APPENDIX H

WATER INFILTRATION MODELLING

ORD RIVER IRRIGATION AREA STAGE 2 PROPOSED DEVELOPMENT OF THE M2 AREA

Water Infiltration Modelling for the Ord Sugar Project

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August 1999

PV8009-FC-007 Rev. 0

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1 Introduction

Wesfarmers Limited, Marubeni Corporation and the Water Corporation of Western Australia are investigating the feasibility of developing approximately 32,000 hectares of land in the East Kimberley region of Western Australia and the Northern Territory, predominately for the irrigated cultivation of sugar cane. As part of these feasibility studies it was necessary to quantify the percolation of rainfall and irrigation water from the surface (unsaturated zone) to underlying groundwater. This was carried out using the numerical water balance model LEACHM (Hutson & Wagnet 1992) to simulate conditions of best practice irrigation management as proposed for the Project.

The LEACHM model is briefly described in Chapter 2 while Chapter 3 describes the input data used, including the physical properties of the soil profile assumed to be representative of the development area and meteorological conditions. The results are summarised in Chapter 4.

The prediction of effects of project development on the underlying groundwater was the subject of a separate study (Kinhill Pty Ltd 1999).

2 Model Description

The simulation of the water balance within the unsaturated zone of the soil profile was undertaken using the LEACHM (Hutson & Wagnet, 1992) model. LEACHM is a process-based model of water movement, including uptake by plants, in the unsaturated zone of the soil profile.

The multi-layer model calculates the water balance on a sub-daily basis. The time step is based on the numerical stability of the finite differencing technique employed to numerically evaluate the equations describing water transport in the soil. Typically each day is divided into at least ten time steps.

The following data is required to evaluate the water balance:

- initial moisture content and hydrological constants for calculation of retentivity (i.e. variation of the soil moisture as a function of pore pressure) and hydraulic conductivity for each soil segment;
- rates of irrigation application and rainfall amounts;
- potential daily evaporation;
- crop details including time of planting and harvest, root and crop growth parameters as well as potential limits for water extraction by plants.

3 Input data

3.1 SOIL PROPERTIES

The area proposed for development has cracking clay soils, predominately Cununurra clay and to a lesser extent Aquitaine clay. Cracking clay soils are often described as black soils or vertisols. They exhibit significant shrinking and swelling with changes in moisture content and when dry they often have deep, open desiccation cracks. The permeability of wet or moist cracking clay soils is very low. Aquitaine clays have a higher clay content than Cununurra clay and are therefore generally even less permeable.

3.1.1 Retentivity

A soil profile of Cununurra clay (alkaline phase) was assumed to be representative of the range of soil types that occur in the area proposed for development. The physical properties of this soil profile are given in Table 3.1.

Table 3.1 Physical properties of Cununurra Clay - Alkaline Phase

Depth Range [cm]	Bulk Density [kg/m^3]	Clay content [%]	Moisture at 1/10 atm pore pressure [%]	Moisture at 1/3 atm pore pressure [%]	Moisture at 1 atm pore pressure [%]	Moisture at 15 atm pore pressure [%]
0-15	1.32	57.8	32.45	26.33	25.96	22.72
15-85	1.43	40.6	33.84	31.90	26.38	20.66
85-145	1.40	24.5	34.82	33.20	28.95	22.27
145-205	1.62	28.4	30.23	28.44	23.89	19.11

Source: Dixon 1996

The numerical evaluation of retentivity is required within the LEACHM model. This is achieved by fitting a curve to the data in Table 3.1, extending from fully saturated soil to wilting point (i.e. for pore pressures in a range from 0 atm to 15 atm). Results of this procedure are shown in Figure 3.1.

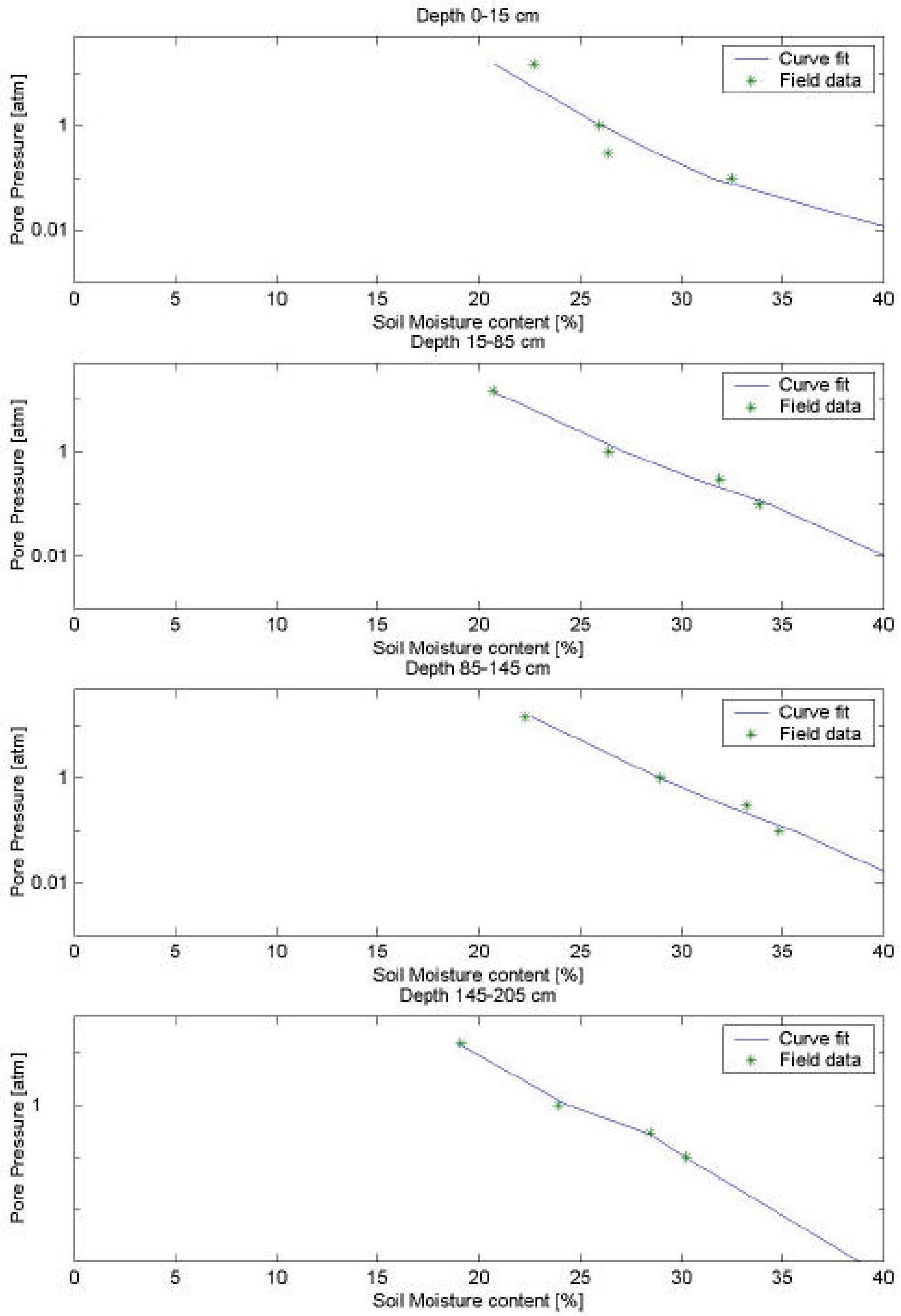

Figure 3.1 Soil retentivity data used in the analysis

3.1.2 Infiltration Rates

Water enters the soil profile readily when it is dry and cracked, but after swelling has occurred and the cracks have closed up the entry of water is restricted (Muchow and Wood 1981). Cultivation and furrow and bed forming practices also modify the behaviour of the surface layer under irrigation. The moisture content of the Cununurra clay under irrigated crops does not vary significantly below depths of around 1.6 m (Muchow and Wood 1981 and others) indicating that this is the limit of the shrinkage and swelling.

Measurement of the saturated hydraulic conductivities of Cununurra clay soils is difficult and only long-term tests lasting over at least several days are considered accurate (R Shaw and A Peck personal communication). The only long term infiltration tests on Cununurra clays are those carried out by Banyard (1983) who investigated channel and drain seepage rates. Ponding tests were carried out on ten 50 m long sections of the irrigation channels on the Ivanhoe Plain over a period of 7 to 13 days. Infiltration rates ranging from 10 mm to 47 mm per day were recorded for channels in the Cununurra clay. These channels had been excavated to depths of 1 to 2 m and water was ponded in them to depths of 0.3 m to 1.0 m. The arithmetic mean of the infiltration rates was 20 mm per day and the median value was 18 mm per day.

Muchow and Wood 1981 investigated infiltration rates for Cununurra clay under furrow irrigation of Kenaf with irrigation applications on 6 day and 12 day intervals. This investigation used flow meters to measure the input and output flows in 160 m long furrows. Irrigation was shut off when the lateral wetting of the bed between the furrows was complete. This generally occurred after 5 to 6 hours. Infiltration rates over this short period averaged 250–300 mm per day but decreased slightly to 180 mm per day by the time irrigation was shut off. Soil moisture readings to a depth of 1.85 m were made immediately before each irrigation and again two days after irrigation as shown in Figure 3.2. Their results show that:

- there was little change in moisture contents below a depth of 1.0 m;
- the major change in moisture content was in the top 300 mm where the moisture content went from wilt point (20%) to saturation (45%) with irrigation.

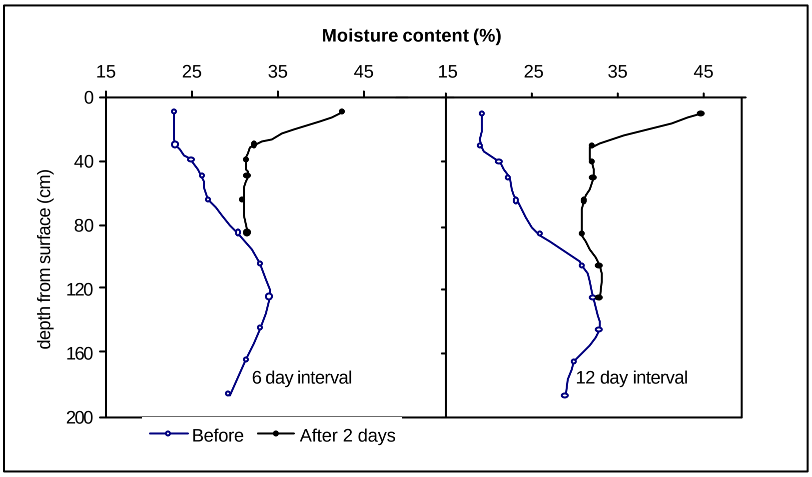

Figure 3.2 Volumetric moisture profiles immediately before, and two days after irrigation (Muchow and Wood 1981).

3.1.3 Sodicity Impact

Cununurra and Aquitaine clays are sodic at depth with Exchangeable sodium percentage (ESP) as high as 27 in the virgin state. Irrigation with Ord River water, which has a bicarbonate content of 110 mg/L, increases ESP in the rootzone (especially at the bottom) through precipitation of calcium carbonate (Lavalle 1983). The ESP levels can be managed by varying the leaching factor (George 1983 and Lavalle 1983).

A target ESP of 15 at a depth of 1.3–1.5 m has been set for this project. Elevated ESP levels reduce the hydraulic conductivity of the soil and Queensland experience (Shaw and Yule 1978) indicates that at an ESP of 15 the infiltration rate of a cracking clay would be reduced from 20 mm/day to 3 to 5 mm/day.

3.1.4 Root Zone Model

The LEACHM model replicates sprinkler or flood irrigation practices where the whole surface is wet evenly. However, in common with other models of this type, it does not replicate furrow irrigation systems where water can soak sideways from the furrow into the dry soil bed on which the crop is established. Water intake in this dry area is not dependent upon saturated hydraulic conductivity, but rather on the sorbtivity of the soil.

A reasonable approximation of the surface conditions and the infiltration rates down the profile were achieved in LEACHM by using:

- a 0.3 m surface layer with hydraulic conductivities in the range of 180 mm–300 mm/day and a mean of 240 mm/day:
- a layer for the balance of the root zone down to 1.5 m with a hydraulic conductivity between 10 mm and 47 mm/day and a mean of 20 mm/day;
- a layer of sodicity affected soil below the bottom of the root zone from 1.5 m to 2.2 m with a hydraulic conductivity between 3 mm–5 mm/day.

Below 2.2 m the clay content of the soil decreases and the hydraulic conductivity increases rapidly. Water passing below this depth therefore has easy accession to the underlying groundwater.

3.1.5 Root Depth

The model allows for roots to penetrate to 1.3 m with root density decreasing with depth. The water uptake weighting factors established for cracking clay soils at Emerald (Shaw and Yule 1978) were used.

3.2 RAINFALL AND EVAPORATION

The year 1991 (Figure 3.3) was selected following a review of rainfall and pan evaporation data as representing typical meteorological conditions for the development area. This approach is preferred to using average figures because it allows the actual evaporation occurring during rainfall events to be used. The high winds associated with some storms cause quite high evaporation to occur during wet periods.

Half hourly rainfall data from the Bureau of Meteorology was used which allowed run-off to be modelled with considerable more accuracy than when daily rainfall data is used. Effective Rainfall was calculated by reducing actual rainfall by 10% to approximate interception of rainfall by the sugar cane.

3.3 EVAPOTRANSPIRATION

The scenario modelled is for a mature sugar cane crop which has a crop factor of 0.85 (Holden 1998) except during the harvest and regrowth period. Cane will be harvested throughout the dry season but in this simulation a harvest at the end of July is assumed. The last irrigation occurs on the June 30th to allow the soil to dry out for harvest and resumes in mid August following re-establishment of the furrows after harvest.

The crop factor used for the bare soil plus young cane is 0.5 in late August, 0.6 in September and 0.8 in October. The LEACHM model does not have provision for variable crop factors and these were therefore simulated by reducing the pan evaporation rate.

3.4 IRRIGATION SCHEDULE

Irrigation water was assumed to be applied after an estimated soil moisture deficit of 75 mm, based on pan evaporation, crop factor and effective rainfall. A simplified irrigation schedule without tailwater return was also assumed, such that each irrigation applied 100 mm of water to allow for an in field irrigation efficiency of approximately 75%. In Queensland infield irrigation efficiencies of 71-73% with furrow lengths of 400–1,200 m can be achieved (Holden 1998), hence the 75% factor is consistent with best practice conditions that would be adopted for the project. It is noted that whole farm irrigation efficiency would be approximately 85% with tailwater recycling as proposed for this project. The irrigation schedule adopted by the model is shown in Figure 3.3.

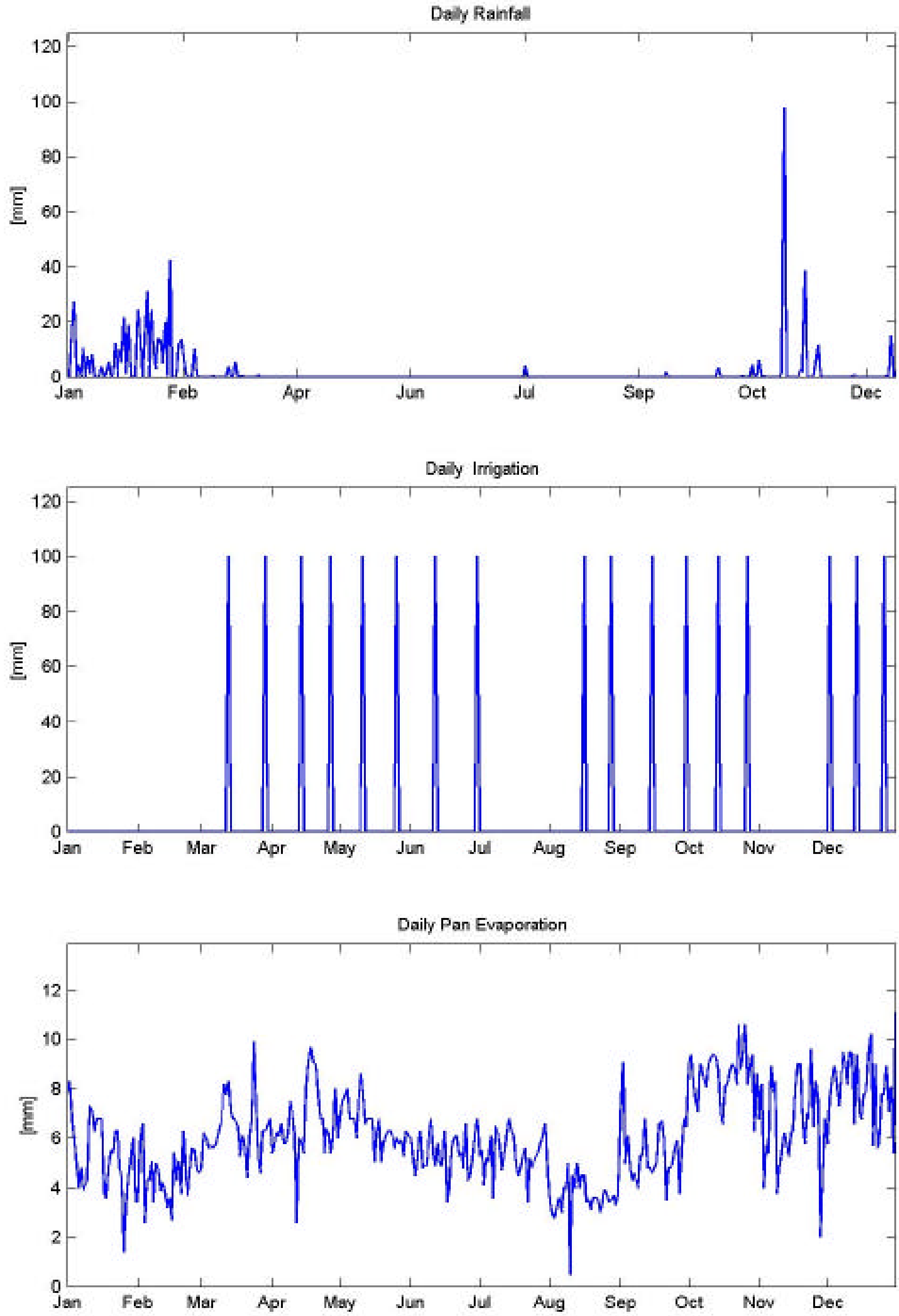

Figure 3.3 Meteorological data from 1991 and irrigation schedule used in the analysis

4 Results

Simulations were undertaken for a range of saturated hydraulic conductivities for each of the three layers of the soil profile used in the model. The investigated alternatives are summarised in Table 4.1.

Table 4.1 Summary of investigated alternatives

Case No.	Hydraulic conductivity within top 300 mm [mm/day]	Hydraulic conductivity at depths 300 – 1500 mm [mm/day]	Hydraulic conductivity at depths 1500 – 2200 mm [mm/day]
1	180	10	3
2	180	47	3
3	180	10	5
4	180	47	5
5	300	10	3
6	300	47	3
7	300	10	5
8	300	47	5
9	240	20	4

Note that Case 9 represents mid values for the range of values investigated for each of the three soil layers.

Relevant water balance parameters derived by the model for typical (mid range) soil properties (Case 9) are shown as daily values in Figure 4.1, cumulative daily values in Figure 4.2 and monthly values in Figure 4.3. These parameters include infiltration of rainfall and irrigation water into the topsoil, evapotranspiration, excess water on the surface which runs off the field and drainage (accessions) to groundwater. Figure 4.4 gives a summary of the main components of the water balance, including the temporal evolution of the soil moisture profile over depth.

The predicted annual accessions to groundwater for all the investigated alternatives are shown in Table 4.2.

Table 4.2 Predicted annual accessions to groundwater for investigated alternatives

Case No.	Accessions to groundwater [mm/year]
1	56
2	84
3	63
4	93
5	68
6	107
7	75
8	119
9	94

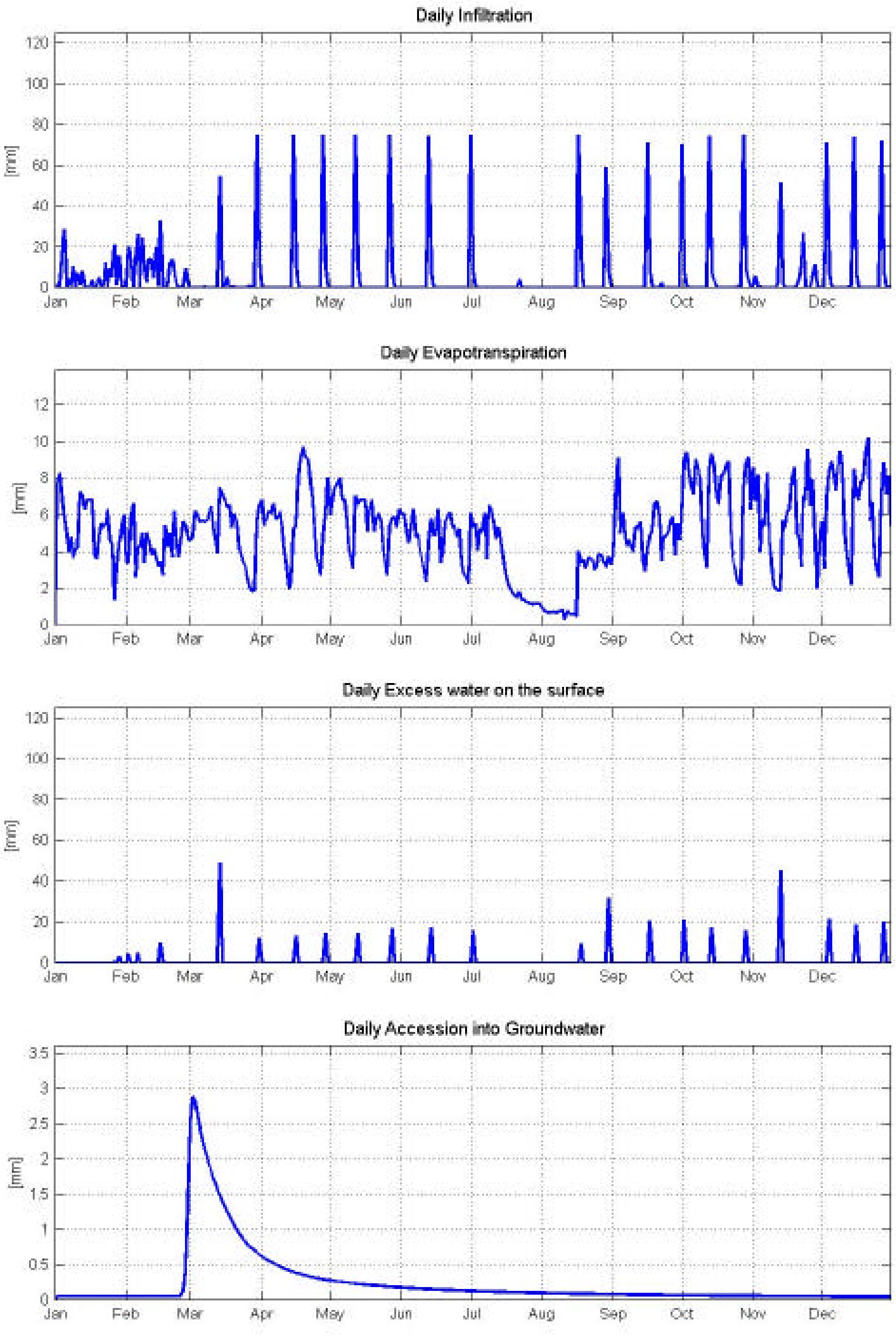

Figure 4.1 Soil water balance – daily basis for Case 9

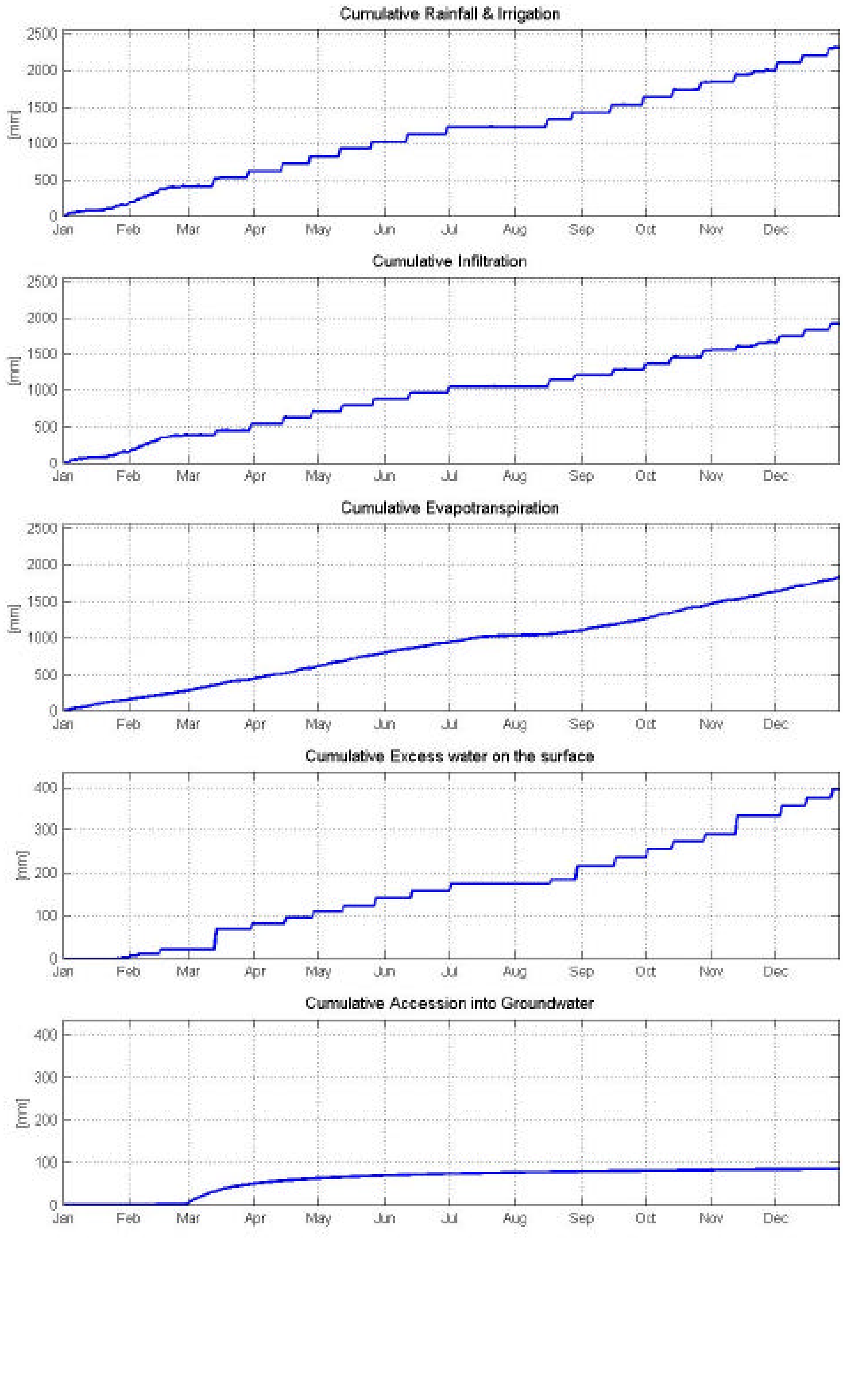

Figure 4.2 Soil water balance - cumulative daily basis for Case 9

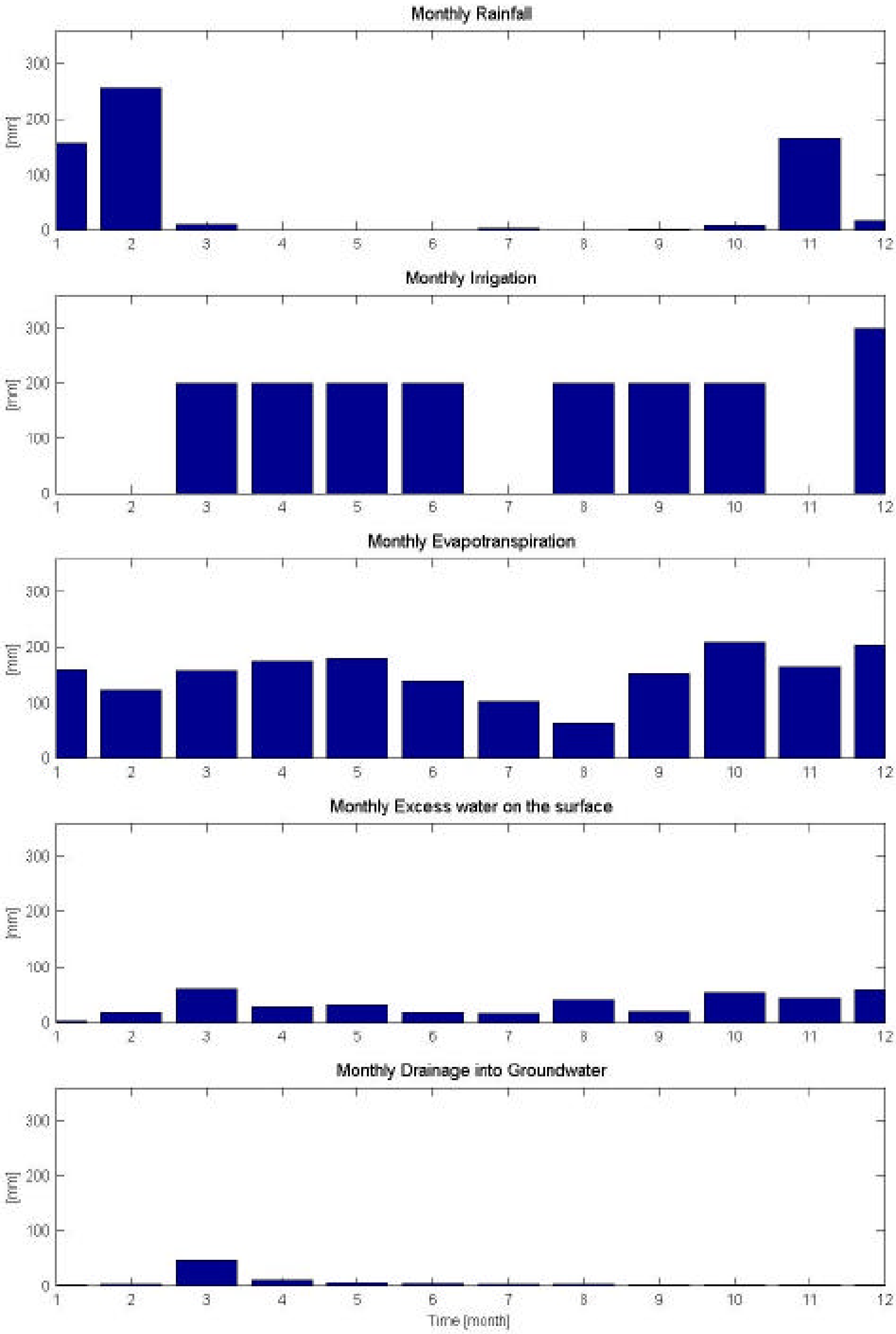

Figure 4.3 **Soil water balance - monthly data for Case 9**

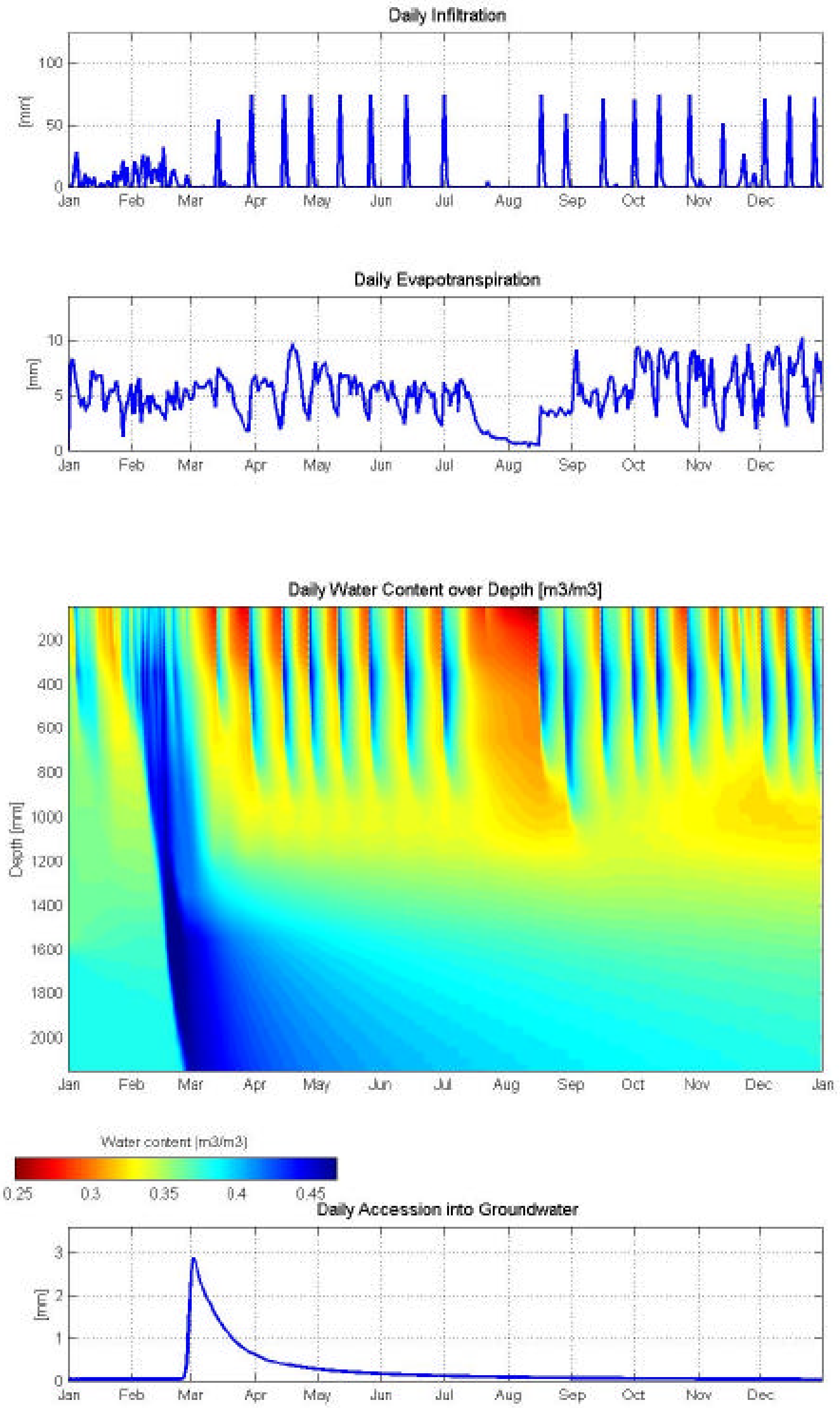

Figure 4.4 Summary of the soil water balance for Case 9

5 Model Output

The model has used a range of soil hydraulic conductivities to estimate the likely range of infiltration rates to groundwater. The following observations are made on the results of Case 9 which uses mid range values for each layer of the soil profile.

5.1 SOIL MOISTURE LEVELS

The soil moisture contents which develop during a typical year are shown graphically in Figure 4.4. These moisture contents demonstrate a reasonable fit with the results of Muchow and Wood 1983 in that:

- The moisture content at a depth of 1.0 m remains constant and at field capacity throughout the irrigation season.
- The shallow part of the root zone approaches saturation for the first few days after each irrigation.

5.2 RUN OFF

The model predicts annual run off from the fields to the tailwater return systems of 400 mm. Approximately 200 mm occurs between April 1 and October 31, when virtually no rain occurred (Figure 4.3). During this period 1,200 mm of irrigation water was applied and run off was therefore approximately 17%.

During the remaining five months rainfall was 678 mm. The model estimates that 68 mm was intercepted (used by the crop) and 200 mm or 32% ran off.

The 20% run-off for irrigation and 32% for rainfall are within the range estimated by (George 1983) from twelve years of gauging record on Drain D2B in Stage One of the Ord River Irrigation Area.

5.3 ACCESSION TO GROUNDWATER

The model predicts that almost all of the accession to groundwater will occur as the result of rainfall in the wet season (Figure 4.4). This is in conformity with studies of other irrigation areas in Australia which show that the main source of infiltration to the groundwater is rainfall. This factor results from the soil profile at the end of the dry season no longer being dry but at field capacity due to irrigation.

The model estimates that 1,900 mm of rainfall and irrigation will infiltrate into the soil (Figure 4.2). The predicted 94 mm/a of infiltration therefore represents a leaching factor of 0.05. This leaching factor is within the range of 0.04–0.07 estimated from furrow irrigated sugar cane in Stage One of the Ord River Irrigation Area using data from the studies by George 1983.

If in practice it is necessary to reduce the accession rate then stopping irrigation ahead of the wet season and allowing the sugar cane to dry out the profile should be the most effective strategy.

5.4 IRRIGATION EFFICIENCY

Of the 1,200 mm of irrigation water applied through the April to October period when no rain occurred, approximately 200 mm was predicted to run-off and 30 mm was predicted to pass into the groundwater. This result is consistent with best practice irrigation management as it indicates an irrigation efficiency of 80% which is at the upper end of the achievable infield irrigation efficiency (J.H. Sherrad, Department of Agriculture, Kununurra pers. comm., 1998).

5.5 GENERAL

The soil properties in the development area vary significantly with location. Therefore the model described in this paper can only be an approximation of the average conditions. However, the model results provide confidence that reasonable irrigation regimes can be designed for a range of soil properties that will contain accessions to groundwater within the range predicted for average conditions.

The use of in field soil moisture probes, which is now common in the vineyard industry in Western Australia, should allow irrigation scheduling with considerable accuracy.

6 Summary and Conclusions

Numerical simulations have been undertaken to evaluate the likely range of accession rates to groundwater that would result from the proposed Ord Sugar Project. The simulations were based on a range of soil data and average meteorological conditions.

The predicted soil moisture values and other parameters which result from using a reasonable irrigation regime are in accordance with the data observed on the Kimberley Research Station and in Stage One of the Ord River Irrigation Area.

For average soil properties and meteorological conditions the LEACHM model predicts an average accession rate to groundwater of 94 mm/a. Simulations for a wide range of soil properties results in predictions of annual accessions to groundwater as low as 56 mm/a or as high as 119 mm/a.

7 References

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