University of Southern Queensland

Faculty of Engineering and Surveying

Preliminary Water Balance Models of the Daly River Catchment

A Dissertation submitted by

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Abstract

Water is a controversial topic in agriculture and future development. The clearing of land and the conversion to cropping and irrigation is currently being discussed for the region of the Daly River catchment. Proposals to develop sheep and cattle grazing country into cropping and irrigation have been put forward to the Northern Territory Government. These proposals have forced the Northern Territory Government to produce an Integrated Regional Land Use Plan to assess hydrological, biological, environmental and social impacts on the catchment and the Daly River.

To assess the hydrological impacts, computer modelling was conducted in MIKE SHE on the changes in water balance. Three soil column water balance models have been produced and calibrated to simulate different land use scenarios. These scenarios include current conditions, native vegetation, and future agricultural development, improved pasture and irrigated peanuts. The analysed results from the water balance models include evapotranspiration, overland flow, crop water use and groundwater recharge.

The computer modelling results were compared for the three land use scenarios. It was found that the canopy density and the root zone depth for the crop type had the greatest influence of the water balance.

The canopy density controlled the level of surface exposure affecting evaporation rates. High canopy densities (high leaf area index) led to increased evaporation from the canopy while a decrease in evaporation from ponded water and from the soil. The root zone depth dictated the crops ability to draw moisture from the unsaturated zone. Shallow root depths of improved pasture and irrigated peanuts led to increased recharge, increased soil water storages and a rapid decrease in the transpiration rate (for improved pasture) during the dry season.

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Limitations of Use

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Certification

I certify that the ideas, design and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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Signature

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Date

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CRAIG ROHDE

University of Southern Queensland

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Chapter 1

Introduction

1.1 The Daly River

The Daly River is the largest perennial river in the wet-dry tropics of the Northern Territory. Its catchment spans 52500 km^2 and supports 3500 km^2 of wetlands (refer to figure 1.3). With very good soils, the Daly River catchment has been identified for future and ongoing agricultural development including pastoral, cropping, irrigated agriculture and horticulture (Wygralag 2006). With 2000 km^2 (or 4%) of land already cleared, future expansion of agricultural development within the catchment is pending completion of an Integrated Regional Land Use Plan.

The Daly River has the highest base flow of all rivers in the Northern Territory. The Daly River catchment is integrated with three significant aquifers that store, transmit and yield water. The Tindall Limestone, Oolloo Dolostone and Jinduckin Formation have formed in a layer of limestone beneath the catchment (refer to figure 1.3). These three aquifers store monsoonal rains during the period of the wet season (November-March), and yield water throughout the dry season (April-October). This vast underground storage provides a reliable groundwater supply to recharge the Daly River throughout the year.

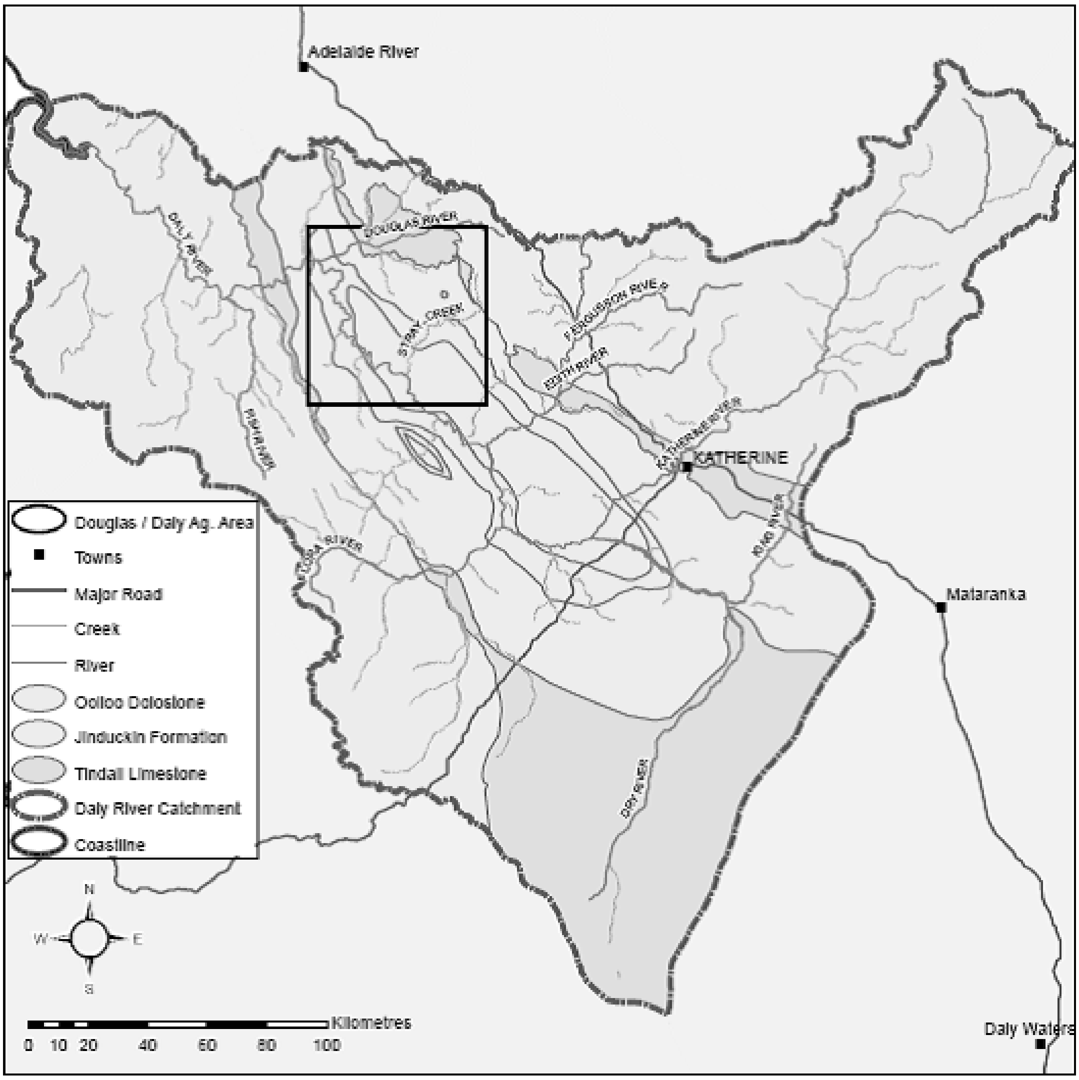

Figure 1.1: The Daly River catchment and aquifers locality map.
(source: Knapton 2006)

1.2 Scope of Project

The project aim is to simulate an unsaturated zone single column soil profile using the MIKE SHE model. This project seeks to analyse the impact of land use on the water balance of a farm. By understanding the capability of hydrological software MIKE SHE, various soil types and land use scenarios will be calibrated and modelled to investigate the infiltration and runoff behaviour. The Project Specification is shown in Appendix A.

This investigation will focus on a study area in the Daly River catchment (refer to figure 1.4) where good soils are encouraging the clearing of native vegetation and grasslands. The cleared land will increase the agricultural development within the study area. This will have an effect on the groundwater and surface water resources which recharge the Oolloo Dolostone Aquifer and the Daly River.

This project will demonstrate generalised predictions on water balance changes for several soil columns (pasture, native vegetation and intensive irrigation) allowing for an analysis of runoff, crop water use and groundwater recharge. Outputs will also include a working hydrological model for future studies by DHI Water and Environment. This will provide for expansion to a three-dimensional model for an entire catchment or farm property analysis. Three-dimensional models are beyond the scope of this project.

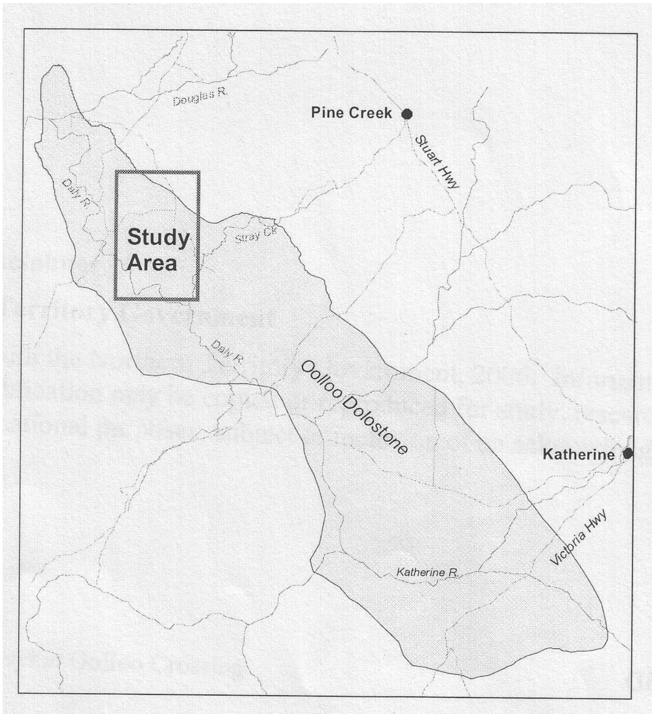

Figure 1.2: Water balance study area of the Daly River catchment.
(source: Wilson et al. 2006)

1.3 The Water Balance

The hydrological cycle depicts the natural circulation of water near the surface of the Earth as illustrated in figure 1.1.

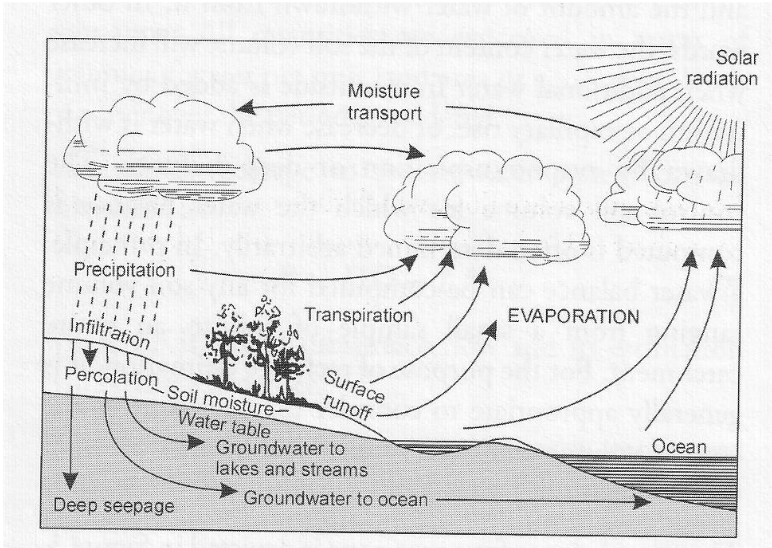

Figure 1.3: The hydrological cycle.
(source: Walker & Shang 2002)

The movement of water through the hydrological cycle can be explained by water balance, based on the law of conservation of mass. Any change in the water content of a soil volume must be equal to the amount of water added or withdrawn from the same soil volume. The water balance varies in time and space and can be analysed from a simple root-zone scale to an entire river catchment.

The water balance of a given site can be evaluated by calculating the input, output and storage change in water to a soil sample at the Earth's surface. The components of the water balance model are depicted in figure 1.2.

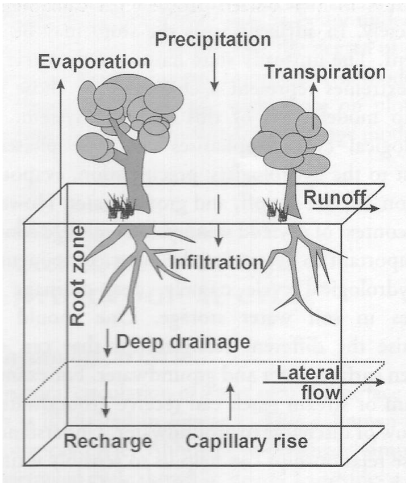

Figure 1.4: The water balance for a root-zone.
(source: Walker & Shang 2002)

- Precipitation varies in the form of rain, snow, sleet, hail, dew or fog. Precipitation is largest term in magnitude of the water balance and will:
  - Infiltrate the soil and evaporate from the soil surface or be transpired by vegetation (evapotranspiration);
  - become surface runoff; or
  - drain through the soil to form groundwater recharge.

- Evapotranspiration is the combination of water evaporating and transpiring directly back to the atmosphere. Evaporation draws water from oceans, lakes and moisture in the soil and transpiration is the result of water evaporating through plants and vegetation.

- Surface runoff and infiltration are a result of excess precipitation. Surface runoff (overland flow) is the water that travels over land towards a creek or river. Infiltration however, can lead to two scenarios:
  - Subsurface flow (lateral flow) travels through the upper soil layers in a lateral direction until it reaches a river or the ocean.
  - Groundwater flow (base flow) contributes to watertables and aquifers. It represents the portion of infiltration that leads to deep drainage. Groundwater flow maintains a steady discharge to the natural surface at springs. This leads to the formation of a wetland or continual flow to a river system.

- Soil water storage or the change in soil water storage is the difference in the water volume entering and discharging a soil sample over a period of time. The soil water storage directly relates to the water balance; the balance between inputs and outputs of water volume and can be expressed as:

$$\Delta S = P - I - ET - SR - SSR - DD \tag{1.1}$$

where ΔS is change in soil water storage [mm];

P is precipitation [mm];

I is infiltration [mm];

ET is evapotranspiration [mm];

SR is surface runoff [mm];

SSR is subsurface runoff [mm]; and

DD is deep drainage [mm].

(Walker & Shang 2002)

1.4 Dissertation Structure

The Dissertation is structured as outlined below.

Chapter 2 presents a review of literature relevant to this project. It analyses previous studies carried out on the Daly River catchment and incorporates techniques and theories applicable to this investigation. These include previous water balance models, applications of MIKE SHE, modelling limestone aquifers and tracing macropore flow.

Chapter 3 presents the theoretical background behind hydrological modelling software, MIKE SHE. The program capabilities and limitations of MIKE SHE were investigated. The MIKE SHE result format and the expected results from changing land use were also discussed.

Chapter 4 outlines the site and data availability for the Daly River catchment. This information was used to calibrate the computer models for the land use scenarios. A validation of these models was investigated through a sensitivity analysis.

Chapter 5 presents the water balance results for the three land uses; native vegetation, improved pasture and irrigated peanuts. The results were detailed in the water balance components of evapotranspiration, overland flow, crop water use and groundwater recharge.

Chapter 6 discusses the calibration and validation of the water balance models and the pending integrated regional land use plan. The hydrological components evapotranspiration, overland flow, crop water use and groundwater recharge are analysed and discussed. Limitations and restrictions to the water balance model are outlined.

Chapter 7 summarises and concludes the water balance changes due to land use. Recommendations for continual and ongoing work into the Daly River catchment are stated.

Chapter 2

Literature Review

2.1 Literature Review

Previous reports and experiments carried out in the Daly River catchment are of primary importance to the validation of this project. These reports analysis and results are required in this chapter. Other literature on previously simulated water balance models, MIKE SHE computer models, the groundwater pattern of limestone aquifers and the flow regime of macropores is included.

2.1.1 Effect of Land Use on the Daly River Catchment

Models were developed by Wilson et al. (2006) to gather an understanding of the recharge and discharge process of the Oolloo Dolostone aquifer, Daly River catchment. Effects of the water cycle that influenced groundwater flow were monitored. Measurements and experiments of surface and subsurface processes, included:

- Evapotranspiration from various vegetation types;
- Rainfall;
- Temporal series of soil moisture content under various vegetation types;
- Groundwater levels and subsurface chemistry.

The investigation results give insight into the recharge process to the Daly River region and the influence of vegetation cover. Water balance results indicate that evapotranspiration is largely reduced over cleared land relative to native savanna. A greater percentage of precipitation drainage therefore flows through to groundwater in cleared land. This is attributed to the rooting depth associated with the various land uses (table 2.1).

Wilson et al. (2006) collected their data throughout the period of one wet season (13 September 2005 to 2 March 2006). Runoff amounts were not measured in this period which led to the uncertainty in the groundwater recharge (table 2.1).

Table 2.1: Cleared land and native vegetation properties. (source: Wilson et al. 2006)

	Land Use	
Property	Sorghum (Cleared Land)	Savanna (Native Vegetation)
Rooting Depth	20-30cm	6-15m (Eucalyptus miniata)
Evapotranspiration	260mm	510mm
Precipitation	1058mm	
Groundwater Recharge	300-540mm	50-200mm

Wilson et al. (2006) observed recharge to be dominated by bypass flow. This is indicated by the difference in water quality (chloride concentrations and stable isotope signatures) between the unsaturated zone and groundwater. The lack of time lag from unsaturated zone infiltration to reach the groundwater indicates rapid recharge. Results beneath native vegetation suggest that 70% of groundwater recharge was contributed from bypass recharge and 30% through diffuse recharge. The mechanism for bypass recharge was found to be via sinkholes and/or soil macropores.

Land clearing led to an increase in groundwater recharge. Wilson et al. (2006) reported on the increase in spring flows being in proportion to the increase in recharge. This will have an immediate effect on groundwater although take decades to increase the discharge of springs to the Daly River. Wilson et al. (2006) suggest that this will result in a watertable rise. This additional groundwater recharge could cause dryland salinity and prolonged water logging in low lying areas.

Knapton (2006) continued the investigation of clearing native vegetation in the Daly River catchment. Knapton (2006) extended the model to quantify likely changes to the regional water balance with respect to land clearing. The analysis also included the likely proportion of recharge derived from direct and diffuse mechanism. The results of his investigation are summarised as:

- An increase of only 2-4 times the recharge in the cleared areas (compared to native vegetation) can be accommodated. Beyond this, Knapton (2006) experienced unrealistic increases in groundwater levels in his model. In contrast, Wilson et al. (2006) estimated a 5-10 times increase in recharge using soil moisture chloride profiles.
- Soil moisture and groundwater chemistry indicate that the major source of recharge is via preferential pathways (macropores and karstic environments).

- The analysis indicates that 20-30% of recharge is via diffuse mechanisms and 70-80% is due to direct recharge mechanisms.
- Although unsaturated zone infiltration rapidly recharges springs and aquifers, it could take decades for the river flow to be altered.
- A groundwater level increase of up to 7 metres in the wet season and 1-2 metres in the dry season could result from the clearing of native vegetation.
- An increase of approximately 15% of land being affected by water logging due to the increase in cleared land.

2.1.2 Daly River Catchment Water Balance

Jolly (2001) investigated the water balance for the Daly River catchment. Jolly (2001) provided an overview of the current state of knowledge for the Daly River catchments water balance. He also documented work that is required to gain an understanding of the components of the water balance.

Over the entire Daly River catchment, groundwater flows into or out of the catchment would occur adjacent to the boundary. Inflows would balance the outflows so that the impact would not be significant.

Runoff was measured at a number of locations throughout the Daly River catchment. The stations analysed had greater than 25 years of data and had experienced significant dry season river flows. The annual runoff is recorded in table 2.2. Jolly (2001) found that the mean total annual runoff equated to 148mm and the mean annual surface runoff came to 135mm.

Table 2.2: Daly River catchment annual runoff data. (source: Jolly 2001)

Gauging Station	Start of record	Catchment Area	Annual Runoff (mm)		
		(km2)	Min	Maximum	Mean
G8140001 Katherine R	1957	8640	44	589	223
G8140008 Ferguson R	1957	4790	47	784	297
G8140011 Dry River	1970	6290	1	177	23
G8140040 Daly R at Nancar	1969	46600	21	362	148
G8140044 Flora River	1967	5900	31	470	146
G8140063 Douglas River	1957	842	24	826	185
G8140067 Daly R at Dorisvale	1961	35800	20	388	119
G8140159 Seventeen Mile Creek	1963	619	27	517	153

Jolly (2001) trialled a range of values for evapotranspiration for the recharge area of the Tindall aquifer, Daly River catchment. Attempts were made to model historical groundwater flows in the Katherine River. A value of 150mm was used for the maximum soil moisture deficit, 5mm/day for potential evapotranspiration and 225mm for annual potential recharge (surface runoff and groundwater recharge).

Jolly (2001) produced table 2.3 to provide an overview of the water balance for the Daly River catchment. The estimated hydrological data was made by Jolly (2001) after the preliminary analysis of the Daly River catchment.

Table 2.3: Daly River catchment water balance summary.

Components of Water Balance	Annual Amounts for Catchment (mm)		
	Minimum	Maximum	Mean
Rainfall (DR014902, period 1957 - 2000)	500	1620	970
Runoff (F8140001, period 1957 - 2000)	50	590	220
Recharge (period 1957 - 2000)	0	300	90
Transpiration by large trees	150	150	150
Understorey Evapotranspiration	300	580	510
Inflow from adjacent aquifers			1
Water stored above and below water table	6500	6600	6550
Pumping for water supply purposes			0.4

2.1.3 Water Balance Models

A single layer soil water balance model was examined by Eilers, Carter & Rushton (2007) to estimate deep drainage.

Eilers, Carter & Rushton (2007) carried out soil water balance calculations using the key hydrological processes. The processes occurred around the soil zone and are illustrated in figure 2.1.

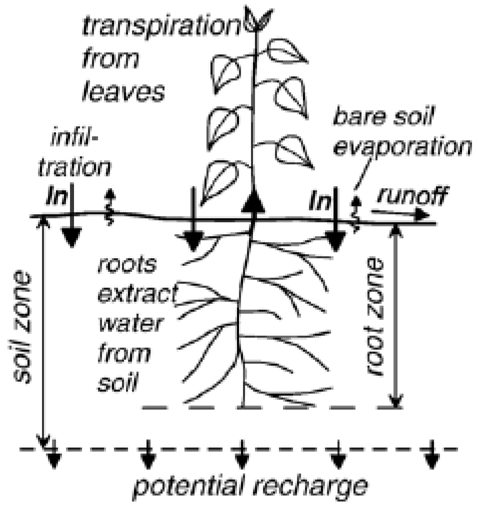

Figure 2.1: Soil water balance components.
(source: Walker & Shang 2002)

Aspects taken into account by Eilers, Carter & Rushton (2007) to estimate deep drainage included:

- Precipitation being intercepted by vegetation and directly evaporated;
- Transpiration from water loss through vegetation;
- Bare soil evaporation (saturated, unsaturated and dry soil);
- The infiltration and infiltration capacity of the soil zone;
- Runoff when the infiltration capacity is exceeded;
- Deep drainage when the soil zone reaches field capacity.

Eilers, Carter & Rushton (2007) examined a continuous soil water content model over a 36 year period. The model took into account the growing phase of a typical millet crop throughout the wet season (refer to figure 2.2). The soil water content was computed at the end of every time step by a simple mass balance approach to the soil zone in figure 2.1.

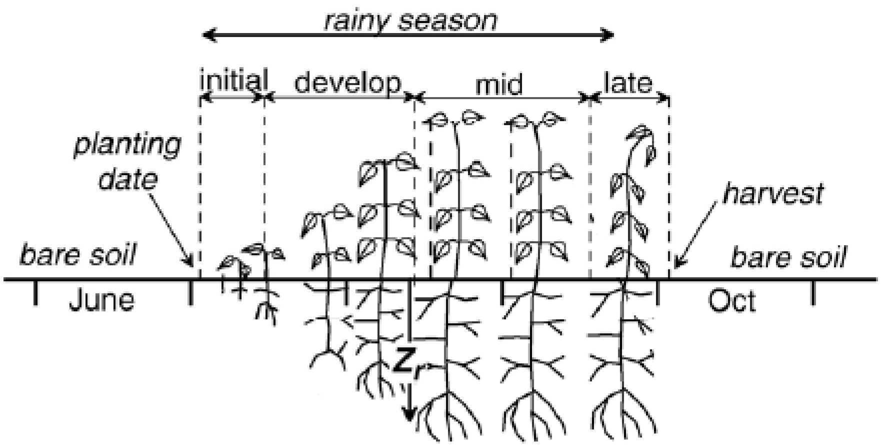

Figure 2.2: Seasonal growth of a typical millet crop.
(source: Eilers, Carter & Rushton 2007)

Eilers, Carter & Rushton (2007) carried out a sensitivity analysis and found limitations and uncertainties that arose due to:

- Empirical errors in field measurements;
- Parameter and crop coefficient variations leading to a range of potential recharge from 11.2 mm/year to 17.8 mm/year;
- Variation in depth of root zone;
- Differences of soil moisture content at field capacity at the wilting point;
- The disregard of by-pass flow and direct recharge.

2.1.4 MIKE SHE

MIKE SHE is a physically-based, spatially distributed hydrological modelling package that simulates all aspects of the hydrological cycle. It has been widely used to study a variety of water resource and environmental problems under diverse climatological and hydrological applications (Centre for Research in Water Resources 2007).

A typical investigation using MIKE SHE was carried out by Vazquez & Feyen (2003). They conducted experiments to estimate the actual evapotranspiration from the potential evapotranspiration. Actual evapotranspiration plays an important role in catchment hydrology when water supply limits evapotranspiration below the potential rate. Land use, crop characteristics, meteorological data and potential evapotranspiration are assessed to produce the actual evapotranspiration.

MIKE SHE was used by Vazquez & Feyen (2003) to model the surface and groundwater flow dynamics. Modelling the components of the water movement, the actual evapotranspiration results from the processes of:

- Interception of rainfall by the canopy;
- Drainage from the canopy;
- Evaporation from the canopy surface;
- Uptake of water by plant roots and its transpiration; and
- Evaporation from the soil surface.

Two stations were calibrated and evaluated using 29 years of meteorological data and 12 years of discharge data. The confidence limits and monthly evapotranspiration data is illustrated in figure 2.4.

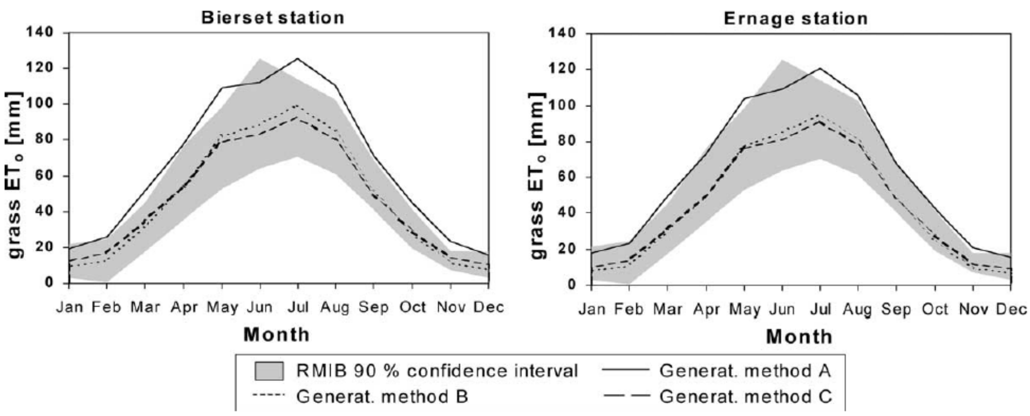

Figure 2.3: Mean evapotranspiration estimates for the Bierset and Ernage stations compared to the 90% confidence intervals in the period 1967-1995.

(source: Vazquez & Feyen 2003)

Vazquez & Feyen (2003) carried out a sensitivity analysis for the three simulated evapotranspiration estimates (refer to figure 2.4). The sensitivity analysis results showed a significant dependency on the MIKE SHE parameters controlling the transpiration rate and the ratio between transpiration and soil evaporation.

Experiments were conducted by McMichael, Hope & Loaiciga (2005) on GLUE methodology for calibration, testing and predictive uncertainty estimation in MIKE SHE hydrological models. One thousand parameter sets between the ranges in table 2.4 were randomly selected to carry out a 20 year simulation.

Table 2.4 The initial and final parameter ranges for the MIKE SHE simulation.

Parameter	Initial Minimum Value	Initial Maximum Value	Final Minimum Value	Final Maximum Value
Interflow and Groundwater Reservoirs				
IF_t (m)	0.0001	0.3	0.0006	0.1901
IF_h (days)	0.0001	3	0.0121	3
IF_v (days)	0.0001	80	0.2085	80
GW_h (days)	0.05	100	0.08	96
Soil				
K_s_Sandy Loam (m s^{-1})	1.0×10^{-6}	5.0×10^{-4}	1.0×10^{-6}	5.0×10^{-4}
n_Sandy Loam	1	30	1	30
K_s_Loam (m s^{-1})	1.0×10^{-6}	5.0×10^{-4}	1.0×10^{-6}	5.0×10^{-4}
n_Loam	1	30	1	30
Vegetation				
C_1	0.01	1	0.13	1
C_2	0.01	1	0.01	1
C_3 (mm day^{-1})	1	60	1	60

Behavioural sets were classified by 109 of the 1000 data simulations. These provide an insight into the strengths and weaknesses of the combined model structure, parameters and input data. This can predict the catchment behaviour. The results are summarised below:

- Up to 68% of the calibrated observed streamflow values fall within the 5% and 95% confidence limits. Prediction errors occur in the wet season months for the calibration period.
- Up to 67% of the tested observed streamflow values fall within the 5% and 95% confidence limits. Prediction errors are found in every year of the test period.
- The total prediction error is less than 10% (the sum of over and under estimation error) of the observed flow.
- Just over 30% of the observed streamflow values fall outside of the 90% confidence limits.

2.1.5 Limestone Aquifers

There is little known about the properties and the complex flow system of limestone aquifers in the Northern Territory. In recent history, hydrologic models have been established to trace the groundwater patterns of limestone aquifers.

Kaufmann (2003) examined conceptual models which resembled the cross-section of a two-dimensional karst aquifer with various boundary conditions. The experiment was trialled while maintaining the physical size of the aquifer, initial conductivities, fracture distributions and the base level of the water table at a fixed magnitude. Varying boundary conditions included:

- Recharge along water table, no vadose zone.
- Surface recharge, vadose zone with no enlargement.
- Surface recharge, vadose zone with enlargement.

Kaufmann (2003) found that the evolution of a karst aquifer is controlled by:

- A falling water table in the vertical direction.
- Calcite dissolution chemically enlarging the limestone aquifer.
- Increasing conductivity and continual lowering of the water table while the aquifers fractures enlarge.
- Groundwater recharge via infiltration and preferential pathways increasing the soils conductivity.

Kaufmann (2003) found that karst aquifers continue to evolve until a pressure equilibrium is reached in the saturated zone. At equilibrium the water table reaches a steady state position forming the base-level.

Jones & Banner (2003) examined the recharge into three limestone aquifers. These three aquifers experience distinct wet and dry season climatic conditions. Jones & Banner (2003) used oxygen isotopes to estimate the amount and timing of recharge to limestone aquifers.

Groundwater quantities in aquifers respond to short and long-term climatic and land use fluctuations. Jones & Banner (2003) investigated the conditions influencing recharge to these aquifers to predict seasonal and inter-annual variations. They found that recharge to the limestone aquifers is influenced primarily by precipitation runoff along dry valleys. This produces discrete recharge by rapid infiltration through karst shafts and sinkholes.

Jones & Banner (2003) found an inverse relationship between rainwater oxygen isotope values and the amount of rainfall. Seasonal fluctuations in rainwater oxygen isotopes has allowed for an estimation of the groundwater recharge in these aquifers. This is due to a tropical climate with distinct wet and dry seasons within a narrow temperature range.

Audouin & Bodin (2007) conducted a sensitivity analysis to investigate the input parameter behaviour of slug tests. Cross-borehole slug tests in fractured media were previously conducted by Barker (1988). Cross-borehole slug tests assess the hydraulic properties of an aquifer. The model used by Audouin & Bodin (2007) assumed homogeneous, isotropic and continuous aquifer properties. Fractured limestone aquifers are inherently heterogeneous. Due to the large number of parameters to assess aquifers, homogeneous models were seen as a practical option for simulation.

The model developed by Barker (1988) included five fitting parameters; flow dimension, n, hydraulic conductivity, K, specific storage coefficient, Ss, effective lengths of test well, Le, and effective lengths of observation well, Le_o. The complex flow system within an aquifer led to new hydraulic parameters per individual flow path. Practical outcomes were diminished by the large number of fitting parameters to model the aquifer.

Audouin & Bodin (2007) identified the influence of changing parameter values by the shape of the slug test responses. The model was based on the standard sensitivity coefficients. The coefficients are based on the fitting parameters and the hydraulic head, $W(t)$:

$$U_n = \frac{\partial W(t)}{\partial n},\ U_K = \frac{\partial W(t)}{\partial K},\ U_{S_S} = \frac{\partial W(t)}{\partial S_S}$$

$$U_{Le} = \frac{\partial W(t)}{\partial Le},\ U_{Le_o} = \frac{\partial W(t)}{\partial Le_o} \qquad (2.1)$$

where U_n is the sensitivity coefficient for flow dimension

U_K is the sensitivity coefficient for hydraulic conductivity

U_{Ss} is the sensitivity coefficient for specific storage

U_{Le} is the sensitivity coefficient for test well length

U_{Leo} is the sensitivity coefficient for observation well length

The results of the sensitivity analysis demonstrated that the flow dimension, n, was the most sensitive parameter. The sensitivity of other parameters were ranked in order of $K > Le \sim Le_o > Ss$; as illustrated in figure 2.5. The initial slug head, H_o, was not considered a fitting parameter.

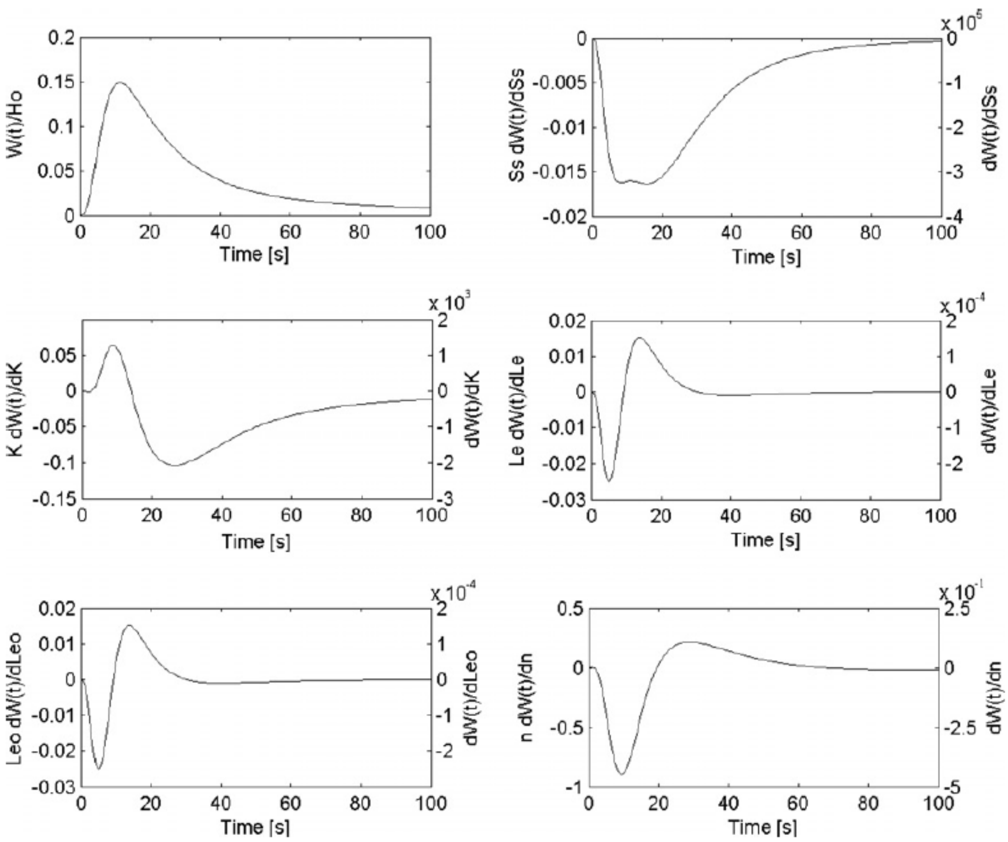

Figure 2.4: Sensitivity curves to K, Ss, Le, Le_o and n for an overdamped hydraulic head W(t).
(source: Audouin & Bodin 2007)

2.1.6 Macropore Flow

Christiansen et al. (2004) produced a catchment scale flow regime to uncover the importance of macropores (preferential flow mechanisms). This was to monitor pesticide leaching in shallow groundwater tables of clayey and loamy soils. Four soil types represented the catchment study area which were loamy sand, sandy loam, loam and organic. These soils are in table 2.5 along with corresponding parameters.

Table 2.5: Hydraulic parameters for the soil types loamy sand, sandy loam, loam and organic.

Soil characteristics		Bulk characteristics		Macropore characteristics				Matrix characteristics			
Soil name	Depth below ground surface (m)	$\theta_{s,bulk}$ (–)	$K_{s,bulk}$ (m/s)	$\theta_{s,mp}$ (–)	$K_{s,mp}$ (m/s)	ψ_t (m)	β_{mp} (m^{-2})	$\theta_{s,matrix}$ (–)	$K_{s,matrix}$ (m/s)	Campbel–Burdine parameters	
										b	Hb (m
Soil 1 loamy sand	0–0.15	0.41	1.7×10^{-5}	0	–	–	–	0.41	1.7×10^{-5}	7.9	0.046
	0.15–0.2	0.41	1.7×10^{-5}	0.02	1.0×10^{-5}	−0.15	300	0.39	6.7×10^{-06}	7.9	0.046
	0.2–0.3	0.41	5.5×10^{-6}	0.02	2.8×10^{-6}	−0.15	300	0.39	$2.7 \times 10^{-}6$	5.5	0.027
	0.3–0.7	0.41	5.5×10^{-5}	0.02	2.8×10^{-5}	−0.15	300	0.39	2.7×10^{-5}	5.5	0.027
	0.7–1.4	0.33	7.1×10^{-6}	0.01	3.2×10^{-6}	−0.15	300	0.32	3.8×10^{-6}	8.3	0.044
	1.4–1.8	0.33	7.1×10^{-6}	0	–	–	–	0.33	7.1×10^{-6}	8.3	0.044
Soil 2 Sandy Loam	0–0.15	0.47	6.0×10^{-6}	0	–	–	–	0.47	6.0×10^{-6}	8.7	0.026
	0.15–0.2	0.47	6.0×10^{-6}	0.02	3.5×10^{-6}	−0.15	300	0.45	2.5×10^{-6}	8.7	0.026
	0.2–0.3	0.36	1.0×10^{-7}	0.02	7.2×10^{-8}	−0.15	300	0.34	2.8×10^{-8}	9.5	0.064
	0.3–0.7	0.38	1.0×10^{-6}	0.02	7.4×10^{-7}	−0.15	300	0.36	2.6×10^{-7}	11.0	0.079
	0.7–1.4	0.35	5.0×10^{-7}	0.01	2.6×10^{-7}	−0.15	300	0.34	2.4×10^{-7}	11.3	0.094
	1.4–1.8	0.32	1.0×10^{-7}	0	–	–	–	0.32	1.0×10^{-7}	12.6	0.149
Soil 3 Loam	0–0.15	0.36	6.2×10^{-6}	0	–	–	–	0.36	6.2×10^{-6}	12.0	0.050
	0.15–0.2	0.36	6.2×10^{-6}	0.02	4.9×10^{-6}	−0.15	300	0.34	1.3×10^{-6}	12.0	0.050
	0.2–0.3	0.40	1.9×10^{-6}	0.02	1.3×10^{-6}	−0.15	300	0.38	5.8×10^{-7}	10.0	0.070
	0.3–0.7	0.40	1.9×10^{-5}	0.02	1.3×10^{-5}	−0.15	300	0.38|	5.8×10^{-6}	10.0	0.070
	0.7–1.4	0.40	1.5×10^{-6}	0.01	7.9×10^{-7}	−0.15	300	0.39	6.8×10^{-7}	13.6	0.140
	1.4–1.8	0.40	1.5×10^{-6}	0	–	–	–	0.40	1.5×10^{-6}	13.6	0.140
Organic soil	0–1.8	0.77	9.3×10^{-7}	0	–	–	–	0.77	9.3×10^{-7}	5.7	0.300

Christiansen et al. (2004) used MIKE SHE software to model unsaturated flow. He tested the importance of macropore flow and the affects they had on the water balance. With no available parameters for modelling macropore systems, Christiansen et al. (2004) used previous studies within the catchment to estimate macropore flow. The macropore system consisted of biopores including worm and root channels.

Christiansen et al. (2004) found through the macropore simulation that:

- Macropore flow is mainly governed by soil moisture conditions in the root zone and influenced by the depth of the groundwater table.
- The macropore process has the primary function of rapidly transporting water. The water is transported from the surface to a depth within the root zone where most of it flows back into the soil matrix. Only a minor part of the macropore flow reaches the groundwater table directly through the macropores.
- The present study suggests that macropore processes appear to have only negligible effects on groundwater levels. This is compared to other similar distributed physically based models. Bypass flow was discussed to account for varying soil hydraulic properties, root zone depth, vegetation types and climate input.

Chapter 3

Modelling Methodology

3.1 MIKE SHE

This project modelled the impact of several different land uses on the water balance and groundwater recharge of the Daly River catchment. The MIKE SHE model was adopted to simulate native vegetation, improved pasture and irrigated peanuts.

MIKE SHE was selected for the project because it is a deterministic, fully-distributed and physically based modular modelling system (Centre for Research in Water Resources 2007). It is capable of simulating all major hydrological processes in the land phase of the hydrological cycle, and is applicable to a wide range of water resource and environmental problems. MIKE SHE is capable of evaluating the surface water balance at scales from a single soil column profile to a full river catchment. The computer model is capable of handling various soil profiles, differing land uses, changing climates and altering topography. This is achieved through the add-on ‘Water Movement Module’ in MIKE SHE. The Water Movement Module combines and models interception/evapotranspiration, overland and channel flow, unsaturated zone, saturated zone, snowmelt and the exchange between aquifers and rivers (channel flow, saturated zone and snowmelt are not applicable to this project) (Thompson Gavin & Hamm 1999).

'MIKE SHE is categorised as being:

- *Integrated; a fully dynamic exchange of water between all major hydrological components (surface water, soil water and groundwater).*
- *Physically based; it solves basic hydrological equations governing the major flow processes within the study area.*
- *Fully distributed; the spatial and temporal variation of meteorological, hydrological, geological and hydro geological data across the model area is utilised in a gridded form. This includes inputs as well as the outputs from the model.*
- *Modular; MIKE SHE has been given a modular structure, which allows expanded water quantity. The modular architecture allows the user to focus only on the processes which are important for the study.'*

  (Centre for Research in Water Resources 2007)

Within the Water Movement Module the key components for inclusion in this project include Overland Flow (OL), Evapotranspiration (ET), the Unsaturated Zone (UZ) and Full Macropore Flow.

3.1.1 Overland Flow

When the net rainfall (canopy throughfall) exceeds the infiltration capacity of the corresponding soil, water begins to pond. Once ponded water reaches its detention storage (depth 2mm) it becomes available for surface water runoff. The surface water runoff is calculated through the Overland Flow Module (OL) in MIKE SHE. For this project, the calibration and analysis were limited to the Finite Difference Method for precision; a simplified Overland Flow Routing Method (through sub-catchments) was also available.

Finite Difference Method

A diffusive wave approximation of St Venant Equations is derived to model the continuity and momentum of overland flow. This allows for variation in depth and velocity of overland flow in neighbouring cells and time steps.

The continuity equation is given by:

$$\frac{\partial h}{\partial t} + \frac{\partial}{\partial x}(uh) + \frac{\partial}{\partial y}(vh) = i \qquad (3.1)$$

where h is the flow depth above the ground surface [m];

u is the velocity in the lateral direction [m.s^{-1}];

v is the velocity in the longitudinal direction [m.s^{-1}]; and

i is the net input into overland flow [m.s^{-1}].

The momentum equations are:

$$S_{fx} = S_{ox} - \frac{\partial h}{\partial x} \qquad (3.2)$$

$$S_{fy} = S_{oy} - \frac{\partial h}{\partial y} \qquad (3.3)$$

where S_f is friction slope in the x and y direction; and

S_o is the slope of ground surface in the x and y direction.

The Stickler Roughness Coefficient (or Manning M) and diffusive wave approximations combine to give:

$$uh = K_x(-\,\partial z/\partial x)^{1/2} h^{5/3} \qquad (3.4)$$

$$vh = K_y(-\,\partial z/\partial y)^{1/2} h^{5/3} \qquad (3.5)$$

where uh and vh are the discharge per unit length along the cell boundary in the x and y direction [$m^2.s^{-1}$]; and

Kx and Ky are the Stickler Roughness Coefficients (or Manning M) in x and y direction.

These Stickler Roughness Coefficients form to give the discharge across any cell boundary during the analysis:

$$Q = \frac{K\Delta x}{\Delta x^{1/2}}(Z_U - Z_D)^{1/2} h_u^{1/2} \qquad (3.6)$$

where Z_U is maximum water level in cell [m];

Z_D is minimum water level in cell [m]; and

h_u is depth of water that can flow in neighbouring cell [m].

The Gauss Seidel method and the Taylor series are used to solve the overland flow equations. These combined methods produce an iterative solution to the non-linear relationship between water levels and flows. The equations of each iteration are explicit. Overland flows can be reduced through the iterations to avoid internal water balance errors and divergence of the solution. Outflow is therefore expressed as:

$$\sum|Q_{out}| \leq \sum Q_{in} + I + \frac{\Delta x^2 h(t)}{\Delta t} \tag{3.7}$$

where $\sum Q_{in}$ is the sum of inflow rates [$m^3.s^{-1}$]; and

I is the net input into overland flow in each grid [$m^3.s^{-1}$].

3.1.2 Evapotranspiration

The calculation and modelling of evapotranspiration in MIKE SHE was conducted in the following order:

1. Rainfall is intercepted by the canopy. The net amount of rainfall intercepted is calculated through the vegetation type, vegetation maturity (leaf area index (LAI)) and rainfall intensity. The rainfall that is intercepted evaporates back to the atmosphere.

2. The remaining rainfall reaches the soil surface (canopy throughfall). It either ponds and becomes overland flow or infiltrates to the unsaturated zone.
3. Part of the infiltrated water in the upper root zone evaporates and another part transpires through the vegetation roots.
4. The remainder of the infiltrated water is either stored in the unsaturated zone or becomes groundwater recharge.

This project uses the Kristensen and Jensen method for the evapotranspiration analysis (Oogathoo 2006).

The canopy interception, I_{max} [mm], must be at its maximum limit before any throughfall can be experienced. Therefore:

$$I_{max} = C_{int}LAI \tag{3.8}$$

where C_{int} is the interception coefficient defining the interception storage coefficient of the vegetation [mm].

The canopy evaporation, E_{can} [mm], is equal to the potential evapotranspiration if sufficient precipitation has been intercepted. Therefore:

$$E_{can} = min(I_{max}, E_p\Delta t) \tag{3.9}$$

where E_p is the reference evapotranspiration rate [$mm.hr^{-1}$]; and
Δt is time step duration for the simulation [hr].

The vegetation actual transpiration, E_{at} [mm/hr], is dependent on LAI, soil moisture content and the root density. Therefore:

$$E_{at} = f_1(LAI) \cdot f_2(\theta) \cdot RDF \cdot E_p \tag{3.10}$$

Where $f_1(LAI)$ is a function depending on the LAI;

$f_2(\theta)$ is a function depending on the soil moisture content in the root zone; and

RDF is a function depending on root distribution.

When no vegetation is defined, E_{at} and $f_1(LAI)$ are equal to zero.

The soil evaporation, E_s [mm/hr], occurs in the upper part of the unsaturated zone due to excess soil water. Therefore:

$$E_s = E_p \cdot f_3(\theta) + \left(E_p - E_{at} - E_p \cdot f_3(\theta)\right) \cdot f_4(\theta) \cdot \left(1 - f_1(LAI)\right) \tag{3.11}$$

where f_3 and $f_4$are functions depending on the soil moisture content.

3.1.3 Unsaturated Zone

The full Richards equation was used to calculate the unsaturated flow due to its comprehensive nature and degree of accuracy (Oogathoo 2006). The full Richards equation requires a tabular or functional relationship for the retention curve and hydraulic conductivity. Unsaturated flow is characterised by cyclic fluctuations of soil moisture and which are modelled vertically in one-dimension. The unsaturated zone is defined by soil zones and subdivided into a large number of cells from the surface through to the saturated zone. The unsaturated flow needs to be calculated only once per cell for every time step throughout the model.

The Richards equation is:

$$C\frac{\partial \psi}{\partial t} = \frac{\partial}{\partial z}\left(K(\theta)\frac{\partial \psi}{\partial z}\right) + \frac{\partial K(\theta)}{\partial z} - S \tag{3.12}$$

Unsaturated flow is driven by a gravity component, z [mm], and a pressure component, ψ [mm]. This leads to the retention of water in the soil matrix due to the capillary forces and short range adsorptive forces. The gravity component is defined through the hydraulic conductivity, K [m.s^{-1}], and the soil moisture content, θ [g.g^{-1}]. A sink term, S (s^{-1}), is included to allow for transpiration in the upper part of the unsaturated zone. All of the above gives the soil water capacity, C (mm^{-1}), which is based on Darcy's Law and the continuity equation to define the full Richards equation.

MIKE SHE uses a fully implicit method to solve the Richards equation which is based on the Gauss Seidel iterative formula. This allows for stability and convergence in the solution. Unsaturated flow is determined by the boundary conditions. This is the upper boundary (soil surface) and the lower boundary (groundwater table). The upper boundary exhibits either constant flux from precipitation or constant head from ponding water. The lower boundary acts as a pressure boundary depending on the elevation of the groundwater table. MIKE

SHE utilises an initial equilibrium soil moisture and pressure profile. These decrease from zero at a linear rate to field capacity moisture content.

3.1.4 Full Macropore Flow

Macropores are a secondary continuous pore domain in the unsaturated zone. Macropore flow is generated due to a rise in the capillary head exceeding the threshold soil matrix pressure head. Flow is due to the action of gravity.

Through the continuity equation and vertical volumetric flux, macropore flow can be related to the Richards equation (unsaturated zone) via the source/sink term, S_{mp}. Therefore:

$$S_{mp} = \beta_{mp} \cdot K(\theta_{matrix}) \cdot (\psi_{mp} - \psi_{matrix}) \tag{3.13}$$

where β_{mp} is the water transfer coefficient between matrix and macropores [m^{-2}];

$K(\theta_{matrix})$ is the hydraulic conductivity of the matrix [m/s];

ψ_{mp} is the capillary head in macropores [m]; and

ψ_{matrix} is the capillary head in matrix [m].

The MIKE SHE analysis considers the different velocity rates of the macropores compared to the soil matrix domains. To accommodate this variation the algorithm consists of a two repetitive sweeps (downwards then upwards).

The downwards sweep models flow from each cell to the cell below throughout the soil profile. Macropore, matrix and exchange flows are calculated for each cell of the iteration while obeying the mass conservation law (outflow must be less than or equal to the storage volume of the cell).

The upwards sweep models the over-saturation of macropores. The macropore water contents from the downwards sweep are checked for exceeding the macropore porosity. If the porosity is exceeded, macropore or exchange flows are reduced to ensure the mass conservation law of each cell.

3.2 MIKE SHE Results

MIKE SHE water balance simulation results are produced through the water balance editor. The water balance editor is a post-processing tool that generates flow depth and storage change data. This data is produced in an accumulated depth format or as a daily balance output. MIKE SHE extracts the simulated data from the previously generated output files. The data can be extracted for the entire catchment or a specified sub-catchment of the simulation. The data can also be extracted for varying time periods within the default simulation period. Relevant MIKE SHE output water balance types to this project include:

- Total Water Balance – including precipitation, evapotranspiration, irrigation, overland boundary flow, subsurface storage change, subsurface boundary outflow and unsaturated zone error.
- Overland Flow – including net precipitation, evaporation, infiltration and overland boundary flow.

- Canopy Interception – including precipitation, canopy throughfall and evaporation.
- Unsaturated Zone – including infiltration, evaporation, transpiration, subsurface storage change, subsurface boundary outflow and unsaturated zone error.

3.3 Expected Results

Expected results from the outcome of this project are in relation to water balance changes arising from evapotranspiration, overland flow, crop water use and groundwater recharge. The water balance changes will result from the variation in land use from native vegetation to improved pasture and irrigated peanuts.

The water balance totals for evapotranspiration are expected to alter significantly throughout each year. Simulated evapotranspiration totals for native vegetation and improved pasture (which continue growth throughout the entire year) are expected to display similar annual patterns to each other. These patterns should be influenced by a higher growth rate (higher transpiration) of improved pasture. This will be offset by greater evaporation experienced via the less dense landscape of native vegetation.

Irrigated peanuts will experience a high growth rate during the crop season (February to June) and limited land cover throughout the remainder of the year. This will lead to very high transpiration rates during the crop season and high evaporation rates during the wet season when no crop is present (November to

January). High evaporation will be experienced due to the soil and ponded water being directly exposed to the atmosphere.

The water balance totals for overland flow will directly change due to land use. Overland flow will result from excess precipitation that does not infiltrate the soil. Higher overland flow totals are expected during the wet season for peanuts in which the crop will not be present (due to no crop water use).

The water balance totals for crop water use are expected to be influenced by the available water in the root zone and the growth rate of the crop. Irrigated peanuts are expected to experience the highest crop water use although for the shortest period. Being supplied with additional water through irrigation, the peanut crop will maintain this high growth rate. Improved pasture is also expected to have a high crop water use when water is available. This will result in the pasture often suffering and even wilting during the dry season. Native vegetation will be capable of drawing water from deeper in the unsaturated zone. It will be capable of maintaining its growth rate and crop water use for an extended period into the dry season.

Groundwater recharge is expected to be influenced by the crops ability to draw water from the unsaturated zone. Groundwater recharge totals for the three land uses are expected to be in increasing order (lowest to highest) from native vegetation, improved pasture and irrigated peanuts. With improved pasture and irrigated peanuts expected to increase the groundwater recharge, the water table level is also expected to fluctuate. With additional water moving through the unsaturated zone an increase in the water table would result.

Chapter 4

Modelling Scenarios

4.1 Site Description

The study area is located within the Daly River catchment; approximately 200 km south east of Darwin (refer to figure 4.1). The Daly River is a perennial river whose tributaries include the Katherine, Flora, Fergusson, Edith and Douglas Rivers. The Daly River catchment has an area of 52500 km^2. The catchment is underlain by three significant aquifers; the Oolloo Dolostone, Jinduckin Formation and Tindal Limestone. The study area for this project is defined within the Oolloo Dolostone Aquifer which is a major contributor to the dry season river flow. During these months the Daly River tributaries often run dry.

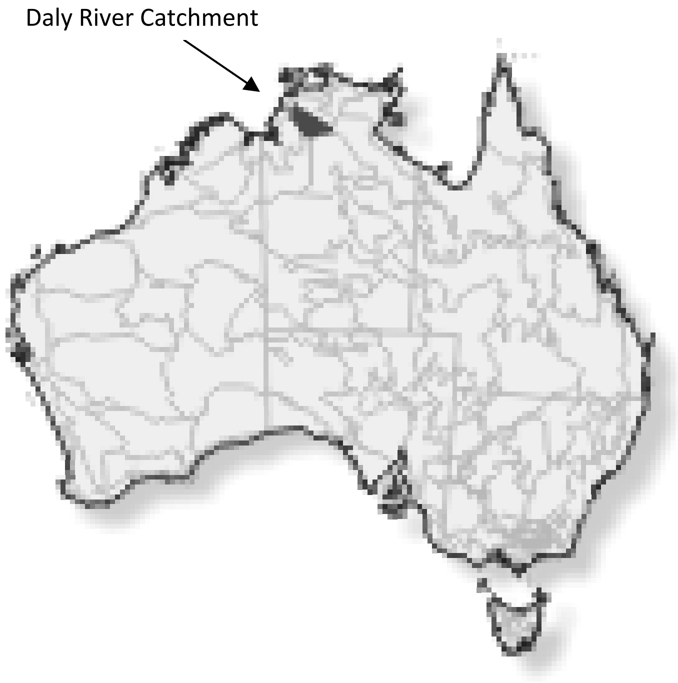

Figure 4.1: Location map of Daly River catchment.
(source: Australian Natural Resources Atlas 2001)

4.1.1 Climate

The study area is located in the wet-dry tropics of the Northern Territory which experience hot and humid conditions. The annual monsoonal rainfall is the main climatic influence. Over 90% of the annual rainfall occurs throughout the months of November to March. High intensity rainfall associated with thunder and lightning is typical throughout the wet season. Maximum recorded events of 218.5 mm in a day and 1990 mm/year have been recorded in the period from 1889 to 2006. Significant differences in annual rainfall are apparent for the region (mean annual rainfall of 1200 mm) leading to large variations in annual recharge. Annual pan evaporation for the site has been measured at 2300 mm (Northern Territory Government of Australia 2006).

4.1.2 Geomorphology and Geology

The Daly River catchment varies in height from 20 metres above Australian Height Datum in rivers and wetlands to 200 metres above Australian Height Datum in elevated plateaus. The study area overlies the Oolloo Dolostone Aquifer which is elliptical in shape; 170 kilometres long by 30 kilometres wide. The Oolloo Dolostone has a maximum depth of 225 metres and overlays the Jinduckin Formation which is dominantly siltstone with beds of limestone and sandstone. Rivers and tributaries exhibit right-angle bends (a rectangular drainage pattern) above the Oolloo Dolostone. They formed in response to faulting and jointing of present geologic structures (Northern Territory Government of Australia 2006).

4.1.3 Karstic Aquifers

Karst aquifers (either granular or fractured aquifers) differ due to their underground rivers. Limestone, dolomite or magnesite are the dominate karst rocks which are dissolved by a mild carbonic acid (produced by carbon dioxide in the atmosphere) in natural water to form underground cavities. The existence of these cavities is usually in the form of rock fractures and conduits. They can also enlarge to form underground cave systems (Kentucky Geological Survey 2004).

The drainage patterns of karst conduits resemble the branching pattern of above ground rivers. The flow is often rapid in comparison to granular aquifers due to the presence of conduits. The flow path is also quite efficient. Water can move from one karst to another or under ridges with little disturbance.

A karst spring receives drainage via sinkholes and sinking streams. These conduits carry the water until they reach the streams within the aquifer. The openings forming the karst aquifer may be partly or completely filled with water. The elevation where all pores are filled with water in an aquifer establishes the level of the water table. The water table in karst areas can be highly irregular in elevation due to perched aquifers. Karst aquifers are suspected to form above the lower, regional water table (Kentucky Geological Survey 2004).

4.1.4 Soils

Red earths (red kandosols) are widely distributed throughout Australia (refer to figure 4.2) and the Daly River catchment. Red earths have a predominately sandy texture varying from loamy sand to sandy clay loam or sandy clay loam to medium clay. They generally exist in areas of mean annual rainfall between 200mm to 4000mm. In high rainfall areas this earthy soil is highly porous, brittle and hard when dry, and very friable when moist (Stace et al. 1968).

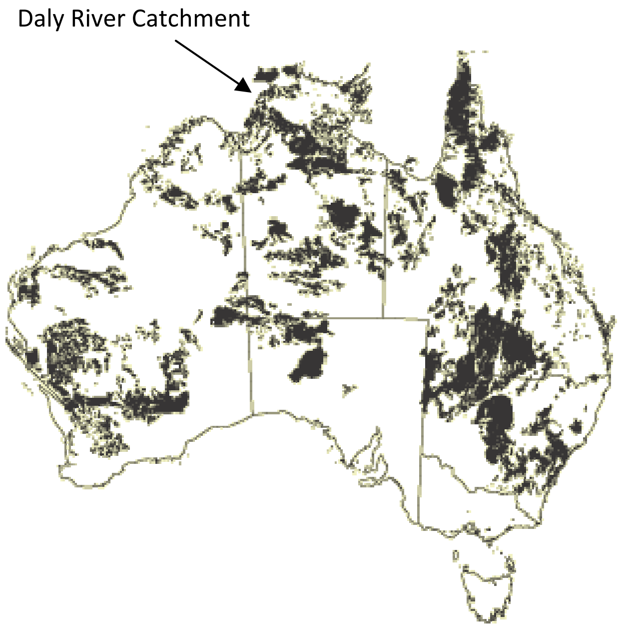

Figure 4.2: The location of red earths location in Australia.
(source: Australian Natural Resources Atlas 2001)

Red Earths are well drained soils that contain a variable soil texture including clay and silt with fine and coarse sands. The clay content is generally between 30 to 70%, silt content less than 10% and sand content greater than 40%. Parent materials consist of dolostones, limestones, sandstones and gravels (Stace et al. 1968). The soil surface is subject to high overland flows due to the intensity and amount of rainfall in the wet season. This leads to the susceptibility of erosion and sediment transfer.

Red earths accompany a range of extensive level plains to low hills, plateaux and maintains. Red earths host native vegetation containing eucalypt and grassy woodlands. Sheep and cattle grazing dominate the current land use. Other land uses include cropping which has been introduced through the clearing of native vegetation. This ranges from cereals and vegetables through to sugar cane, peanuts and pasture (Australian Natural Resources Atlas 2001).

4.1.5 Groundwater

The Oolloo Dolostone is the smallest aquifer in size but the largest contributor to the perennial flow of the Daly River. Due to its fractured and karstic nature, the aquifer is recharged through macropores in the wet season and discharges via springs throughout the year. The aquifer structure allows a high transmissivity and large storage capacity to be the main source of base flow for the Daly River.

4.1.6 Vegetation (Native – Pasture – Peanuts)

Native vegetation equates for 90% of land cover in the Daly River catchment. Eucalypt woodlands (particularly Eucalypt *miniata*) accompanied by open forests (for sheep and cattle grazing) is the dominant land type.

Increasing interest in horticulture production and field crops has brought the

The Northern Territory Government has allowed 4% of the Daly River catchment to be cleared. This was led by increasing interest in horticulture production and field crops. The presence of fertile soils in the Daly River catchment has led to increased political pressure on the Government to allow further clearing. Fertile soils where future land clearing is possible provided the basic need for this project and led to the study site selection. The native vegetation at the site could be cleared in the future and replaced by horticulture (tree crops) or field crops (irrigation, peanuts, maize and fodder).

Current land practice in the Daly River catchment is dominated by cattle grazing. The cattle industry in the Northern Territory focuses strongly on meeting beef markets and maintaining cattle breeding herds. To increase cattle production, local property owners have introduced improved pasture into their current farming techniques. They seek to accommodate introduced cropping by clearing native trees and grasses. Pastures of interest to the local area include grasses, legume and fodder.

The conversion of grazing to cropping involves introducing dryland crops such as sesame, sorghum, soybeans, mungbeans and cavalcade along with irrigated crops of peanuts and maize (Department of Primary Industries, Fisheries & Mines 2008). Current interest lies in the production of irrigated peanuts with the Katherine region producing Australia's biggest peanut crop. The 2008 peanut season saw the Peanut Company of Australia produce and harvest a 1200 hectare crop and there is now a planned expansion to 4000 hectares (Landline 2006).

4.2 Data Availability

Data for the water balance model production was sourced through literature and from the Katherine Research Centre for the Daly River catchment. These data are required MIKE SHE inputs to specify climatic conditions and allow for differences in land use; from native vegetation to pasture and to crop irrigation (peanuts).

4.2.1 Simulation Specification

The MIKE SHE water movement modules simulated are overland flow (finite difference), unsaturated flow (Richards equation) and evapotranspiration. The simulation period encompasses the decade from 1st January 1990 to 31st December 1999. The time step, overland flow and unsaturated flow parameters are modelled through the MIKE SHE defaults. The model domain is based on a single column profile with a uniform ten metre topography.

Precipitation and reference evapotranspiration data were supplied from Natural Resources and Mines (2008). The data was recorded at a weather station at the study site in the Daly River catchment. The patched point dataset includes continuous daily precipitation and reference evapotranspiration for the period from 01/01/1889 to 29/05/2006.

LAI and root depths for the land uses in the Daly River catchment were assembled from published literature. The three land uses modelled were native vegetation, improved pasture and peanut irrigation.

The dominate native vegetation in the Daly River catchment is Eucalypt woodlands. Tree species include Eucalyptus *Miniata* with sparse grasslands for sheep and cattle grazing. The LAI is modelled at 1.0 throughout the wet season (November – March) and 0.65 throughout the dry season (April – October) (Hutley, O'Grady & Eamus 2000). The root depth was measured at a uniform 5000 mm throughout the year and the crop coefficient (Kc) was equal to 1.0 (Wilson et al. 2006).

Model LAI and root depths for pasture grown within the Daly River catchment are based on literature from Clifton & Schroder (1996) together with MIKE SHE default grass parameters. The LAI and root depth are 4.0 and 700mm respectively in the wet season (November – March) and 1.0 and 300mm respectively throughout the dry season (April – October). The crop coefficient (Kc) is equal to 1.0 and uniform throughout the year.

Peanut irrigation was simulated due to the expansion within the peanut industry in the Northern Territory (particularly the Daly River catchment). The peanut crop was modelled with a 150 day maturity span and an annual planting date of 1st February. The crop characteristics (crop stages, LAI, root depths and crop coefficients) throughout the growing season are recorded in table 4.1.

Table 4.1: Irrigated peanut crop characteristics.

Period	End Day	LAI	Root (mm)	Kc
1	0	0	0	1
2	30	1	200	1.1
3	60	2	700	1.1
4	90	5	1000	1.3
5	120	4	1000	1
6	150	3	1000	1

The irrigation component of MIKE SHE is controlled by the moisture content of the root zone at field capacity. Irrigation is initiated when 60 percent of the maximum available water (at field capacity) in the root zone is used and ceases when the water content at field capacity is reached. The available water in the root zone is defined as the maximum available water for crop transpiration. This is the difference between the field capacity and wilting point of the crop. Irrigation is supplied to the peanut crop through an external unlimited source.

4.2.2 Overland Flow

Overland flows require three controlling parameters; Manning M, detention storage and initial water depth. The Manning M is the inverse of the more conventional Mannings n. The Manning M varies between 10.0 for complete overland flow and 100.0 for pure channel flow. As complete overland flow is rarely experienced due to depressions and the convergence to stream flow, the Manning number was set at 30.0 for the model simulation.

The detention storage is the ponding limit which must be exceeded before overland flow commences. The MIKE SHE default value of 2.0mm was modelled. Finally, the initial water depth was set to 0.0mm. This eliminates any overland flow from adjacent cells flowing into the modelled cell (single column profile). It is expected that inflows will balance the outflows producing an insignificant water balance change.

4.2.3 Unsaturated Flow

The unsaturated flow through the soil profile was modelled with full macropore flow, an eight metre deep groundwater table and a uniform soil profile. The soil profile was classified through NeuroTheta.

NeuroTheta is a program for predicting soil water retention curves and saturated hydraulic conductivities from basic soil properties for Australian soil (Minasny & McBraney 2002). The program uses neural networks to predict the parameters of the Van Genuchten and Campbell functions. The first two inputs required are for training data and textural class for the soil. These are described by NeuroTheta for the study site as an Australian clayey sand. The program also requires clay, silt, fine sand and coarse sand weight percentages. This data was sourced from the literature published literature by McKenzie et al. (2004) and Wilson et al. (2006). These literature sources state that red kandosols in the Daly River catchment consist of 27% clay, 8% silt, 53% fine sand and 12% coarse sand. This is a general soil description for the B horizon.

MIKE SHE models the retention curve and hydraulic conductivity using the Van Genuchten equation and Averjanov equation respectively. The outputs from NeuroTheta include the saturated moisture content, θ_s, of 0.396, residual moisture content, θ_r, of 0.0373, alpha, α, of 0.0494 and the empirical constant, n, of 1.177. The hydraulic conductivity was modelled through the saturated and residual moisture contents, the saturated hydraulic conductivity, K_s, of 5 x 10^{-8} m.s^{-1} and empirical constant, n, of 13.0. These final two parameters were both estimated by calibration to compensate for the lack of soil data.

4.2.4 Macropores

Full macropore flow is modelled and included as a characteristic of the clayey sand soil profile for the study site. The parameters for macropore flow are:

- Porosity 0.04
- Saturated Conductivity 3 x 10^{-8} [m.s^{-1}]
- Conductivity Exponent 2.1
- Psi Threshold -0.05 [m]
- Beta MP to Matrix 10 [m^{-2}]
- Beat Matrix to MP 10 [m^{-2}]

These parameters are based on the literature published by Christiansen et al. (2004). He modelled macropores in loam and sand soil profiles. Due to a different soil type and the lack of published literature on macropores, the parameters were altered to those above through calibration.

4.3 Model Calibration

In theory, the calibration of a physically based system (MIKE SHE) is not required when sufficient accurate data is available for the model production. But in reality, uncertainties in the model structure and parameter values mean a calibration process is necessary to reduce model error. The objective of the calibration process for this physically based system is to find realistic model parameters that accurately simulate water movement in the Daly River catchment. The optimal set of parameters was found within known physical ranges of parameters to avoid the process giving unrealistic results. This was achieved through a *'trial and error'* procedure.

MIKE SHE requires values for a large number of model parameters to compute the water balance for a soil column. The lack of field data was a major constraint in using the model for this study site. Minimal data was therefore available for calibration.

MIKE SHE model parameters were largely found in the published literature although not always based on Northern Territory sites. The calibration reduced model error through correcting parameter and model structure uncertainties. The calibration developed the most accurate water balance model possible leaving any remaining error as a result of field data input.

The water balance model calibration was carried out over a one year simulation. A longer period was not possible because of the time constraint of running the model and producing water balance calculations. Also, a one year period allowed an entire season of vegetation growth and the climate characteristics of the wet-dry monsoonal conditions to be incorporated. The water balance model was then extended to a full analysis of ten years. This eliminated significant rainfall or drought periods that could be magnified in a shorter period. As native vegetation had been previously modelled in the study site, it was the vegetation of choice for the calibration process.

The daily water balance calculations are accumulated throughout the calibration period (one year) and reported as precipitation, recharge, overland (boundary) flow and evapotranspiration. These values are then compared with results of previous projects in the Daly River catchment as reported in literature.

Table 4.2: Daly River catchment calibration data.

Source:	**Knapton (2006)**	**Wilson et al. (2006)**	**Jolly (2001)**
Data Period	Annual	13/09/05-02/03/06	Annual
Rainfall	1150mm	1058mm	970mm
Total Recharge	58mm	50-200mm	90mm
Evapotranspiration	-	510mm (810-958mm annual)	-
Overland Flow	-	-	135-148mm

The initial MIKE SHE model runs were based on parameters found in literature. These parameters are as outlined in Section 4.2 except for saturated hydraulic conductivities. The initial saturated hydraulic conductivities for the soil and macropores is 4.0983×10^{-7} m.s^{-1} which yielded the following results in table 4.3.

Table 4.3: Preliminary water balance results (K_s = 4.0983×10^{-7} m.s^{-1}).

Data Period	**01/01/95-31/12/95**
Rainfall	1401 mm
Total Recharge	642 mm
Evapotranspiration	909 mm
Overland Flow	0 mm

The year 1995 was modelled in MIKE SHE which has a higher annual rainfall than any other investigations found in the literature. The model simulated an unreasonably high total recharge and no overland flow. The MIKE SHE model was then calibrated by adjusting the saturated hydraulic conductivity to resemble the data of table 4.2. The calibrated saturated hydraulic conductivities for soil and macropores of 5×10^{-8} m.s^{-1} and 3×10^{-8} m.s^{-1} respectively resulted in the following data.

Table 4.4: Final water balance results for 1995.

Data Period	**01/01/95-31/12/95**
Rainfall	1401mm
Total Recharge	132mm
Evapotranspiration	972mm
Overland Flow	131mm

Table 4.5: Final water balance results for the 10 year simulation including the annual average results.

Data Period	**01/01/90-31/12/99**	**Annual Average**
Rainfall	13051mm	1305mm
Total Recharge	1112mm	111mm
Evapotranspiration	9570mm	957mm
Overland Flow	1593mm	159mm

4.4 Sensitivity Analysis

A sensitivity analysis was carried out to investigate the water balance response to variations of model input. The influence of model parameters was examined step by step to discover uncertainties in the field data. The sensitivity analysis identified the effect of parameters on the model output and the parameters that produced the largest influence on water balance calculations.

4.4.1 Precipitation

Rainfall is a required input parameter, and was recorded for the Daly River catchment. The temporal rainfall distribution directly affects the water balance calculations of evapotranspiration, soil storage, recharge and overland flow.

For a one year calibration period (refer to Section 4.3) rainfall events influence water balance results. Flood, drought or a minor occurrence of either event can dramatically alter the recharge and overland flow from a soil column. For the model simulation period from 1st January 1990 to 31st December 1999 the minimum rainfall of 1108 mm occurred in 1992 and maximum rainfall of 1545 mm occurred in 1998. The results for these years are compared in table 4.6. The table shows that a higher annual rainfall will lead to a much higher overland flow and a marginal increase in recharge. The ten year water balance simulation accounts for the discrepancies in the annual rainfall intensity distributions and integrates the impact of any one year.

Table 4.6: Water balance results for the maximum and minimum precipitation years

Year	Precipitation	Evapotranspiration	Recharge	Overland Flow
1992	1108 mm	1001 mm	22 mm	68 mm
1998	1545 mm	982 mm	45 mm	304 mm

4.4.2 Evapotranspiration

Reference evapotranspiration is a required input value for the MIKE SHE model. The actual evapotranspiration can be different to the reference evapotranspiration because of:

- Rainfall amount, distribution and intensity.
- LAI of vegetation.
- Root distribution of vegetation.
- Soil moisture content in root zone.

4.4.3 Land Use

Native vegetation, pasture and irrigated peanuts were modelled in MIKE SHE. As land use forms the major part of project, the results are extensively analysed in Chapter 5 and discussed in Chapter 6. These land use alternatives are primarily controlled by two parameters; LAI and rooting depth. The LAI largely controls the canopy interception and evaporation. The rooting depth controls transpiration and moisture content in the root zone.

An irrigated crop (peanuts) requires an additional parameter. This parameter controls the type of irrigation (drip, sprinkler or sheet), the source of this water (external, well or river), the amount of water available for irrigation and the band of moisture contents in which irrigation will commence and cease. Figures 4.1 and 4.2 show the water content in the root zone for the growing period of 1st February 1995 to 30th June 1995. Irrigation commences in May for both examples. Figure 4.1 commenced at a soil moisture deficit of 60% below field content compared to figure 4.2 commencing at 30% below field content. This resulted in three irrigation applications (approximately every fortnight) with an average of 93mm/irrigation for a 60% deficit and seven irrigation applications (approximately every week) with an average of 47mm/irrigation for a 30% moisture deficit.

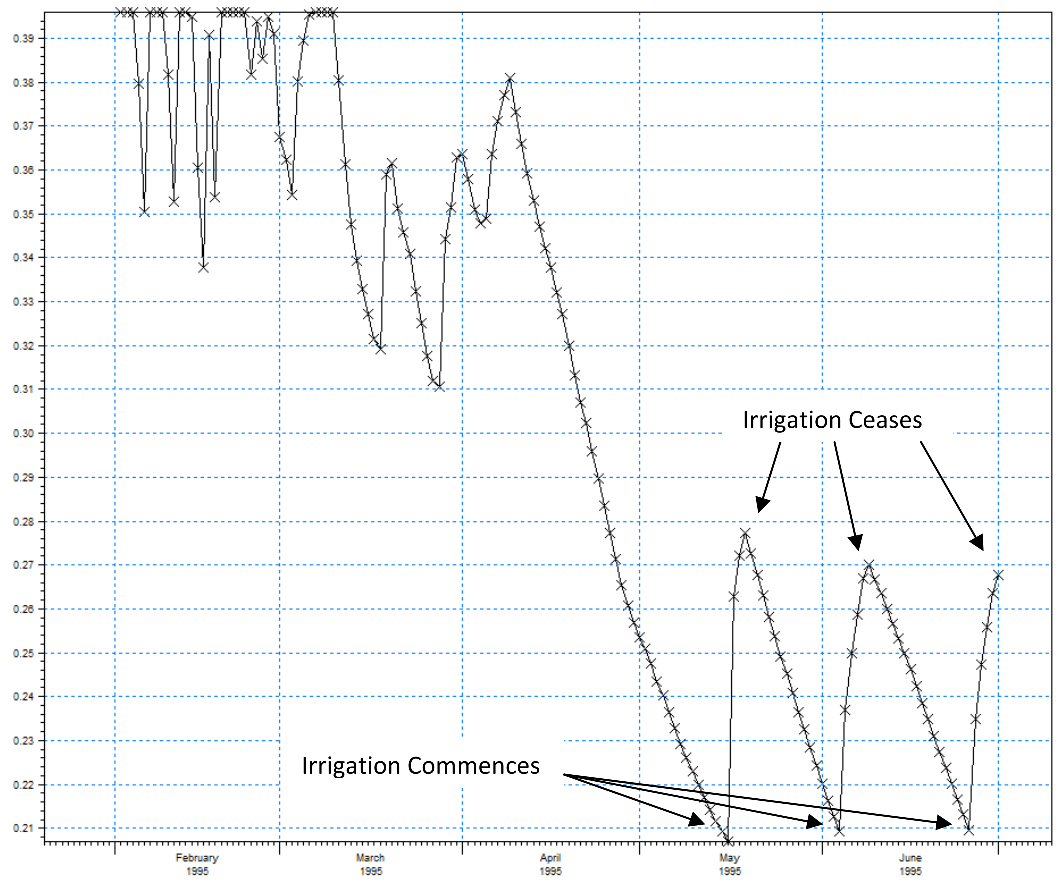

Figure 4.3: Root zone water content for irrigated peanuts with irrigation at 60% field content deficit (1/2/1995 to 30/6/1995).

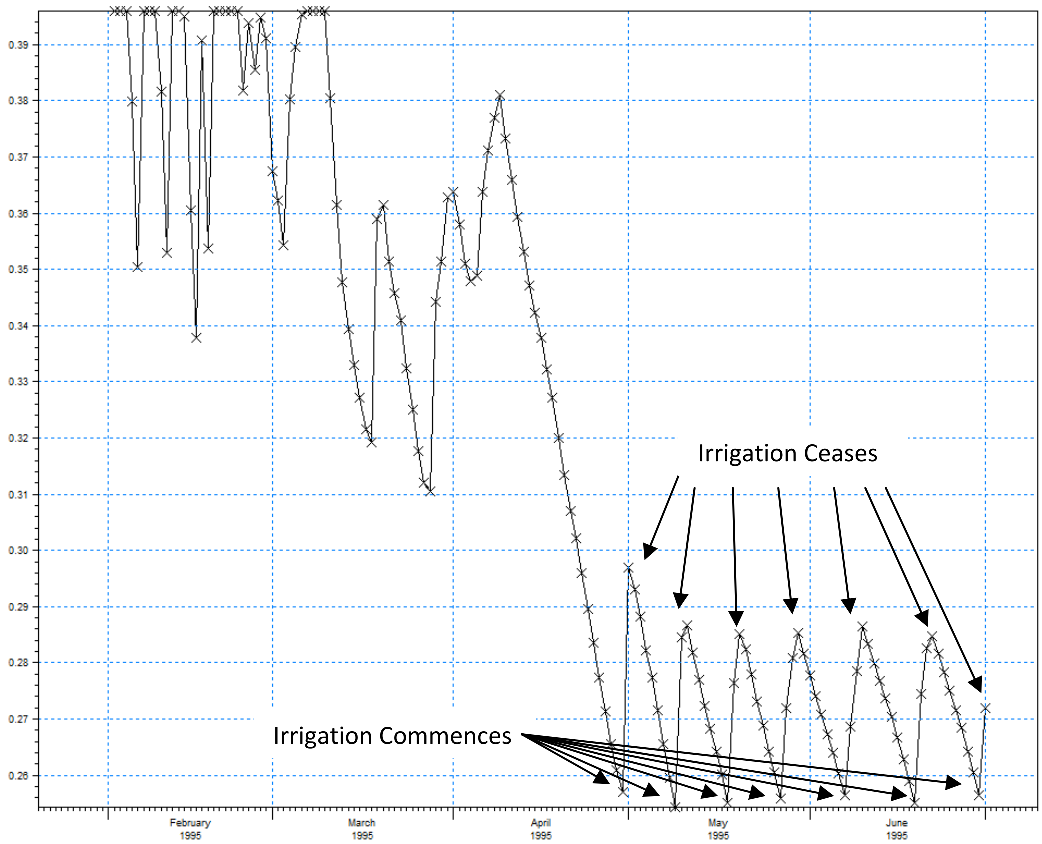

Figure 4.4: Root zone water content for irrigated peanuts with irrigation at 30% field content deficit (1/2/1995 to 30/6/1995).

4.4.4 Overland Flow

The overland flow parameters restrict or increase flow. The Manning number varies the time at which it takes overland flow to travel between modelled cells and towards river networks. In a single cell (soil column) project the Manning M had no significant effect.

The detention storage limits the ponding depth of water before flow will occur. Greater depths lead to more water ponding and less water running off the modelled surface.

4.4.5 Unsaturated Soil Flow

Unsaturated soil flow is governed by three functions; hydraulic conductivity, retention curve and macropore flow. These three functions were a focus area for model calibration (refer to Section 4.3). The unsaturated zone defines the movement of water between the ground surface and the groundwater table. The saturated hydraulic conductivity along with shape factors model water movement. As defined in the model calibration, a high saturated hydraulic conductivity increases the quantity of water recharging the aquifer system. This is offset by smaller conductivities slowing downward soil water movement and increasing overland flow. A lack of soil field data led to highly computational soil parameters. Calibration was necessary to increase the model accuracy.

Chapter 5

Water Balance Results

5.1 Introduction

The results of the hydrological model are presented in this chapter for native vegetation, improved pasture and irrigated peanuts. Accumulated water balance totals for these three land use scenarios are quantified from MIKE SHE. The results are based on a ten year simulation period from 1st January 1990 to 31st December 1999. Daily precipitation data, evapotranspiration data and daily MIKE SHE calculations adequately represent all physical processes involved in the water balance. These calculations provide realistic data for actual evapotranspiration, overland flow, groundwater recharge and soil water storage. These components of the water balance are produced in a tabular form at three levels; overland flow, canopy interception and the unsaturated zone.

5.2 Water Balance Charts

The post-processing capabilities allow MIKE SHE to utilise stored data from a previously run ‘Water Movement’ module. MIKE SHE produces an accumulated summary of flow and storage change to the profiled soil column. This summary is displayed in chart format for the accumulated ten year simulation period. The chart displays water balance data (millimetres depth of water) for the incorporated modules of MIKE SHE. For native vegetation, improved pasture and irrigated peanuts these include overland flow, unsaturated flow and evapotranspiration. These include the results for precipitation, evapotranspiration, unsaturated zone storage change, surface boundary flow (overland flow) and groundwater boundary flow (groundwater recharge). Irrigation is also included in the peanut irrigation land use scenario. These results are depicted in the following figures 5.1, 5.2 and 5.3 and are described in the accompanying text.

5.2.1 Native Vegetation

The MIKE SHE representation of the water balance for native vegetation is displayed in figure 5.1. Native vegetation represents the current water movement and storage change scenario in the Daly River catchment. The soil and crop parameters for native vegetation are given in Section 4.2.

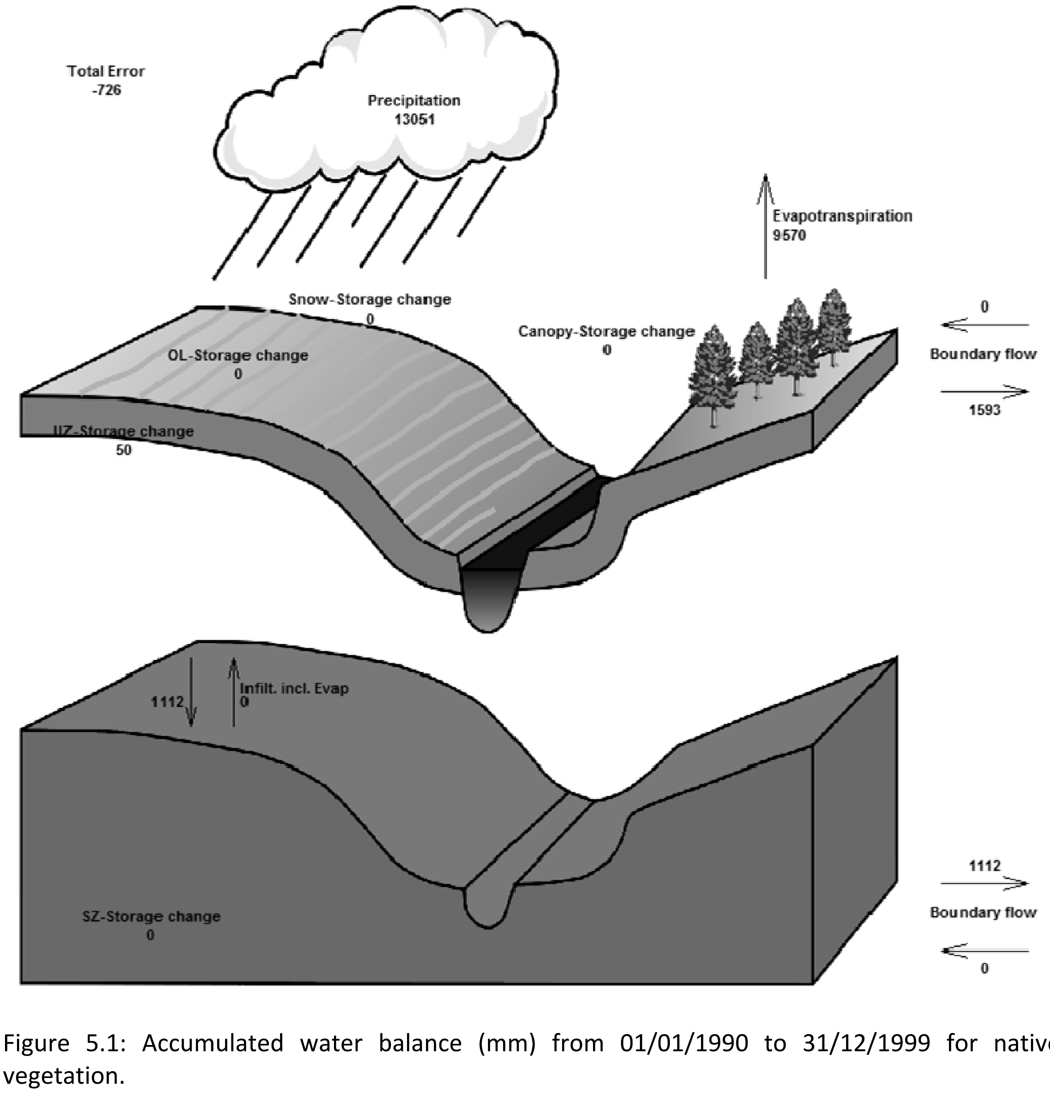

Figure 5.1: Accumulated water balance (mm) from 01/01/1990 to 31/12/1999 for native vegetation.

5.2.2 Improved Pasture

The MIKE SHE representation of the water balance for improved pasture is displayed in figure 5.2. The improved pasture scenario represents a major component of the Daly River catchment for beef cattle production. The soil and crop parameters to simulate water movement and storage change for improved pasture are given in Section 4.2.

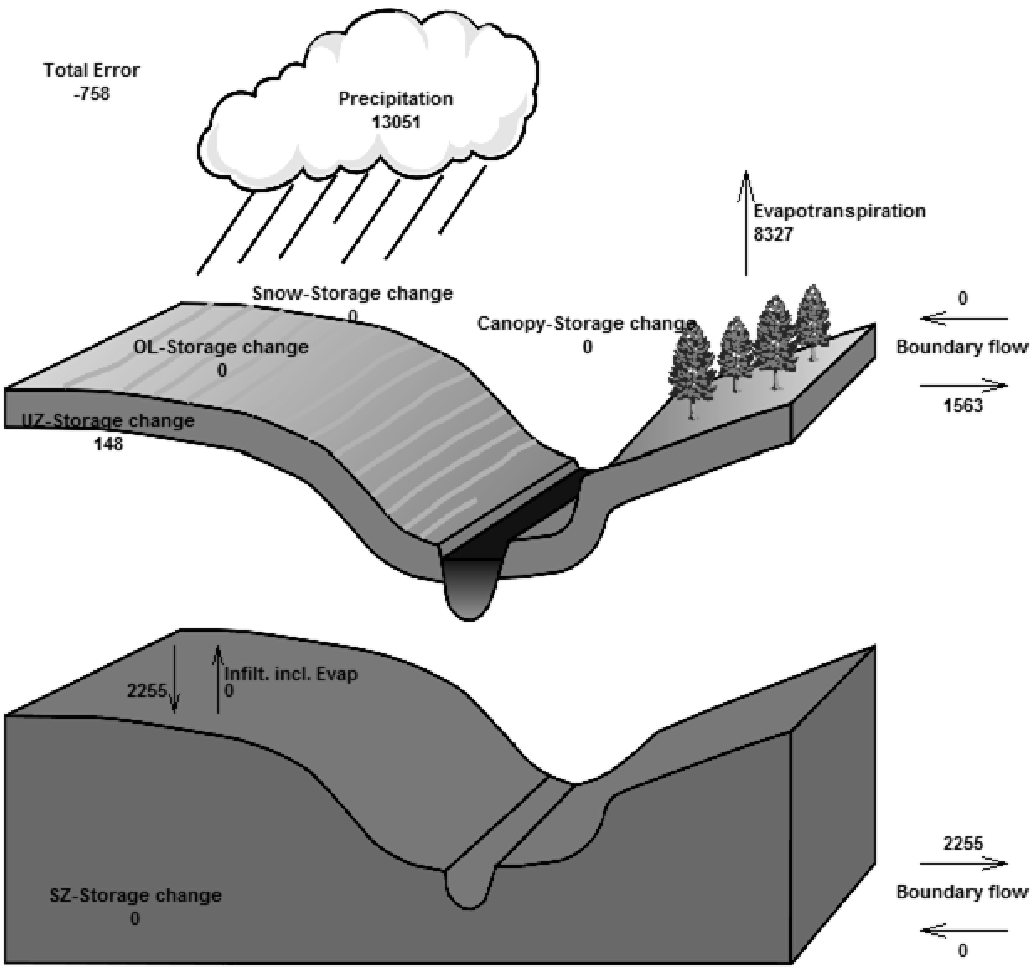

Figure 5.2: Accumulated water balance (mm) from 01/01/1990 to 31/12/1999 for improved pasture.

5.2.3 Irrigated Peanuts

The MIKE SHE representation of the water balance for irrigated peanuts is displayed in figure 5.3. This scenario represents a likely increase in agricultural development in the Daly River catchment. The soil and crop parameters to simulate water movement and storage change for irrigated peanuts are given in Section 4.2.

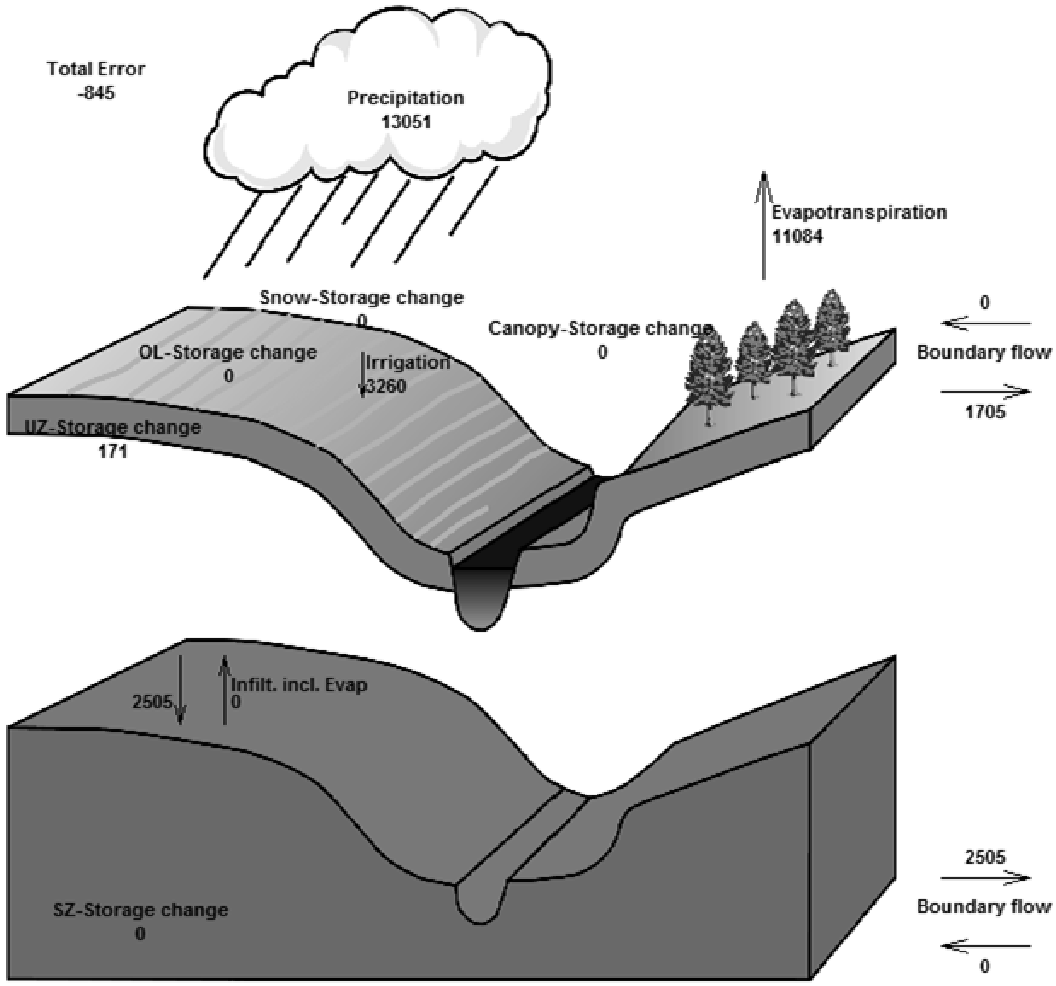

Figure 5.3: Accumulated water balance (mm) from 01/01/1990 to 31/12/1999 for irrigated peanuts.

5.3 Water Balance Tables

The accumulated water balance results are tabulated for comparison in Chapter 6. The tables include evapotranspiration, precipitation, overland flow, unsaturated zone storage change and groundwater recharge as separate entities. These accumulated parameters are shown through tables 5.1 to 5.3. They are recorded as an accumulation for the simulation period (1st January 1990 to 31st December 1999) and also as an annual average.

5.3.1 Native Vegetation

Table 5.1: Native vegetation water balance data.

Water Balance Data		
Water Balance Component	Period	
	01/01/1990 to 31/12/1999	Annual Average
Precipitation	13051mm	1305mm
Canopy Throughfall	12226mm	1223mm
Canopy Evaporation	825mm	83mm
Evaporation from ponded water	1809mm	181mm
Infiltration from Overland to UZ	8825mm	883mm
Overland Flow	1593mm	159mm
Evaporation from soil	3401mm	340mm
Transpiration from root zone	3535mm	354mm
Infiltration form UZ to SZ	1112mm	111mm
Change in UZ Deficit	50mm	5mm
Unsaturated Zone Error	727mm	73mm

5.3.2 Improved Pasture

Table 5.2: Improved pasture water balance data.

Water Balance Data		
Water Balance Component	Period	
	01/01/1990 to 31/12/1999	Annual Average
Precipitation	13051mm	1305mm
Canopy Throughfall	10929mm	1093mm
Canopy Evaporation	2122mm	212mm
Evaporation from ponded water	959mm	96mm
Infiltration from Overland to UZ	8408mm	841mm
Overland Flow	1563mm	156mm
Evaporation from soil	1340mm	134mm
Transpiration from root zone	3847mm	385mm
Infiltration form UZ to SZ	2255mm	226mm
Change in UZ Deficit	148mm	15mm
Unsaturated Zone Error	759mm	76mm

5.3.3 Irrigated Peanuts

Table 5.3: Irrigated peanuts water balance data.

Water Balance Data		
Water Balance Component	Period	
	01/01/1990 to 31/12/1999	Annual Average
Precipitation	13051mm	1305mm
Canopy Throughfall	12725mm	1273mm
Canopy Evaporation	326mm	33mm
Crop Irrigation	3260mm	326mm
Evaporation from ponded water	2713mm	271mm
Infiltration from Overland to UZ	11569mm	1157mm
Overland Flow	1705mm	171mm
Evaporation from soil	4601mm	460mm
Transpiration from root zone	3445mm	345mm
Infiltration form UZ to SZ	2505mm	251mm
Change in UZ Deficit	171mm	17mm
Unsaturated Zone Error	846mm	85mm

5.4 Water Balance Results

MIKE SHE water balance results comprise the above tabulated results. MIKE SHE provides daily water balance results. In total the ten year simulation results in over 3650 rows of data for each land use scenario. The water balance results are summarised and given in Appendix B. The summarised results include the starting and final results along with annual initial dry and wet season results. This includes an annual data row on the 1^{st} April (start of dry season) and 1^{st} November (start of wet season) throughout the simulation period.

5.4.1 Precipitation

- The ten years of precipitation data is included in Appendix C.
- The model separates the precipitation into two components; canopy interception and canopy throughfall. Canopy interception is precipitation that does not reach the soil. It is intercepted and stored by the canopy or crop until it is entirely evaporated. Canopy throughfall is the remaining precipitation that reaches the soil. This precipitation either ponds, flows from the surface or infiltrates into the unsaturated zone.

5.4.2 Evapotranspiration

- Actual evapotranspiration is calculated from the input reference evapotranspiration as described in Section 3.1.2.
- The evaporation component of evapotranspiration has three components; canopy evaporation, evaporation from ponded water and evaporation from the soil. Canopy evaporation is limited by the amount of precipitation that is intercepted by the crop, which is evaporated back to the atmosphere. The remaining precipitation (canopy throughfall) reaches the soil and initially ponds or infiltrates into the ground. The evaporation terms associated with canopy throughfall are evaporation from ponded water (on the surface which leads to overland flow) and evaporation from the soil (the unsaturated zone).
- Transpiration from the root zone is associated with crop water use. Transpiration is the water used by the crop. Transferring the water from the unsaturated zone (root zone) to the atmosphere. This water is taken through the crops roots and transpired through the crops leaves.
- The reference evapotranspiration graph is shown in Appendix D.

5.4.3 Surface Water

- Surface water is the remaining available precipitation (canopy throughfall) that does not infiltrate the soil.
- Surface water that does not infiltrate, initially ponds on the soil surface before flowing across the surface as overland flow.

- Overland flow readily occurs in a MIKE SHE soil column simulation. A soil column simulation does not allow for the time that the water takes to reach the cell boundary. The surface gradient of the soil column is also not considered.
- The irrigation of peanuts adds an additional dimension to surface water. Irrigation is an additional water supply that is available for overland flow, evapotranspiration and infiltration to the unsaturated zone.

5.4.4 Groundwater

- Groundwater resources are purely dependant (in a soil column) on infiltration as a result of precipitation and irrigation (in crop irrigation scenarios).
- Infiltration is controlled by soil moisture conditions and the hydraulic conductivity of the soil. Generally dry soils will absorb more water while wetter soils will shed the water to overland flow.
- Infiltrated water enters the unsaturated zone and the root zone. The root zone is present from the soil surface to the rooting depth of the crop. Transpiration (crop water use) occurs in the root zone and consumes a large part of infiltrated water. Soil evaporation is also apparent in the upper part of the unsaturated zone; drying the soil from the top down.
- Excess water flows through the unsaturated zone and reaches the saturated zone. This water leaves the simulated soil column as groundwater boundary flow.

Chapter 6

Water Balance Discussion

6.1 Introduction

The ten year MIKE SHE simulation provides water balance results for native vegetation, improved pasture and irrigated peanuts. Direct hydrological outcomes can be inferred from these results by comprising the three modelled land uses. They are also discussed with respect to the integrated regional land use plan which will be prepared by the Northern Territory Government. The land use plan offsets the financial benefits of land use changes against the hydrological, biological, environmental and social aspects of continual clearing and further land development. The integrated regional land use plan will cover the following four areas:

- Hydrological Analysis – Running the same simulation with different crop types allows the water balance to be analysed for each land use. This includes the groundwater and surface water resources. Infiltration, overland flow, groundwater recharge, soil water storage and evapotranspiration are all affected by land use.

- Biological Analysis – The aquatic ecosystem of the Daly River is maintained during the dry season by continual aquifer spring flows which recharge the river.
- Environmental Analysis – Large scale clearing of the Daly River catchment will increase overland flow and amplify flood events. Soil erosion will increase and salinity increases may be experienced due to a rising water table.
- Social Analysis – Aborigines live throughout the Daly River catchment. Water holds a sacred quality to their worldview and way of life.

6.2 Calibration Analysis

The native vegetation model scenario was calibrated against data sources from Knapton (2006), Wilson et al. (2006) and Jolly (2001). These reports identified annual precipitation, groundwater recharge, evapotranspiration and overland flow depths through weather stations, overland flow gauging stations and chloride concentrations of the groundwater. These results are presented in Chapter 5. The annual accumulated water balance results were then modelled and are displayed in table 6.1. These results are presented in an accumulated water depth format for a water year. Each water year commences at the beginning of the wet season (1st November) and ceases at the end of the dry season (31st October). The first ten months (1/1/1990 to 31/10/1990) of the simulation were excluded from the results analysis as they were affected by initial model conditions. The last two months, November and December of 1999 were also excluded from the analysis.

Table 6.1: MIKE SHE simulation results for calibration analysis

Water Year	Precipitation (mm)	Evapotranspiration (mm)	Overland Flow (mm)	Recharge (mm)
1990-1991	1563	919	247	172
1991-1992	1028	974	67	109
1992-1993	1218	901	273	35
1993-1994	1147	862	148	16
1994-1995	1354	959	130	21
1995-1996	1005	949	2	116
1996-1997	1480	954	205	133
1997-1998	1568	970	349	182
1998-1999	1626	1017	162	277
Annual Average	1332	945	176	118

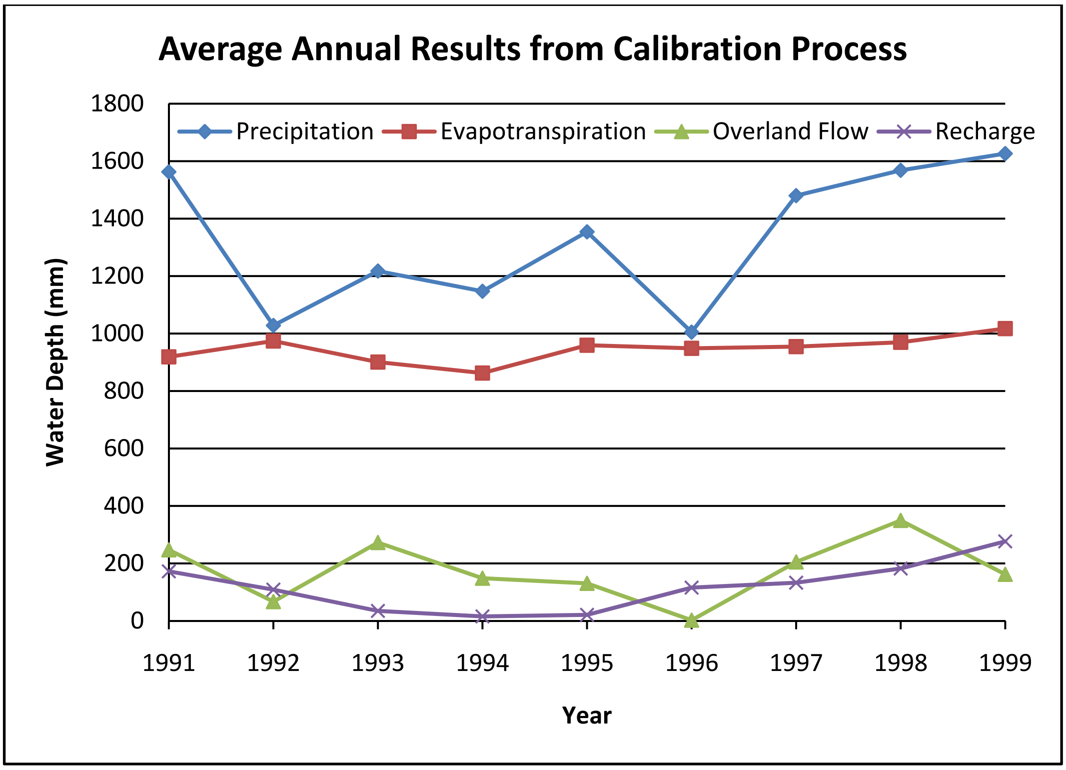

Figure 6.1: MIKE SHE simulation results for calibration analysis.

6.2.1 Overland Flow

Table 6.1 shows an average precipitation of 1332 mm, average evapotranspiration of 945 mm, average overland flow of 176 mm and average groundwater recharge of 118 mm for the water balance model period. These results compare comparatively well with the calibration data in Section 4.3. Differences resolve from a 200-300 mm higher annual simulated precipitation compared to literature sources. This leads to annual simulated overland flow and groundwater recharge values being slightly higher (20-30 mm) than found through literature.

The average overland flow for the simulation is 176 mm. Annual accumulated overland flow totals vary from close to nil (2 mm) in 1995-96 up to 349 mm in the 1997-98 water year. The precipitation charts for these water years (refer to figures 6.2 and 6.3 below) directly relate to generating overland flows. General wet season rainfall totals fail to generate significant overland flow; it is a result of particular storm events. The storm event in 1997-1998 from the 26th to 30th January 1998 generated over 85% of the annual overland flow. This storm event contains three consecutive days of rainfall exceeding all daily totals of the 1995-1996 water year which failed to generate any significant overland flow. The 1995-1996 water year simulated two days of overland flow each of 1 mm in total. These days resulted from the rainfall events around the dates of the 10th December 1995 and 25th February 1996. Each of these periods experienced three to four days of consecutive rainfall over 10 mm. The annual overland flow totals generally parallel the precipitation totals (refer to figure 6.1 for the trend lines); however significantly depend on individual storm events.

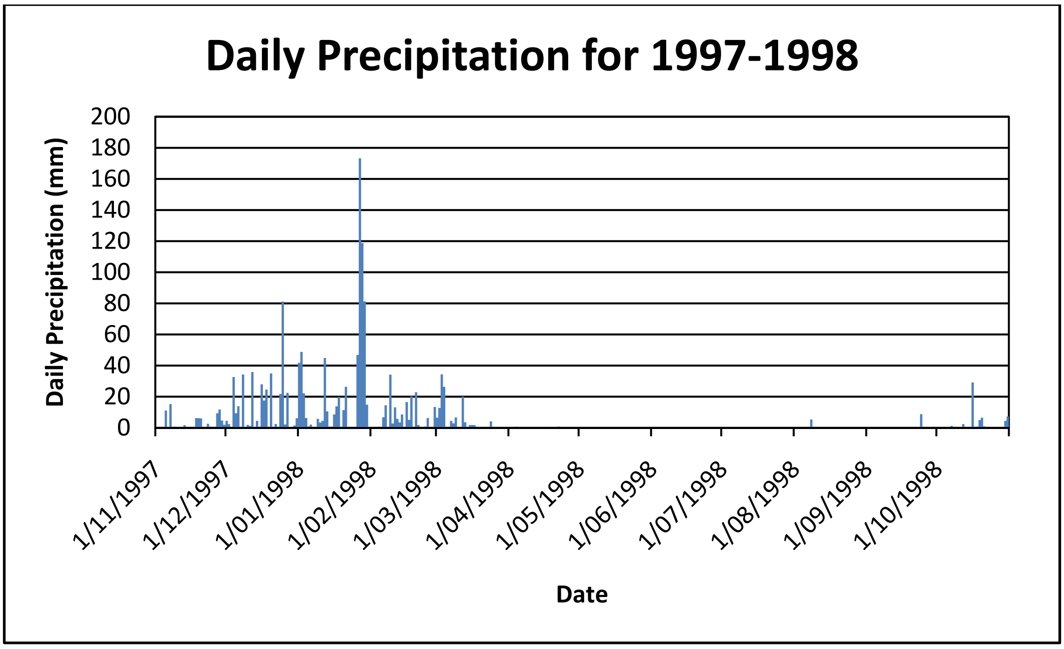

Figure 6.2: Daily precipitation for 1997-98 water year.

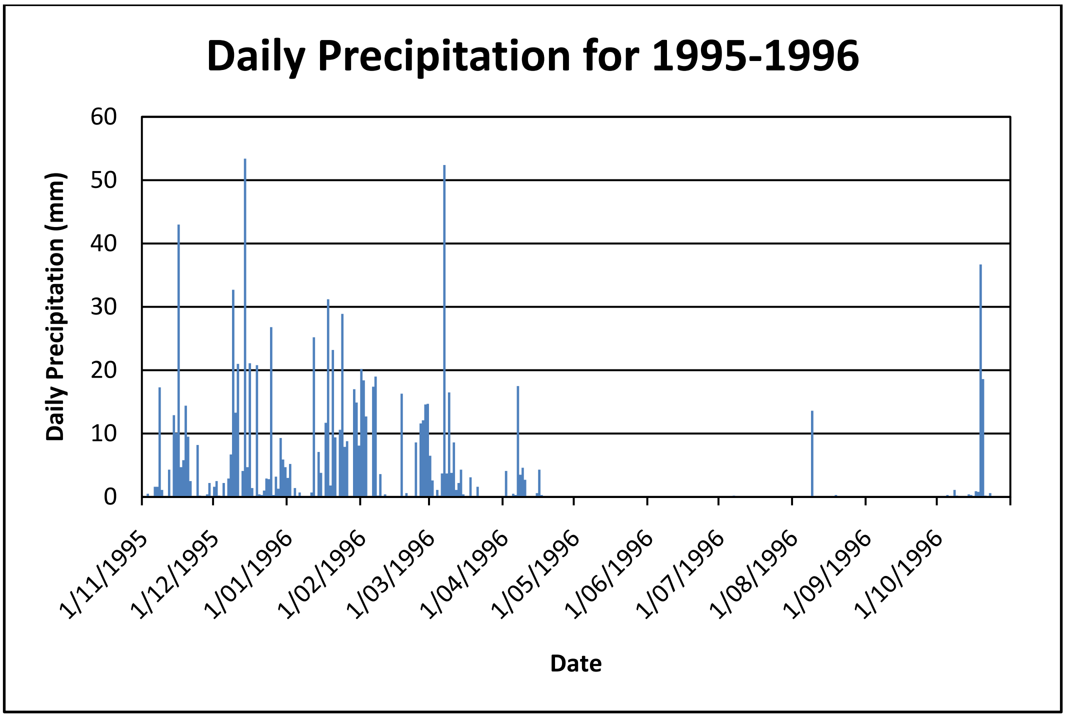

Figure 6.3: Daily precipitation for 1995-96 water year.

6.2.2 Groundwater Recharge

Figure 6.1 displays the groundwater recharge as relatively low from 1993 to 1996. The precipitation fluctuates annually above and below the precipitation average for this time period (1993 to 1996). After 1996 the recharge steadily increases to a high of 277 mm in the final water year. This is accompanied by above average precipitation for the final three years of the model simulation.

Displayed in figure 6.4, infiltration into the unsaturated zone ceases during the dry season. With zero infiltration, the totals for evaporation, transpiration and recharge continue throughout the year (demonstrated in 1998-1999). This is achieved by the height of the saturated zone lowering in the analysed soil column. This is displayed in figure 6.5. The unsaturated zone deficit increases significantly during the wet season (1st November 1998 to 31st March 1999) and then lowers for the remainder of the year. The water level of the saturated zone is also enhanced due to above average annual precipitation of 1626 mm. Infiltration ceased on 10th April 1999 which was followed by an immediate lowering of the saturated zone. Groundwater recharge, evaporation and transpiration continued throughout the dry season by lowering the saturated zone.

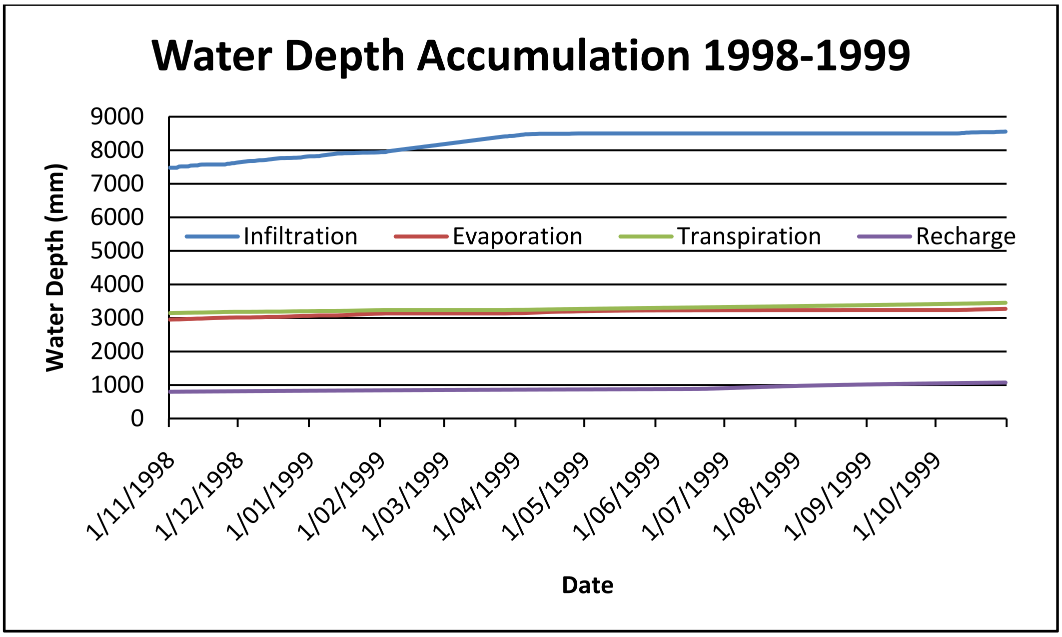

Figure 6.4**:** Total water depths (native vegetation) for infiltration, evaporation, transpiration and recharge for the 1998-1999 water year. Initial and final water depths (for 1998-1999) are; infiltration 7480 mm & 8557 mm, evaporation 2951 mm & 3271 mm, transpiration 3146 mm & 4353 mm, recharge 799 mm & 1075 mm respectively.

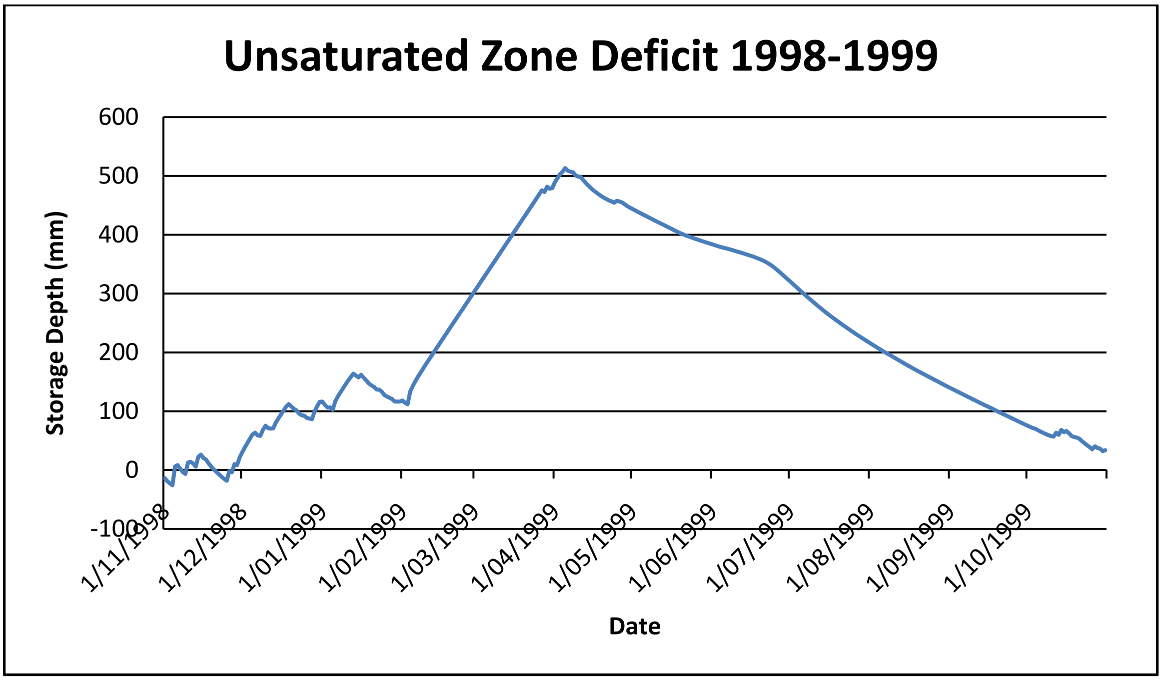

Figure 6.5: Water storage deficit for native vegetation during the 1998-1999 water year. An initial deficit of -14 mm and a final deficit of 34 mm were produced.

6.3 Hydrological Analysis

The hydrological changes due to land use are discussed in four sections; evapotranspiration, overland flow, crop water use and groundwater recharge. These sections adequately summarise the crop variation on the water balance.

6.3.1 Evapotranspiration

Evaporation from the canopy is highly dependent on the crops capability to intercept the precipitation (LAI). Precipitation that was intercepted by the canopy was evaporated during the same simulation time step (daily time steps). Native vegetation and irrigated peanuts displayed similar maximum canopy evaporation rate of 3.4 $mm.day^{-1}$. This is due to irrigated peanuts having a lower LAI during the early crop growth stages during the wet season. Irrigated peanuts only grow during two months (February and March) of the wet season. The average annual canopy evaporation is limited to 33mm compared to 83mm for native vegetation.

Improved pasture has a higher ability to intercept precipitation. Grown for beef cattle production, this crop had numerous daily rates of canopy evaporation above 5 $mm.day^{-1}$ (in the wet season) with an annual average of 212 mm.

Evaporation from ponded water and evaporation from the soil are related through net precipitation. These two evaporation sources are only affected by precipitation that reaches the soil and either ponds on the surface or infiltrates into the unsaturated zone. The surface water is then available for evaporation.

Irrigated peanuts experience high annual evaporation from surface water and from within the soil having values of 211 mm and 460 mm respectively. Annual crops of irrigated peanuts leave the soil bare during the first three months (November, December and January) of the wet season and with minimal cover for the remaining two months (February and March) of the wet season. The irrigation of peanuts during April to June increases the total evaporation from the profile. This time period usually experiences minimal precipitation but is boosted by the additional water from irrigation. This results in continual evaporation during the dry season.

Improved pasture with a dense canopy through the wet season has a lower average annual evaporation. The results are 96 mm from surface water and 134 mm from the soil profile. Daily evaporation rates are displayed in figure 6.6. Figure 6.6 shows that native vegetation has evaporation rates between improved pasture and irrigated peanuts. The results for native vegetation are 181 mm from surface water and 340 mm from the soil profile. Figure 6.6 refers to daily surface water evaporation rates for an intense storm period (from 1st December 1997 to 31st January 1998) which yielded 992 mm of precipitation.

Average annual evapotranspiration totals for native vegetation, irrigated peanuts and improved pasture are 957 mm, 1108 mm and 833 mm respectively. The evapotranspiration for native vegetation equated to 73% of the precipitation, 68% of the precipitation (and irrigation) for peanuts and 64% of the precipitation for improved pasture.

Irrigated peanuts are supplied with an additional average annual amount of 326 mm of water through irrigation. This crop experiences the highest evapotranspiration from a longer period of time that evaporation was possible. This included evaporation from the soil profile and from surface water. Water supplied through irrigation allowed consistent evaporation rates to continue throughout the April to June (dry season months) peanut crop growing period.

Native vegetation and improved pasture model crop growth throughout the entire year and simulation period. Differences in evapotranspiration totals between native vegetation and improved pasture are experienced from the evaporation sources. A dense canopy of the improved pasture resulted in high canopy evaporation, low evaporation rates from surface water and low evaporation rates from the soil profile.

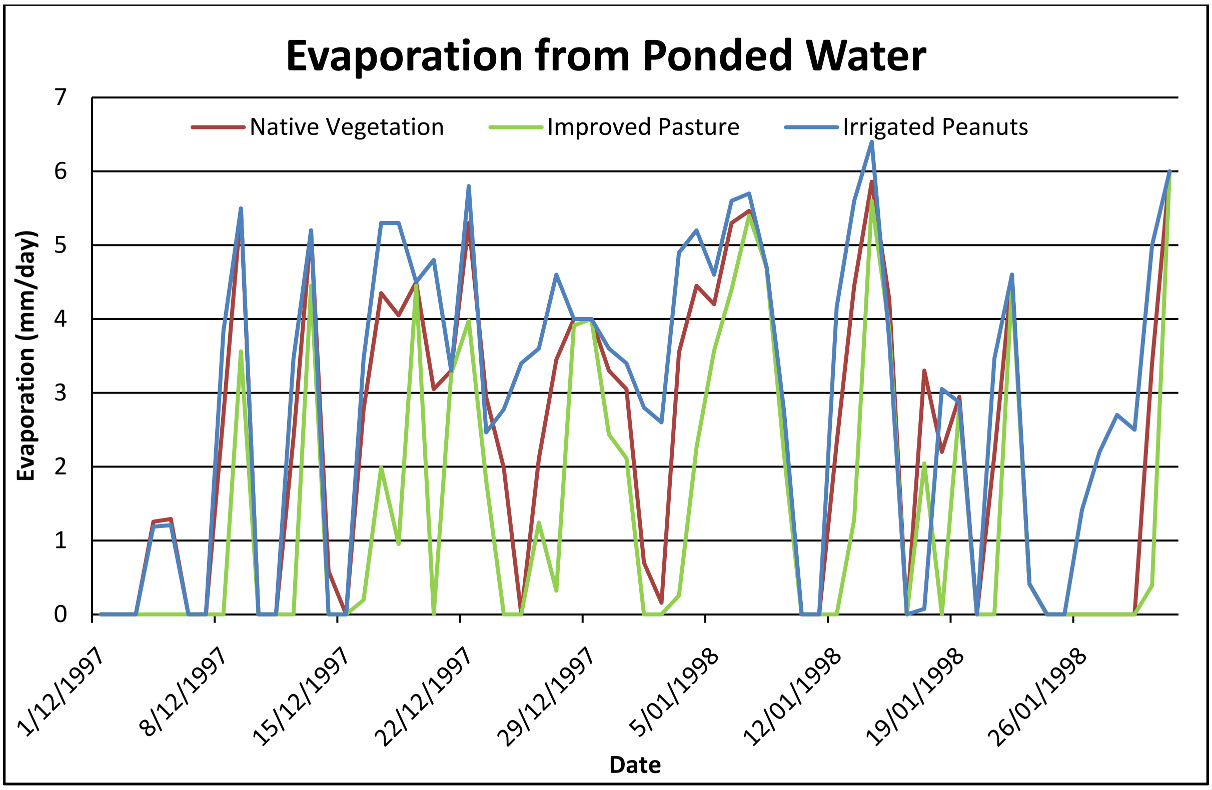

Figure 6.6: Daily evaporation rates from ponded water for the period 1st December 1997 to 31st January 1998.

6.3.2 Overland Flow

The three land use model scenarios result in close to identical overland flow rates on a daily basis. These daily rates vary from 0 mm up to a maximum of 115 mm during the model period. The average annual overland flow totals are 159 mm, 156 mm and 171 mm for native vegetation, improved pasture and irrigated peanuts respectively. Irrigated peanuts had a marginally higher overland flow total due to an average of 15 mm.year^{-1} accumulated in the crop irrigation cycles.

Net precipitation totals vary with land use. Higher net precipitation values increase the soil profiles infiltration. This is an increase in groundwater recharge and crop water use with no effect on overland flow totals. The similar overland flow totals result from simulating a soil column profile rather than a catchment size model.

Overland flow is initiated when the infiltration capacity of the soil is exceeded and the maximum ponding depth of surface water is reached. This excess water is then available for overland flow and it travels across the topography towards the boundary of the water balance model. For a soil column, excess surface water immediately reaches the model boundary. The overland flow of a soil column is therefore not inhibited by the topography of the site or the land use. Surface water immediately reaches the model boundary leading to similar totals and the same daily rates of overland flow. The overland flow is not affected by bare soil or dense pasture.

6.3.3 Crop Water Use

Crop water use is a function of the water in the root zone. This incorporates transpiration from the root zone, root water uptake and the water content in the root zone. These components are all controlled by infiltration.

Infiltration to the unsaturated zone (and root zone) has average annual totals of 883 mm, 841 mm and 1157 mm for native vegetation, improved pasture and irrigated peanuts respectively. Improved pasture has a lower infiltration total than native vegetation due to the dense canopy. The net precipitation reaching the soil surface and available to infiltrate is reduced. Irrigated peanuts have a significantly higher infiltration total due to irrigation. The annual average irrigation component is 326 mm of additional water. This leaves the infiltration from precipitation for peanuts at 831 mm (infiltration minus irrigation). This total was less than the infiltration for native vegetation and improved pasture due to a higher surface water evaporation rate. This results from the bare soil throughout the wet season until the peanut crop was planted on the 1st February annually.

Peanut irrigation was initiated when a 60% deficit of moisture content (below field capacity) in the root zone was reached and ceased at the field capacity water content. Irrigation therefore commenced at a moisture content of 0.21 $g.g^{-1}$ (60% deficit) and ceased at a moisture content of 0.27 $g.g^{-1}$ (field capacity). Shown in figure 6.7, irrigation was required four times during 1997 to maintain the water content limits within the root zone. Irrigation was simulated on approximately a fortnightly basis, with 3.9 $mm.hour^{-1}$ of water supplied to the crop in one day. This equated to an application of 93.6 mm each irrigation. The water content in the root zone for the peanut crop of 1997 (refer to figure 6.7) represented a typical year within the model period. Each model year for ten years required the peanut crop to be irrigated three or four times once the dry season had commenced.

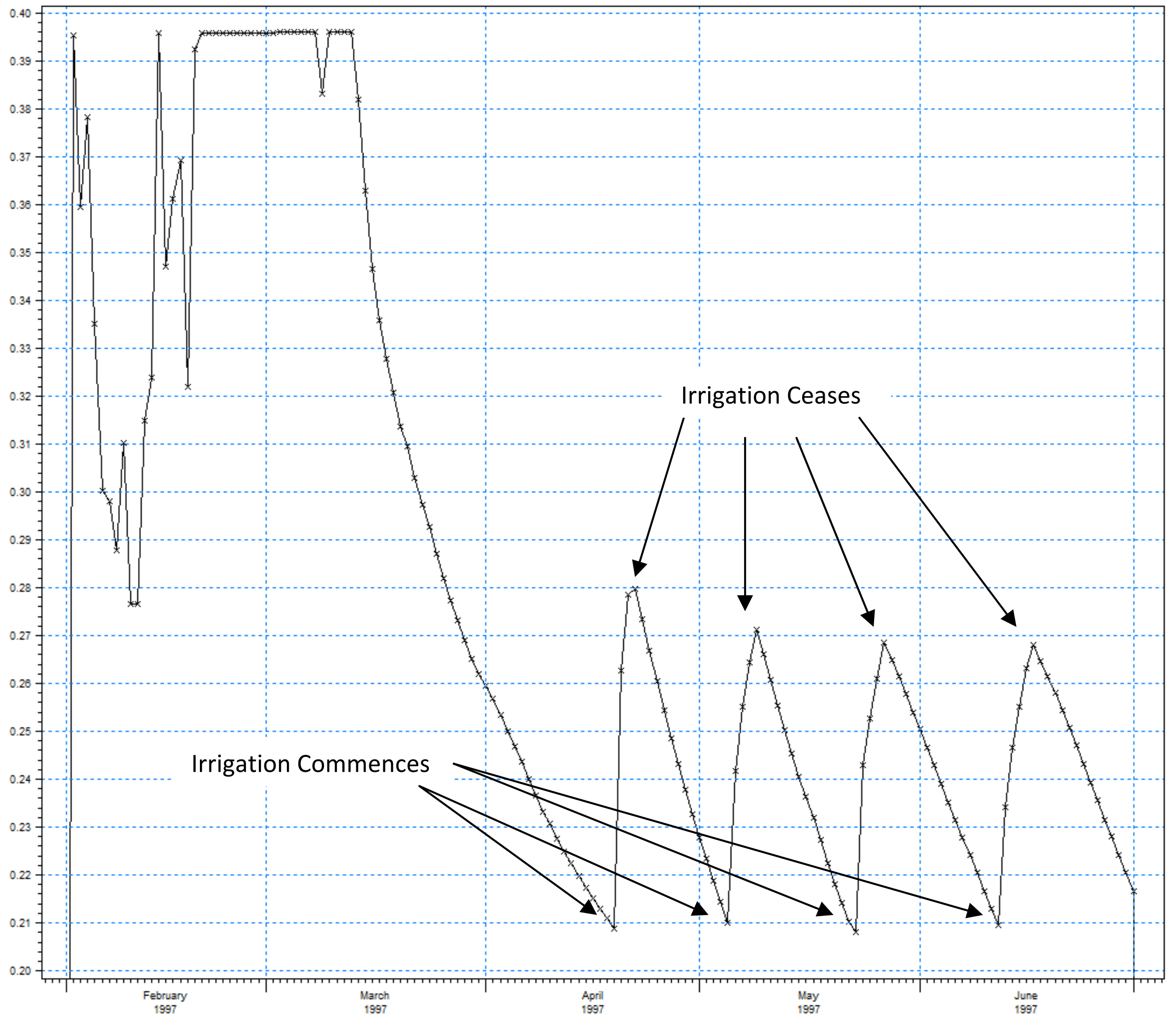

Figure 6.7: Average water content in the root zone for irrigated peanuts (April to June of 1997).

Transpiration rates for the three land uses vary significantly on a daily basis as shown in figure 6.8. The average annual transpiration totals do not alter significantly. They are 354 mm, 385 mm and 345 mm for native vegetation, improved pasture and irrigated peanuts respectively.

Native vegetation and improved pasture transpire throughout the year while irrigated peanuts only draw moisture from the root zone during the growing cycle (February to June). A clear distinction also exists between wet and dry season transpiration rates for native vegetation and improved pasture. The growing rate of improved pasture is greater than native vegetation during the wet season resulting in a high transpiration rate of 4-5 $mm.day^{-1}$. This is in contrast to the low dry season improved pasture transpiration rate. The rate is consistently less than 0.2 $mm.day^{-1}$ due to a shallow root system. Native vegetation has a more constant transpiration rate throughout the year of 1-2 $mm.day^{-1}$ during the wet season and approximately 0.9 $mm.day^{-1}$ in the dry season. Native vegetation has a slower growth rate during the wet season than improved pasture although it maintains its growth rate during the dry season. This results from a deeper root zone being able to access water from a greater depth.

Irrigated peanuts has a lower annual total of 345 $mm.day^{-1}$, but they only transpire for five months of the year. This represents an average transpiration rate of 2.3 $mm.day^{-1}$ for the growing period. Due to the high growth rate and the availability of a constant water supply through irrigation, simulated peanuts had the highest transpiration rates. The rates were close to 5.5 $mm.day^{-1}$ during peak growth.

Many days and periods of zero transpiration are experienced throughout the model as shown in figure 6.8. Transpiration rates of 0.0 $mm.day^{-1}$ are associated with days and periods of intense precipitation. Individual daily storms of greater than 30 mm (21st November 1996) or sustained periods of precipitation ranging from 10 mm to 20 mm (27th December 1996 to 10th January 1997) are sufficient to stop crop transpiration. The four irrigation applications in the months from April to June in 1997 also stop crop transpiration for up to a three day period. The days of zero transpiration correlate to saturation of the unsaturated zone but not necessarily the root zone. The unsaturated zone will have a water content of 0.396 $g.g^{-1}$ and in the root zone a water content of field capacity (0.27 $g.g^{-1}$) or greater.

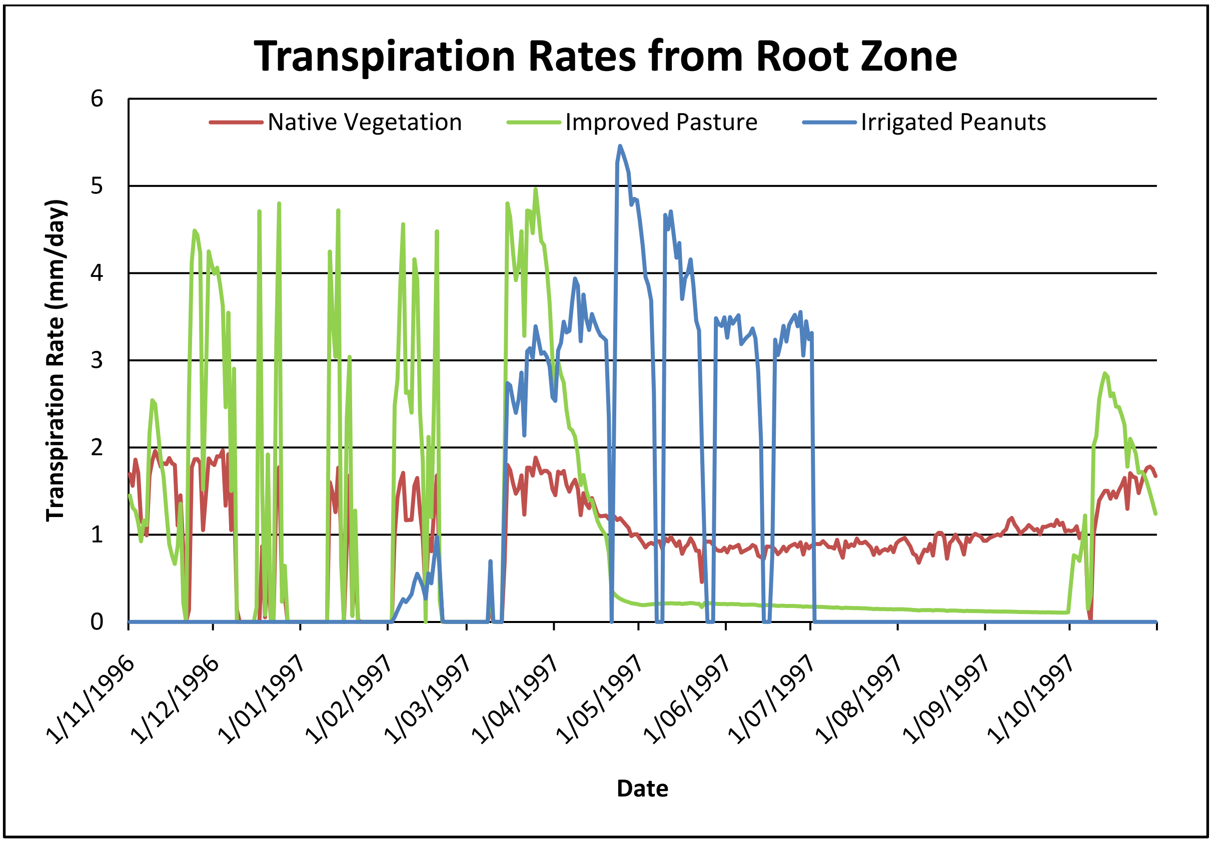

Figure 6.8: Crop transpiration rates from the root zone for the 1996-1997 water year.

All three land use scenarios use a relatively similar amount of water on an annual basis. The growth rate and transpiration rate for native vegetation and improved pasture differ due to available water and the rooting depth of the crop. This includes infiltration and water stored in the soil profile. Native vegetation is able to maintain a reasonably constant growth rate during the dry season due to its ability to draw water from a greater depth in the unsaturated zone.

An irrigated peanut crop requires the same annual quantity of water for the five month growing period. Figure 6.8 shows a similar transpiration rate for improved pasture as for irrigated peanuts. Differences result from high transpiration rates for peanut growth being continued through the dry season until the end of June.

This places a high demand on the root zone to provide water for peanut crop growth. Irrigation is therefore a necessity to successfully grow peanuts.

Transpiration from the root zone is the largest use of water from within the unsaturated zone. Transpiration for native vegetation equated to 27% of the precipitation, 21% of the precipitation (and irrigation) for peanuts and 30% of the precipitation for improved pasture. These transpiration figures are a partial inclusion for total evapotranspiration.

6.3.4 Groundwater Recharge

Average daily groundwater recharge rates from the unsaturated to the saturated zone are shown in figure 6.9. The groundwater recharge for the three land use scenarios settled into an annual daily recharge pattern as shown below. This pattern took six years of model simulation to establish. Groundwater recharge occurs when water leaves the unsaturated zone of the soil column model. Simulations of soil water storage and soil moisture contents must stabilise to physical operating conditions before valid unsaturated zone results will occur. Up to six years of precipitation and annual crop rotational cycles are required for the full unsaturated zone soil profile to produce this groundwater recharge pattern.

Average annual groundwater recharge for native vegetation, irrigated peanuts and improved pasture are 111 mm, 251 mm and 226 mm respectively. The annual recharge totals are produced by daily rates of generally less than 1 $mm.day^{-1}$ with a rate peak experienced in the middle of the dry season. Assuming this recharge rate peak physically occurs, it could be produced by a number of factors. The most likely is a delay to seasonal precipitation and a reduced dry season crop water use.

High wet season precipitation has an immediate effect on the soil water storage. The soil water storage increases during the wet season and is drawn down during the dry season (refer to figure 6.10). Infiltration rates during the wet season are higher than the combined crop water use and groundwater recharge increasing the soil water storage. The dry season follows in which infiltration ceases. While crops continue to grow throughout the dry season (until the end of June for peanuts), they use the water stored in the soil for transpiration rather than water supplied through precipitation and irrigation. Evaporation from the soil and groundwater recharge also reduces the soil water storage during the dry season. Preliminary predictions indicate a delay in time for high wet season infiltration to reach the saturated zone. The delay in infiltration to reach the saturated zone causes an annual peak recharge rate in May for irrigated peanuts and improved pasture and in August for native vegetation.

Groundwater recharge also models macropore flow through the unsaturated zone. While macropore flow represents 16.7% (native vegetation), 14.6% (improved pasture) and 16.7% (irrigated peanuts) of infiltrated water, they fail to recharge the saturated zone. Macropore flow is fully exchanged to the soil matrix in the unsaturated zone under current model parameters. Infiltration leading to groundwater recharge is purely accounted for through diffuse recharge.

Groundwater recharge for irrigated peanuts and improved pasture have a very similar daily rate and annual total for the simulation period. With varying infiltration rates, the groundwater recharge for the two crops is dependent on their very shallow root systems. In contrast, native vegetation has a root zone of greater depth, and is capable of drawing water from closer to the bottom of the unsaturated zone. Overall, the groundwater recharge for native vegetation equated to 8.5% of the precipitation, 15% of the precipitation (and irrigation) for peanuts and 17% of the precipitation for improved pasture.

The soil water storage of the unsaturated zone demonstrated a similar scenario to the comparison of groundwater recharge and land use. Figure 6.10 shows that irrigated peanuts and improved pasture have similar soil water storage levels throughout the year with an average annual increase of 17 mm and 15 mm respectively. These two crops are compared with native vegetation which experiences between 0 mm and 150 mm less storage (throughout the year) and an average annual increase of only 5 mm. The difference in soil water storage results from a shallower root system of irrigated peanuts and improved pasture. This could lead to the water table rising with prolonged waterlogging during the wet season and the introduction of salinity to farmland.

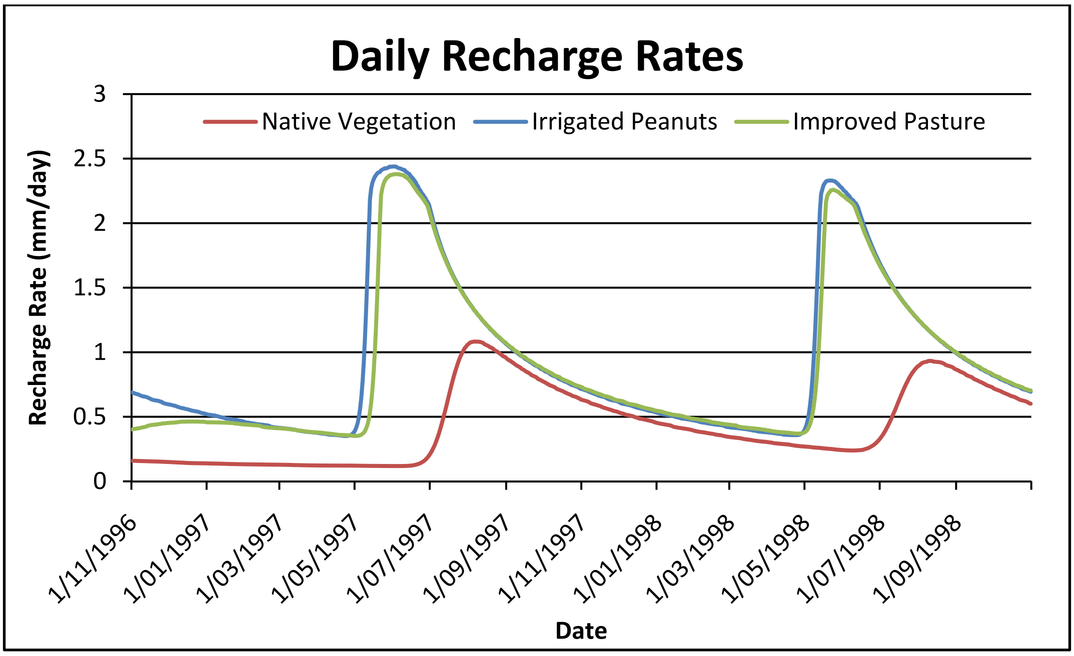

Figure 6.9: Daily groundwater recharge rates for two consecutive water years (1996-98).

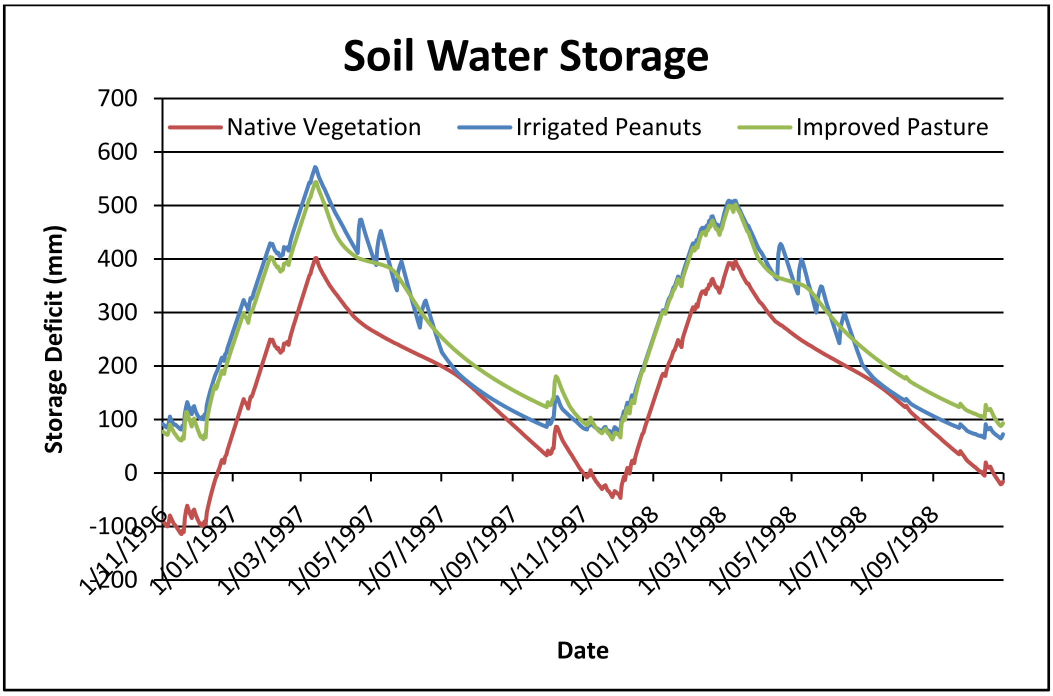

Figure 6.10: Change in soil water storage levels for two consecutive water years (1996-98).

6.4 Integrated Regional Land Use Plan

The Daly Region Community Reference Group and the Northern Territory Government are looking to increase ecologically sustainable agricultural development within the Daly River catchment. A balanced approach is necessary for further agricultural development requiring hydrological, biological, environment and social effects to be evaluated for the study site. Hydrological impacts due to the change in land use have previously been discussed. The other requirements are discussed below.

6.4.1 Biological Impacts

Dry season flows in the Daly River are a significant aspect of the Daly River catchments environment. Perennial river flow is rare in the wet and dry seasonal tropics. The dry season river flow provides local wildlife with a water resource during the annual months of scarce precipitation. The habitat of a wide array of native wildlife would be put in doubt if dry season river flows ceased or even reduced. The wildlife can be categorised as either birds with habitats in the land that will be cleared, or aquatic animals that live in the Daly River and tributaries.

The Daly River catchment is home to around 350,000 animals and any clearing would devastate the habitats of these wildlife species. While free roaming animals can readily move from region to region, increased competition for food and territory would impact survival rates and breeding cycles of local wildlife. Sugar gliders, quolls, bower birds, possums, finches and cockatoos will be among the affected animals (The Environmental Centre of the Northern Territory 2003).

The Daly River is also home to eight of the nine Australian freshwater turtle species. This includes the threatened Pig Nosed Turtle. The Daly River is home to the endangered freshwater sawfish and the endangered sawtooth shark. The Daly is also well known for barramundi fishing and supports nearly 50 species of freshwater and estuarine fish (Crase, J., & Wakeham, M., 2003). Altering flows into the Daly River could have a dramatic effect on the feeding and breeding of these aquatic animals. Increased overland flow from the change in land use could also lead to higher fish kills resulting from the initial wet season river flush. Agricultural products (fertilisers and chemicals) will be washed into creeks and rivers from the increased overland flow.

6.4.2 Environmental Impacts

The Daly River catchment is covered in vast forests and woodlands that are dominated by native grasses and eucalypt savannah. This is the marked vegetation for extensive land clearing in the Daly River catchment to increase agricultural development. The two major environmental impacts associated with land clearing are the increase in overland flow, and the change in groundwater storage and groundwater recharge due to cropping.

Land clearing leads to a top layer destabilisation of the soil profile. The top soil is exposed to increased erosion during intense storms throughout the wet season. Eroded soil from cropping fields removes valuable nutrients and is deposited in waterways and the Daly River. Soil erosion leads to the silting of rivers and affects the biological habitat of the Daly. Soil erosion is also enhanced when there is little or no vegetation established in the cropping fields. This is a result of increased overland flow which also leads to amplified flood events. Silting of the Daly River will also occur as a result of top soil erosion, overland flow transportation and deposits into the river.

The dynamics of groundwater storage and recharge can be altered by a change in land use. Native vegetation in the Daly River catchment has an established deep root system. This root system can extract water from up to five metres below the surface. By contrast, crop varieties rarely draw water from greater than one metre in depth. This allows the groundwater table to rise introducing the possibility of salinity and increased waterlogging to the area. Irrigation will also affect the groundwater level and flows in the Daly River. Pumping water from the Daly River to irrigate agricultural crops will lower perennial flows. Continual dry season river flow in the Daly River is critical to the biological habitat and health of the river system (The Environmental Centre of the Northern Territory 2003).

6.4.3 Social Impacts

Water, its origins, features and appropriate use is highly significant to the way of life, sense of identity, economy and cosmology of Aboriginal groups in the Daly River catchment (Jackson 2003).

Aboriginal people represent a large majority of the population currently living in the Daly River catchment region. The Aboriginal community hold a distinctly different worldview and way of life (particularly with respect to water) that is not well known by the wider society. Emphasis has gone into ensuring that the interests of the native people are addressed in the planning and development for the region. This includes liaising and reporting on Aboriginal social and cultural values of the Daly River catchment region (Jackson 2003).

Cultural values of the native Aborigines are in relation to their way of life. This includes their culture, traditions, customs and beliefs. Social impacts arise from the ability of the Aboriginal people to alter their cultural values to adapt to new agricultural development.

The native Aborigines have voiced concerns in the following areas which will dictate future agricultural development:

- Sustainable agricultural development.
- Continual catchment planning and management.
- Intensification of agricultural crops.
- Water allocation and use for agriculture.
- Aboriginal participation in the planning process.

(Jackson 2003)

6.5 Limitations and Model Restrictions

MIKE SHE water balance modelling limitations and restrictions are due to simulation uncertainties and a lack of data.

Coupling the Overland Flow Module to the Unsaturated Flow Module in MIKE SHE introduced error into the unsaturated zone. The error existed as a surplus of water in the unsaturated zone with infiltration exceeding outflow. The error accumulated during the times of peak infiltration (including macropore infiltration). This led to the assumption that the infiltration rate during storm events exceeded the unsaturated zones capability of using the water.

Another factor that influenced the limitations of the unsaturated zone was the saturated hydraulic conductivity. This parameter was estimated during calibration to approximate previous reported results on overland flow, groundwater recharge and evapotranspiration. This led to a lower value of saturated hydraulic conductivity for the soil profile than expected. Reducing the water flow rate through the unsaturated zone allowed overland flow to be simulated. This was at a cost of producing an error in the unsaturated zone. The unsaturated zone error as a proportion of total precipitation is 5.6% for native vegetation, 5.8% for improved pasture and 6.5% for irrigated peanuts.

Limitations also existed in the modelling of macropores. Water directly infiltrates into the macropores (refer to section 6.3.4) and flows through the unsaturated zone at a rate up to 2.6 mm.day^{-1}. This flow however, fails to directly recharge the groundwater. The modelled result is that the macropores fill with water and then transfer to the soil matrix in the unsaturated zone. The macropores do not bypass the unsaturated zone from infiltration to groundwater recharge.

Finally, the results from a MIKE SHE simulation must be interpreted with care. The water balance is heavily influenced by the movement of water throughout the soil column model. The results are highly influenced by individual storm periods and changing soil moisture contents. It is therefore important to establish seasonal precipitation and evapotranspiration patterns before results are analysed in depth.

Chapter 7

Conclusions

7.1 Summary

This project analysed the impacts of land use on the water balance of a farm by modelling a one-dimensional soil profile. To determine the change on the water balance from varying land use, an investigation was carried out using hydrological software MIKE SHE. The computer modelling program required input values for precipitation and reference evapotranspiration to produce the water balance. This resembles water movement on the surface and within the unsaturated zone of the simulated soil column. An analysis of surface water included actual evapotranspiration and overland flow. The unsaturated zone analysis incorporated scenarios for different crop water use, soil water storage and groundwater recharge.

The water balance investigation focused on a study area in the Daly River catchment (refer to figure 1.4). This catchment has good soils suitable for agricultural development. Three land use scenarios were selected to represent current and future farming practices. They were native vegetation, improved pasture and peanut irrigation.

Results were produced through the MIKE SHE water balance editor. These results were calibrated against previous Daly River catchment water balance results to validate the computer models. These results were critically analysed and a number of conclusions were made. Further project outcomes include the three working hydrological models (for the three land use scenarios) for ongoing and future studies by DHI Water and Environment.

7.2 Conclusions

The conclusions reached from this investigation are:

1. Average annual evapotranspiration totals throughout the simulation period for native vegetation, irrigated peanuts and improved pasture were 957 mm, 1108 mm and 833 mm respectively. The evapotranspiration totals equated to 73% of precipitation use for native vegetation, 68% of precipitation and irrigation use for peanuts and 64% of precipitation use for improved pasture.

   Irrigated peanuts experienced the highest evaporation rates from the surface water and the upper layers of the soil profile. These evaporation totals were enhanced due to a bare soil profile during the months of July through to January. An average annual addition of 326 mm through irrigation also increased the evaporation total. Differences in evapotranspiration totals for native vegetation and improved pasture also arose due to the effect of crop canopy on evaporation. The dense canopy of improved pasture resulted in higher canopy evaporation.

When compared to the less dense native vegetation canopy, higher evaporation rates were simulated from ponded water and the soil profile.

2. Average annual overland flow totals throughout the simulation period for native vegetation, irrigated peanuts and improved pasture were 159 mm, 171 mm and 156 mm respectively. The overland flow totals equated to 12% of precipitation use for native vegetation, 10% of precipitation and irrigation use for peanuts and 12% of precipitation use for improved pasture.

   Average overland flow totals and daily rates for the three land use scenarios were close equal throughout the simulation of the soil column. A catchment sized hydrological model would incorporate overland flow losses over the flow path.

   Irrigated peanuts produced a higher average annual overland flow due to irrigation. Irrigation cycles produced an additional average 15 $mm.year^{-1}$. As a result, higher infiltration was experienced from surface water to the unsaturated zone for irrigated peanuts.

3. Average annual transpiration totals throughout the simulation period for native vegetation, irrigated peanuts and improved pasture were 354 mm, 345 mm and 385 mm respectively. The transpiration totals equated to 27% of precipitation use for native vegetation, 21% of precipitation and irrigation use for peanuts and 30% of precipitation use for improved pasture.

   The transpiration totals for the three land use scenarios are similar, however daily transpiration rates differ significantly. With a deep root system, native vegetation was able to maintain a relatively stable growth rate (transpiration rate) on an annual basis. Improved pasture had a shallow root system with a higher water demand. Wet season transpiration rates were more than double native vegetation rates but went close to ceasing during the dry season. In contrast, irrigated peanuts only transpired during the months from February to June (the growing period). In this period peanuts have a high water demand which could only be met through irrigation. Irrigated peanuts have a similar root depth and wet season growth rate to improved pasture, resulting in similar maximum transpiration rates.

4. Average annual groundwater recharge totals throughout the simulation period for native vegetation, irrigated peanuts and improved pasture were 111 mm, 251 mm and 226 mm respectively. The groundwater recharge totals equated to 8.5% of precipitation use for native vegetation, 15% of precipitation and irrigation use for peanuts and 17% of precipitation use for improved pasture. Macropore flow did not influence the groundwater recharge.

   Groundwater recharge totals took six years of model simulation to stabilise before daily rates settled into an annual pattern. Groundwater recharge was affected more by the crops rooting depth than any other crop characteristics. Native vegetation had a deeper root zone and was capable of drawing water from deeper in the unsaturated zone. This lowered groundwater recharge.

5. Soil water storage was closely related to groundwater recharge. The soil water storage of the three land use scenarios had an average annual increase of 5 mm, 17 mm and 15 mm for native vegetation, irrigated peanuts and improved pasture respectively. A rise in the water table level

is more likely to occur under the crop types of irrigated peanuts or improved pasture than native vegetation.

I conclude that intensive agricultural development of the Daly River catchment is not appropriate at present. There is a risk of soil salinisation and extensive waterlogging associated with the clearing of native vegetation and the introduction of cropping. River flows would significantly fluctuate increasing the susceptibility to floods and droughts. Dry season flows in the Daly River would decrease as a result of irrigated agriculture.

7.3 Further Work

A number of areas were identified for continued analysis and work on the water balance in the Daly River catchment.

Soil column water balance models produced for the Daly River catchment constitute a preliminary point based analysis for future agricultural development. The one dimensional soil column models should be expanded to a three dimensional model of the catchment to gain a better understanding of the impacts of changing the land use. A three dimensional water balance model could incorporate the topography of a typical property within the study area. Overland flow would be assessed with greater accuracy including land use interaction and natural waterways located in the study site.

A further investigation should be carried out into the calibration of the three soil column models. This would require extensive work due to the present lack of water balance models and river flow data. Possible measuring devices and experiments may include a lysimeter, a neutron moisture probe and monitoring bores. A lysimeter is capable of measuring actual evapotranspiration from measured precipitation readings and water lost through the soil. A neutron moisture probe is a device used to measure groundwater recharge and the daily recharge yield. Monitoring bores enable the depth of the water table to be recorded daily and simulated in computer models.

Macropores are a key aspect of the soil profile in the study area. Macropore computer modelling is limited at present and cannot be easily simulated with a deep soil profile. Parameters in MIKE SHE to model macropores are also not widely available. Further work into macropore modelling would greatly assist future studies.

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Appendix A

Project Specification

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG4111/4112 Research Project
PROJECT SPECIFICATION

FOR: Craig Rohde

TOPIC: Preliminary Water Balance Models of the Daly River Catchment

SUPERVISOR: Associate Professor Mark Porter

SPONSORHSIP: Graeme Cox – DHI Water and Environment

PROJECT AIM: The aim of this project is to simulate the water balance due to three different land use scenarios in the Daly River catchment. Incorporating changes in overland flow, crop water use and groundwater recharge, predictions on water balance changes can be developed.

PROGRAMME: (**Issue B, September 2008**)

1. Demonstrate a sound understanding of the soil types, current land use and predicted land use scenarios in the Daly River catchment.

2. Undertake a literature review to determine current practices and techniques used to develop hydrological maps to represent the water balance.

3. Investigate the capability of hydrological modelling software (MIKE SHE), and describe the theoretical background, operational characteristics and limitations of the software package.

4. Produce MIKE SHE models for single XY coordinates (soil columns) that are capable of analysing the water balance for various types of land use scenarios.

5. Calibrate the MIKE SHE models to assess the water balance under the land use of native vegetation, pasture and intensive irrigation under corresponding soil types.

6. Analyse the results of the MIKE SHE models including precipitation, evapotranspiration, overland flow, groundwater recharge and soil water storage with respect to the change in land use.

AGREED ____________________ (student) ____________________ (supervisor)
Date: / / 2008 Date: / / 2008

Co-examiner:________________________

Appendix B

Summarised Water Balance Results

Figure B.1, B.2 and B.3 show the water balance summaries for the corresponding land use scenarios. Precip is Precipitation, ET is Evapotranspiration, OL is Overland Flow, Storage Change is Soil Water Storage Change, Recharge is Groundwater Recharge and Error is Unsaturated Zone Error.

Date	**Precip**	**ET**	**OL**	**Storage Change**	**Recharge**	**Error**
1/01/1990	0.00	0.00	0.00	0.00	0.00	0.00
1/04/1990	-563.70	407.23	7.85	121.07	2.04	-25.51
1/11/1990	-745.20	808.82	7.95	-114.51	15.74	-27.20
1/04/1991	-2187.00	1386.32	254.98	375.21	25.98	-144.52
1/11/1991	-2308.10	1727.73	254.98	-9.64	188.15	-146.88
1/04/1992	-3230.40	2391.61	321.79	85.11	252.68	-179.20
1/11/1992	-3336.10	2701.84	321.79	-166.15	296.91	-181.71
1/04/1993	-4540.40	3335.39	594.33	57.50	314.96	-238.22
1/11/1993	-4553.70	3602.57	594.33	-214.06	331.51	-239.35
1/04/1994	-5680.20	4201.31	742.62	94.09	339.34	-302.85
1/11/1994	-5700.90	4465.07	742.62	-157.70	347.06	-303.85
1/04/1995	-6934.81	5073.38	873.03	267.55	351.05	-369.79
1/11/1995	-7055.01	5424.44	873.11	15.38	367.93	-374.13
1/04/1996	-7946.31	6042.42	875.42	178.33	434.72	-415.41
1/11/1996	-8059.81	6373.05	875.42	-89.63	483.78	-417.17
1/04/1997	-9440.31	7008.47	1080.43	332.38	504.60	-514.41
1/11/1997	-9539.90	7327.54	1080.44	-0.69	616.54	-516.07
1/04/1998	-11020.91	7989.19	1429.92	325.47	682.45	-593.87
1/11/1998	-11108.10	8297.16	1429.92	-13.63	798.67	-595.98
1/04/1999	-12607.10	8954.74	1591.85	489.19	862.03	-704.26
1/11/1999	-12734.50	9314.44	1591.85	29.50	1075.33	-723.38
31/12/1999	-13050.50	9569.55	1592.65	50.38	1112.35	-725.56

Figure B.1: Native vegetation water balance summary (mm).

Date	Precip	ET	OL	Irrigation	Storage Change	Recharge	Error
1/01/1990	0	0	0	0	0	0	0
1/04/1990	-563.7	399.6882	6.892696	-7.47659	139.9142	2.035379	-22.6463
1/11/1990	-745.2	881.6891	15.41821	-195.413	3.649078	16.10892	-23.7479
1/04/1991	-2187	1434.933	258.2967	-195.413	503.1156	45.28412	-140.785
1/11/1991	-2308.1	1917.708	274.0792	-478.725	67.93211	330.6749	-196.432
1/04/1992	-3230.4	2528.057	339.1307	-478.725	211.6829	407.0844	-223.169
1/11/1992	-3336.1	3057.814	357.4131	-853.132	81.58186	468.4362	-223.985
1/04/1993	-4540.4	3640.902	627.2405	-853.132	320.2657	523.321	-281.802
1/11/1993	-4553.7	4116.642	644.0509	-1219.93	61.00766	668.2556	-283.678
1/04/1994	-5680.2	4677.226	784.5229	-1219.93	347.8955	743.5945	-346.892
1/11/1994	-5700.9	5155.413	802.2349	-1592.01	81.40437	905.3367	-348.513
1/04/1995	-6934.81	5741.076	931.4615	-1592.01	461.7423	983.8511	-408.667
1/11/1995	-7055.01	6269.995	944.9548	-1874.92	93.9843	1207.796	-413.172
1/04/1996	-7946.31	6852.936	946.9302	-1874.92	282.4077	1287.795	-451.131
1/11/1996	-8059.81	7389.462	965.5186	-2248.52	91.14032	1409.012	-453.167
1/04/1997	-9440.31	8009.249	1166.612	-2248.52	480.985	1484.934	-547.023
1/11/1997	-9539.9	8540.177	1182.894	-2613.44	83.62264	1765.291	-581.342
1/04/1998	-11020.9	9183.462	1530.209	-2613.44	423.3422	1842.916	-654.392
1/11/1998	-11108.1	9696.812	1546.345	-2977.4	75.42618	2099.099	-667.793
1/04/1999	-12607.1	10335.76	1691.07	-2977.4	605.3978	2174.832	-772.802
1/11/1999	-12734.5	10877.43	1704.441	-3260.46	106.4327	2464.833	-841.808
31/12/1999	-13050.5	11084.2	1705.293	-3260.46	171.4987	2505.063	-844.893

Figure B.2: Irrigated peanuts water balance summary (mm).

Date	Precip	ET	OL	Storage Change	Recharge	Error
1/01/1990	0	0	0	0	0	0
1/04/1990	-563.7	447.172	7.632452	87.64999	2.0354	-19.2103
1/11/1990	-745.2	720.7129	7.6331	-18.7741	15.96433	-19.664
1/04/1991	-2187	1325.149	251.9637	449.9966	28.0881	-131.804
1/11/1991	-2308.1	1501.581	251.9637	90.8489	289.1346	-174.573
1/04/1992	-3230.4	2183.776	315.9522	166.7635	366.5239	-197.385
1/11/1992	-3336.1	2349.12	315.9522	44.02253	428.7678	-198.237
1/04/1993	-4540.4	3013.858	580.8224	241.5297	461.3021	-242.89
1/11/1993	-4553.7	3118.689	580.8224	78.16254	531.8802	-244.147
1/04/1994	-5680.2	3755.04	714.1379	304.2559	606.7369	-300.029
1/11/1994	-5700.9	3859.717	714.1379	96.00797	729.8396	-301.193
1/04/1995	-6934.81	4455.114	844.718	457.632	811.1882	-366.143
1/11/1995	-7055.01	4685.635	844.8051	117.2522	1036.637	-370.664
1/04/1996	-7946.31	5356.13	846.5931	216.4784	1125.578	-401.512
1/11/1996	-8059.81	5534.539	846.5931	77.08445	1199.117	-402.458
1/04/1997	-9440.31	6191.869	1050.068	441.9521	1264.436	-491.965
1/11/1997	-9539.9	6355.789	1050.07	94.53149	1525.746	-513.744
1/04/1998	-11020.9	7023.897	1400.658	403.9998	1605.601	-586.725
1/11/1998	-11108.1	7164.77	1400.658	96.1114	1853.173	-593.372
1/04/1999	-12607.1	7840.827	1562.761	573.1787	1930.771	-694.409
1/11/1999	-12734.5	8079.236	1562.762	123.7141	2211.577	-757.193
31/12/1999	-13050.5	8326.946	1563.048	148.1147	2254.754	-757.618

Figure B.3 Improved pasture water balance summary (mm).

Appendix C

Precipitation Model Input

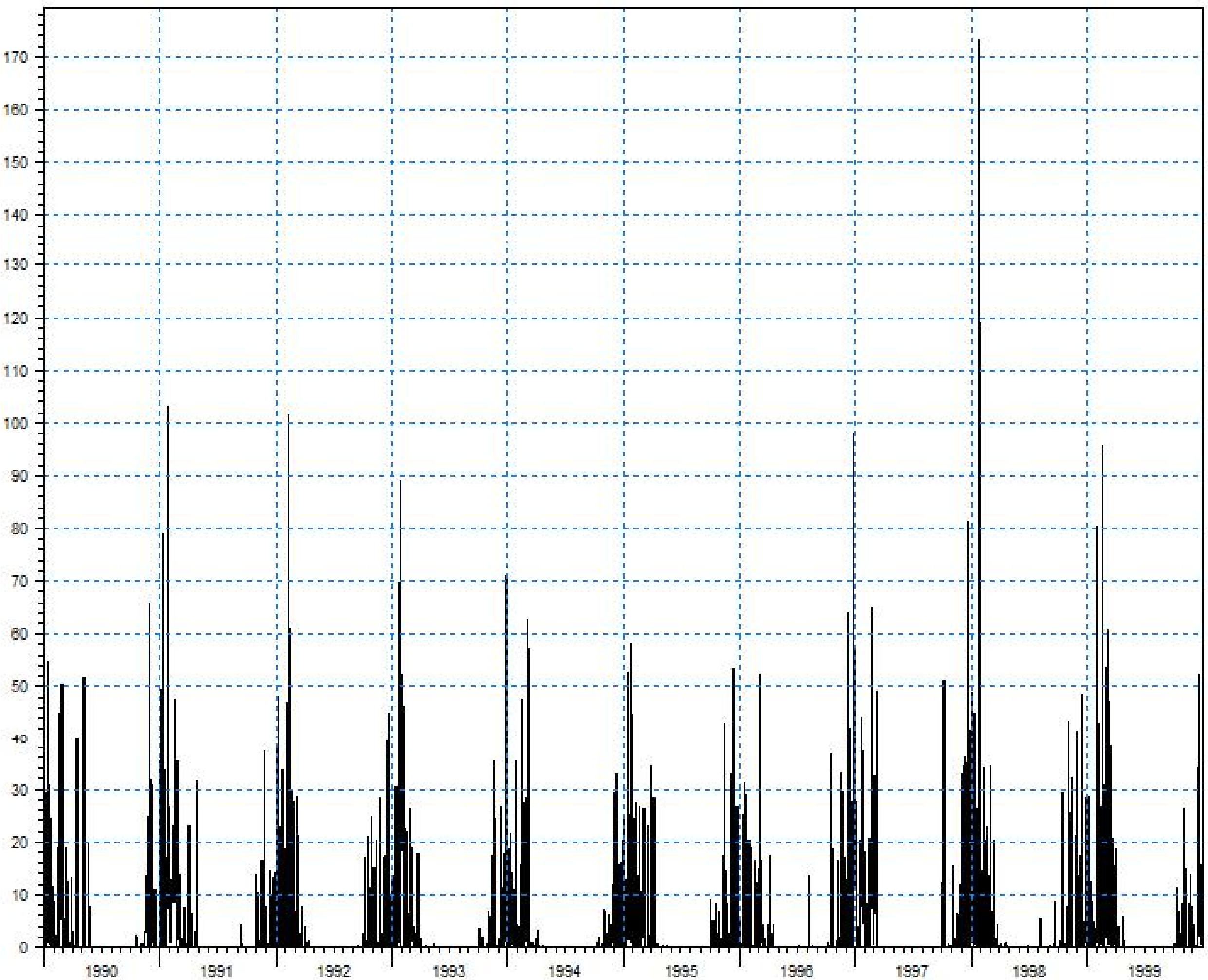

Figure C.1: MIKE SHE daily precipitation input from 1990 to 1999 (mm.day^{-1}).

Appendix D

Reference Evapotranspiration Model Input

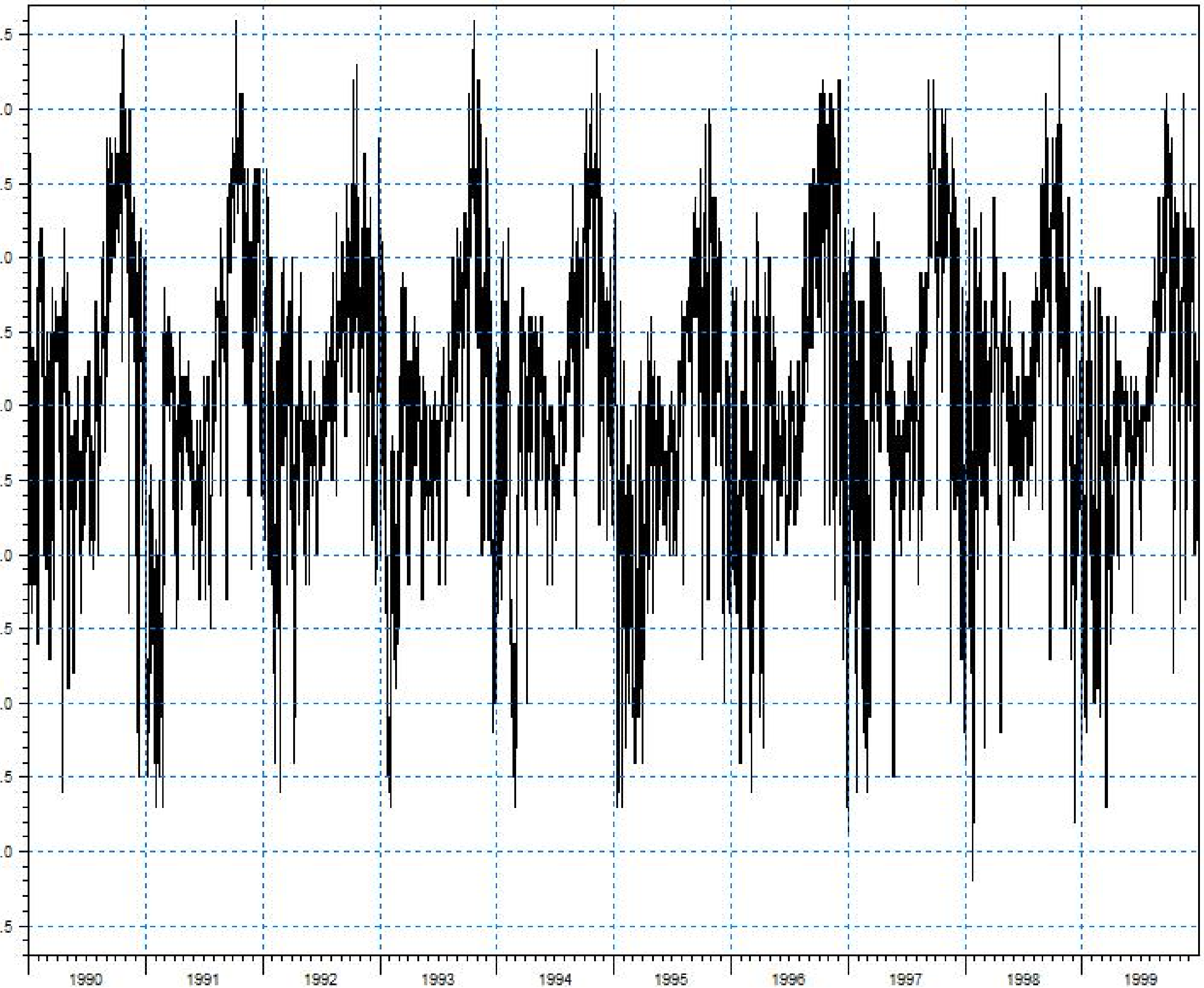

Figure D.1: MIKE SHE daily reference evapotranspiration input from 1990 to 1999 ($mm.day^{-1}$).