Government of **Western Australia**
Department of **Water**

Raised bed trial at Blackboy Creek, near Esperance

Looking after all our water needs

Salinity and land use impacts series

Report no. SLUI 49
June 2010

Raised bed trial at Blackboy Creek, near Esperance

by

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Department of Water

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Disclaimer

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Cover photo: Construction of raised beds at the Blackboy Creek study site

Photo by Andrew and Marie Fowler

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Summary

This study suggests that raised beds are effective in dealing with long-term waterlogging and therefore may also delay the onset of salinity on the farm. This trial highlighted that raised beds were a problem for stock management, as after cattle grazing the raised beds would need to be reformed every few years. The proponents also decided that the raised beds were too expensive to set up in comparison to their yield return. Since then they have moved to more of a grazing rather than cropping enterprise. The trial could have benefited from longer term monitoring if the raised beds could have been maintained.

Raised beds are a farming practice used to deal with waterlogging within a landscape. They were trialled at Orleans Farm in the Blackboy Creek catchment, Esperance, to address waterlogging, an issue which can occur in association with the salinisation of land. This trial was one of the farm scale engineering evaluations conducted through the Engineering Evaluation Initiative (EEI) Program. Surface water and groundwater monitoring facilities were established on a 19.2 ha raised bed field and an adjacent 22.9 ha control plot, with monitoring from July 2004 to February 2007.

Raised beds are seedbeds separated by furrows which are aligned with the gradient of the land. They are designed to improve conditions for plant growth by increasing lateral drainage from the beds into the furrows, reducing waterlogging. Forming raised beds reduces the density of the soil and encourages the formation of large pore spaces which improve soil aeration, infiltration and drainage.

The surface flows from the raised beds had an average monthly discharge of 0.82 mm compared with 0.74 mm for the control. This same trend was seen with the average monthly runoff from the raised beds being 0.63 mm and from the control site 0.47 mm.

Different seasonal patterns were highlighted in the surface flows from the raised beds and control sites. In a summer storm the peak discharges from the raised beds were higher than those of the control. The discharges also peaked five minutes earlier than the control. In winter the raised beds peaked three hours earlier than the control beds. They also had a higher peak flow than the control but a lower total discharge. The lower discharge was because the raised beds provided more pore spaces and aeration for water to move through, therefore draining the soil profile quicker.

For the study period the deep groundwater levels changed little beneath the raised beds and control plot and showed no definitive change in groundwater response between the plots. The shallow bore data records were too infrequent to make definitive conclusions.

The groundwater quality results were from two samplings only and showed no difference between plots. They indicated that the elements aluminium and iron, and nitrate concentrations and the pH were higher in the shallow bores than in the deeper bores. The salinity, potassium, magnesium, nitrogen, sodium and silicate were higher in the deep bores than in the shallow bores. Further samples are required before any conclusions can be made.

The surface water quality results showed the mean salinity for raised beds was 110 mg/L while the mean salinity for the control was 73 mg/L. The phosphorus and nitrogen levels

varied widely within the surface water while the total suspended sediments and turbidity were higher on the raised bed plots. These results indicate more water movement through the soil on the raised bed plot.

Crop trials were conducted on the site to see whether raised beds could increase crop production on the waterlogged sites. Anecdotally the raised beds helped improve crop yields with the crops looking healthier than the control.

The cost per hectare of installing raised beds depends on the topography and soil type. The cost to construct the research plot was approximately $20/ha.

1 Introduction

The National Action Plan on Salinity and Water Quality (NAPSWQ) was launched in 2000 to address the issues of salinity and water quality. The federal, state and territory governments committed joint funding to support action by communities and land managers in 21 regions across Australia.

The Engineering Evaluation Initiative (EEI) Program was a $4 million priority project under the NAPSWQ to find and demonstrate better ways to implement engineering works to tackle salinity with the least damage to the environment.

The EEI commenced in 2002 and consists of three main programs:

1. Evaluation of specific engineering options at farm-scale
2. Regional drainage evaluation
3. Safe disposal of water and soil remediation

This report presents the findings of one of the farm-scale engineering evaluations. Raised beds were trialled at Orleans Farm near Blackboy Creek to address waterlogging, an issue which can occur in association with the salinisation of land.

1.1 Land salinisation and waterlogging

Considerable volumes of salt are stored within the soil profile in Western Australia, following the transportation of ocean salt by rainfall over tens of thousands of years. If the watertable rises this salt is dissolved and carried to the surface.

The large-scale clearing of native vegetation for agricultural purposes has altered the hydrological balance causing groundwater levels to rise. Crops and pastures do not intercept as much rainfall as native vegetation, and take up less water from the soil. Consequently more rainfall is able to soak into the soil which causes the watertable to rise. This process, known as ‘dryland salinisation’, leads to waterlogging of the soil and salinisation of the land (Fig. 1).

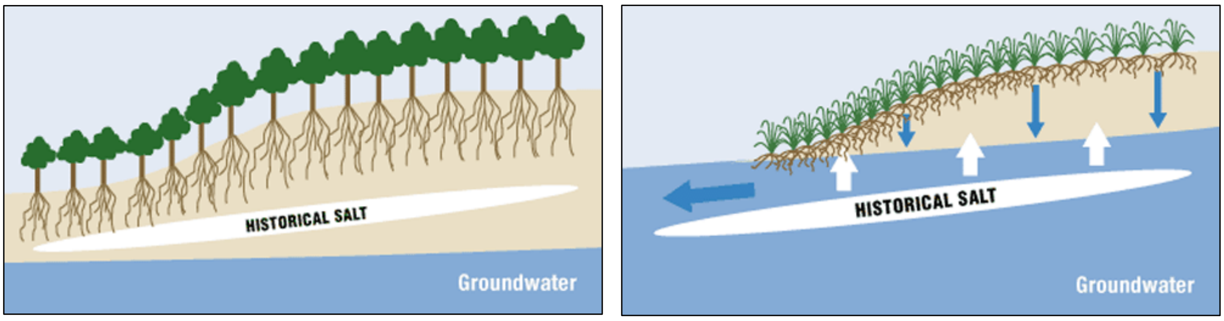

Figure 1 The process of dryland salinity

Source: Commonwealth Government of Australia, n.d.

Soil can be described as waterlogged when the plant root zone becomes saturated with water and displaces the majority of the oxygen in the soil pore spaces, leading to anaerobic conditions (Moore 1998). Plants require oxygen around their roots in order to respire, so waterlogging reduces plant growth and decreases the productivity of agricultural crops.

Waterlogging can be caused by a rise in the watertable, or can occur when rainfall exceeds the amount of water that can be absorbed by soils or evaporated by the atmosphere. Much of the agricultural area of Western Australia is prone to waterlogging in winter because the landscape is characterised by duplex soils and shallow gradients, and rain falls predominantly in winter (Hamilton et al. 2005).

The duplex soils of Western Australia have significant differences in texture and hydraulic properties between the A and B horizons (Bakker et al. 2005). Thin gravelly soils lying over clays provide little pore space for water absorption throughout the profile and, like a bucket, can easily fill with water.

Low gradients and shallow watertables (commonly within 2 m of the surface in valley floors) also impede runoff and drainage, contributing to soil saturation and waterlogging.

The Mediterranean-type climate of south-west Western Australia is characterised by cool wet winters and hot dry summers. During winter showers evaporation is minimal and soils become saturated rapidly, resulting in excess water which can lead to waterlogging (Hamilton et al. 2005).

1.2 Use of raised beds in Australia

The use of a raised bed farming system involves the modification of a paddock surface to create seedbeds above the normal ground surface, separated by furrows aligned with the gradient of the land (Fig. 2). Collector drains are placed at right angles to the furrows to carry water away from the paddock. Bed height and width and furrow width can be varied depending on the soil type, gradient, availability of machinery and farm finances (Wightman et al. 2005).

Raised beds are designed to improve conditions for plant growth by stimulating lateral drainage from the beds into the furrows, reducing waterlogging of the bed. The process of forming deepened seedbeds reduces the density of the soil and encourages the formation of large pore spaces which improve soil aeration, infiltration and drainage (Hamilton et al. 2005).

Raised beds have been promoted as a potentially beneficial method for cropping in waterlogged areas, and their use has increased in recent years. In Western Australia, for example, Bakker et al. (2005) estimated that over 30 000 ha of crops were grown on raised beds just seven years after they were introduced into broad-acre farming in the state. In southern Victoria the area of land under broad acre raised bed crops increased from 300 ha in 1997 to 35 000 ha in 2003 (Peries et al. 2004).

In addition, it has been suggested that, as waterlogging often occurs prior to salinisation of land, the use of raised beds to reduce waterlogging may prevent a paddock from becoming saline (Bakker 2007).

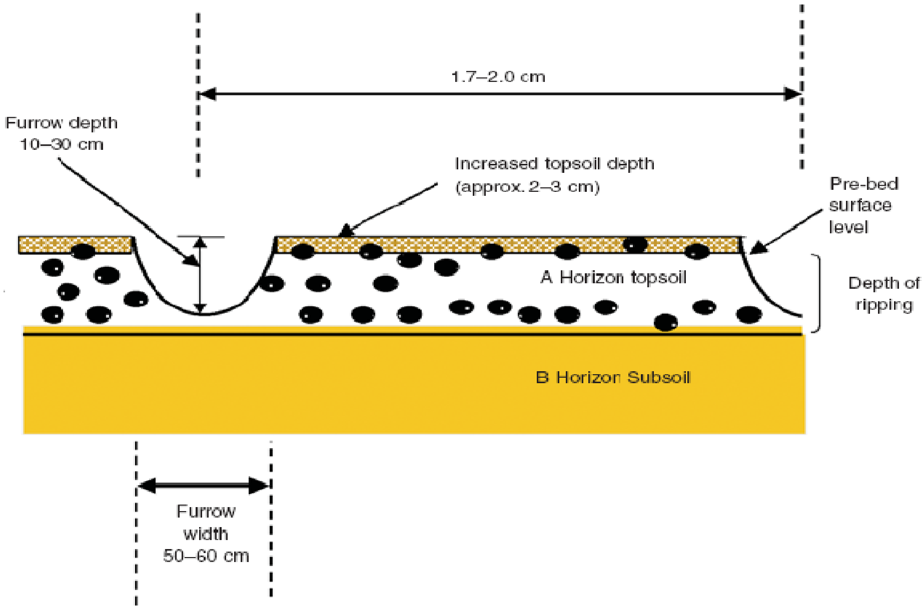

Figure 2 Schematic diagram of a raised bed

Source: Wightman et al. 2005

1.3 Previous studies of raised beds

A number of studies have been conducted in the eastern states of Australia to investigate whether crop yields are improved by the use of raised beds.

Riffkin and Evans (2003) compared growth and yields of wheat on raised beds and conventional flat beds in Hamilton, south western Victoria. They found that crops grown on raised beds were more vigorous but the yield was similar to crops from conventional flat beds due to loss of production area in the furrows. They also found that raised bed crops were less susceptible to weeds due to reduction in stress on the plants from decreased waterlogging. They indicated that raised beds may therefore benefit from lower chemical use due to higher crop competitiveness with weeds.

Johnston et al. (2001) investigated runoff volumes and water quality from raised beds 30 km west of Geelong in Victoria. They observed higher runoff volumes from raised beds than from flat bed crops and pasture during intense rainfall events, but no difference during less intense rain. Mean flow-weighted total phosphorus was lower in the runoff from raised beds than from flat beds and pasture, possibly due to dilution.

Cotching and Dean (2003) studied differences in soil structure, chemistry and biology between raised bed and conventional bed areas in Tasmania's Northern Midlands. They found that areas under raised bed soil management systems for one or two seasons had improved physical properties (greater infiltration, lower bulk density, lower shear strength, and lower penetration resistance). Biological and chemical properties were not significantly different.

Raised beds have been researched by the Southern Farming Systems partnership in Victoria since 1993. Peries et al. (2004) present crop productivity results for four years of the trial from 1999/2000 to 2002/2003. They concluded that improved drainage and differences in soil structure in raised beds lead to an increase in plant available water capacity (PAW), resulting in improved crop growth. The use of raised beds leads to the control of traffic within and across paddocks, so soil compaction only occurs in the furrows. Peries et al. (2004) suggest that this contributed to the improvements in soil structure of the raised beds.

Raised beds have been trialled in two major studies in Western Australia. Bakker et al. (2005) studied the impact of raised beds on waterlogging, soils structure and productivity at a number of sites across the south west of Western Australia. Five experimental sites were established and monitored over a five-year period, and three larger-scale demonstration sites were operated for up to four years.

The study found that the use of raised beds in waterlogged soils reduced the bulk density of the soils and decreased waterlogging. This created favourable root zone conditions, which resulted in an average grain yield increase of 18%. The favourable root zone conditions were maintained for several years due to the lack of soil compaction by vehicular traffic. Surface water runoff was greater from raised beds than from control plots at all sites, with the exception of one site in one year. Bakker et al. (2005) attributed the increased runoff to the drainage pathways created by the furrows between the raised beds.

The potential of raised beds to cultivate and therefore reclaim waterlogged and saline land was investigated at Cunderdin, Woodanilling and North Stirling in Western Australia. The report, published by Bakker (2007), states that the use of beds did not improve the productivity of pasture because the sward composition was adjusted to accommodate the waterlogged conditions. The use of raised beds and no till beds led to improved crop productivity, primarily because of reduced waterlogging.

The raised beds did not alter the salt dynamics compared to the control plots, with both experiencing seasonal changes in salinity. Bakker (2007) suggests that the undulating topography of the furrows reduced the efficiency of drainage, resulting in salt accumulating on the soil surface during spring and summer. A further study of the effectiveness of grading furrows is being conducted at a site near Woodanilling, WA.

1.4 Objectives of the study

The objectives of the EEI raised bed project were:

- Assess the potential of raised beds to reduce groundwater recharge.
- Work out the impact of raised beds and shallow drainage versus shallow drainage alone on catchment runoff yield and peak flow.
- Observe changes in surface water and shallow groundwater quality that may occur as a result of raised bed installation.
- Assess the costs, benefits and practicalities of raised beds for improving cropping potential in a waterlogged paddock.

1.5 Site selection

Andrew and Marie Fowler began to construct raised beds to counter waterlogging on Orleans Farm in 2003, following successful implementation of raised beds on another Fowler family property. The site was chosen by the EEI Steering Committee as an EEI surface water management site since the management features (raised beds) were already in place, and the Fowlers showed a keen interest in managing surface water on their farm.

Before the study began there was no evidence of salinity on the property. Nearby bores indicated that the watertable was at a depth of around 15 m and rising at an average rate of 0.1 m per year. Groundwater salinity within the bores was in the order of 16 500 mg/L TDS. Lower in the catchment, groundwater had started to express as saline seeps adjacent to and within drainage lines.

2 Site characteristics

2.1 Study area

Orleans Farm is approximately 100 km east of Esperance, in the Blackboy Creek–Thomas River catchment area (Fig. 3). The property is located on Fisheries Road and is bounded by Exchange Road to the west, Merivale Road to the south and Tagon Road to the east (Fig. 4).

The property, covering approximately 6000 ha, is used for grazing cattle and sheep and cropping cereal and oilseed.

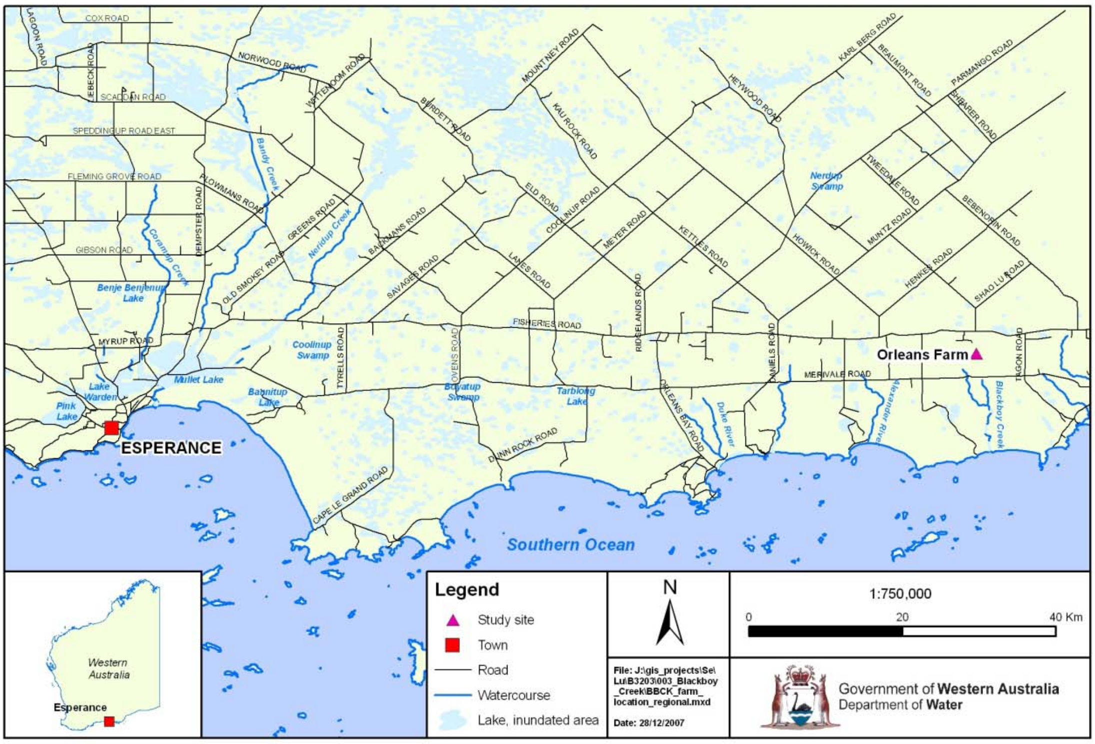

Figure 3 Location of Orleans farm, near Esperance, Western Australia

2.2 Climate

The climate of the study area is classified as 'temperate' with distinctly dry and warm summers. The area falls within the 'winter' seasonal rainfall zone, which is characterised by wet winters and low summer rainfall (Bureau of Meteorology 2007).

Seasonal climatic patterns are evident at the Bureau of Meteorology (BOM) station 009789 in Esperance (Fig. 5), approximately 100 km west of the study site. The mean annual rainfall for Esperance is 622 mm (1969–2007), with the highest monthly mean rainfall in July and the lowest in December. The monthly mean maximum temperatures vary from 17.1°C in July to 26.2°C in February, and the mean daily evaporation ranges from 2.2 mm in June and July to 7.2 mm in January (Bureau of Meteorology 2007).

Rainfall has been recorded at Orleans Farm by the property owners since 2003. The mean average rainfall between 2003 and 2006 was 534 mm (Table 1). The mean average rainfall for the same period for Esperance (BOM station no. 009789) was 606.5 mm.

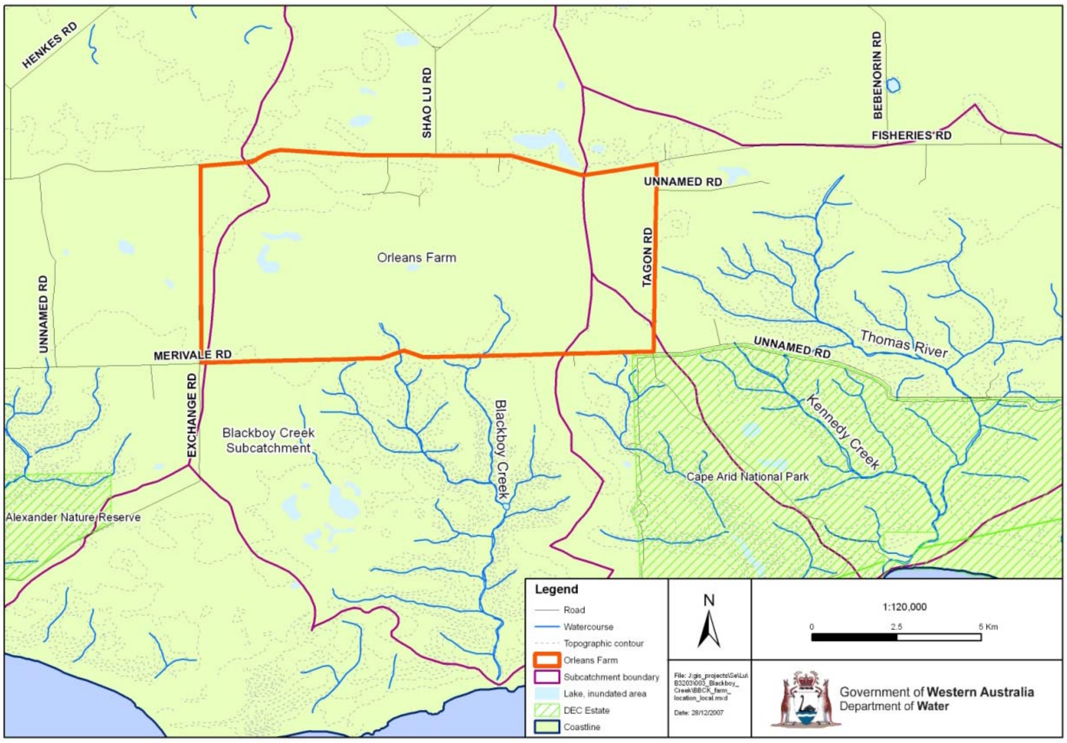

Figure 4 Orleans farm property and the Blackboy Creek subcatchment

Table 1 Total annual rainfall recorded at Orleans farm and Esperance (2003–06)

Year	Total annual rainfall (mm)	
	Blackboy Creek Station no. 509605	BOM Esperance Station no. 009789
2003	725	749
2004	428	512
2005	588	693
2006	389	472
Mean	*534*	*607*

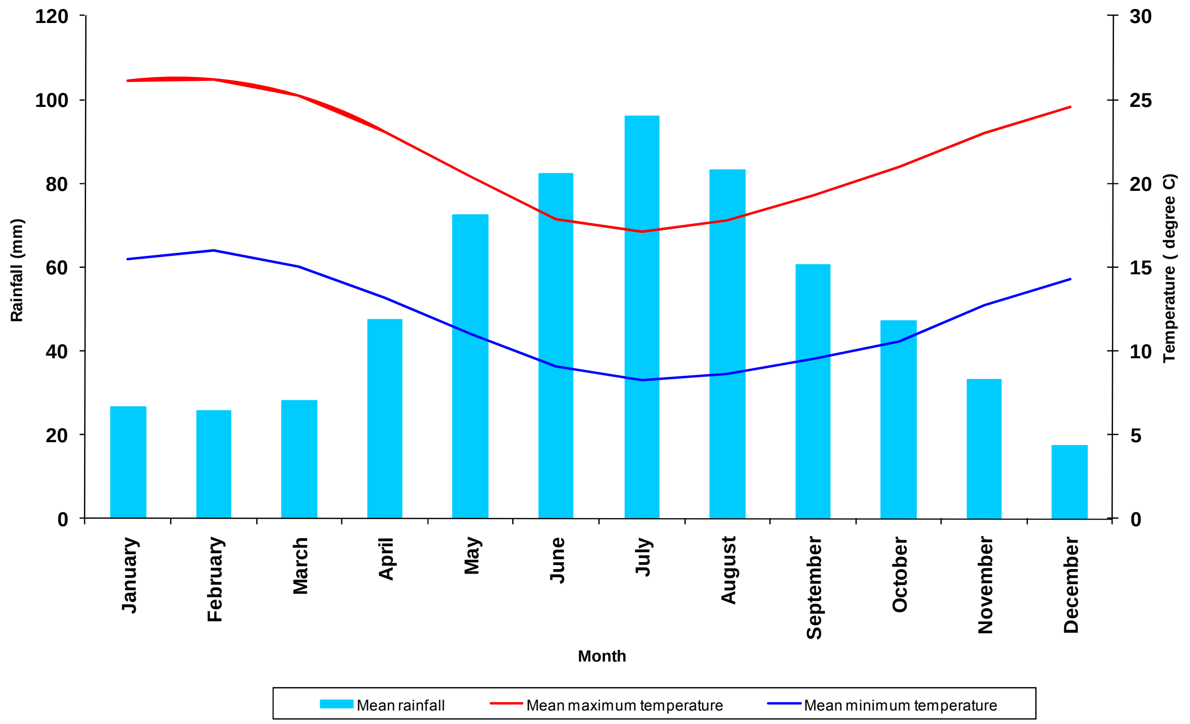

Figure 5 Mean monthly rainfall and minimum and maximum temperatures for Esperance (BOM station 009789) 1969–2007

Source: Bureau of Meteorology (2007)

2.3 Topography and drainage

The property is relatively flat, with elevation ranging from 75 m AHD in the south and south west to a 95 m AHD mound in the north (Lot 122) and the west (Lot 118). Surface water is likely to flow towards Merivale Road and the Cape Arid National Park directly south of the property.

2.4 Soils

The site lies in the Department of Agriculture soil–landscape zone 'Esperance Sandplain (245)', described as alkaline grey deep sandy duplex. During the installation of the project groundwater bores the soils were found to consist of sand and sandy clay to depths of 0.5 m over clays (Appendix A).

2.5 Geology and hydrogeology

The geology of the region is described as Tertiary Pallinup Siltstone overlying Proterozoic granitoid and gneiss (Baddock 1996).

Pallinup Siltstone at the site comprises a highly permeable spongolite (fossilised sponge) facies interlayered with clay. The siltstone forms a confined to semi-confined aquifer. Recharge to the aquifer is by rainfall, and may increase with runoff from granite outcrops.

Discharge is by evapotranspiration and seeps along creek beds. Groundwater is brackish to saline (1000–7000 mg/L TDS).

The deeper Proterozoic aquifer generally contains hypersaline groundwater (up to 36 000 mg/L TDS – seawater is 35 000 mg/L) which may be merely brackish close to surface catchment divides. Clay in-filling of fractures can result in low permeability. The basement is considered by Johnson and Baddock (1998) to contain additional minor localised aquifers due to the low permeability.

The regional watertable exists wherever there is sufficient permeability for saturation. There may be no watertable in elevated areas where fractures are weathered or poorly developed. Depth to groundwater may exceed 20 m along the coast.

The two research plots are located on a flat section of the landscape with poorly defined surface water drainage system. Many depressions existing at the soil surface become waterlogged after heavy rainfall.

At shallow and deep bores surrounding the plots the watertable was anywhere from 0.08 to 18 metres below ground level. A shallower perched watertable can form after heavy rainfall events and cause surface soil waterlogging.

Refer to Appendix A for descriptions of soil profiles for boreholes drilled for the project.

3 Methods

3.1 Raised beds

3.1.1 Installation

Prior to commencement of the EEI project, the Fowlers commissioned Westclay Pty Ltd to survey the property. Topographic contours were mapped at 10 cm height intervals to assist with planning the location and direction of raised beds and surface drainage structures.

Paddock 3F, situated in the centre of Orleans Farm, was selected as the location for the EEI project plots. A raised bed trial plot and a non bedded control plot were delineated within the paddock (Fig. 6).

Raised beds were installed on the trial plot by the Fowlers using a 375 hp tractor, a 12' carry grader, and a bedformer (Fig. 7). The beds were constructed to a height of 0.2 m furrow depth. The beds were installed in March 2004 and were not reformed during the project. Installation of the raised beds cost approximately $15 per hectare.

Surface water management drains and levees were installed around the raised bed plot and control plot by the Fowlers. The structures consisted of shallow (less than 0.5 m) drains which collected runoff from the plots. Flows were directed past the gauging stations, under the vehicle track, through another paddock, and into an existing creekline south of the property.

Construction of the beds, levees and shallow surface water drains created paddock-scale catchments for the control and raised bed trial plots. These catchments were slightly different sizes, with the raised beds plot covering 19.2 ha and the control plot covering 22.9 ha.

3.1.2 Costs

The cost per hectare of installing raised beds is dependent on site topography and soil type. For example, shallower soils require more intensive surface drainage than deeper soils.

The proponents estimated that the cost of running a tractor with bucket for drain construction was $250/hr, making a total of $25 000 for 100 hours of work. This cost is to drain 80 ha. The cost of the raised bed machine was $40 000. The cost of the drains however, would be less under normal conditions, as for the project the runoff from the two treatments had to be separated.

Constructing the raised beds is relatively cheap as it is only a 'one pass' operation. For the project 7 ha/hr was constructed at a cost of $150/hr which included running the machine and included fuel, labour and depreciation. Therefore it costs approximately $20/ha to construct raised beds at this site.

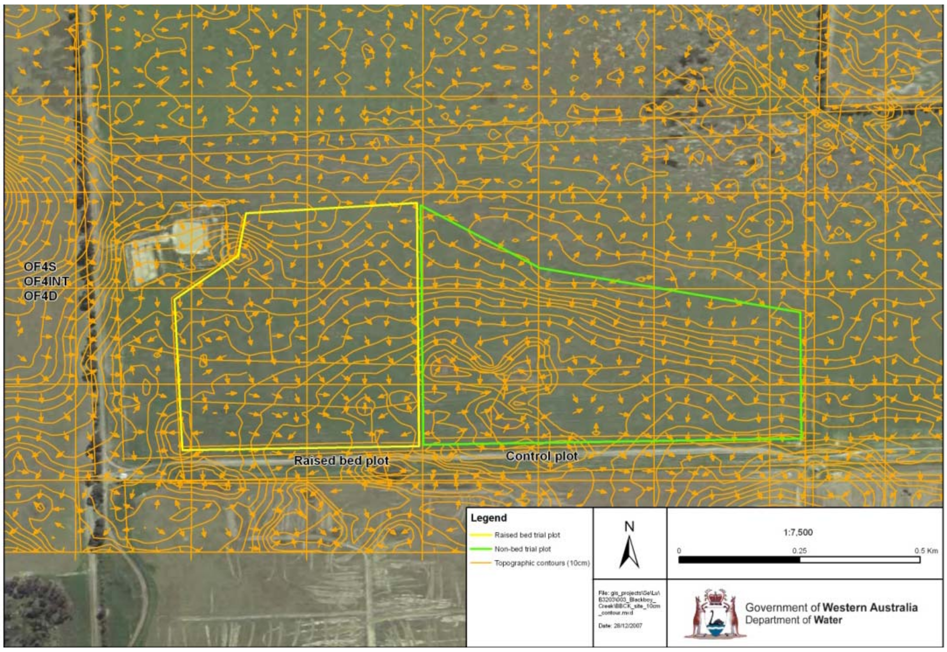

Figure 6 Boundary of project plots, 10 cm contours and flow directions

Data source: Westclay Pty Ltd

Figure 7 Installing raised beds

3.1.3 Cropping

Paddock 3F, which contains the raised bed plot and control plot, was sown with crops each winter and had stock run on it each summer (Table 2).

The crop yield from the two trial plots was measured during harvesting by the harvester computer program.

Table 2 Crops sown and stock run on paddock 3F

Year	Winter crop	Summer stock
2003	Pasture	Sheep, cattle
2004	Canola	Sheep, cattle
2005	Wheat	Sheep, cattle
2006	Barley	Sheep, cattle

3.2 Surface water gauging stations

3.2.1 Site selection and installation

Stream gauging stations were used to measure surface water runoff from the raised bed plot (DoW station no. 601013) and the control plot (601014) (Figs 8 & 9). The stations were installed on the southern end of the plots, between the paddock and a vehicle track. A wire fence was erected to protect the equipment from stock.

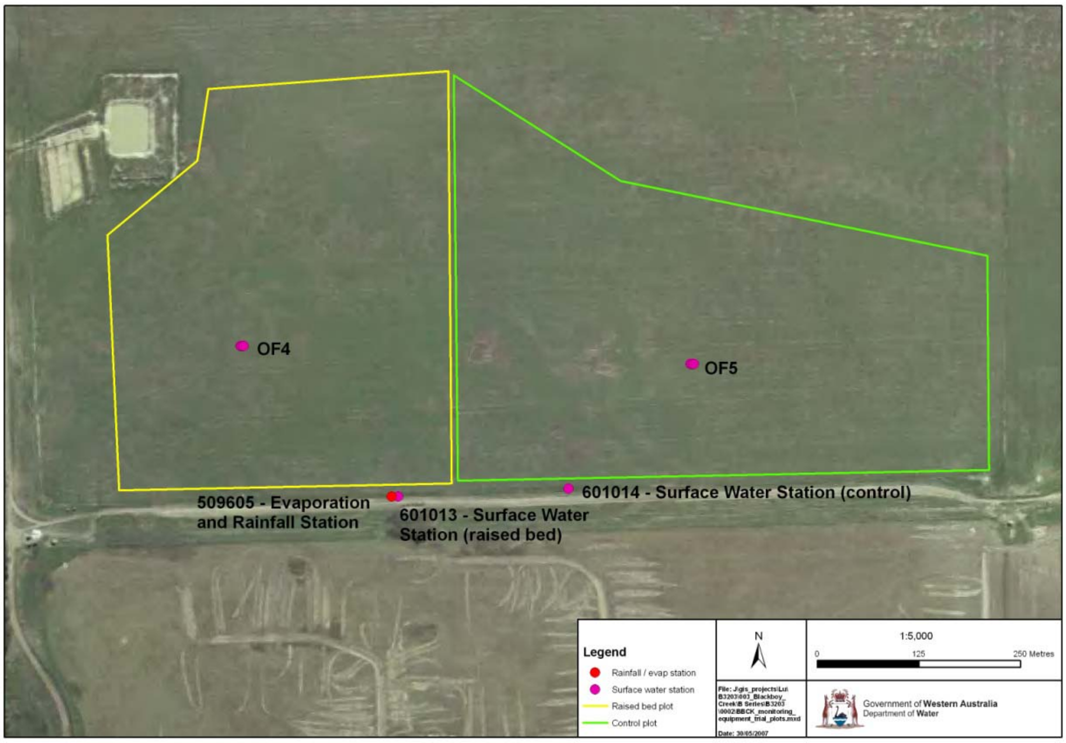

Figure 8 Surface water gauging stations and rainfall/evaporation station

The stream gauging stations were equipped with a flume, a stilling well, a float operated sensor (shaft encoder) and a data logger to measure surface water flow. The salinity of the water was measured using an electrical conductivity probe, a temperature probe and a data logger.

A rain gauge and an evaporation pan were installed (DoW station no. 509605) alongside the raised bed stream gauging station to record rainfall and evaporation (Figs 8 & 9).

Figure 9 Gauging station equipment at the raised bed station

3.2.2 Data collection

Surface water flow was recorded as stage data (in m) at 5 minute intervals from 29 July 2004 to 4 February 2007. The rating curve used to convert stage data to flows is given in Appendix B. Surface water temperature (degrees Celsius) and uncompensated conductivity (µS/m) were recorded at 20 minute intervals for the same period.

Rainfall (mm) was recorded at 5 minute intervals between 20 July 2004 and 4 February 2007. Pan evaporation (mm) was measured as a daily total for the period 3 September 2004 to 4 February 2007. Data was downloaded periodically from the various data loggers.

Surface water samples were collected manually on nine occasions during the monitoring period, and sent to the National Measurement Institute (NMI) for analysis. The water quality parameters measured were total nitrogen and phosphorus, total suspended solids and turbidity.

In addition, salinity and pH were measured once on 7 July 2005 using a hand-held meter.

3.3 Groundwater bores

3.3.1 Site selection

Groundwater bores were located in the centre of the raised bed plot (bore site OF4) and the control plot (OF5) to measure changes in groundwater level and quality. Three additional bore sites were selected to the west of the trial site (OF1 to OF3) to provide control data on groundwater recharge by rainfall, and to delineate and compare geology with that at the trial site (Fig. 10).

3.3.2 Bore installation

The groundwater bores were drilled by Albany Drilling Contractors on 29 and 30 April 2004, using rotary air blast (RAB) methods. A set of shallow, intermediate and deep bores was installed at each location, with the exception of OF1, where it was not possible to drill the intermediate depth bore. The bore depths are given in Table 3. Bores were constructed with Class 9 slotted PVC, with a gravel pack and a cement seal. The bores were not developed after construction.

Table 3 Depth of the groundwater bores (in m)

Bore	Location	Shallow (m)	Intermediate (m)	Deep (m)
OF1	Control	4	n/a	11
OF2	Control	4	8	20
OF3	Control	4	8	50
OF4	Raised bed	4	8	20
OF5	Control	4	8	20

Data loggers were installed in the shallow, intermediate and deep bores on the raised bed plot (OF4) and control plot (OF5).

3.3.3 Data collection

The groundwater levels in the bores equipped with capacitance water level sensors were measured at 15 minute intervals during the monitoring period. Data was downloaded from the water sensors periodically.

Groundwater levels in all shallow and deep bores were measured manually using a handheld tape measure with dipper, on various occasions between July 2004 and February 2007. This was carried out by the property holder (Marie Fowler) as well as officers from the Department of Water.

The ground surfaces at each bore location were not surveyed, so comparative water levels below ground level (BGL) are used in this study.

Groundwater quality samples were collected from bores OF3S, OF2D, OF3D, OF4D, and OF5D on two occasions (10–11 January 2006 and 6 November 2006). To collect water representative of the aquifer, the bores were pumped or bailed for three casing volumes before sampling. Samples were analysed by the NMI for a range of dissolved metals and dissolved inorganics (Appendix D).

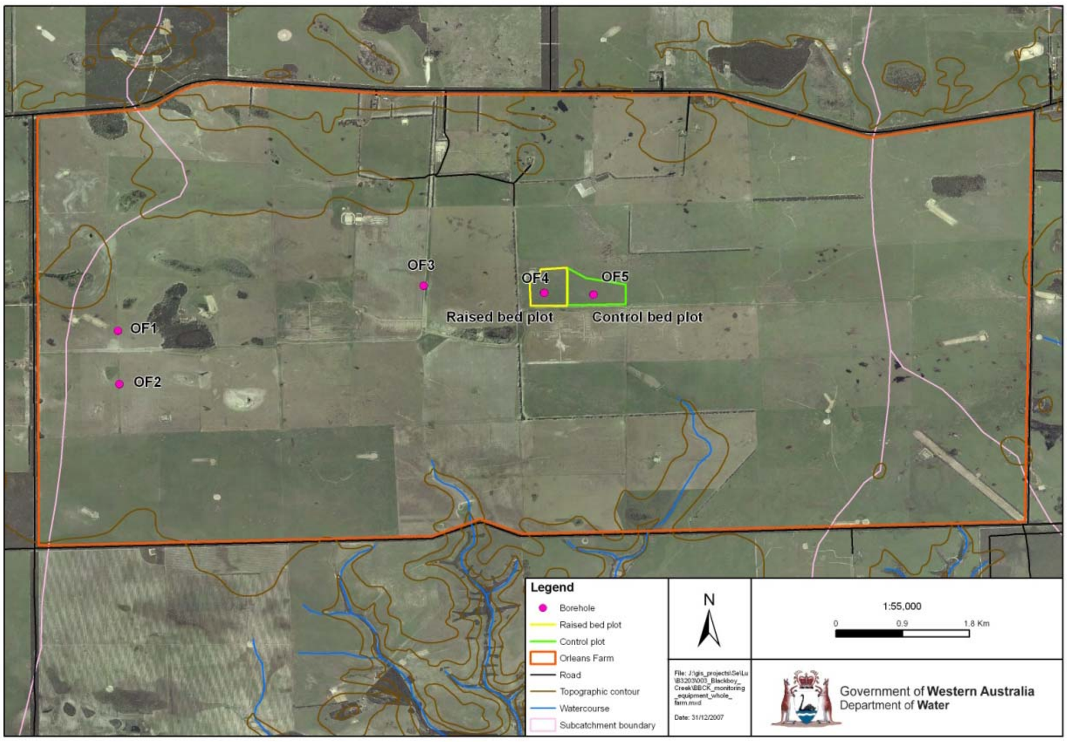

Figure 10 Location of groundwater bores

4 Monitoring results

4.1 Rainfall and evaporation

Total daily rainfall, recorded at the trial site gauging station over the monitoring period 20 July 2004 to 4 February 2007, was 1330 mm, and the mean monthly rainfall for August 2004 to January 2007 (complete months monitored only) was 51 mm (Fig. 11).

Total daily pan evaporation, recorded over the period 3 September 2004 to 4 February 2007, was 2246 mm, and the mean monthly evaporation for October 2004–January 2007 (complete months monitored only) was 77 mm (Fig. 11).

During the period 3 September 2004 to 4 February 2007, evaporation exceeded rainfall by 1027 mm. The difference between the monthly rainfall and evaporation is shown in Figure 12.

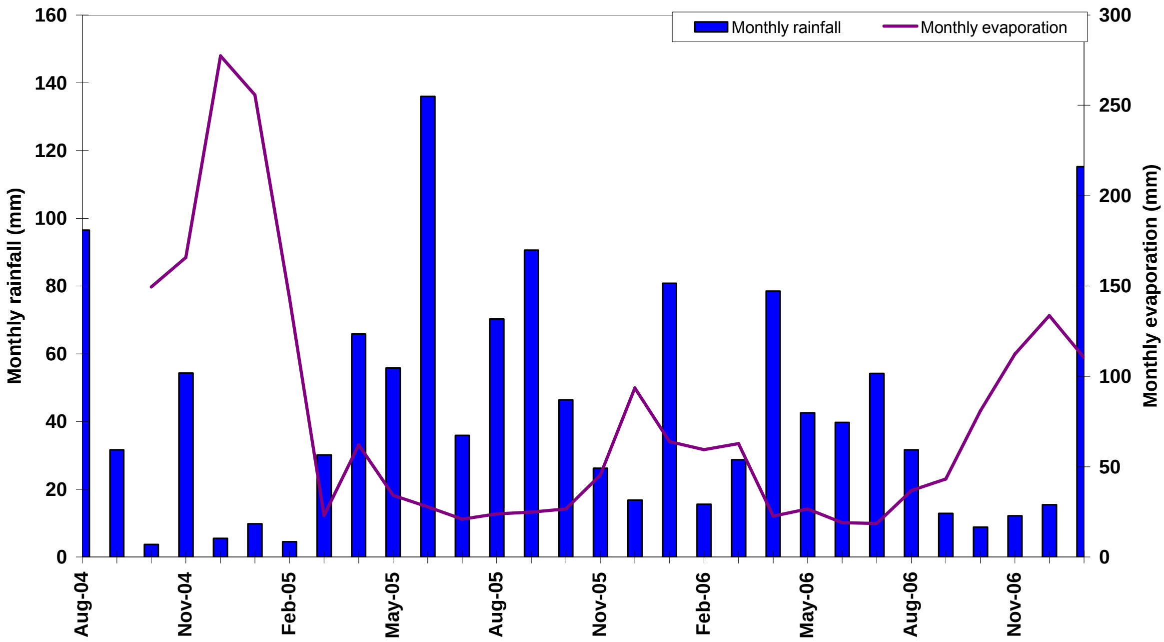

Figure 11 Monthly rainfall and evaporation data collected at the trial site gauging station, August 2004–January 2007

For comparison purposes, data from the Bureau of Meteorology (BOM) station at Esperance (BOM site 009789) is presented in Figures 13 and 14. The BOM station at Esperance is approximately 100 km west of the trial site (Fig. 3). While evaporation rates are interpolated at other BOM stations in the region, this is the closest station to the trial site where daily evaporation is actually measured.

Total daily rainfall, recorded at BOM station 009789 (Esperance) over the monitoring period 20 July 2004 to 4 February 2007, was 1567 mm, and the mean monthly rainfall for August 2004 to January 2007 was 51 mm (Fig. 13). Total daily pan evaporation, recorded over the period 3 September 2004 to 4 February 2007, was 4168 mm, and the mean monthly evaporation for October 2004 to January 2007 was 144 mm (Fig. 14).

Monthly evaporation totals are considerably lower at the Blackboy Creek trial site than at the Esperance BOM station, and there is a marked difference between total monthly evaporation during the first five months of monitoring and the remaining months in the period, which suggests that the evaporation data from the trial site may not be accurate. This is discussed in Section 5.

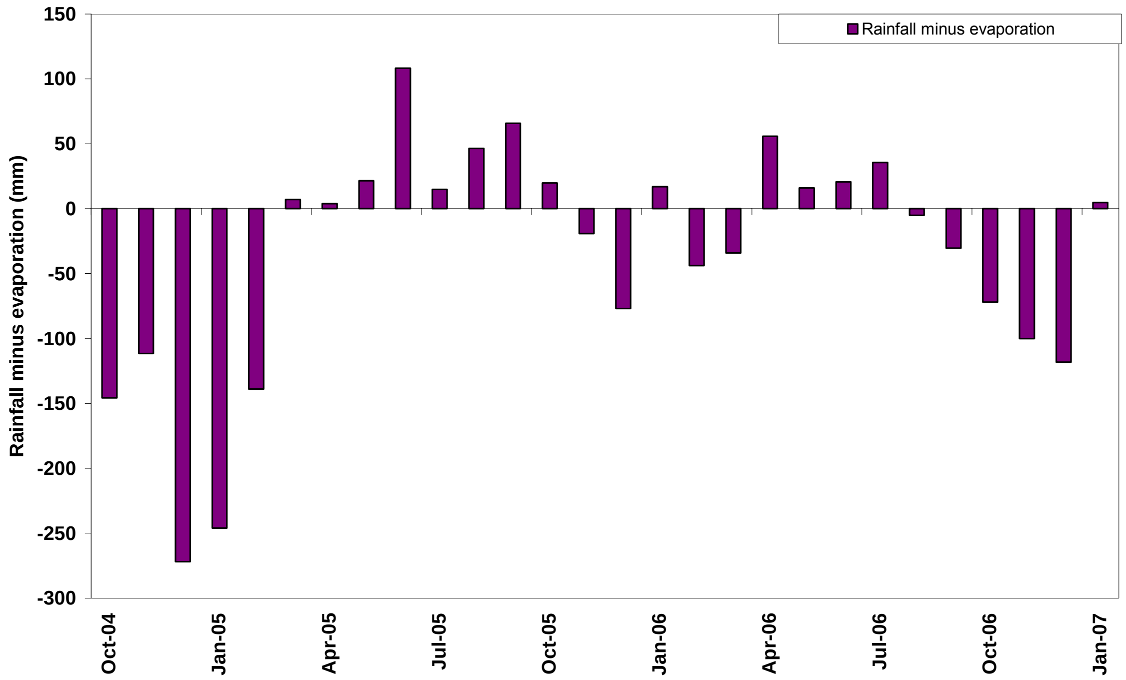

Figure 12 Monthly rainfall minus monthly evaporation at the trial site gauging station, October 2004–January 2007

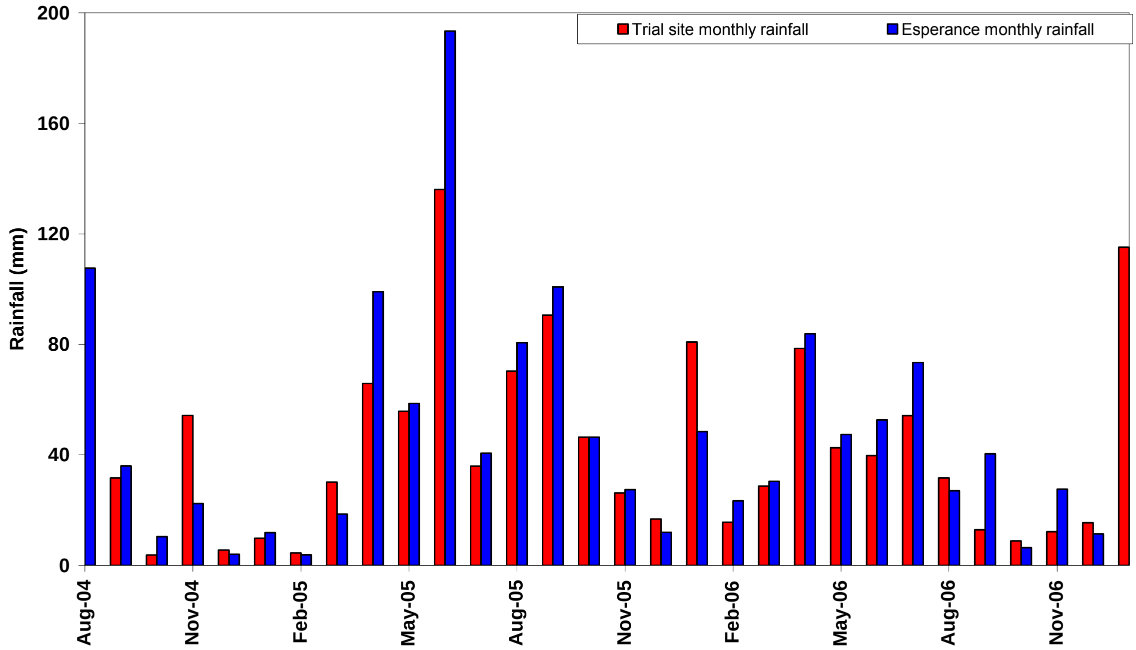

Figure 13 Total monthly rainfall at trial site gauging station at Esperance station (009789), August 2004–January 2007

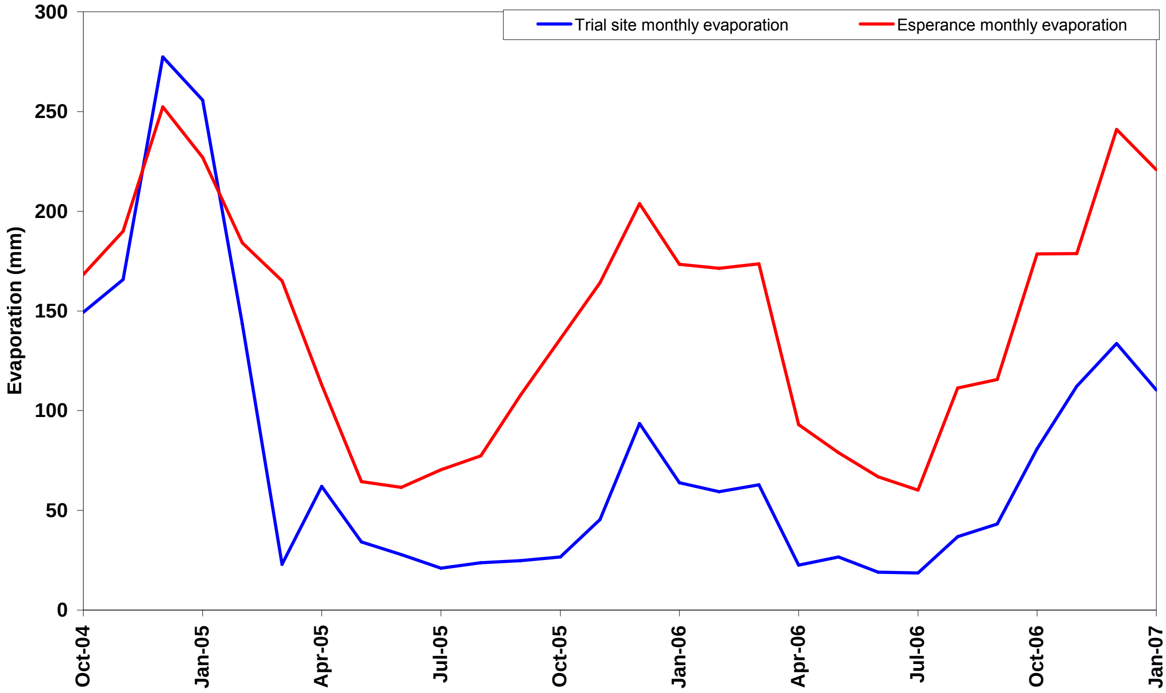

Figure 14 Total monthly evaporation at trial site gauging station and Esperance station, August 2004–January 2007

4.2 Surface water flows

4.2.1 Discharge

The quality (Q) of most stage data from 601014 (control) and 601013 (raised bed) has been labelled as 'very good' (Q1), or 'very good with corrections applied' (Q2). There were periods in late March 2005, late October 2005 and most of March 2006 at site 601013 when data was estimated to be 'good quality' (Q4). A more detailed explanation of the quality coding system is outlined in Appendix D (the rating curve used to convert stage data to discharge is given in Appendix B).

During the monitoring period 29 July 2004–4 February 2007 the total surface water discharge from the raised beds was 4754 kL and 5055 kL from the control site. Note that the raised bed area was smaller (19.2 ha) than the control bed area (22.9 ha) and so for the values to be representative and easily compared, all calculations from here onwards will be normalised to these areas (hectares) respective to their plot.

The mean daily discharge to 9 am from the raised bed plot was 0.027 mm and 0.024 mm from the control bed plot.

The highest daily discharge recorded from the raised bed plot was 3.98 mm on 1 April 2005, in response to a rainfall event of 34 mm on the same day and 25.4 mm the day prior. This was after a period of several months of little rainfall (Fig. 15). The highest daily discharge from the control was 2.81 mm on 18 June 2005, following two weeks of persistent rain.

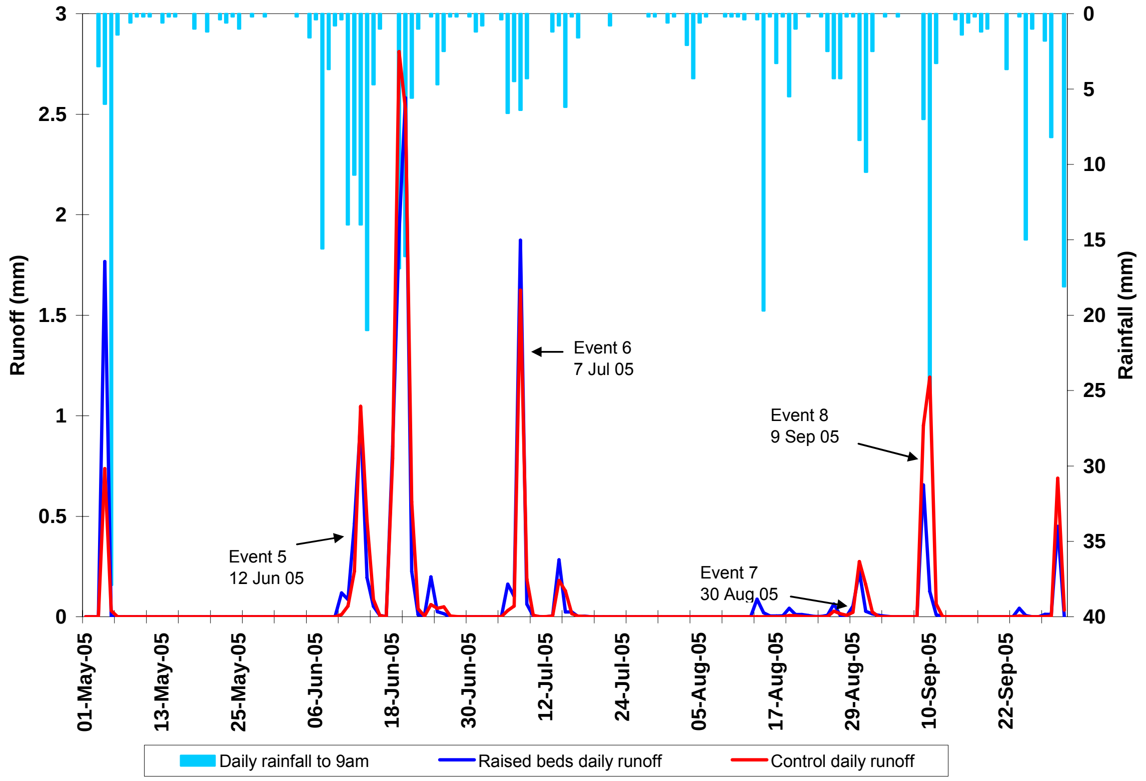

Figure 15 Comparison of daily surface water flow from raised beds and control with rainfall

The mean monthly discharge was 0.82 mm from the raised bed plot and 0.74 mm from the control bed plot.

Monthly total discharge from the raised beds was higher than that from the control beds for 11 of the 30 months of the monitoring period (excluding partial months on July 2004 and February 2007) and higher from the control beds for 6 of the 30 months. For two months only the raised beds generated discharge and no discharge was recorded from either plots during the remaining 10 months (Fig. 16).

Table 4 shows the number of days when total daily discharge fell within specified discharge categories, and the proportion of days of each category as a percentage of the total number of monitoring days for each plot.

The proportion of days with the total daily discharge was 18.2% for the raised beds and 13.8% for the control plot.

The number and proportion of days of high discharge was greater for the control beds than the raised beds. High discharge (exceeding 100 kL) was recorded on 14 days (1.5% of the monitoring days) for the control bed, and on 10 days (1.1% of the total number of monitoring days) for the raised beds.

Percentage of days of low discharge (between 0.01 kL and 5.99 kL) was 12.1% for raised beds and 7.8% for the control beds.

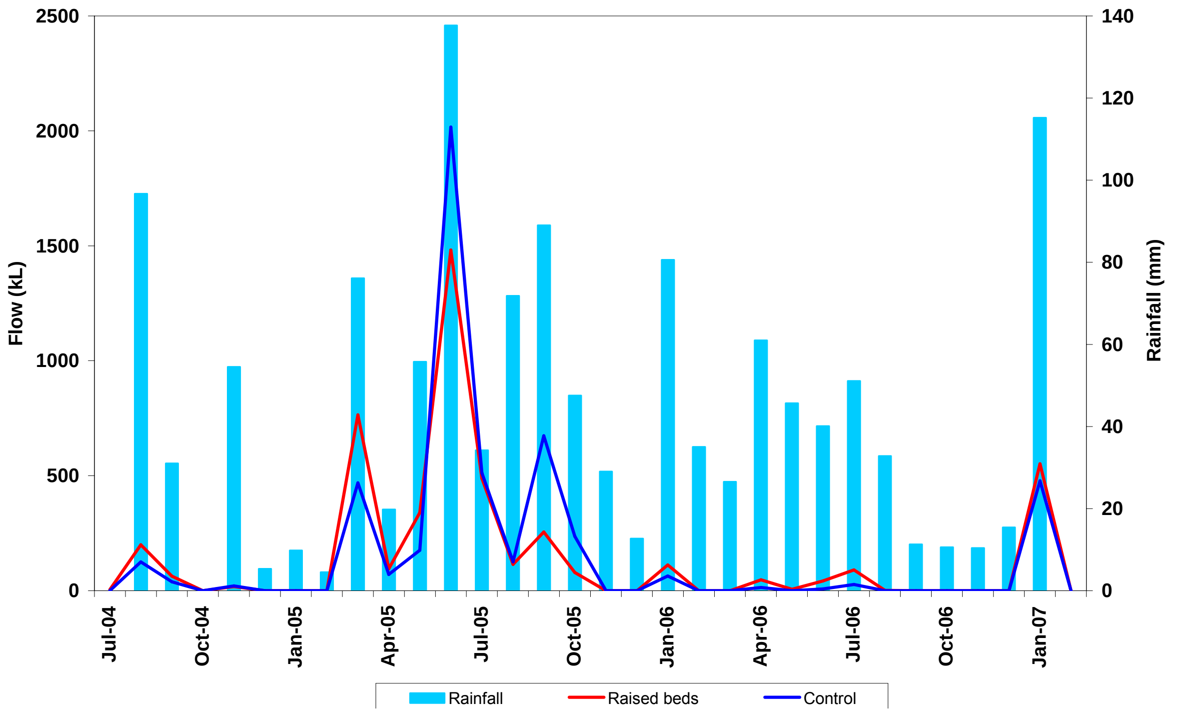

Figure 16 Comparison of total monthly surface water flow (kL) of raised and control beds with rainfall

Table 4 Days and discharge volumes during the monitoring period

Total daily discharge (kL)	Raised bed		Control bed	
	Days	% of days with discharge	Days	% of days with discharge
No flow	753	81.8	794	86.2
0.01–5.9	111	12.1	72	7.8
6.0–10.9	11	1.2	16	1.7
11.0–15.9	6	0.7	9	1.0
16.0–20.9	6	0.7	3	0.3
21.0–40.9	16	1.7	6	0.7
41.0–100	8	0.9	7	0.8
> 100	10	1.1	14	1.5

4.2.2 Runoff

Discharge volumes were normalised into millimetres of runoff for the respective plot areas. Total runoff from the raised bed plot was 24.8 mm for the monitoring period (29 July 2004 to 4 February 2007) compared with 22.1 mm from the control plot. The runoff from the raised beds represented 1.87% of the rainfall over the monitoring period and 1.67% from the control beds.

Figure 17 shows the cumulative total daily runoff and Figure 18 the monthly runoff totals from the raised beds and control plot catchments compared with rainfall.

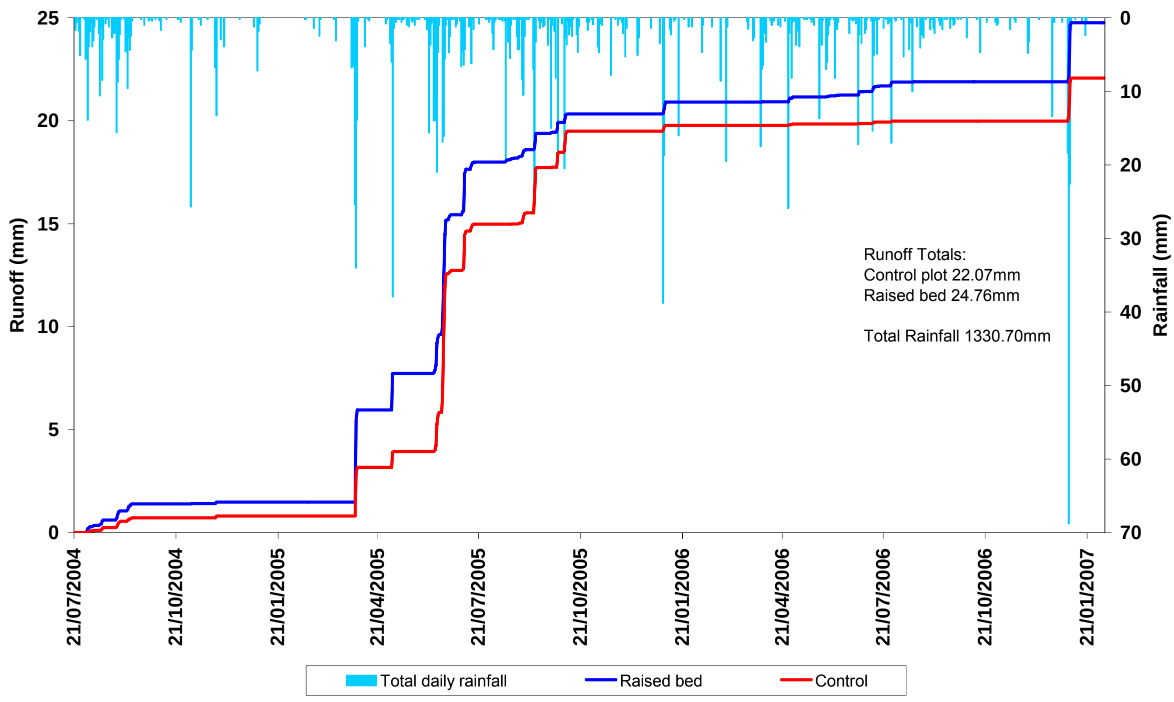

Figure 17 Cumulative total daily runoff for the raised beds and control plots

The mean monthly runoff was 0.63 mm from the raised beds and 0.47 mm from the control beds.

Monthly total runoff from the raised beds was higher than that from the control for 14/30 months (excluding partial months in July 2004 and February 2007). Monthly total runoff was higher from the control plot in 2 of the 30 months. Equal runoff was recorded during 1 month and 0 mm or <0.01 mm of discharge was recorded from both plots for the remaining 10 months (Fig. 18).

4.2.3 Peak flow and runoff events following prolonged dry periods

All four most significant rainfall events during the monitoring period occurred after a prolonged dry period (Fig. 19) with <5 mm of rain in the preceding week and <10 mm within the preceding two weeks. This provides discrete datasets with clearly defined start and end times for each flow event.

It is important to note that while these are the four largest rainfall events they do not strictly represent the four largest runoff events. For example, the runoff events between May and October 2005 received frequent rainfall and are often larger than the 4 January 2006 event. This series of events is analysed in Section 4.2.4.

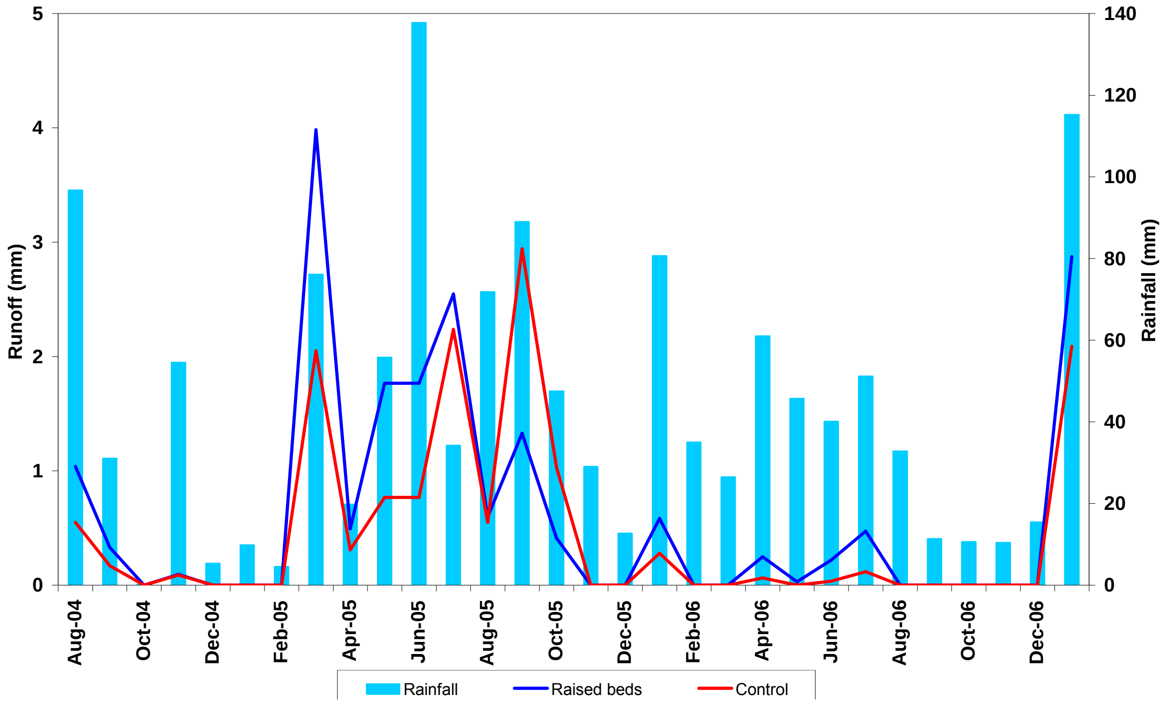

Figure 18 Total monthly runoff from the raised bed and control plots, and rainfall

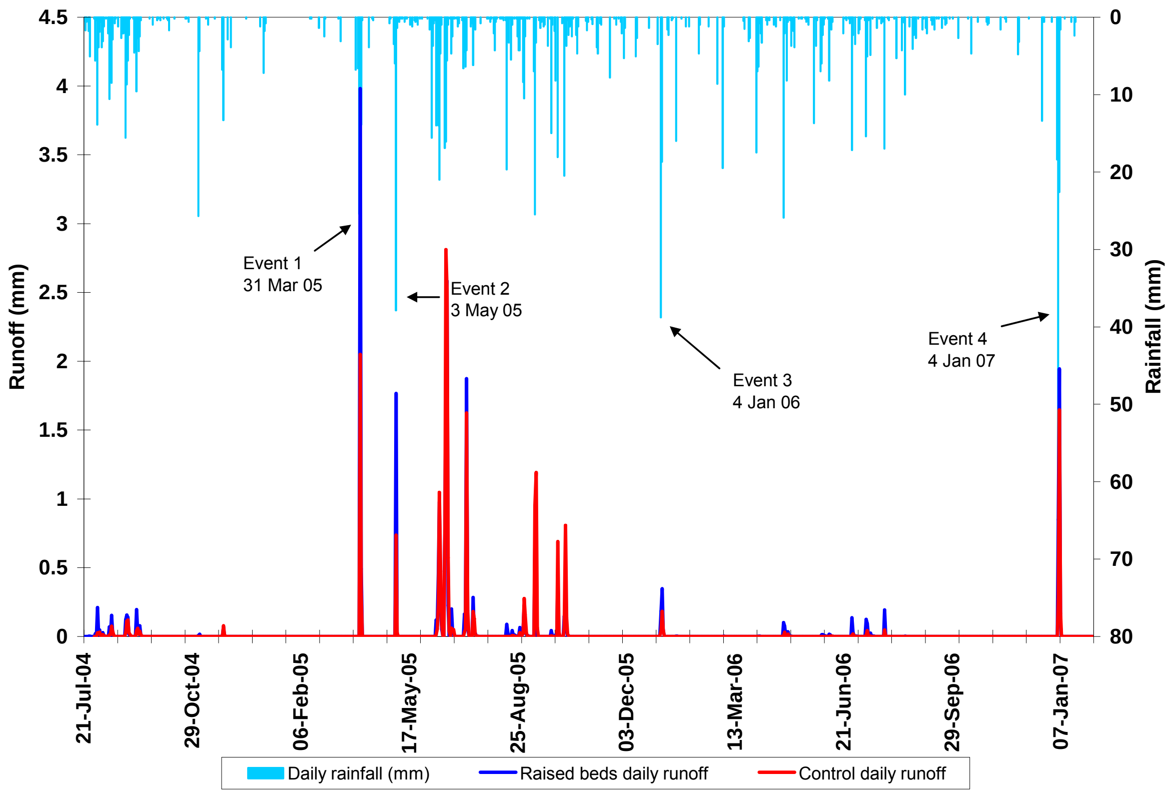

Figure 19 Peak rain events compared with total daily runoff (mm)

The highest flows during the monitoring period were observed on 31 Mar 2005 (Event 1, Table 5) with 45.50 L/sec (2.37 L/s/ha) recorded from the raised bed and 19.70 L/sec

(0.86 L/s/ha) from the control plot. The peak instantaneous flow rates from each of the outlined four largest rainfall events are summarised in Table 5.

Table 5 Events summary (Events 1–4)

		Raised bed		Control		
Event	Peak date	Peak time	Peak (L/s/ha)	Peak time	Peak flow (L/s/ha)	Ratio L/s/ha
1	31–Mar–05	16:45	2.37	16:45	0.86	2.75:1
2	3–May–05	19:30	2.40	19:40	0.31	7.62:1
3	4–Jan–06	10:00	0.15	10:10	0.07	2.25:1
4	4–Jan–07	16:05	1.51	16:25	0.54	2.81:1

The peak flows (L/s/ha) are significantly higher from the raised beds in all four rainfall events studied (2.25:1 to 7.62:1, Table 5). The peak flows during Events 2 and 4 occurred 10 minutes earlier from the raised bed than from the control plot and 15 minutes earlier during Event 3. This may also suggest a more rapid response in runoff during high rainfall events from raised beds, assuming the same rainfall start time on the two plots. Figure 20 shows the four rainfall and subsequent runoff events on an hourly basis. The rainfall is cumulative for the period of runoff and all events occur over a 78-hour period.

Runoff from the raised beds appears just before runoff from the control plot in Events 2 and 4 (Fig. 20). Runoffs in Events 1 and 3 appear to start simultaneously.

The total runoff (mm) from the raised beds is significantly greater during the four rainfall events studied (ratios of 1.38:1 to 2.31:1; Table 6) with runoff as % of rainfall between 1.5% (Event 3) and 5.4% (Event 1) compared with only 0.3% and 2.3% for the same events from the control plot. Events 1, 2 & 4 were all greater than the overall 1.9% for raised bed whereas only 1 & 4 were greater than the overall 1.7% for control plot.

The two sites have similar duration of runoff in Events 2 and 3. The control plot has a longer runoff period for Event 4 and during Event 1 the raised bed site maintains runoff for a longer period (Table 6). Following the peak, runoff from the control plot can be seen (Fig. 19) to maintain a marginally higher runoff rate toward the end of the recession limb except during Event 1 where the raised bed maintains a runoff rate of <0.01 mm (not visible at this scale) for a longer period.

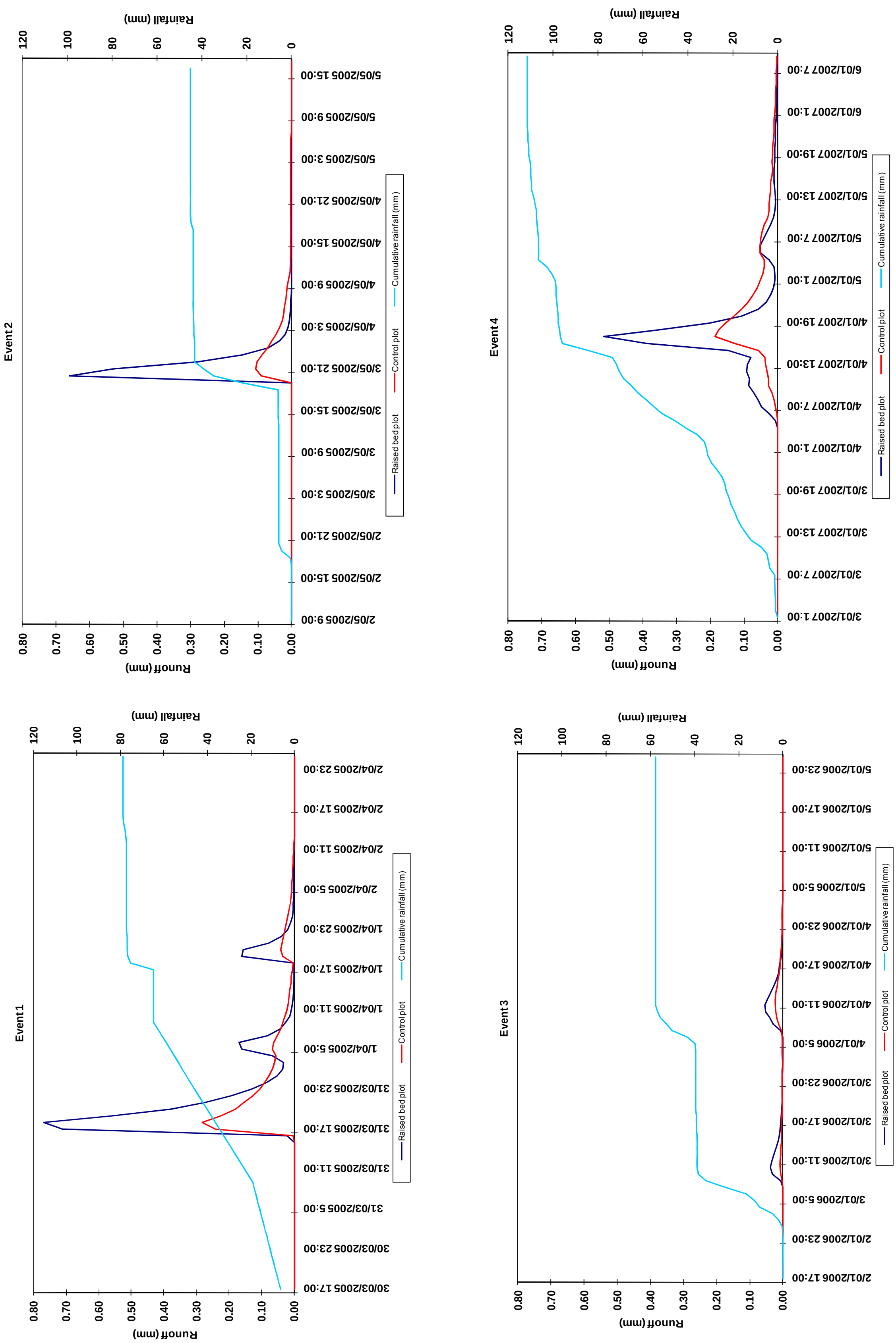

Figure 20 Hourly runoff from the raised beds and control plots for Events 1–4

Runoff from the raised beds appears just before runoff from the control plot in Events 2 and 4 (Fig. 20). Runoffs in Events 1 and 3 appear to start simultaneously.

The total runoff (mm) from the raised beds is significantly greater during the four rainfall events studied (ratios of 1.38:1 to 2.31:1; Table 6) with runoff as % of rainfall between 1.5% (Event 3) and 5.4% (Event 1) compared with only 0.3% and 2.3% for the same events from the control plot. Events 1, 2 & 4 were all greater than the overall 1.9% for raised bed whereas only 1 & 4 were greater than the overall 1.7% for control plot.

The two sites have similar duration of runoff in Events 2 and 3. The control plot has a longer runoff period for Event 4 and during Event 1 the raised bed site maintains runoff for a longer period (Table 6). Following the peak, runoff from the control plot can be seen (Fig. 19) to maintain a marginally higher runoff rate toward the end of the recession limb except during Event 1 where the raised bed maintains a runoff rate of <0.01 mm (not visible at this scale) for a longer period.

Table 6 Comparison of runoff from the raised beds and control plots for Events 1–4

Event	Rainfall (mm)	Duration of rainfall (hrs)	Raised beds			Control			Ratio Total Runoff (mm)
			Duration (hrs)	Runoff (mm)	Runoff as % rainfall	Duration (hrs)	Runoff (mm)	Runoff as % rainfall	
1	80.60	96	71	4.32	5.36	46	2.33	2.89	1.85:1
2	48.40	86	41	1.77	3.65	43	0.76	1.58	2.31:1
3	39.50	36	55	0.58	1.47	54	0.28	0.70	2.09:1
4	109.80	71	59	2.87	2.62	73	2.09	1.90	1.38:1

4.2.4 Peak flow and runoff events May to September 2005

The period May to September 2005 was dominated by persistent rainfall compared with the overall study period and produced some significant runoff events. Four events within this period have been randomly chosen for further analysis (Fig. 21).

Peak instantaneous flows (L/s/ha) are significantly greater from the raised bed during three of the rainfall events studied (1.28:1 to 1.62:1, Table 7). Event 8 was only slightly smaller for the raised beds than the control with a ratio of 0.91:1. The peak flows for the raised beds during all the events were at least 2 hours earlier than for the control site (Table 7). This may also suggest a faster runoff response during high rainfall events from raised beds but this assumes the rain started at the same time on the two plots. Figure 22 presents hourly data for the four rainfall and subsequent runoff events.

Total runoff (mm) from the control beds is greater during three of the four events studied (0.36:1 to 0.95:1; Table 6) with runoff as % of rainfall between 3.72% (Event 7) and 7.77% (Event 8) compared with 2.26% and 2.79% for the same events from the raised beds (Table 8). In Event 6 the raised bed and control plots have higher runoff ratios and higher percentages of runoff to rainfall (20.5% for raised beds and 18.9% for control) than in the other events. These findings are supported by the shallow bore data.

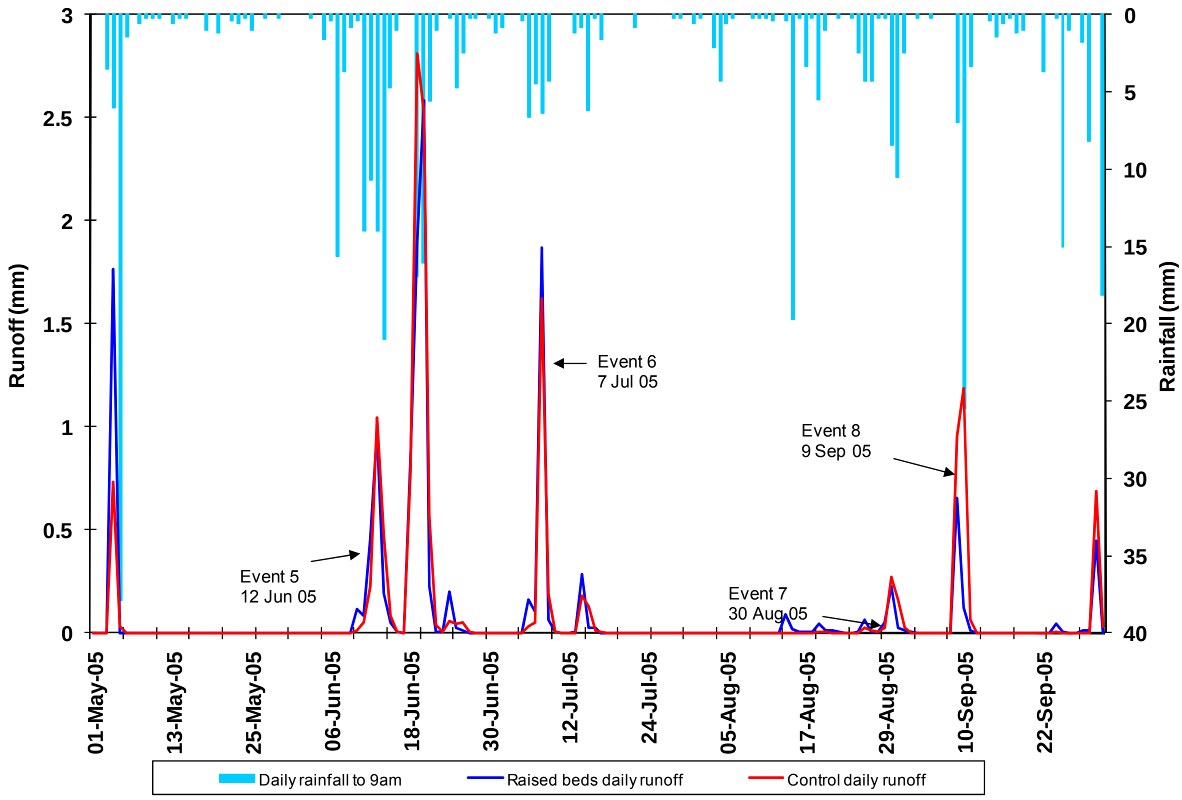

Figure 21 Peak rain events compared with total daily runoff (mm), May to October 2005

Table 7 Events summary (Events 5–8)

		Raised beds		Control		
Event	Peak date	Peak time	Peak flow (L/s/ha)	Peak time	Peak flow (L/s/ha)	Ratio L/s/ha
5	12–Jun–05	22:10	0.22	0:05	0.17	1.28:1
6	7–Jul–05	19:25	0.53	21:45	0.33	1.62:1
7	30–Aug–05	4:35	0.11	9:45	0.08	1.38:1
8	9–Sep–05	10:15	0.48	12:00	0.53	0.91:1

Note: The peak time of Event 5 on the control plot is 00:05 on 13 Jun 2005.

Table 8 Comparison of runoff from the raised bed and control plots for Events 5–8

			Raised Bed			Control			
Event	Rainfall (mm)	Duration (hr)	Duration (hr)	Runoff (mm)	Runoff as % of rainfall	Duration (hrs)	Runoff (mm)	Runoff as % of rainfall	Ratio total runoff (mm)
5	50.10	97	152	1.75	3.50	127	1.85	3.70	0.95 : 1
6	9.90	24	89	2.04	20.57	88	1.87	18.90	1.09 : 1
7	12.20	38	114	0.28	2.26	85	0.45	3.72	0.61 : 1
8	28.40	42	80	0.79	2.79	77	2.21	7.77	0.36 : 1

Note: The shallow bore data supports these ‘unusual’ high values for Event 6.

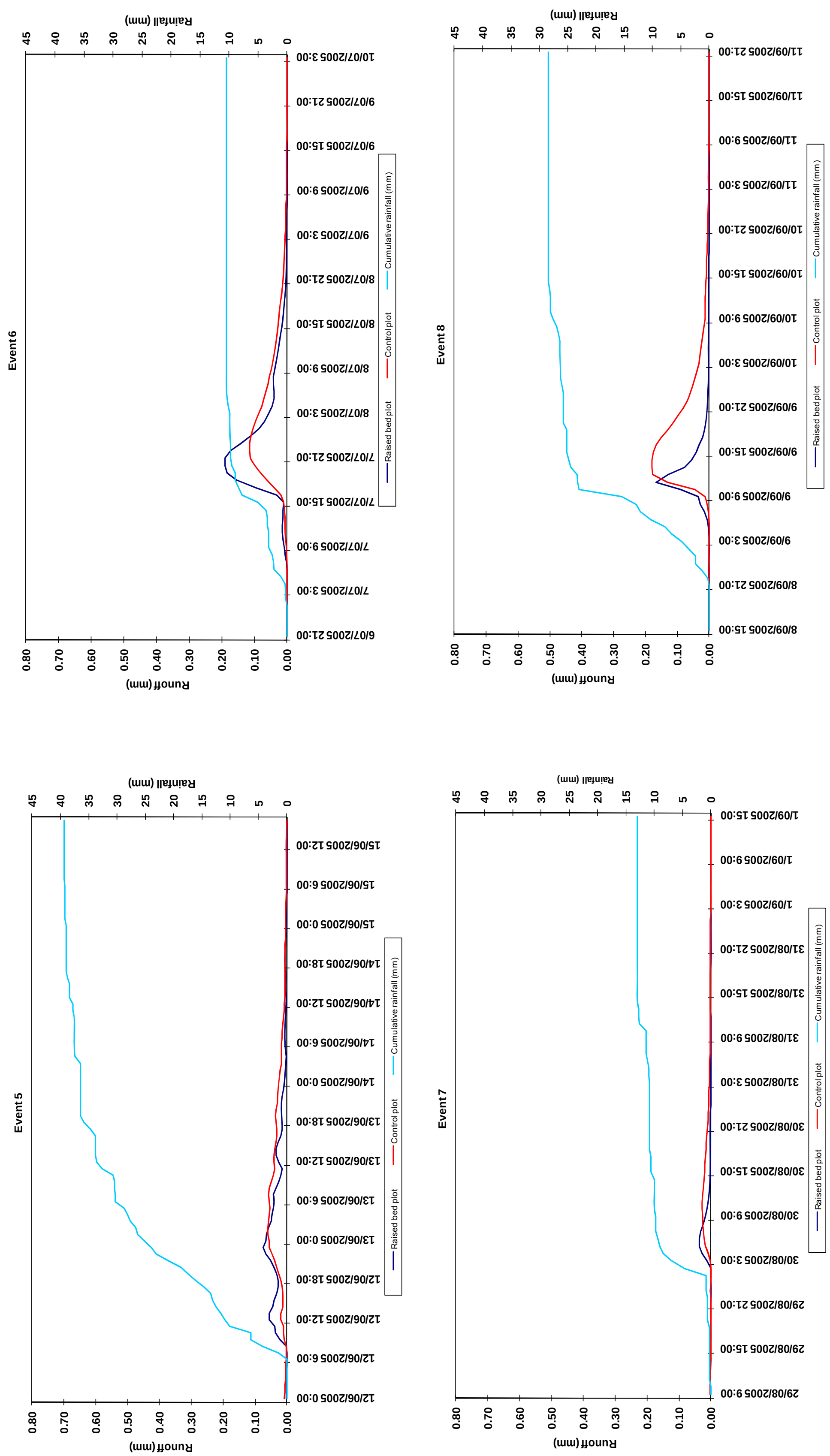

Figure 22 Hourly runoff from the raised beds and control plots for Events 5–8

Note: as these storm events occurred during winter there were small baseflows from both plots. Each hydrograph was examined to establish a start and end time for runoff from the storm.

In Event 5 in late March 2005 (Fig. 22) 6.8 mm of rainfall was recorded on 27 March; 6.6 mm on 29 March; 25.4 mm on the 30; 34 mm on the 31 March and 13.9 mm on 1 April. This event produced a peak runoff of 3.98 mm from the raised beds on 31 March but only 2.05 mm on 31 March from the control bed. Minor runoffs (0–0.49 mm) were recorded from the raised beds on the following three days, while runoff from the control bed was recorded for only one further day (0.31 mm on 1 April).

A second large rain event not long after, in early May 2005 (Fig. 21), provided one main fall on 3 May 2005 of 37.9 mm with recorded flows this day of 1.77 mm from the raised beds and 0.74 mm from the control beds.

A large summer event on 2–3 January 2006 of 57.5 mm in total (Fig. 21) produced small flows of 0.58 mm from the raised beds and 0.28 mm from the control beds over the days 2–4 January.

In another large summer event, in early January 2007, when 111.4 mm fell between 2–5 January, there was serious flooding in the Esperance township (around 100 km west) at this time. At Blackboy Creek, 2.87 mm was recorded from the raised beds on 3–5 January, and 2.09 mm from the control beds between 3 and 6 January.

The largest runoff produced by the control beds occurred after a prolonged period of medium rainfall in early–mid June 2005; highest runoff from the raised beds resulted from one large event in March 2005 that followed a long dry period.

Figures 21 and 22 present the same four largest rain events and the pattern that peak flows displayed over these events broken down into hourly intervals.

For these events, the flow from raised beds peak higher and slightly earlier than from the control beds. In the March and May 2005 events, the control beds flows recede over a longer time than the raised beds. In the January events, both bed types have similar flow drop-off patterns.

4.2.5 Comparison of peak events, rainfall and discharge

The events for this analysis were the same as those used for the peak flows and runoff events in the above sections.

In both experimental plots, after a rainfall event, peak runoff in winter occurred 15–20 hours later while peak runoff in summer was more than 25 hours later.

Peak discharges in summer were generally two-fold higher on raised beds than on the control bed, with the exception of Even 3a/3b (Table 9). Raised beds peak discharge was also higher than the control in winter, with the exception of Event 8.

From the raised beds, peak runoff occurred slightly earlier in summer (~5 minutes) with total discharges consistently higher than for the control beds.

In winter the runoff from the raised beds peaked 3 or more hours earlier than from the control, with lower total discharges.

There were only three months in the overall experimental period where only the raised beds produced runoff: July 2004, May 2006 and August 2006. Runoff never occurred just from the control plot.

Table 9 Peak events and runoff for rainfall Events 1–8

	Event	Plot	Time from start of rainfall to start of peak (hh:mm)	Time to peak (hh:mm)	Rainfall received at start of peak (mm)	Rainfall received at peak (mm)	Max discharge at peak (L/s/ha)	Total discharge (mm)
Summer	1 (30/3/05–3/4/05)	Raised	33:15	34:30	47.7	49.9	2.37	4.32
		Control	33:15	34:30	47.7	49.9	0.86	2.36
	2 (2/5/05–5/5/05)	Raised	25:00	25:35	21.8	33.5	2.4	1.77
		Control	25:10	25:45	29.4	33.7	0.31	0.77
	3a (1/1/06–4/1/06)	Raised	6:25	8:20	30.8	37.4	0.11	0.23
		Control	6:30	8:25	39.4	55.8	0.13	0.073
	3b (4/1/06–6/1/06)	Raised	0:45	5:30	31	37.4	0.03	0.36
		Control	0:15	5:40	38.6	56	0.07	0.21
	4 (2/1/07–6/1/07)	Raised	27:00	32.55	41.4	65.2	0.26	2.87
		Control	27:45	32.55	45.2	65.2	0.08	2.08
Winter	5 (12/6/05–17/6/05)	Raised	15:00	15:30	1	23.0	0.22	1.55
		Control	17:20	18:40	1.6	25.8	0.17	2.08
	6 (6/7/05–11/7/05)	Raised	2:20	17:40	0.4	9.4	0.56	2.05
		Control	3:10	20:10	1	9.6	0.33	1.88
	7 (29/8/05–4/9/05)	Raised	7:10	10:15	3	8.6	0.11	0.29
		Control	6:50	15:25	2.4	9.6	0.08	047
	8 (8/9/05–13/9/05)	Raised	5:35	12:45	5.4	22.7	0.48	0.79
		Control	8:05	14:30	9.2	23.1	0.53	2.21

4.2.6 Water quality/nutrient loads

Continuous conductivity/salinity and temperature

Salinity data for both plots and rainfall in Figure 23 illustrate a general correlation between salinity and rainfall events. The salinities of water from the raised and control beds peaked at 631 mg/L TDS and 391 mg/L respectively on 1 December 2004 (Fig. 23). Salinities from the raised and control beds were regularly recorded, with the lowest value being 10 mg/L. The mean salinity over the whole monitoring period was 110 mg/L (raised beds) and 73 mg/L (the control plot). The highest salinity was recorded after a short 25 mm rain event that followed two months of little rain in late 2004.

Except for a few days in May 2005, salinity from the raised beds was consistently higher. On 15 May 2005, the salinity from the control plot reached 335 mg/L TDS; on 17 May 2005 salinity from the raised beds reached 298 mg/L TDS.

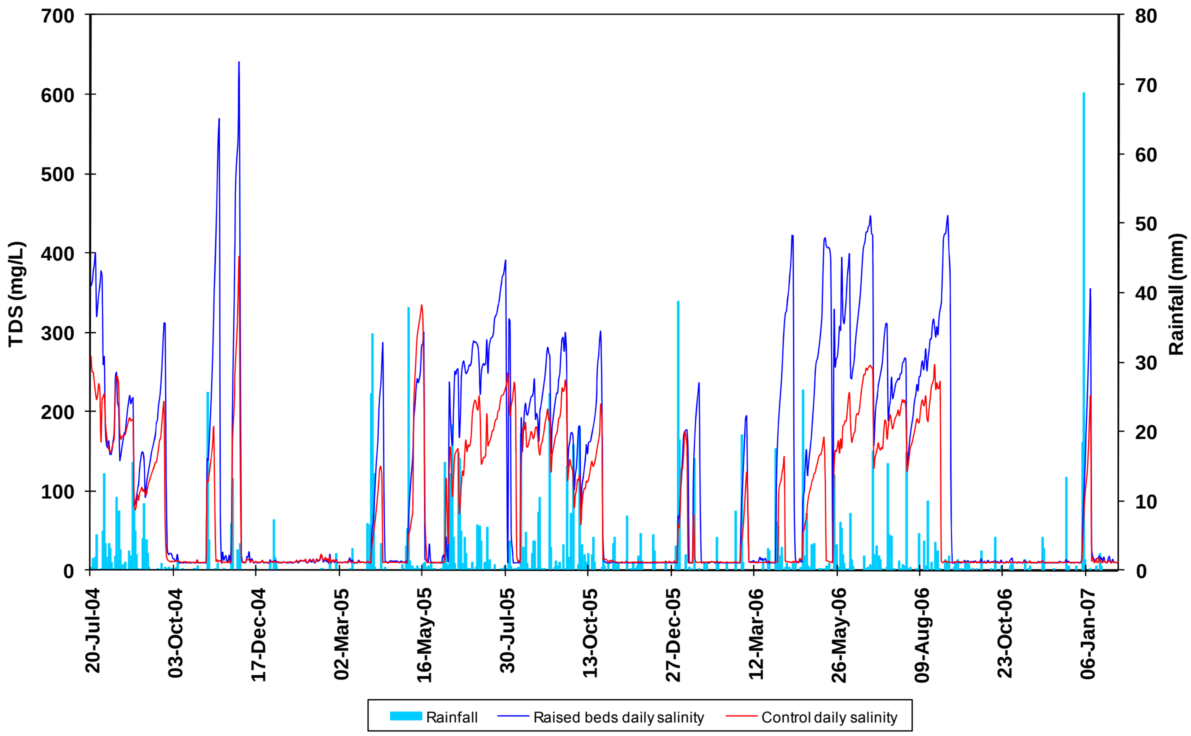

Figure 23 Daily surface water salinities from the raised and control beds

Salt loads for raised beds and control plots

The salt loads observed at the Blackboy Creek study site were highest in April–December 2005. The rest of the time there was very little salt movement (Fig. 24). It appears that most salt movement from both sites occurred when rainfall was consistent. There does not appear to be much of a difference between the salt loads from the raised or control bed plots. The highest salt load movement comes from the raised bed plot, which suggests that the raised beds may have the potential to move more salt from the site than the control beds but further testing would have to be conducted to support this statement.

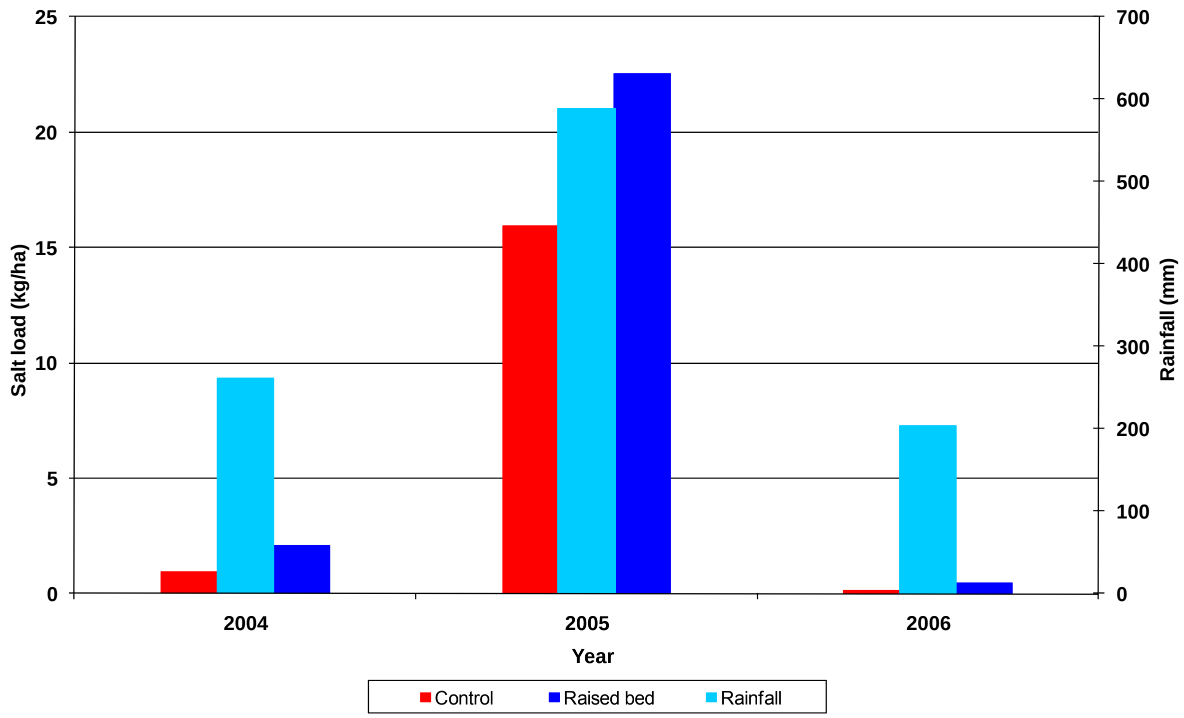

Figure 24 Comparison of annual salt loads in raised beds and control sites

Discontinuous nutrient measurements

The concentration of total nitrogen varied between 2.2 and 50 mg/L from the raised beds and 1.9 and 66 mg/L for the control plot (Table 10). On five of the sampling occasions water from the raised beds had higher nitrogen levels than the control and the control had higher nitrogen concentrations on four occasions.

The surface water nitrogen concentrations have a seasonal pattern for both the control and raised bed plots: nitrogen levels are higher in winter than in summer, suggesting that higher surface water nitrogen will follow periods of persistent rain (Table 10).

Runoff from the raised beds had higher phosphorus levels than the control on six of the sampling occasions, while the control was higher on two occasions (Table 10). Runoff from both plots had the same levels on one occasion (April 2006).

Like the nitrogen levels, phosphorus levels have seasonal patterns.

The concentration of total suspended sediments (TSS) in the runoff from the raised beds varied between 118 (22 June 2005) and 1390 mg/L (2 August 2004) and in the control runoff ranged from 163 (7 July 2005) to 1310 mg/L (2 August 2004). During the monitoring period, suspended sediment levels were highest in winter 2004.

The turbidity of surface water ranged between 130 and 3000 NTU (Nephelometric Turbidity Units) for the raised beds (on 22 June 2005 and 2 August 2004), and 170 and 1800 NTU for the control (on 7 July 2005 and 2 August 2004) (Table 10). These highs and lows corresponded with the variations in sediments.

Temperature and pH were manually sampled twice.

Table 10 Discontinuous nutrient measures

	Raised beds	Control
Total nitrogen (mg/L)	2.2–50	1.9–66
Total phosphorous (mg/L)	0.19–0.75	0.17–0.88
Turbidity (NTU)	130–3000	170–1800
Total suspended sediments (TSS) (mg/L)	118–1390	163–1310

4.3 Groundwater

4.3.1 Drilling results

Geology

The drill logs recorded during bore construction in April 2004 indicate that the site geology consists of shallow Quaternary sediments (sands) to 0.3 m over Tertiary sediments of clay and siltstone. The sands were generally a fine to medium grained grey–brown while the clays varied from grey–green to yellow, containing calcrete and quartz grains. Silty clay (weathered granite/saprolite) was intercepted at 4.0–5.0 m below ground level (Refer to Appendix A for detailed descriptions).

Groundwater interception

Groundwater was intercepted at a depth of around 16 m during drilling of four of the five deep bores (OF2D, OF3D, OF4D and OF5D) which were drilled to 20 m depth or greater. The remaining deep bore (OF1D) was drilled to a depth of 11 m (BGL), and groundwater was not intercepted. The bore number system is OF = Orleans Farm, with 'D' representing deep, 'S' for shallow and 'INT' for intermediate depth bores.

Groundwater was not intercepted while drilling the four intermediate bores (8 m in depth) nor while drilling the five shallow bores (4 m in depth), although water entered the shallow bores during the monitoring period after significant rainfall.

4.3.2 Groundwater levels

Shallow bores

The groundwater depth in the shallow bore on the raised bed plot (bore OF4S) was measured manually on 12 occasions during the monitoring period. The bore was found to be dry on six occasions and the groundwater level was 0.8–3.9 m BGL on the other six visits.

The shallow bore on the control plot (bore OF5S) was monitored on the same 12 occasions during the monitoring period. It was dry on eight occasions, and water was at 0.30–2.58 m BGL on the remaining four visits.

The groundwater levels in bores OF4S and OF5S followed a similar trend (Fig. 25), with the level lower in the raised bed bore, except in March and May 2006 when the raised bed bore (OF4S) contained water and the control bed bore (OF5S) was dry.

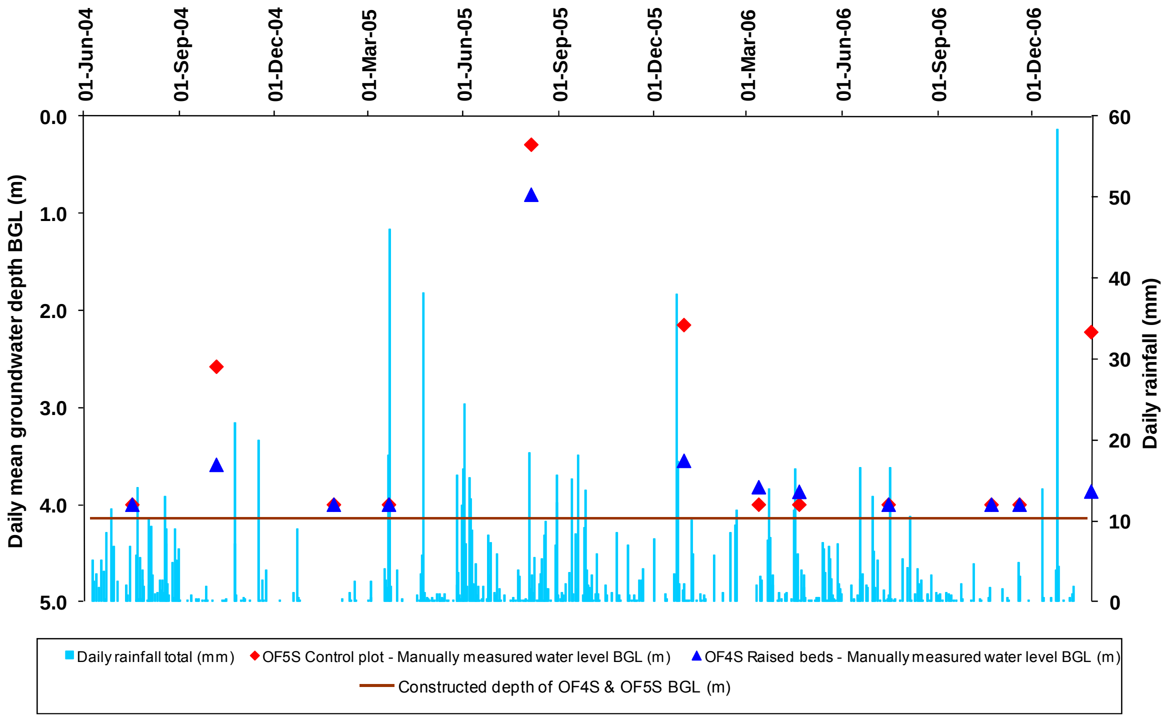

Figure 25 Comparison of manually measured groundwater levels in bores OF4S (raised bed) and OF5S (control bed)

Groundwater levels in the regional control bores OF1S and OF2S were measured on 13 occasions and in bore OF3S on 20 occasions. All three bores were dry during the visits July 2004–April 2005. Between April 2005 and February 2007 groundwater levels in bore OF1S were 1.15–4.13 m BGL and the levels in bore OF2S were 2.42–4.63 m. Groundwater levels followed a similar pattern of rise and fall in these two bores.

Groundwater in bore OF3S was considerably shallower than in the other bores, with groundwater 0.08–1.92 m deep in April 2004 and February 2007. Due to the paucity of data no conclusions can be made to explain these differences except that local drainage and soil conditions at each bore site must play a part.

Figure 26 presents shallow regional bore groundwater level data with rainfall. Manual monitoring provides a 'snapshot' of the groundwater level, but does not record changes between monitoring occasions. Groundwater in these shallow bores is episodic and the levels due to sandy soils, are very responsive to rainfall. It would be inappropriate to draw conclusions about recharge differences due to overall lack of data.

Intermediate bores

Intermediate depth bores OF2INT, OF4INT and OF5INT were monitored on 12 occasions and OF3INT was visited on 20 occasions. All four bores were dry on all occasions.

Deep bores

The consistency in groundwater levels measured in these bores could suggest that the deep groundwater did not respond to changes in rainfall (Fig. 27) but it would be inappropriate to draw this conclusion from 'snapshot' rather than continuous data.

The regional control bore OF1D was monitored 13 times and was dry each time. OF2D was also monitored on 13 occasions, and was dry on 3 visits, with the groundwater between 18.47–18.84 m BGL on the remaining visits. Bore OF3D was wet on all 20 occasions, with the groundwater depth varying between 13.0 and 13.2 m.

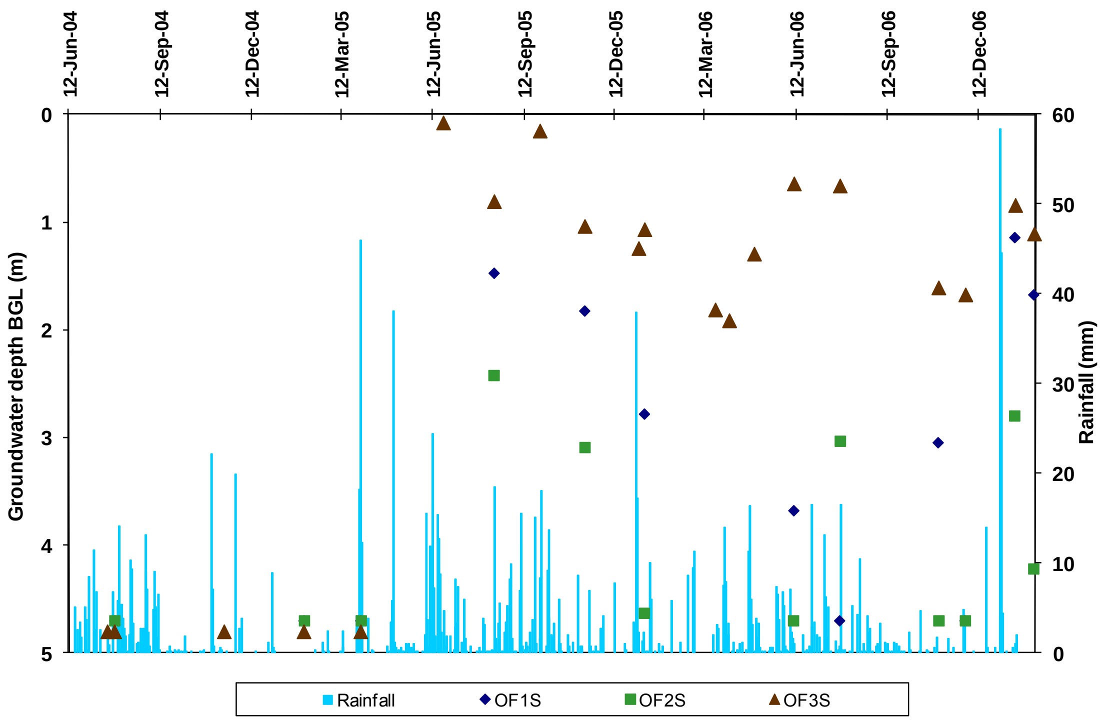

Figure 26 Shallow bore (regional control bores) groundwater depths

The depth to groundwater in the deep bores decreased across the study site from west to east (Table 11). This trend may suggest a change in the depth across the site, but the data is not conclusive because the change in ground level between the bore locations is not known as the bores were not surveyed.

Longer term monitoring data are required to establish any trends in groundwater depths.

Table 11 Mean depth to groundwater (m below ground level) in deep bores OF1D to OF5D

Bore	OF1D	OF2D	OF3D	OF4D	OF5D
Location – Eastings (m)	485,541	485,557	488,981	490,338	490,892
Mean average groundwater level (m BGL)	Dry	18.7	13.15	11.29	11.04

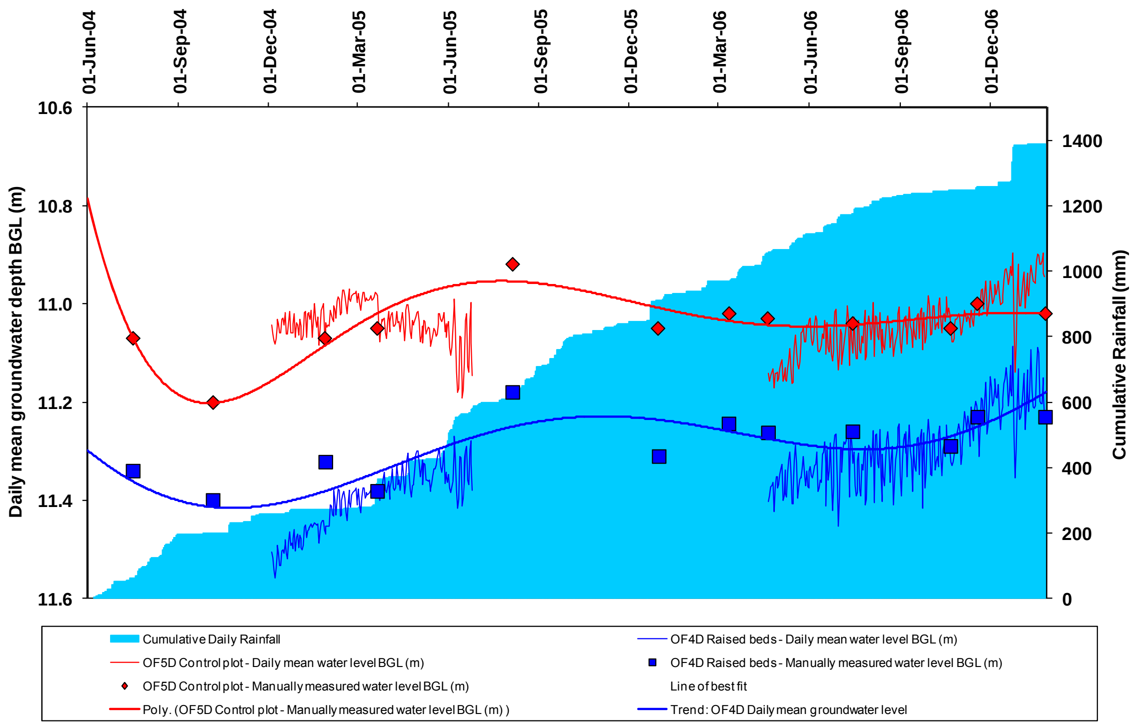

Figure 27 Comparison of groundwater levels in bores OF4D (raised bed) and OF5D (control bed)

4.3.3 Groundwater quality

Groundwater quality was sampled twice. Four of the five bores sampled were deep and the other shallow. Results are given in Appendix B.

OF3S was the only shallow bore sampled. The bore was purged then sampled by pump. Aluminium, iron and nitrate concentrations and pH were higher in the shallow bore OF3S than in the deep bores. Concentrations of dissolved salts (salinity), potassium, magnesium, nitrogen, sodium, and silicate were lower in OF3S than in the deep bores.

It is impossible to establish any trend in the groundwater quality in deeper bore results from two samplings alone. Many results are similar to the deep groundwater trends, in that levels of analytes in the groundwater increased from west to east across the site (i.e. alkalinity, salinity, calcium, chloride, salinity, fluoride, potassium, magnesium, sodium and sulfate). Manganese, nitrogen and silica decreased from west to east. In the groundwater in control bores OF2D and 3D (both west of the raised beds trial site) there were lower levels of most analytes than in OF4D and 5D. Furthermore, OF5D (the most easterly bore) groundwater tended to have higher concentrations of analytes than all bores on the trial site.

4.4 Crop yields

Crop yields were compared to see if raised beds could reduce waterlogging to allow for improved crop productivity. Anecdotally, raised beds helped improve crop yields with the raised beds crops looking healthier than the control (Fig. 28).

Quantitative data (yields) were collected during the project and were measured by a harvester computer program. As the two plots were harvested together, there was no way to distinguish the yields from raised beds and the control plot. The different types of crops grown also meant that no comparison could be made between different growing seasons. So, even though quantitative data was collected, no crop yield comparisons were analysed for the trial.

Control Raised beds

Figure 28 Comparison photos of the canola crop grown on the control and raised bed plots (August 2003)

5 Discussion

5.1 Surface water

The mean daily discharge from the raised beds plots was 0.027 mm and 0.024 mm from the control plot, with the highest discharges for the raised beds being 3.98 mm and 2.81 mm for the control beds (Fig. 15). The monthly data showed the raised bed plots (0.82 mm) produced higher discharge than the control plots (0.74 mm) (Fig. 16). Even though the discharge results from the raised and control beds are not statistically different ($p > 0.05$), these results suggest that the raised beds are more efficient at discharging water per hectare from a site.

The runoff results suggest that the raised beds had higher monthly runoff than the control and also had a higher peak volume (i.e. 2.37kL/ha for the raised beds and 0.86kL/ha for the control). In general, the runoff was at least 1.5 to 2 times greater from the raised bed site than from the control site for rainfall Events 1–8 (Tables 6 & 7).

Runoff from the raised beds peaked slightly earlier and after less rainfall than the control beds and had a higher maximum and total discharge (Table 9). However, these results are only for Events 1–4 and the opposite occurs for Events 5–8 with the control site having higher discharges (Table 9). Further analysis shows that these changes in results are due to a change in seasons. Events 1–4 occurred in summer while Events 5–8 were across the winter months. The higher flow volumes on raised beds in summer compared to winter suggest that infiltration and saturation on the sites depend on the season. For the summer Events 1–4, it can be suggested that there was infiltration excess as the raised beds had higher discharge than the control.

Runoff occurs when rainfall intensity exceeds soil infiltration capacity (Wightman et al. 2005). This is supported in data from Wightman et al. (2005) where infiltration excess occurs when the runoff is higher in the raised beds than the control plot.

During winter (Events 5–8) when there are periods of prolonged rainfall the total runoff from the control beds was higher than from the raised beds (Table 8). In winter there can be saturation excess when the soil is waterlogged (i.e. the soil profile is saturated) and additional water becomes runoff. The Blackboy Creek data shows that in some of the shallow bores the watertable is less than 500 mm deep, indicating that saturation of the profile can occur at this site. The idea of saturation excess is supported in the literature where one study also found that the volumes of runoff from conventional flat-cropping treatments are greater than from raised beds due to waterlogging or saturation of the soil profile (Wightman et al. 2005).

The higher runoff produced by the raised beds during the monitoring period suggests that raised beds are more efficient at moving water from a site than conventional flat beds. The intensity, duration and timing of rainfall during the season are significant contributors to measured differences in runoff volumes between raised bed and flat-cropped treatments. This is supported by the Fowlers (landholders) who suggest that raised beds are useful only during wet years as in average or dry years this more efficient runoff is detrimental to cropping.

5.1.1 Water quality

Salinity

There appears to be a general relationship between surface water salinity and the duration of rainfall. Most peaks in salinity seem to coincide with rain events i.e. short, sharp rain events are associated with similar 'spikes' in salinity while longer rain events over autumn and winter resulted in longer more gradual rises (Fig. 23). Except for a few days in May 2005, salinity was consistently higher from the raised beds. If bed runoff is feeding into a local creek system with good quality water, the higher salinities from the raised beds could be a cause for concern. For how long these raised salinities would occur is unknown as no soil storage data are available.

The higher salt loads correspond to higher annual rainfalls. The highest salt load (22 kg/ha) for the raised bed plot is considered low, since the site is not very saline (Fig. 24).

Nutrients

This was a short-term project and therefore only a few samples could be collected for nutrient levels. Despite the duration of the project samples were still collected to find possible trends for nutrient export from raised beds. It is understood, however, that for nutrient levels to be properly interpreted the frequency of data collection should have been higher. The data suggests that the concentrations of nitrogen and phosphorus fluctuated widely and had some relationship with rain events and seasons. The more consistent the rain in winter the higher the nitrogen and phosphorus levels seem to be at both sites (Table 10). Fertiliser is applied in winter, therefore this may be the reason for the increased nitrogen and phosphorus levels, not the consistent rainfall. There was no distinctive pattern of nutrients from the raised beds being higher or lower than the control. More frequent sampling would be needed to work out any relationship that may exist between the two sites. In some literature growers are shown to lose significant amounts of nitrogen and phosphorus from farm land, with phosphorus loads higher from the control site than the raised beds, but the nitrogen loads higher from the raised beds site (Wightman et al. 2005). This information may give some idea of what could have occurred on the Blackboy Creek trial site if sufficient data was collected.

Total suspended sediments and turbidity in the runoff were generally higher from the raised beds (Table 10). The high and low turbidity results corresponded to those of the total suspended sediments with higher turbidity moving more sediments on the site. This may account for the higher proportion of silt on the site at certain times.

Temperature and pH results provided no defining variations between the raised and control beds.

5.2 Groundwater

5.2.1 Groundwater levels

The planned monitoring program included manual measurements by the property owners and water level data loggers operated by Department of Water staff. Manual recordings were more infrequent than planned.

The water level data loggers used were a new type and did not provide the quality or consistency of data required. Problems with site remoteness, cattle interfering with logger set-up and shallow bores dry for long periods also contributed to lack of quality data.

Shallow groundwater

No conclusive results of shallow groundwater levels are possible from this study due to the lack of continuous data. Trends could be established if groundwater levels were measured in the future.

Fluctuations in shallow bores are likely to be the result of rainfall and seasonality and no conclusions can be made or recharge to groundwater.

The distance between the easterly bores OF1, 2, 3 and the raised beds trial bores OF4 and 5 means it is likely that these bores have been installed in different shallow groundwater systems. While trends in all shallow bores were similar over the monitoring period, the easterly control bores have water level rises between the last two readings (Jan/March 2006 and February 2007) not seen in the trial plot bores. The water levels in bores OF4S and 5S decreased slightly over this time.

The levels in bores OF4S and 5S also indicate the possibility that there was more recharge to the control plot bore (OF5S) than to the raised bed bore (OF4S), as OF5S water levels were 1.4 m higher in January 2006 and 1.64 m higher in February 2007 than in OF4S. These bores are close together (approximately 550 m apart), decreasing (but not completely removing) the likelihood of hydrogeological differences between the two bores. Drill logs indicate these two bores to be in the same lithologies.

Deep groundwater

It is likely that the deep bores are installed in the underlying basement aquifer. Groundwater levels recorded for bores OF2–5D displayed similar trends, remaining fairly stable throughout the monitoring period. Water levels in OF4D and OF5D appear uninfluenced by the raised beds trial.

One possible pattern that emerged from the deep bores was that groundwater depths appeared to increase west to east across the site (presuming the site is flat). This is in line with Johnson and Baddock's (1998) suggestion that regional watertables increase with depth to the west in the Esperance area. This pattern may also reflect variations in depth to bedrock at this site.

Geological mapping shows that bores OF2 (and possibly OF3) are located in Proterozoic granitoid gneiss while bores OF4 and 5 are located in Tertiary sediments. Tertiary sediments are likely to have been deposited in a basement rock depression, and indicate potentially deeper underlying bedrock than that at OF2. The highly permeable Tertiary Pallinup Siltstone, mapped at OF4 and 5, also has a higher storage capacity than the bedrock, which may explain higher groundwater levels in these two bores.

Inconsistent with drill logs, OF1D remained dry during the monitoring period. This may have been due to faulty bore installation, or an unobserved geological variation to other deep bores during drilling, such as fractures.

Further monitoring of both deep and shallow groundwater levels at the raised and control beds are required to see whether groundwater increases, decreases, or is unaffected by the raised beds.

5.2.2 Groundwater quality

Groundwater was sampled twice period during the sampling period, too infrequently to derive any trends or changes to water quality during the lifetime of the raised beds. Groundwater from the deep aquifer was sampled in four of the five bores sampled. The deep aquifer sampled is likely to be the same regional groundwater system at all bores, or may be affected by geological factors noted in 5.2.1 above.

Groundwater level results have already shown that the deep bore water levels were relatively stable throughout the monitoring period whereas shallow groundwater was influenced by rain events and seasonality. The trial plot bores OF4S and 5S also showed water level differences, either due to geological variations, or maybe due to effects from the raised beds. Because of these differences between the deep and shallow aquifers, groundwater quality results from this study are thought to be of little use in detecting water quality variations resulting from the raised and control beds, as the deep bores showed little to no potential influence from the raised beds trial.

Future sampling of shallow bores could be compared with OF3S, especially of the raised bed and control bores OF4S and OF5S, to detect any variations between recharge from the raised beds and control bores.

5.3 Downstream impacts of raised beds

Demonstrating the impacts of raised beds on runoff and peak flow was an objective of this project. The raised beds were implemented on a paddock scale and their impacts assessed in terms of this scale. At the beginning of the project the proponents were considering installing raised beds across the majority of their property, therefore allowing the impact of raised beds on a ‘catchment’ scale to be assessed, along with downstream impacts especially in terms of a flood risk and peak flows.

As a result of the land owners’ change in farm plan the raised beds were not implemented on a wider scale so the impact at catchment scale in terms of a flood risk downstream could not be assessed.

6 Conclusions

Even though the monitoring period for this study was only three years, and included below-average winter rainfall, the data obtained was consistent with other studies and showed that:

The raised beds produced more runoff than the control.

Runoff from the raised beds was earlier, greater and sometimes of shorter duration than runoff from the control plot.

This study implies that raised beds are effective in dealing with waterlogging and therefore may also reduce the onset of salinity on the farm. This study highlighted that raised beds require maintenance and would need to be reformed every few years, and more frequently due to stock grazing. There may also be issues with stock management due to the livestock getting trapped in the furrows. The proponents also decided that the raised beds were too expensive to set up compared to their yield return. Since then they have moved to more of a grazing rather than cropping enterprise.

Further monitoring of deep and shallow bores would demonstrate whether recharge to groundwater is increased, decreased, or unaffected by the raised beds. The trial would have also benefited from longer term monitoring if the raised beds could have been maintained.

Appendix A Drill logs

Drill log bore code	Bore monitoring code	DoW Station Reference
008BB	OF1S	60118413
007BB	OF1D	60118415
011BB	OF2S	60118416
010BB	OF2INT	60118417
009BB	OF2D	60118418
014BB	OF3S	60118419
013BB	OF3INT	60118420
012BB	OF3D	60118421
006BB	OF4S	60118422
005BB	OF4INT	60118423
004BB	OF4D	60118424
003BB	OF5S	60118425
002BB	OF5INT	60118426
001BB	OF5D	60118427

The data below are from the unpublished hydrogeology report – *Piezometer drilling program Blackboy Creek* (Dogramaci 2004).

Observation Bore 001BB (Deep)

CONSTRUCTION

METHOD RAB
DRILLED 29/04/2004
ELEVATION Natural surface
DIAMETER 100 mm
DEPTH 20 m

CASING

Interval (m bns)	Type	ID (mm)	Comments
–0.5–17.0	Class 9 Plain PVC	50	
17.0–20.0	Class 9 Slotted PVC	50	End cap installed

GRAVEL PACK AND SEAL

Interval (m bns)	Item	Type	Description
0–15.0	Seal	Concrete	Cement
15.0–20.0	Gravel		gravel 8/16 grade

HEADWORK DETAILS

Item	Type	Description
Extension of casing	Class 9 PVC	0.6 m above natural surface
Cap	50 mm PVC protective cap	
Surface protection pad	Concrete	300 x 300 x 300 mm

GEOLOGICAL DATA

SAMPLES Cuttings logged at 1.0 m intervals,

SUMMARY LOG

Depth (m)	Age	Stratigraphic unit	Lithology
0.0–1	Quaternary	Surficial	Sand
1–14.5	Tertiary	sediments	Clay, siltstone

HYDROGEOLOGICAL DATA

AQUIFER	Tertiary sediments
WATER LEVELS	16 m (below ground level)

LOG OF SAMPLES

Depth (m bns)	Lithology	Description
0.0–0.5	Sandy clay	Brown grey sandy clay, fine, angular to sub angular fine to medium sand
0.5–1.8	Clay	Grey green clay, minor well round fine sand
1.8–2.0	Clay	Yellow grey clay, minor fine sand and silt, calcrete grains up to 5 mm
2.0–3.0	Clay	Yellow green silty clay, fine to medium (1 to 3 mm) angular quartz grains embedded in white clay matrix
3.0–4.0	Clay	Yellow brown silty clay, minor fine sand
4.0–5.0	Silty clay	Brown semi indurated silty clay, minor quartz grains, and up to 5 mm granite rock fragments
5.0–6.0	Clay	Brown silty clay, interbedded with limy clay minor fine sand,
6.0–20.0	Clay	Yellow clay, minor fine sand, occasional calcrete grains up to 2 mm

Observation Bore 002BB (intermediate)

CONSTRUCTION

METHOD	RAB
DRILLED	29/04/2004
ELEVATION	Natural surface
DIAMETER	100 mm
DEPTH	8 m

CASING

Interval (m bns)	Type	ID (mm)	Comments
–0.5–5.0	Class 9 Plain PVC	50	
5.0–8.0	Class 9 Slotted PVC	50	End cap installed

GRAVEL PACK AND SEAL

Interval (m bns)	Item	Type	Description
0–3.0	Seal	Concrete	Cement
3.0-8.0	Gravel		Gravel 8/16 grade

HEADWORK DETAILS

Item	Type	Description
Extension of casing	Class 9 PVC	0.6 m above natural surface
Cap	50 mm PVC protective cap	
Surface protection pad	Concrete	300 x 300 x 300 mm

GEOLOGICAL DATA

SAMPLES Cuttings logged at 1.0 m intervals

SUMMARY LOG

Depth (m)	Age	Stratigraphic unit	Lithology
0.0–1	Quaternary	Surficial	Sand
1–8.0	Tertiary	sediments	Clay, siltstone

HYDROGEOLOGICAL DATA

AQUIFER	Tertiary sediments
WATER LEVELS	Dry

LOG OF SAMPLES

Depth (m bns)	Lithology	Description
0.0–0.5	Sandy clay	Brown grey sandy clay, fine, angular to sub angular fine to medium sand
0.5–1.8	Clay	Grey green clay, minor well round fine sand
1.8–2.0	Clay	Yellow grey clay, minor fine sand and silt, calcrete grains up to 5 mm
2.0–3.0	Clay	Yellow green silty clay, fine to medium (1 to 3 mm) angular quartz grains embedded in white clay matrix
3.0–4.0	Clay	Yellow brown silty clay, minor fine sand
4.0–5.0	Silty clay	Brown semi–indurated silty clay, minor quartz grains, and up to 5 mm granite rock fragments
5.0–6.0	Clay	Brown silty clay, interbedded with limy clay minor fine sand,
6.0–8.0	Clay	Yellow clay, minor fine sand, occasional calcrete grains up to 2 mm

Observation Bore 003BB (Shallow)

CONSTRUCTION

METHOD	RAB
DRILLED	29/04/2004
ELEVATION	Natural Surface
DIAMETER	100 mm
DEPTH	4 m

CASING

Interval (m bns)	Type	ID (mm)	Comments
–0.5–1.0	Class 9 Plain PVC	50	
1.0–4.0	Class 9 Slotted PVC	50	End cap installed

GRAVEL PACK AND SEAL

Interval (m bns)	Item	Type	Description
0–3.0	Cuttings	sediment	Clay, sand
1.0–4.0	Gravel		Gravel 8/16 grade

HEADWORK DETAILS

Item	Type	Description
Extension of casing	Class 9 PVC	0.6 m above natural surface
Cap	50 mm PVC protective cap	
Surface protection pad	Concrete	300 x 300 x 300 mm

GEOLOGICAL DATA

SAMPLES Cuttings logged at 1.0 m intervals

SUMMARY LOG

Depth (m)	Age	Stratigraphic unit	Lithology
0.0–1	Quaternary	Surficial	Sand
1–4.0	Tertiary	sediments	Clay, siltstone

HYDROGEOLOGICAL DATA

AQUIFER	Tertiary sediments
WATER LEVELS:	Dry

LOG OF SAMPLES

Depth (m bns)	Lithology	Description
0.0–0.5	Sandy clay	Brown grey sandy clay, fine, angular to sub–angular fine to medium sand
0.5–1.8	Clay	Grey green clay, minor well round fine sand
1.8–2.0	Clay	Yellow grey clay, minor fine sand and silt, calcrete grains up to 5 mm
2.0–3.0	Clay	Yellow green silty clay, fine to medium (1 to 3 mm) angular quartz grains embedded in white clay matrix
3.0–4.0	Clay	Yellow brown silty clay, minor fine sand

Observation Bore 004BB (Deep)

CONSTRUCTION

METHOD	RAB
DRILLED	29/04/2004
ELEVATION	Natural Surface
DIAMETER	100 mm
DEPTH	20 m

CASING

Interval (m bns)	Type	ID (mm)	Comments
–0.5–17.0	Class 9 Plain PVC	50	
17.0–20.0	Class 9 Slotted PVC	50	End cap installed

GRAVEL PACK AND SEAL

Interval (m bns)	Item	Type	Description
0–15.0	Seal	Concrete	Cement
15.0–20.0	Gravel		Gravel 8/16 grade

HEADWORK DETAILS

Item	Type	Description
Extension of casing	Class 9 PVC	0.6 m above natural surface
Cap	50 mm PVC protective cap	
Surface protection pad	Concrete	300 x 300 x 300 mm

GEOLOGICAL DATA

SAMPLES Cuttings logged at 1.0 m intervals

SUMMARY LOG

Depth (m)	Age	Stratigraphic unit	Lithology
0.0–1	Quaternary	Surficial	Sand
1–14.5	Tertiary	sediments	Clay, siltstone

HYDROGEOLOGICAL DATA

AQUIFER	Tertiary sediments
WATER LEVELS	16 m (below ground level)

LOG OF SAMPLES

Depth (m bns)	Lithology	Description
0.0–0.5	Sandy clay	Brown grey sandy clay, fine, angular to sub angular fine to medium sand
0.5–1.8	Clay	Grey green clay, minor well rounded fine sand
1.8–2.0	Clay	Yellow grey clay, minor fine sand and silt, calcrete grains up to 5 mm
2.0–3.0	Clay	Yellow green silty clay, fine to medium (1 to 3 mm) angular quartz grains embedded in white clay matrix
3.0–4.0	Clay	Yellow brown silty clay, minor fine sand
4.0–5.0	Silty clay	Brown semi indurated silty clay, minor quartz grains, and up to 5 mm granite rock fragments
5.0–6.0	Clay	Brown silty clay, interbeded with limy clay minor fine sand,
6.0–20.0	Clay	Yellow clay, minor fine sand, occasional calcrete grains up to 2 mm

Observation Bore 005BB (intermediate)

CONSTRUCTION

METHOD	RAB
DRILLED	29/04/2004
ELEVATION	Natural Surface
DIAMETER	100mm
DEPTH	8 m

CASING

Interval (m bns)	Type	ID (mm)	Comments
–0.5–5.0	Class 9 Plain PVC	50	
5.0–8.0	Class 9 Slotted PVC	50	End cap installed

GRAVEL PACK AND SEAL

Interval (m bns)	Item	Type	Description
0–3.0	Seal	Concrete	Cement
3.0–8.0	Gravel		Gravel 8/16 grade

HEADWORK DETAILS

Item	Type	Description
Extension of casing	Class 9 PVC	0.6 m above natural surface
Cap	50 mm PVC protective cap	
Surface protection pad	Concrete	300 x 300 x 300 mm

GEOLOGICAL DATA

SAMPLES Cuttings logged at 1.0 m intervals

SUMMARY LOG:

Depth (m)	Age	Stratigraphic unit	Lithology
0.0–1	Quaternary	Surficial	Sand
1–8.0	Tertiary	sediments	Clay, siltstone

HYDROGEOLOGICAL DATA

AQUIFER	Tertiary sediments
WATER LEVELS	Dry

LOG OF SAMPLES

Depth (m bns)	Lithology	Description
0.0–0.5	Sandy clay	Brown grey sandy clay, fine, angular to sub–angular fine to medium sand
0.5–1.8	Clay	Grey green clay, minor well round fine sand
1.8–2.0	Clay	Yellow grey clay, minor fine sand and silt, calcrete grains up to 5 mm
2.0–3.0	Clay	Yellow green silty clay, fine to medium (1 to 3 mm) angular quartz grains embedded in white clay matrix
3.0–4.0	Clay	Yellow brown silty clay, minor fine sand
4.0–5.0	Silty clay	Brown semi–indurated silty clay, minor quartz grains, and up to 5 mm granite rock fragments
5.0–6.0	Clay	Brown silty clay, interbeded with limy clay minor fine sand,
6.0–8.0	Clay	Yellow clay, minor fine sand, occasional calcrete grains up to 2 mm

Observation Bore 006BB (Shallow)

CONSTRUCTION

METHOD	RAB
DRILLED	29/04/2004
ELEVATION	Natural Surface
DIAMETER	100 mm
DEPTH	4 m

CASING

Interval (m bns)	Type	ID (mm)	Comments
–0.5–1.0	Class 9 Plain PVC	50	
1.0–4.0	Class 9 Slotted PVC	50	End cap installed

GRAVEL PACK AND SEAL

Interval (m bns)	Item	Type	Description
0–3.0	Cuttings	sediment	Clay, sand
1.0–4.0	Gravel		Gravel 8/16 grade

HEADWORK DETAILS

Item	Type	Description
Extension of casing	Class 9 PVC	0.6 m above natural surface
Cap	50 mm PVC protective cap	
Surface protection pad	Concrete	300 x 300 x 300 mm

GEOLOGICAL DATA

SAMPLES Cuttings logged at 1.0 m intervals,

SUMMARY LOG:

Depth (m)	Age	Stratigraphic unit	Lithology
0.0–1	Quaternary	Surficial	Sand
1–4.0	Tertiary	sediments	Clay, siltstone

HYDROGEOLOGICAL DATA

AQUIFER	Tertiary sediments
WATER LEVELS	Dry

LOG OF SAMPLES

Depth (m bns)	Lithology	Description
0.0–0.5	Sandy clay	Brown grey sandy clay, fine, angular to sub angular fine to medium sand
0.5–1.8	Clay	Grey green clay, minor well round fine sand
1.8–2.0	Clay	Yellow grey clay, minor fine sand and silt, calcrete grains up to 5 mm
2.0–3.0	Clay	Yellow green silty clay, fine to medium (1 to 3 mm) angular quartz grains embedded in white clay matrix
3.0–4.0	Clay	Yellow brown silty clay, minor fine sand

Observation Bore 007BB (Deep)

CONSTRUCTION

METHOD	RAB
DRILLED	30/04/2004
ELEVATION	Natural Surface
DIAMETER	100 mm
DEPTH	11 m

CASING

Interval (m bns)	Type	ID (mm)	Comments
–0.5–18.0	Class 9 Plain PVC	50	
18.0–11.0	Class 9 Slotted PVC	50	End cap installed

GRAVEL PACK AND SEAL

Interval (m bns)	Item	Type	Description
0–6.0	Seal	Concrete	Cement
6.0–11.0	Gravel		Gravel 8/16 grade

HEADWORK DETAILS

Item	Type	Description
Extension of casing	Class 9 PVC	0.6 m above natural surface
Cap	50 mm PVC protective cap	
Surface protection pad	Concrete	300 x 300 x 300 mm

GEOLOGICAL DATA

SAMPLES Cuttings logged at 1.0 m intervals

SUMMARY LOG

Depth (m)	Age	Stratigraphic unit	Lithology
0.0–0.3	Quaternary	Surficial	Sand
0.3–11	Tertiary	sediments	Clay, siltstone

HYDROGEOLOGICAL DATA

AQUIFER	Tertiary sediments
WATER LEVELS	Dry

LOG OF SAMPLES

Depth (m bns)	Lithology	Description
0.0–0.3	Sand	Grey, fine sand, well sorted
0.3–1.0	Clay	Brown yellow fine clay
1.0–4.0	Clay	Brown fine clay, minor fine sand and silt
4.0–5.0	Clay	Red yellow fine clay
5.0–10.0	Clay	Yellow silty clay, indurated chips of yellow angular fine to medium sand, multicoloured clay and texture resembling granite saprolite.
10.0–11.0	Bedrock	Granite

Observation Bore 008BB (Shallow)

CONSTRUCTION

METHOD	RAB
DRILLED	30/04/2004
ELEVATION	Natural surface
DIAMETER	100 mm
DEPTH	4 m

CASING

Interval (m bns)	Type	ID (mm)	Comments
–0.5–1.0	Class 9 Plain PVC	50	
1.0–4.0	Class 9 Slotted PVC	50	End cap installed

GRAVEL PACK AND SEAL

Interval (m bns)	Item	Type	Description
0–3.0	Cuttings	sediment	Clay, sand
1.0–4.0	Gravel		Gravel 8/16 grade

HEADWORK DETAILS

Item	Type	Description
Extension of casing	Class 9 PVC	0.6 m above natural surface
Cap	50 mm PVC protective cap	
Surface protection pad	Concrete	300 x 300 x 300 mm

GEOLOGICAL DATA

SAMPLES Cuttings logged at 1.0 m intervals

SUMMARY LOG

Depth (m)	Age	Stratigraphic unit	Lithology
0.0–0.3	Quaternary	Surficial	Sand
0.3–4.0	Tertiary	sediments	Clay, siltstone

HYDROGEOLOGICAL DATA

AQUIFER	Tertiary sediments
WATER LEVELS	Dry

LOG OF SAMPLES

Depth (m bns)	Lithology	Description
0.0–0.3	Sand	Grey, fine sand, well sorted
0.3–1.0	Clay	Brown yellow fine clay
1.0–4.0	Clay	Brown fine clay, minor fine sand and silt

Observation Bore 009BB (Deep)

CONSTRUCTION

METHOD	RAB
DRILLED	30/04/2004
ELEVATION	Natural surface
DIAMETER	100 mm
DEPTH	20 m

CASING

Interval (m bns)	Type	ID (mm)	Comments
–0.5–17.0	Class 9 Plain PVC	50	
17.0–20.0	Class 9 Slotted PVC	50	End cap installed

GRAVEL PACK AND SEAL

Interval (m bns)	Item	Type	Description
0–15.0	Seal	Concrete	Cement
15.0–20.0	Gravel		Gravel 8/16 grade

HEADWORK DETAILS

Item	Type	Description
Extension of casing	Class 9 PVC	0.6 m above natural surface
Cap	50 mm PVC protective cap	
Surface protection pad	Concrete	300 x 300 x 300 mm

GEOLOGICAL DATA

SAMPLES Cuttings logged at 1.0 m intervals

SUMMARY LOG

Depth (m)	Age	Stratigraphic unit	Lithology
0.0–0.3	Quaternary	Surficial	Sand
0.3–20.0	Tertiary	sediments	Clay, siltstone

HYDROGEOLOGICAL DATA

AQUIFER	Tertiary sediments
WATER LEVELS	16.2 m below ground level

LOG OF SAMPLES

Depth (m bns)	Lithology	Description
0.0–0.3	Sand	Grey fine sand clay, fine, well sorted
0.3–1.0	Clay	Brown yellow fine clay
1.0–4.0	Clay	Brown fine clay, minor fine sand and silt
4.0–5.0	Clay	Red yellow fine clay
5.0–10.0	Clay	Yellow silty clay, indurated chips of yellow angular fine to medium sand, multicoloured clay
11.0–19.0	Clay	Yellow green clay, minor fine to medium sand
19.0–20.0	Clay	Brown clay, fine to medium well sorted sand

Observation Bore 010BB (intermediate)

CONSTRUCTION

METHOD	RAB
DRILLED	30/04/2004
ELEVATION	Natural surface
DIAMETER	100 mm
DEPTH	8 m

CASING

Interval (m bns)	Type	ID (mm)	Comments
–0.5–6.5	Class 9 Plain PVC	50	
6.5–8.0	Class 9 Slotted PVC	50	End cap installed

GRAVEL PACK AND SEAL

Interval (m bns)	Item	Type	Description
0.0–4.0	Seal	Concrete	Cement
4.0–8.0	Gravel		Gravel 8/16 grade

HEADWORK DETAILS

Item	Type	Description
Extension of casing	Class 9 PVC	0.6 m above natural surface
Cap	50 mm PVC protective cap	
Surface protection pad	Concrete	300 x 300 x 300 mm

GEOLOGICAL DATA

SAMPLES Cuttings logged at 1.0 m intervals

SUMMARY LOG

Depth (m)	Age	Stratigraphic unit	Lithology
0.0–0.3	Quaternary	Surficial	Sand
0.3–8.0	Tertiary	sediments	Clay, siltstone

HYDROGEOLOGICAL DATA

AQUIFER	Tertiary sediments
WATER LEVELS	Dry

LOG OF SAMPLES

Depth (m bns)	Lithology	Description
0.0–0.3	Sand	Grey fine sand clay, fine, well sorted
0.3–1.0	Clay	Brown yellow fine clay
1.0–4.0	Clay	Brown fine clay, minor fine sand and silt
4.0–5.0	Clay	Red yellow fine clay
5.0–8.0	Clay	Yellow silty clay, indurated chips of yellow angular fine to medium sand, multicoloured clay

Observation Bore 011BB (Shallow)

CONSTRUCTION

METHOD	RAB
DRILLED	30/04/2004
ELEVATION	Natural surface
DIAMETER	100 mm
DEPTH	4 m

CASING

Interval (m bns)	Type	ID (mm)	Comments
–0.5–2.5	Class 9 Plain PVC	50	
2.5–4.0	Class 9 Slotted PVC	50	End cap installed

GRAVEL PACK AND SEAL

Interval (m bns)	Item	Type	Description
0.0–3.0	Cuttings	sediment	Clay, sand
1.0–4.0	Gravel		Gravel 8/16 grade

HEADWORK DETAILS

Item	Type	Description
Extension of casing	Class 9 PVC	0.6 m above natural surface
Cap	50 mm PVC protective cap	
Surface protection pad	Concrete	300 x 300 x 300 mm

GEOLOGICAL DATA

SAMPLES Cuttings logged at 1.0 m intervals

SUMMARY LOG

Depth (m)	Age	Stratigraphic unit	Lithology
0.0–0.3	Quaternary	Surficial	Sand
1–4.0	Tertiary	sediments	Clay, siltston

HYDROGEOLOGICAL DATA

AQUIFER	Tertiary sediments
WATER LEVELS	Dry

LOG OF SAMPLES

Depth (m bns)	Lithology	Description
0.0–0.3	Sand	Grey fine sand clay, fine, well sorted
0.3–1.0	Clay	Brown yellow fine clay
1.0–4.0	Clay	Brown fine clay, minor fine sand and silt

Observation Bore 012BB (Deep)

CONSTRUCTION

METHOD	RAB
DRILLED	01/05/2004
ELEVATION	Natural surface
DIAMETER	100 mm
DEPTH	50 m

CASING

Interval (m bns)	Type	ID (mm)	Comments
–0.5–47.0	Class 9 Plain PVC	50	
44.0–50.0	Class 9 Slotted PVC	50	End cap installed

GRAVEL PACK AND SEAL

Interval (m bns)	Item	Type	Description
0.0–15.0	Seal	Concrete	Cement
30.0–50.0	Gravel		Gravel 8/16 grade

HEADWORK DETAILS

Item	Type	Description
Extension of casing	Class 9 PVC	0.6 m above natural surface
Cap	50 mm PVC protective cap	
Surface protection pad	Concrete	300 x 300 x 300 mm

GEOLOGICAL DATA

SAMPLES Cuttings logged at 1.0 m intervals

SUMMARY LOG

Depth (m)	Age	Stratigraphic unit	Lithology
0.0–0.3	Quaternary	Surficial	Sand
0.3–50.0	Tertiary	sediments	Clay, siltstone

HYDROGEOLOGICAL DATA

AQUIFER	Tertiary sediments
WATER LEVELS	16 m (below ground level)

LOG OF SAMPLES

Depth (m bns)	Lithology	Description
0.0–0.3	Sand	Grey fine sand clay, well sorted
0.3–4.0	Clay	Multi coloured fine clay, minor fine well sorted sand
4.0–9.0	Clay	Greenish brown fine clay, minor fine sand and silt
9.0–12.0	Clay	Brown green clay interbedded with semi indurated layer of multi coloured clay, minor fine well sorted sand
12.0–17.0	Clay	Green clay, minor fine sand
17.0–21.0	Clay	Dark brown sandy clay
21.0–50.0	Clay	Brown clay, fine to medium sub angular quartz sand embedded in clay matrix. The texture of the sediments resembles that of the well weathered granite.

Observation Bore 013BB (intermediate)

CONSTRUCTION

METHOD	RAB
DRILLED	30/04/2004
ELEVATION	Natural surface
DIAMETER	100 mm
DEPTH	8 m

CASING

Interval (m bns)	Type	ID (mm)	Comments
–0.5–5.0	Class 9 Plain PVC	50	
5.0–8.0	Class 9 Slotted PVC	50	End cap installed

GRAVEL PACK AND SEAL

Interval (m bns)	Item	Type	Description
0.0–3.0	Seal	Concrete	Cement
3.0–8.0	Gravel		Gravel 8/16 grade

HEADWORK DETAILS

Item	Type	Description
Extension of casing	Class 9 PVC	0.6 m above natural surface
Cap	50 mm PVC protective cap	
Surface protection pad	Concrete	300 x 300 x 300 mm

GEOLOGICAL DATA

SAMPLES Cuttings logged at 1.0 m intervals

SUMMARY LOG

Depth (m)	Age	Stratigraphic unit	Lithology
0.0–0.3	Quaternary	Surficial	Sand
0.3–8.0	Tertiary	sediments	Clay, siltstone

HYDROGEOLOGICAL DATA

AQUIFER	Tertiary sediments
WATER LEVELS	Dry

LOG OF SAMPLES

Depth (m bns)	Lithology	Description
0.0–0.3	Sand	Grey fine sand clay, well sorted
0.3–4.0	Clay	Multi coloured fine clay, minor fine well sorted sand
4.0–8.0	Clay	Greenish brown fine clay, minor fine sand and silt

Observation Bore 014BB (Shallow)

CONSTRUCTION

METHOD	RAB
DRILLED	30/04/2004
ELEVATION	Natural surface
DIAMETER	100 mm
DEPTH	4 m

CASING

Interval (m bns)	Type	ID (mm)	Comments
–0.5–2.5	Class 9 Plain PVC	50	
2.5–4.0	Class 9 Slotted PVC	50	End cap installed

GRAVEL PACK AND SEAL

Interval (m bns)	Item	Type	Description
0.0–1.0	Cuttings	sediment	Clay, sand
1.0–4.0	Gravel		Gravel 8/16 grade

HEADWORK DETAILS

Item	Type	Description
Extension of casing	Class 9 PVC	0.6 m above natural surface
Cap	50 mm PVC protective cap	
Surface protection pad	Concrete	300 x 300 x 300 mm

GEOLOGICAL DATA

SAMPLES Cuttings logged at 1.0 m intervals

SUMMARY LOG

Depth (m)	Age	Stratigraphic unit	Lithology
0.0–0.3	Quaternary	Surficial	Sand
1–4.0	Tertiary	sediments	Clay, siltstone

HYDROGEOLOGICAL DATA

AQUIFER	Tertiary sediments
WATER LEVELS	Dry

LOG OF SAMPLES

Depth (m bns)	Lithology	Description
0.0–0.3	Sand	Grey fine sand clay, well sorted
0.3–4.0	Clay	Multi coloured fine clay, minor fine well sorted sand

Appendix B Stage data rating curve

Applied to surface water stage values recorded at gauging stations 601013 and 601014.

Stage (m)	Discharge (kL/s)	Quality
10.0000	0.0000	11
10.0061	0.0000	11
10.0090	0.0000	11
10.0127	0.0000	11
10.0166	0.0001	11
10.0208	0.0001	11
10.0274	0.0002	11
10.0315	0.0003	11
10.0349	0.0004	11
10.0390	0.0005	11
10.0424	0.0007	11
10.0465	0.0008	11
10.0499	0.0010	11
10.0746	0.0021	11
10.1003	0.0039	11
10.1089	0.0048	11
10.1181	0.0059	11
10.1267	0.0070	11

Stage (m)	Discharge (kL/s)	Quality
10.1359	0.0083	11
10.1445	0.0097	11
10.1509	0.0108	11
10.1608	0.0128	11
10.1708	0.0150	11
10.1808	0.0175	11
10.1908	0.0201	11
10.2007	0.0230	11
10.2200	0.0290	11
10.2400	0.0360	11
10.2600	0.0440	11
10.2800	0.0540	11
10.3000	0.0640	11
10.3200	0.0760	11
10.3400	0.0880	11
10.3600	0.1020	11
10.3800	0.1170	11
10.4000	0.1340	11

Appendix C Groundwater quality results

NB: Date 1 = 11 January 2006 and Date 2 = 29 November 2006

Date	Name	Collection Method Code	Std Depth (m)	Bottom Depth (m below top of casing)	SWL (m btoc)	Al (sol) (mg/L)	Alkalinity (tot) ($CaCO_3$) (mg/L)	Ca (sol) (mg/L)	Cl (sol) (mg/L)	Cond comp (mS/m)	Cond uncomp (lab) (mS/m)	F (sol) (mg/L)
1	OF2D	BAILR	20.5	21.28	~19.8	<0.005	100	64	8300	2570	2540	0.4
2	OF2D	BAILR				0.022	65	41	6700	1380	1210	0.4
1	OF3S	PUMPS	4.5	5.72	1.03–2.87	0.005	310	96	1700	631	625	0.7
2	OF3S	PUMPS	4			0.072	360	56	1100	491	421	1.9
1	OF3D	BAILR	50	51.3	~14.1	<0.005	420	240	6300	2060	2040	1.6
2	OF3D	BAILR	30			<0.005	400	230	7600	1550	1310	<0.2
1	OF4D	PUMPS	15	20.99	~12.1	<0.005	530	290	9400	2670	2640	1.7
2	OF4D	PUMPS	13			0.005	490	280	9600	2040	1870	
1	OF5D	PUMPS	15	21.34	~11.9	<0.005	640	340	10000	2820	2790	1.7
2	OF5D	PUMPS	13			<0.005	690	370	12000	2130	1880	1

Date	Name	Fe (sol) (mg/L)	K (sol) (mg/L)	Mg (sol) (mg/L)	Mn (sol) (mg/L)	N (sum sol ox) (mg/L)	NO_2–N (sol) (mg/L)	Na (sol) (mg/L)	SO_4 (sol) (mg/L)	SiO_2 (sol react) (mg/L)	Temp (deg C)	**pH**
1	OF2D	<0.005	140	540	0.48	0.48	<0.01	5700	1200	44	24.5	6.5
2	OF2D	0.011	98	340	0.47	0.6	<0.01	4400	1000	30	17.7	6.4
1	OF3S	0.027	49	100	0.32	0.87	0.076	1100	160	12	24.5	7.9
2	OF3S	0.021	52	43	0.05	0.56	<0.01	770	140	11	16.7	7.4
1	OF3D	0.009	110	440	0.12	0.32	<0.01	4300	1100	25	24.6	8
2	OF3D	0.028	140	440	0.19	0.15	<0.01	4800	1100	23	15.9	7.4
1	OF4D	<0.005	140	620	<0.001	0.19	<0.01	5800	1700	39	24.5	7.4
2	OF4D	<0.005	170	500	0.001	0.17	<0.01	6100	1700	43	20.5	7.1
1	OF5D	0.026	160	620	1.2	0.026	<0.01	5900	1700	21	24.4	7.3
2	OF5D	0.014	210	620	0.67	0.039	<0.01	7700	2000	28	18.4	7

Appendix D: Continuous data verification – quality codes

Quality Codes – abridged guidelines

This table is a summary for the application of the main quality codes.

Q = 1 Very good record	
Stage	Calibration checks within accepted tolerances (TG 3 mm, ID < 5 mm)
Conductivity	Calibration checks within accepted tolerances
Rainfall	≤ 2% calibration variation

Q = 2 Very good record – corrections applied	
Stage	Corrections < 10 mm
Conductivity	Corrections < 2%
Rainfall	≤ 4% calibration variation

Q = 3 Good record – corrections or estimations applied	
Stage	Corrections (lesser of < 50 mm or 10% flow rate), or estimates (< ~2 days)
Conductivity	Corrections < 5%
Rainfall	Not usually applicable

Q = 4 Estimated record – good	
Stage	Estimated, good correlation, peak usually known (< ~14 days)
Conductivity	Corrections < 10%
Rainfall	Estimated, good correlation, storage total known

Q = 5 Estimated record – fair	
Stage	Estimated, fair correlation, peak usually known (> ~14 days)
Conductivity	Corrections < 20%
Rainfall	Estimated, fair correlation, storage total known

Q = 6 Estimated record – poor	
Stage	Estimated, poor correlation, peak not usually known (several months in length)
Conductivity	Corrections < 50%
Rainfall	Estimated, poor correlation, total estimated from long term correlation

Extracted from Water Information Bookshelf, Continuous Data Verification (Davies, 1996).

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