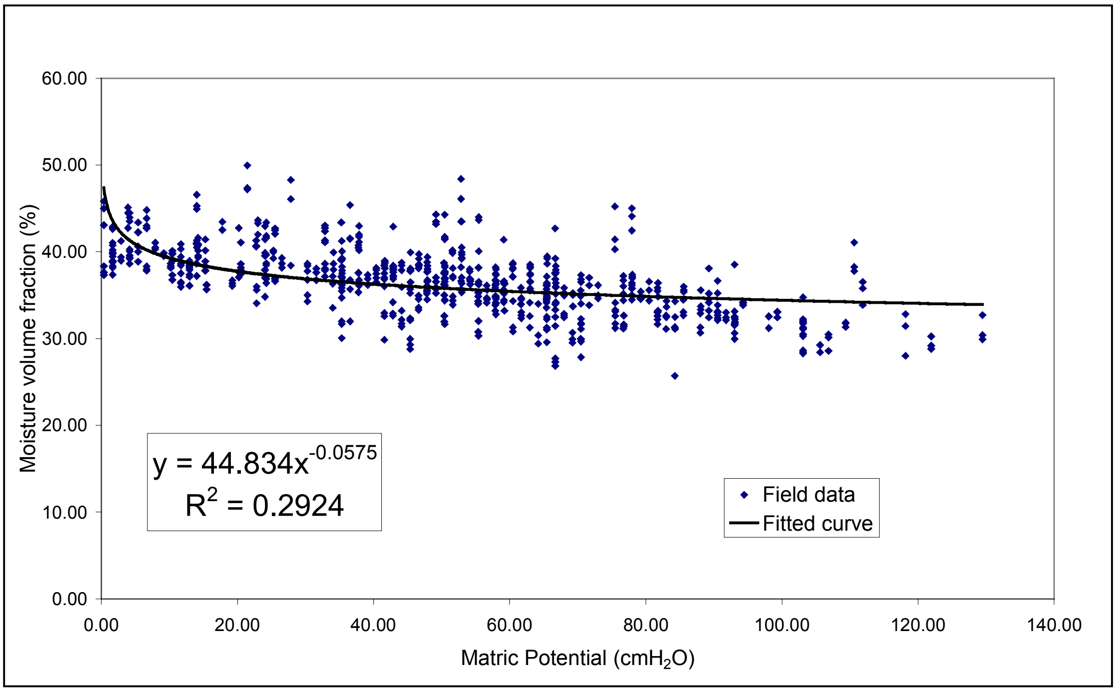
Appendix 2 pF Curve Developed at the Field Site.

Soil samples were collected from a range of positions and depths over the two crop seasons at the field site, and the matric potential recorded at the same time from the tensiometers closest to the soil sampling point. The gravimetric moisture content of the samples was determined in the laboratory, and converted to volumetric moisture content by multiplying by the soil bulk density (determined as $1.6g/cm^3$). This enabled a soil moisture release curve (or pF curve) to be developed for the field site soil. This is shown in the figure below together with the fitted curve.

This curve was used to convert daily matric potential (from the tensiometers) data to moisture content data for use in the water balance. It was also used to estimate values for the soil parameters required by the WaSim simulation model.

These parameters with adopted values were:

Saturation moisture content (vol)	48%
Field capacity moisture content (vol)	33%
Permanent wilting point moisture content (vol)	26%



Appendix 3

Water Balance for the Maize Season

Appendix 3 Water Balance for the Maize Season.

Tables B and C show the daily water balance for the conventional and controlled drainage plots during the maize season.

All parameters in the water balance were monitored on a daily basis, except the lateral seepage which was estimated from the equation below on a daily basis:

$R + I - ET_c - D + LS = \Delta S$

ie

$R + I + LS = D + ET_c + \Delta S$

R = rainfall (mm)
I = irrigation (mm)
L = lateral seepage (mm)
ΔS = change in soil moisture down to 1.4m depth (mm)
ET_c = crop evapotranspiration (mm)
D = drainflow (mm)
Surface runoff was observed to be negligible.

Table D shows the seasonal water balance.

Table D Seasonal Water Balance Table for Maize

	Rain	Irrigation	Lateral seepage**	=	Drainflow	ET_{crop}	Change in soil moisture*
Maize-Conventional	0	871	+172		287	569	53
Maize-Controlled Drainage	0	869	-118		46	569	2

*positive value indicates increase in moisture content over the season.
**positive value indicates water enters plot, negative value indicates water leaves plot.

For the maize season the balance was calculated daily from 10/6/99 to 9/10/99. The total profile moisture contents at start and end are given below:

Table E Total profile moisture contents at start and end of the maize season.

	Moisture content at start	Moisture content at end
Maize – Conventional	517mm	570mm
Maize – Controlled	539mm	541mm

Table B Daily Water Balance for the Maize Season Conventional Plot

Date	Irrigation (mm)	Et_{crop} (mm)	Drainage (mm)	Moisture content mm/1.4m depth	Change in storage (mm)	Lateral Seepage (mm)
10/06/99	82.5	1.98	25.01	516.99		14.40
11/06/99	0	2.35	5.78	586.91	69.92	-29.24
12/06/99	0	2.40	3.88	549.54	-37.37	1.36
13/06/99	0	2.69	1.91	544.61	-4.93	2.85
14/06/99	0	2.43	2.65	542.86	-1.75	4.60
15/06/99	0	2.25	1.52	542.38	-0.48	3.91
16/06/99	0	2.22	1.19	542.51	0.14	0.55
17/06/99	0	2.58	1.15	539.65	-2.86	2.64
18/06/99	0	2.82	0.72	538.57	-1.08	3.36
19/06/99	57.8	2.24	6.53	538.39	-0.18	-31.63
20/06/99	0	2.32	2.44	555.79	17.40	-5.86
21/06/99	0	2.48	1.11	545.17	-10.61	-0.95
22/06/99	0	3.12	0.68	540.63	-4.54	1.78
23/06/99	0	2.63	0.56	538.62	-2.01	3.52
24/06/99	0	1.89	0.41	538.95	0.33	1.24
25/06/99	0	2.01	0.32	537.89	-1.06	1.58
26/06/99	0	2.36	0.24	537.13	-0.75	1.39
27/06/99	0	2.05	0.15	535.93	-1.21	2.46
28/06/99	0	2.30	0.14	536.18	0.25	-15.01
29/06/99	0	1.95	0.14	518.73	-17.45	5.47
30/06/99	82	1.87	9.28	522.11	3.38	-28.98
01/07/99	0	1.87	15.05	563.98	41.87	11.95
02/07/99	0	1.76	10.29	559.02	-4.96	11.58
03/07/99	0	1.91	9.79	558.54	-0.47	6.94
04/07/99	0	1.92	8.63	553.79	-4.76	9.56
05/07/99	0	1.90	6.21	552.80	-0.99	4.67
06/07/99	0	1.77	0.23	549.35	-3.44	-0.31
07/07/99	0	1.92	2.59	547.04	-2.31	2.04
08/07/99	0	2.14	1.54	544.57	-2.47	2.23
09/07/99	0	2.75	1.05	543.11	-1.46	1.63
10/07/99	0	2.85	0.67	540.94	-2.18	1.14
11/07/99	0	2.84	0.55	538.56	-2.38	1.60
12/07/99	0	3.14	0.38	536.76	-1.79	2.26
13/07/99	0	3.44	0.31	535.50	-1.26	1.59
14/07/99	0	3.29	0.24	533.35	-2.16	1.51
15/07/99	0	3.57	0.09	531.32	-2.02	-8.86
16/07/99	0	3.92	1.53	518.80	-12.53	-5.07
17/07/99	0	3.90	0.00	508.27	-10.52	-1.72
18/07/99	0	4.23	1.69	502.65	-5.63	2.00
19/07/99	68.7	4.26	3.22	498.73	-3.92	-34.20
20/07/99	0	4.21	4.87	525.75	27.02	48.62
21/07/99	0	4.50	7.29	565.29	39.54	5.75
22/07/99	0	5.20	5.74	559.24	-6.04	11.53
23/07/99	0	4.58	4.15	559.84	0.60	3.50
24/07/99	0	4.51	1.53	554.61	-5.23	2.96
25/07/99	0	4.59	0.61	551.54	-3.08	2.28
26/07/99	0	5.10	0.40	548.61	-2.92	3.40
27/07/99	0	5.66	0.27	546.52	-2.10	2.58
28/07/99	0	5.44	0.19	543.16	-3.35	-6.96
29/07/99	0	5.13	0.00	530.57	-12.59	-4.43
30/07/99	0	5.27	0.00	521.00	-9.57	-1.24

Date	Irrigation (mm)	Et_{crop} (mm)	Drainage (mm)	Moisture content mm/1.4m depth	Change in storage (mm)	Lateral Seepage (mm)
31/07/99	0	5.37	0.00	514.50	-6.50	-1.26
01/08/99	0	5.09	0.00	507.87	-6.63	6.43
02/08/99	0	5.10	0.00	509.21	1.34	1.81
03/08/99	0	5.19	0.00	505.92	-3.29	-5.32
04/08/99	0	5.62	0.00	495.41	-10.51	4.78
05/08/99	0	5.53	0.00	494.57	-0.84	2.98
06/08/99	0	6.10	0.00	492.02	-2.55	6.26
07/08/99	0	5.54	6.24	492.18	0.16	10.60
08/08/99	112.8	6.42	1.17	491.00	-1.18	-31.19
09/08/99	0	6.78	0.28	565.02	74.02	6.15
10/08/99	0	6.88	0.23	564.11	-0.91	4.32
11/08/99	0	7.33	11.36	561.33	-2.78	22.59
12/08/99	0	7.25	0.00	565.22	3.89	-2.97
13/08/99	0	7.12	2.70	555.00	-10.22	-1.19
14/08/99	0	7.83	1.14	543.99	-11.01	4.61
15/08/99	0	7.85	6.87	539.62	-4.37	17.22
16/08/99	0	7.11	1.68	542.12	2.50	7.17
17/08/99	0	6.81	0.55	540.49	-1.63	3.43
18/08/99	0	7.41	0.39	536.56	-3.94	4.69
19/08/99	0	7.61	0.00	533.45	-3.11	-5.84
20/08/99	0	7.66	0.05	520.00	-13.45	-1.99
21/08/99	0	7.62	0.00	510.30	-9.70	2.40
22/08/99	0	7.78	0.00	505.09	-5.21	-0.54
23/08/99	0	7.58	0.00	496.77	-8.32	6.20
24/08/99	0	7.62	2.69	495.40	-1.37	7.20
25/08/99	105.2	7.31	5.50	492.29	-3.11	-35.20
26/08/99	0	7.25	0.00	549.47	57.18	3.78
27/08/99	0	7.07	0.63	546.00	-3.47	4.86
28/08/99	0	7.25	0.42	543.16	-2.84	4.13
29/08/99	0	6.78	0.32	539.62	-3.54	6.32
30/08/99	0	6.56	9.23	538.84	-0.78	19.61
31/08/99	0	6.88	3.82	542.65	3.81	10.68
01/09/99	0	5.18	1.93	542.63	-0.02	4.40
02/09/99	0	5.55	0.00	539.93	-2.71	2.63
03/09/99	0	6.17	0.27	537.00	-2.93	5.27
04/09/99	0	5.85	0.26	535.83	-1.17	4.31
05/09/99	0	5.76	0.14	534.02	-1.81	4.40
06/09/99	0	6.83	0.00	532.52	-1.50	-10.98
07/09/99	0	6.52	0.00	514.72	-17.80	1.59
08/09/99	0	6.16	0.00	509.79	-4.93	-0.61
09/09/99	0	5.69	0.00	503.02	-6.77	3.66
10/09/99	0	5.20	11.32	501.00	-2.02	15.74
11/09/99	113.9	5.67	11.00	500.23	-0.77	26.16
12/09/99	0	5.63	3.26	623.61	123.38	-26.26
13/09/99	0	5.46	2.67	588.47	-35.14	-28.57
14/09/99	0	6.37	2.49	551.76	-36.70	8.29
15/09/99	0	6.42	1.51	551.20	-0.56	7.30
16/09/99	0	5.79	0.00	550.57	-0.63	4.22
17/09/99	0	5.79	0.63	549.00	-1.57	5.42
18/09/99	0	5.84	0.54	548.00	-1.00	6.41
19/09/99	0	7.19	0.28	548.03	0.03	19.61
20/09/99	0	6.13	0.60	560.17	12.14	-6.50
21/09/99	0	5.64	0.43	546.93	-13.23	5.68
22/09/99	0	5.26	0.38	546.53	-0.40	4.76

Date	Irrigation (mm)	Et_{crop} (mm)	Drainage (mm)	Moisture content mm/1.4m depth	Change in storage (mm)	Lateral Seepage (mm)
23/09/99	0	5.06	0.00	545.65	-0.88	3.41
24/09/99	0	5.05	0.24	544.00	-1.65	5.11
25/09/99	0	4.60	0.00	543.81	-0.19	0.58
26/09/99	0	4.66	15.58	539.79	-4.02	23.98
27/09/99	114.3	4.88	8.23	543.53	3.74	-20.59
28/09/99	0	4.50	3.77	624.13	80.60	-44.49
29/09/99	0	4.44	4.10	571.37	-52.76	49.08
30/09/99	0	4.40	0.00	611.92	40.54	13.03
01/10/99		3.39	7.11	620.55	8.63	-32.20
02/10/99		3.76	0.00	577.84	-42.71	2.96
03/10/99		3.05	0.00	577.04	-0.80	2.31
04/10/99		3.17	0.00	576.31	-0.73	1.44
05/10/99		3.09	0.00	574.58	-1.73	1.07
06/10/99		2.85	0.00	572.56	-2.02	2.07
07/10/99		2.77	0.00	571.79	-0.77	1.94
08/10/99		2.72	0.00	570.96	-0.83	1.99
09/10/99		2.85	0.00	570.23	-0.73	2.85
10/10/99				569.57		
Seasonal total	737.20	569.18	286.94		53.24	172.16

Table C Daily Water Balance for the Maize Season Controlled Drainage Plot

Date	Irrigation (mm)	Et_{crop} (mm)	Drainage (mm)	Moisture content mm/1.4m depth	Change in storage (mm)	Lateral Seepage (mm)
10/06/99	81.5	1.98	9.92	539.38		20.08
11/06/99	0	2.35	0.00	629.07	89.69	-68.81
12/06/99	0	2.40	0.00	557.90	-71.17	-6.67
13/06/99	0	2.69	0.00	548.83	-9.07	-0.78
14/06/99	0	2.43	0.00	545.37	-3.47	12.61
15/06/99	0	2.25	0.00	555.54	10.18	1.94
16/06/99	0	2.22	0.00	555.23	-0.31	-3.79
17/06/99	0	2.58	0.00	549.22	-6.01	0.90
18/06/99	0	2.82	3.01	547.54	-1.68	1.85
19/06/99	58	2.24	0.00	543.56	-3.98	-7.16
20/06/99	0	2.32	0.00	592.17	48.60	-34.16
21/06/99	0	2.48	0.00	555.69	-36.47	-5.15
22/06/99	0	3.12	0.00	548.06	-7.63	-0.88
23/06/99	0	2.63	0.00	544.06	-4.00	57.67
24/06/99	0	1.89	0.00	599.09	55.04	1.68
25/06/99	0	2.01	0.00	598.89	-0.21	1.58
26/06/99	0	2.36	0.00	598.45	-0.43	2.06
27/06/99	0	2.05	0.00	598.15	-0.30	-60.64
28/06/99	0	2.30	0.00	535.46	-62.69	3.03
29/06/99	0	1.95	0.93	536.20	0.74	3.22
30/06/99	81.6	1.87	3.24	536.54	0.34	-15.30
01/07/99	0	1.87	0.00	597.73	61.19	-5.37
02/07/99	0	1.76	0.00	590.48	-7.24	2.21
03/07/99	0	1.91	6.34	590.92	0.44	8.56
04/07/99	0	1.92	3.45	591.23	0.30	4.46
05/07/99	0	1.90	0.64	590.32	-0.91	-1.25
06/07/99	0	1.77	0.00	586.54	-3.79	-1.00
07/07/99	0	1.92	0.00	583.77	-2.77	-15.10
08/07/99	0	2.14	0.00	566.74	-17.03	-10.34
09/07/99	0	2.75	0.00	554.26	-12.48	-2.22
10/07/99	0	2.85	0.00	549.29	-4.97	-1.19
11/07/99	0	2.84	0.00	545.24	-4.04	-0.10
12/07/99	0	3.14	0.00	542.31	-2.94	3.15
13/07/99	0	3.44	0.00	542.32	0.01	-1.46
14/07/99	0	3.29	0.00	537.42	-4.90	0.92
15/07/99	0	3.57	0.00	535.04	-2.37	0.73
16/07/99	0	3.92	0.00	532.20	-2.85	5.61
17/07/99	0	3.90	0.00	533.88	1.68	-12.50
18/07/99	0	4.23	0.85	517.47	-16.41	-2.46
19/07/99	65.3	4.26	1.11	509.93	-7.54	-26.10
20/07/99	0	4.21	2.94	543.77	33.84	61.93
21/07/99	0	4.50	0.00	598.55	54.78	1.66
22/07/99	0	5.20	0.00	595.72	-2.84	0.53
23/07/99	0	4.58	0.00	591.04	-4.68	2.70
24/07/99	0	4.51	0.00	589.16	-1.88	2.92
25/07/99	0	4.59	0.00	587.57	-1.59	1.79
26/07/99	0	5.10	0.00	584.77	-2.80	3.59
27/07/99	0	5.66	0.00	583.26	-1.51	-12.50
28/07/99	0	5.44	0.00	565.10	-18.16	-0.28
29/07/99	0	5.13	0.00	559.38	-5.72	-4.24
30/07/99	0	5.27	0.00	550.00	-9.38	3.72

Date	Irrigation (mm)	Et_{crop} (mm)	Drainage (mm)	Moisture content mm/1.4m depth	Change in storage (mm)	Lateral Seepage (mm)
31/07/99	0	5.37	0.00	548.46	-1.54	-17.40
01/08/99	0	5.09	0.00	525.69	-22.77	-2.16
02/08/99	0	5.10	0.00	518.44	-7.25	1.47
03/08/99	0	5.19	0.00	514.80	-3.64	2.37
04/08/99	0	5.62	0.00	511.98	-2.82	3.64
05/08/99	0	5.53	0.00	509.99	-1.98	2.54
06/08/99	0	6.10	0.00	507.00	-2.99	5.00
07/08/99	0	5.54	0.00	505.91	-1.09	2.63
08/08/99	112.6	6.42	2.12	503.00	-2.91	-15.67
09/08/99	0	6.78	0.00	591.40	88.40	-22.05
10/08/99	0	6.88	0.00	562.57	-28.83	4.26
11/08/99	0	7.33	0.00	559.95	-2.61	29.29
12/08/99	0	7.25	0.00	581.91	21.96	7.34
13/08/99	0	7.12	0.00	582.00	0.09	8.95
14/08/99	0	7.83	0.00	583.83	1.83	-21.73
15/08/99	0	7.85	0.00	554.27	-29.56	33.75
16/08/99	0	7.11	0.00	580.17	25.90	-3.09
17/08/99	0	6.81	0.00	569.96	-10.21	-13.79
18/08/99	0	7.41	0.00	549.35	-20.61	1.90
19/08/99	0	7.61	0.00	543.85	-5.50	3.76
20/08/99	0	7.66	0.00	540.00	-3.85	4.80
21/08/99	0	7.62	0.00	537.14	-2.86	4.94
22/08/99	0	7.78	0.00	534.47	-2.68	-5.84
23/08/99	0	7.58	0.00	520.85	-13.62	-2.71
24/08/99	0	7.62	2.16	510.57	-10.28	1.07
25/08/99	111.3	7.31	0.00	501.86	-8.71	-15.58
26/08/99	0	7.25	0.00	590.26	88.41	3.99
27/08/99	0	7.07	0.00	587.00	-3.26	3.51
28/08/99	0	7.25	0.00	583.44	-3.56	4.59
29/08/99	0	6.78	0.00	580.78	-2.65	5.80
30/08/99	0	6.56	0.00	579.81	-0.98	7.99
31/08/99	0	6.88	0.00	581.23	1.43	8.05
01/09/99	0	5.18	0.00	582.40	1.17	2.97
02/09/99	0	5.55	0.00	580.19	-2.21	3.36
03/09/99	0	6.17	0.00	578.00	-2.19	4.43
04/09/99	0	5.85	0.00	576.26	-1.74	4.23
05/09/99	0	5.76	0.00	574.65	-1.62	9.50
06/09/99	0	6.83	0.00	578.39	3.75	-15.77
07/09/99	0	6.52	0.00	555.80	-22.59	-3.18
08/09/99	0	6.16	0.00	546.10	-9.70	29.16
09/09/99	0	5.69	0.00	569.10	23.00	3.59
10/09/99	0	5.20	0.00	567.00	-2.10	3.38
11/09/99	115.2	5.67	0.00	565.19	-1.81	-37.04
12/09/99	0	5.63	0.00	637.68	72.49	-46.85
13/09/99	0	5.46	0.00	585.19	-52.48	3.63
14/09/99	0	6.37	0.00	583.36	-1.83	4.40
15/09/99	0	6.42	0.00	581.40	-1.96	5.07
16/09/99	0	5.79	0.00	580.04	-1.35	3.74
17/09/99	0	5.79	0.00	578.00	-2.04	4.99
18/09/99	0	5.84	0.00	577.19	-0.81	28.67
19/09/99	0	7.19	0.00	600.03	22.83	-15.44
20/09/99	0	6.13	0.00	577.39	-22.63	-28.59
21/09/99	0	5.64	0.00	542.67	-34.72	3.15
22/09/99	0	5.26	0.00	540.18	-2.49	3.31

Date	Irrigation (mm)	Et_{crop} (mm)	Drainage (mm)	Moisture content mm/1.4m depth	Change in storage (mm)	Lateral Seepage (mm)
23/09/99	0	5.06	0.00	538.23	-1.96	2.83
24/09/99	0	5.05	0.00	536.00	-2.23	2.98
25/09/99	0	4.60	0.00	533.92	-2.08	3.51
26/09/99	0	4.66	9.24	532.83	-1.09	12.61
27/09/99	109.1	4.88	0.00	531.54	-1.29	-38.81
28/09/99	0	4.50	0.00	596.95	65.41	-5.36
29/09/99	0	4.44	0.00	587.09	-9.85	3.67
30/09/99		4.40	0.00	586.33	-0.77	2.81
01/10/99		3.39	0.00	584.73	-1.59	3.87
02/10/99		3.76	0.00	585.22	0.48	1.64
03/10/99		3.05	0.00	583.10	-2.11	-16.52
04/10/99		3.17	0.00	563.54	-19.57	-14.35
05/10/99		3.09	0.00	546.01	-17.52	1.66
06/10/99		2.85	0.00	544.58	-1.43	2.13
07/10/99		2.77	0.00	543.86	-0.72	1.18
08/10/99		2.72	0.00	542.27	-1.59	2.29
09/10/99		2.85	0.00	541.84	-0.43	2.85
10/10/99				540.88		
Total Season	734.60	569.18	45.95		2.46	-117.02

Appendix 4

Recorded rainfall for the wheat season at the field site

Appendix 4 Recorded rainfall for the wheat season at the field site.

Table F presents the rainfall data recorded during the wheat season (20/11/99 - 5/5/00) at the field site. Note: no rainfall was recorded during the maize season.

Table F Rainfall data during the wheat season at the field site.

Date	Rainfall (mm)
23/11/99	0.4
09/12/99	0.4
15/12/99	0.4
17/12/99	0.2
20/12/99	0.2
22/12/99	0.2
25/12/99	0.2
26/12/99	0.4
03/01/00	5
04/01/00	8.8
05/01/00	18.8
06/01/00	1.4
07/01/00	5.8
08/01/00	1.8
09/01/00	4.2
11/01/00	1.2
12/01/00	0.6
15/01/00	0.2
16/01/00	1.2
20/01/00	3.8
21/01/00	1.6
22/01/00	0.2
27/01/00	28.1
28/01/00	3.1
05/02/00	0.2
08/02/00	0.2
09/02/00	0.2
13/02/00	8.4
16/02/00	0.2
22/02/00	1
23/02/00	4.4
27/02/00	0.2
02/03/00	7.6
21/03/00	0.6
22/03/00	3.4
23/03/00	0.4
24/03/00	1
04/04/00	0.2
Total	116.2

Appendix 5

Water Balance for the Wheat Season

Appendix 5 Water Balance for the Wheat Season.

The tables G and H show the daily water balance for the conventional and controlled drainage plots during the wheat season.

For the wheat season there was some missing tensiometer (and hence moisture content) data from the 20th March onwards. The end of season profile moisture content was thus estimated from the depth of the watertable. For example on the conventional plot the watertable depth on 4/5/00 was 0.98m. The watertable was also this depth on the 25/12/99 so the moisture content from that date was used as the end of season moisture content.

All parameters in the water balance were monitored on a daily basis, except the lateral seepage which was estimated from the equation below on a daily basis:

$R + I - ET_c - D + LS = \Delta S$

ie

$R + I + LS = D + ET_c + \Delta S$

R = rainfall (mm)
I = irrigation (mm)
L = lateral seepage (mm)
ΔS = change in soil moisture down to 1.4m depth (mm)
ET_c = crop evapotranspiration (mm)
D = drainflow (mm)
Surface runoff was observed to be negligible.

Table I shows the seasonal water balance.

Table I Seasonal Water Balance Table for Wheat

	Rain	Irrigation	Lateral seepage**	=	Drainflow	ET_{crop}	Change in soil moisture*
Wheat – Conventional	116	515	+479		753	358	-1
Wheat – Controlled Drainage	116	470	+77		290	358	15

*positive value indicates increase in moisture content over the season.
**positive value indicates water enters plot, negative value indicates water leaves plot.

For the wheat season the balance was computed from 19/11/99 to 4/5/00.

The total profile moisture contents at start and end are given below:

Table J Total profile moisture contents at start and end of wheat season.

	Moisture content at start	Moisture content at end
Wheat - Conventional	542mm	541mm
Wheat – Controlled	555mm	570mm

Table G Daily Water Balance for the Wheat Season Conventional Plot

Date	Rainfall (mm)	Irrigation (mm)	Et_{crop} (mm)	Drainage (mm)	Moisture content mm/1.4m depth	Change in storage (mm)	Lateral Seepage (mm)
19/11/99	0	0		0.98	542.15		1.22
20/11/99	0	75	0.94	4.46	542.38	0.24	-26.07
21/11/99	0	0	1.12	10.71	585.92	43.54	13.52
22/11/99	0	0	0.96	17.59	587.61	1.69	-12.80
23/11/99	0.4	0	0.94	11.37	556.26	-31.35	9.17
24/11/99	0	0	0.93	9.90	553.52	-2.74	7.74
25/11/99	0	0	1.11	9.53	550.43	-3.09	9.88
26/11/99	0	0	1.08	10.24	549.68	-0.75	10.54
27/11/99	0	0	1.09	7.95	548.90	-0.78	6.65
28/11/99	0	0	0.73	6.25	546.50	-2.39	6.10
29/11/99	0	0	0.76	5.18	545.63	-0.88	4.86
30/11/99	0	0	0.74	4.26	544.55	-1.08	3.86
01/12/99	0	0	0.76	3.31	543.41	-1.14	3.24
02/12/99	0	0	0.65	2.65	542.58	-0.83	6.70
03/12/99	0	0	0.57	2.38	545.97	3.40	-1.66
04/12/99	0	0	0.63	2.23	541.36	-4.62	3.57
05/12/99	0	0	0.73	2.62	542.07	0.71	2.68
06/12/99	0	0	0.76	1.78	541.40	-0.67	16.77
07/12/99	0	0	0.69	2.64	555.63	14.22	-3.31
08/12/99	0	85.8	0.58	7.54	548.99	-6.64	-53.00
09/12/99	0.4	0	0.62	18.04	573.67	24.68	2.62
10/12/99	0	0	0.62	9.67	558.03	-15.64	5.37
11/12/99	0	0	0.65	9.13	553.12	-4.92	7.85
12/12/99	0	0	0.65	8.01	551.19	-1.93	7.48
13/12/99	0	0	0.52	7.23	550.00	-1.18	5.76
14/12/99	0	0	0.68	5.49	548.02	-1.99	5.14
15/12/99	0.4	0	0.59	4.34	546.99	-1.03	2.72
16/12/99	0	0	0.57	3.43	545.19	-1.81	3.25
17/12/99	0.2	0	0.60	3.09	544.43	-0.75	3.31
18/12/99	0	0	0.64	2.49	544.26	-0.18	1.99
19/12/99	0	0	0.59	2.32	543.12	-1.14	3.09
20/12/99	0.2	0	0.50	2.15	543.30	0.18	1.98
21/12/99	0	0	0.77	1.84	542.83	-0.47	2.48
22/12/99	0.2	0	0.62	1.59	542.70	-0.13	1.25
23/12/99	0	0	0.87	1.37	541.93	-0.76	1.35
24/12/99	0	0	0.83	1.34	541.05	-0.89	2.15
25/12/99	0.2	0	1.02	1.37	541.02	-0.03	2.71
26/12/99	0.4	64.6	0.95	11.08	541.53	0.51	-28.67
27/12/99	0	0	1.24	10.97	565.84	24.31	29.01
28/12/99	0	0	1.56	12.35	582.64	16.80	5.57
29/12/99	0	0	1.31	11.81	574.32	-8.33	-6.13
30/12/99	0	0	1.23	8.33	555.06	-19.25	6.66
31/12/99	0	0	0.94	6.79	552.17	-2.90	4.40
01/01/00	0	0	1.24	5.05	548.84	-3.33	5.84
02/01/00	0	0	1.24	4.35	548.38	-0.45	4.80
03/01/00	5	0	1.29	3.38	547.60	-0.78	12.54
04/01/00	8.8	0	1.38	3.01	560.47	12.87	-9.82
05/01/00	18.8	0	1.43	8.43	555.07	-5.41	4.41
06/01/00	1.4	0	1.27	5.34	568.42	13.35	0.76
07/01/00	5.8	0	1.01	5.43	563.97	-4.44	-0.73
08/01/00	1.8	0	1.00	8.83	562.61	-1.37	6.26

Date	Rainfall (mm)	Irrigation (mm)	Et_{crop} (mm)	Drainage (mm)	Moisture content mm/1.4m depth	Change in storage (mm)	Lateral Seepage (mm)
09/01/00	4.2	0	1.07	8.21	560.83	-1.77	-0.91
10/01/00	0	0	1.28	7.38	554.84	-5.99	10.13
11/01/00	1.2	0	1.40	5.76	556.31	1.47	4.54
12/01/00	0.6	0	1.58	5.66	554.89	-1.43	35.97
13/01/00	0	39.8	1.60	11.42	584.21	29.32	-28.11
14/01/00	0	0	1.26	10.76	582.87	-1.34	12.09
15/01/00	0.2	0	1.63	9.92	582.94	0.07	11.52
16/01/00	1.2	0	1.25	10.08	583.12	0.18	-5.89
17/01/00	0	0	1.30	9.97	567.09	-16.02	4.14
18/01/00	0	0	2.15	12.05	559.96	-7.13	12.78
19/01/00	0	0	2.34	8.44	558.54	-1.42	5.53
20/01/00	3.8	0	2.20	6.11	553.29	-5.25	2.79
21/01/00	1.6	0	1.52	4.97	551.56	-1.73	2.51
22/01/00	0.2	0	1.69	4.17	549.17	-2.39	9.90
23/01/00		0	2.10	3.21	553.41	4.24	-0.51
24/01/00		0	2.10	2.87	547.59	-5.82	5.53
25/01/00		0	2.10	2.01	548.15	0.56	22.28
26/01/00		0	2.10	1.73	566.33	18.18	2.17
27/01/00	28.1	0	2.10	4.09	564.67	-1.66	-28.86
28/01/00	3.1	0	2.10	7.41	557.72	-6.95	2.24
29/01/00		0	2.10	5.80	553.56	-4.16	5.82
30/01/00		0	2.10	4.29	551.48	-2.08	7.89
31/01/00		0	2.10	3.52	552.98	1.50	4.06
01/02/00		0	2.10	3.56	551.42	-1.56	6.71
02/02/00		0	2.10	3.64	552.47	1.05	4.32
03/02/00		0	2.10	3.83	551.05	-1.42	9.60
04/02/00	0	0	1.77	2.36	554.72	3.67	0.83
05/02/00	0.2	0	2.36	2.14	551.43	-3.30	3.32
06/02/00	0	0	3.21	2.18	550.44	-0.98	7.02
07/02/00	0	0	2.39	2.03	552.07	1.63	2.94
08/02/00	0.2	0	2.07	1.88	550.59	-1.48	5.55
09/02/00	0.2	0	2.06	1.66	552.39	1.80	3.16
10/02/00	0	0	2.39	1.62	552.03	-0.36	4.99
11/02/00	0	0	2.42	1.31	553.01	0.97	3.39
12/02/00	0	0	2.35	1.41	552.67	-0.34	4.58
13/02/00	8.4	0	1.98	1.14	553.49	0.82	-5.74
14/02/00	0	0	2.67	1.11	553.03	-0.46	4.87
15/02/00	0	0	2.50	1.18	554.11	1.08	36.66
16/02/00	0.2	86.7	2.19	4.81	587.09	32.98	-83.26
17/02/00	0	0	2.88	10.78	583.73	-3.36	12.09
18/02/00	0	0	2.94	9.75	582.17	-1.57	11.46
19/02/00	0	0	2.95	6.01	580.93	-1.24	7.17
20/02/00	0	0	2.78	5.24	579.14	-1.79	8.09
21/02/00	0	0	2.60	4.62	579.21	0.07	12.95
22/02/00	1	0	2.55	3.56	584.93	5.73	-5.04
23/02/00	4.4	0	2.76	3.06	574.78	-10.16	13.46
24/02/00	0	0	2.34	2.22	586.83	12.05	-12.01
25/02/00	0	0	2.51	1.94	570.26	-16.57	18.87
26/02/00	0	0	2.62	1.77	584.68	14.42	-2.13
27/02/00	0.2	0	2.38	1.63	578.15	-6.53	8.24
28/02/00	0	0	2.78	1.42	582.59	4.44	-16.54
29/02/00		0	3.15	1.44	561.85	-20.74	28.20
01/03/00	0	0	3.61	1.23	585.45	23.60	-1.79
02/03/00	7.6	0	3.41	0.99	578.82	-6.63	-3.48

Date	Rainfall (mm)	Irrigation (mm)	Et_{crop} (mm)	Drainage (mm)	Moisture content mm/1.4m depth	Change in storage (mm)	Lateral Seepage (mm)
03/03/00	0	0	2.62	0.00	578.55	-0.27	13.03
04/03/00	0	79.6	3.30	7.47	588.96	10.41	-72.28
05/03/00	0	0	3.42	11.67	585.51	-3.45	12.31
06/03/00	0	0	3.26	11.06	582.72	-2.79	14.06
07/03/00	0	0	3.43	8.67	582.46	-0.26	11.39
08/03/00	0	0	3.97	11.07	581.75	-0.71	14.34
09/03/00	0	0	3.58	8.89	581.05	-0.71	11.09
10/03/00	0	0	3.72	6.86	579.67	-1.38	11.06
11/03/00	0	0	3.38	4.92	580.15	0.48	6.79
12/03/00	0	0	3.33	3.95	578.65	-1.51	6.09
13/03/00	0	0	2.50	2.74	577.45	-1.19	3.26
14/03/00	0	0	2.66	2.23	575.47	-1.98	2.75
15/03/00	0	0	2.79	1.55	573.33	-2.14	6.95
16/03/00	0	0	3.30	1.13	575.95	2.62	4.77
17/03/00	0	0	3.35	1.07	576.30	0.35	5.36
18/03/00	0	0	3.40	0.73	577.24	0.94	2.97
19/03/00	0	0	2.81	0.64	576.08	-1.16	
20/03/00	0	0	2.67	0.83			
21/03/00	0.6	83.7	2.55	8.38			
22/03/00	3.4	0	2.76	9.27			
23/03/00	0.4	0	3.50	6.62			
24/03/00	1	0	4.15	5.06			
25/03/00	0	0	3.57	8.01			
26/03/00	0	0	2.95	5.33	542.85		
27/03/00	0	0	2.76	3.72			
28/03/00	0	0	3.17	2.76			
29/03/00		0	3.57	2.70			
30/03/00		0	3.50	3.66			
31/03/00		0	3.43	2.01			
01/04/00	0	0	4.91	1.21			
02/04/00	0	0	5.33	0.81	530.80		
03/04/00	0	0	3.39	0.65			
04/04/00	0.2	0	4.52	0.49	524.32		
05/04/00	0	0	4.32	0.48			
06/04/00	0	0	4.38	0.47			
07/04/00	0	0	2.82	0.42			
08/04/00	0	0	3.73	0.59			
09/04/00	0	0	3.23	3.05			
10/04/00	0	0	2.88	4.14			
11/04/00	0	0	3.09	3.14			
12/04/00	0	0	4.56	1.64			
13/04/00	0	0	5.56	1.35			
14/04/00	0	0	3.46	1.24			
15/04/00	0	0	2.57	0.76			
16/04/00	0	0	2.86	0.67			
17/04/00	0	0	3.16	0.52			
18/04/00	0	0	3.13	0.49			
19/04/00	0	0	2.87	0.33			
20/04/00	0	0	3.02	0.24			
21/04/00	0	0	2.55	0.21			
22/04/00	0	0	2.63	0.28			
23/04/00	0	0	2.13	0.29			
24/04/00	0	0	1.93	0.57			
25/04/00	0	0	1.98	2.56			

Date	Rainfall (mm)	Irrigation (mm)	Et_{crop} (mm)	Drainage (mm)	Moisture content mm/1.4m depth	Change in storage (mm)	Lateral Seepage (mm)
26/04/00	0	0	1.69	7.38			
27/04/00	0	0	1.66	7.53			
28/04/00	0	0	1.53	5.37			
29/04/00	0	0	1.59	4.13			
30/04/00	0	0	1.67	3.78			
01/05/00	0	0	1.74	2.75			
02/05/00	0	0	1.50				
03/05/00	0	0	1.63				
04/05/00	0	0	2.01		541.00		
05/05/00							
Total Season	116.20	515.20	357.74	753.48			

Note: missing moisture content data from 20/3/00 onwards. End of season moisture content estimated using watertable depth on 4/5/00 (0.98m) and using moisture content from 25/12/99 when watertable depth was the same.

Table H Daily Water Balance for the Wheat Season Controlled Drainage Plot

Date	Rainfall (mm)	Irrigation (mm)	Et_{crop} (mm)	Drainage (mm)	Moisture content mm/1.4m depth	Change in storage (mm)	Lateral Seepage (mm)
19/11/99	0	0		0.00	554.84		0.17
20/11/99	0	75	0.94	0.00	555.01	0.17	-49.74
21/11/99	0	0	1.12	21.45	579.33	24.33	59.00
22/11/99	0	0	0.96	7.68	615.77	36.43	-13.71
23/11/99	0.4	0	0.94	8.91	593.42	-22.35	6.36
24/11/99	0	0	0.93	3.86	590.34	-3.09	3.18
25/11/99	0	0	1.11	5.03	588.72	-1.61	3.56
26/11/99	0	0	1.08	4.37	586.14	-2.58	5.51
27/11/99	0	0	1.09	0.83	586.19	0.05	-0.38
28/11/99	0	0	0.73	0.00	583.89	-2.31	0.19
29/11/99	0	0	0.76	0.00	583.35	-0.54	0.18
30/11/99	0	0	0.74	0.00	582.77	-0.58	-0.33
01/12/99	0	0	0.76	0.00	581.70	-1.07	0.32
02/12/99	0	0	0.65	0.00	581.26	-0.44	0.53
03/12/99	0	0	0.57	0.00	581.14	-0.12	0.03
04/12/99	0	0	0.63	0.00	580.59	-0.55	0.33
05/12/99	0	0	0.73	0.00	580.29	-0.30	0.86
06/12/99	0	0	0.76	0.00	580.41	0.12	0.31
07/12/99	0	0	0.69	0.00	579.96	-0.45	1.20
08/12/99	0	78.4	0.58	7.18	580.48	0.52	-7.12
09/12/99	0.4	0	0.62	17.53	644.00	63.52	-27.39
10/12/99	0	0	0.62	3.08	598.85	-45.15	-4.55
11/12/99	0	0	0.65	0.25	590.60	-8.25	-1.78
12/12/99	0	0	0.65	0.00	587.93	-2.68	-0.75
13/12/99	0	0	0.52	0.00	586.52	-1.41	-0.87
14/12/99	0	0	0.68	0.00	585.14	-1.38	-15.98
15/12/99	0.4	0	0.59	0.00	568.48	-16.66	5.15
16/12/99	0	0	0.57	0.00	573.45	4.97	-9.20
17/12/99	0.2	0	0.60	0.00	563.68	-9.77	-14.38
18/12/99	0	0	0.64	0.00	548.90	-14.77	8.67
19/12/99	0	0	0.59	0.00	556.94	8.04	1.24
20/12/99	0.2	0	0.50	0.00	557.59	0.65	-1.20
21/12/99	0	0	0.77	0.00	556.09	-1.50	0.01
22/12/99	0.2	0	0.62	0.00	555.33	-0.75	2.04
23/12/99	0	0	0.87	0.00	556.96	1.63	0.54
24/12/99	0	0	0.83	0.00	556.63	-0.33	0.39
25/12/99	0.2	0	1.02	0.00	556.19	-0.45	1.40
26/12/99	0.4	58.5	0.95	25.15	556.77	0.58	24.33
27/12/99	0	0	1.24	10.69	613.90	57.13	2.86
28/12/99	0	0	1.56	4.90	604.83	-9.07	-4.47
29/12/99	0	0	1.31	1.59	593.91	-10.92	-2.65
30/12/99	0	0	1.23	0.00	588.35	-5.55	-0.94
31/12/99	0	0	0.94	0.00	586.18	-2.17	-0.11
01/01/00	0	0	1.24	0.00	585.13	-1.05	0.49
02/01/00	0	0	1.24	0.00	584.38	-0.75	-0.22
03/01/00	5	0	1.29	0.00	582.93	-1.45	0.92
04/01/00	8.8	0	1.38	0.00	587.55	4.63	-4.48
05/01/00	18.8	0	1.43	0.00	590.49	2.94	-9.63
06/01/00	1.4	0	1.27	0.00	598.24	7.74	-1.37
07/01/00	5.8	0	1.01	0.00	597.00	-1.23	-18.24
08/01/00	1.8	0	1.00	0.33	583.56	-13.45	9.47

Date	Rainfall (mm)	Irrigation (mm)	Et_{crop} (mm)	Drainage (mm)	Moisture content mm/1.4m depth	Change in storage (mm)	Lateral Seepage (mm)
09/01/00	4.2	0	1.07	0.00	593.50	9.95	-8.19
10/01/00	0	0	1.28	0.00	588.45	-5.06	2.85
11/01/00	1.2	0	1.40	0.00	590.01	1.56	-1.48
12/01/00	0.6	0	1.58	0.00	588.33	-1.68	16.17
13/01/00	0	35.4	1.60	20.97	603.52	15.19	-20.80
14/01/00	0	0	1.26	10.03	595.55	-7.97	10.98
15/01/00	0.2	0	1.63	8.47	595.24	-0.31	9.69
16/01/00	1.2	0	1.25	12.34	595.03	-0.21	9.69
17/01/00	0	0	1.30	11.36	592.33	-2.70	7.68
18/01/00	0	0	2.15	5.53	587.34	-4.99	4.33
19/01/00	0	0	2.34	1.23	583.98	-3.36	3.38
20/01/00	3.8	0	2.20	0.00	583.78	-0.20	-1.70
21/01/00	1.6	0	1.52	0.00	583.68	-0.11	3.98
22/01/00	0.2	0	1.69	0.00	587.74	4.06	-14.49
23/01/00		0	2.10	0.00	571.76	-15.98	-8.00
24/01/00		0	2.10	0.00	561.66	-10.10	1.04
25/01/00		0	2.10	0.00	560.60	-1.06	34.91
26/01/00		0	2.10	0.00	593.41	32.81	-1.72
27/01/00	28.1	0	2.10	0.38	589.59	-3.82	-28.56
28/01/00	3.1	0	2.10	0.30	586.65	-2.94	-3.15
29/01/00		0	2.10	0.17	584.20	-2.45	1.04
30/01/00		0	2.10	0.00	582.97	-1.23	1.47
31/01/00		0	2.10	0.00	582.34	-0.63	2.12
01/02/00		0	2.10	0.21	582.35	0.02	1.65
02/02/00		0	2.10	0.00	581.69	-0.66	0.97
03/02/00		0	2.10	0.00	580.56	-1.13	-8.19
04/02/00	0	0	1.77	0.00	570.28	-10.29	-3.66
05/02/00	0.2	0	2.36	0.00	564.85	-5.42	-1.85
06/02/00	0	0	3.21	0.00	560.84	-4.01	3.03
07/02/00	0	0	2.39	0.00	560.66	-0.18	1.69
08/02/00	0.2	0	2.07	0.00	559.96	-0.70	-1.44
09/02/00	0.2	0	2.06	0.00	556.65	-3.31	0.31
10/02/00	0	0	2.39	0.00	555.10	-1.55	2.30
11/02/00	0	0	2.42	0.00	555.00	-0.10	-0.12
12/02/00	0	0	2.35	0.00	552.46	-2.54	1.32
13/02/00	8.4	0	1.98	0.00	551.44	-1.03	-5.15
14/02/00	0	0	2.67	0.00	552.71	1.28	6.48
15/02/00	0	0	2.50	0.00	556.52	3.81	64.50
16/02/00	0.2	77	2.19	17.28	618.52	62.00	-80.35
17/02/00	0	0	2.88	3.91	595.90	-22.62	0.76
18/02/00	0	0	2.94	3.62	589.88	-6.02	4.31
19/02/00	0	0	2.95	2.00	587.64	-2.24	2.06
20/02/00	0	0	2.78	0.00	584.75	-2.88	0.70
21/02/00	0	0	2.60	0.00	582.67	-2.08	3.01
22/02/00	1	0	2.55	0.00	583.08	0.41	1.21
23/02/00	4.4	0	2.76	0.00	582.74	-0.34	-2.35
24/02/00	0	0	2.34	0.00	582.03	-0.71	-8.79
25/02/00	0	0	2.51	0.00	570.89	-11.13	1.50
26/02/00	0	0	2.62	0.00	569.88	-1.01	-8.01
27/02/00	0.2	0	2.38	0.00	559.26	-10.62	19.23
28/02/00	0	0	2.78	0.00	576.30	17.05	-12.07
29/02/00		0	3.15	0.00	561.45	-14.85	-2.51
01/03/00	0	0	3.61	0.00	555.79	-5.66	3.76
02/03/00	7.6	0	3.41	0.00	555.94	0.15	-1.71

Date	Rainfall (mm)	Irrigation (mm)	Et_{crop} (mm)	Drainage (mm)	Moisture content mm/1.4m depth	Change in storage (mm)	Lateral Seepage (mm)
03/03/00	0	0	2.62	0.00	558.43	2.49	61.45
04/03/00	0	70.8	3.30	12.33	617.26	58.83	-70.91
05/03/00	0	0	3.42	16.50	601.51	-15.75	11.21
06/03/00	0	0	3.26	5.28	592.80	-8.71	6.49
07/03/00	0	0	3.43	1.71	590.75	-2.05	-0.11
08/03/00	0	0	3.97	2.39	585.50	-5.25	7.03
09/03/00	0	0	3.58	0.70	586.17	0.67	2.04
10/03/00	0	0	3.72	0.00	583.93	-2.23	1.43
11/03/00	0	0	3.38	0.00	581.65	-2.29	1.58
12/03/00	0	0	3.33	0.00	579.85	-1.80	1.84
13/03/00	0	0	2.50	0.00	578.36	-1.49	1.07
14/03/00	0	0	2.66	0.00	576.92	-1.43	-0.45
15/03/00	0	0	2.79	0.00	573.82	-3.10	0.03
16/03/00	0	0	3.30	0.00	571.06	-2.76	9.47
17/03/00	0	0	3.35	0.00	577.23	6.18	-1.94
18/03/00	0	0	3.40	0.00	571.94	-5.29	-13.60
19/03/00	0	0	2.81	0.00	554.94	-17.01	18.08
20/03/00	0	0	2.67	0.00	570.21	15.27	44.45
21/03/00	0.6	74.6	2.55	20.60	611.99	41.78	-72.86
22/03/00	3.4	0	2.76	6.56	591.17	-20.81	0.61
23/03/00	0.4	0	3.50	0.63	585.87	-5.31	1.75
24/03/00	1	0	4.15	0.00	583.88	-1.98	1.83
25/03/00	0	0	3.57	0.00	582.56	-1.33	1.62
26/03/00	0	0	2.95	0.00	580.60	-1.95	1.71
27/03/00	0	0	2.76	0.00	579.36	-1.25	-21.90
28/03/00	0	0	3.17	0.00	554.69	-24.67	2.10
29/03/00		0	3.57	0.00	553.62	-1.07	
30/03/00		0	3.50	0.00			
31/03/00		0	3.43	0.00	563.61		
01/04/00	0	0	4.91	0.00			
02/04/00	0	0	5.33	0.00			
03/04/00	0	0	3.39	0.00			
04/04/00	0.2	0	4.52	0.00	535.18		
05/04/00	0	0	4.32	0.00			
06/04/00	0	0	4.38	0.00			
07/04/00	0	0	2.82	0.00			
08/04/00	0	0	3.73	0.00			
09/04/00	0	0	3.23	0.00			
10/04/00	0	0	2.88	0.00			
11/04/00	0	0	3.09	0.00			
12/04/00	0	0	4.56	0.00			
13/04/00	0	0	5.56	0.00			
14/04/00	0	0	3.46	0.00			
15/04/00	0	0	2.57	0.00			
16/04/00	0	0	2.86	0.00			
17/04/00	0	0	3.16	0.00			
18/04/00	0	0	3.13	0.00			
19/04/00	0	0	2.87	0.00			
20/04/00	0	0	3.02	0.00			
21/04/00	0	0	2.55	0.00			
22/04/00	0	0	2.63	0.00			
23/04/00	0	0	2.13	0.00			
24/04/00	0	0	1.93	0.00			
25/04/00	0	0	1.98	0.00			

Date	Rainfall (mm)	Irrigation (mm)	Et_{crop} (mm)	Drainage (mm)	Moisture content mm/1.4m depth	Change in storage (mm)	Lateral Seepage (mm)
26/04/00	0	0	1.69	0.00			
27/04/00	0	0	1.66	0.00			
28/04/00	0	0	1.53	2.71			
29/04/00	0	0	1.59	0.00			
30/04/00	0	0	1.67				
01/05/00			1.74				
02/05/00			1.50				
03/05/00			1.63				
04/05/00			2.01		570.00		
05/05/00							
Total Season	116.20	469.70	357.74	290.05			

Note: missing moisture content data from 30/3/00 onwards. End of season moisture content estimated using watertable depth on 4/5/00 (0.84m) and using moisture content data from 16/03/00 when watertable depth was the same.

Appendix 6

WaSim Controlled Drainage Notes

Appendix 6 WaSim Controlled Drainage Notes.

Modifications to the WaSim programme for controlled drainage - Features only available in the controlled drainage version

Drainage flow in response to weir setting

The daily change in water table level due to drainage is calculated from (Youngs et al., 1989[1]).

$$\Delta h = \frac{K}{\mu\left(\frac{L}{2}\right)^{\beta}}\left(\left(\frac{\phi}{2}\right)^{\beta} - h^{\beta}\right) \qquad (1)$$

where

h	mid-drain head, m
K	saturated hydraulic conductivity, m d^{-1}
μ	drainable porosity, dimensionless
L	drain spacing, m
ϕ	ditch water level or drain diameter, m
β	exponent dependant on the depth to the impermeable layer, m^{-1}

For each day of the simulation the head at the drain outfall can be specified by a weir depth (depth below surface). Three conditions are permitted;

- 'OPEN'. Free discharge from the drains. Model operates as for normal drained situation. *h* = water table position, m above drain depth.
- 'CLOSED'. No discharge from the drains. Model operates as for undrained situation and *h* = 0.
- Weir level. A value between 0 and drain depth gives the weir level (m below surface). If the water table is below the weir level, *h* = 0, otherwise, *h* = water table position, m above weir level.

Partitioning of salt removal from above and below the drains

In the original version of WaSim, the quality of the drain water is a weighted average of the water quality above and below the drain depth. The weighting factor, f, is calculated from;

$$f = \frac{8hd}{8hd + 4h^2} \qquad (2)$$

where

h height of the mid-drain water table above the drain depth, m

d Hooghoudt's equivalent depth, m, which is a function of the depth to the impermeable layer.

The same procedure is used for controlled drainage[2].

Variable irrigation water quality

The electrical conductivity of the irrigation water, EC_w, can be varied daily. This over-rides any value set in the irrigation screen.

Lateral seepage

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[1] Youngs, E. G., Leeds-Harrison, P.B. and Chapman, J.M., 1989. Modelling water-table movement in flat low-lying lands. Hydrological Processes 3:301-315.

[2] It is recognised that this is only an approximation and the true solution is far more complex.

The daily lateral seepage ($+^{ve}$ inwards) can be varied daily. This over-rides any value set in the drainage screen.

Appendix 7

Field Site Climate Data File for WaSim Simulations

Appendix 7 Field Site Climate Data File for WaSim Simulations.

Table K summarises the field site climate data file for WaSim. The file runs from the 1st Jan 1999 to 31st May 2000, and includes the daily rainfall (mm) and the reference crop evapotranspiration ET_0 (mm), calculated from the meteorological data using the Penman method (Doorenbos and Pruitt, 1984).

Table K Field site climate data file for WaSim simulations

Date	ETo	Rainfall
01-Jan-99	1.8	0
02-Jan-99	1.8	0
03-Jan-99	1.8	0
04-Jan-99	1.6	0
05-Jan-99	1.6	0
06-Jan-99	1.2	0
07-Jan-99	1.2	0
08-Jan-99	1.7	0
09-Jan-99	1.9	0
10-Jan-99	1.4	0
11-Jan-99	1.6	0
12-Jan-99	1.7	0
13-Jan-99	1.4	0
14-Jan-99	1.3	0
15-Jan-99	1.5	0
16-Jan-99	1.3	0
17-Jan-99	1.3	0
18-Jan-99	1.2	0
19-Jan-99	1.5	0
20-Jan-99	1.4	0
21-Jan-99	1.5	0
22-Jan-99	1.5	0
23-Jan-99	1.9	0
24-Jan-99	1.5	0
25-Jan-99	1.5	0
26-Jan-99	1.8	0
27-Jan-99	2	0
28-Jan-99	2.1	0
29-Jan-99	2	0
30-Jan-99	1.6	0
31-Jan-99	1.9	0
01-Feb-99	1.7	0
02-Feb-99	2.3	0
03-Feb-99	1.8	0
04-Feb-99	2.3	0
05-Feb-99	2.5	0.2
06-Feb-99	2	1
07-Feb-99	2.8	0.2
08-Feb-99	2.9	0
09-Feb-99	2.5	0
10-Feb-99	2.5	0
11-Feb-99	2.6	0
12-Feb-99	2.7	0
13-Feb-99	2.3	0
14-Feb-99	2.6	0
15-Feb-99	2.5	0
16-Feb-99	2.3	0
17-Feb-99	5.7	0
18-Feb-99	2.9	0
19-Feb-99	2.2	6.2

Date	ETo	Rainfall
25-Feb-99	2.7	0
26-Feb-99	2.6	0
27-Feb-99	2.5	0
28-Feb-99	2.6	0
01-Mar-99	3.7	0
02-Mar-99	3.2	0
03-Mar-99	3.2	0
04-Mar-99	3	0
05-Mar-99	3.2	0
06-Mar-99	4.2	0
07-Mar-99	4.2	0.2
08-Mar-99	4.3	0
09-Mar-99	3.3	0
10-Mar-99	3.2	0
11-Mar-99	3.5	0
12-Mar-99	3.5	0
13-Mar-99	3.7	0
14-Mar-99	3.2	0
15-Mar-99	3.2	0
16-Mar-99	3.2	0
17-Mar-99	3.6	0
18-Mar-99	5.2	0
19-Mar-99	4.5	0
20-Mar-99	3.2	0
21-Mar-99	3.2	0
22-Mar-99	3.1	0
23-Mar-99	3.5	0
24-Mar-99	5.5	0
25-Mar-99	3.4	9.2
26-Mar-99	3.7	0
27-Mar-99	4.5	0
28-Mar-99	5.9	0
29-Mar-99	3.8	0
30-Mar-99	5.1	0
31-Mar-99	3.8	0
01-Apr-99	4.5	0.4
02-Apr-99	4.7	0
03-Apr-99	4.8	0.2
04-Apr-99	5.9	0
05-Apr-99	5.9	0
06-Apr-99	4.5	0
07-Apr-99	4.2	1.2
08-Apr-99	4	0
09-Apr-99	4.6	0
10-Apr-99	4.9	0
11-Apr-99	4.5	0
12-Apr-99	4.2	0
13-Apr-99	4.6	0
14-Apr-99	6.2	0
15-Apr-99	5.1	0

Date	ETo	Rainfall
21-Apr-99	4.5	0
22-Apr-99	4.4	0.4
23-Apr-99	4	0
24-Apr-99	4.4	0
25-Apr-99	4.8	0
26-Apr-99	5.3	0
27-Apr-99	4.9	0
28-Apr-99	4	0
29-Apr-99	4.4	0
30-Apr-99	4.8	0
01-May-99	5.7	0
02-May-99	6	0
03-May-99	6.2	0
04-May-99	5.5	0
05-May-99	6.4	0
06-May-99	6.3	0
07-May-99	4.8	0
08-May-99	4.4	0
09-May-99	4.8	0
10-May-99	4.5	0
11-May-99	4.9	0
12-May-99	4.7	0
13-May-99	4.8	0
14-May-99	4.5	0
15-May-99	5	0
16-May-99	6.2	0
17-May-99	6.6	0
18-May-99	5.4	0
19-May-99	5.7	0
20-May-99	6.2	0
21-May-99	7.6	0
22-May-99	9	0.2
23-May-99	5.8	0
24-May-99	4.8	0
25-May-99	4.8	0
26-May-99	5.6	0
27-May-99	5.3	0
28-May-99	4.8	0
29-May-99	5.7	0
30-May-99	5.4	0
31-May-99	5.4	0
01-Jun-99	5.6	0
02-Jun-99	5.6	0
03-Jun-99	5.4	0
04-Jun-99	5.5	0
05-Jun-99	6.1	0
06-Jun-99	6.8	0
07-Jun-99	6.8	0.2
08-Jun-99	5.7	0
09-Jun-99	5.6	0

Date	ETo	Rainfall
20-Feb-99	3.3	0
21-Feb-99	2.3	0
22-Feb-99	2.3	0
23-Feb-99	3	0
24-Feb-99	3.4	0
15-Jun-99	6.4	0
16-Jun-99	6.4	0
17-Jun-99	7.4	0
18-Jun-99	8.1	0
19-Jun-99	6.4	0
20-Jun-99	6.6	0
21-Jun-99	7.1	0
22-Jun-99	8.9	0
23-Jun-99	7.5	0
24-Jun-99	5.4	0
25-Jun-99	5.8	0
26-Jun-99	6.7	0
27-Jun-99	5.9	0
28-Jun-99	6.6	0
29-Jun-99	5.6	0
30-Jun-99	5.4	0
01-Jul-99	5.3	0
02-Jul-99	5	0
03-Jul-99	5.5	0
04-Jul-99	5.5	0
05-Jul-99	5.4	0
06-Jul-99	4.8	0
07-Jul-99	4.9	0
08-Jul-99	5.2	0
09-Jul-99	6.4	0
10-Jul-99	6.3	0
11-Jul-99	6	0
12-Jul-99	6.4	0
13-Jul-99	6.7	0
14-Jul-99	6.2	0
15-Jul-99	6.5	0
16-Jul-99	6.9	0
17-Jul-99	6.6	0
18-Jul-99	6.9	0
19-Jul-99	6.7	0
20-Jul-99	6.4	0
21-Jul-99	6.7	0
22-Jul-99	7.5	0
23-Jul-99	6.4	0
24-Jul-99	6.1	0
25-Jul-99	6.1	0
26-Jul-99	6.6	0
27-Jul-99	7.1	0
28-Jul-99	6.7	0
29-Jul-99	6.1	0
30-Jul-99	6.2	0
31-Jul-99	6.1	0
01-Aug-99	5.7	0
02-Aug-99	5.6	0
03-Aug-99	5.5	0
04-Aug-99	5.9	0
05-Aug-99	5.7	0
06-Aug-99	6.1	0
07-Aug-99	5.4	0

Date	ETo	Rainfall
16-Apr-99	5.5	0
17-Apr-99	6.1	0
18-Apr-99	6.6	0
19-Apr-99	4.4	0
20-Apr-99	4.1	0
09-Aug-99	6.4	0
10-Aug-99	6.4	0
11-Aug-99	6.7	0
12-Aug-99	6.5	0
13-Aug-99	6.2	0
14-Aug-99	6.9	0
15-Aug-99	6.9	0
16-Aug-99	6.2	0
17-Aug-99	6	0
18-Aug-99	6.5	0
19-Aug-99	6.7	0
20-Aug-99	6.7	0
21-Aug-99	6.7	0
22-Aug-99	6.8	0
23-Aug-99	6.6	0
24-Aug-99	6.7	0
25-Aug-99	6.4	0
26-Aug-99	6.4	0
27-Aug-99	6.2	0
28-Aug-99	6.4	0
29-Aug-99	6	0
30-Aug-99	5.8	0
31-Aug-99	6	0
01-Sep-99	4.5	0
02-Sep-99	4.9	0
03-Sep-99	5.4	0
04-Sep-99	5.1	0
05-Sep-99	5.1	0
06-Sep-99	6	0
07-Sep-99	5.7	0
08-Sep-99	5.4	0
09-Sep-99	5	0
10-Sep-99	4.6	0
11-Sep-99	5	0
12-Sep-99	4.9	0
13-Sep-99	4.8	0
14-Sep-99	5.6	0
15-Sep-99	5.6	0
16-Sep-99	5.1	0
17-Sep-99	5.1	0
18-Sep-99	5.1	0
19-Sep-99	6.3	0
20-Sep-99	5.4	0
21-Sep-99	5.1	0
22-Sep-99	4.8	0
23-Sep-99	4.8	0
24-Sep-99	4.9	0
25-Sep-99	4.6	0
26-Sep-99	4.8	0
27-Sep-99	5.1	0
28-Sep-99	4.9	0
29-Sep-99	5	0
30-Sep-99	5.1	0
01-Oct-99	4	0

Date	ETo	Rainfall
10-Jun-99	5.7	0
11-Jun-99	6.7	0
12-Jun-99	6.9	0
13-Jun-99	7.7	0
14-Jun-99	6.9	0
03-Oct-99	3.9	0
04-Oct-99	4.2	0
05-Oct-99	4.2	0
06-Oct-99	4	0
07-Oct-99	4.1	0
08-Oct-99	4.2	0
09-Oct-99	4.5	0
10-Oct-99	3.7	0.2
11-Oct-99	4	0.4
12-Oct-99	3.8	0
13-Oct-99	4.1	0
14-Oct-99	3.9	0
15-Oct-99	3.9	0
16-Oct-99	3.5	0.6
17-Oct-99	4	0
18-Oct-99	3.8	0.2
19-Oct-99	3.8	0
20-Oct-99	3.8	0
21-Oct-99	3.9	0
22-Oct-99	3.6	0
23-Oct-99	3.8	0
24-Oct-99	3.6	0
25-Oct-99	4.4	0.6
26-Oct-99	4.1	0
27-Oct-99	3.8	0
28-Oct-99	3.5	0
29-Oct-99	3.7	0
30-Oct-99	3.1	0
31-Oct-99	3.6	0
01-Nov-99	2.4	0
02-Nov-99	2.7	0
03-Nov-99	2.4	0
04-Nov-99	3.1	1.6
05-Nov-99	2.8	0
06-Nov-99	2.7	0
07-Nov-99	2.6	0
08-Nov-99	2.6	0
09-Nov-99	2.6	0
10-Nov-99	2.7	0
11-Nov-99	2.4	0
12-Nov-99	2.6	0
13-Nov-99	2.5	0
14-Nov-99	2.5	1.2
15-Nov-99	2.5	0
16-Nov-99	2.5	0
17-Nov-99	2.5	0
18-Nov-99	2.3	0.2
19-Nov-99	2.7	0
20-Nov-99	2.7	0
21-Nov-99	3.2	0
22-Nov-99	2.7	0
23-Nov-99	2.7	0.4
24-Nov-99	2.7	0
25-Nov-99	3.2	0

Date	ETo	Rainfall
08-Aug-99	6.2	0
27-Nov-99	3.1	0
28-Nov-99	2.1	0
29-Nov-99	2.2	0
30-Nov-99	2.1	0
01-Dec-99	2.2	0
02-Dec-99	1.9	0
03-Dec-99	1.6	0
04-Dec-99	1.8	0
05-Dec-99	2.1	0
06-Dec-99	2.2	0
07-Dec-99	2	0
08-Dec-99	1.7	0
09-Dec-99	1.8	0.4
10-Dec-99	1.8	0
11-Dec-99	1.8	0
12-Dec-99	1.9	0
13-Dec-99	1.5	0
14-Dec-99	1.9	0
15-Dec-99	1.7	0.4
16-Dec-99	1.6	0
17-Dec-99	1.6	0.2
18-Dec-99	1.6	0
19-Dec-99	1.4	0
20-Dec-99	1.1	0.2
21-Dec-99	1.7	0
22-Dec-99	1.3	0.2
23-Dec-99	1.7	0
24-Dec-99	1.6	0
25-Dec-99	1.8	0.2
26-Dec-99	1.6	0.4
27-Dec-99	2.1	0
28-Dec-99	2.5	0
29-Dec-99	2	0
30-Dec-99	1.8	0
31-Dec-99	1.3	0
01-Jan-00	1.6	0
02-Jan-00	1.6	0
03-Jan-00	1.6	5
04-Jan-00	1.7	8.8
05-Jan-00	1.7	18.8
06-Jan-00	1.4	1.4
07-Jan-00	1.1	5.8
08-Jan-00	1.1	1.8
09-Jan-00	1.1	4.2
10-Jan-00	1.3	0
11-Jan-00	1.4	1.2
12-Jan-00	1.5	0.6
13-Jan-00	1.5	0
14-Jan-00	1.2	0
15-Jan-00	1.5	0.2
16-Jan-00	1.1	1.2
17-Jan-00	1.2	0
18-Jan-00	1.9	0
19-Jan-00	2.1	0
20-Jan-00	2	3.8
11-May-00	5.3	0
14-May-00	5.4	0
15-May-00	6.2	0

Date	ETo	Rainfall
02-Oct-99	4.6	0
22-Jan-00	1.5	0.2
23-Jan-00	2	0
24-Jan-00	2	0
25-Jan-00	2	0
26-Jan-00	2	0
27-Jan-00	2	28.1
28-Jan-00	2	3.1
29-Jan-00	2	0
30-Jan-00	2	0
31-Jan-00	2	0
01-Feb-00	2	0
02-Feb-00	2	0
03-Feb-00	2	0
04-Feb-00	1.5	0
05-Feb-00	2.1	0.2
06-Feb-00	2.8	0
07-Feb-00	2.1	0
08-Feb-00	1.9	0.2
09-Feb-00	1.8	0.2
10-Feb-00	2.1	0
11-Feb-00	2.2	0
12-Feb-00	2.1	0
13-Feb-00	1.7	8.4
14-Feb-00	2.4	0
15-Feb-00	2.3	0
16-Feb-00	1.9	0.2
17-Feb-00	2.5	0
18-Feb-00	2.5	0
19-Feb-00	2.5	0
20-Feb-00	2.5	0
21-Feb-00	2.3	0
22-Feb-00	2.1	1
23-Feb-00	2.4	4.4
24-Feb-00	2	0
25-Feb-00	2.2	0
26-Feb-00	2.3	0
27-Feb-00	2.1	0.2
28-Feb-00	2.4	0
29-Feb-00	3	0
01-Mar-00	3.1	0
02-Mar-00	3.1	7.6
03-Mar-00	2.3	0
04-Mar-00	2.9	0
05-Mar-00	2.9	0
06-Mar-00	2.8	0
07-Mar-00	3	0
08-Mar-00	3.5	0
09-Mar-00	3	0
10-Mar-00	3.2	0
11-Mar-00	2.9	0
12-Mar-00	3	0
13-Mar-00	2.3	0
14-Mar-00	2.3	0
15-Mar-00	2.4	0
16-Mar-00	2.8	0
17-Mar-00	2.9	0
20-May-00	6.9	0
21-May-00	7	0

Date	ETo	Rainfall
26-Nov-99	3.1	0
18-Mar-00	3.1	0
19-Mar-00	2.6	0
20-Mar-00	2.4	0
21-Mar-00	2.2	0.6
22-Mar-00	2.4	3.4
23-Mar-00	3.2	0.4
24-Mar-00	3.8	1
25-Mar-00	3.3	0
26-Mar-00	2.9	0
27-Mar-00	2.7	0
28-Mar-00	3.1	0
29-Mar-00	4	0
30-Mar-00	4	0
31-Mar-00	4	0
01-Apr-00	5.1	0
02-Apr-00	5.7	0
03-Apr-00	3.7	0
04-Apr-00	5	0.2
05-Apr-00	4.9	0
06-Apr-00	5.2	0
07-Apr-00	3.4	0
08-Apr-00	4.6	0
09-Apr-00	4.2	0
10-Apr-00	3.8	0
11-Apr-00	4.1	0
12-Apr-00	6.3	0
13-Apr-00	7.7	0
14-Apr-00	4.9	0
15-Apr-00	3.8	0
16-Apr-00	4.4	0
17-Apr-00	5.2	0
18-Apr-00	5.3	0
19-Apr-00	4.8	0
20-Apr-00	5.2	0
21-Apr-00	4.7	0
22-Apr-00	4.9	0
23-Apr-00	4.1	0
24-Apr-00	3.9	0
25-Apr-00	4.2	0
26-Apr-00	3.9	0
27-Apr-00	3.9	0
28-Apr-00	3.7	0
29-Apr-00	3.9	0
30-Apr-00	4.4	0
01-May-00	5.4	0
02-May-00	5	0
03-May-00	5.7	0
04-May-00	7.5	0
05-May-00	5	0
06-May-00	4.5	1.6
07-May-00	4.7	0
08-May-00	5.2	0
09-May-00	5.3	0
10-May-00	5.3	0
12-May-00	4.9	0
13-May-00	5.5	0
26-May-00	5.8	0
27-May-00	6.2	0

Date	ETo	Rainfall
16-May-00	6.6	0
17-May-00	9.6	0
18-May-00	6.5	0
19-May-00	6.7	0

Date	ETo	Rainfall
22-May-00	6.1	0
23-May-00	5	0
24-May-00	6.6	0
25-May-00	6.5	0

Date	ETo	Rainfall
28-May-00	6.2	0
29-May-00	7.4	0
30-May-00	0	0
31-May-00	0	0