IMPACTS OF SUGARCANE PRODUCTION AND CHANGING LAND USE ON CATCHMENT HYDROLOGY

by

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REPORT TO WATER RESEARCH COMMISSION

on the project

Water Quality and Quantity Assessment in Catchments with Changing Land Use in the Umzinto Coastal Area

by

The South African Sugar Association
Experiment Station

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EXECUTIVE SUMMARY

1. BACKGROUND AND OBJECTIVES

The current area under sugarcane production in South Africa is some 400 000 ha. There is increased need to quantify the impact of sugarcane production on water resources. This impact could include reduction in stream flow, modification in flood size (volume and peak) and impact on sediment yield and water quality.

In 1992 a joint project between the Water Research Commission, Illovo Sugar Ltd and the South African Sugar Association was initiated to address these issues. The main aims of the project were:

- To measure water yield and quality from steep catchment areas planted to a commercial timber crop.
- To measure the changes in water and sediment yield and water quality when the forested area is planted to sugarcane, requiring different management and slope preparation methods.
- To compare results from the above areas with runoff from natural grassland.

2. METHODOLOGY

Initially the project focussed on measuring hydrological response from eight small catchments, located at Umzinto (70 km south of Durban), undergoing a land use change from timber to sugarcane. Various factors resulted in limited data being collected from the catchments during the project. Accordingly, emphasis of the project was placed on use of a hydrological model, validated using available data for sugarcane catchments, to meet project objectives.

The *ACRU* model (Schulze, 1995) was selected as an appropriate model since it is a physical, conceptual model which has been widely tested over the past 15 years for a wide range of land uses including timber, sugarcane and grassland. The model was verified for sugarcane using data collected of the period 1977 to 1995 at four catchments located at La Mercy. The model was then applied for various land use scenarios to the Umzinto catchments.

3. RESULTS AND CONCLUSIONS

The major results and conclusions from the study are given below in three sections which focus in turn on:

(i) Hydrological trends and relationships evident from the data collected from sugarcane catchments and plots.
(ii) Adequacy of hydrological simulations using the *ACRU* model when compared with observed data.
(iii) Assessment of the impact of changing land use (sugarcane, timber and grassland) on catchment hydrology based on model scenarios.

3.1 Hydrological Trends and Relationships

Based on hydrological data collected from runoff plots and research catchments the following trends were evident:

- Soil type and slope have a marked impact on runoff, especially under bare fallow conditions.
- On average, there was a 60% reduction in soil loss and 34% reduction in runoff from plot experiments when minimum tillage as opposed to full tillage methods were adopted.
- Average annual runoff as a percentage of rainfall from plots under sugarcane ranged from 1 to 20 per cent depending on soil conditions.
- Average annual soil erosion from sugarcane plots ranged form 21 $t.ha^{-1}.an^{-1}$ to less than 2 $t.ha^{-1}.an^{-1}$.
- Annual runoff as a percentage of rainfall from four catchment experiments varied between 0 and 25 per cent of annual rainfall. Typically, runoff response is less than 5% when annual rainfall was less than 850 mm, and rose to above 25% when rainfall exceeded 1 200 mm.
- Generally a few large storm events produce most of the runoff. During such storms more than 50% of rainfall can run off.
- Rainfall intensity and soil moisture conditions have a major influence on runoff response.
- Soil loss declines to a greater extent than runoff as sugarcane cover increases.
- Runoff appears to be mostly affected by soil type (infiltration rate), storm intensity and antecedent moisture conditions.
- Crop cover and management practices such as strip cropping, minimum tillage and trash retention appear to reduce runoff and soil loss to a greater extent than conservation structures such as contour banks and waterways.
- No signs of excessive wash-off of nutrients or minerals from the catchments were evident.

The above results illustrate how variable hydrological response is on small catchments and how local soils, rainfall and crop management practices will affect this response. Recommendations in terms of catchment management thus need to be site specific.

3.2 Hydrological Simulation using the *ACRU* Model

Based on validation of the *ACRU* model using observed daily data from four sugarcane catchments the following results and conclusions can be made:

- The *ACRU* model adequately simulated runoff volume from sugarcane catchments.
- A decision support system to improve estimation of the *ACRU* model parameters for sugarcane catchments was developed.
- Certain events were not well presented by the model. This was ascribed to an inadequate representation for the events of :
    - rainfall intensity (*ACRU* is a daily model)
    - initial abstractions prior to runoff occurrence
    - land preparation and crop management practices.

- Good estimates of peak discharge were achieved with the model when using actual rainfall intensity data. Catchment response time was generally under-estimated. Use of design rainfall distributions resulted in over-estimation of peak discharge.
- Hydrograph shape was reasonably well represented by the model. Increasing catchment response time provided better representation of catchment storage.
- Estimation of sediment yield using the modified USLE equation did not prove successful. Generally sediment yield was over-estimated. Varying the cover parameter improved estimates but it was concluded that the role of sediment transport and deposition was not well represented by the model.
- Local land management practices such as crop cultivation, repair to waterways and contour banks can have a major impact on timing and magnitude of sediment yield. Flushing out of previous deposits during a large flood will also play a role.

3.3 Modelling the Impact of Grassland, Forestry and Sugarcane

The *ACRU* model was used to simulate the impacts of *eucalyptus grandis,* sugarcane and grassland on water yield at Umzinto. The results of the model runs are site specific and limited by the assumptions and adequacy of how well the model represents the real world processes. The *ACRU* model is however hyrdologically sensitive to land use changes and has been widely verified for grassland, sugarcane and timber. Based on the model runs, the following conclusions can be made:

- Afforestation had a greater impact on stream flow than sugarcane at Umzinto.
- The impact of land cover on runoff is least when soils are shallow and is exacerbated as the soil thickness increases.
- Differences between runoff response under different land covers is smallest during wet years and seasons.
- On thin soils the runoff simulated from grassland and sugarcane land covers were similar. On thicker soils runoff from grassland generally exceeded that from sugarcane.
- Use of stochastic rainfall series did not provide good representation of runoff conditions during high and low flow periods.

4. RECOMMENDATIONS

Owing to the limited hydrological data recorded from the Umzinto catchments over the project period, no direct comparison between measured water yield and water quality under different land uses could be made. Nevertheless, the project objectives were addressed in an indirect way by using a widely recognised hydrological model, which was validated using hydrological data from a range of sugarcane catchments and runoff plot requirements.

The resulting improvements in *ACRU* model representation for sugarcane will be of great assistance in assessing the impact of sugarcane, relative to other land uses in other parts of the sugar industry where no gauged data is available.

Furthermore, the project allowed preparation of a data base containing hydrological information from sugarcane catchment and plot experiments, which will be invaluable for further research studies.

The major recommendations emanating from the project are highlighted below.

4.1 Data Collection

A crucial aspect in the successful collection of data is frequent analysis and use of the data. This enables any problems in data acquisition methods to be detected and corrected timeously. Based on analyses undertaken in the project, various improvements for further data collection and processing have been identified.

4.2 *ACRU* Model Development and Application for Sugarcane

Useful guidelines have been developed during this study for improved estimation of parameter values for use in the *ACRU* model for sugarcane catchments. Further refinements to model structure for application to sugarcane is recommended, namely:

- The method of simulating initial rainfall abstractions should be investigated, especially as they are related to antecedent moisture conditions.

- Further research is required into identifying the factors affecting runoff concentration times under various management practices.

- Further research into the use of regional rainfall intensity distributions based on actual daily rainfall amount is required.

- A more detailed investigation is required into integration of the factors affecting sediment yield on sugarcane catchments into the ACRU model. Factors that need to be addressed include the role of soil moisture status on soil erodibility, variation of crop and management factors through the year and sediment transport within a catchment.

4.3 Other Water Research

The study focussed on the Umzinto catchments to indicate the impact of different land covers (timber, grassland and sugarcane) on hydrological processes. It is recommended that more generalised investigations be initiated to determine whether the trends evident vary between regions and climatic regimes. Catchment attributes that influence these trends also need to be further investigated.

Further work needs to be undertaken on the appropriateness of using stochastic rainfall series in simulating hydrological response.

This study has focussed only on rainfed sugarcane. The impact of irrigated sugarcane on water resources should be investigated on a regional scale.

Finally, further research is required on the water quality characteristics of surface and subsurface flow from sugarcane catchments.

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The Steering Committee responsible for this project consisted of the following people:

Mr HM du Plessis	Water Research Commission	(Chairman)
Mr H Maaren	Water Research Commission	
Mr FP Marais	Water Research Commission	(Secretary)
Prof RE Schulze	University of Natal	
Mr P Braithwaite	Illovo Sugar Ltd	
Mr KP Taylor	Department of Agriculture	
Mr CW Smith	Commercial Forestry Research	
Mr JM Bosch	Forestek Institute CSIR	
Mr AD Manson	Department of Agriculture	
Mr P McPhee	Department of Agriculture	

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1. INTRODUCTION

Currently some 400 000 ha of land supports sugarcane production in South Africa, stretching from southern KwaZulu-Natal to Mpumalanga.

Limited information exists on the water and soil losses that can be expected from sugarcane catchments and under different slope, soil and management practices. Furthermore the impact of a change in land use, for example from natural grassland or commercial timber to sugarcane, is not understood.

In 1992 a joint project between the Water Research Commission, Illovo Sugar and the South African Sugar Association was initiated to address these issues.

1.1 Project Objectives and Methodology

Initially the project focussed on measuring hydrological response from 8 small catchments, located at Umzinto (70 km south of Durban), undergoing a land use change from timber to sugarcane. The main objectives of the project were:

- to measure water yield and quality from steep catchment areas planted to a commercial timber crop
- to measure the changes in water and sediment yield and water quality when the forested area is planted to sugarcane, requiring different management and slope preparation methods, and
- to compare results from the above areas with runoff from natural grassland.

Various factors resulted in limited data being collected from the catchments during the project. These factors included:

- severe drought over the period 1992 to April 1995 during which time only 4 days of rainfall exceeding 50 mm were recorded
- vandalism of all 8 recorder huts and theft of loggers in April 1995, and
- instrumentation problems.

The paucity of runoff data and ongoing vandalism forced a reappraisal of monitoring at the Umzinto catchments and adjustment in methodology to achieve the project objectives. Accordingly monitoring was discontinued in April 1995 with emphasis of the project focussing on use of a hydrological model to meet the project objectives.

The *ACRU* model (Schulze, 1995) was selected as an appropriate model since it is a physical, conceptual agrohydrological model which has been widely tested over the past 15 years for a wide range of land uses including timber, sugarcane and grassland. It was proposed that in the absence of suitable hydrological data from Umzinto the *ACRU* model would be verified, for sugarcane, using data collected by the South African Sugar Association Experiment Station over the period 1977 to 1995 at four catchments located at La Mercy. Various conservation layouts and replanting methods are practised at La Mercy which allowed assessment of the model for a range of management practices.

It was furthermore proposed that in order to address the project objectives of comparing runoff response under different land uses, the *ACRU* model would be applied for various land use scenarios to three of the Umzinto catchments with differing soil and slope characteristics.

Adoption of a modelling approach using a credible model is a cost effective and efficient method of assessing the impact of a crop on water resources in the absence of measured data. The results are however limited by the adequacy with which the model represents catchment processes. Extensive verification of the *ACRU* model does however provide confidence in its use.

1.2 Report Structure

The report has been presented in four parts.

Part 1 provides a description of the various catchments and runoff plots monitored by the South African Sugar Association Experiment Station (SASEX) as well as a brief review of past research results, and hydrological trends and relationships.

Part 2 investigates the use of the *ACRU* model to simulate runoff volume, peak discharge, hydrograph shape as well as sediment yield from the La Mercy catchments in order to verify its performance on sugarcane catchments with varying management practices.

Part 3 investigates the expected seasonal and annual runoff trends from three of the Umzinto catchments with changing land cover based on *ACRU* model simulations. Specifically the impact of natural grassland, sugarcane and commercial timber on water yield is compared.

Part 4 provides conclusions and recommendations from the research.

2. CATCHMENT DESCRIPTIONS

2.1 La Mercy Catchments

The La Mercy catchments cover some 18 hectares of sugarcane land, north of the Umdloti River (Figure 2.1.1). The project was initiated in 1977 to provide information on the impact of sugarcane management practices on hydrological response. This information is important for the effective and economic design of water control structures (dams, waterways and terraces).

2.1.1 Topography and Soils

The topography and soil characteristics of the four catchments at La Mercy are typical of those found in many sugarcane growing areas of the Natal Coast. Catchment area ranges from 2.7 ha to 6.6 ha and average slopes from 12% to 29% as indicated in Table 2.1.1 and Figure 2.1.2. Figure 2.1.3 illustrates soil characteristics and typical properties of the major soil types. Soils are dominated by the Dolerite derived Arcadia Form and Middle Ecca derived Swartland Form. Soil type distributions are given in Table 2.1.2.

Table 2.1.1:Area and slope details of La Mercy catchments

	101	102	103	104
Area (ha)	2.7	4.7	4.4	6.6
Slope (%)	29	21	12	17
Altitude	75	75	90	80

Table 2.1.2 : Soil type distributions in each catchment

Soil Form	Soil Series	Soil Code	% Area per Catchment			
			101	102	103	104
Hutton	Clansthal	Hu24	0	0	0	10
Arcadia	Rydalvale	Ar30	71	97	98	37
Swartland	Swartland	Sw31	29	3	2	53

2.1.2 Land Use

Table 2.1.3 summarises the land use and management practices in the La Mercy catchments. Up to September 1984 (January 1986 in the case of catchment 104) catchments were maintained in a bare fallow condition (ie no crop cover). Thereafter various agronomic practices were planned and different field layouts and management practices implemented (see Figure 2.1.4).

Table 2.1.3 : Land use and catchment management practices

Practice	Catchment			
	101	102	103	104
Period of fallow	<Sept 1984	<Sept 1984	<Sept 1984	<Jan 1986
Method of planting	Minimum tillage	Conventional tillage	Conventional tillage	Conventional tillage
Method of harvesting	Strip	No strip	No Strip	Strip
Structures	Spillover roads	Water conveying structures	No structures	Water conveying structures
Waterways	Yes	Yes	No	Yes

A description of the land management practices is given below:

Catchment 101: The conservation layout is made up of spillover roads and a flat based waterway. The spillover roads are constructed at a gradient of 1:150, and a vertical interval of 9 metres. Alternative panels are harvested and the minimum tillage system of replanting has been introduced. Cane is burnt before harvesting.

Catchment 102: The conventional system of conservation layout is used, i.e. water carrying terraces at a gradient of 1:150 discharging into a grassed waterway. Cane is burnt before harvesting and cane ploughed out when replanting. No strip cropping or minimum tillage is practiced.

Catchment 103: No structures have been implemented. Sugarcane is planted over the entire area including the natural depression which would normally require a waterway. Cane is burnt before harvesting and ploughed out before replanting. No strip cropping or minimum tillage is practiced.

Catchment 104: The conventional system of conservation works has been used, similar to that of catchment 102, except that there are diagonal roads in the catchment. Two panel are left bare fallow while the remaining were planted to cane. Cane is burnt before harvesting.

2.1.3 Hydrological Instrumentation and Data Collection

Measuring equipment at the catchments is described below.

(i) Rainfall and met data

A clock driven autographic recorder chart is sited centrally between catchments 102 and 103. A standard rain-gauge is located at each flume as well as at the autographic recorder. Autographic rainfall data have been digitised at Natal University for the period 1978 to 1990. Daily rainfall totals as well as selected event hyetographs have been extracted manually from rainfall charts since 1990.

Daily temperature and A Pan evaporation data are available from a meteorological station at Mount Edgecombe some 12 km from the catchments.

(ii) Runoff

Discharge is measured at each catchment through H flumes with a maximum rating of 2.4 m^3s^{-1}. A pressure bladder connected to a clock driven recorder chart records water depth in the stilling well.

Hydrograph co-ordinates are extracted by hand from autographic runoff charts at break points on the trace and input to spread sheet files where discharge is computed from the rating table. Data is stored as an event runoff file as well as daily runoff total.

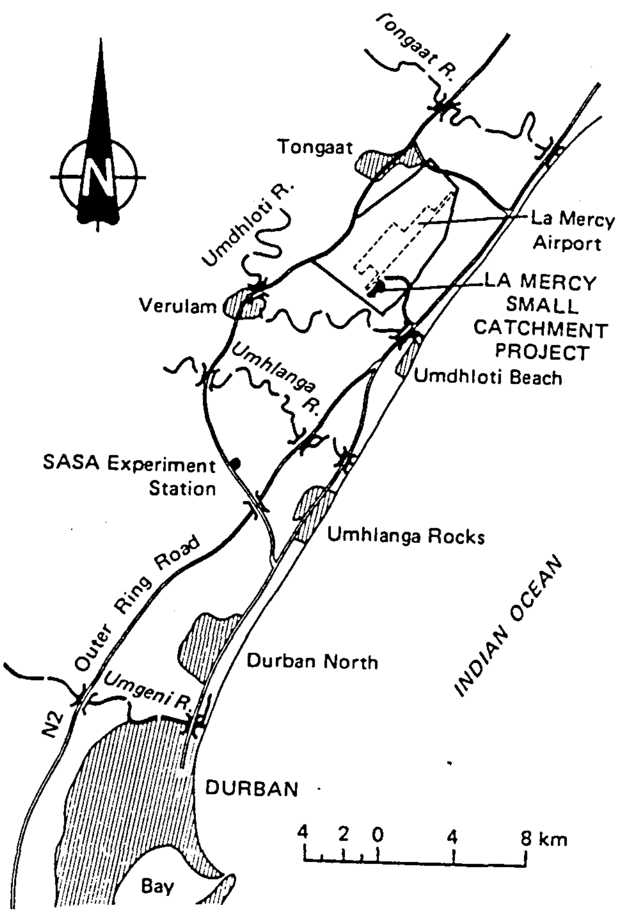


Figure 2.1.1 : Location of La Mercy catchments

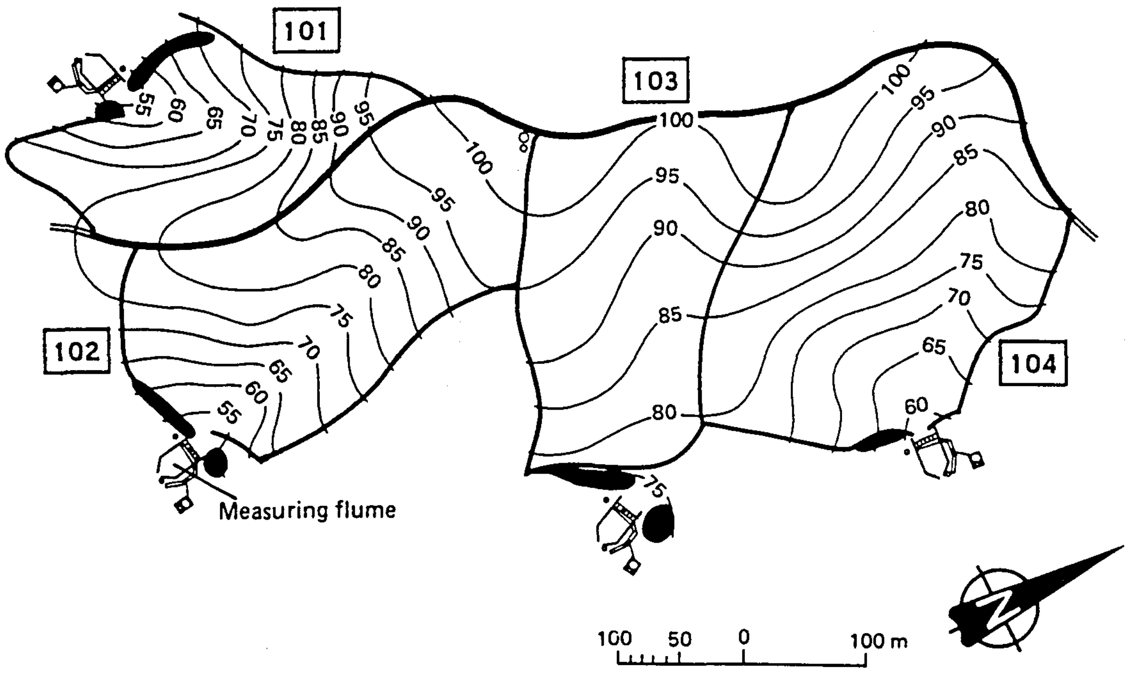
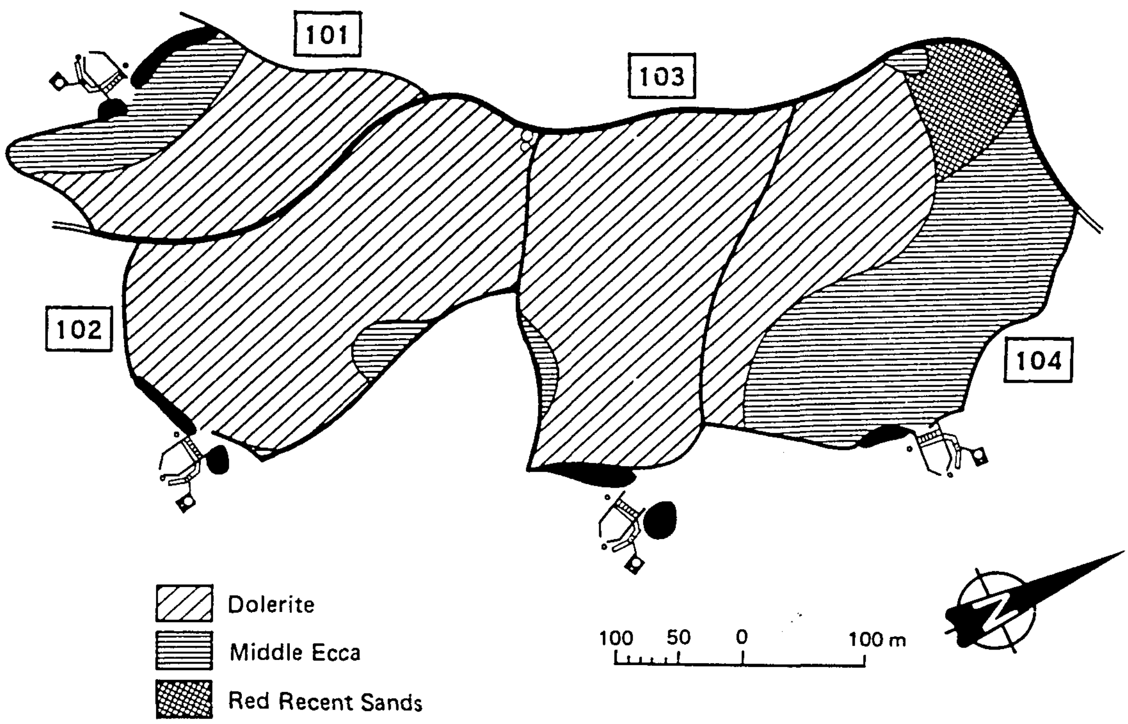


Figure 2.1.2 : Catchment topography



Properties of the three major soil forms

Parent material	Soil form	% clay	% silt	% sand	% OM	Structure	Area (ha)
Recent Sand	Hutton	9	4	87	1	fine granular	0,6
Dolerite	Arcadia	49	18	32	4	blocky vertic	13,0
Middle Ecca sediments	Swartland	46	18	35	3	blocky	4,5

Figure 2.1.3 : Soil characteristics of La Mercy catchments

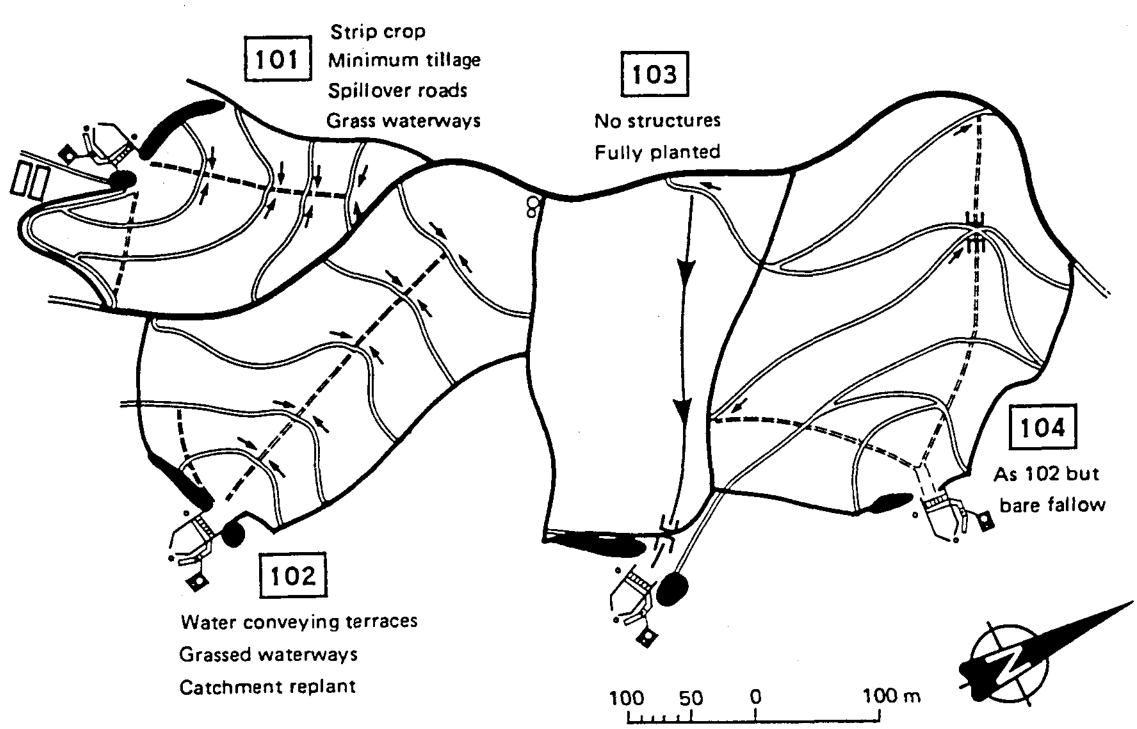


Figure 2.1.4 : Conservation and management practices

(iii) Soil Loss and Water Quality

A splitter arrangement is used to take water samples to determine soil loss. A 5% sample is removed at the entrance to the flume and thereafter another 5% is removed before deposition into a 4001 settling tank. Any overflow is directed onto a Coshocton Wheel extracting a further 1% sample into a 200 l tank. After each storm accumulated sediment loads are determined and noted. Water samples are also used to determine concentrations of selected water quality determinands.

2.2 Umzinto Catchments

The Umzinto catchments covering approximately 140 ha are located inland of Scottburgh some 70km south of Durban (Figure 2.2.1). Catchment monitoring was initiated in 1992 to measure the effects of different land covers (grassland, trees and sugarcane) and management practices on catchment hydrology.

2.2.1 Topography and Soils

The catchments are located on steep land with slopes ranging from 23% to 40%. Catchment areas vary from 11.5 ha to 25.8 ha (see Table 2.2.1). Figure 2.2.2 indicates soil distributions which are summarised in Table 2.2.2. Soils are dominated by the Glenrosa and Mispah Forms.

Table 2.2.1: Catchment area and slope

Catchment	1	2	3	4	5	6	7	8
Area (ha)	14.8	11.9	20.2	25.8	16.8	22.7	11.5	11.9
Slope %	40	36	39	32	31	23	31	31

Table 2.2.2: Soil type distributions in each catchment

Catchment No	Soil Form	%	Runoff Potential	Typical Texture Class	Erosion Hazard Rating
1	Glenrosa	100	Mod/low	SaLm	Mod
2	Glenrosa	70	Mod/low	SaLm	Mod
	Oakleaf	30	Mod/low	LmSa	High
3	Glenrosa	90	Mod/Low	SaLm	Mod
	Oakleaf	10	Mod/Low	LmSa	High
4	Glenrosa	85	Mod/Low	SaLm	Mod
	Oakleaf	15	Mod/Low	LmSa	High
5	Mispah	60	Mod/High	SaClLm	Mod
	Glenrosa	40	Mod/Low	SaLm	Mod
6	Mispah	65	Mod/High	SaClLm	Mod
	Nomanci	35	Mod/Low	SaClLm	Low
7	Glenrosa	100	Mod/Low	SaLm	Mod
8	Glenrosa	50	Mod/Low	SaLm	Mod
	Clovelly	10	Mod/Low	SaLm	High
	Valsrivier	40	Mod/High	SaClLm	High

2.2.2 Land Use

Figure 2.2.3 identifies the transition in cover over the period of catchment monitoring which is summarised below:

Catchment 1 and 2 represent a change in cover from eucalyptus to sugarcane. Different conservation practices were implemented in each catchment, (i.e. keyline - catchment 1 and conventional systems - catchment 2).

Catchment 8 also represents a change from eucalyptus to sugarcane, but after a fire in June 1992 stumps were treated and left until planting of cane in March 1994.

Catchment 3, 4 and 7 represent continuous gum cultivation. Terracing of catchment 3 for cane was not undertaken as intended owing to budget constraints. Continuos cutback of ratooning saplings took place subsequent to felling in January 1994. Trees in catchment 4 were felled in May 1994 and have subsequently ratooned. Owing to the drought there was an estimated 40% loss in timber. Trees in catchment 7 were felled after a fire in June 1992.

Catchment 6 has 100% grassland cover and **Catchment 5** has 60% grassland and 40% trees.

2.2.3 Hydrological Instrumentation and Data Collection

(i) Rainfall and met data

An automatic weather station was installed in 1993 to collect rainfall and other meteorological data at the site. Long term rainfall and evaporation records are available at the Esperanza site (Weather Bureau No 0211140) located some 10 km from the catchment.

(ii) Runoff and soil loss

Discharge was measured at each catchment through V-notch weirs. A float and cable was linked to a potentiometer and data logger (Campbell BDR 320). Pump samples (ISCO 2900 series) were triggered at incremental stage height to assess water quality.

Figure 2.2.3 indicates dates of recorded storms. A combination of severe drought conditions, instrumentation problems and vandalism resulted in little useable data being collected over the period 1993 to April 1995 when monitoring was curtailed owing to continuous vandalism.

Dates and details of recorded events are given in Figure 2.2.3 and Table 2.2.3

2.3 Runoff Plots

Runoff plots have been established at five sites in the industry. The sites, covering a range of soil type and topography were established primarily to determine soil erodibility indices and crop cover factors for use in the Universal Soil Loss Equation. The plots were established in 1977 and kept bare fallow until 1983, whereafter various management practices were monitored. The sites are located on the Natal North Coast as indicated below:

Table 2.2.3: Data base of recorded events at Umzinto

Storm date	File name	Rainfall (mm)	Peak discharge (l/s	Disk No.
23/9/93	MZ06S01	158	15.0	1
5/10/93	MZ06S02	88	22.4	1
3/12/93	MZ04S03	167	154.4	1
3/12/93	MZ05S03	167	63.0	1
3/12/93	MZ06S03	167	113.7	1
3/12/93	MZ08S03	167	42.8	1
27/12/93	MZ01S04	64	13.4	1
27/12/93	MZ02S04	64	48.7	1
27/12/93	MZ04S04	101	25.8	2
27/12/93	MZ06S04	101	30.0	2
9/3/94	MZ01S05	56	26.6	3
7/3/94	MZ02S05	106	62.7	3
7/3/94	MZ04S05	106	2.0	3
7/3/94	MZ06S05	106	93.0	5
26/12/94	MZ06S06	66	13.5	3
17/1/95	MZ02S07	40	31.0	2
15/1/95	MZ04S07	95	11.0	4
15/1/95	MZ06S07	95	9.4	4
23/3/95	MZ02S08	111	9.3	3
24/3/95	MZ04S08	117	7.0	4
9/4/95	MZ02S09	129	3.9	4

File name code:

MZ	Umzinto
06	Weir 6
S01	Storm 1

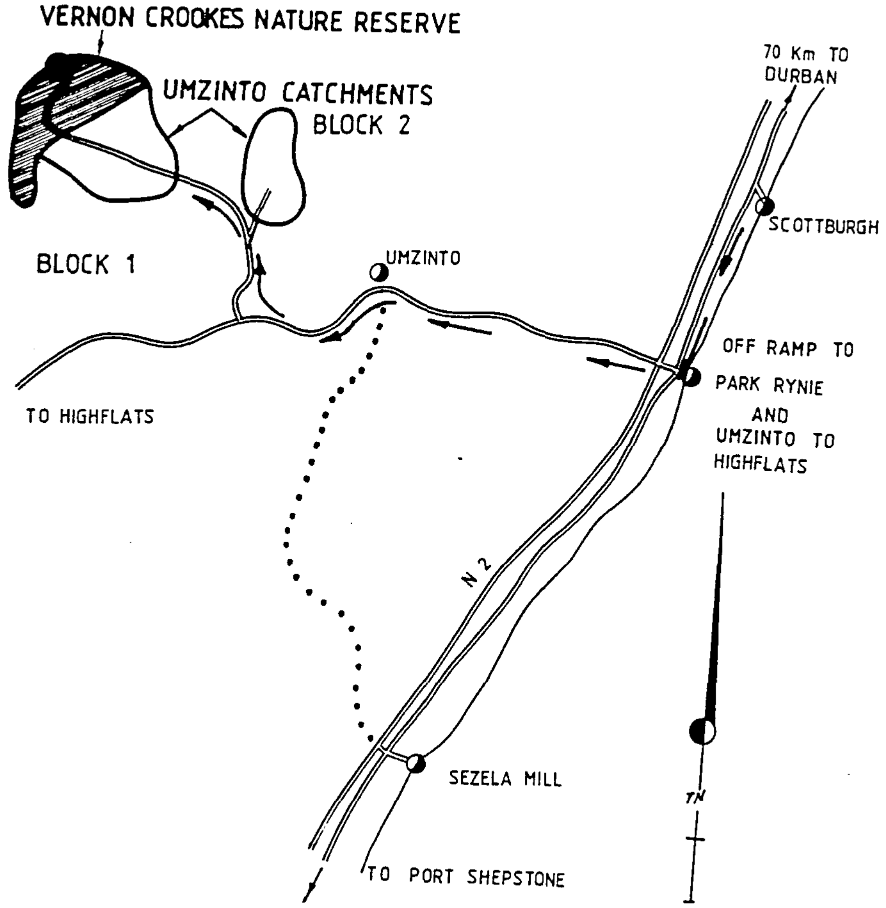


Figure 2.2.1 : Location of Umzinto catchments

Table 2.3.1: Position of runoff plots

Site	Lat (° ')	Long (° ')	MAP (mm)	MAE (mm)
Mt Edgecombe	29 42	31 02	995	1544
CFS	29 43	31 03	995	1544
La Mercy	29 37	31 05	1005	1645
Shakaskraal	29 27	31 12	983	1598
Mtunzini	28 56	31 42	1285	2037

2.3.1 Topography and Soils

Details of the soils and slopes of the 5 sites are given in Figure 2.3.1 below.

2.3.2 Land Use

Each site comprises two plots of the standard USLE size (22 m by 3.6 m). Various crop management practices have been monitored on the plots including bare fallow conditions, conventional versus minimum tillage planting and different crop and trash cover conditions.

The first phase of the project (1977 to 1983) recorded water and sediment yield from bare fallow conditions. Thereafter the impact of crop and trash cover was monitored.

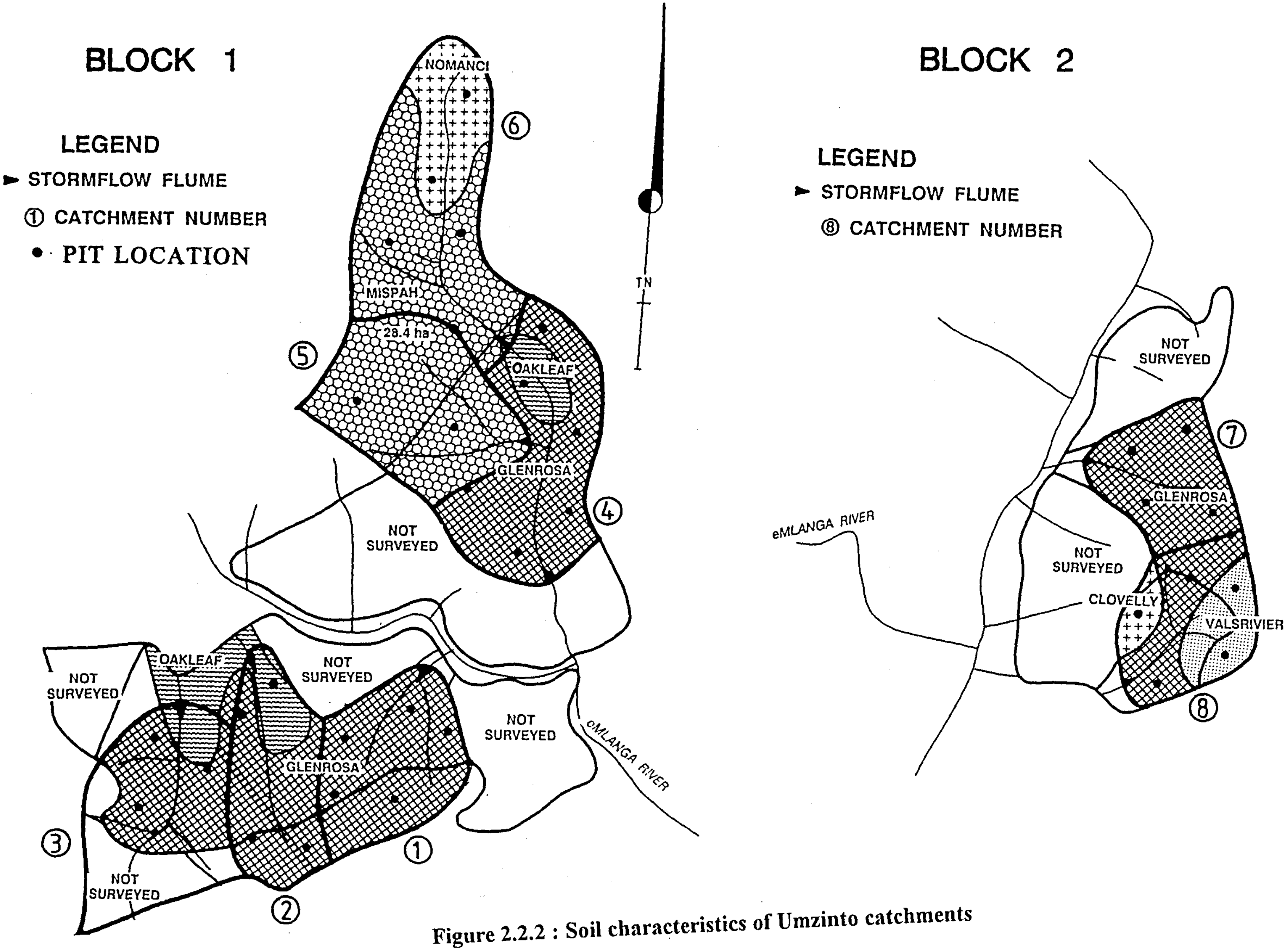


Figure 2.2.2 : Soil characteristics of Umzinto catchments

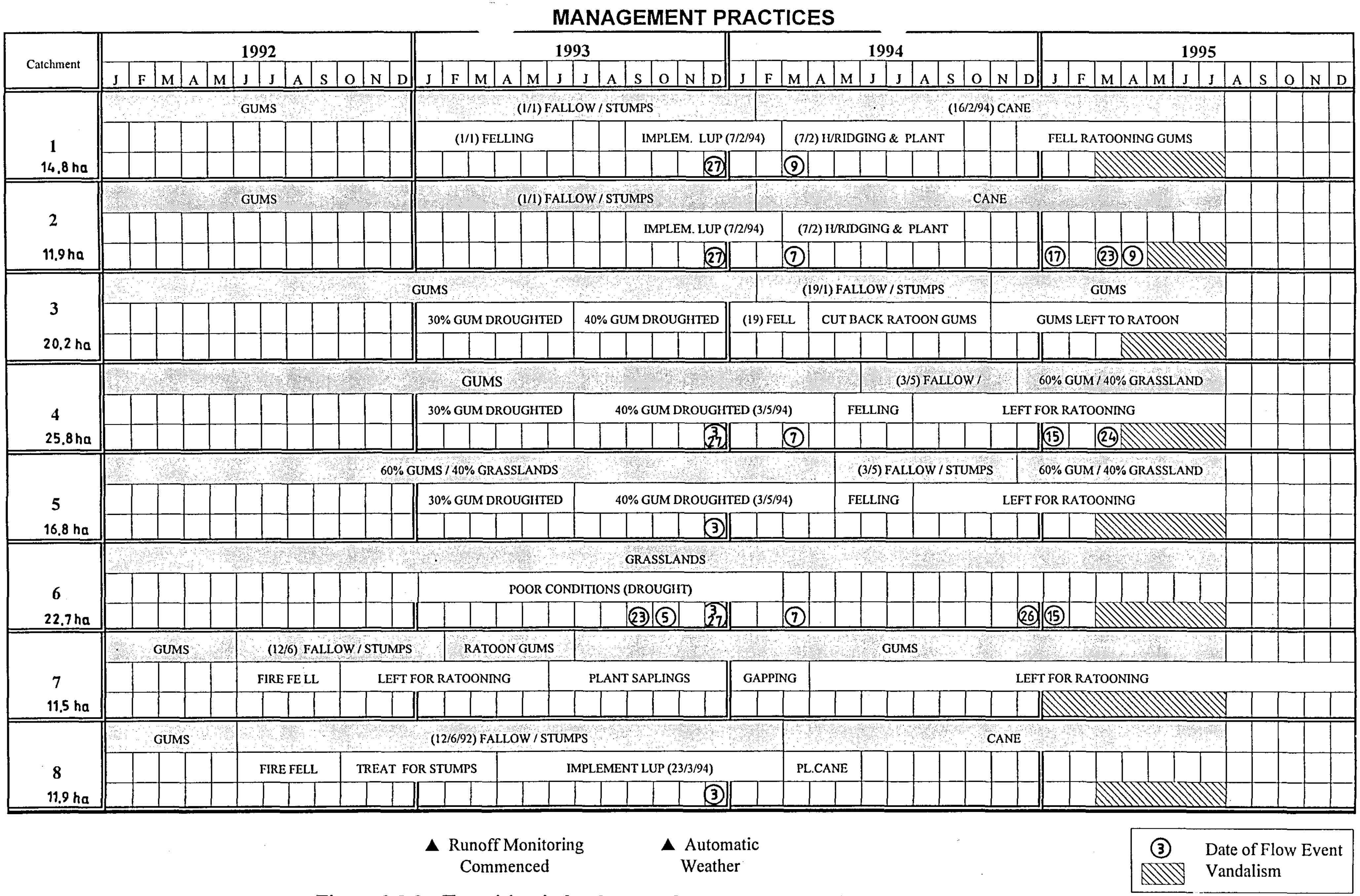


Figure 2.2.3 : Transition in land use and management during period of monitoring

2.3.3 Instrumentation and Data

Sampling equipment comprises a Coshocton wheel sampler taking a 2% sample. Daily rainfall is measured at each site. Runoff and soil loss are measured at each plot following a runoff event.

3. REVIEW OF PAST RESEARCH

The focus of SASEX's catchment experiments has been to measure soil and water losses from sugarcane fields. In particular the impacts of various crop and conservation management practices on hydrological response have been sought. Monitoring has focused on both small catchments and runoff plots as described in Section 2. Platford (1979) outlined the philosophy behind the monitoring programme and how the Universal Soil Loss Equation (USLE) provides a useful framework of the factors which SASEX sought to quantify in order to provide guidelines for conservation management in the sugar industry, these include:

- Tolerable soil loss levels (A)
- Rrainfall erosivity (R)
- Soil Erodibility (K)
- Topographic Effect (LS)
- Crop Management Practice (C)
- Conservation Support Practices (P)

Tolerable levels of soil loss were derived for the major soil types in the industry based on texture analyses and depth criteria (Platford, 1979) and ranged between 5 $t.ha^{-1}.an^{-1}$ and 23 $t.ha^{-1}.an^{-1}$.

An industry-wide map of the potential of rainfall to cause erosion (rainfall erosivity) was also compiled based on annual rainfall energy, derived from long term rainfall records in the industry (Platford, 1979).

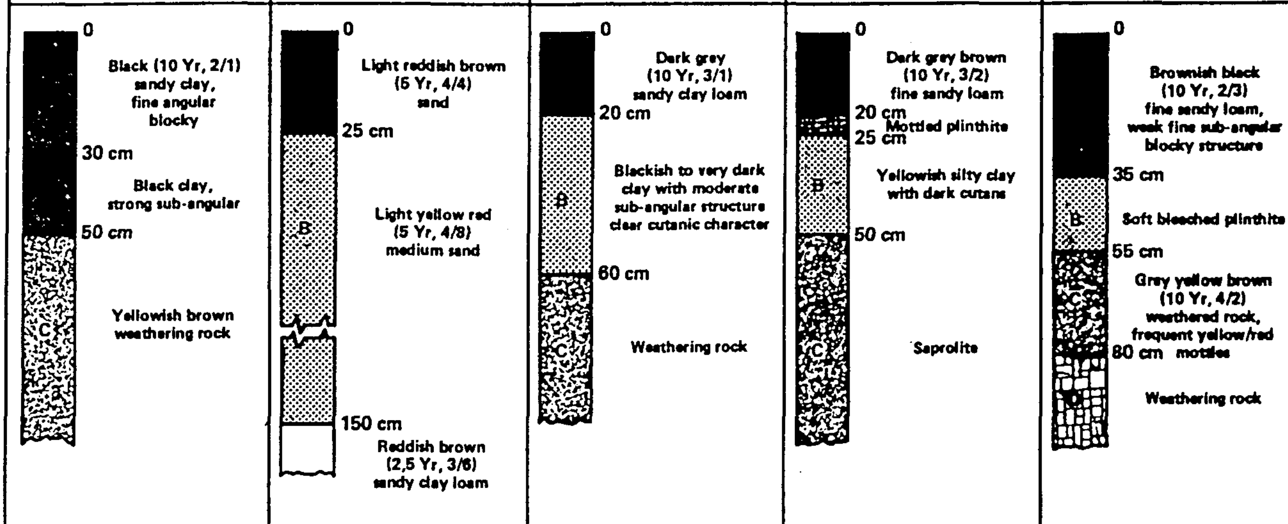
3.1 Runoff Plots

Runoff plot experiments were used to measure soil erodibility (K) in the absence of any crop cover (ie bare fallow conditions), as well as the role the sugarcane crop and various management practices play in reducing erosion.

Rainfall simulator plots were also used to accelerate the rate of data accumulation (Platford, 1982). The rainfall simulator applied two storms of 1 hour duration and approximately 63 $mm.hr^{-1}$ intensity on consecutive days to runoff plots under bare fallow conditions. The simulator trials allowed measurement of relative soil and water losses from different soil types, slope conditions as well as determination of soil erodibility (K). Table 3.1.1 summarises measured soil and water losses for a range of soils under bare fallow conditions during the second storm (i.e. wet soil conditions).

Run-off Plots — Soils

PLOT 1 Mount Edgecombe	PLOT 2 CFS	PLOT 3 La Mercy	PLOT 4 Shakaskraal	PLOT 5 Mtunzini



	PLOT 1	PLOT 2	PLOT 3	PLOT 4	PLOT 5
Parent material	DOLERITE	RECENT SANDS	MIDDLE ECCA SEDIMENTS	DWYKA TILLITE	MIDDLE ECCA SANDSTONE
Soil form	ARCADIA	HUTTON	SWARTLAND	LONGLANDS	LONGLANDS
Soil series	RYDALVALE	CLANSTHAL	SWARTLAND	WALDENE	WALDENE
Slope	16%	16%	35%	24%	9%

Run-off Plots — Grading analyses

PER CENT / LOCATION	CLAY <0,0002 mm	SILT 0,002 to 0,02 mm	FINE SAND 0,02 to 0,2 mm	MEDIUM SAND 0,2 to 0,5 mm	COARSE SAND 0,5 to 2,0 mm	NOMOGRAPH: SILT & V.F.SAND 0,002 to 0,10	NOMOGRAPH: SAND 0,1 to 2,0	NOMOGRAPH: O.M. %	NOMOGRAPH: Structure	NOMOGRAPH: Perm.	NOMOGRAPH: Approximate K value
PLOT 1 MOUNT EDGECOMBE	32	13	41	11	3	36	32	3–4	Fine granular to medium coarse	Moderate to slow	0,05
PLOT 2 CFS	9	4	61	25	1	32	58	0–1	Fine granular	Rapid	0,16
PLOT 3 LA MERCY	46	18	26	5	5	38	14	2–3	Granular	Slow to moderate	0,18
PLOT 4 SHAKASKRAAL	23	12	44	14	7	43	34	0–1	Fine granular	Slow	0,29
PLOT 5 MTUNZINI	18	10	56	14	3	46	36	1–2	Fine granular	Slow	0,29

Figure 2.3.1 : Soil and slope characteristics of runoff plots

Table 3.1.1 : Measured soil and water losses from 7 sites under bare fallow conditions (after Platford, 1982).

Soil Series	Slope %	Soil Loss ($t.ha^{-1}$)	Runoff (%)	Final Infiltration Rate ($mm.h^{-1}$)
Cartref	9.0	30.0	87	9
Waldene	7.0	24.0	82	11
Kroonstad	3.5	1.5	37	30
Clansthal	12.0	3.5	47	35
Clansthal	3.5	1.5	31	44
Bonheim	7.5	1.0	40	9
Fernwood	3.0	0	0	63

The greatest soil loss, 30 $t.ha^{-1}$ was recorded for the Cartref series soil (0.6 cm deep) where 87% runoff was recorded with a final infiltration rate of 9 $mm.h^{-1}$. The tests on the Fernwood Series (>200 cm sand) produced no runoff. The influence of soil type on hydrological response is clear. The impact of slope can be seen in the two Clansthal tests where the steeper plot produced significantly greater runoff and soil loss.

Similar trials were undertaken to look at soil erosion following planting of the crop using full tillage versus minimum tillage methods (Haywood and Mitchell, 1987). Full tillage included mechanical removal of the old stool followed by seed bed preparation with a rotary hoe. Minimum tillage comprised chemical kill of the old crop and manual planting in the interrow leaving the old cane row undisturbed.

Figure 3.1.1 illustrates the runoff percentage and soil loss for both the first and second storms for 8 trial sites. The average reduction in soil loss due to minimum tillage was 60% and reduction in runoff 34%. The two main elements of the erosion process are soil detachment and transportation

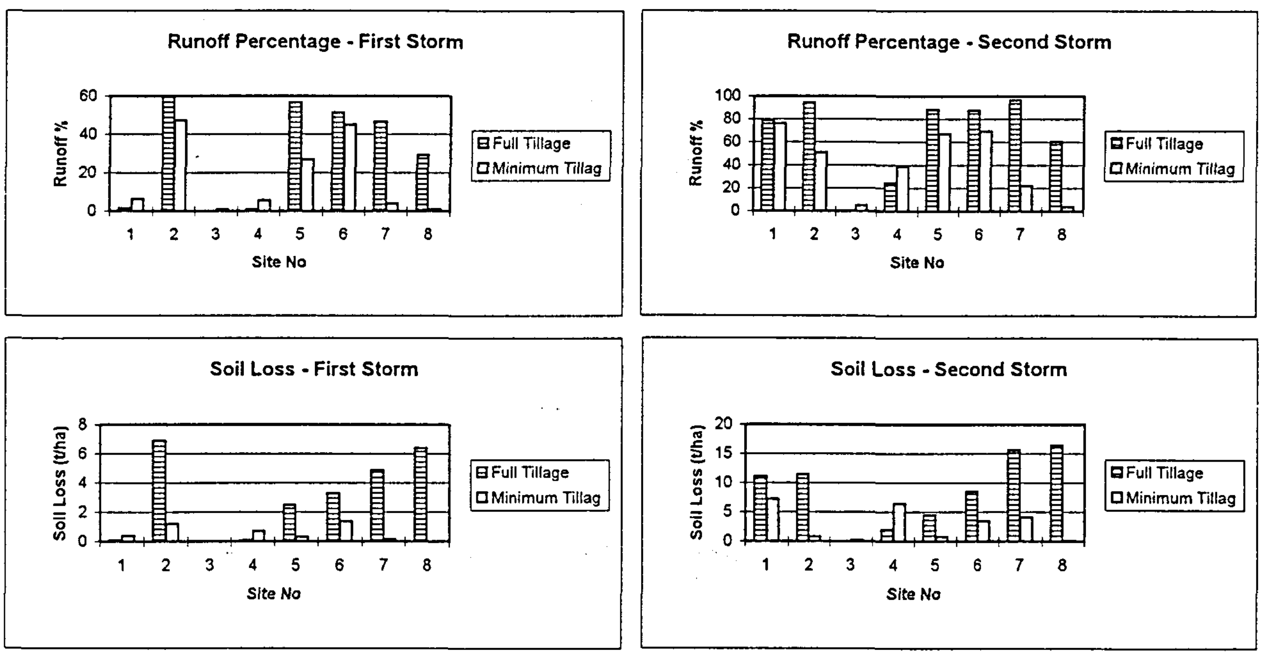


Figure 3.1.1 : Runoff and soil loss from simulator plots

by runoff. The role of minimum tillage in increasing infiltration to reduce runoff and limiting soil detachment through increased residue cover is evident. As expected higher runoff and soil loss was recorded for the second storm (ie on the wet soil profile).Two instances (sites 3 and 4) where higher runoff and soil loss were recorded under minimum tillage conditions for both storms were noted. This was ascribed to poor residue cover under minimum tillage and bands of compacted soil along cane rows where infiltration rates were low.

Standard USLE runoff plots monitored by SASA have been described in section 2.3 of the report. Graphs of annual rainfall and accumulated runoff and soil loss for the period 1983 to 1995 (period of sugarcane production) are indicated in Figure 3.1.2. Generally there is a close correlation between amount of rainfall and resulting runoff and soil loss. Anomalies exist however such as the high soil loss at Mount Edgecombe in 1993 corresponding with low runoff response. Table 3.1.2 below indicates average annual runoff as a percentage of rainfall and average annual soil loss ($t.ha^{-1}.an^{-1}$) at each site for the period 1983 to 1995.

Table 3.1.2 : Average annual rainfall, runoff response and soil loss from runoff plots under sugarcane

Location	Rainfall	Runoff (%)	Soil Loss ($t.ha^{-1}.an^{-1}$)
Mount Edgecombe	1 049	4	0.2
CFS	1 065	<1	0.7
La Mercy	935	5	1.8
Shakaskraal	922	20	21.1
Mtunzini	1 258	17	4.9

High runoff response and soil loss is found at Shakaskraal and Mtunzini where soils have low permeability and high soil erodibility (Figure 2.3.1). Soil loss under sugarcane is shown to be below tolerable levels at all but one site.

3.2 Research Catchments

The La Mercy research catchments were developed in two phases. Phase 1 (1978 to 1984) aimed to supplement the runoff plot and rainfall simulator data on hydrological response under bare fallow conditions. Phase 2 (1985 onwards) evaluated the impact of different crop management practices and conservation measures on hydrological response. Platford and Thomas (1985) summarise trends in soil loss and runoff from the catchments over the bare fallow period. Table 3.2.1 provides information on average annual runoff and soil loss from the four bare fallow catchments. Annual runoff response as a percentage of rainfall is shown to increase with annual rainfall and ranges from 0% to 20%.

Table 3.2.1 : Average annual rainfall, runoff and soil loss from the four bare fallow catchments

Year	1978	1979	1980	1981	1982	1983	1984
Rainfall (mm)	984	724	816	969	678	833	1214
Runoff (mm)	64	1	93	156	12	29	241
Runoff (%)	6.5	0	11.4	16.1	1.8	3.5	19.8
Soil Loss ($t.ha^{-1}$)	0	0	59	115	6	29	72

details of runoff response for specific events are indicated in Table 3.2.2 which identifies average runoff response from all four catchments for large storms. It is evident when comparing Table 3.2.1 with the totals for each year in Table 3.2.2, that the majority of runoff was a result of a few large storms when runoff as a percentage of rainfall is often well above 20% and up to 85%. The interaction of the many variables which cause or influence runoff from catchments such as rainfall intensity and antecedent moisture condition, results in varied runoff response between storms and makes it difficult to draw precise conclusions on how a catchment will react to rainstorms from trends alone. Use of a hydrological model as discussed in part 3 of this report assists in this regard.

The high annual soil loss during 1980, 1981 and 1984 (see Table 3.2.1) were well in excess of deemed tolerable levels (20 $t.ha^{-1}.an^{-1}$) and corresponded with heavy storm events (Table 3.2.2). The combination of tilled bare conditions and heavy rainfall are the major cause of soil erosion in the sugar industry.

Phase 2 of the catchment experiments (1985 onwards) saw planting of sugarcane in the catchments and implementation of various crop management practices and conservation measures (see section 2.1.2). Table 3.2.3 indicates average annual runoff and soil loss from the four catchments over the period 1985 to 1994.

Table 3.2.2: Daily runoff events from La Mercy catchments (average from 4 catchments)

1978				1980			
Date	Rain(mm)	Runoff(mm)	Runoff %	Date	Rain(mm)	Runoff(mm)	Runoff %
23-Sep	72	9	12.5	07-Sep	328	75	22.9
04-Oct	77	4	5.2	29-Nov	28	9	32.1
11-Oct	68	10	14.7				
18-Oct	14	8	57.1				
18-Nov	103	26	25.2				
21-Nov	29	1	3.4				
25-Nov	10	1	10.0				
28-Nov	12	1	8.3				
TOTAL	385	60	15.6	TOTAL	356	84	23.6

1981				1982			
Date	Rain(mm)	Runoff(mm)	Runoff %	Date	Rain(mm)	Runoff(mm)	Runoff %
31-Jan	102	87	85.3	23-Mar	62	2	3.2
18-Feb	57	28	49.1				
06-May	35	1	2.9				
16-May	39	5	12.8				
30-Aug	118	27	22.9				
10-Sep	43	8	18.6				
TOTAL	394	156	39.6	TOTAL	62	2	3.2

1983				1984			
Date	Rain(mm)	Runoff(mm)	Runoff %	Date	Rain(mm)	Runoff(mm)	Runoff %
14-Jan	37	4	10.8	06-Jan	37	6	16.2
10-Nov	60	7	11.7	12-Jan	64	15	23.4
29-Nov	35	4	11.4	30-Jan	140	69	49.3
17-Dec	64	12	18.8	17-Feb	160	67	41.9
TOTAL	196	27	13.8	TOTAL	401	157	39.2

Table 3.2.3 : Average annual rainfall, runoff and soil loss from the four catchments under sugarcane production

Year	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
Rainfall (mm)	1094	810	1400	1236	1160	882	944	401	849	585
Runoff (mm)	252	18	376	255	286	58	109	3	10	2
Runoff (%)	23.0	2.2	26.9	20.6	24.6	6.6	11.5	0.7	1.1	0.3
Soil Loss ($t.ha^{-1}$)	15.9	0.1	7.8	1.4	3.0	0.5	0.1	0.0	0.4	0.2

Figure 3.2.1 plots data for the combined period of bare fallow and sugarcane cover indicating accumulated runoff and soil loss against year of record. The low runoff recorded in the drought years of 1990 to 1994 is evident. While the runoff trend did not change markedly over the period 1978 to 1990, soil loss shows a significant decline following 1984 when sugarcane was established.

A scatter plot of rainfall versus runoff response for the period of sugarcane cover (Figure 3.2.2) indicates that annual runoff as a percentage of rainfall is less than 5% in dry years (rainfall < 850 mm) but increases up to 25% in wet years (rainfall > 1200 mm).

Maher (1990) compared runoff response between the four catchments for selected events following crop establishment. Catchment 101 is the steepest and smallest catchment. Runoff was initially high under bare fallow conditions but following crop establishment through minimum tillage and strip planting declined the most. Figure 3.2.3 illustrates this trend by plotting accumulated runoff from catchment 101 (full cane cover under minimum tillage) against that for catchments 102 and 103 (full sugarcane cover under conventional tillage).

It can be concluded from examination of trends that crop cover is more important in reducing soil loss than runoff. This trend is highlighted in Figure 3.2.1. Runoff appears to be mostly affected by soil type (infiltration rate), storm intensity and antecedent moisture status. Soil loss is affected mainly by crop cover and management practices which reduces the power of falling raindrops. Maher (1990) concluded from examination of individual events that crop cover and management practices (strip cropping, minimum tillage and retention of trash at harvest) appeared to reduce runoff and soil loss to a greater extent than conservation structures (contour banks and waterways). The role of conservation structures becomes important when the crop cover is removed at harvest and more importantly at replanting.

The results from the catchment and plot experiments have been used to develop standards for the design of conservation measures for a field based on soil, slope and crop management practices such as minimum tillage or strip cropping (Platford, 1987). The standards recognise that 85% to 90% of soil loss occurs when replanting takes place. If soil loss can be limited during this time by retaining surface cover the level of protection required through conservation structures is reduced.

Graphs of annual averages for selected water quality indices are given in Figure 3.2.4 both for individual catchments and as an average from all four catchments. It should be noted the trends are based on few recorded runoff events (typically less than five from each catchment per year). Generally fertilisation practices did not change over the study period and one would expect consistency in between year concentrations. The following trends are evident from the data.

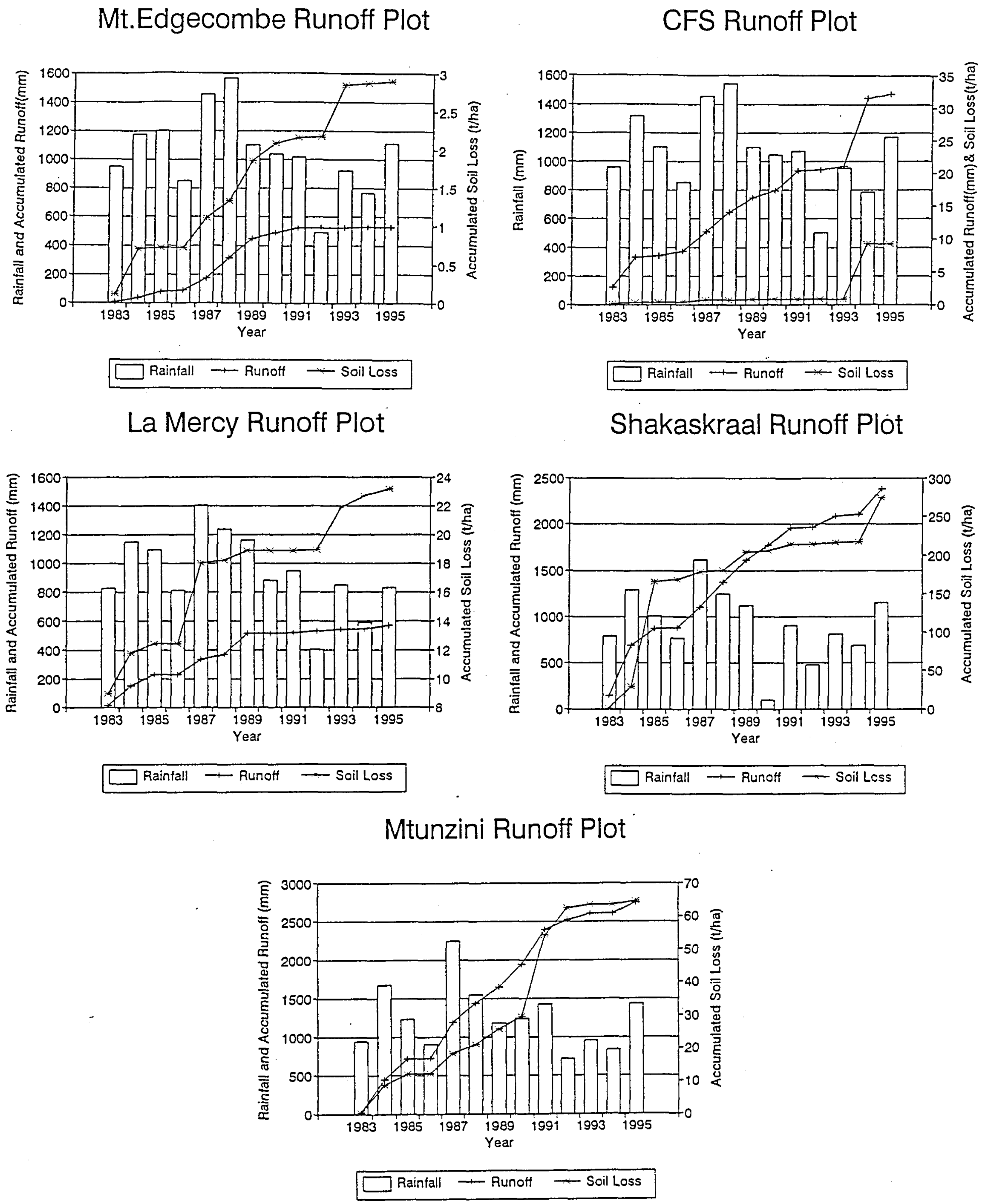


Figure 3.1.2: Annual rainfall and accumulated runoff and soil loss for runoff plots under sugarcane

- pH

The pH levels are similar to those found in major rivers throughout the Sugar Industry where pH typically ranges between 6.7 and 8 (Meyer and Van Antwerpen, 1995). The plot shows a falling pH over the period 1991 to 1994 coinciding with the period of drought. It can be expected that during drought periods considerable amounts of N are mineralised increasing the acidity component of runoff (Meyer, pers com).

- Potassium (K)

The levels of K found in major rivers of Natal (Meyer and Van Antwerpen, 1995) typically vary between .025 and .05 meq.ℓ^{-1}. Levels recorded from the catchments are thus significantly higher than that for large rivers where dilution of agricultural runoff will have occured. It is known that large concentrations of non-exchangeable K are made available following drying out of the soil profile (Schroeder and Wood, 1991) which could explain the increase in K over the drought period.

- Calcium (Ca), Magnesium (Mg) and Sodium (Na)

The levels of Ca found in major rivers of Natal typically vary between 0.2 and 1 meq/l which is similar to that found in the catchment runoff samples. Once again soil mineralisation of nutrients following the drought could explain the spikes recorded in 1993 and 1995.

The annual trends in Mg appear similar to that for Ca. Values of Mg in Natal rivers typically range from 0.4 to 1.5 meq.ℓ^{-1} which is similar to that recorded from the catchments.

Between year variations in Sodium concentration were similar to that for Magnesium. Values of Na in Natal Rivers range from 0.4 to 1.7 meq.ℓ^{-1} which is comparable to levels recorded from the catchments (0.5 to 2.0 meq.ℓ^{-1}).

- Electrical Conductivity (EC) and Sodium Adsorption Ratio (SAR)

EC levels typically ranged between 20 and 40 mS.m^{-1} which is similar to trends from major rivers in Natal (Meyer and Van Antwerpen, 1995). Values of SAR were also comparable to those generally recorded in rivers (1 to 2).

From the above there is no sign of excessive wash-off of nutrients or minerals from the catchments although levels of K were high. The influence of drought years on mineralisation of N, to decrease pH and on making large concentrations of non-exchangeable K available has been illustrated (Meyer pers com). The affect of storm timing relative to date of fertiliser application would also affect individual sample characteristics which have not been addressed in this report.

3.3 Hydrological Modelling

Hydrological models are required to extend trends and relationships to ungauged catchments. Such models must be verified against measured data to demonstrate confidence in their ability to perform in ungauged situations. Haywood and Schulze (1990) used two physical conceptual models, namely the *ACRU* Model (Schulze, 1995) and CREAMS Model (Knisel, 1980) to simulate hydrological response from the La Mercy catchments. The period of simulation was from 1978 to 1989 incorporating the bare fallow period and period under crop. Both models performed well and in a similar manner on catchments 102, 103 and 104. They performed better under sugarcane cover when agronomic practice records were more accurate. Neither model performed well on catchment 101 where management practices included strip cropping and spillover terraces. Thus the models could not account for runoff flowing overland through alternate panels of vegetation with differing densities of cover.

Haywood and Schulze (1991b) reassessed the *ACRU* model on catchment 102 focussing on the models ability to simulate soil moisture status as well as runoff and soil loss. *ACRU* simulated the soil water status well for the topsoil but poorly for the subsoil horizon. Problems in the neutron probe calibration curve as reported by Haywood (1991) were considered to have contributed to the results.

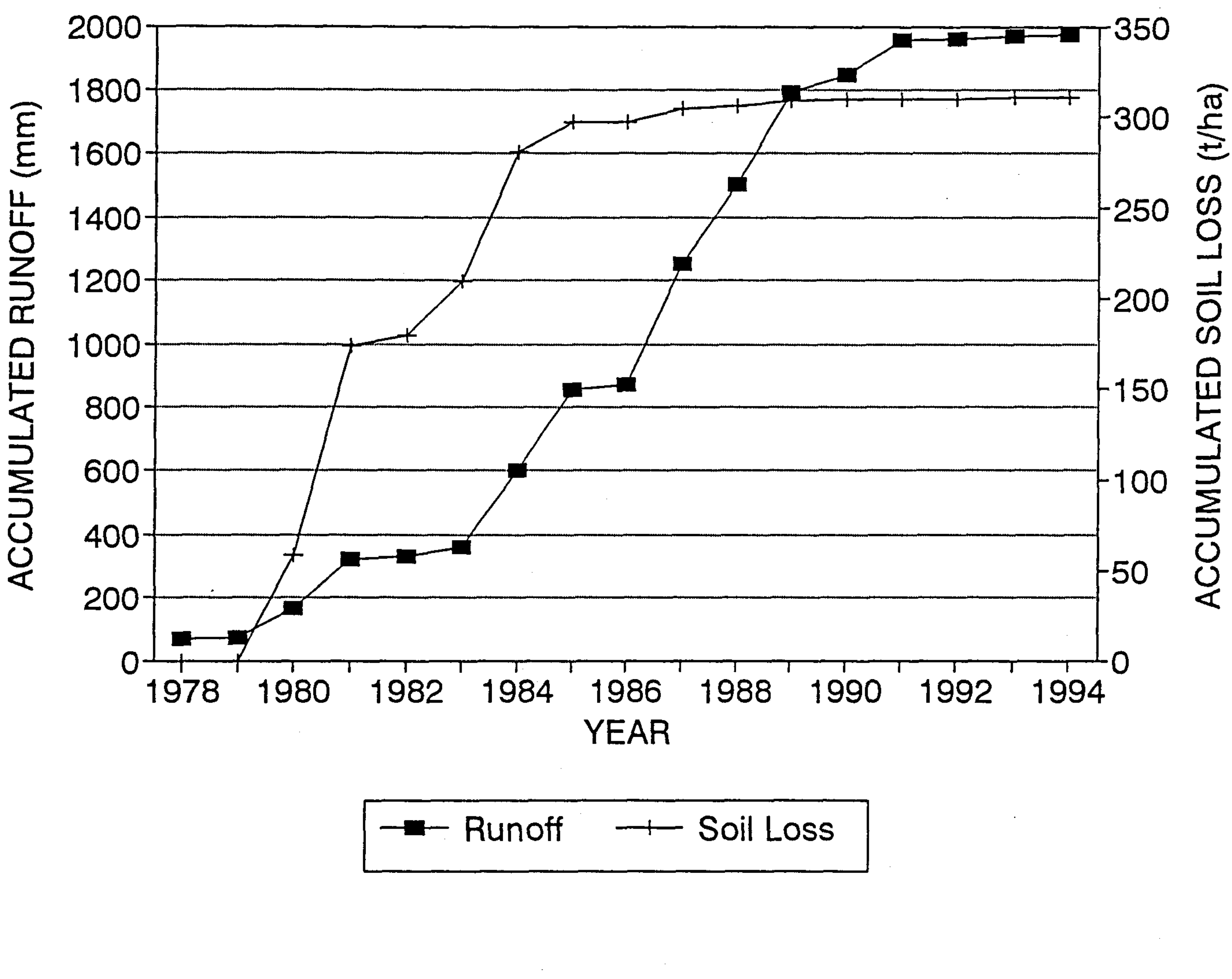


Figure 3.2.1 : Accumulated runoff and soil loss from La Mercy catchments

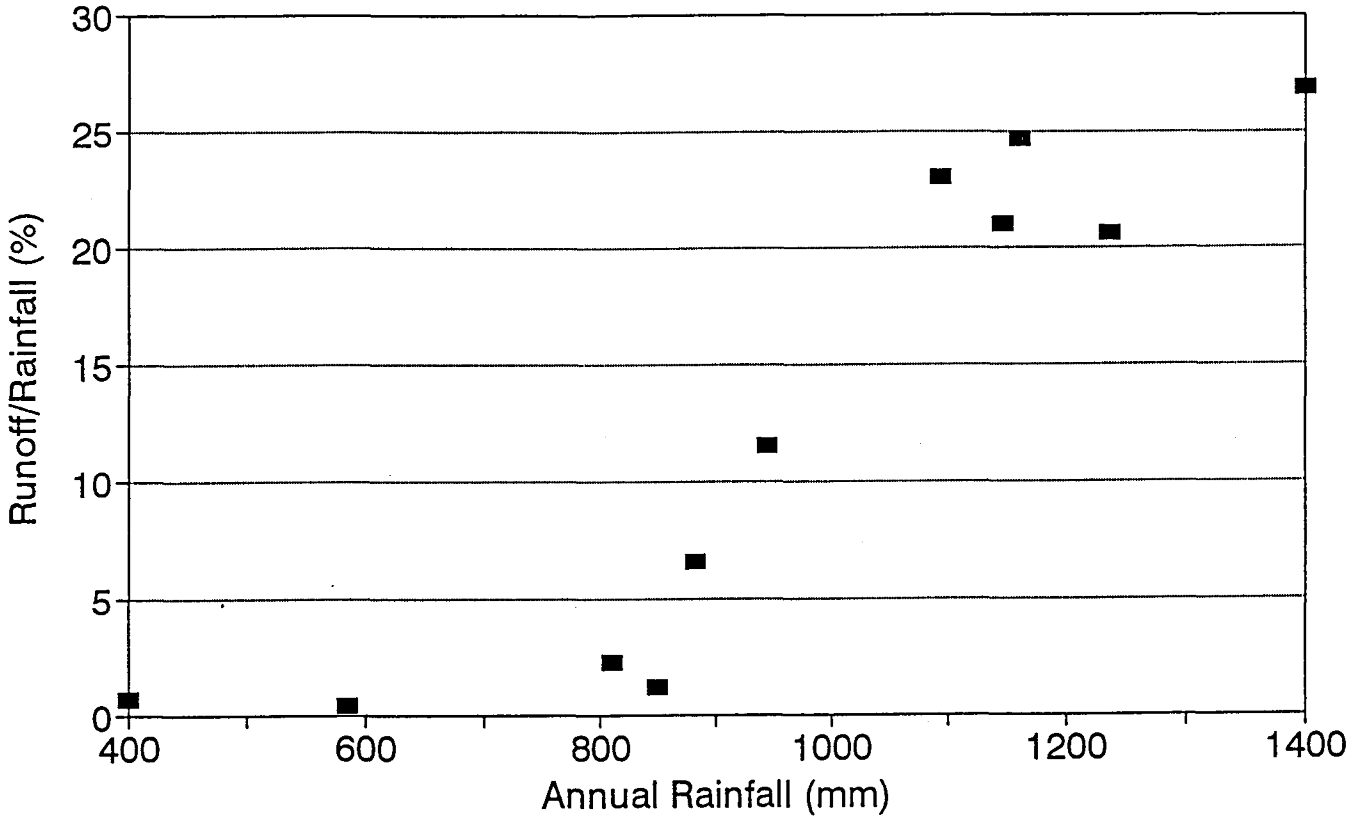


Figure 3.2.2: Scatter plot of runoff response and rainfall for La Mercy catchment under sugarcane

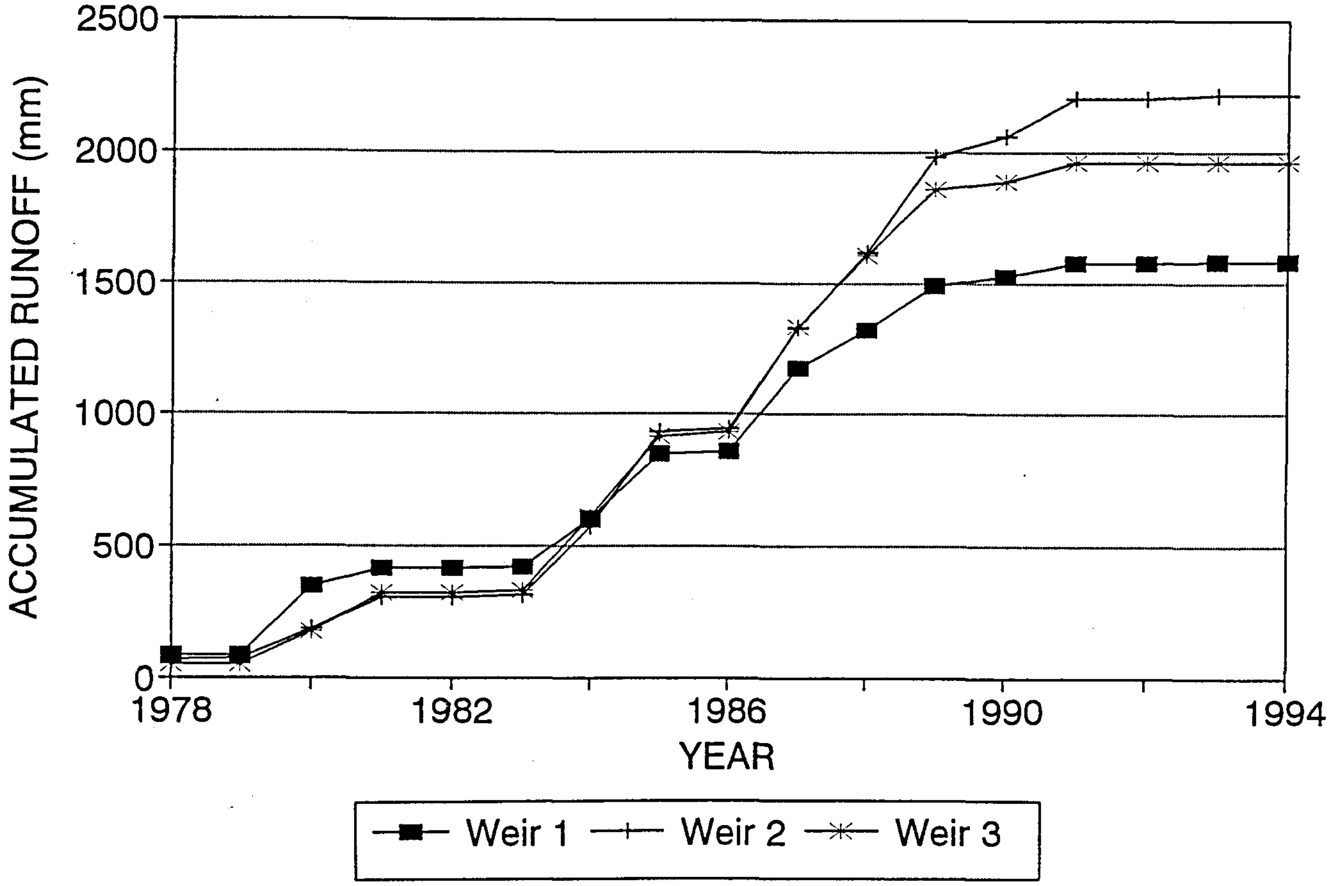


Figure 3.2.3 : Accumulated runoff from individual La Mercy catchments

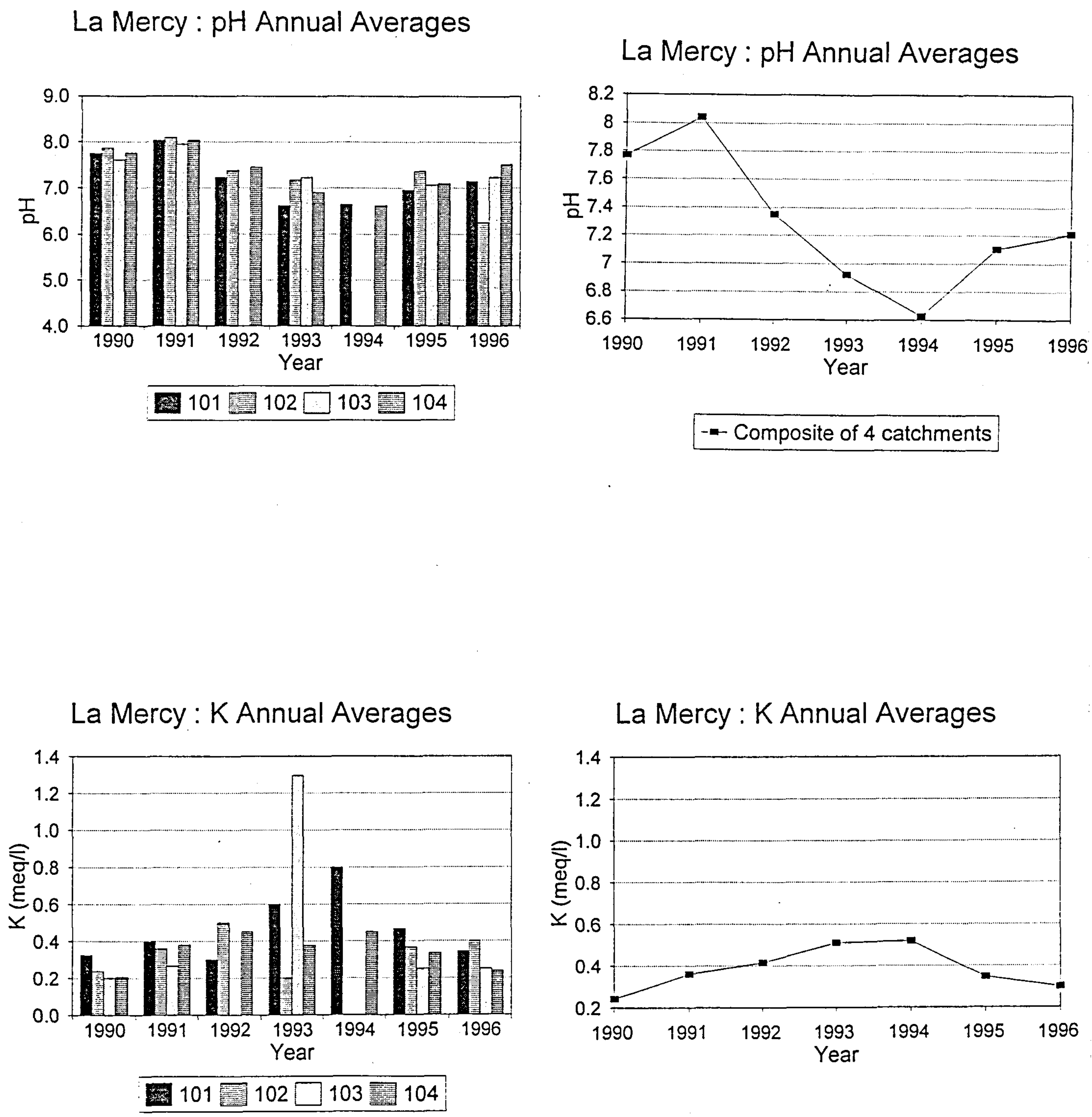
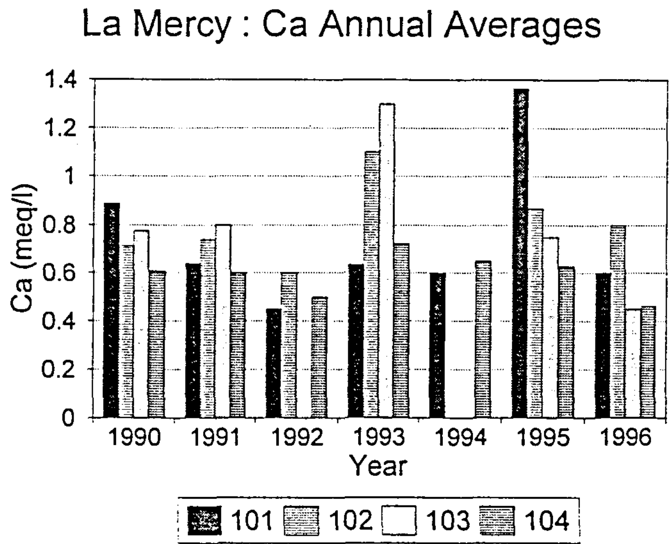
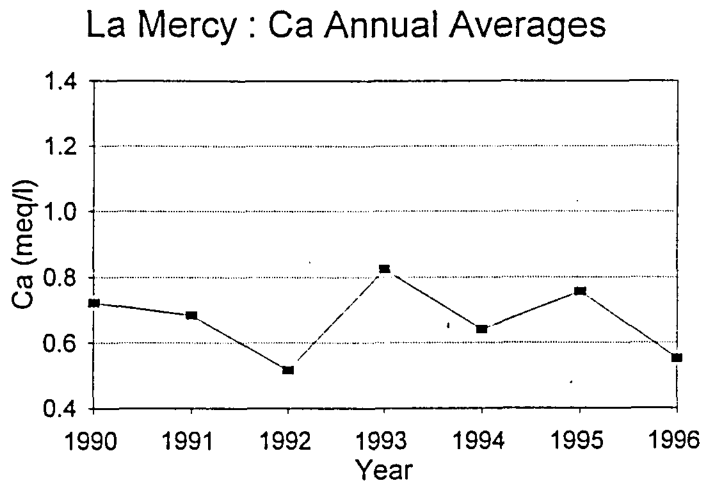
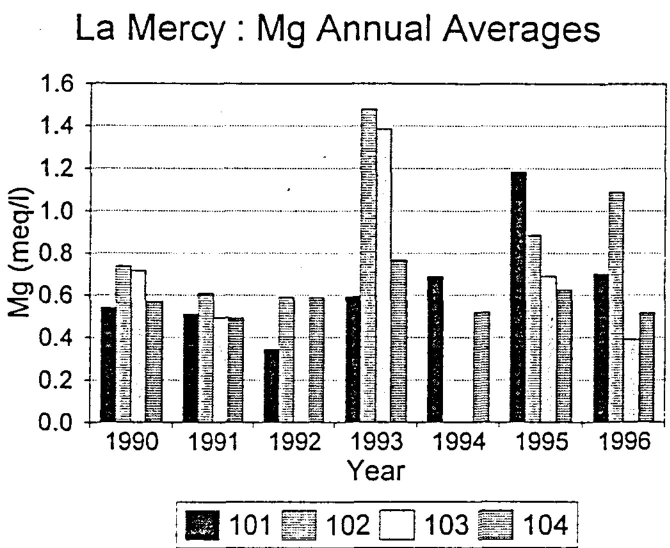


Figure 3.2.4 : Trend lines of water quality characteristics







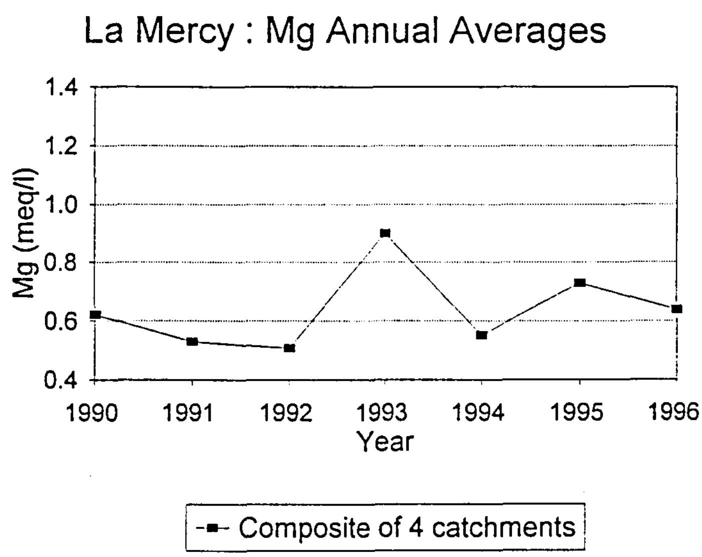
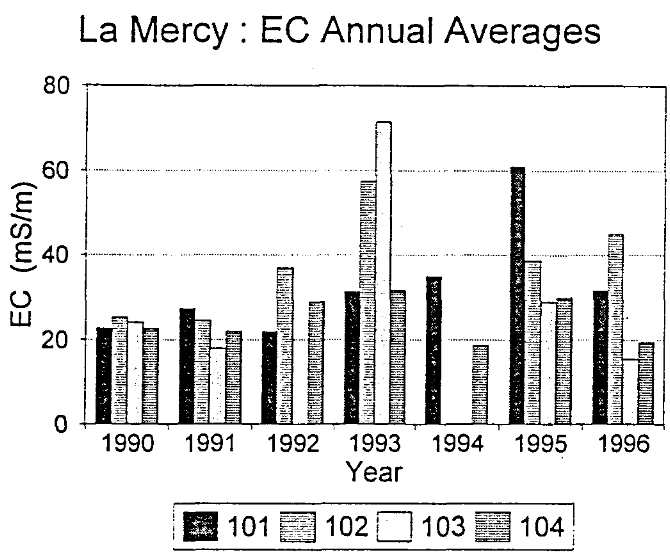
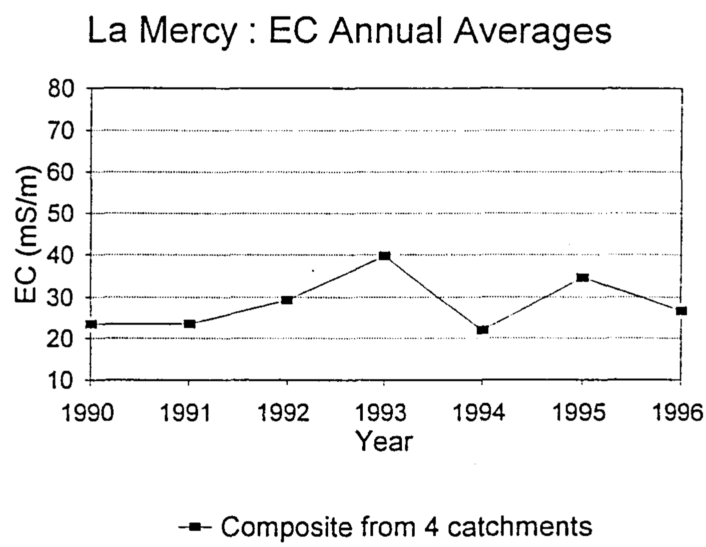
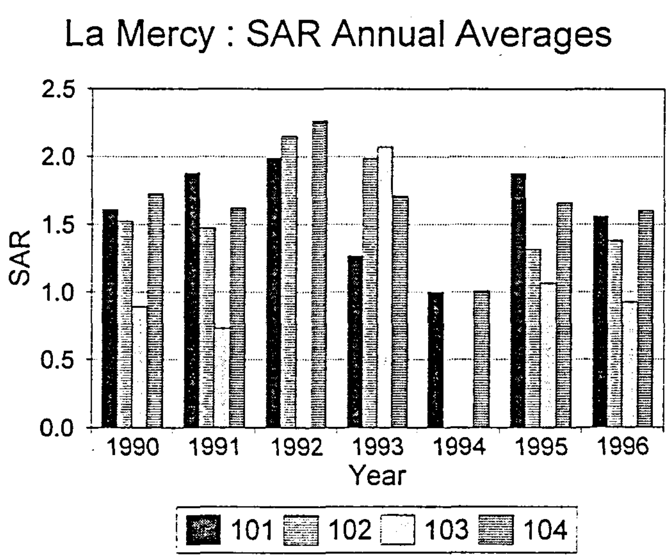


Figure 3.2.4 : Trend lines of water quality characteristics (Continued)







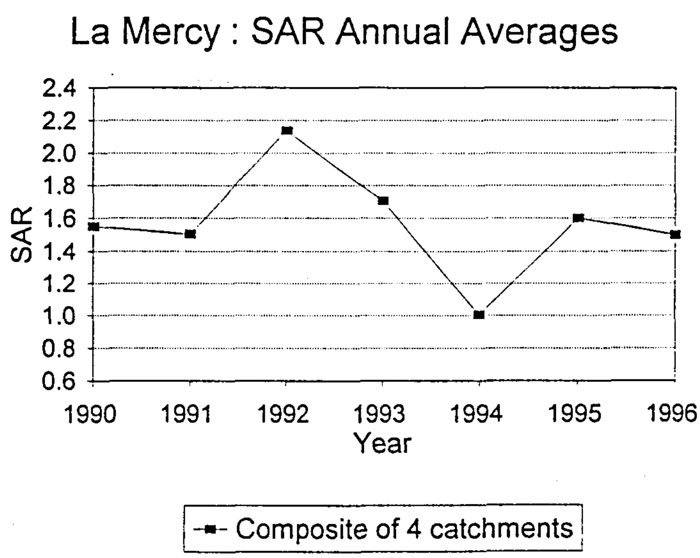


Figure 3.2.4 : Trend lines of water quality characteristics (Continued)

The results presented in Part 2 of this report outline further verification of the *ACRU* model based on data collected up to December 1995. Based on the research, improved decision rules to select input parameters to the *ACRU* model are developed which provide increased confidence in application of the model in an ungauged situation.

The emphasis in all research directed at the La Mercy catchments and runoff plots has been hydrological response in sugarcane catchments. The initiation of the Umzinto research catchments in 1992 aimed to extend this research to steeper catchments and to investigate hydrological response with change in land cover from timber and grassland to sugarcane. Limited data collection at Umzinto did not allow meaningful evaluation of trends or verification the *ACRU* model. The model was however used in scenarios to assess the impact of land cover on hydrology.

PART TWO

SIMULATION OF RUNOFF AND SEDIMENT YIELD FROM CATCHMENTS UNDER SUGARCANE PRODUCTION AT LA MERCY

JC Smithers, P Mathews and RE Schulze

1. INTRODUCTION

A cost effective and efficient method to assess the impact of any crop on water resources is to develop credible simulation models that are able to simulate the runoff response from a catchment and which are sensitive to land cover and soils characteristics. The alternative to modelling is long- term field monitoring experiments, which produce results that are site specific, require long records and are costly to maintain. An added advantage of adopting a modelling strategy to water resource impact assessments is that the modelling process clarifies existing knowledge of a particular physical process and highlights areas that require further investigation.

This section of the report investigates trends and relationships emanating from data from gauged catchments in order to verify and improve the simulation of hydrological responses from catchments under sugarcane production. The *ACRU* model (Schulze, 1995), a physical-conceptual agrohydrological model which has been widely verified, particularly in KwaZulu-Natal, was applied to the La Mercy catchments and daily storm flow volume, peak discharge and hydrograph shape as well as sediment yield simulated by the model were verified against observed data. As a result of the modelling, a SugarCane Decision Support System (SCDSS) was developed for the *ACRU* model which incorporates knowledge gained from the modelling of the hydrology from sugarcane land covers under different management practices. Thus the results from application of the model to ungauged catchments with sugarcane land covers may be used with more confidence.

2. DESCRIPTION OF RUNOFF PLOTS AND CATCHMENTS

A detailed description of the runoff plots and catchments has been given in Part 1, Section 2 of this report. Data were available from runoff plots located at Mount Edgecombe, La Mercy, CFS, Shakaskraal and Mtunzini.

Four Catchments (101, 102, 103 and 104), located at La Mercy, had long record daily rainfall, runoff and soil loss data. The layout of the catchments was depicted in Figure 2.1.2 and catchment information and management practices summarised in Table 2.1.3 of Part 1 of the report.

The following section describes the hydrological data base used in the study.

3. HYDROLOGICAL DATA BASE

3.1 Sources of Data

Daily rainfall data for the period 1978 - 1990 were extracted from the digitised rainfall database stored at the Computing Centre for Water Research (CCWR) for the SAL10 raingauge in the La Mercy catchments. These data had been digitised by the Department of Agricultural Engineering at the University of Natal in the early 1990s from autographically recorded charts from station SAL10. The daily rainfall data were extended to the end of 1995 using data files provided by SASEX for La Mercy. Daily values of observed runoff for the period 1978 - 1995 were also obtained from SASEX data files, which were also the source of daily sediment yield data for the period 1985 - 1995. Daily temperature and A-pan data were obtained for the Experiment Station at Mount Edgecombe for the study period. The relevant data were collated into the correct format required for an *ACRU* composite hydrometeorological data file.

3.2 Data Problems

3.2.1 Climate and runoff data

During the setting up of *ACRU* hydrometeorological files for La Mercy, it became apparent that some of the digitised rainfall data and/or runoff data were erroneous or of suspect quality. For example, it was noted that observed daily runoff values occurred in the absence of any rainfall digitised on the day in question. Problem rainfall data were isolated and checked by comparing the CCWR extracted data with SASEX data files, data from the Mount Edgecombe station and an *ACRU* hydrometeorological file compiled by Haywood (1991). By comparing data from these various sources, obvious problems could be identified and corrected. However, in some cases data problems could not be resolved and data from the SASEX files for La Mercy were then used. A few cases of missing data were encountered, and these were similarly filled in with data from the SASEX files for La Mercy. Table 3.2.1 below lists all rainfall data changes made to the original climate file obtained from digitised data. Observed runoff data that appeared suspect were investigated by SASEX personnel and subsequently corrected in the hydrometeorological files.

Table 3.2.1: Rainfall corrections to the climate data file for La Mercy

Date	Action
15/03/78	Rainfall replaced with SASEX data
18-20/11/78	Rainfall on the 19th and 20th shifted to the 18th and 19th
7-9/09/80	Rainfall on the 8th, 9th and 10th shifted to the 7th, 8th and 9th
18/02/81	Rainfall replaced with SASEX data
17/05/81	Rainfall replaced with SASEX data
28-31/08/81	Rainfall replaced with SASEX data
13-14/01/83	Rainfall replaced with SASEX data
6-7/01/84	Rainfall replaced with SASEX data
12-14/01/84	Rainfall replaced with SASEX data
30-31/01/84	Rainfall replaced with SASEX data
17-19/02/84	Rainfall replaced with SASEX data
8-10/04/84	Rainfall replaced with SASEX data
30-31/01/81	Rainfall replaced with SASEX data
12-14/11/83	Rainfall replaced with SASEX data
21-24/07/84	Rainfall replaced with SASEX data

3.2.2 Water quality and runoff plot data

No problems were encountered with the quality of the water quality and runoff plot data. The format in which the data were stored, however, presented practical difficulties. In some cases, numeric data were stored in a spreadsheet as "labels" rather than "values", so that these data had to be reformatted for use in analyses.

Furthermore, water quality data were not always sourced from all catchments or all bins, in the case of the runoff plots, on the same day. For a comparison of data from different sources, concurrent dates are required. It is therefore suggested that data be stored in separate columns for different data sources, with a common corresponding date listed in rows alongside the columns. To illustrate this,

Table 3.2.2 shows an example of the original water quality data files, with a suggested format illustrated in Table 3.2.3.

Table 3.2.2: Format of current data storage in SASEX water quality files

Source	Date	Sample	pH	K ($meq.l^{-1}$)	Ca ($meq.l^{-1}$)
C1A	21/04/90	PW2918	7.85	0.30	0.50
C2A	21/04/90	PW2919	8.15	0.20	0.70
C4A	21/04/90	PW2920	8.10	0.20	0.40
C4B	21/04/90	PW2921	7.95	0.20	0.60

In the format represented in Table 3.2.2, a comparison of water quality for different dates is made difficult, especially where a different selection of sources is listed for different dates. Analysis of these data required considerable sorting of the data.

Table 3.2.3: Suggested format for storing SASEX water quality data

Date	Sample C1A	pH C1A	Sample C1B	pH C1B	SAMPLE C2A	pH C2A	etc
21/04/90	PW2918	7.85	-	-	PW2919	8.15	

The format illustrated in Table 3.2.3 allows all samples for concurrent dates to be compared easily.

Runoff plot data presented similar difficulties and it is suggested that a data storage format similar to that illustrated in Table 3.2.3 be employed for ease of future analysis.

3.2.3 Storage of hydrographs

Hydrographs are currently stored by SASEX on an event basis, i.e. for each event the hydrographs are stored within the same file for the four different catchments. The data are in breakpoint digitised form and hence no common time data are possible for all four catchments. The data for each catchment are thus stored as separate sets of time and flow values.

In order to plot a number of events from the same catchment, a considerable amount of reformatting was necessary to collate the events together in a single file. It is thus suggested that, in future, the hydrographs from each catchment be stored in individual files. Thus a single set of time and flow values would be present in each file. These data could be arranged chronologically to facilitate easy graphing and manipulation of the data.

Trends and relationships between data from the four catchments at La Mercy are investigated in Chapter 4. Possible erroneous values in the observed data are highlighted where relevant.

4. ASSESSMENT OF TRENDS AND RELATIONSHIPS

Before attempting to simulate the hydrological responses in the La Mercy catchments, trends and relationships evident from the observed data were investigated. Observed runoff data measured by means of an H-flume at the outlet of each catchment were available from January 1978 to March 1996. In addition, observed sediment yield data were available from January 1983 to March 1996 from samples collected via splitters at the entrance to each flume. Rainfall data from the centrally located autographic raingauge were used for the study period.

4.1 Event Rainfall versus Runoff

Some data recorded for a particular day represent accumulated daily totals over several days. Thus the daily data were grouped into discrete events such that rainfall preceding a runoff event was totalled from the first day with no measured rainfall or runoff before the event. If rainfall continued after the runoff event, the rainfall for the day following the runoff event was included in the total to account for the possibility of the data being recorded on the incorrect day. The rainfall and associated runoff event totals were plotted against each other and are illustrated for the four catchments in Figures 4.1.1. to 4.1.4. These scatter plots represent all measured events for the period January 1978 to December 1995.

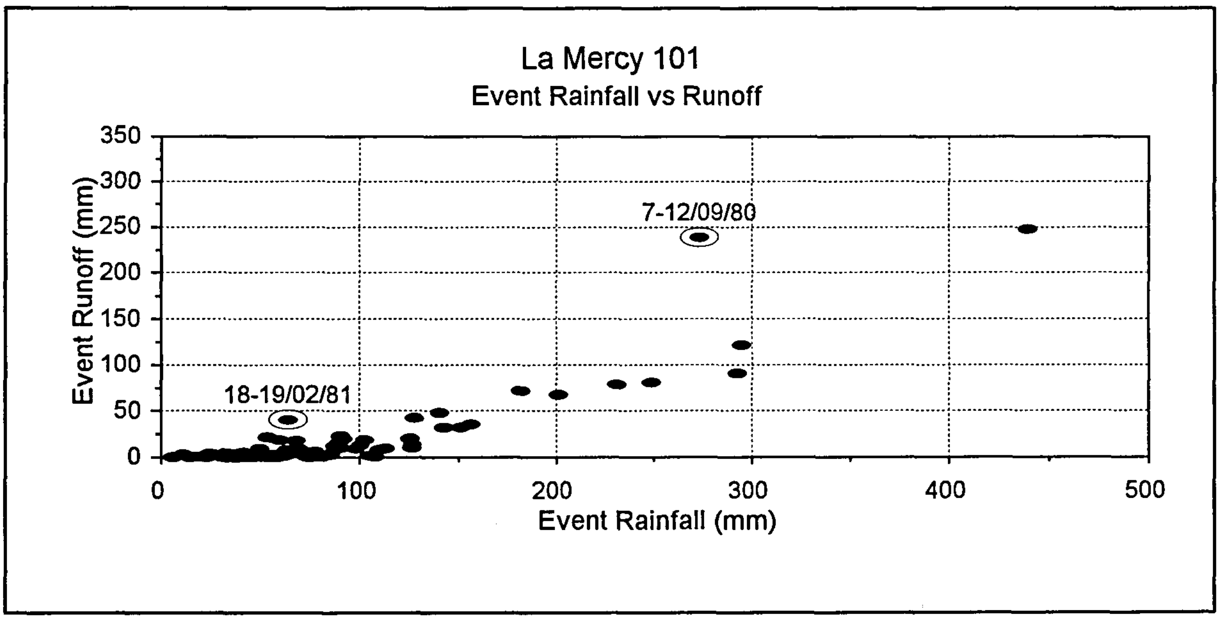


Figure 4.1.1: Observed runoff vs rainfall events - Catchment 101

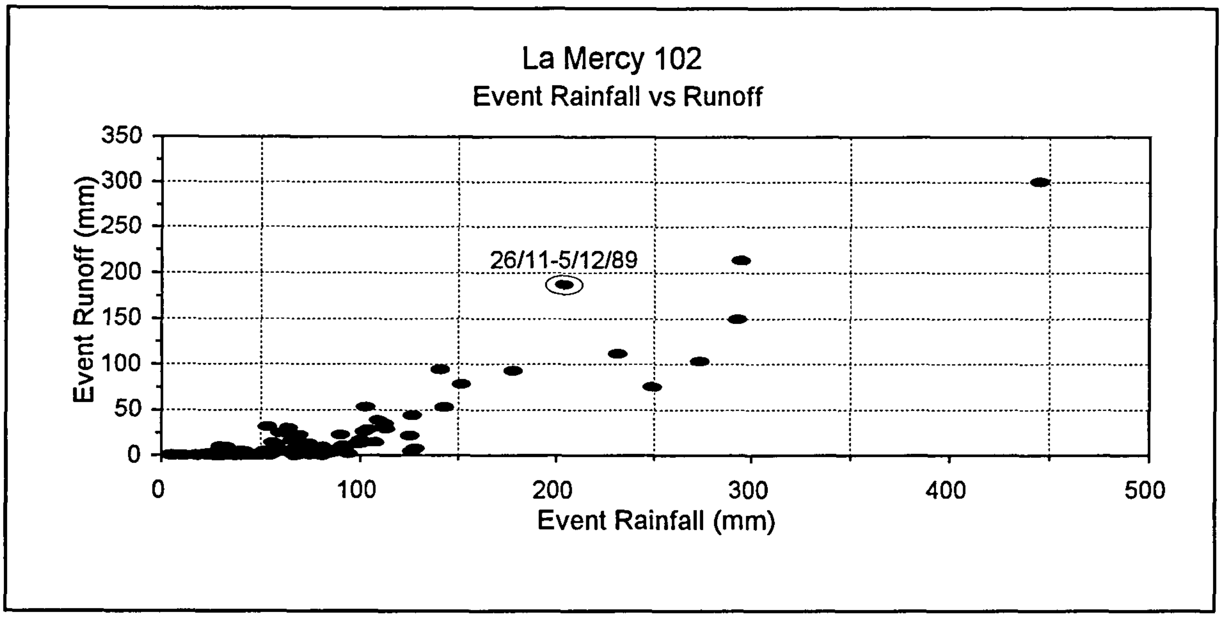


Figure 4.1.2: Observed runoff vs rainfall events - Catchment 102

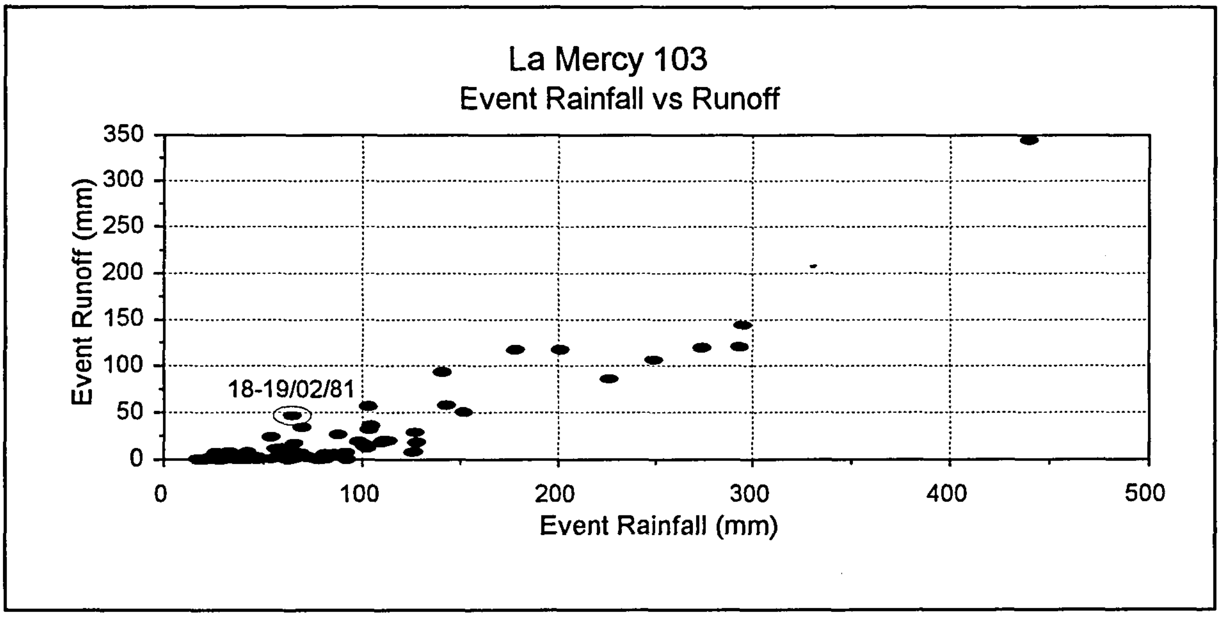


Figure 4.1.3: Observed runoff vs rainfall events - Catchment 103

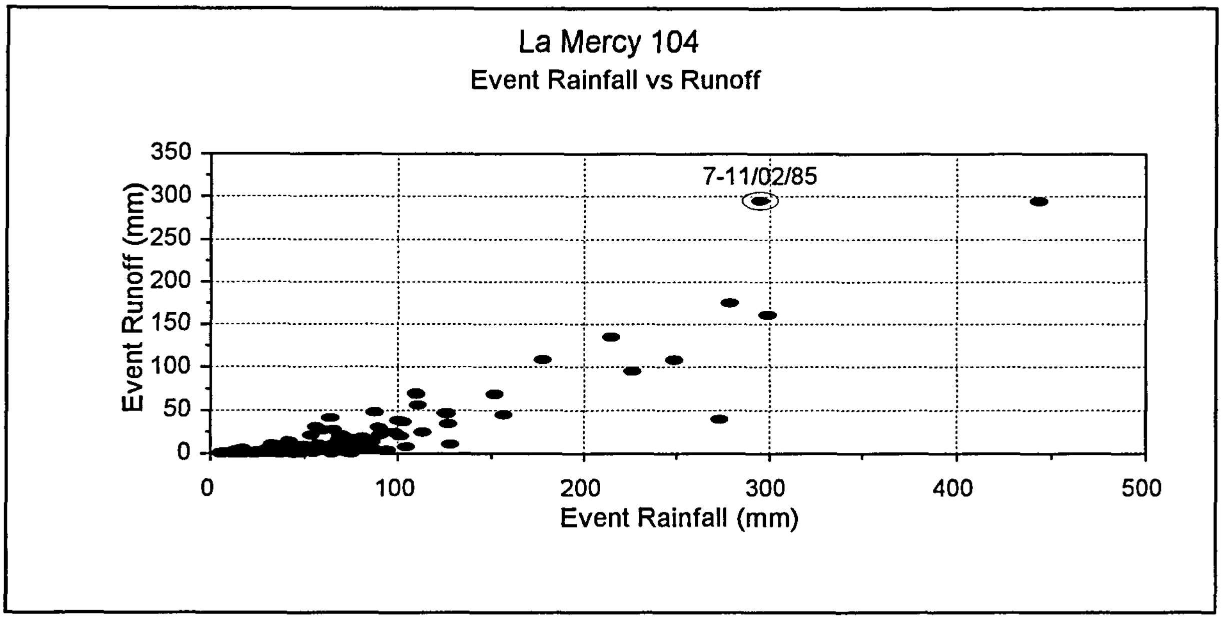


Figure 4.1.4: Observed runoff vs rainfall events - Catchment 104

Figures 4.1.1 to 4.1.4 show typical relationships between discrete events of rainfall and runoff. Runoff response for an individual rainfall event is a function of many interacting factors, which include rainfall intensity, antecedent soil moisture conditions of the catchment and prevailing land cover. For some events, there is a high ratio between runoff and rainfall, indicating that high values of runoff may be associated with relatively lower rainfall amounts.

For Catchment 101 two events, indicated by circles in Figure 4.1.1, were noted to have very high runoff responses. The rainfall for the period 18-19/02/81 was 62.8 mm and the observed runoff was 41.1 mm. However, 24.6 mm of rain was recorded on 16/02/81, thus the catchment was relatively wet when this event occurred, making the high runoff response plausible. In addition, the runoff recorded for the event spanning 18-19/02/81 for Catchments 102, 103 and 104 was 44 mm, 33 mm and 48 mm respectively. Thus, although the runoff relative to the rainfall for this event is high, there is no justification for excluding the event. The rainfall recorded for the period 7-12/09/80 was 276 mm and the observed runoff from Catchment 101 was 239 mm. The rainfall in the week preceding this event was only 4 mm, indicating that the catchment was relatively dry when the event occurred. The runoff recorded for this event from Catchment 102, 103 and 104 was 104 mm, 119 mm and 39 mm respectively. Thus it appears that the observed runoff from Catchments 101 and 104 for the period 7-12/09/80 may be erroneous.

The event for the period 26/11-3/12/89, which is circled in Figure 4.1.2, had 204 mm of rainfall and 187 mm of runoff recorded from Catchment 102. The rainfall in the week preceding the event was 6.6 mm, indicating that the catchment was relatively dry before the event. The runoff recorded from Catchments 101, 103 and 104 for the event was 67 mm, 117 mm and 134 mm respectively. All the catchments had been under a sugarcane land cover, and records of land management indicate that all the catchments were harvested between May and July in 1989, discounting the possibility that the relatively high runoff recorded for this event from Catchment 102 may be due to management practices. Hence the high runoff for the event 26/11-3/12/89 recorded from Catchment 102 should be viewed as possibly being erroneous.

In Figure 4.1.3, the circled event for the period 18-19/02/81, which was initially thought to be possibly erroneous, has been shown to be plausible for the same reasons as those discussed for Catchment 101.

With the exception of one event in Catchment 104, all runoff responses appear to be plausible. The event which occurred for the period 7-11/02/85 is circled in Figure 4.1.4. The data for this apparently spurious event, which was excluded from the *ACRU* hydrometeorological file and from further analyses, are detailed in Table 4.1.1. Comparison with the runoff recorded from the other catchments for this event would not be meaningful, as sugarcane had already been established in the other catchments by 1985, whereas Catchment 104 was still under a bare fallow land cover during 1985.

Table 4.1.1: Data for outlier event in catchment 104

Date	Rainfall (mm)	Runoff (mm)	Maximum Rainfall Intensity (mm.h^{-1})
07/02/85	38.4	1.8	21.0
08/02/85	28.1	10.6	2.8
09/02/85	157.3	177.0	34.9
10/02/85	71.1	104.4	14.6
11/02/85	0.0	2.2	0.0
Total	294.9	295.0	

4.2 Accumulated Runoff Totals

Accumulated daily totals of observed runoff from all four catchments at La Mercy are illustrated in Figure 4.2.1 for periods when all the catchments were under bare fallow (January 1978 to December 1983) and under sugarcane (January 1986 to March 1996) land covers.

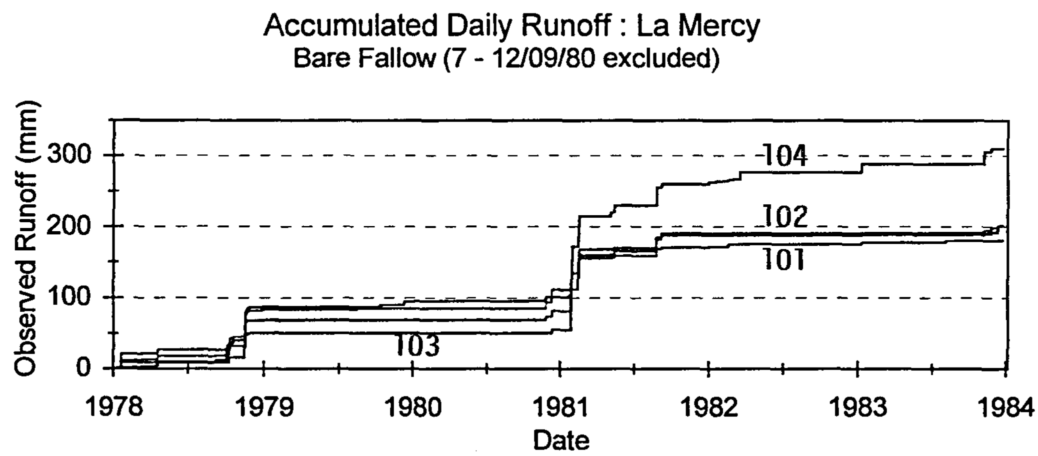


Figure 4.2.1: Accumulated daily runoff - La Mercy catchments (1986 = 1 January 1986; 1987 = 1 January 1987, etc)

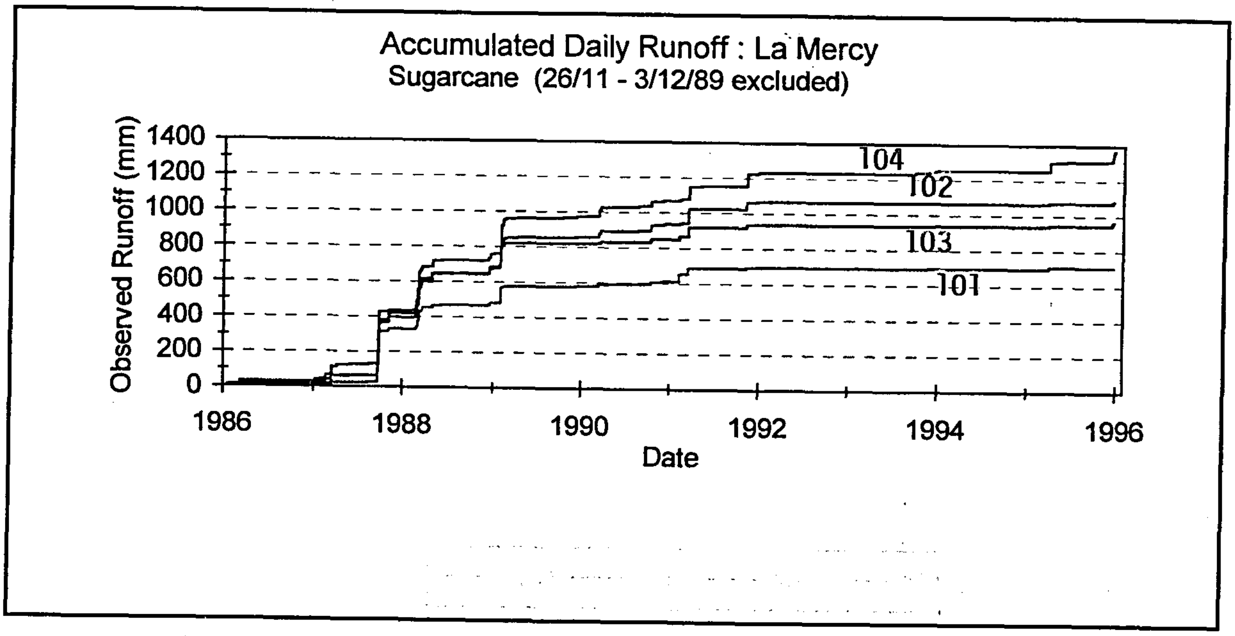


Figure 4.2.1: Accumulated daily runoff - La Mercy catchments (1986 = 1 January 1986; 1987 = 1 January 1987, etc) - Continued

Under bare fallow land cover conditions, the total observed runoff for the period January 1978 to December 1983 was very similar from Catchments 101, 102, and 103. Hence the expected effect of catchment steepness on runoff produced, with Catchment 101 (29%) being the steepest and Catchment 103 (12%) being the least steep catchment, was not evident. The runoff measured from Catchment 104 was similar to that measured from the other catchments up to then end of 1980, whereafter the runoff measured from Catchment 104 was consistently higher than that measured from the other catchments. It would appear (Figure 4.2.1) as if a change occurred in the measuring system early in 1981, and as shown in Figure 4.2.2, the observed runoff data from Catchment 104 are not consistent when compared to observed runoff data from Catchments 102 and 104. Thus the data from Catchment 104 were regarded with circumspection in future analyses and it is suggested that the record of calibration of the monitoring structure in Catchment 104 be investigated.

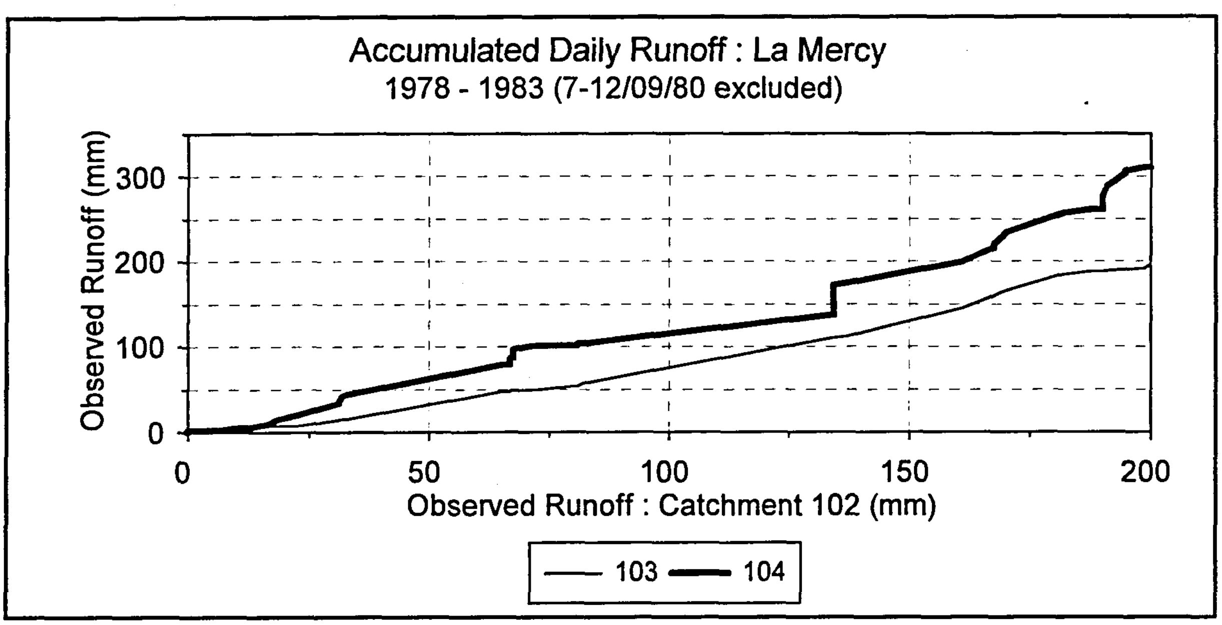


Figure 4.2.2: Double mass plot of observed runoff - La Mercy catchments

During the period when all the catchments were under a sugarcane land cover, the observed data indicate Catchment 101 to exhibit the lowest accumulated runoff for the period January 1986 to December 1995. The reduction of runoff below that of the other catchments after planting, is postulated to be the result of the minimum tillage practice in Catchment 101.

Subsequent to the establishment of sugarcane in all the catchments, runoff response is highest in Catchment 104, which may be attributed to the influence of the bare fallow panels in the catchment. However, as noted above, the apparent high runoff response in Catchment 104 may also be the result of a inconsistent measuring system.

Under sugarcane land cover conditions, the runoff from Catchment 102 is consistently higher than that from Catchment 103, although the trends are very similar. Generally a lower runoff response would be expected from Catchment 102 than from Catchment 103, since 102 contains conservation structures (cf. Table 2.2.1). Catchment steepness on runoff was shown not to be a factor under bare fallow conditions, and hence this "anomaly" cannot be explained in terms of the steepness of the different catchments. Based on this evidence, it is postulated that the effect of the conservation structures, when the land cover is dense, is to increase the runoff from a catchment.

All four catchments show little runoff response between 1992 and 1994, during which time annual rainfall totals were low. Statistics reflecting total runoff response and total rainfall for the periods when the catchment's land covers were bare fallow and sugarcane are contained in Table 4.2.1. Under both bare fallow and sugarcane land cover conditions the highest runoff response was recorded from Catchment 104. The lowest runoff response under bare fallow conditions was from Catchment 102 and from Catchment 101 after the establishment of sugarcane.

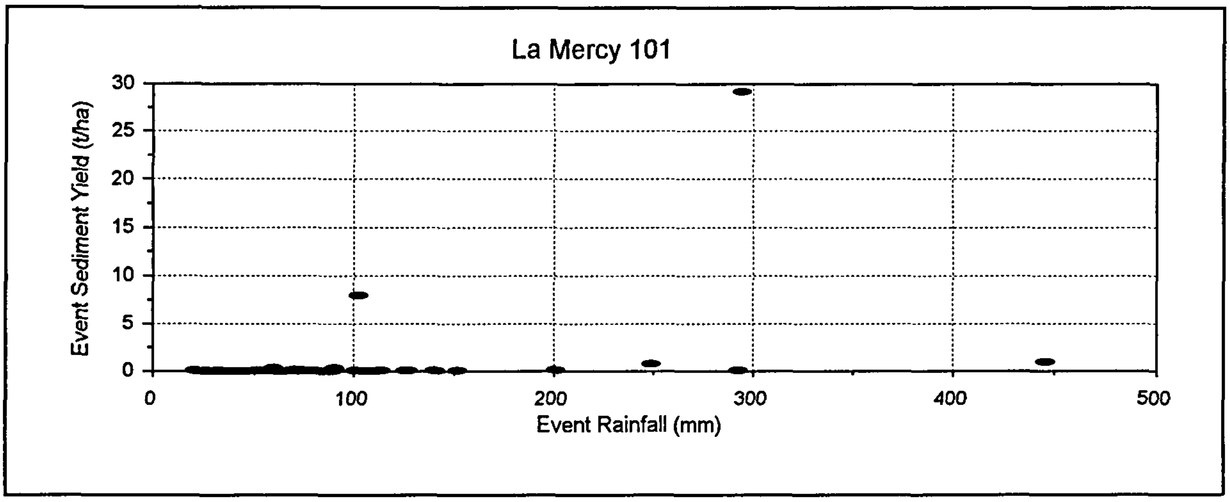
Table 4.2.1: Accumulated daily rainfall and runoff statistics for the entire observation period (1978-1995)

Catchment	Condition	Accumulated Rainfall (mm)	Accumulated Runoff (mm)	Runoff as a Percentage of Rainfall and Rank ()
101	Bare Fallow Sugarcane	5127 11427	419 1198	8.2 (2) 10.5 (4)
102	Bare Fallow Sugarcane	5127 11427	305 1873	6.0 (4) 16.4 (2)
103	Bare Fallow Sugarcane	5127 11427	320 1640	6.3 (3) 14.4 (3)
104	Bare Fallow Sugarcane	7416 9183	864 1505	11.7 (1) 16.5 (1)

4.3 Event Sediment Yield

From the observed sediment yield data, it is apparent that many daily sediment yield values actually represent accumulations of several days as a result of the sampling of sediment after each event. Event totals were thus extracted, together with the associated rainfall and runoff, according to the procedure used in Section 4.2. Event sediment yield was plotted against the corresponding event rainfall and runoff. This is illustrated for all four catchments in Figures 4.3.1 to 4.3.4.

From Figure 4.3.1 it is apparent that the sediment yield from Catchment 101 is generally low for the period considered (1985- 1995). Two large sediment yield events are evident and these events are characterised in Table 4.3.1.



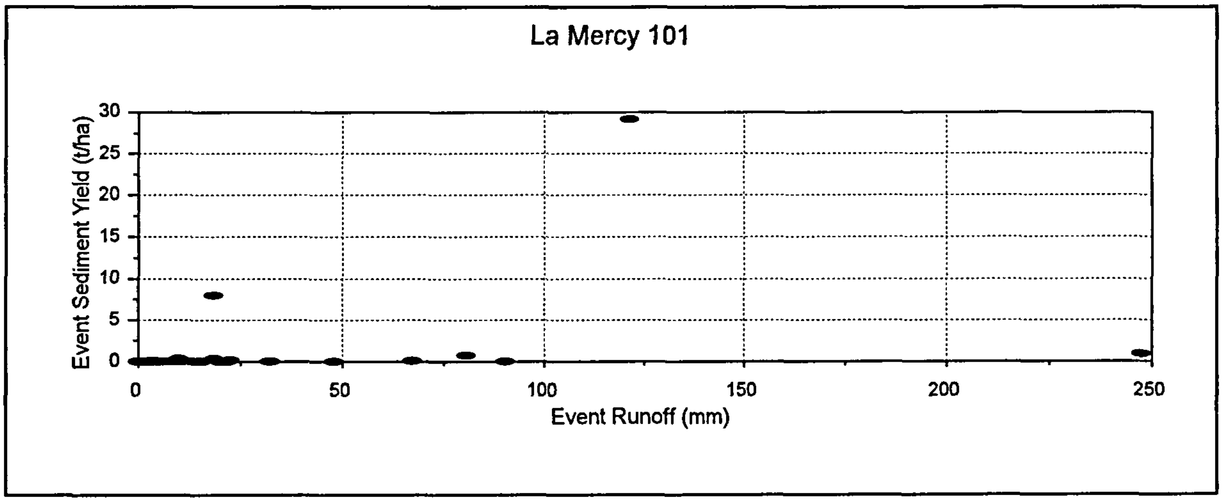


Figure 4.3.1: Event sediment yield vs event rainfall and runoff - Catchment 101

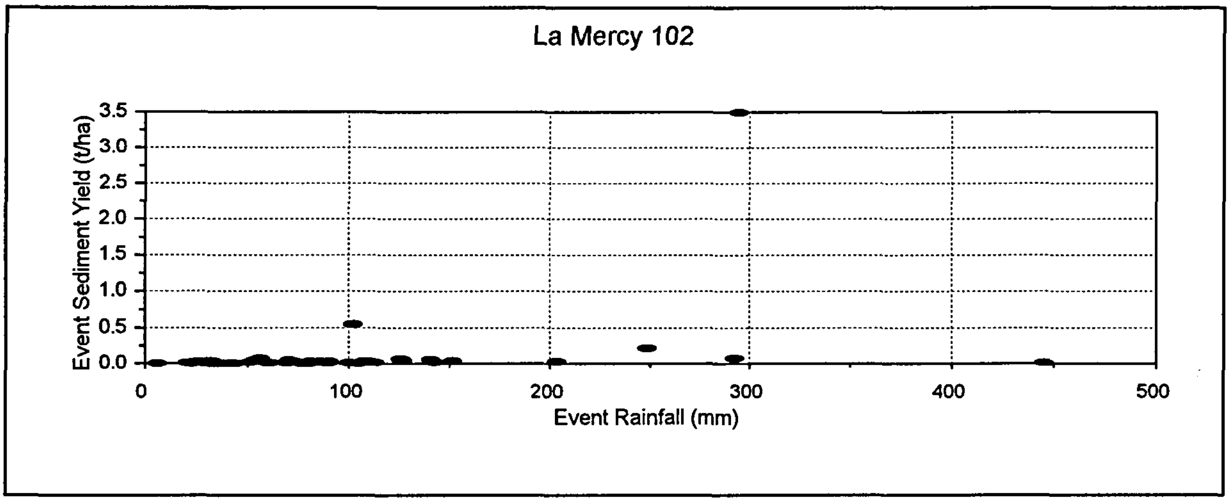
The sediment yield data for the two events listed in Table 4.3.1 have been checked and are correct as recorded. Conservation structures were implemented in Catchment 101 during the middle of 1984. The catchment land cover was bare fallow up to September 1984, when sugarcane was established. Hence a full cover of sugarcane had not yet developed at the time of the events. It should also be noted that this catchment is the steepest of the four, hence high intensity rainfall events would be expected to produce high sediment yield under such conditions. The extremely high sediment yield values could be the result of errors in measurement of the sediment yield. A further explanation may be that sediment is transported and then deposited in the waterway and along contours by smaller rainfall events, and that this accumulated sediment is flushed out during As indicated in Figures 4.3.2, relatively low sediment yield was measured from Catchment 102, where conservation structures are in place. Two events are larger than the other events and their characteristics are analysed in Table 4.3.2.

Table 4.3.1: Characteristics of large soil loss events in Catchment 101

Date	Rainfall (mm)	Runoff (mm)	Sediment Yield ($t.ha^{-1}$)	Maximum Rainfall Intensity ($mm.h^{-1}$)
15 /1/85	7.7	0.0	0.0	3.8
16 /1/85	6.9	0.0	0.0	2.3
17 /1/85	86.2	0.0	0.0	18.9
18 /1/85	1.3	18.5	8.0	0.9
19 /1/85	0.4	0.0	0.0	0.1
Total	102.5	18.5	8.0	
7 /2/85	38.4	0 .0	0.0	21.0
8 /2/85	28.1	0 .0	0.0	2.8
9 /2/85	157.3	0 .0	0.0	33.9
10 /2/85	71.1	121.4	0.0	14.6
11 /2/85	0.0	0 .0	29.2	0.0
Total	294.9	121.4	29.2	

Table 4.3.2: Characteristics of large soil loss events in Catchment 102

Date	Rainfall (mm)	Runoff (mm)	Sediment Yield ($t.ha^{-1}$)	Maximum Rainfall Intensity ($mm.h^{-1}$)
15/01/85	7.7	0.0	0.0	3.8
16/01/85	6.9	0.0	0.0	2.3
17/01/85	86.2	0.0	0.0	18.9
18/01/85	1.3	26.0	0.6	0.9
19/01/85	0.4	0.0	0.0	0.1
Total	102.5	26.0	0.6	
7/01/85	38.4	1.2	0.0	21.0
8/01/85	28.1	3.9	0.0	2.8
9/01/85	157.3	127.1	0.0	33.9
10/01/85	71.1	75.5	0.0	14.6
11/01/85	0.0	5.8	3.5	0.0
Total	294.9	213.5	3.5	



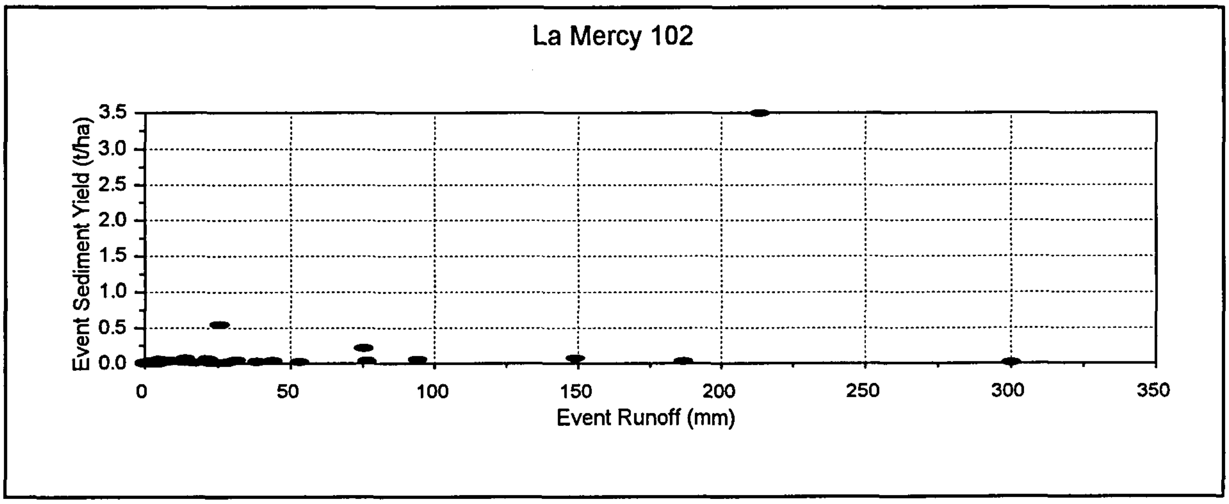
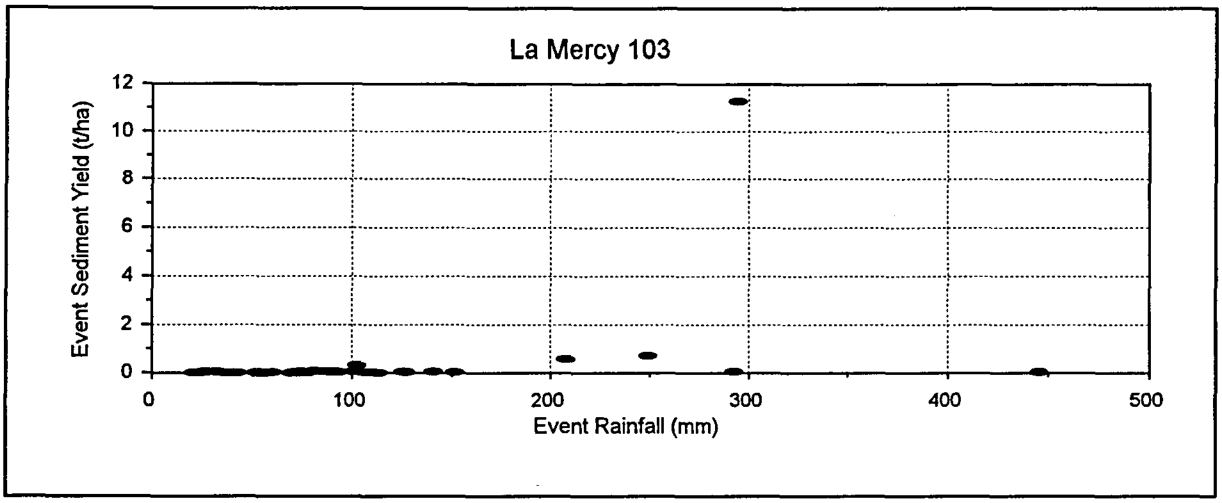


Figure 4.3.2: Event sediment yield vs event rainfall and runoff - Catchment 102

The two events in Table 4.3.2 are the highest observed in Catchment 102, but sediment yield in this case is much lower than that from Catchment 101. These maximum sediment yield events occur for the same rainfall events that were considered in Catchment 101 above, and their magnitude may again be attributed to high rainfall intensity in the presence of partial sugarcane cover.

Sediment yield measured from Catchment 103 and shown in Figure 4.3.3, indicates that similar trends in sediment yield exist between Catchments 102 and 103. One very large sediment yield event was measured and emanates from the same rainfall event in February 1985 which also produced a high sediment yield from Catchments 101 and 102. The characteristics of this event in Catchment 103 are contained in Table 4.3.3.



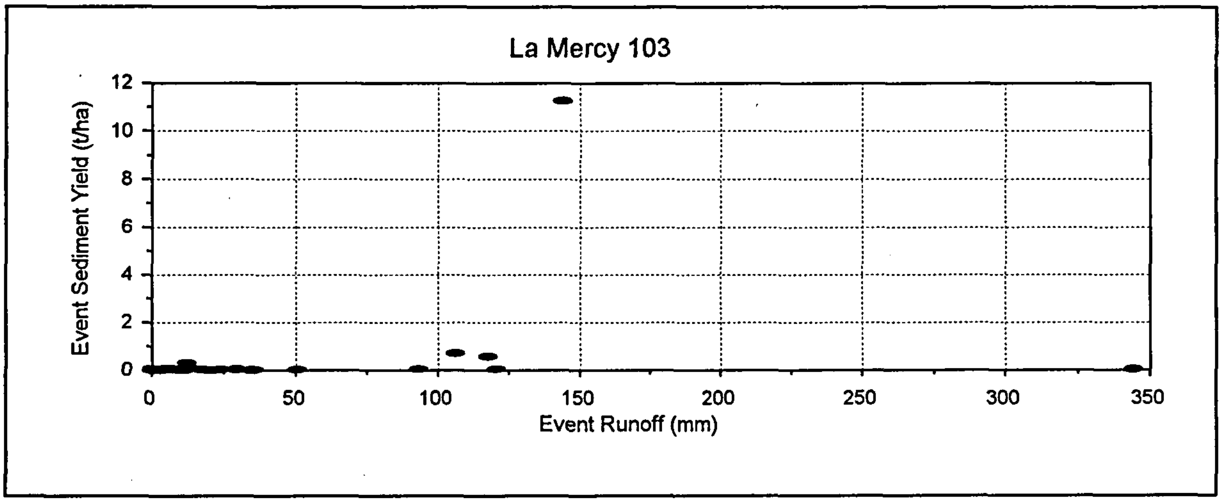
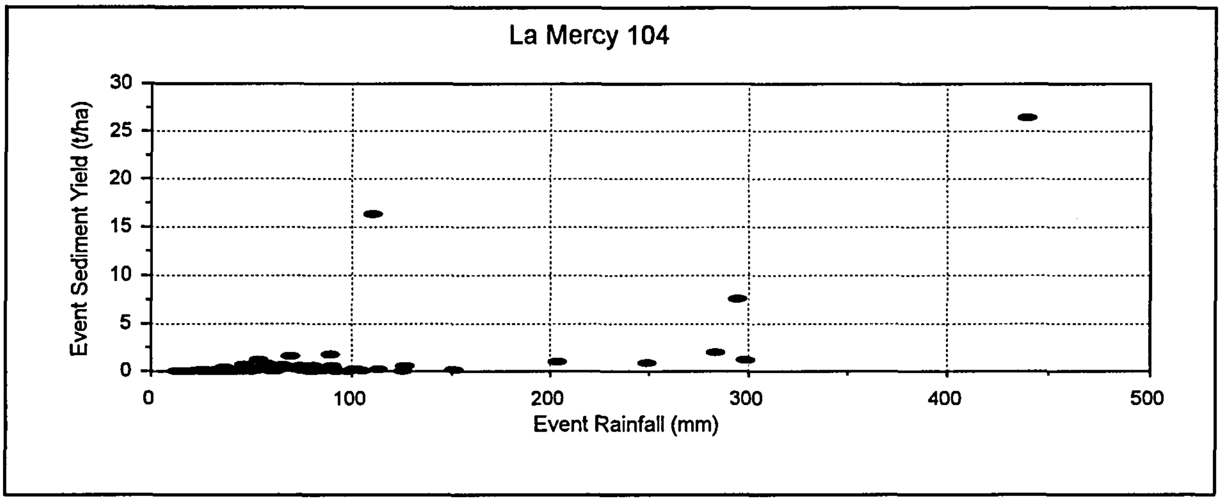


Figure 4.3.3: Event sediment yield vs event rainfall and runoff - Catchment 103

Table 4.3.3: Characteristics of a large sediment yield event in Catchment 103

Date	Rainfall (mm)	Runoff (mm)	Sediment Yield ($t.ha^{-1}$)	Maximum Rainfall Intensity ($mm.h^{-1}$)
7/02/85	38.4	0.1	0.0	21.0
8/02/85	28.1	0.1	0 0	2.8
9/02/85	157.3	89.4	0.0	33.9
10/02/85	71.1	53.6	0.0	14.6
11/02/85	0.0	0.8	11.3	0.0
Total	294.9	144.0	11.3	

Higher sediment yield than from the other three catchments was measured from Catchment 104, with a number of large events evident in Figure 4.3.4. This catchment has bare fallow panels which constitute approximately 50% of the catchment area and which are hypothesised to be the major contributing source in the production of sediment yield.



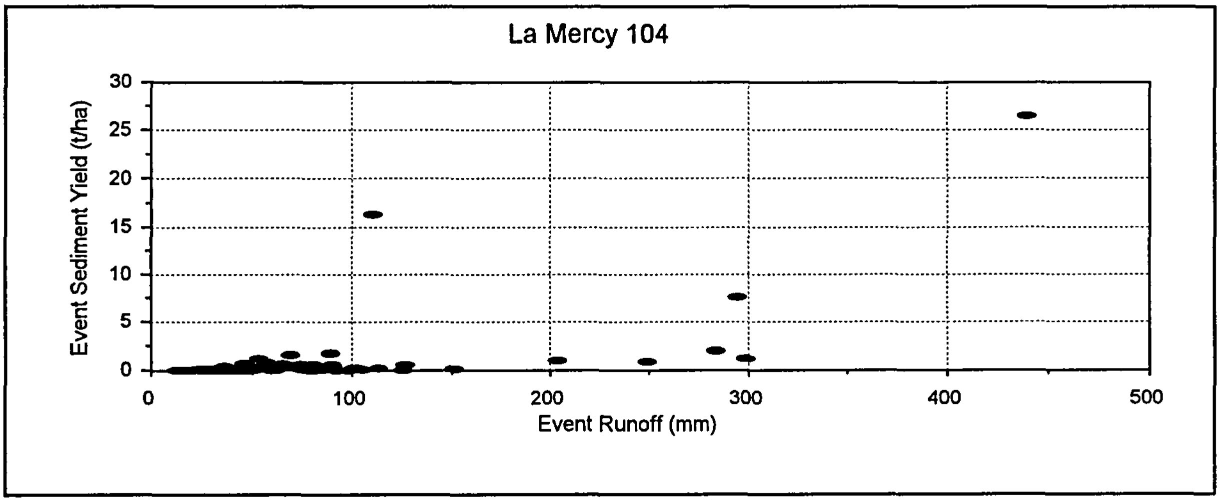


Figure 4.3.4: Event sediment yield vs event rainfall and runoff - Catchment 104

4.4 Accumulated Sediment Yield

Comparative plots of accumulated daily sediment yields of each of the four catchments are contained in Figure 4.4.1, for the period 1983 - 1995.

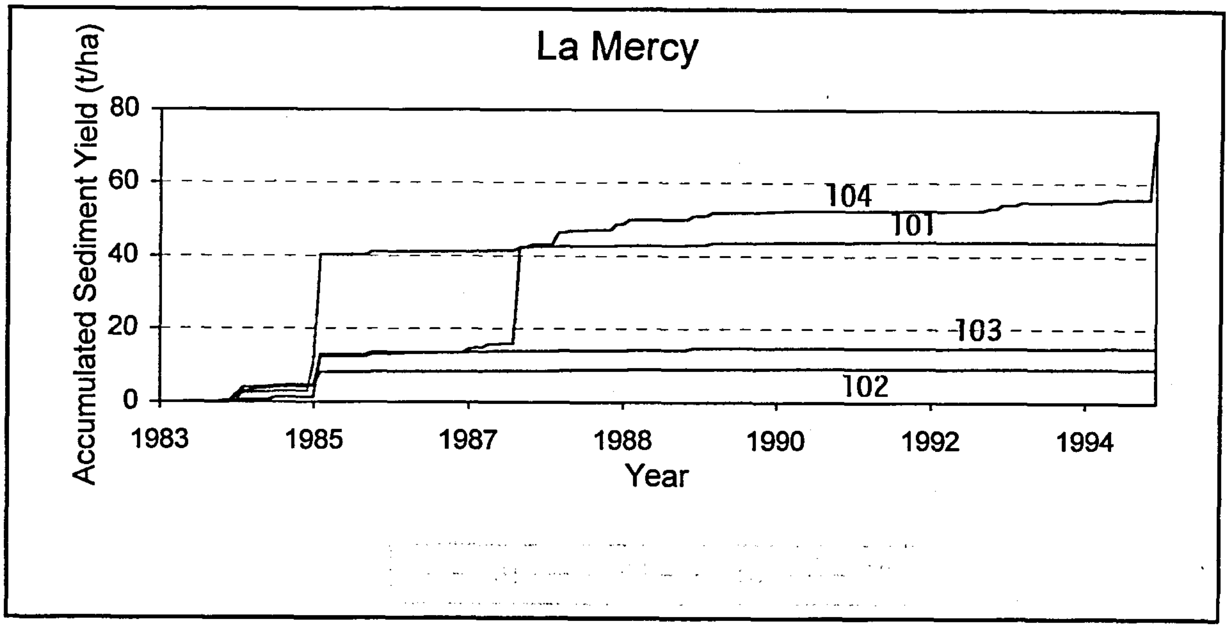


Figure 4.4.1: Accumulated sediment yield - La Mercy catchments

All catchments show appreciable sediment yields for the events in January and February 1985, which have been previously identified as large sediment yield events. As discussed earlier, the sugarcane on Catchments 101, 102 and 103 would not have reached full canopy when the events occurred. Sugarcane was established in Catchment 104 in 1986 and hence the catchment was under bare fallow conditions when the events occurred. The extremely high sediment yield (29.2 $t.ha^{-1}$) measured from Catchment 101 for the event on 7-11/02/85 may be attributed to the influence of slope in the absence of a full vegetation cover. For this same event the sediment yield from Catchment 104, which was bare fallow at the time of the event, was recorded as 7.6 $t.ha^{-1}$. Although the runoff (295 mm) for this event from Catchment 104 was shown previously to be erroneous, it is speculated that the runoff from Catchment 104 was at least as large as that from Catchment 101 (121 mm). Thus, for the event on 7-11/02/85 the measured data indicate that more sediment yield was produced from a catchment that had partial cover (Catchment 101) than from a bare fallow catchment, which produced at least the same volume runoff as the catchment with the partial cover. This is not plausible and therefore the sediment yield data recorded for the period 7-11/02/85 from Catchment 101 is suspected to be erroneous.

After the establishment of the first full canopy of the sugarcane (March 1985) in Catchments 101, 102 and 103 the data indicate relatively little sediment yield. Catchment 104, however, does not exhibit the same constancy, showing a marked sediment yield event in 1987. This would appear to be due to the effect of the bare fallow portion in Catchment 104 and heavy rains in 1987. Table 4.4.1 characterises the large event which caused the high sediment yield. The rainfall and runoff data for this event have been deemed previously to be acceptable.

Table 4.4.1 Characteristics of the large sediment yield event in Catchment 104

Date	Rainfall (mm)	Runoff (mm)	Sediment Yield ($t.ha^{-1}$)	Maximum Rainfall Intensity ($mm.h^{-1}$)
25/9/87	1.9	0.0	0.0	1.1
26/9/87	74.1	21.7	0.0	12.6
27/9/87	108.1	70.4	0.0	7.7
28/9/87	203.8	159.9	0.0	28.5
29/9/87	51.8	40.9	0.0	15.9
30/9/87	0.0	1.3	26.5	0.0
Total	439.7	294.2	26.5	

The investigations described above allowed preparation of "clean" data sets with erroneous events removed, as well as clarification of possible inconsistencies in observed data between catchments.

The *ACRU* model was used to simulate the runoff volume, peak discharge and hydrograph as well sediment yield for all the La Mercy catchments. A brief description of the how these processes are simulated by the model follows in Chapter 5.

5. THE *ACRU* AGRO-HYDROLOGICAL MODELLING SYSTEM

The *ACRU* model (Schulze, 1995), which has been developed in South Africa over the past fifteen years and is still undergoing further development and refinement, is a physical conceptual agrohydrological model which generally operates with a daily time step. The model simulates all major processes of the hydrological cycle which affect the soil water budget and is capable of simulating, *inter alia,* streamflow volume, peak discharge and hydrograph, reservoir yield, sediment yield, crop yields for selected crops and irrigation supply and demand. *ACRU* can operate at a point, as a lumped catchment model or as a distributed cell-type model in order to account for variability in climate, land use and soils.

Where automatically recorded rainfall data are not available, the model is capable of using synthetic rainfall distributions to dis-aggregate daily rainfall values into shorter time increments, which enables the generation of hydrographs displaying intra-daily variations in discharge. The lagging and attenuation of the hydrograph as it passes through a river reach or reservoir is also modelled with time increments of less than one day.

5.1 Simulation of Stream Flow Volume

In *ACRU* the storm flow depth is simulated using a modified SCS (United States Department of Agriculture, 1985) approach where the soil moisture deficit, computed from a daily water budget of the soil profile, is used as a surrogate for a Curve Number. The baseflow, derived from drainage from the subsoil horizon into a baseflow "store", is released on a daily basis from the baseflow "store" and added to the storm flow to compute the volume of stream flow for each day.

5.2 Simulation of Peak Discharge

The *ACRU* model simulates peak discharge from individual sub-catchments using the SCS triangular-shaped unit hydrograph approach. The equation used to simulated peak discharge is:

$$q_p = \frac{0.2083\ A\ Q}{D_e/2 + L}$$

where

q_p	=	peak discharge ($m^3.s^{-1}$)
Q	=	storm flow depth (mm)
A	=	catchment area (km^2)
L	=	catchment lag time (h) and
D_e	=	effective storm duration (h).

One of the options in the *ACRU* model which may be used to estimate the catchment lag time is

$$L = 0.6\ Tc$$

where

Tc = catchment time of concentration (h)

The catchment time of concentration is the time taken for storm flow to travel from the hydraulically most distant part of a catchment to the catchment outlet and may be determined by dividing the reach length (m) by the flow velocity ($m.s^{-1}$).

5.3 Simulation of Hydrograph Shape

Where automatically recorded rainfall data with time increments of less than one day are not available, the synthetic design rainfall distributions developed for southern Africa by Weddepohl (1988) may be used to dis-aggregate daily rainfall totals into shorter time intervals, thus allowing incremental storm hydrographs to be generated for each time interval. These are then aggregated to form the composite storm flow hydrograph at the outlet to each sub-catchment.

The composite hydrographs are routed from the outlet of a sub-catchment through the next downstream sub-catchment to the outlet of the downstream sub-catchment, and are added to the hydrographs generated for both the downstream sub-catchment and all other upstream sub-catchments which flow directly into the downstream catchment. This procedure has been detailed by Smithers and Caldecott (1993; 1995).

5.4 Simulation of Sediment Yield

The Modified Universal Soil Loss Equation (MUSLE) is implemented in the *ACRU* model to simulate sediment yield from a catchment on an event-by-event basis. The method of implementation in *ACRU* is described by Lorentz and Schulze (1995). The MUSLE is expressed as:

$$Y_{sd} = \alpha(Q_v \cdot q_p)^{\beta} K \cdot LS \cdot C \cdot P$$

where

Y_{sd}	=	sediment yield from an individual event (tonne)
Q_v	=	storm flow volume for the event (m^3)
q_p	=	peak discharge for the event ($m^3.s^{-1}$)
K	=	soil erodibility factor ($tonne.h.N^{-1}.ha^{-1}$)
LS	=	slope length and gradient factor (dimensionless)
C	=	cover and management factor (dimensionless)
P	=	support practice factor (dimensionless) and
α, β	=	location specific MUSLE coefficients.

From the above equation, it is evident that simulated sediment yield is a function of, *inter alia*, the storm flow volume and peak discharge. Hence, any errors in the simulated volume and peak discharge will compound errors in the simulation of sediment yield caused by any of the other factors. Chapter 6 addresses the simulation of runoff volume, peak discharge and sediment yield from the La Mercy catchments.

6. MODEL APPLICATION AND PERFORMANCE

The *ACRU* model (version 3.25) was applied to the four La Mercy catchments and daily runoff volume, daily peak discharge, runoff hydrographs and daily sediment yield were simulated. The model was verified by comparing simulated values and observed data. Where the model did not perform adequately, the concepts used by the model and the data were examined in order to identify the cause of the differences between the simulated and observed values.

6.1 Simulation of Runoff Volume

Initial values of the variables input to the model were based on published documentation (Smithers and Schulze, 1995) and on expert opinion. The hydrological dynamics of the catchments became clearer as a result of the trends evident in the observed data, and from modelling the catchments. Consequently new guidelines were developed for applying the model to catchments with sugarcane land covers. This led to the development of a SugarCane Decision Support *S*ystem (SCDSS) for the model.

6.1.1 Initial estimation of *ACRU* variables

The ACRU model is a physical conceptual model and initial parameters for the four catchments were estimated using default values suggested in the ACRU User Manual (Smithers and Schulze, 1995).

6.1.1.1 Soils information

Information on catchment soil characteristics were obtained from Haywood (1991) and Haywood and Schulze (1990). Three soil types have been identified in the La Mercy catchments and the areas occupied by each soil, classified by the Binomial soil classification system (MacVicar *et al*, 1977), within each catchment are contained in Table 6.1.1.

Table 6.1.1: Distribution of soil types in each catchment

Soil Form	Soil Series	Soil Code	% Area per Catchment			
			101	102	103	104
Hutton	Clansthal	Hu24	0	0	0	10
Arcadia	Rydalvale	Ar30	71	97	98	37
Swartland	Swartland	Sw31	29	3	2	53

The above soil information together with average thicknesses of each catchment's top- and subsoil horizons were input into an ACRU utility program called AUTOSOIL. This program area-weights pre-programmed values of soil water content at permanent wilting point (WP), drained upper limit (FC) and saturation (PO) for both the top- and subsoil. However, the output from AUTOSOIL does not account for disturbances of the soil by tillage practices, which will effect PO. Tillage at La Mercy will have only affected the topsoil, so the topsoil value of PO was adjusted to account for this. Furthermore, PO of a tilled topsoil will vary from freshly tilled conditions to end of season conditions. Table 5.6.1 in *Hydrology and Agrohydrology* (Schulze, 1995) provides typical values of PO under freshly tilled and end of season conditions for different soil textural classes. Topsoil PO values for freshly tilled conditions were thus obtained for use in simulations of bare fallow conditions, and end of season values, for use in simulations under sugarcane. A final topsoil value of PO was obtained by area-weighting values for the different soil textural classes representing soil types in each catchment. The final inputs required in terms of soil properties, the "saturated redistribution fraction from the top- to subsoil horizon (ABRESP) and from the subsoil horizon to intermediate/groundwater store (BFRESP), were also obtained from AUTOSOIL. The initial soil variable/parameter selections for input into ACRU are presented in Table 6.1.2.

Table 6.1.2: Initial soil variable/parameter selections

Variable/Parameter	Catchment 101	Catchment 102	Catchment 103	Catchment 104
DEPAHO	0.30	0.30	0.30	0.30
DEPBHO	0.43	0.49	0.49	0.49
WP1	0.228	0.248	0.248	0.192
WP2	0.239	0.244	0.245	0.220
FC1	0.344	0.367	0.368	0.304
FC2	0.370	0.375	0.376	0.347
PO1 (BF)	0.523	0.534	0.534	0.522
PO1 (AP)	0.505	0.523	0.523	0.493
PO2	0.455	0.475	0.475	0.433
ABRESP (BF)	0.25	0.25	0.25	0.28
ABRESP (AP)	0.25	0.25	0.25	0.22
BFRESP	0.21	0.25	0.25	0.22

Key :

(BF)	Bare fallow value of the variable/parameter
(AP)	Value of the variable/parameter after planting to sugarcane
DEPAHO, DEPBHO	Thicknesses of top- and subsoil respectively (m)
WP1, WP2	Permanent wilting points of top- and subsoil respectively ($m.m^{-1}$)
FC1, FC2	Drained upper limits of top- and subsoil respectively ($m.m^{-1}$)
PO1, PO2	Porosities of top- and subsoil horizons respectively ($m.m^{-1}$)
ABRESP	Saturated redistribution fraction from topsoil to subsoil
BFRESP	Saturated redistribution fraction from subsoil horizon to intermediate/ groundwater store.

6.1.1.2 Land cover information

Land cover inputs required by the *ACRU* model are the monthly average crop coefficient (CAY), the fraction of active roots in the topsoil (ROOTA) and interception loss per rainfall event (VEGINT), all of which are input on a monthly basis. Typical values of these inputs are tabled in the *ACRU* User Manual (Smithers and Schulze, 1995) for various crop types. Although typical values are not presented for sugarcane, estimates were made based on prior experience and expert opinion. The land cover variables/parameters selected for use in the simulations are given in Table 6.1.3.

Table 6.1.3: Initial estimates of land cover variables

Variable	Bare Fallow All Catchments	Sugarcane All Catchments
CAY	0.30	0.80
ROOTA	1.00	0.80
VEGINT	0.00	1.80

Key :

CAY	Average crop coefficient, input on a monthly basis (dimensionless)
ROOTA	Fraction of roots active in the topsoil, input on a monthly basis
VEGINT	Interception loss ($mm.rainday^{-1}$), input on a monthly basis

6.1.1.3 Stream flow simulation variables

The coefficient of initial abstraction (COIAM), which is input month-by-month, is a coefficient used to estimate the rainfall abstracted by surface storage and initial infiltration before storm flow commences. Different management practices implemented in the La Mercy catchments are likely to influence rainfall abstractions and thus storm flow. Guidelines as to the selection of the COIAM parameter are contained in the *ACRU* User Manual (Smithers and Schulze, 1995). Under bare fallow conditions, and with regular tillage, the COIAM is higher than under a crop cover, owing to the higher surface roughness. It was postulated that the presence of conservation structures would result in higher initial abstraction than would be the case where these structures are absent. Thus a higher value of COIAM was chosen for Catchments 101, 102 and 104 than the COIAM value selected for Catchment 103, which has no conservation structures. Minimum tillage produces more surface cover in the form of litter, which acts to intercept rainfall and retard surface flow, thus increasing infiltration. It was postulated that the initial abstraction would be higher when minimum tillage was practised in the catchment. Thus the value of COIAM chosen for Catchment 101 was increased above that of the other catchments, owing to the minimum tillage practice.

A second *ACRU* input parameter which affects stream flow response is SMDDEP, the effective depth of soil for storm flow generation. The value for this parameter is based largely on experience, with guidelines given in the *ACRU* User Manual for its selection. The value of SMDDEP chosen can be defaulted to the topsoil thickness. The initial estimations of the COIAM and SMDDEP parameters are given in Table 6.1.4.

Table 6.1.4: Initial stream flow variable/parameter selections for runoff simulations

Variable/ Parameter	Bare Fallow All Catchments	Catchment 101	Catchment 102	Catchment 103	Catchment 104
COIAM	0.35	0.30	0.25	0.20	0.25
SMDDEP	0.30	0.30	0.30	0.30	0.36

Key:

COIAM Coefficient of initial abstraction, input on month-by-month basis
SMDDEP Effective depth of soil for storm flow response (m)

6.1.1.4 Catchment configuration

Catchments 101, 102 and 103 were treated as lumped catchments. Consequently, the selected variables/parameters are constant for the entire area. Half of Catchment 104 has been bare- fallow following the introduction of sugarcane in 1986. It was thus divided into two sub-catchments, each with their own sets of variables/parameters. No attempt has been made to account for temporal and spatial variations of variables/parameters due to seasonal changes in vegetation characteristics and harvesting and re-growth of sugarcane. Thus the variables and parameters used are considered to be representative of average conditions in a sugarcane field, where the sugarcane is not all at the same growth stage as a result of the widely practised method of strip crop harvesting.

The influence of baseflow has been excluded from the simulated runoff, as it is hypothesised that the gauging structures do not measure baseflow as the structures are not founded on bedrock.

6.1.2 Initial Results

6.1.2.1 Catchment 101

The accumulated daily values for Catchment 101 under bare fallow conditions from simulations performed using the initial input selections discussed above, are presented in Figure 6.1.1.

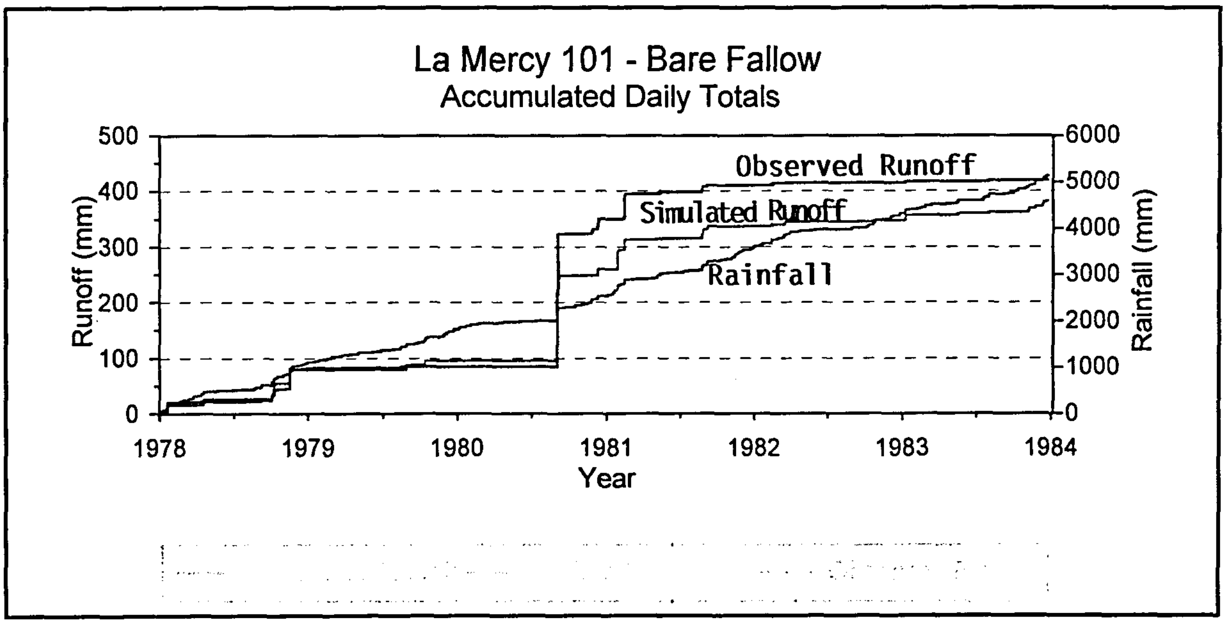


Figure 6.1.1: Accumulated daily values: Catchment 101, bare fallow land cover

The simulation of runoff from bare fallow conditions in Catchment 101 were excellent up until 1980, where a single large event was under simulated. Hereafter, it can be seen that many small events are being simulated as producing runoff, whereas observed data show little or no runoff response for the same period. Total simulated runoff for the period is 381 mm and total observed runoff is 419 mm, an overall under-simulation of 9%. Accumulated daily values for Catchment 101 under sugarcane are shown in Figure 6.1.2.

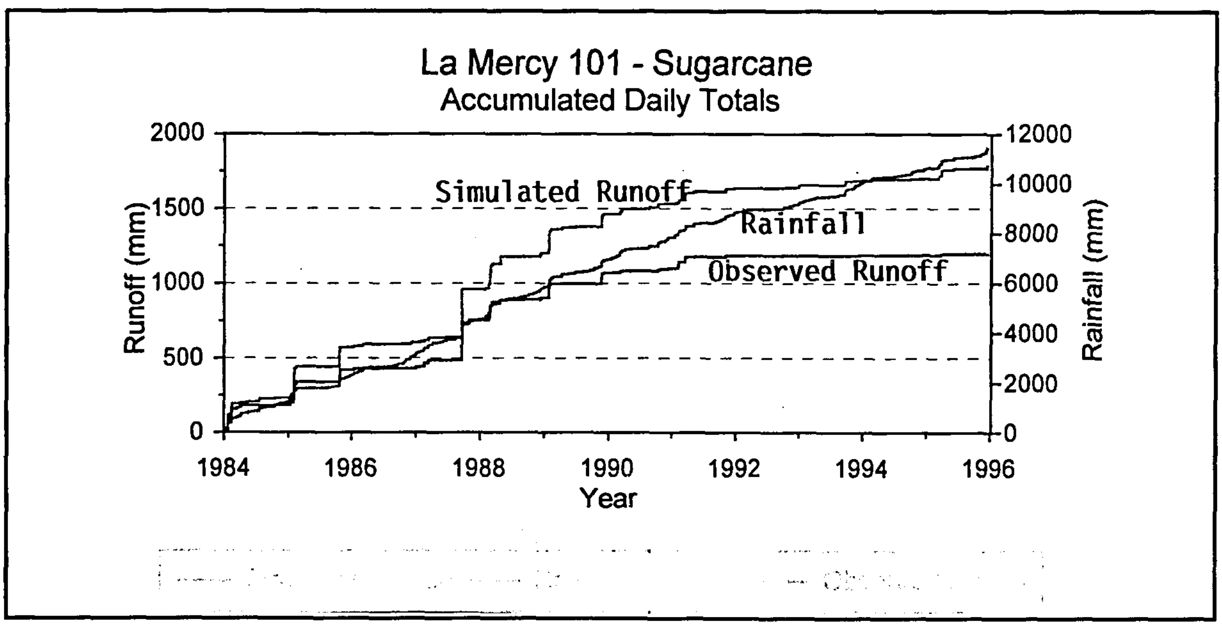


Figure 6.1.2 Accumulated daily values: Catchment 101, sugarcane land cover

In the case of a sugarcane land cover, the variables and parameters initially selected for Catchment 101 resulted in a consistent over-simulation of runoff. Large events were over-simulated, with smaller events being simulated as generating runoff where no observed runoff was measured. Total simulated runoff for the period of simulation is 1720 mm, compared with observed runoff for the period of 1198 mm. This represents an over simulation of 30.3 %. The initial set-up of the model were clearly producing too much storm flow.

6.1.2.2 Catchment 102

The accumulated daily values for Catchment 102 under bare fallow conditions are shown in Figure 6.1.3. The initial estimates of the input variables produced a consistent over-simulation of runoff in the case of the bare fallow period on Catchment 102. Again, it was not only large events which were being poorly simulated, but many small rainfall events were producing simulated runoff where no runoff was observed. The total simulated runoff for this period of simulation is 404 mm, compared with a total observed runoff of 305 mm. This represents an over simulation of 24.5 %.

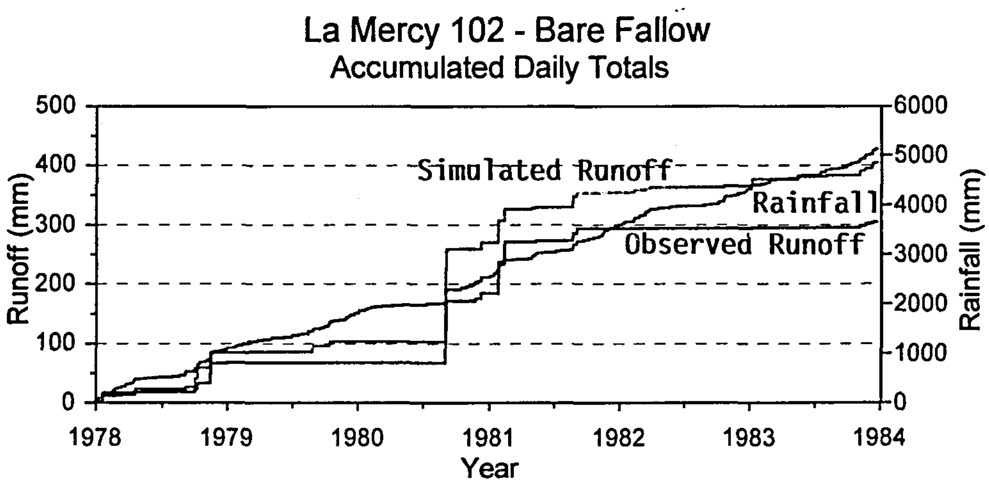


Figure 6.1.3 Accumulated daily values: Catchment 102, bare fallow land cover

The accumulated daily values for Catchment 102 under sugarcane land cover are shown in Figure 6.1.4. Good agreement between the observed and simulated runoff is evident for a sugarcane land cover in Catchment 102. However, the runoff is slightly under-simulated during the drought years (1990-1994) and then over-simulated during 1995. The total simulated runoff for this period of simulation is 1950 mm, compared with the observed runoff total of 1872 mm. Overall, runoff is over-simulated by only 4 %.

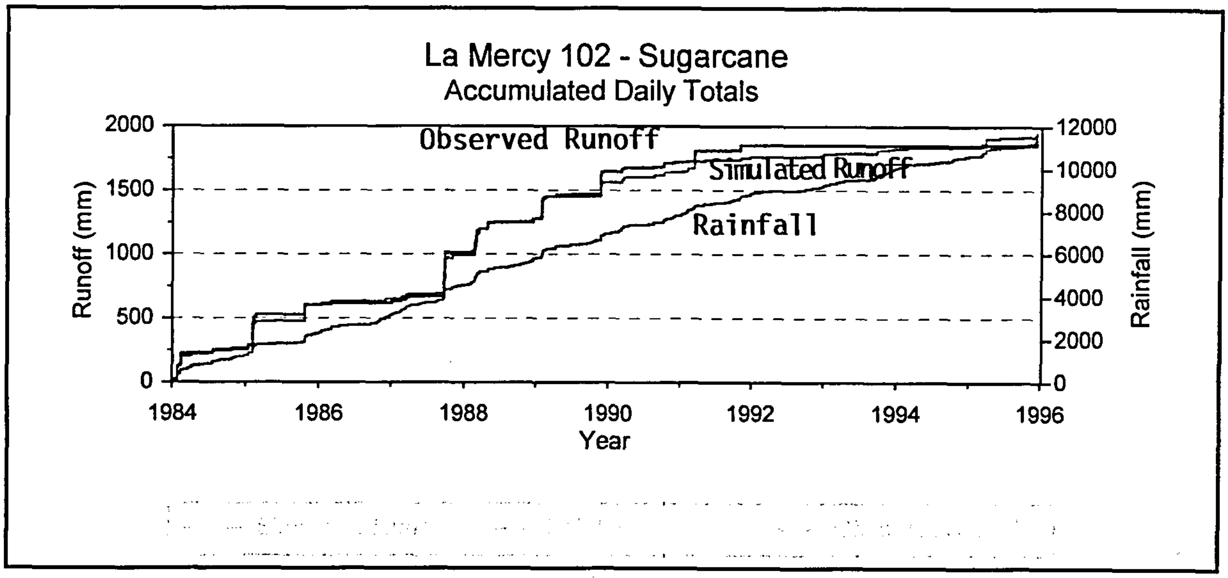


Figure 6.1.4 Accumulated daily values: Catchment 102, sugarcane land cover

6.1.2.3 Catchment 103

The accumulated daily values for Catchment 103 under bare fallow conditions are shown in Figure 6.1.5. Similar to Catchment 102, the initial estimation of input variables for bare fallow conditions in Catchment 103 resulted in a consistent over-simulation of runoff. Again, both large and small events were over-simulated and small rainfall events, for which no runoff was observed, were producing simulated runoff. The total simulated runoff for this simulation is 406 mm, compared with an observed runoff total of 320 mm. This represents an overall over-simulation of 21.1 %

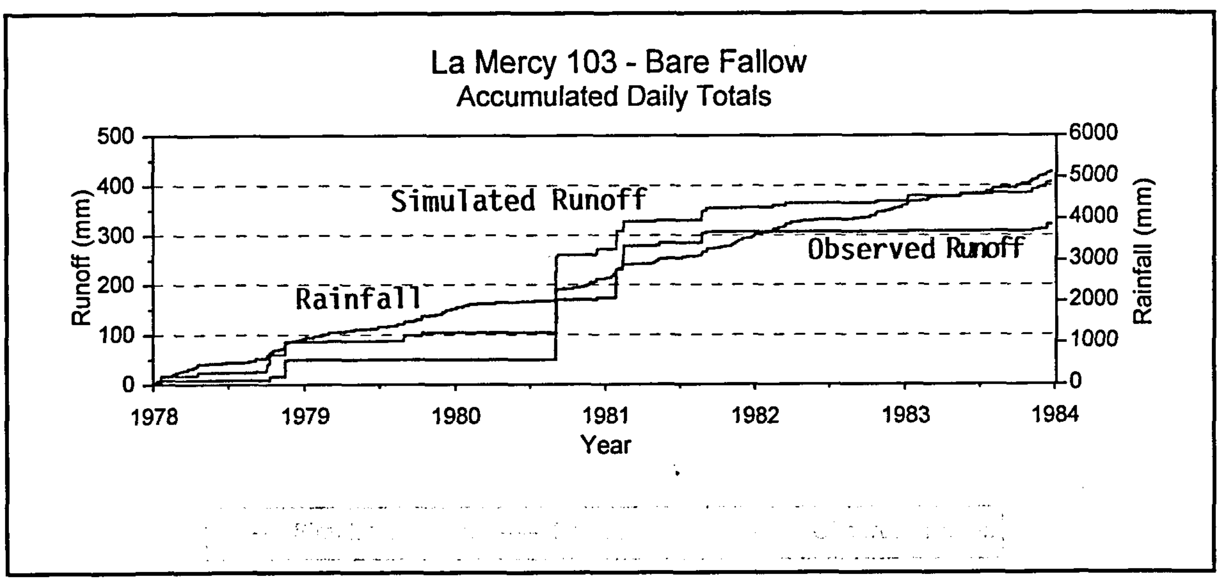


Figure 6.1.5 Accumulated daily values: Catchment 103, bare fallow land cover

Although Catchments 102 and 103 appear to behave similarly under bare fallow conditions, this was not the case under a sugarcane land cover, as shown in Figure 6.1.6. Catchment 103 differs from Catchment 102 in that it contains no conservation structures. For Catchment 103, runoff was over-simulated, particularly during the drought years of 1991 to 1994 where runoff was simulated whilst little observed runoff is indicated. The total simulated runoff for the simulation period is 2112 mm, compared with total observed runoff of 1640 mm. This represents an overall over- simulation of 22.4%.

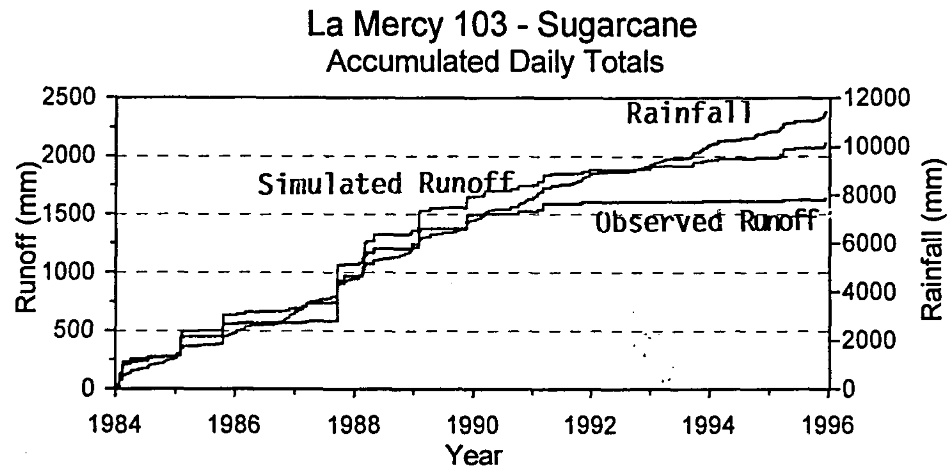


Figure 6.1.6 Accumulated daily values: Catchment 103, sugarcane land cover

6.1.2.4 Catchment 104

As shown in Figure 6.1.7, the initial estimates of the input variables for Catchment 104 under bare fallow conditions resulted in a significant under-simulation of runoff. This is particularly evident in 1984 and 1985, where a single large observed event was not well simulated. Half of this catchment is bare fallow, which may have a larger influence on runoff production than expected during large events. Another explanation for the poor simulation could be that the observed runoff data in Catchment 104 are erroneous. As discussed in Chapter 4, the nature of the observed data appeared to change during 1981. This conclusion is in agreement with the simulation results shown in Figure 6.1.7. The total simulated runoff for Catchment 104 for this simulation period is 643 mm, compared with a total observed runoff of 864 mm. This represents a significant under-simulation of 26 %.

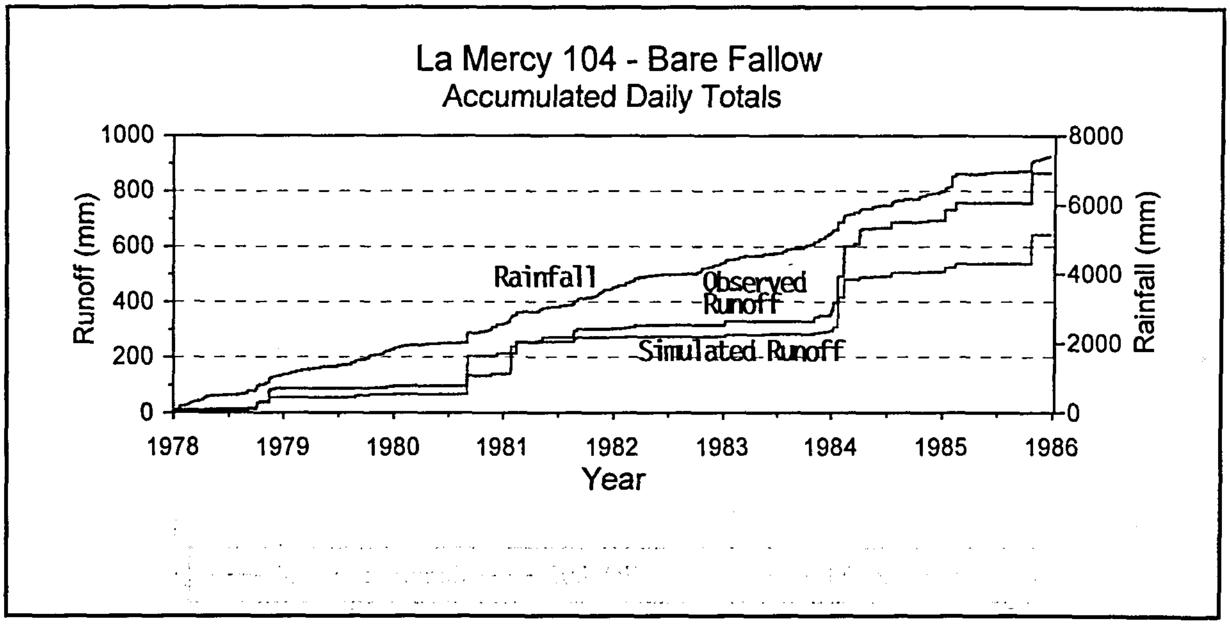


Figure 6.1.7 Accumulated daily values: Catchment 104, bare fallow land cover

Under a sugarcane land cover in Catchment 104, runoff is again significantly under-simulated for the initial estimates of the input variables, as shown in Figure 6.1.8. The under-simulation occurs throughout the period considered and again may be due to the larger than expected influence of the bare fallow portion of this catchment or the possibly erroneous observed runoff data. Total simulated runoff for Catchment 104 for this simulation period is 1019 mm, compared with an observed total of 1505 mm. This represents an overall under-simulation of 32 %.

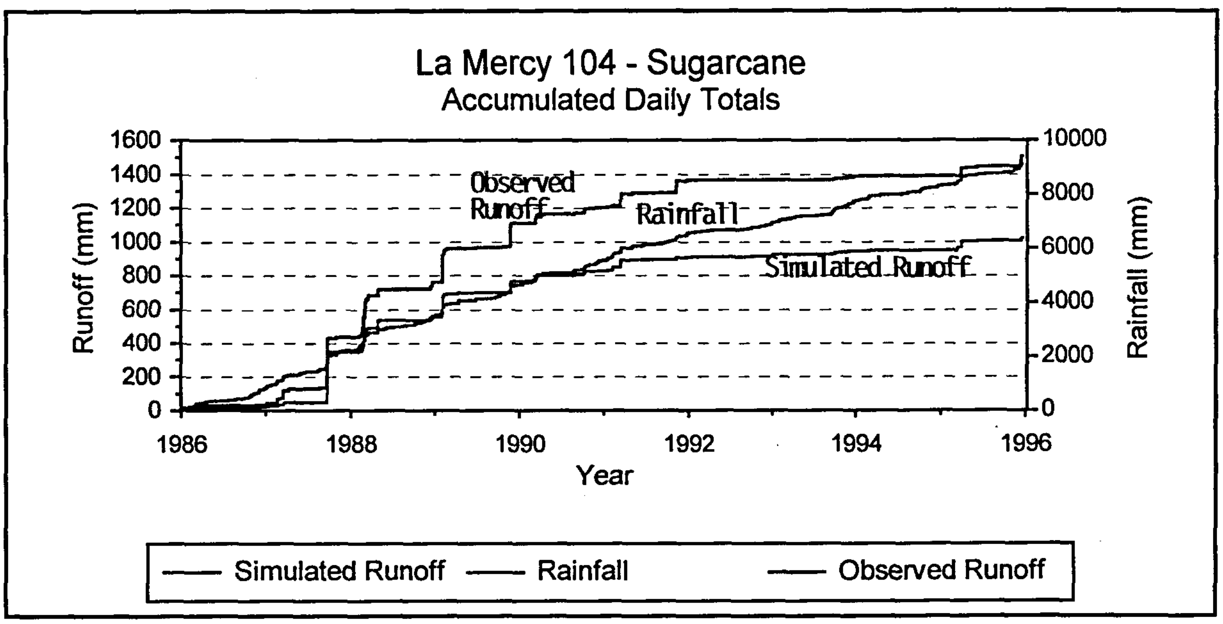


Figure 6.1.8 Accumulated daily values: Catchment 104, sugarcane land cover

6.1.3 Sugarcane Decision Support System (SCDSS)

Subsequent to the above simulations, which were based on initial estimation of input variables and parameters, the input to the model was amended to better simulate the observed runoff data from the La Mercy catchments. The adjustments were made as improved understanding of the hydrology was gained from the simulations and were founded on hydrological concepts consistent with the physical conceptual modelling philosophy used in the *ACRU* model.

It was postulated that bare fallow conditions, where the topsoil had been disturbed by ploughing and was regularly rotavated to keep it free of vegetation, would result in increased infiltration and storage in the topsoil, with a subsequent increased drainage to the subsoil. ABRESP, the 'saturated' redistribution fraction from the top- to the subsoil, was consequently increased for the simulations of bare fallow conditions. An ABRESP value of 0.7 (from the previous value of 0.25) was thus adopted for bare fallow conditions.

The generation of storm flow is particularly sensitive to the effective depth of soil for storm flow response (SMDDEP) parameter. According to Smithers, Schulze, Lecler, Kienzle, Lorentz and Kunz (1995), SMDDEP is a function of vegetation, drainage, climate and rainfall intensity. In addition, it was postulated that SMDDEP is also a function of catchment steepness, with more storm flow expected from steeper catchments.

A value of SMDDEP=0.30 was used in the initial simulations for bare fallow conditions on Catchments 102, 103 and 104 where a lack of vegetal cover implied less impedance of surface runoff and thus decreased infiltration. Owing to the steepness of Catchment 101, a reduced value of SMDDEP, 0.25, was used for bare fallow land cover. For a sugarcane land cover, SMDDEP was increased to 0.35 to account for the dense biomass. The conditions under which ABRESP and SMDDEP are adjusted are summarized below.

ABRESP : Bare fallow   Sugarcane (full cover)
0.7<----------------->0.25

SMDDEP : Bare fallow (Slope >25%)   Bare fallow (Slope <25%)   Sugarcane
| | |
0.25 <----------------0.30---------------->0.35

Different management practices were also accounted for by varying the coefficient of initial abstraction, COIAM. This coefficient was increased under bare fallow conditions owing to surface roughness and thus increased infiltration and depression storage. COIAM is hypothesised to be higher under minimum tillage practice than conventional tillage owing to increased litter on the ground surface which prevents compaction of the soil by raindrops, retards surface flow and thus increases infiltration. COIAM is decreased in the absence of conservation structures as it is hypothesised that these structures provide increased opportunity for infiltration. Where minimum tillage is practised in the presence of conservation structures and spillover roads, COIAM was increased further. The conditions under which COIAM were varied are summarised below.

COIAM :

Sugarcane (Minimum tillage + Conservation structures) | Sugarcane (Conventional tillage) | Sugarcane (No Structures)

0.35 <---------- 0.40-------------- - 0.30 ----------- 0.25-------------------> 0.20

Bare fallow (0.35) | Sugarcane (Minimum tillage) (0.30)

6.1.4 Final Results

The above parameter adjustments generally improved the simulation of runoff, and may serve as a guide in subsequent simulations of catchments which have a sugarcane land cover. However, it is noted that the use of the amended parameters, which are generalised over the four catchments, did not improve the simulations on all the catchments.

After parameter adjustments as discussed above, a final set of input values was decided on for each of the four catchments. As indicated in Table 6.1.5, the only changes from the initial input selections are SMDDEP and ABRESP under bare fallow conditions and COIAM under sugarcane land cover.

Table 6.1.5: Final input values for SMDDEP, COIAM and ABRESP

Parameter	Cover	Catchment 101	Catchment 102	Catchment 103	Catchment 104
SMDDEP	Bare Fallow	0.25	0.30	0.30	0.30
SMDDEP	Sugarcane	0.35	0.35	0.35	0.35
ABRESP	Bare Fallow	0.70	0.70	0.70	0.70
COIAM	Sugarcane	0.40	0.25	0.20	0.25

6.1.4.1 Catchment 101

As shown in Figure 6.1.9, an improved simulation of runoff from bare fallow conditions in Catchment 101 was achieved using the amended set of input variables and parameters. Total simulated runoff for the period simulated is 411 mm, compared with a total observed runoff of 419 mm for the same period. This represents an overall under-simulation of 2 %. Although simulated and observed runoff totals for the simulation period are in close agreement, it is apparent that several individual events are not well simulated. It can be seen in Figure 6.1.9 that a large event in 1980 was under-simulated and a number of smaller events during 1981 and 1982 were over-simulated. The characteristics of some events which were poorly simulated under bare fallow conditions in Catchment 101 are listed in Table 6.1.6.

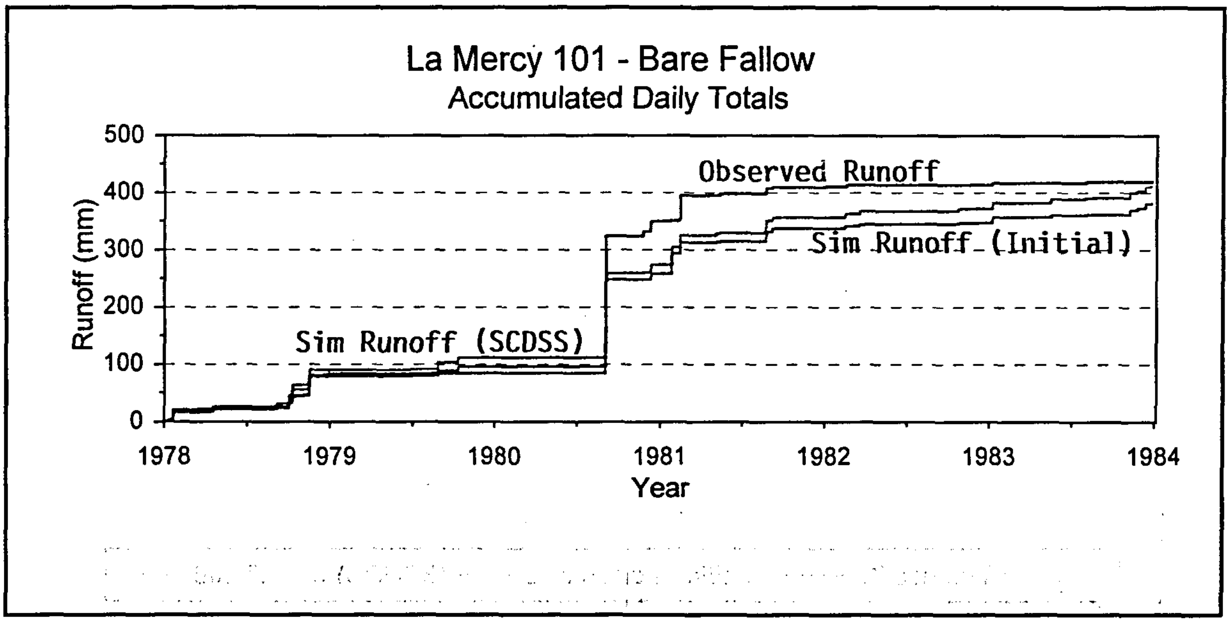


Figure 6.1.9 Accumulated runoff simulated using both SCDSS and initial parameters: Catchment 101, bare fallow land cover

Event 3 in Table 6.1.6 (7-11/09/80) had a total depth of rainfall of 273.6 mm, and a total simulated runoff depth of 148.0 mm and total observed runoff of 238.9 mm. Runoff thus appears to be significantly under simulated for this event. The observed total for the event does, however, seem unusually large, in spite of a high maximum intensity rainfall of 43.4 mm.h^{-1} on one day of the event. The other events extracted and listed in Table 6.1.6 show little or no observed runoff despite relatively large rainfall totals. The model is simulating runoff for these events, resulting in a number of events being over-simulated. It is postulated that the model is not abstracting enough rainfall prior to the commencement of surface runoff. The effect of excluding the events listed in Table 6.1.6 from the simulation is illustrated in Figure 6.1.10.

Table 6.1.6: Characteristics of some events which were simulated poorly under bare fallow conditions in Catchment 101

Event No.	Date	Rainfall (mm)	Simulated Runoff (mm)	Observed Runoff (mm)	Maximum Intensity (mm.h^{-1})	Total rain in preceding week (mm)	Catchment condition
1	01/09/79	57.6	10.7	0.0	19.5	0.0	Bare Fallow No structures
	02/09/79	4.8	1.1	0.0	2.3		
	03/09/79	2.4	0.1	0.0	0.8		
	04/09/79	0.4	0.0	0.0	0.2		
	Total	65.2	11.9	0.0			
2	14/10/79	28.0	0.1	0.0	6.4	10.8	Bare Fallow No structures
	15/10/79	40.1	6.6	0.0	15.0		
	16/10/79	0.4	0.7	0.0	0.4		
	17/10/79	0.0	0.1	0.0	0.0		
	18/10/79	0.0	0.0	0.0	0.0		
	Total	68.5	7.5	0.0			
3	07/09/80	200.4	102.6	27.0	43.4	4.3	Bare Fallow No structures
	08/09/80	70.1	40.9	211.3	10.7		
	09/09/80	3.1	4.1	0.6	1.3		
	10/09/80	0.0	0.4	0.0	0.0		
	11/09/80	0.0	0.0	0.0	0.0		
	Total	273.6	148.0	238.9			

Continued

Event No.	Date	Rainfall (mm)	Simulated Runoff (mm)	Observed Runoff (mm)	Maximum Intensity (mm.h-1)	Total rain in preceding week (mm)	Catchment condition
4	28/08/81	21.0	0.0	0.4	NR*	2.0	Bare Fallow
	29/08/81	69.0	19.5	9.1	NR*		No structures
	30/08/81	8.0	1.9	0.0	NR*		
	31/08/81	0.0	0.2	0.0	0.0		
	01/09/81	0.3	0.0	0.0	NR*		
	Total	98.3	21.6	9.5			
5	12/01/83	6.0	0.0	0.0	M*	0.0	Bare Fallow
	13/01/83	42.6	4.6	0.0	M*		No structures
	14/01/83	32.8	5.1	3.0	M*		
	15/01/83	0.0	0.5	0.0	M*		
	16/01/83	0.0	0.1	0.0	M*		
	17/01/83	0.0	0.0	0.0	M*		
	Total	81.4	10.3	3.0			

*NR = No rainfall in digitised data
*M = Digitised data missing

The exclusion of the large event of 7-11/09/80 results in a large improvement in the simulation of runoff for the period prior to 1982. However, for the period 1982 - 1984, runoff was simulated for numerous small rainfall events and little or no observed runoff recorded. These smaller events have characteristics similar to those shown in Table 6.1.6.

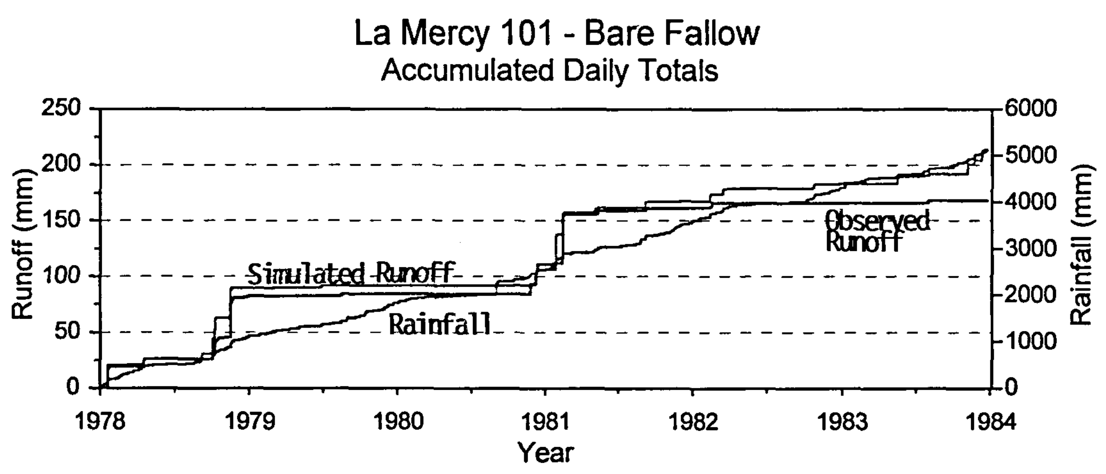


Figure 6.1.10: **Accumulated values simulated using SCDSS: Catchment 101, bare fallow land cover with events listed in Table 6.1.6 excluded**

The simulation of runoff from a sugarcane land cover in Catchment 101, using the SCDSS and initial parameters, is illustrated in Figure 6.1.11. The SCDSS resulted in an improved simulation of runoff for a sugarcane land cover in Catchment 101. Total simulated runoff for the simulation period is 1406 mm, compared with an observed total of 1198 mm. This represents a total over-simulation of 15%. The characteristics of some events which were poorly simulated are listed in Table 6.1.7.

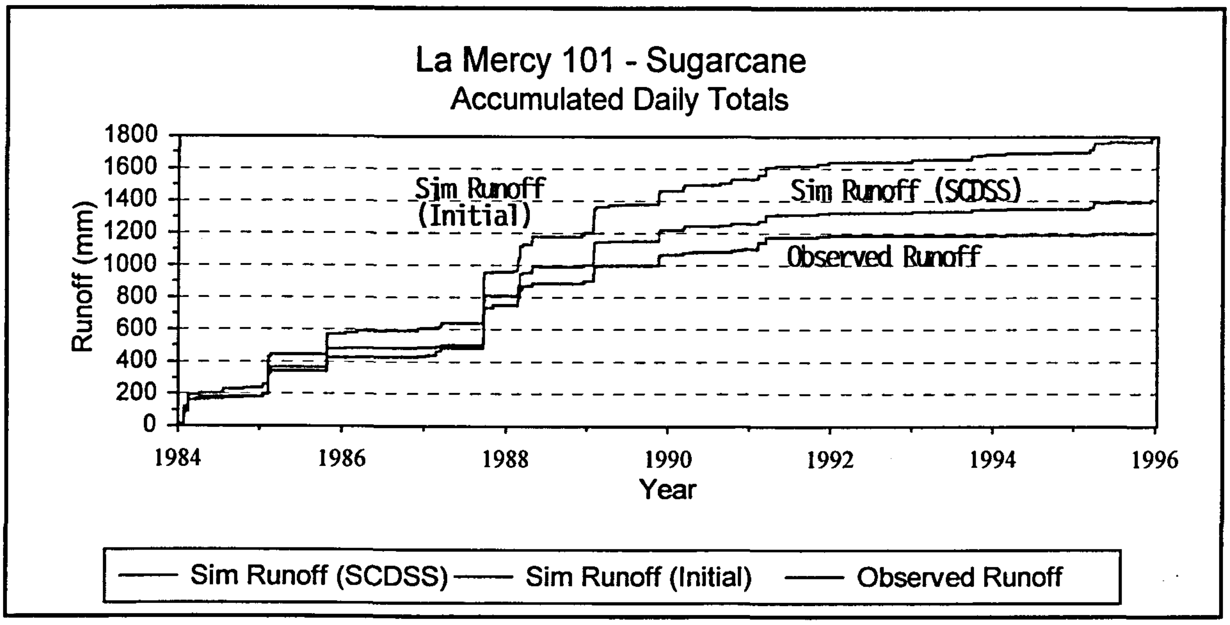


Figure 6.1.11: Accumulated values simulated using both SCDSS and initial parameters: Catchment 101, sugarcane land cover

Table 6.1.7: Characteristics of some poorly simulated events in the simulation of a sugarcane land cover in Catchment 101

Event No.	Date	Rainfall (mm)	Simulated Runoff (mm)	Observed Runoff (mm)	Maximum Intensity (mm.h^{-1})	Total rain in preceding week (mm)	Catchment condition
1	29/10/85	27.1	0.0	0.0	3.1	0	Panels 1.2 and 4 were harvested in 09/85
	30/10/85	157.5	69.9	6.3	47.8		
	31/10/85	50.2	36.3	66.3	19.4		
	01/11/85	14.4	6.7	6.9	3.5		
	02/11/85	0.0	0.7	1.3	0.0		
	03/11/85	0.0	0.1	0.0	0.0		
	04/11/85	3.1	0.0	0.0	1.8		
	Total	252.3	113.7	80.8			
2	25/09/87	1.9	0.0	0.0	1.1	30.1	Panel 4 harvested and burnt 29/9/87
	26/09/87	74.1	10.8	6.4	12.6		
	27/09/87	108.1	62.8	43.6	7.7		
	28/09/87	203.8	174.8	144.3	28.5		Panels 1,2 and 5 were harvested and burnt in 04/87
	29/09/87	51.8	50.5	52.8	15.9		
	30/09/87	0.0	5.1	0.5	0.0		
	01/10/87	6.0	0.5	0.0	2.8		
	02/10/87	2.4	0.5	0.0	1.9		
	03/10/87	0 .0	0.0	0.0	0.0		
	Total	448.1	305.0	247.6			

Continued

Event No.	Date	Rainfall (mm)	Simulated Runoff (mm)	Observed Runoff (mm)	Maximu m Intensity (mm.h-1)	Total rain in preceding week (mm)	Catchment condition
3	01/02/89	0.4	0.0	0.0	0.4	0	Fully planted
	02/02/89	4.2	0.0	0.0	3.8		
	03/02/89	87.1	13.1	0.6	8.8		
	04/02/89	13.8	1.3	0.0	2.0		
	05/02/89	29.5	4.9	0.0	12.7		
	06/02/89	58.5	30.5	12.2	16.3		
	07/02/89	99.4	77.5	76.9	48.0		
	08/02/89	0.0	7.8	0.7	0.0		
	09/02/89	0.0	0.8	0.0	0.0		
	10/02/89	6.3	0.1	0.0	6.3		
	11/02/89	0.0	0.0	0.0	0.0		
	Total	299.2	136.0	90.4			
4	09/04/95	68.2	6.7	3.8	31.8	0	Fully planted
	10/04/95	57.4	19.5	6.6	12.5		
	11/04/95	1.0	1.9	0.0	0.7		
	10/04/95	0 .0	0.2	0.0	0.0		
	13/04/95	0 .0	0.0	0.0	0.0		
	Total	126.6	28.3	10.4	45.0		

In the examples listed in Table 6.1.7, rainfall events in excess of 100 mm produced relatively small observed runoff response and hence both large, intense events and smaller events were over-simulated. It is apparent, that for a sugarcane land cover, the model is not accounting correctly for large rainfall abstractions prior to surface runoff commencement. The effect of excluding the events listed in Table 6.1.7 from the simulation is shown in Figure 6.1.12. Even with some events excluded, Figure 6.1.12 illustrates that the model is simulating runoff for numerous small rainfall events, with no or little observed runoff recorded for these events.

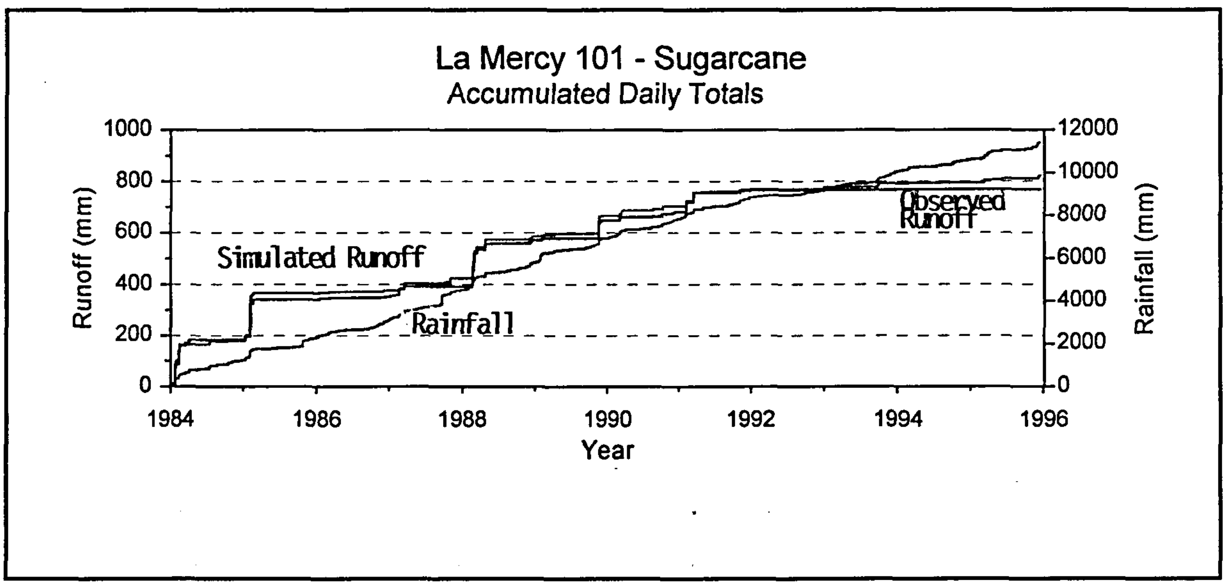


Figure 6.1.12: **Accumulated values simulated using SCDSS: Catchment 101, sugarcane land cover, with events listed in Table 6.1.7 excluded**

6.1.4.2 Catchment 102

As shown in Figure 6.1.13, the runoff simulation for bare fallow conditions in Catchment 102 improved when the SCDSS was used to select input variables. Total simulated runoff for the simulation period is 335 mm, compared with the observed total of 305 mm. This represents an overall over-simulation of 9 %. Several individual events are not well simulated in spite of the good agreement between simulated and observed runoff totals. Table 6.1.8 contains the characteristics some of the events which are simulated poorly.

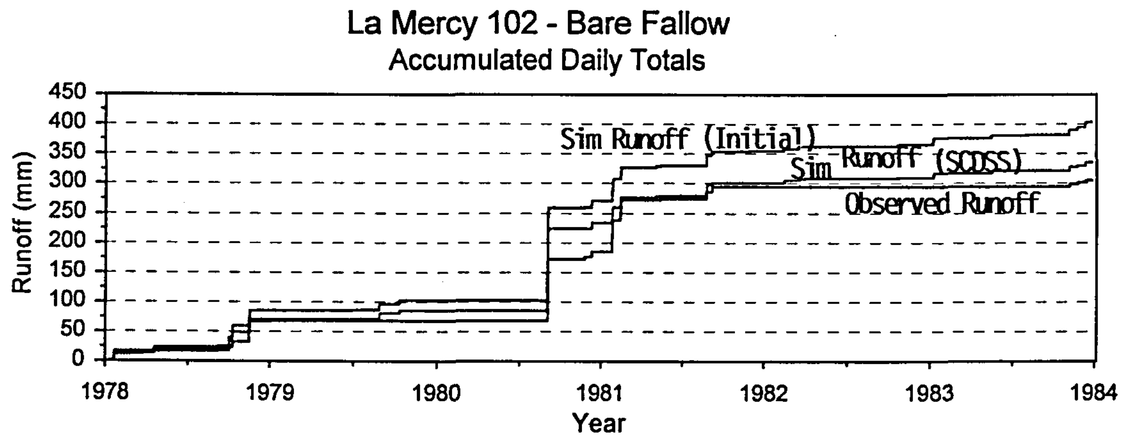


Figure 6.1.13: **Accumulated runoff simulated using both SCDSS and initial parameters: Catchment 102, bare fallow land cover**

Table 6.1.8: Characteristics of some poorly simulated events in the simulation of bare fallow conditions in Catchment 102

Event No.	Date	Rainfall (mm)	Simulated Runoff (mm)	Observed Runoff (mm)	Maximu m Intensity (mm.h^{-1})	Total rain in preceding week (mm)	Catchment condition
1	04/10/78	18.3	0.0	0.0	7.2	0.0	Bare Fallow
	05/10/78	58.1	10.1	3.3	11.2		No structures
	06/10/78	1.5	1.0	1.8	0.9		
	07/10/78	0.0	0.1	0.0	0.0		
	08/10/78	0.0	0.0	0.0	0.0		
	Total	77.9	11.1	5.1			
2	01/09/79	57.6	8.1	0.0	19.5	0.0	Bare Fallow
	02/09/79	4.8	0.8	0.0	2.3		No structures
	03/09/79	2.4	0.1	0.0	0.8		
	04/09/79	0.4	0.0	0.0	0.2		
	Total	65.2	9.0	0.0			

Continued

Event No.	Date	Rainfall (mm)	Simulated Runoff (mm)	Observed Runoff (mm)	Maximu m Intensity ($mm.h^{-1}$)	Total rain in preceding week (mm)	Catchment condition
3	07/09/80	200.4	94.4	9.4	43.4	4.3	Bare Fallow
	08/09/80	70.1	39.2	94.2	10.7		No structures
	09/09/80	3.1	3.9	0.0	1.3		
	10/09/80	0.0	0.4	0.0	0.0		
	11/09/80	0.0	0.0	0.0	0.0		
	12/09/80	2.3	0.0	0.0	NR*		
	Total	275.9	137.9	103.6			
4	30/01/81	36.0	2.2	1.1	NR*	43.6	Bare Fallow
	31/01/81	66.9	22.5	52.2	NR*		No stuctures
	01/02/81	0.0	2.3	0.0	0.0		
	02/02/81	2.6	0.2	0.0	0.6		
	03/02/81	4.5	0.0	0.0	2.1		
	Total	110.0	27.2	53.3			
5	16/02/81	24.6	0.0	2.8	15.9	3.6	Bare Fallow
	17/02/81	0.0	0.0	0.0	0.0		No structures
	18/02/81	62.8	14.6	23.9	NR*		
	19/02/81	1.5	1.5	6.4	0.7		
	20/02/81	0.0	0.2	0.0	0		
	21/02/81	0.0	0.0	0.0	0		
	Total	88.9	16.3	33.1			
6	22/05/83	51.6	3.7	0.0	M*	15.3	Bare Fallow
	23/05/83	0.0	0.4	0.0	0		No structures
	24/05/83	0.0	0.0	0.0	0		
	Total	51.6	4.1	0.0			

*NR = No rainfall in digitised data
*M = Digitised data missing

Generally, individual events were over-simulated, with some rainfall events in excess of 50 mm producing no observed runoff. Some under-simulations were also evident, such as the events from 30/01/81 - 03/02181(event 4 in Table 6.1.8) and 16/02/81 - 21/02/81 (event 5 in Table 6.1.8). Rainfall intensities are not available for these events and antecedent moisture conditions are variable. It is suspected that the high observed runoff on the 31/01/81 may be the result of a high rainfall intensity, which is not accounted for in daily simulations of the model. The effect of excluding these events from the simulation is illustrated in Figure 6.1.14. The exclusion of the above events and the removal of the large event of the 07-12/9/80 (event 3 in Table 6.1.8) were most noticeable. As was the case with Catchment 101, very little observed runoff is was measured between 1982 and 1984, although a number of runoff events were simulated during this period, thus indicating that the model did not adequately simulate the initial abstractions prior to the commencement of storm flow.

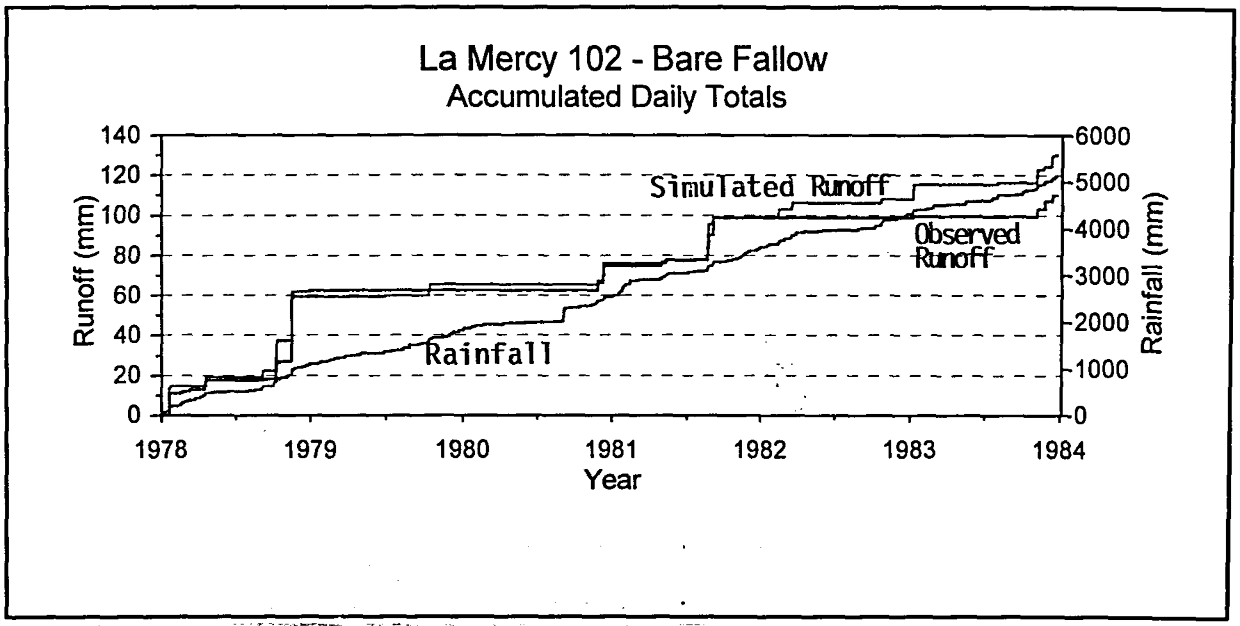


Figure 6.1.14: **Accumulated values simulated using SCDSS: Catchment 102, bare fallow land cover , with events listed in Table 6.1.8 excluded**

The simulation of runoff from a sugarcane land cover using the SCDSS for Catchment 102, is illustrated in Figure 6.1.15. Total observed runoff for the period January 1984 - December 1995 was 1872 mm, compared with a total simulated runoff of 1720 mm. This represents an overall under-simulation of 8.1 %. Comparison with Figure 6.1.4 shows that the use of the SCDSS did not improve the simulation in this case. However, the SCDSS suggests values, based on the current understanding of the hydrological processes, that are conceptually consistent for all cases.

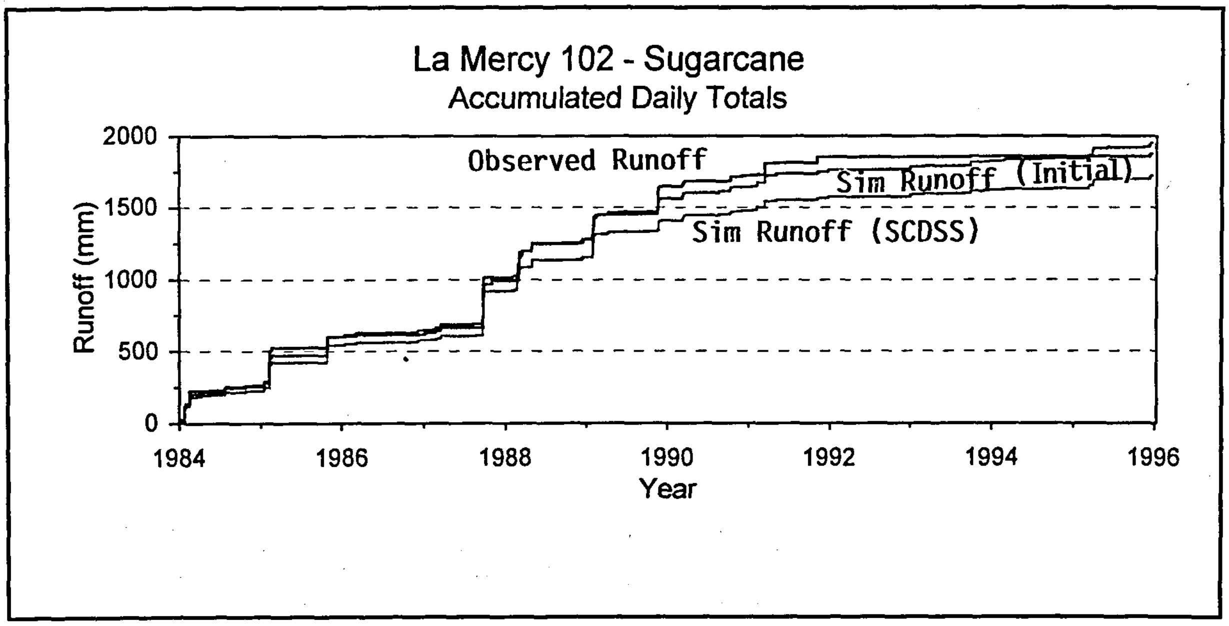


Figure 6.1.15: **Accumulated values simulated using both SCDSS and initial parameters - Catchment 102, sugarcane land cover**

Selected individual events which were not well simulated, were extracted and are listed in Table 6.1.9. The events listed in Table 6.1.9 show different dynamics to those from Catchment 102 under bare fallow conditions and from the simulations in Catchment 101. In this case, surface runoff is generally being under-simulated. Some events are over-simulated and there is no clear relationship between either the rainfall intensity or catchment antecedent soil moisture conditions on runoff response. The simulations excluding the events listed in Table 6.1.9 are illustrated in Figure 6.1.16.

Table 6.1.9 Characteristics of events which were simulated poorly for sugarcane land cover in Catchment 102

Event No.	Date	Rainfall (mm)	Simulated Runoff (mm)	Observed Runoff (mm)	Maximum Intensity (mm.h^{-1})	Total rain in preceding week (mm)	Catchment condition
1	17/02/84	25.3	0 .0	0.2	NR*	0	Bare Fallow
	18/02/84	88.5	28.8	48.5	NR*		
	19/02/84	59.8	32.4	44.1	NR*		
	20/02/84	4.7	3.2	0.0	4.7		
	21/02/84	3.8	0.3	0.0	1.3		
	22/02/84	0.0	0.0	0.0	0.0		
	Total	182.1	64.7	92.8			
2	07/02/85	38.4	1.2	1.2	21	0	Fully planted in 09/84
	08/02/85	28.1	1.3	3.9	2.8		
	09/02/85	157.3	97.1	127.1	33.9		
	10/02/85	71.1	57.4	75.5	14.6		
	11/02/85	0 .0	5.7	5.8	0.0		
	12/02/85	0.0	0.6	0.0	0.0		
	13/02/85	2.3	0.1	0.0	1.6		
	14/02/85	2.9	0.0	0.0	1.0		
	Total	300.1	163.4	213.5			
3	21/03/88	10.3	0 .0	0.0	M*	32.8	Fully planted
	22/03/88	43.4	8.2	31.0	M*		
	23/03/88	0.0	0.8	0.4	0.0		
	24/03/88	0.0	0.1	0.0	0.0		
	25/03/88	0.0	0.0	0.0	0.0		
	Total	53.7	9.1	31.5			
4	26/11/89	0.0	0 .0	5.3	0.0	6.6	Fully planted Last harvested in 05/89
	27/11/89	0.0	0 .0	2.1	0.0		
	28/11/89	8.3	0 .0	0.0	3.6		
	29/11/89	94.5	25.4	67.5	23.8		
	30/11/89	68.6	33.0	76.1	18.6		
	01/12/89	29.9	14.4	35.4	13.2		
	02/12/89	0.0	1.4	0.6	0.0		
	03/12/89	2.7	0.1	0.0	1.9		
	04/12/89	0.0	0.0	0.0	0.0		
	05/12/89	0.8	0 .0	0.0	0.8		
	Total	204.8	74.3	187.0			
5	15/02/91	28.0	0.0	0.1	17.9	15	Fully planted
	16/02/91	67.5	17.6	3.8	15.3		
	17/02/91	3.5	1.8	0.0	1.8		
	18/02/91	21.2	2.0	2.7	5.8		
	19/02/91	8.0	0.2	1.0	1.9		
	20/02/91	0.0	0.0	0.1	0.0		
	Total	128.2	21.6	7.7			

Continued

Event No.	Date	Rainfall (mm)	Simulated Runoff (mm)	Observed Runoff (mm)	Maximum Intensity (mm.h-1)	Total rain in preceding week (mm)	Catchment condition
6	24/03/91	65.4	11.4	11.0	37.1	17.6	Fully planted
	25/03/91	70.8	30.6	65.6	17.8		
	26/03/91	0.0	3.1	1.7	0.0		
	27/03/91	0.0	0.3	0.0	0.0		
	28/03/91	0.0	0.0	0.0	0.0		
	Total	136.2	45.4	78.3			
7	23/03/95	85.5	18.9	0.0	NR*	0	Fully planted
	24/03/95	7.0	1.9	0.0	3.1		
	24/03/95	5.7	0.2	0.0	4.2		
	26/03/95	0.0	0.0	0.0	0		
	27/03/95	3.1	0.0	0.0	2.9		
	Total	101.3	21.0	0.0			
8	09/04/95	68.2	12.2	0.5	31.8	0	Fully planted
	10/04/95	57.4	21.4	4.7	12.5		
	11/04/95	1.0	2.1	0.0	0.7		
	12/04/95	0.0	0.2	0.0	0.0		
	13/04/95	0.0	0.0	0.0	0.0		
	14/04/95	0.0	0 .0	0.0	0.0		
	15/04/95	15.0	0.0	0.0	NR*		
	Total	141.6	35.9	5.2			

*NR = No rainfall in digitised data
*M = Digitised data missing

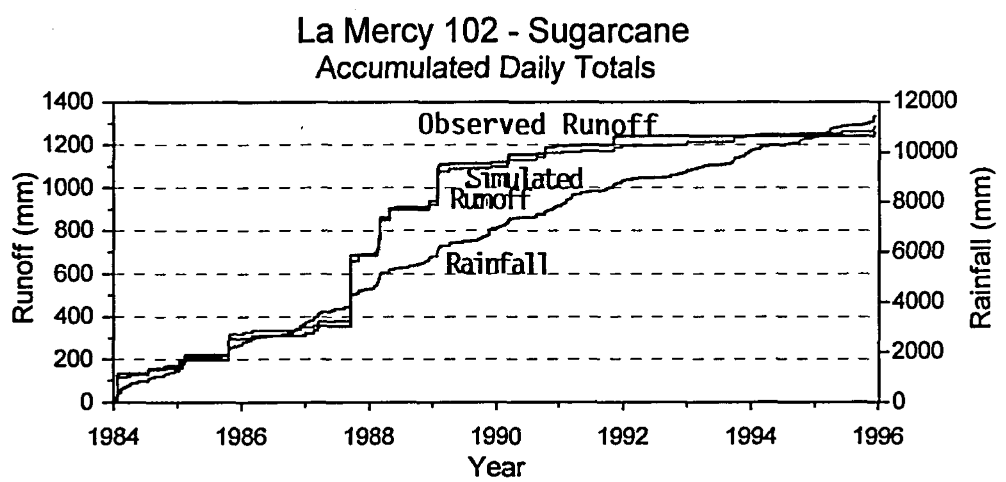


Figure 6.1.16: **Accumulated values simulated using SCDSS - Catchment 102, sugarcane land cover with events listed in Table 6.1.9 excluded**

6.1.4.3 Catchment 103

As shown in Figure 6.1.17, an improved simulation was achieved when the SCDSS was used for Catchment 103 under bare fallow conditions. Total simulated runoff for the period 1978 - 1984 was 337 mm, compared with the observed total of 320 mm. This represents an overall over- simulation of 5.3 %. Again, although overall totals are in close agreement, it can be seen that several individual events are poorly simulated. Details of the events which were poorly simulated are given in Table 6.1.10.

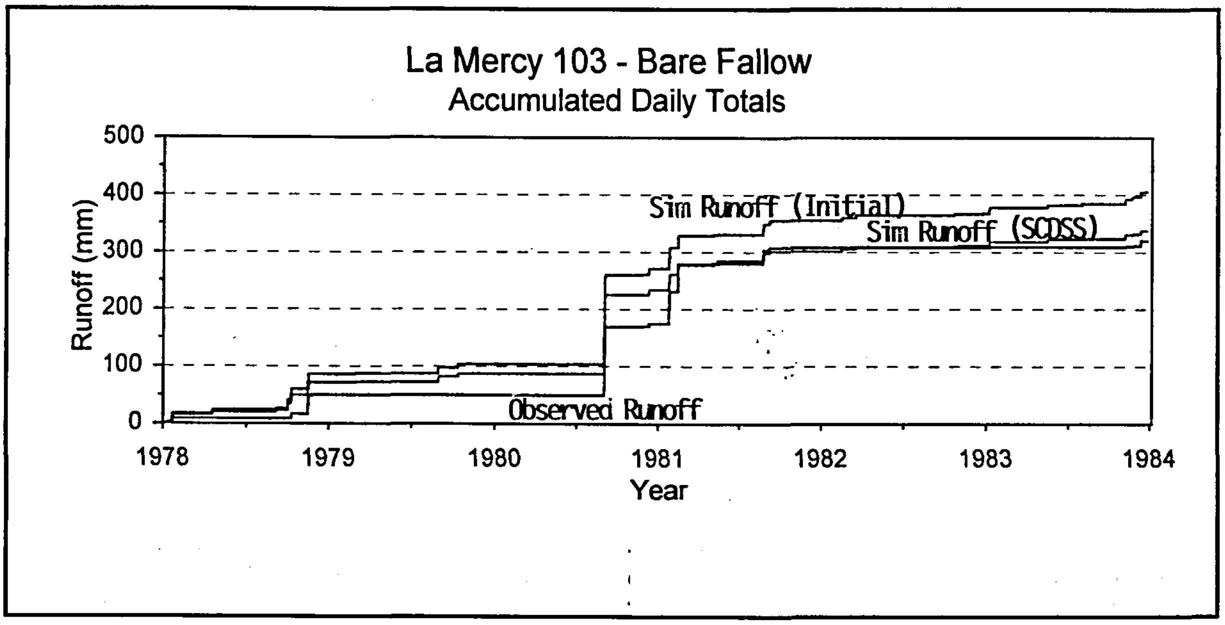


Figure 6.1.17: Accumulated runoff simulated using both SCDSS and initial parameters: Catchment 103, bare fallow land cover

Table 6.1.10: Characteristics of selected events which were poorly simulated under bare fallow conditions in Catchment 103

Event No.	Date	Rainfall (mm)	Simulated Runoff (mm)	Observed Runoff (mm)	Maximum Intensity ($mm.h^{-1}$)	Total rain in preceding week (mm)	Catchment condition
1	19/01/78	11.8	0.0	0.0	9.5	46.4	Bare Fallow No structures
	20/01/78	0.5	0.0	0.0	0.2		
	21/01/78	8.4	0.0	0.0	4.7		
	22/01/78	17.5	0.0	0.0	7.4		
	23/01/78	53.6	11.4	7.7	14.3		
	24/01/78	0.0	1.14	0.0	0.0		
	25/01/78	4.8	0.1	0.0	1.5		
	26/01/78	0.0	0.0	0.0	0.0		
	27/01/78	2.2	0.0	0.0	1.0		
	Total	98.8	12.6	7.7			

Continued

Event No.	Date	Rainfall (mm)	Simulated Runoff (mm)	Observed Runoff (mm)	Maximum Intensity ($mm.h^{-1}$)	Total rain in preceding week (mm)	Catchment condition
2	22/04/78	41.5	4.2	0.0	17.5	30.8	Bare Fallow No structures
	23/04/78	0.1	0.4	0.0	0.1		
	24/04/78	0.0	0.0	0.0	0.0		
	Total	41.6	4.6	0.0			
3	04/10/78	18.3	0.0	0.0	7.2	0.0	Bare Fallow No structures
	05/10/78	58.1	10.2	0.1	11.2		
	06/10/78	1.5	1.0	0.1	0.9		
	07/10/78	0.0	0.1	0.0	0.0		
	08/10/78	0.0	0.0	0.0	0.0		
	Total	77.9	11.3	0.2			
4	11/10/78	12.9	0.0	0.0	5.7	77.9	Bare Fallow No structures
	12/10/78	54.0	13.8	6.6	12.7		
	13/10/78	1.7	1.4	0.7	1.7		
	14/10/78	0.0	0.1	0.0	0.0		
	15/10/78	0.0	0.0	0.0	0.0		
	16/10/78	8.5	0.0	0.0	3.5		
	Total	77.1	15.3	7.3			
5	01/09/79	57.6	8.2	0.0	19.5	0.9	Bare Fallow No structures
	02/09/79	4.8	0.8	0.0	2.3		
	03/09/79	2.4	0.1	0.0	0.8		
	04/09/79	0.4	0.0	0.0	0.2		
	Total	65.2	9.1	0.0			
6	07/09/80	200.4	94.4	30.9	43.4	4.3	Bare Fallow No structures
	08/09/80	70.1	39.4	88.4	10.7		
	09/09/80	3.1	3.9	0.0	1.3		
	Total	273.6	137.7	119.3			
7	30/01/81	36.0	2.2	3.0	NR*	43.6	Bare Fallow No structures
	31/01/81	66.9	22.6	54.0	NR*		
	01/02/81	0.0	2.3	0.0	0.0		
	02/02/81	2.6	0.2	0.0	0.6		
	03/02/81	4.5	0.0	0.0	2.1		
	Total	110.0	27.3	57.0			
8	18/02/81	62.8	14.7	32.7	NR*	28.2	Bare Fallow No structures
	19/02/81	1.5	1.5	14.1	0.7		
	20/02/81	0.0	0.2	0.0	0.0		
	21/02/81	0.0	0.0	0.0	0.0		
	Total	64.3	16.4	46.8			

*NR = No rainfall in digitised data

From Table 6.1.10 it is evident that in Catchment 103, under bare fallow conditions, surface runoff is generally under-simulated when dry antecedent soil moisture conditions prevail prior to rainfall events (events 3, 5 and 6). It is postulated that, under dry soil moisture conditions, the model is not abstracting sufficient rainfall prior to storm flow. With the exception of events 7 and 8, the model is performing adequately under wet antecedent soil moisture conditions. For both these events, rainfall intensity information is not available and hence the effect of rainfall intensity being the possible cause of the high runoff cannot be discounted. The high runoff response for event 7 is corroborated by observed runoff from Catchments 102 and 104 of 53 mm and 68 mm respectively. Similarly the runoff from Catchments 101, 102 and 104 for event 8 were 40 mm, 30 mm and 41 mm respectively. The cause of the high runoff response is thus suspected to be due to rainfall intensity, which is not directly accounted for in the model. The effect of excluding the events listed in Table 6.1.10 from the simulation is shown in Figure 6.1.18.

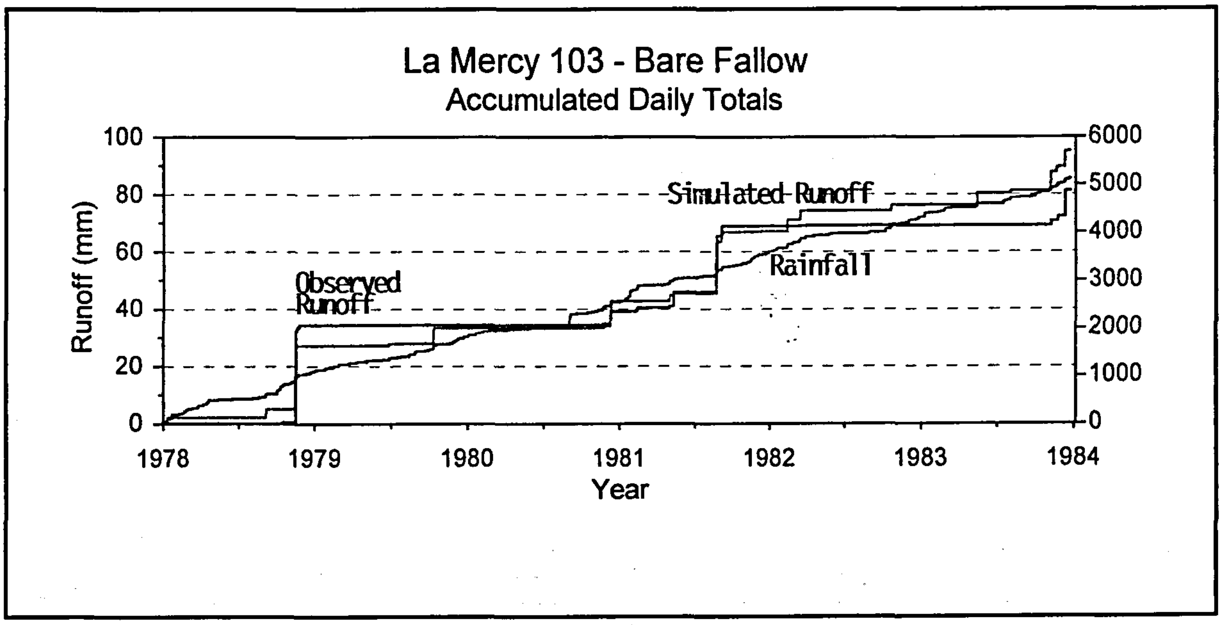


Figure 6.1.18: Accumulated values simulated using SCDSS: Catchment 103, bare fallow land cover, with events listed in Table 6.1.10 excluded

The improved simulation of surface runoff from a sugarcane land cover in Catchment 103 using the SCDSS is shown in Figure 6.1.19. Total observed runoff for the period January 1984 - December 1995 was 1639 mm and the simulated total was 1877 mm, which represents an overall over-simulation of 12.6 %. This is an improvement on the simulation using initial estimations of the model input. Table 6.1.11 lists the characteristics of some events which were poorly simulated.

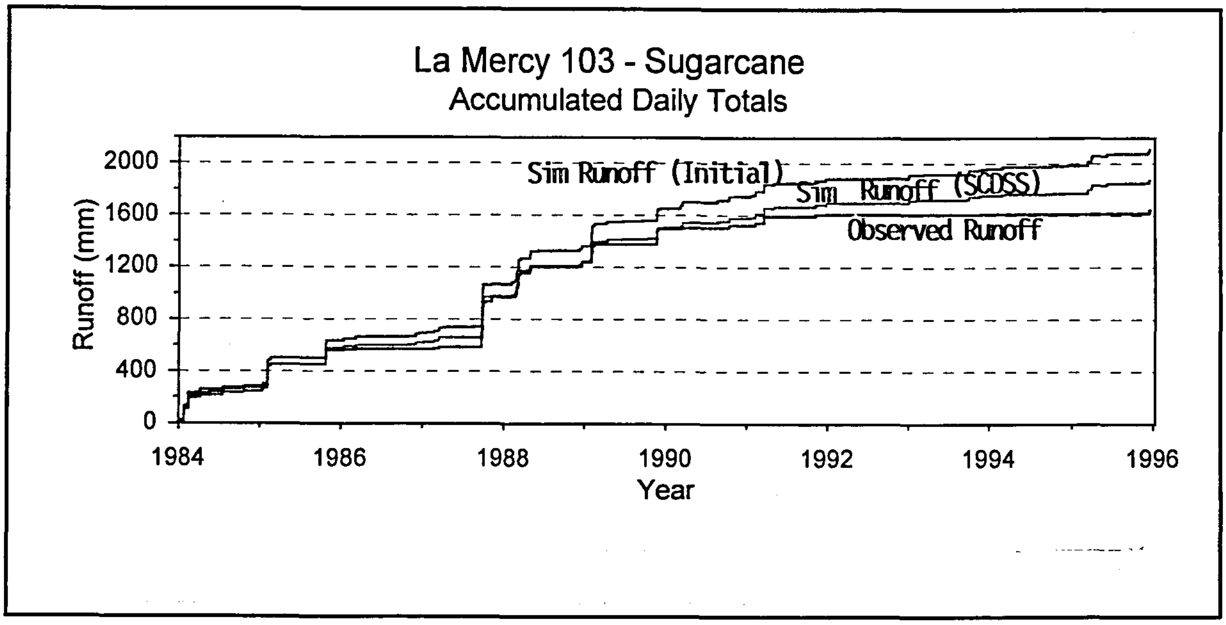


Figure 6.1.19: Accumulated runoff simulated using both SCDSS and initial parameters: Catchment 103, sugarcane land cover

Table 6.1.11: Characteristics of selected events which were poorly simulated for Catchment 103 under sugarcane land cover

Event No.	Date	Rainfall (mm)	Simulated Runoff (mm)	Observed Runoff (mm)	Maximum Intensity ($mm.h^{-1}$)	Total rain in preceding week (mm)	Catchment condition
1	15/03/90	54.0	8.8	0.4	27.8	21.3	No structures implemented in 103 Fully planted
	16/03/90	36.4	8.5	3.8	21.3		
	17/03/90	0.0	0.9	0.0	0.0		
	18/03/90	0.0	0.1	0.0	0.0		
	19/03/90	2.1	0.0	0.0	1.9		
	Total	92.5	17.4	4.2			
2	25/03/90	64.7	18.5	3.6	18.5	8.6	Fully planted
	26/03/90	3.2	1.9	0.8	1.2		
	27/03/90	0.0	0.2	0.0	0.0		
	28/03/90	0.0	0.0	0.0	0.0		
	Total	67.9	20.6	??			
3	29/08/90	24.4	0.1	0.0	10.3	0	Harvested in 07/90 Little cover
	30/08/90	53.0	11.1	0.0	9.3		
	31/08/90	0.0	1.1	0.0	0.0		
	01/09/90	0.0	0.1	0.0	0.0		
	02/09/90	0.0	0.0	0.0	0.0		
	Total	77.4	12.5	0.0			
4	10/05/91	34.0	1.3	0.0	30.5	0	Full canopy Harvested 07/91
	11/05/91	1.0	0.1	0.0	0.9		
	12/05/91	45.0	7.8	0.0	9.1		
	13/05/91	0.0	0.8	0.0	0.0		
	14/05/91	0.0	0.1	0.0	0.0		
	15/05/91	0.0	0.0	0.0	0.0		
	Total	80.0	10.1	0.0			
5	01/01/92	61.8	10.1	0.0	49.8	2.8	Full canopy Harvested 07/91
	02/01/92	20.9	2.1	0.0	16.5		
	03/01/92	2.7	0.2	0.0	2.0		
	04/01/92	0.0	0.0	0.0	0.0		
	Total	85.4	12.4	0.0			
6	08/01/93	1.5	0.0	0.0	0.8	3.2	Full canopy Harvested 08/93
	09/01/93	76.5	16.9	0.0	73.0		
	10/01/93	0.0	1.7	0.0	0.0		
	11/01/93	0.0	0.2	0.0	0.0		
	12/01/93	0.0	0.0	0.0	0.0		
	Total	78.0	18.7	0.0			
7	23/03/95	85.5	21.6	0.0	NR*	0.0	Full canopy Harvested 6/95
	24/03/95	7.0	2.2	0.0	3.1		
	25/03/95	5.7	0.2	0.0	4.2		
	26/03/95	0.0	0.0	0.0	0.0		
	Total	98.2	23.9	0.0			
8	09/04/95	68.2	14.4	0.4	31.8	2	Full canopy Harvested 6/95
	10/04/95	57.4	22.4	7.7	12.5		
	11/04/95	1.0	2.2	0.4	0.9		
	12/04/95	0.0	0.2	0.0	0.0		
	13/04/95	0.0	0.0	0.0	0.0		
	Total	125.6	39.2	8.5			

*NR = No rainfall in digitised data

From Table 6.1.11 it is evident that, even for rainfall events greater than 50 mm, very little or no runoff is observed. For these events (2,3,4,5,6,7 and 8), which have dry antecedent moisture conditions, and generally occur in seasons of below average rainfall, the model over-simulates the surface runoff. Again, it recommended that the method of simulating the initial rainfall abstraction be investigated, possibly as an abstraction total or as function of soil moisture. The effect of excluding the events listed in Table 6.1.11 from the simulation is shown in Figure 6.1.20.

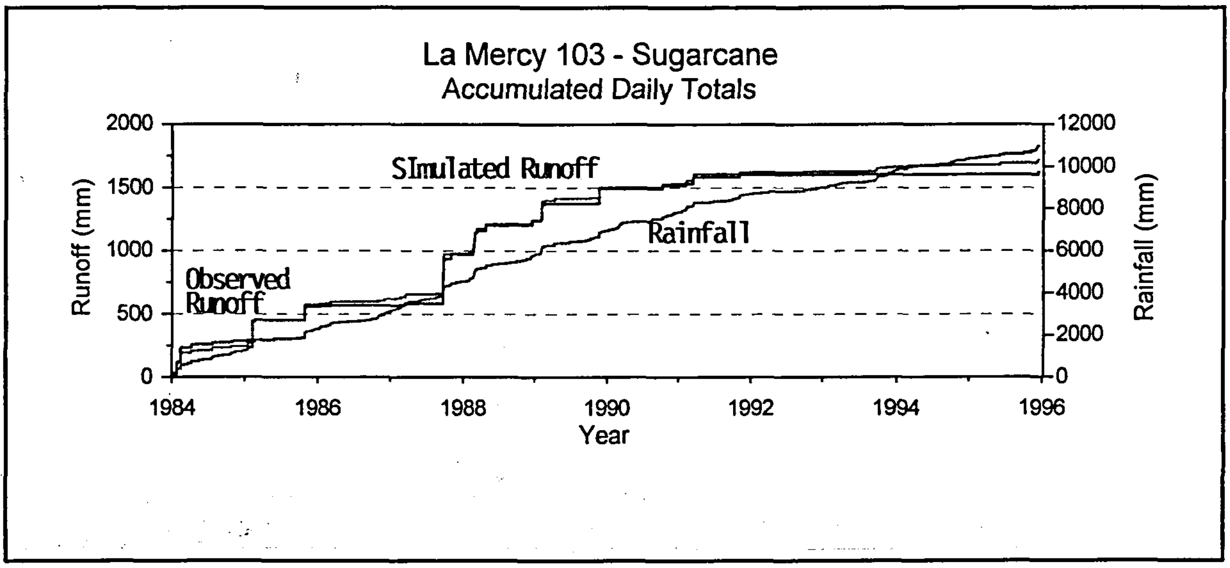


Figure 6.1.20: **Accumulated values simulated using SCDSS: Catchment 103, sugarcane land cover with events listed in Table 6.1.11 excluded**

6.1.4.4 Catchment 104

The surface runoff simulated using the SCDSS from bare fallow conditions in Catchment 104 is shown in Figure 6.1.21. With the exception of one event, the surface runoff is consistently under-simulated. Total observed surface runoff for the period 1978-1984 was 864 mm, compared with a simulated total of 525 mm. This represents an overall under-simulation of 39 % which indicates that, in Catchment 104 under bare fallow conditions, the SCDSS did not improve the simulation. The characteristics of selected events which were poorly simulated are contained in Table 6.1.12.

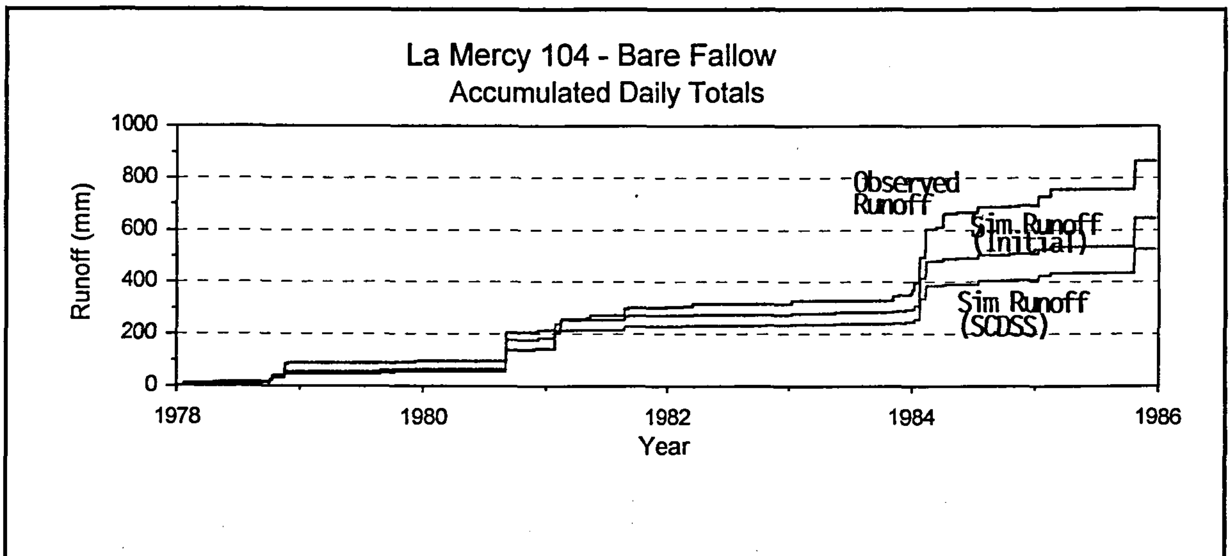


Figure 6.1.21: **Accumulated values simulated using both SCDSS and initial parameters: Catchment 104, bare fallow land cover**

Table 6.1.12: Characteristics of some events which were poorly simulated in Catchment 104 under bare fallow conditions

Event No.	Date	Rainfall (mm)	Simulated Runoff (mm)	Observed Runoff (mm)	Maximum Intensity (mm.h^{-1})	Total rain in preceding week (mm)	Catchment condition
1	11/10/78	12.9	0.0	0.0	5.7	77.9	Bare Fallow No structures
	12/10/78	54.0	9.0	13.3	12.7		
	13/10/78	1.7	0.9	2.9	1.7		
	14/10/78	0.0	0.1	0.2	0.0		
	15/10/78	0.0	0.0	0.0	0.0		
	16/10/78	8.5	0.0	0.0	3.5		
	Total	77.1	10.0	16.4			
2	18/11/78	36.2	0.1	2.18	6.5	11.3	Bare Fallow No structures
	19/11/78	67.0	14.1	35.0	14.2		
	20/11/78	0.0	1.4	1.0	0.0		
	21/11/78	9.5	0.1	0.2	2.7		
	22/11/78	9.4	0.0	2.5	2.4		
	23/11/78	10.6	0.0	0.3	7.9		
	24/11/78	0.0	0.0	0.9	0.0		
	25/11/78	7.4	0.0	0.4	3.6		
	26/11/78	9.7	0.0	1.7	2.9		
	27/11/78	0.0	0.0	0.0	0.0		
	28/11/78	6.6	0.0	0.7	2.2		
	29/11/78	0.5	0.0	0.1	0.5		
	Total	156.9	15.7	45.0			
3	07/09/80	200.4	86.0	6.6	43.4	4.3	Bare Fallow No structures
	08/09/80	70.1	32.3	32.8	10.7		
	09/09/80	3.1	3.2	0.0	1.3		
	10/09/80	0.0	0.3	0.0	0.0		
	11/09/80	0.0	0.0	0.0	0.0		
	12/09/80	2.3	0.0	0.0	NR*		
	Total	275.9	121.9	39.4			
4	30/01/81	36.0	0.8	0.0	NR*	43.6	Bare Fallow No structures
	31/01/81	66.9	16.1	33.5	NR*		
	01/02/81	0.0	1.6	33.2	0.0		
	02/02/81	2.6	0.2	1.8	0.6		
	03/02/81	4.5	0.0	0.0	2.1		
	Total	110.0	18.6	68.5			
5	16/02/81	24.6	0.0	1.9	15.9	3.6	Bare Fallow No structures
	17/02/81	0.0	0.0	0.0	0.0		
	18/02/81	62.8	10.2	24.7	NR*		
	19/02/81	1.5	1.0	16.4	0.7		
	20/02/81	0.0	0.1	0.0	0.0		
	21/02/81	0.0	0.0	0.0	0.0		
	Total	88.9	11.3	43.0			

Continued

Event No.	Date	Rainfall (mm)	Simulated Runoff (mm)	Observed Runoff (mm)	Maximum Intensity (mm.h^{-1})	Total rain in preceding week (mm)	Catchment condition
6	06/01/84	6.3	0.0	0.0	NR*	33.7	Bare Fallow
	07/01/84	32.3	0.4	7.8	NR*		No structures
	08/01/84	0.0	0.0	6.4	0.0		
	09/01/84	3.5	0.0	0.0	1.9		
	Total	42.1	0.5	14.2			
7	14/01/84	62.3	9.9	23.9	NR*	39.2	Bare Fallow
	15/01/84	0.0	1.0	3.9	0.0		No structures
	16/01/84	0.0	0.1	0.0	0.0		
	17/01/84	0.0	0.0	0.0	0.0		
	Total	62.3	11.0	27.7			
8	30/01/84	98.5	23.5	34.0	NR*	0	Bare Fallow
	31/01/84	107.0	48.6	54.2	NR*		No structures
	01/02/84	20.9	6.2	7.2	4.9		
	02/02/84	0.0	0.6	0.0	0.0		
	03/02/84	1.9	0.1	0.0	0.9		
	04/02/84	3.4	0.0	0.0	3.4		
	Total	231.7	79.0	95.5			
9	17/02/84	25.3	0.0	0.0	NR*	0	Bare Fallow
	18/02/84	88.5	26.1	59.7	NR*		No structures
	19/02/84	59.8	19.3	48.9	NR*		
	20/02/84	4.7	1.9	0.0	4.7		
	21/02/84	3.8	0.2	0.0	1.3		
	22/02/84	0.0	0.0	0.0	0.0		
	Total	182.1	47.5	108.6			
10	09/04/84	47.0	2.0	9.6	NR*	5	Bare Fallow
	10/04/84	35.8	2.7	34.3	NR*		No structures
	11/04/84	0.0	0.3	3.7	0		
	12/04/84	0.0	0.0	0.0	0		
	Total	82.8	5.0	47.7			

*NR = No rainfall in digitised data

From Table 6.1.12 it is evident that with the exception of event 3, for both wet and dry antecedent soil moisture conditions, all the events are under-simulated by the model. The observed runoff for event 3 from Catchments 101, 102 and 103 are 239, 104 and 119 mm respectively. Thus clearly the 39 mm recorded at Catchment 104 is incorrect. The simulation of bare fallow conditions at Catchment 104 with the events listed in Table 6.1.12 excluded are shown in Figure 6.1.22. Good simulations of runoff are evident in Figure 6.1.22 prior to 1981, whereafter the observed runoff exceeds the simulated values. This trend concurs with the observation made in Section 4.2 that a change appears to have been made to the measuring system during 1981. Hence the apparent poor simulation of runoff in Catchment 104 may be the result of incorrect observed data.

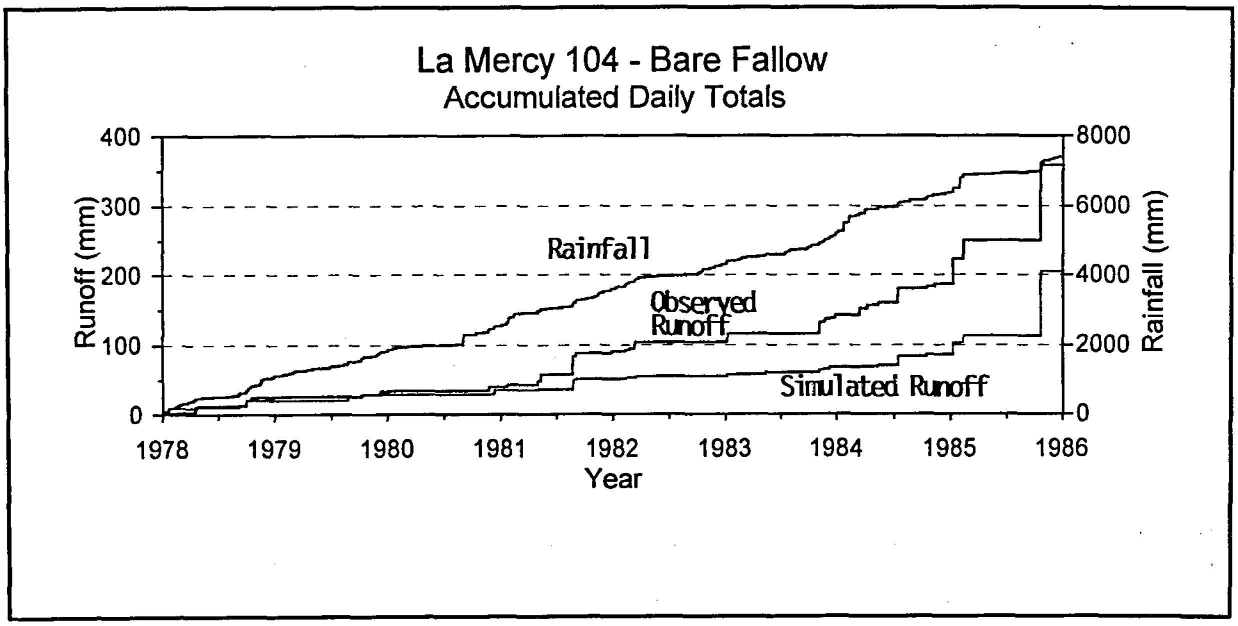


Figure 6.1.22: **Accumulated values simulated using SCDSS: Catchment 104, bare fallow land cover with events listed in Table 6.1.12 excluded**

The surface runoff from Catchment 104 under sugarcane simulated using the SCDSS is shown in Figure 6.1.23. As was the case with Catchment 104 under bare fallow conditions, the observed runoff is consistently under-simulated by the model, which may again be the result of incorrect observed runoff. Selected events which were poorly simulated are characterised in Table 6.1.13. The simulation with the events listed in Table 6.1.13 excluded is shown in Figure 6.1.24.

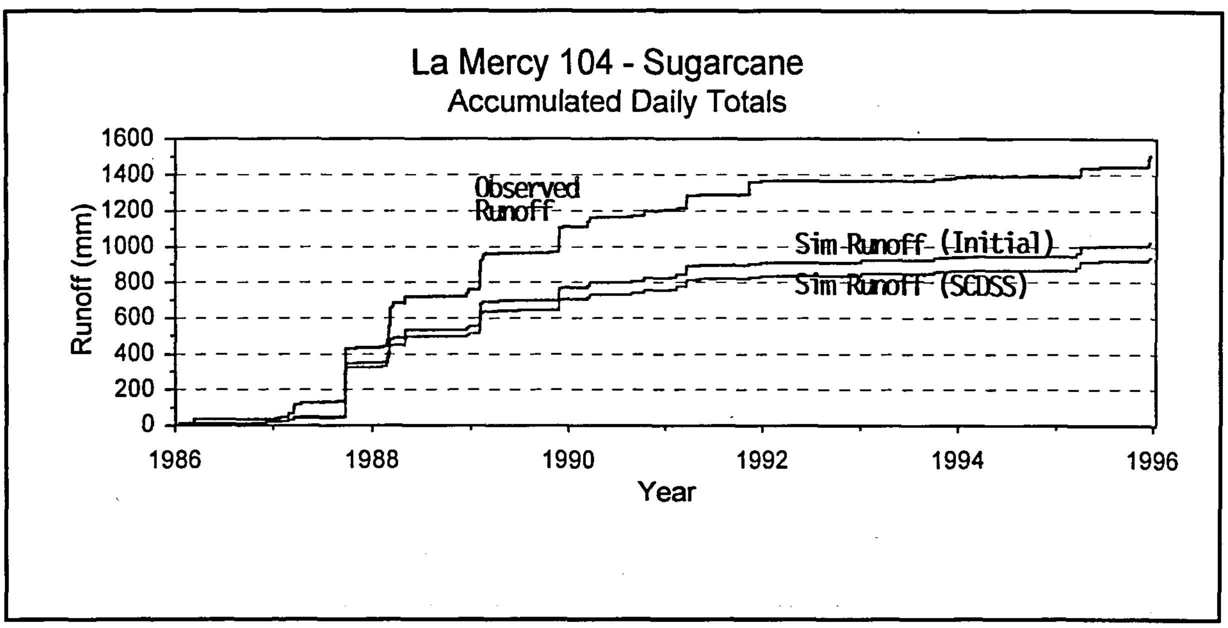


Figure 6.1.23: **Accumulated runoff simulated using both SCDSS and initial parameters: Catchment 104, sugarcane land cover**

Table 6.1.13: Characteristics of selected events which were poorly simulated in Catchment 104 under sugarcane land cover

Event No.	Date	Rainfall (mm)	Simulated Runoff (mm)	Observed Runoff (mm)	Maximum Intensity (mmh^{-1})	Total rain in preceding week (mm)	Catchment condition
1	17/01/86	0.9	0.0	0.0	0.9	5.4	First planted in this month
	18/01/86	49.3	2.2	1.4	11.6		
	19/01/86	35.6	2.5	11.9	9.6		
	20/01/86	0.0	0.3	0.1	0		
	21/01/86	0.8	0.0	0.0	0.5		
	22/01/86	3.5	0.0	0.0	1.5		
	Total	90.1	5.0	13.4			
2	18/03/87	8.7	0.0	0.0	4.0	8.7	Incomplete cover Sugarcane 2 months old
	19/03/87	5.0	0.0	0.0	4.9		
	20/03/87	63.3	8.7	18.5	38.9		
	21/03/87	10.2	0.9	14.6	5.9		
	22/03/87	34.3	3.5	11.8	19.5		
	23/03/87	4.4	0.4	2.5	0.9		
	24/03/87	0.0	0.0	0.0	0.0		
	Total	125.9	13.5	47.4			
3	25/02/88	16.8	0.0	0.1	5.3	5.8	Fully planted
	26/02/88	80.8	20.8	37.1	36.9		
	27/02/88	0.0	2.1	0.9	0.0		
	28/02/88	0.0	0.2	0.0	0.0		
	29/02/88	0.0	0.0	0.0	0.0		
	01/03/88	3.0	0.0	0.0	2.0		
	02/03/88	76.9	22.6	32.3	29.7		
	03/03/88	28.9	6.8	21.6	5.3		
	04/03/88	21.2	3.5	20.2	12.9		
	05/03/88	12.0	0.8	0.9	5.2		
	06/03/88	1.1	0.1	0.6	1.1		
	07/03/88	0.0	0.0	1.0	0.0		
	08/03/88	20.9	0.5	5.5	16.9		
	09/03/88	103.8	50.3	76.3	26.0		
	10/03/88	13.9	6.56	16.7	3.9		
	11/03/88	0.0	0.7	0.0	0.0		
	12/03/88	2.4	0.1	0.0	0.9		
	13/03/88	0.0	0.0	0.0	0.0		
	14/03/88	8.0	0.0	0.1	8.0		
	15/03/88	24.8	1.1	5.9	23.3		
	16/03/88	0.0	0.1	0.9	0.0		
	17/03/88	0.0	0.0	0.3	0.0		
	Total	376.3	115.0	219.0			

Continued

Event No.	Date	Rainfall (mm)	Simulated Runoff (mm)	Observed Runoff (mm)	Maximum Intensity (mmh^{-1})	Total rain in preceding week (mm)	Catchment condition
4	01/02/89	0.4	0.0	0.0	0.4	0.0	Fully planted
	02/02/89	4.2	0.0	0.0	3.8		
	03/02/89	87.1	16.6	7.6	8.8		
	04/02/89	13.8	1.7	5.1	2.0		
	05/02/89	29.5	2.9	1.0	12.7		
	06/02/89	58.5	20.0	34.0	16.3		
	07/02/89	99.4	64.2	111.7	48.0		
	08/02/89	0.0	6.4	0.7	0.0		
	09/02/89	0.0	0.6	0.0	0.0		
	10/02/89	6.3	0.0	0.8	6.3		
	11/02/89	0.0	0.0	0.0	0.0		
	12/02/89	2.7	0.0	0.0	0.9		
	Total	301.9	112.5	160.9			
5	26/11/89	0.0	0.0	7.0	0.0	6.6	Harvested in 07/89 Incomplete cover Sugarcane 3 months old
	27/11/89	0.0	0.0	3.2	0.0		
	28/11/89	8.3	0.0	0.2	3.6		
	29/11/89	94.5	22.2	50.1	23.8		
	30/11/89	68.6	26.0	49.2	18.6		
	01/12/89	29.9	8.9	24.7	13.2		
	02/12/89	0.0	0.9	0.3	0.0		
	03/12/89	2.7	0.1	0.1	1.9		
	04/12/89	0.0	0.0	0.0	0.0		
	05/12/89	0.8	0.0	0.0	0.8		
	Total	204.8	58.1	134.8			
6	15/03/90	54.0	5.9	7.9	27.8	21.3	Fully planted
	16/03/90	36.4	4.9	22.3	21.3		
	17/03/90	0.0	0.5	0.0	0.0		
	18/03/90	0.0	0.1	0.0	0.0		
	19/03/90	2.1	0.0	0.0	1.9		
	Total	92.5	11.4	30.2			
7	24/03/91	65.4	9.7	10.4	18.5	17.6	Fully planted
	25/03/91	70.8	24.6	57.6	M*		
	26/03/91	0.0	2.5	0.6	M*		
	27/03/91	0.0	0.3	0.0	M*		
	28/03/91	0.0	0.0	0.0	M*		
	Total	136.2	37.1	68.6			
8	12/11/91	31.0	0.0	1.2	21.4	2.0	Harvested in 08/91 Incomplete cover Sugarcane 2 months old
	13/11/91	24.8	0.0	3.1	15.4		
	14/11/91	6.3.0	0.0	0.5	3.0		
	15/11/91	47.0	6.7	64.8	24.3		
	16/11/91	0.7	0.7	0.0	0.5		
	17/11/91	0.0	0.1	0.0	0.0		
	18/11/91	0.0	0.0	0.0	0.0		
	Total	109.8	7.5	69.6			

*M = Missing data

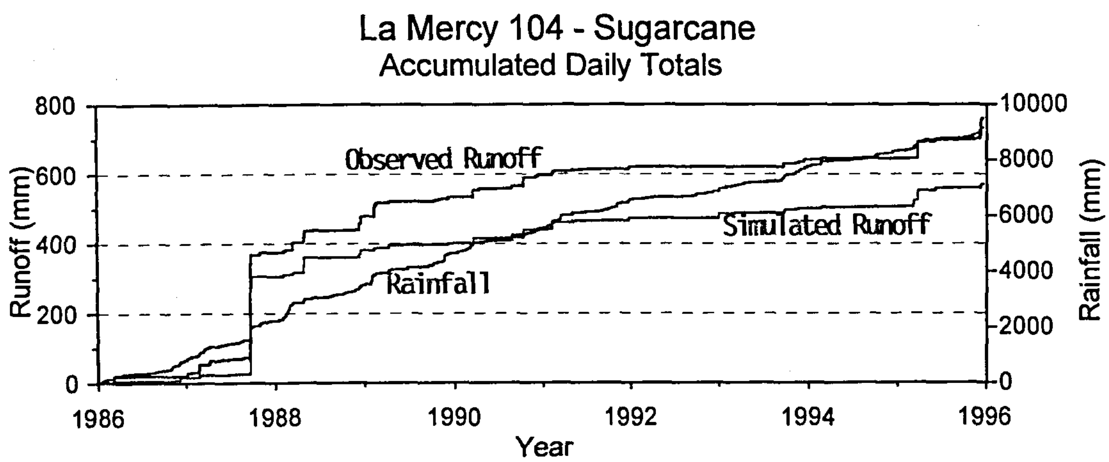


Figure 6.1.24: **Accumulated values simulated using SCDSS: Catchment 104, sugarcane land cover with the events listed in Table 6.1.13 excluded**

From the plot of cumulative daily observed runoff values under bare fallow land cover shown in Figure 6.1.25, it is clear that the runoff recorded at the outlet from Catchment 104 is considerably greater than that from the other catchments. For the period shown in Figure 6.1.25, the land cover in all the catchments was bare fallow, and hence it is suspected that the data recorded for Catchment 104 may be incorrect.

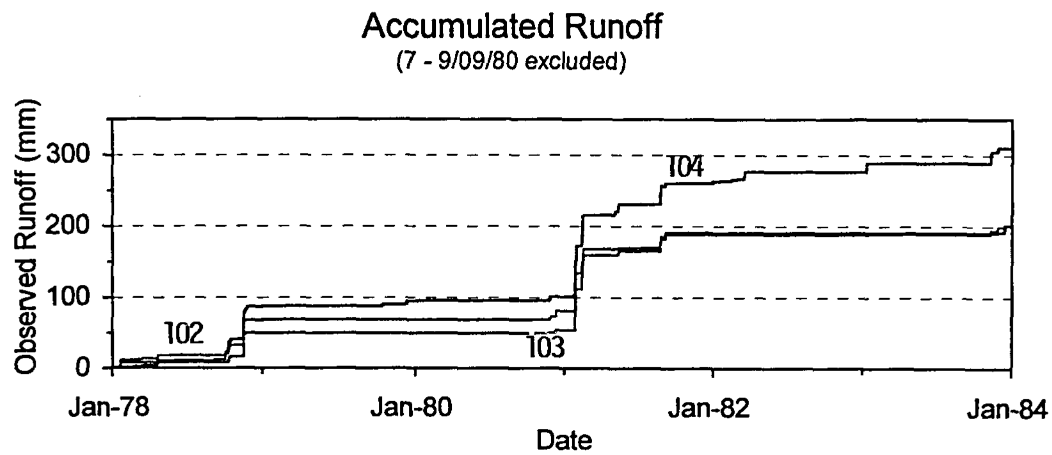
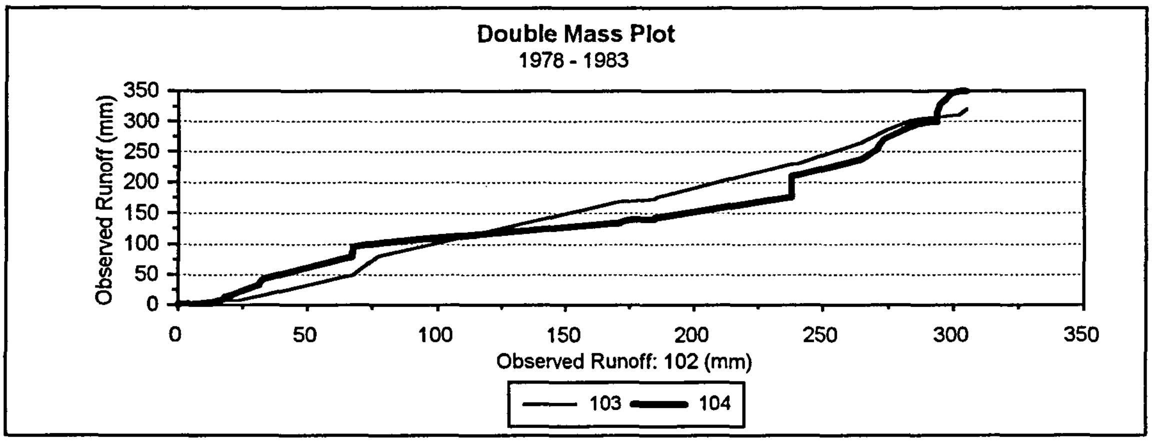


Figure 6.1.25: **Inter-catchment comparison of cumulative observed runoff from La Mercy catchments under bare fallow land cover**

As shown in Figure 6.1.26, the over-estimation of runoff from Catchment 104 was not consistent when compared with the observed runoff from Catchments 102 and 103. Therefore, although the simulations results for Catchment 104 appear to be poor, it is suspected that the observed runoff recorded from Catchment 104 are not correct.



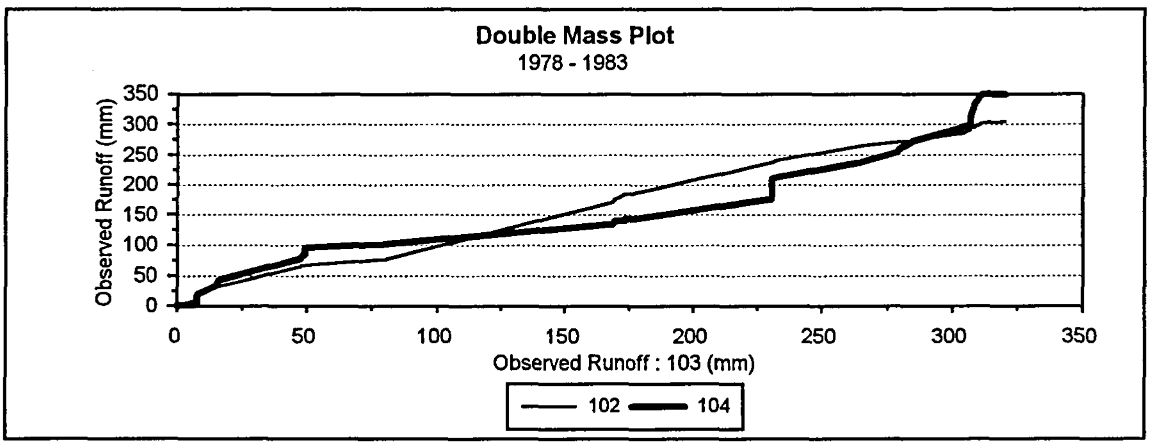


Figure 6.1.26: **Double mass plot comparing observed runoff from La Mercy Catchment 102, 103 and 104**

6.1.5 Concluding Remarks

The development of the SCDSS generally improved the simulation of runoff for both bare fallow and sugarcane land covers. Using the SCDSS, the simulation of runoff from different sugarcane management practises was considered to be adequate.

However, some model deficiencies were also noted. These appear to be related primarily to the amount of rainfall abstracted prior to the generation of storm flow, with the model simulating some storm flow when no storm flow was observed, particularly under dry antecedent rainfall conditions. This problem may also be related to the intensity of the rainfall event, as the model does not directly account for rainfall intensity in the simulation of storm flow. It is recommended that the method of simulating the initial rainfall abstraction be investigated, possibly as an abstraction total or as function of soil moisture.

The simulation of runoff from Catchment 104 after 1981 appears to be poor. However, comparison of the observed runoff from Catchment 104 to that from the other catchments under the same land cover indicates that the observed data from Catchment 104 may be incorrect.

Section 6.2 investigates the simulation of daily peak discharge.

6.2 Simulation of Daily Peak Discharge

Comparisons between simulated and observed values are contained in the following sections for both daily peak discharges and event hydrographs. Simulations of peak discharges were performed using observed hyetographs as input. In addition, the use of synthetic design rainfall distributions to simulate peak discharge was investigated for use at locations where continuously recorded data are not available.

6.2.1 Observed hyetograph input

Manually extracted rainfall data from autographic rainfall charts were used to create the input hyetograph for the *ACRU* model. The breakpoint data were linearly interpolated to develop 5-minute interval rainfall data.

The times of concentration (Tc) for each of the catchments were estimated using hydraulic calculations. The following section contains the results from simulating daily peak discharge using the *estimated* Tc and *simulated* daily storm flow (i.e. runoff excluding baseflow) volumes. The effect of using the *observed* storm flow volume in conjunction with the *estimated* Tc to estimate daily peak discharge was also investigated.

6.2.1.1 Estimated lag time

The simulated storm flow volume was initially used in conjunction with the estimated Tc to simulate daily peak discharge. This represents the method that would be adopted for an ungauged situation. This was followed by simulating daily peak discharge using the observed storm flow volume and estimated Tc.

6.2.1.1.1 Simulated storm flow volumes

The results of using the observed hyetograph together with simulated volumes and estimated Tc values to simulate daily peak discharges are shown in Figure 6.2.1. Linear regression statistics for the simulations are contained in Table 6.2.1. Included in Figure 6.2.1 is an indication of how well the daily storm flow volumes were simulated in order to identify possible reasons for the poor simulation of peak discharge and/or to ascertain, in cases where reasonable simulations of peak discharge were obtained, if the results were valid. For example, in Catchment 104 reasonable simulations of peak discharge were obtained. However, as shown in Chapter 5, peak discharge is a function of storm flow volume and, as illustrated in Figure 6.2.1, the storm flow volume was under-simulated for Catchment 104. Hence it is apparent that other factors, such as lag times, may have been incorrectly estimated.

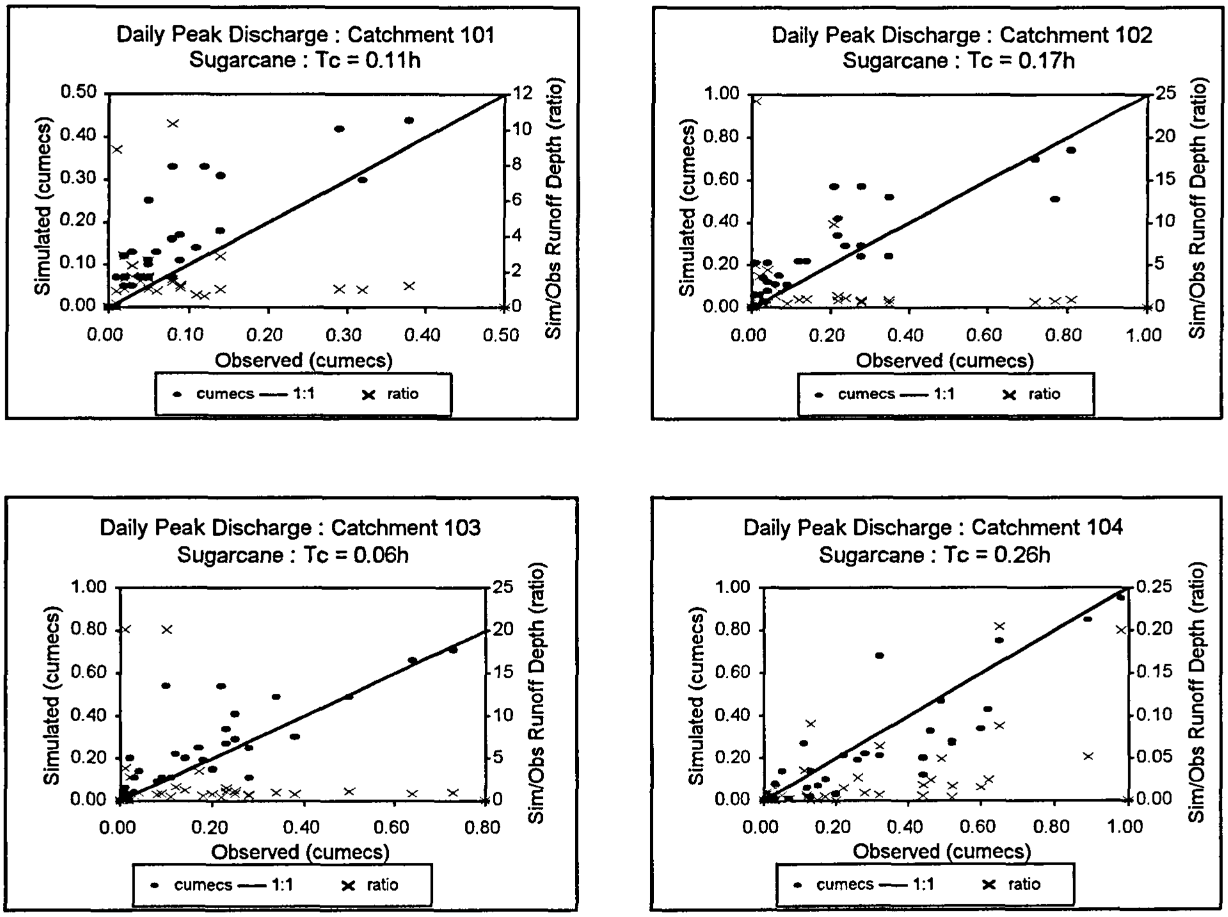


Figure 6.2.1: Daily peak discharges simulated using the observed hyetograph, simulated storm flow volumes and estimated catchment times of concentrations (cumecs = $m^3.s^{-1}$)

Table 6.2.1: Regression statistics for simulated (using observed hyetograph, estimated times of concentrations and simulated storm flow volumes) vs observed daily peak discharge

Catchment	Time of concentration (h)	X-coefficient	R^2
101	0.11	1.39	0.82
102	0.17	1.01	0.84
103	0.06	1.10	0.84
104	0.26	0.85	0.87

6.2.1.1.2 Observed storm flow volumes

On days where daily observed stream flow data are available and the hyetograph daily rainfall total is greater than the observed stream flow, hydrographs were generated with a volume equal to the observed stream flow. On some occasions the hyetograph daily rainfall total is less than the observed stream flow which occurs, for example, when data are missing in the digitised rainfall data. In such cases both stream flow volume and daily peak discharge were excluded from further analyses. Similarly, on occasion daily peak discharge is reported for a particular day with the stream flow volume reported as occurring on the next day. These events are also excluded from Figure 6.2.2, which shows the simulated and observed daily peak discharge, where the simulated peak discharge is computed using the observed runoff volume. From Table 6.2.2, which contains linear regression statistics for the graphs shown in Figure 6.2.2, it is evident that the use of observed volumes has improved the simulation of peak discharge. However, the peak discharge is generally over-estimated, thus indicating that the estimated Tc values may be incorrect.

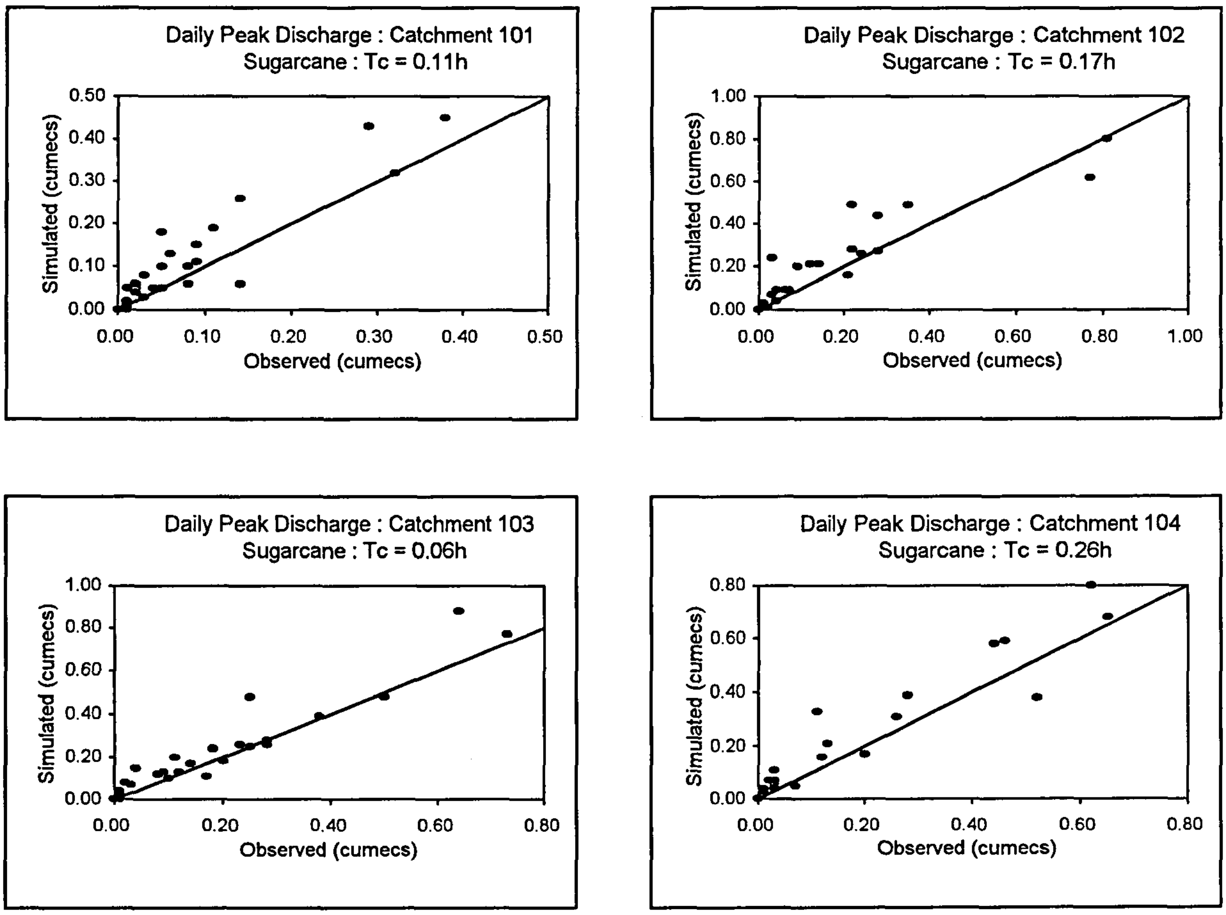


Figure 6.2.2: Daily peak discharge simulated using the observed hyetograph, observed storm flow volumes and estimated catchment times of concentrations (cumecs = $m^3.s^{-1}$)

Table 6.2.2: Regression statistics for simulated (using observed hyetograph, estimated times of concentrations and observed storm flow volumes) vs observed daily peak discharge

Catchment	Time of Concentration (h)	X-coefficient	R^2
101	0.11	1.25	0.91
102	0.17	1.04	0.90
103	0.06	1.14	0.96
104	0.26	1.15	0.94

6.2.1.2 Optimised lag time

In order to improve the estimate of Tc, an "optimised" Tc was computed for each catchment using the observed runoff volume and varying Tc such that the best X-coefficient was obtained in a linear regression analysis between the observed (X) and simulated (Y) daily peak discharges. Improvements to the simulated peak discharge estimated using simulated volumes and optimised Tc values are reported.

6.2.1.2.1 Observed volumes

For all catchments the lag time was "optimised" by selecting a Tc which resulted in the linear regression X-coefficient being closest to the ideal value of 1.0. The simulated, using optimised Tc values, and observed daily peak discharges are contained in Figure 6.2.3 and the optimised lag times and regression coefficients are tabulated in Table 6.2.3.

Table 6.2.3: Estimated and optimised times of concentrations

Catchment	Estimated Time of Concentration (h)	Optimised		
		Time of Concentration (h)	X-Coefficient	R^2
101	0.11	0.40	1.02	0.93
102	0.17	0.25	0.98	0.90
103	0.06	0.30	0.99	0.97
104	0.26	0.45	1.02	0.95

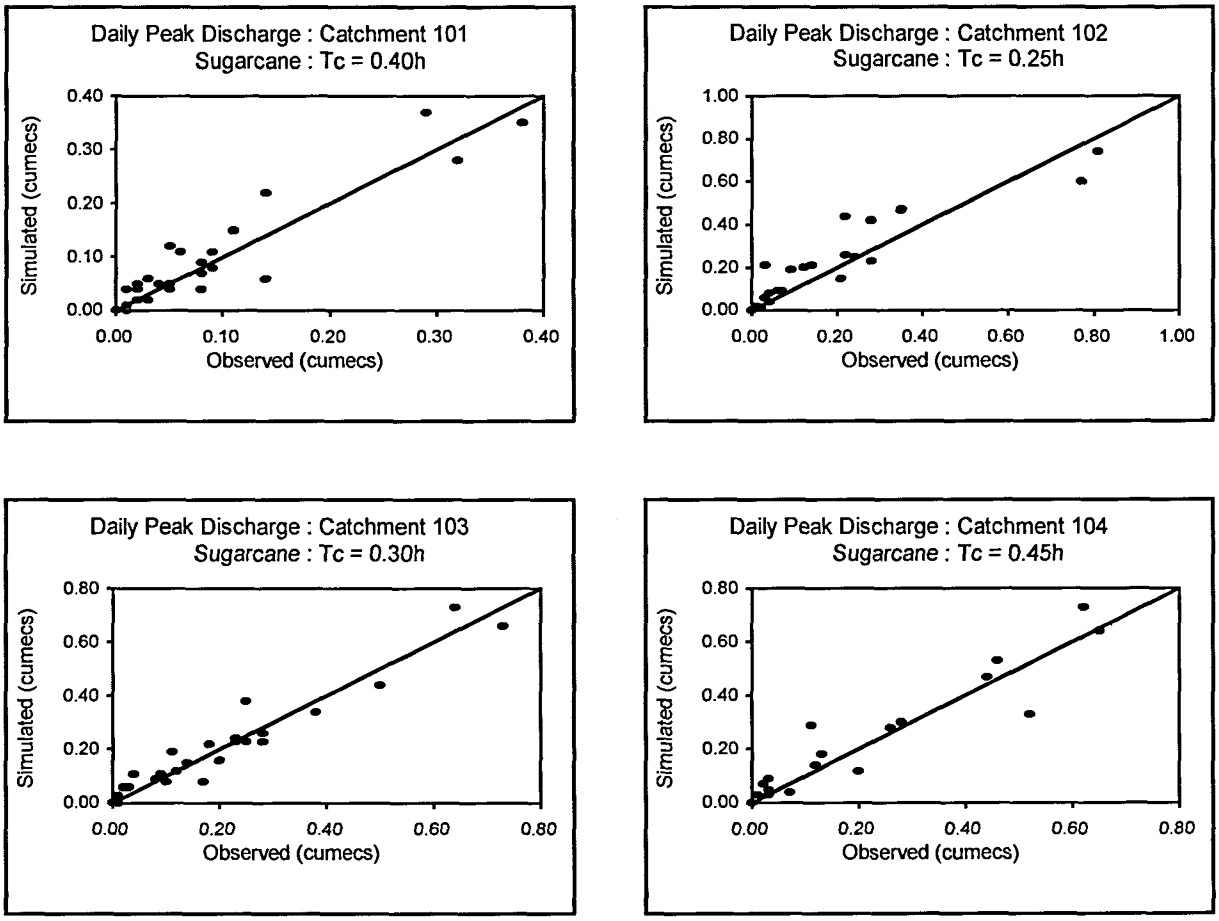


Figure 6.2.3 Daily peak discharge simulated using the observed hyetograph, observed storm flow volumes and optimised catchment times of concentration (cumecs = $m^3.s^{-1}$)

6.2.1.2.2 Simulated storm flow volumes

The results of using the optimised Tc values and simulated volumes to estimate daily peak discharge are contained in Figure 6.2.4 and related linear regression statistics are given in Table 6.2.4.

Table 6.2.4: Regression statistics for simulated (using the observed hyetograph, optimised times of concentrations and simulated volumes) vs observed daily peak discharge

Catchment	Time of Concentration (h)	X-coefficient	R^2
101	0.40	1.15	0.81
102	0.25	0.97	0.84
103	0.30	0.97	0.83
104	0.45	0.73	0.85

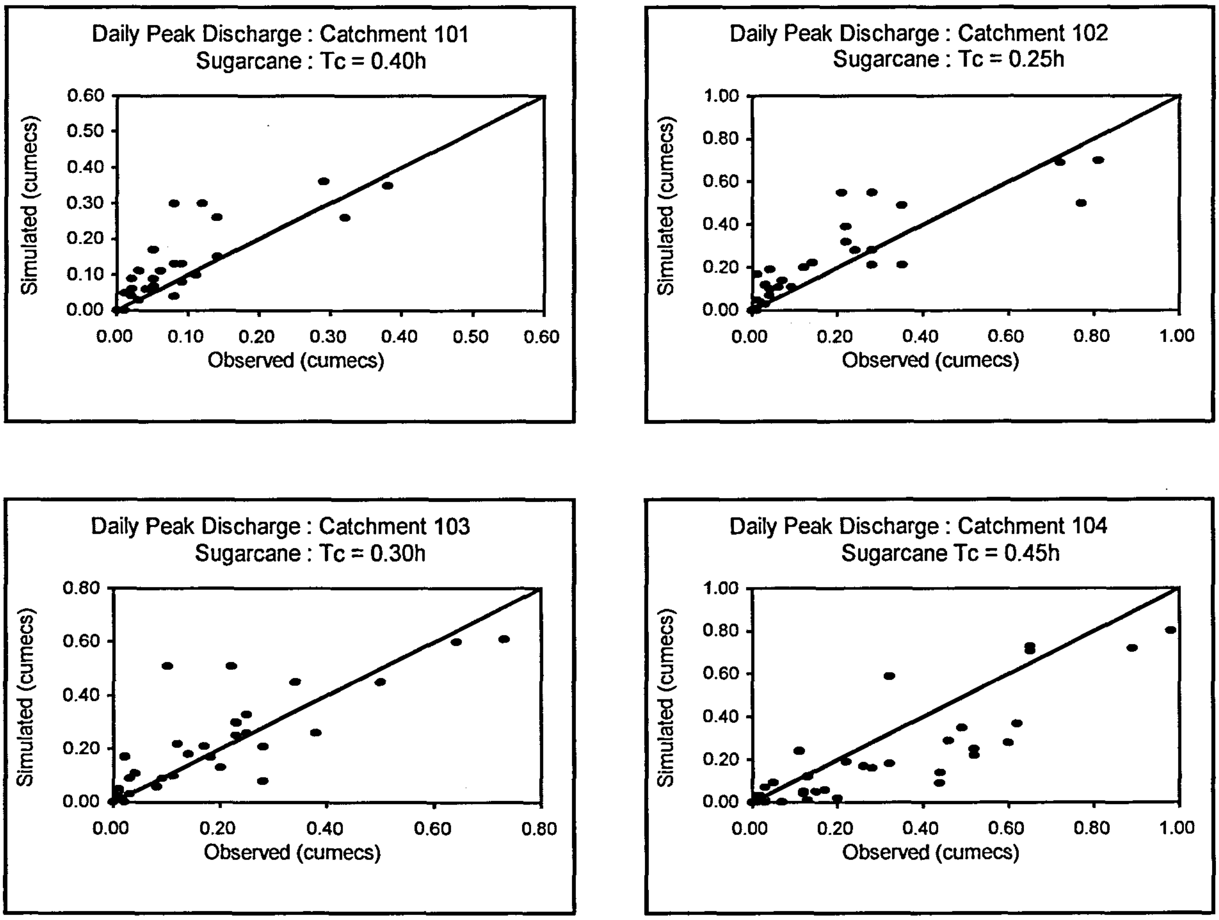


Figure 6.2.4: Daily peak discharge simulated using the observed hyetograph, simulated storm flow volumes and optimised catchment times of concentrations (cumecs = $m^3.s^{-1}$)

6.2.2 Synthetic hyetograph input

Observed hyetographs are frequently not available at a site, and design rainfall distributions have to be used to generate synthetic hyetographs from the daily rainfall total. For the La Mercy catchments, design rainfall distribution Type 2 (IRDIST=2) is applicable (Schulze and Schmidt, 1995).

6.2.2.1 Design rainfall distribution Type 2

Results when using the synthetic hyetograph to simulate peak discharge in conjunction with optimised lag times and observed storm flow volumes are shown in Figure 6.2.5 and the associated regression statistics are contained in Table 6.2.5.

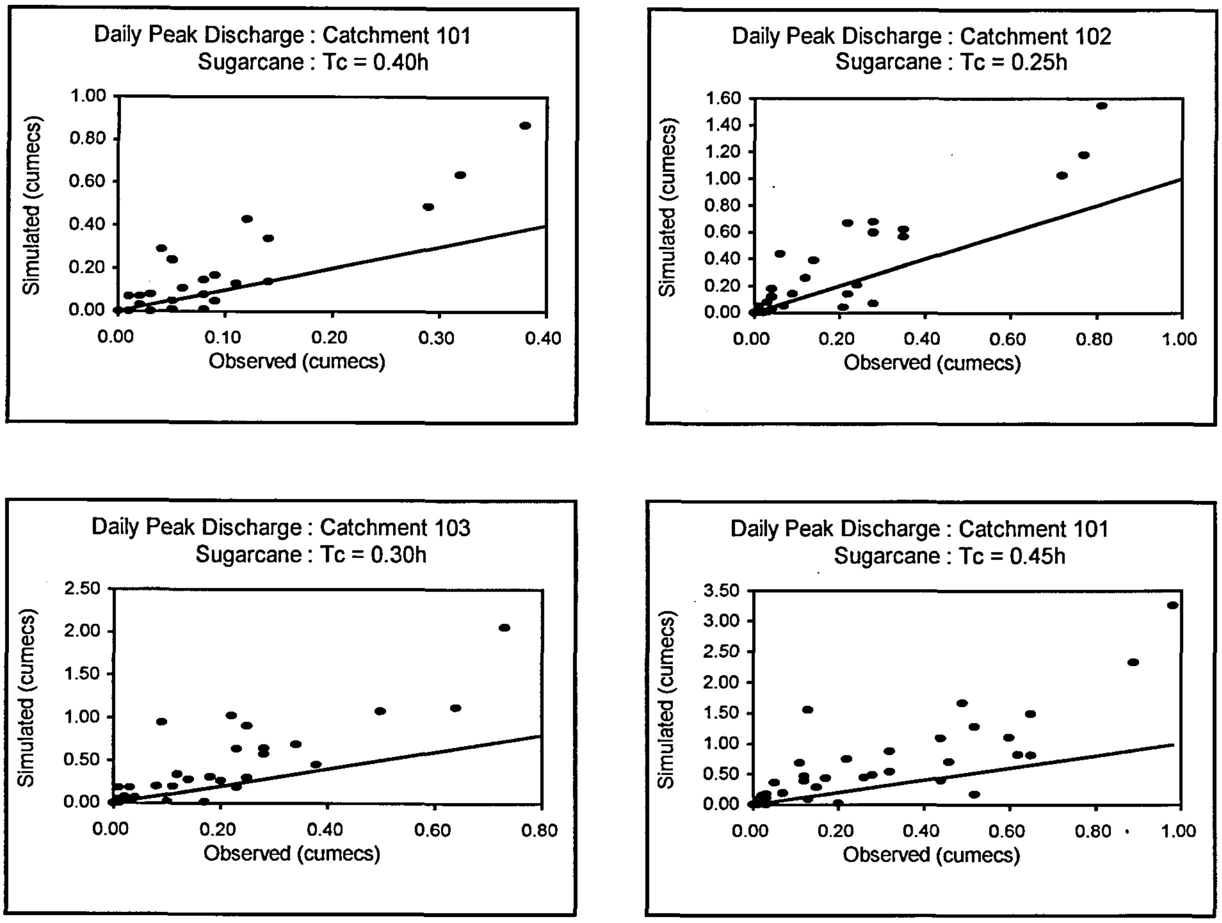


Figure 6.2.5: Daily peak discharge simulated using a synthetic time distribution of rainfall (Type 2), observed storm flow volumes and optimised catchment times of concentrations (cumecs = $m^3.s^{-1}$)

Table 6.2.5: Regression statistics for simulated vs observed daily peak discharge. Peak discharge simulated using a synthetic time distribution of rainfall (Type 2), optimised times of concentration and observed storm flow volumes

Catchment	Time of Concentration (h)	X-coefficient	R^2
101	0.40	1.97	0.89
102	0.25	2.60	0.90
103	0.30	2.21	0.84
104	0.45	2.23	0.81

From Figure 6.2.5 and Table 6.2.5 it is noted that when using rainfall distribution Type 2, the daily peak discharge is over-simulated. Therefore the less intense rainfall distribution Type 1 was used in order to assess the effect of a less intense synthetic rainfall distribution. Although the delineations for rainfall distribution type suggested by Schulze and Schmidt (1995) indicate that Type 2 is appropriate for the La Mercy catchments, it was postulated that the Type 1 distribution may be more correct as the La Mercy catchments are located near the coast where coastal low pressure systems are the dominant rainfall producing mechanisms.

6.2.2.2 Design rainfall distribution Type 1

The results of using design rainfall intensity distribution Type 1 to generate synthetic hyetographs in order to simulate peak discharge, using optimised times of concentrations and observed storm flow volumes, are shown in Figure 6.2.6 and the associated regression statistics are contained in Table 6.2.6. It is noted that daily peak discharge is still over-simulated when Type 1 distribution is used, but to a lesser extent than when Type 2 distribution is used.

Table 6.2.6: Regression statistics for simulated vs observed daily peak discharge. Peak discharge simulated using a synthetic time distribution of rainfall (Type 1), optimised times of concentrations and observed storm flow volumes

Catchment	Times of Concentration (h)	X-coefficient	R^2
101	0.40	1.26	0.88
102	0.25	1.63	0.89
103	0.30	1.41	0.84
104	0.45	1.46	0.81

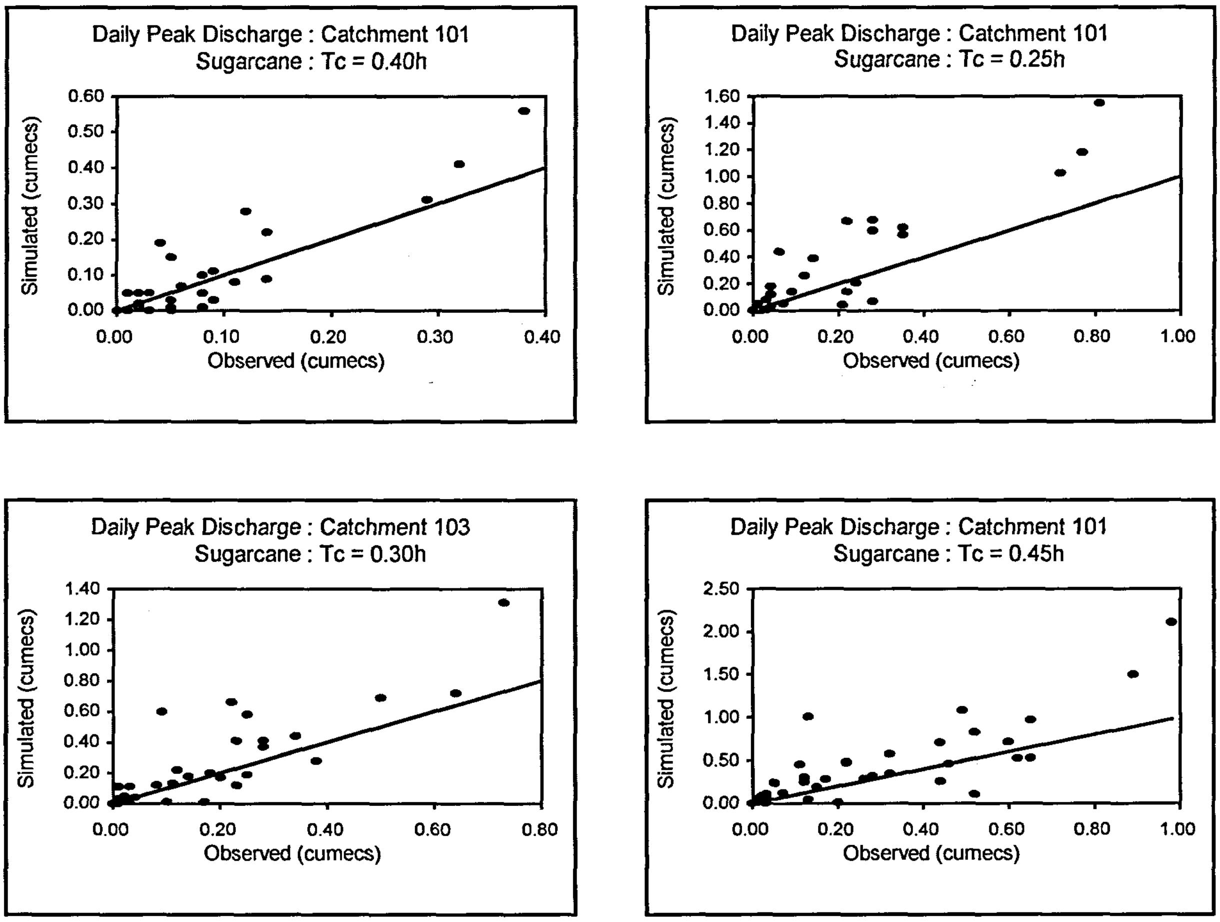


Figure 6.2.6 Daily peak discharge simulated using a synthetic time distribution of rainfall (Type 1), simulated storm flow volumes and optimised catchment times of concentrations (cumecs = $m^3.s^{-1}$)

6.2.3 Concluding remarks

As illustrated in Figure 6.2.1 and from the regression statistics contained in Table 6.2.1, the model simulated daily peak discharge reasonably well using the estimated times of concentrations and simulated volumes. However, comparison of the simulated with the observed volumes for each event indicates that, for some events where the daily peak discharge was reasonably simulated despite a poor simulation of the storm flow volume, the simulation of peak discharge was not necessarily valid, i.e. a reasonable simulation of peak discharge was obtained with incorrect input.

Comparison of Table 6.2.1 with Table 6.2.2 and as illustrated in Figure 6.2.2, substituting the simulated storm flow volume with the observed volumes resulted in some improvements, particularly for the smaller daily peak discharges. Examination of Figure 6.2.2 and Table 6.2.2 indicates that the previously marked over- and under-simulation of daily peak discharge at Catchments 101 and 104 respectively (Figure 6.2.1) are somewhat improved by the use of the observed daily storm flow volume in the simulation of daily peak discharge. In the case of Catchment 104, the use of observed volumes resulted in the over-simulation of peak discharge, whereas when simulated volumes were used, the peak discharge was under-simulated. The over-simulation of peak discharge when observed volumes were used in the simulation indicates that the Tc values had been incorrectly estimated.

From Figure 6.2.2 and Table 6.2.2, where observed storm flow volumes were used to simulate peak discharge, it is concluded that generally the catchment lag times had been under-estimated, resulting in the over-estimation of peak discharge. For Catchments 101 and 103 the optimised values of Tc are much larger than the estimated values, thus indicating the difficulty of accurately estimating Tc. The effect of using an optimised, hence improved, estimate of Tc is evident when Figures 6.2.2 and 6.2.3 and associated regression statistics are compared. The two catchments with the shortest times of concentration (101 and 103) have non-conventional conservation structures (101: spill-over roads) and no conservation structures (103). Hence it is suggested that the calculations of the hydraulic flow lengths and velocities on these two sub-catchments may be difficult to estimate correctly. Further research is thus required into estimating peak discharge from catchments which have a very short time of concentration and into estimating lag times with unconventional and no conservation structures.

It is apparent from Figure 6.2.5 and Table 6.2.5 that, in the absence of observed hyetographs, the use of the designated design intensity distributions for the catchments, which were derived from design rainfall and not directly from recorded rainfall, results in the over-simulation of peak discharge. However, as illustrated in Figure 6.2.6 and Table 6.2.6, the use of a less intense rainfall distribution, as would be expected in a coastal region, resulted in an improved simulation of peak discharge.

The results in this section indicate that, when the hyetograph option for rainfall input is used and observed hyetograph data are available, good results of simulated daily peak discharge are obtained using calculated times of concentrations and simulated volumes. These results were derived from sugarcane fields which have widely differing management practises.

It is noted that the optimised Tc values are approximately 0.2 h longer than the calculated values, suggesting that for small sugarcane fields with areas less than 10 ha, the calculated Tc value should be further increased. The magnitude of the increase and other factors, as well as the use of other techniques for estimating catchment lag times, requires further investigation.

Based on the results presented in this section, it is postulated that the *ACRU* model may be used to simulate daily peak discharge from sugarcane fields in KwaZulu-Natal with a fair degree of confidence when observed hyetographs are available. The use of recommended rainfall intensity distributions, which were derived from values of design rainfall, results in hyetographs which have periods of rainfall that are too intense resulting in the over-simulation of peak discharge. It is recommended that regionalised intensity distributions which are based on actual (recorded) rainfall data be developed for use in daily simulation modelling.

6.3 Hydrograph simulation

For each of the La Mercy catchments, 5-minute interval hyetographs were used to simulate incremental hydrographs which were summed to compute a composite hydrograph. The composite hydrographs were simulated with the *ACRU* model using the observed hyetograph and simulated storm flow volumes. It has been shown in Section 6.2 that the model simulated daily peak discharges reasonably well and the objective in this section was to assess how well the hydrograph shape was simulated by the model. Five events were selected from all four catchments at La Mercy and a visual assessment was made regarding the adequacy of the hydrographs simulated by the model. Estimated times of concentrations were initially used in the simulation of the hydrographs and thereafter the effect of using the optimised times of concentrations on the simulated hydrographs was also investigated. The hydrographs from selected events are presented below, based on optimised times of concentration.

6.3.1 Catchment 101

Simulated and observed hydrographs for selected events from Catchment 101 are depicted in Figure 6.3.1. The optimised Tc for Catchment 101 was 0.40 h (see Table 6.2.3), while Tc estimated from hydraulic calculations was 0.11 h.

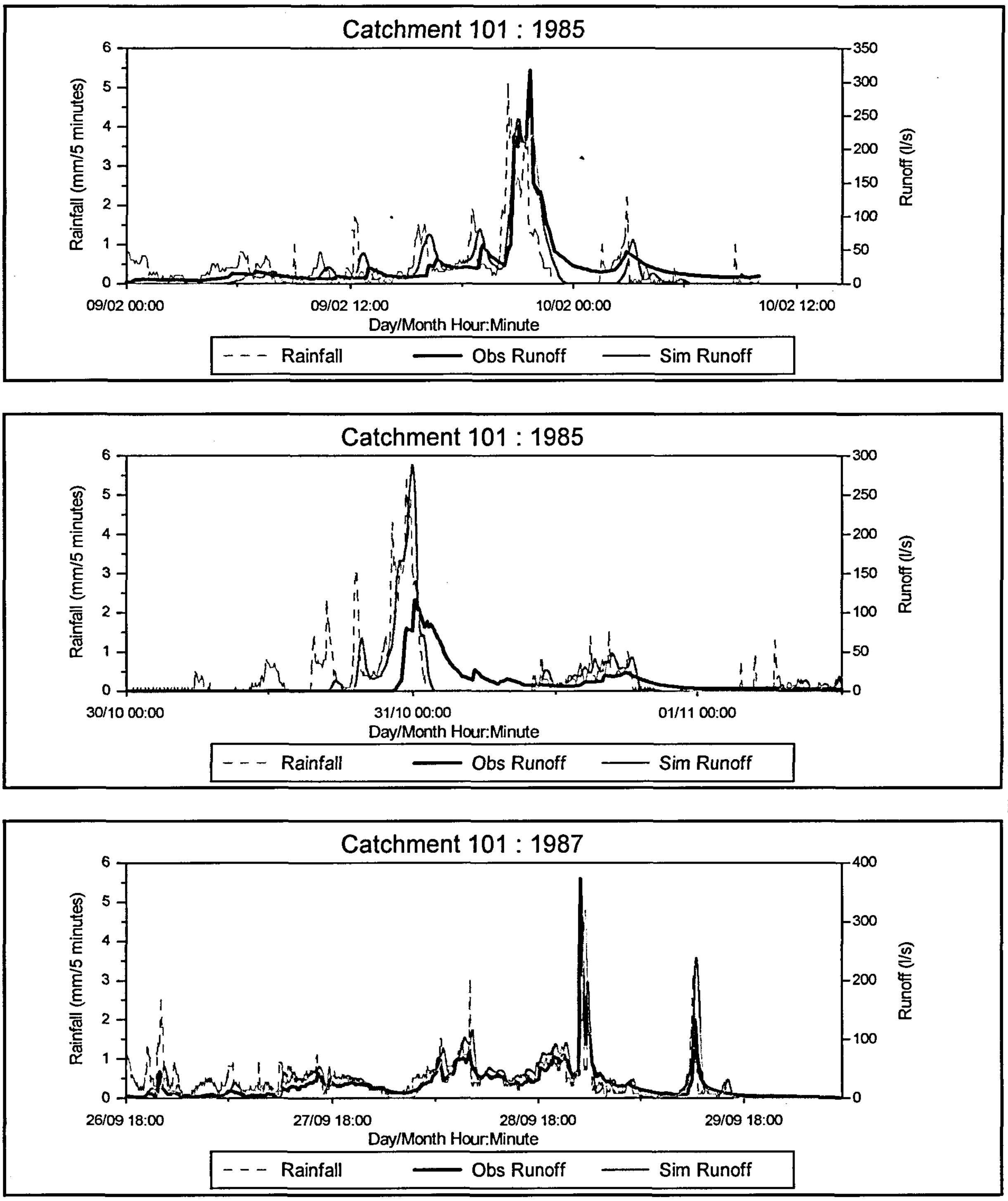
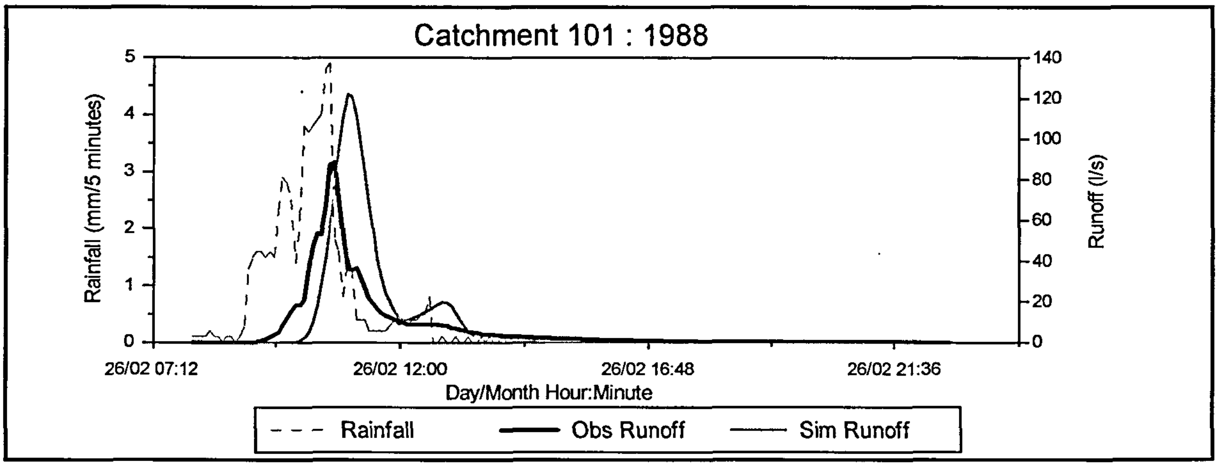


Figure 6.3.1 : Hydrographs from Catchment 101 simulated using simulated storm flow volumes and optimised time of concentration.



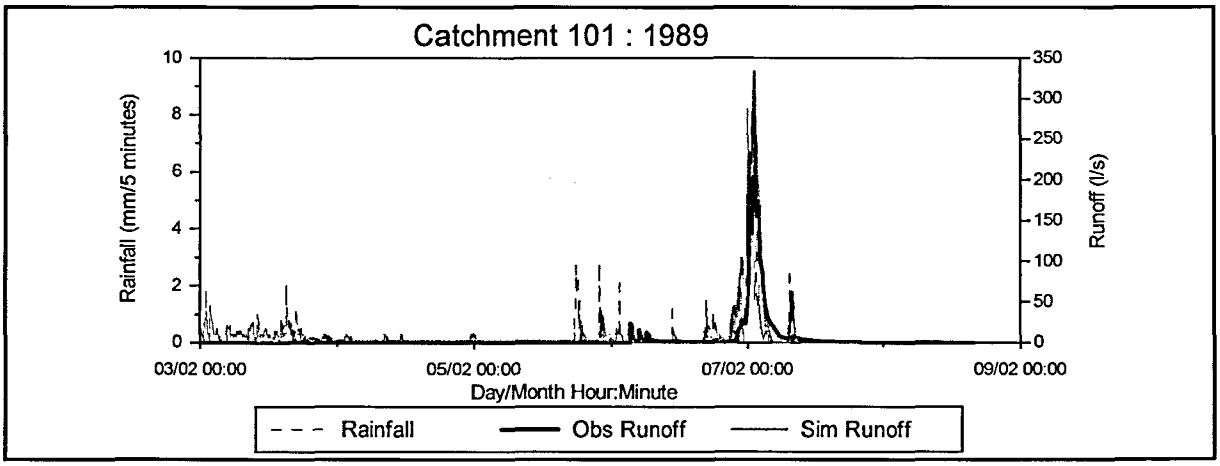


Figure 6.3.1: Hydrographs from Catchment 101 simulated using simulated storm flow volumes and optimised time of concentration (Continued)

6.3.2 Catchment 102

Simulated and observed hydrographs for selected events from Catchment 102 are depicted in Figure 6.3.2. The optimised Tc for Catchment 102 was 0.25 h (see Table 6.2.3), while Tc estimated from hydraulic calculations was 0.17 h.

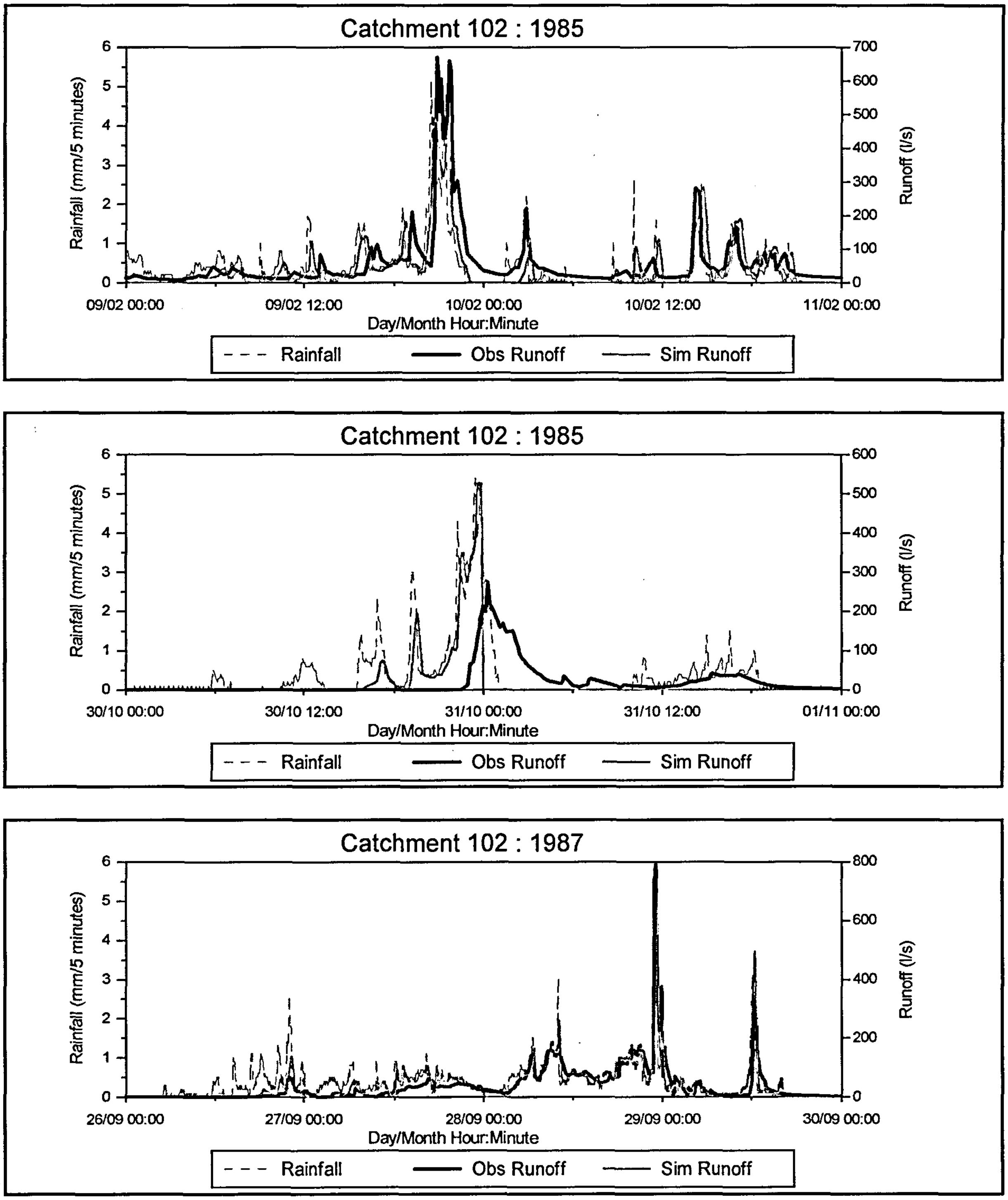
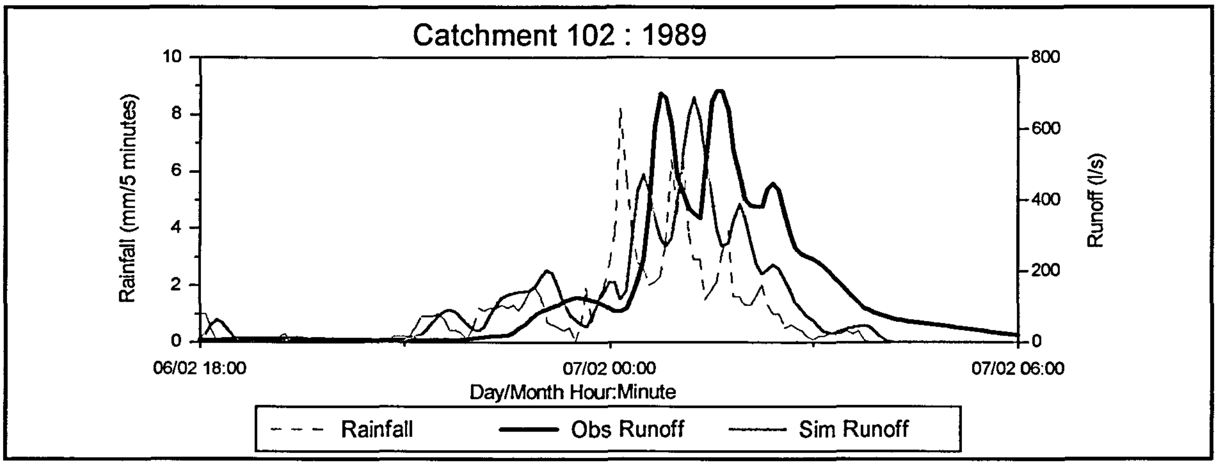


Figure 6.3.2: Hydrographs from Catchment 102 simulated using simulated storm flow volumes and optimised time of concentration



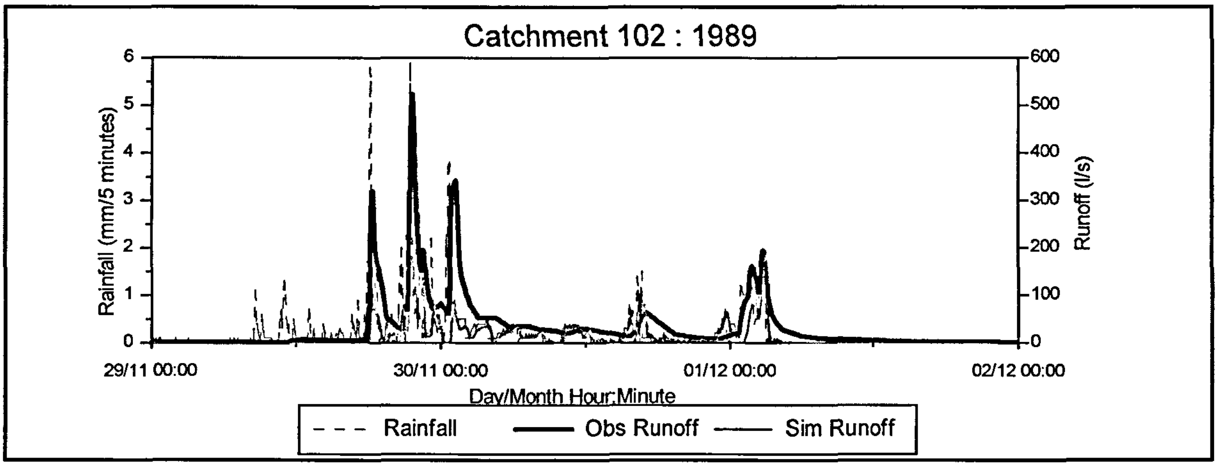
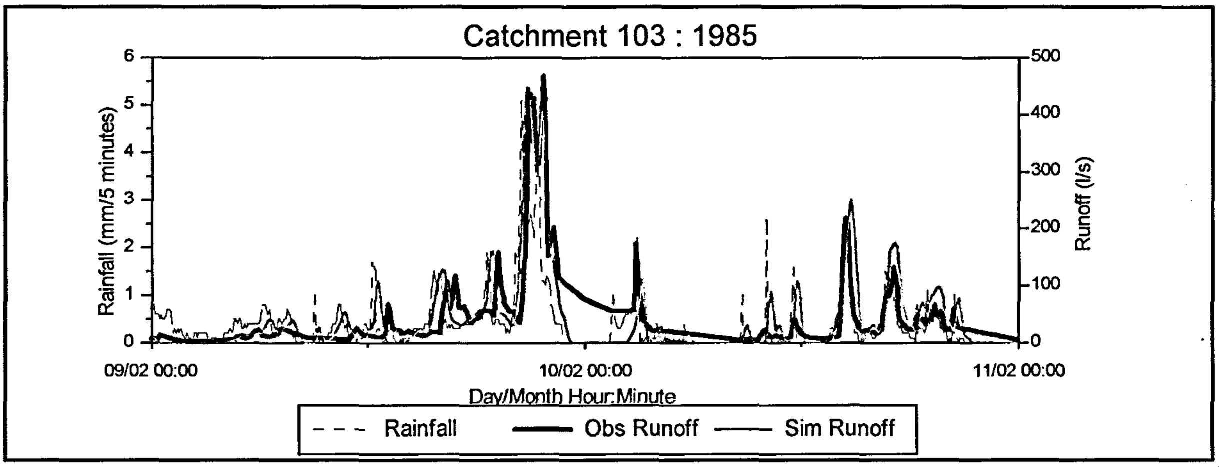
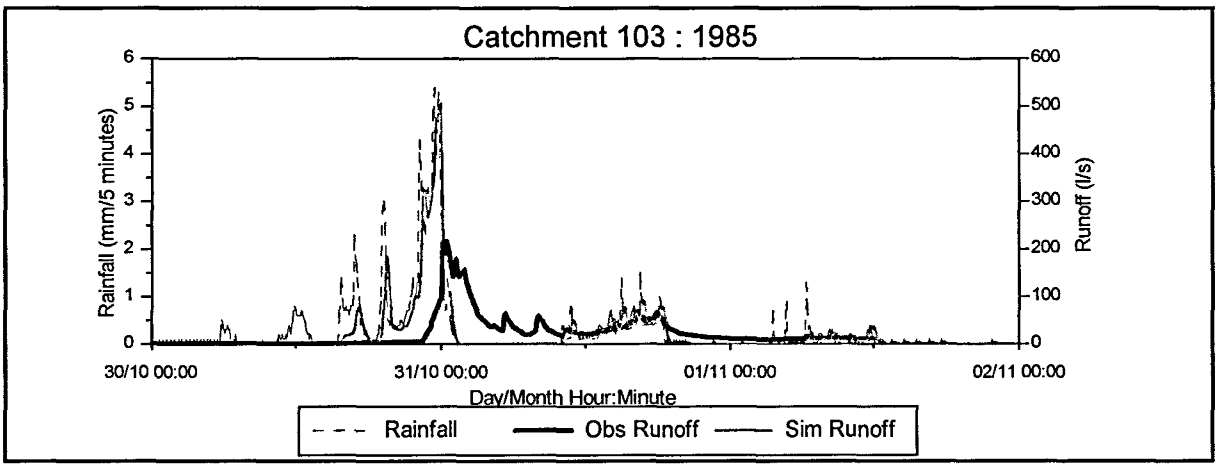


Figure 6.3.2: Hydrographs from Catchment 102 simulated using simulated storm flow volumes and optimised time of concentration (Continued)

6.3.3 Catchment 103

Simulated and observed hydrographs for selected events from Catchment 103 are depicted in Figure 6.3.3. The optimised Tc for Catchment 103 was 0.30 h (see Table 6.2.3), while Tc estimated from hydraulic calculations was 0.06 h.





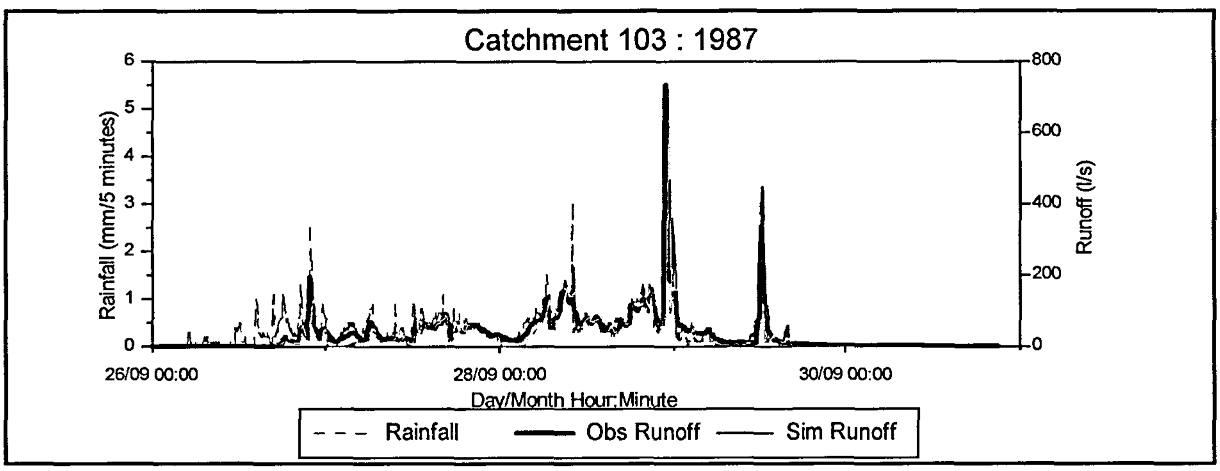
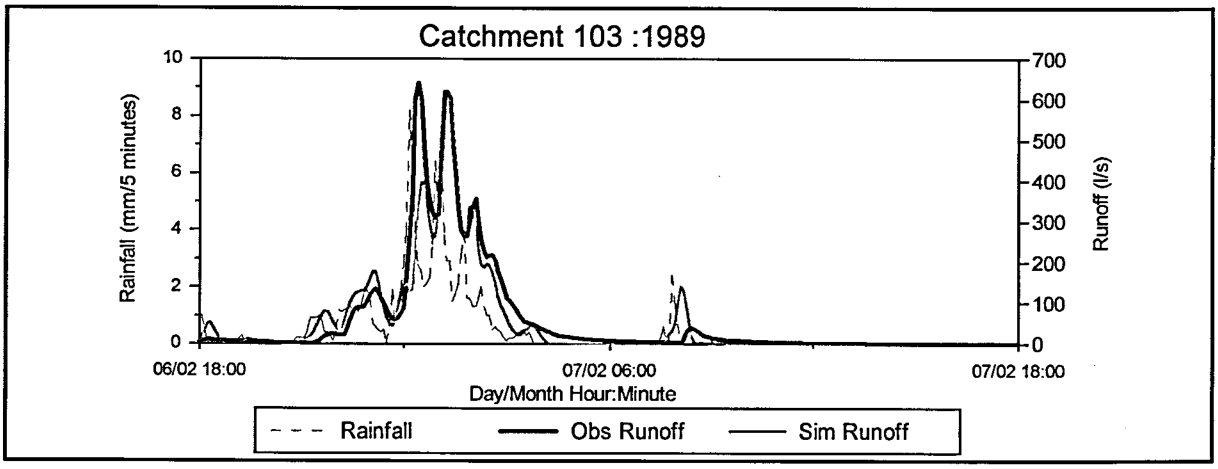


Figure 6.3.3: Hydrographs from Catchment 103 simulated using simulated storm flow volumes and optimised time of concentration



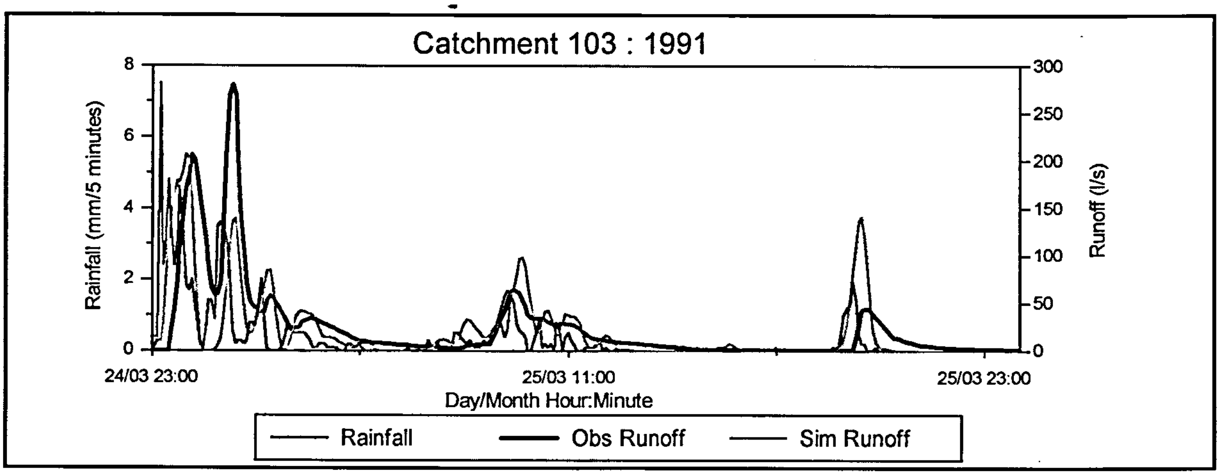


Figure 6.3.3: Hydrographs from Catchment 103 simulated using simulated storm flow volumes and optimised time of concentration (Continued)

6.3.4 Catchment 104

Simulated and observed hydrographs for selected events from Catchment 104 are depicted in Figure 6.3.4. The optimised Tc for Catchment 104 was 0.45 h (see Table 6.2.3), while Tc estimated from hydraulic calculations was 0.26 h.

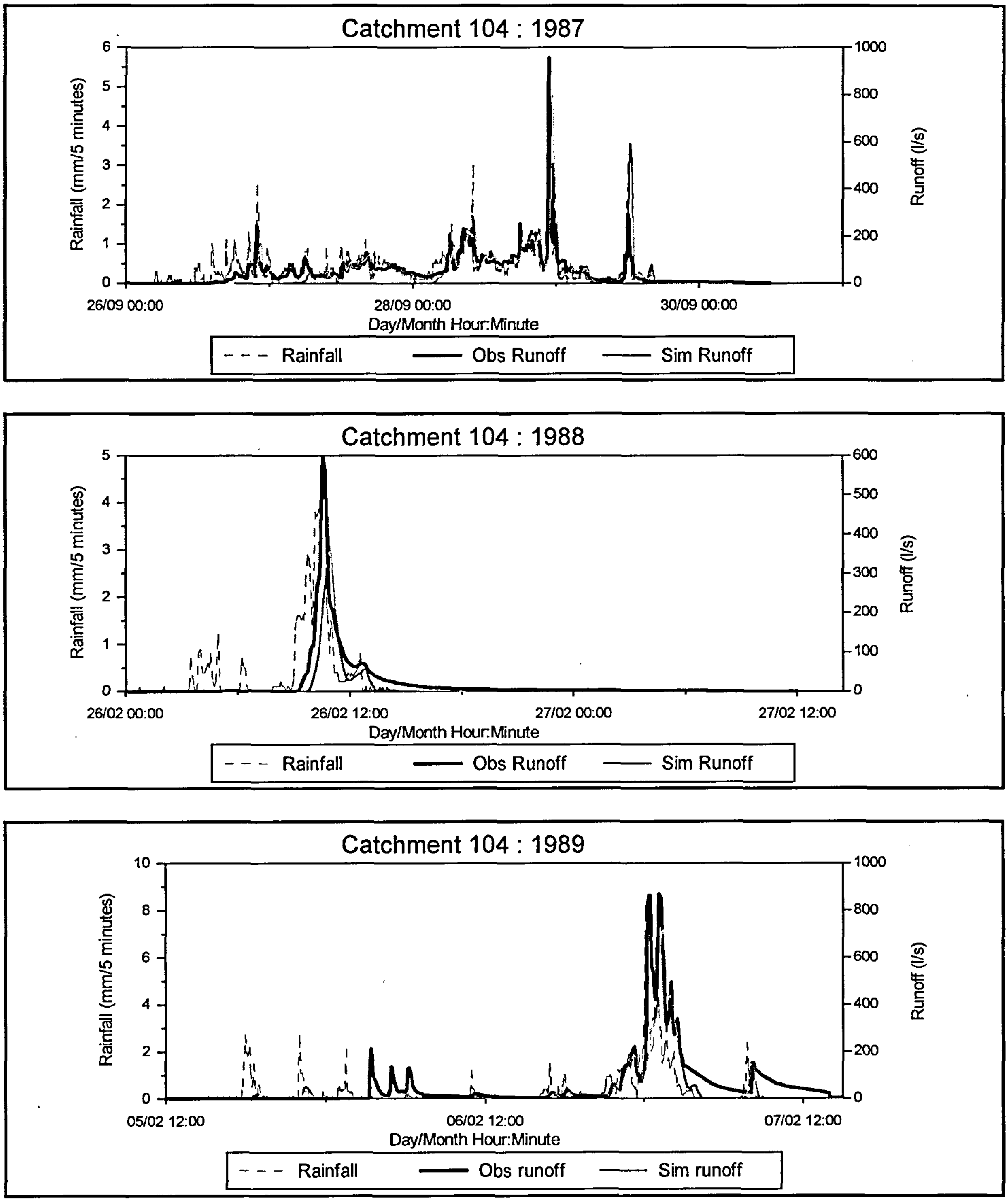
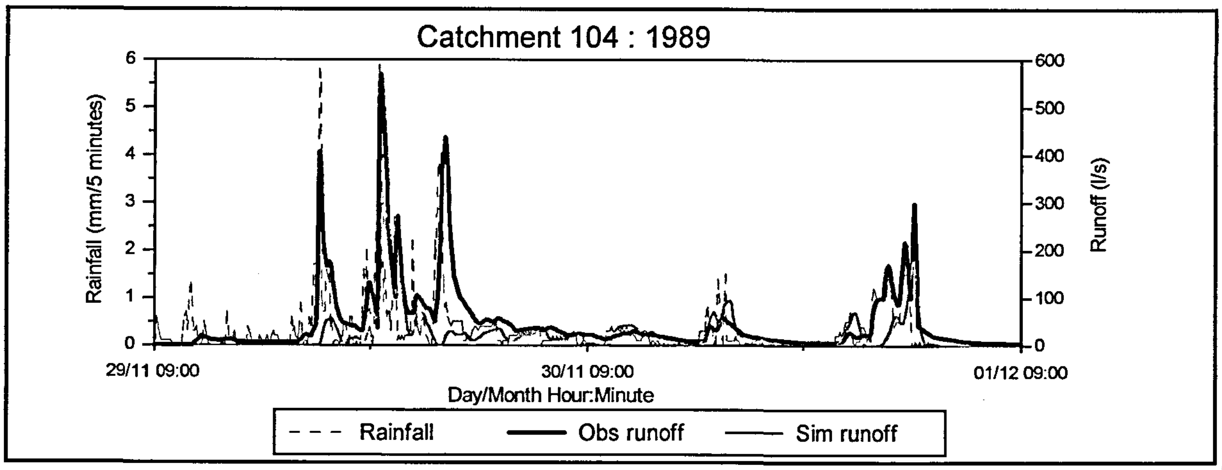


Figure 6.3.4: Hydrographs from Catchment 104 simulated using simulated storm flow volumes and optimised time of concentration



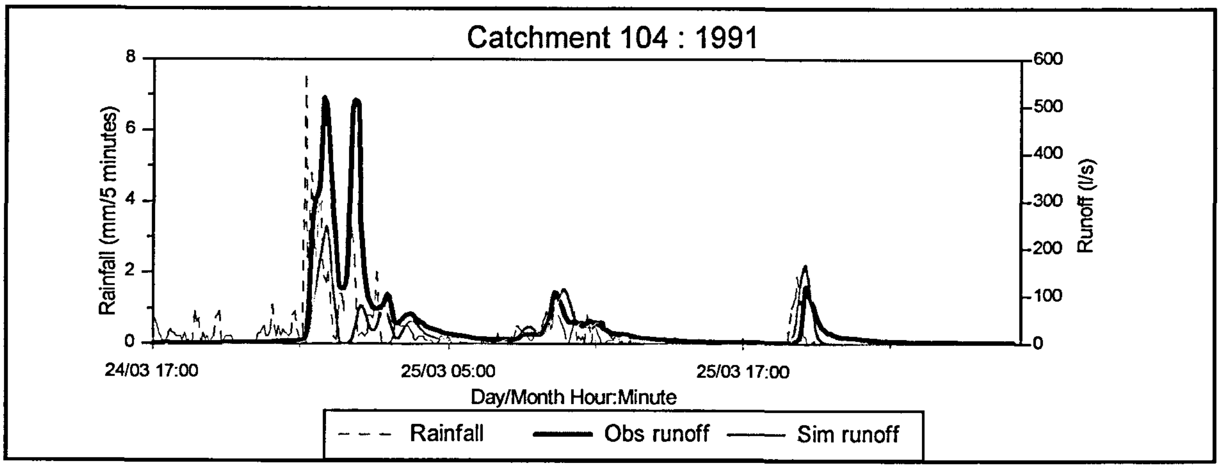


Figure 6.3.4: Hydrographs from Catchment 104 simulated using simulated storm flow volumes and optimised time of concentration (Continued)

6.3.2.5 Concluding remarks

The use of optimised time of concentration values, which in all four catchments are larger than the estimated time of concentration values, resulted in a slight reduction in simulated peak discharge. However, the optimised time of concentration values resulted in hydrographs which are flatter and "smoother" and which better reflect the shape of the observed hydrographs.

It is concluded that the model appears to be simulating the recorded hydrographs reasonably well under sugarcane land cover conditions. No observed hydrographs were available prior to 1985, and hence no comparisons under bare fallow conditions could be performed.

Baseflow is excluded from the simulated hydrographs as it was suspected that the gauging structures do not measure this component of runoff. With some exceptions, this assumption appears to be correct with the hydrograph recession limbs being reasonably simulated.

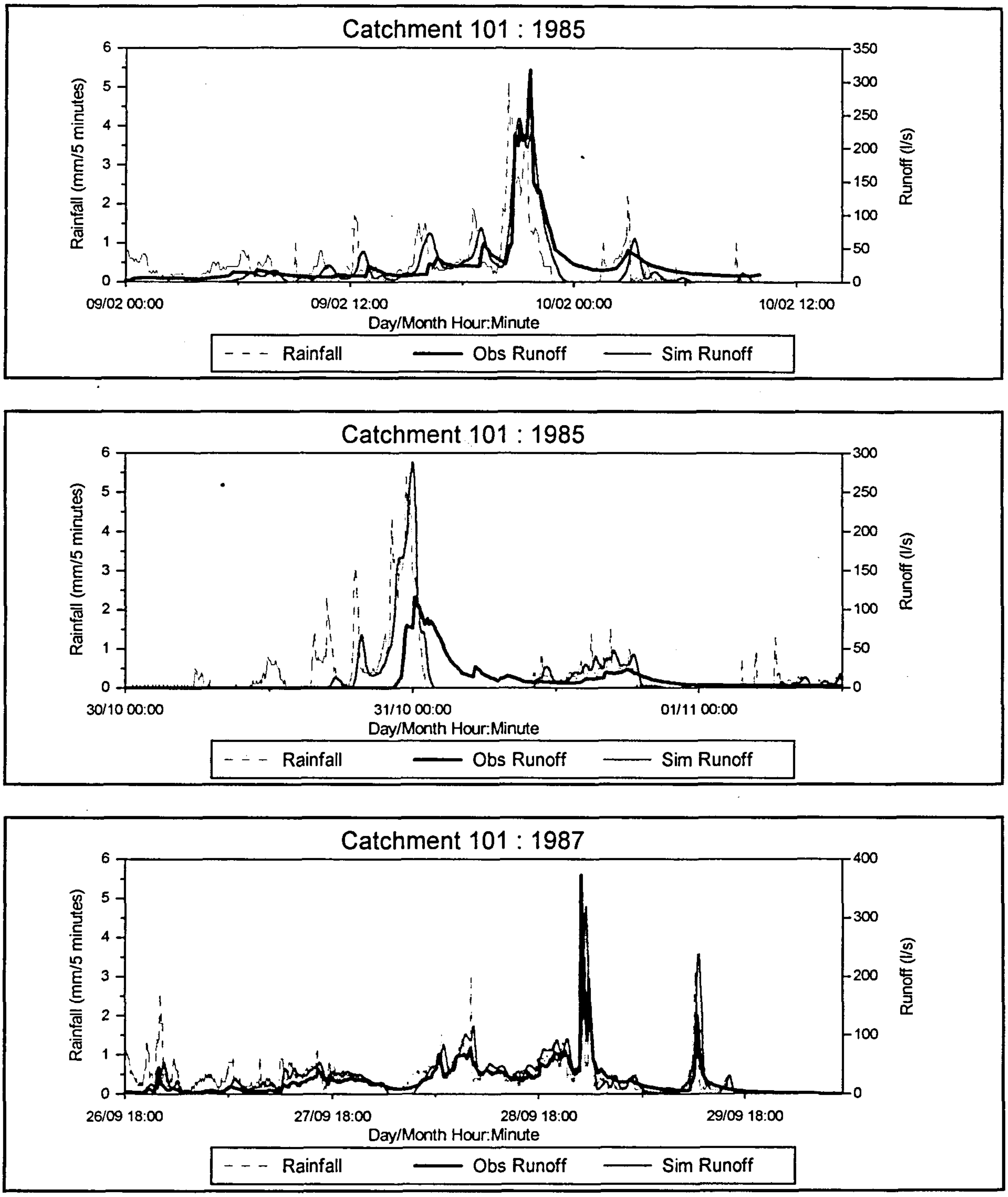
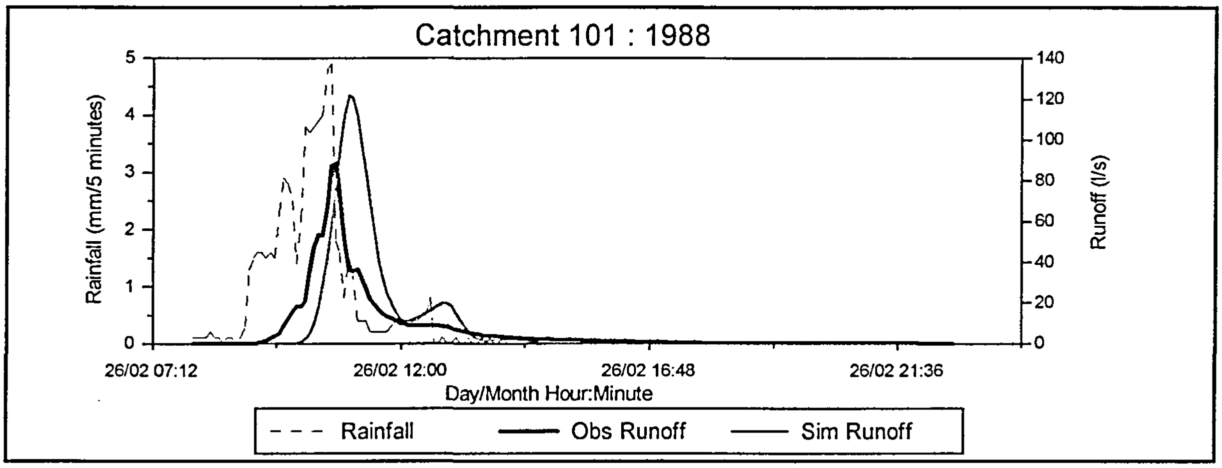


Figure 6.3.1 : Hydrographs from Catchment 101 simulated using simulated storm flow volumes and optimised time of concentration.



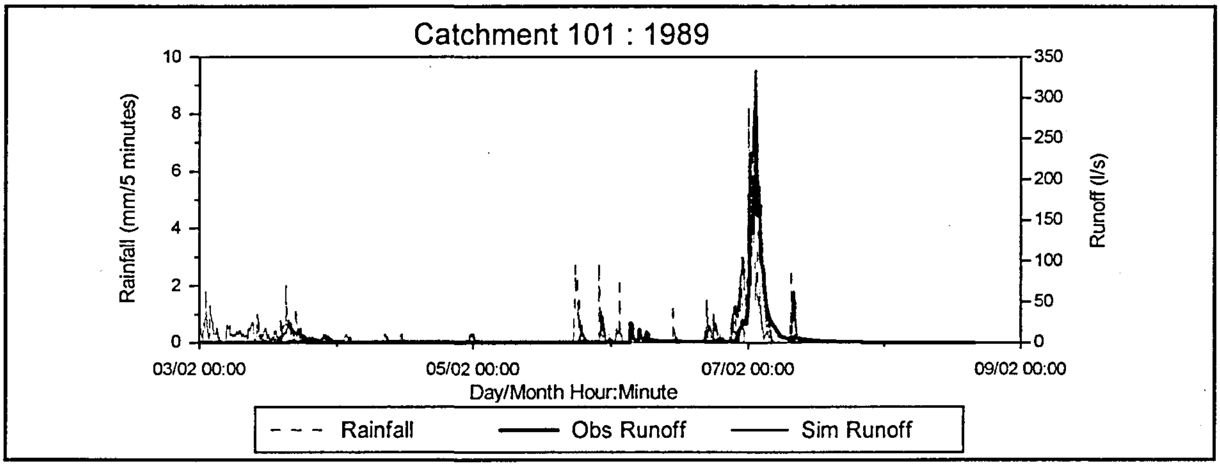


Figure 6.3.1: Hydrographs from Catchment 101 simulated using simulated storm flow volumes and optimised time of concentration (Continued)

6.3.2 Catchment 102

Simulated and observed hydrographs for selected events from Catchment 102 are depicted in Figure 6.3.2. The optimised Tc for Catchment 102 was 0.25 h (see Table 6.2.3), while Tc estimated from hydraulic calculations was 0.17 h.

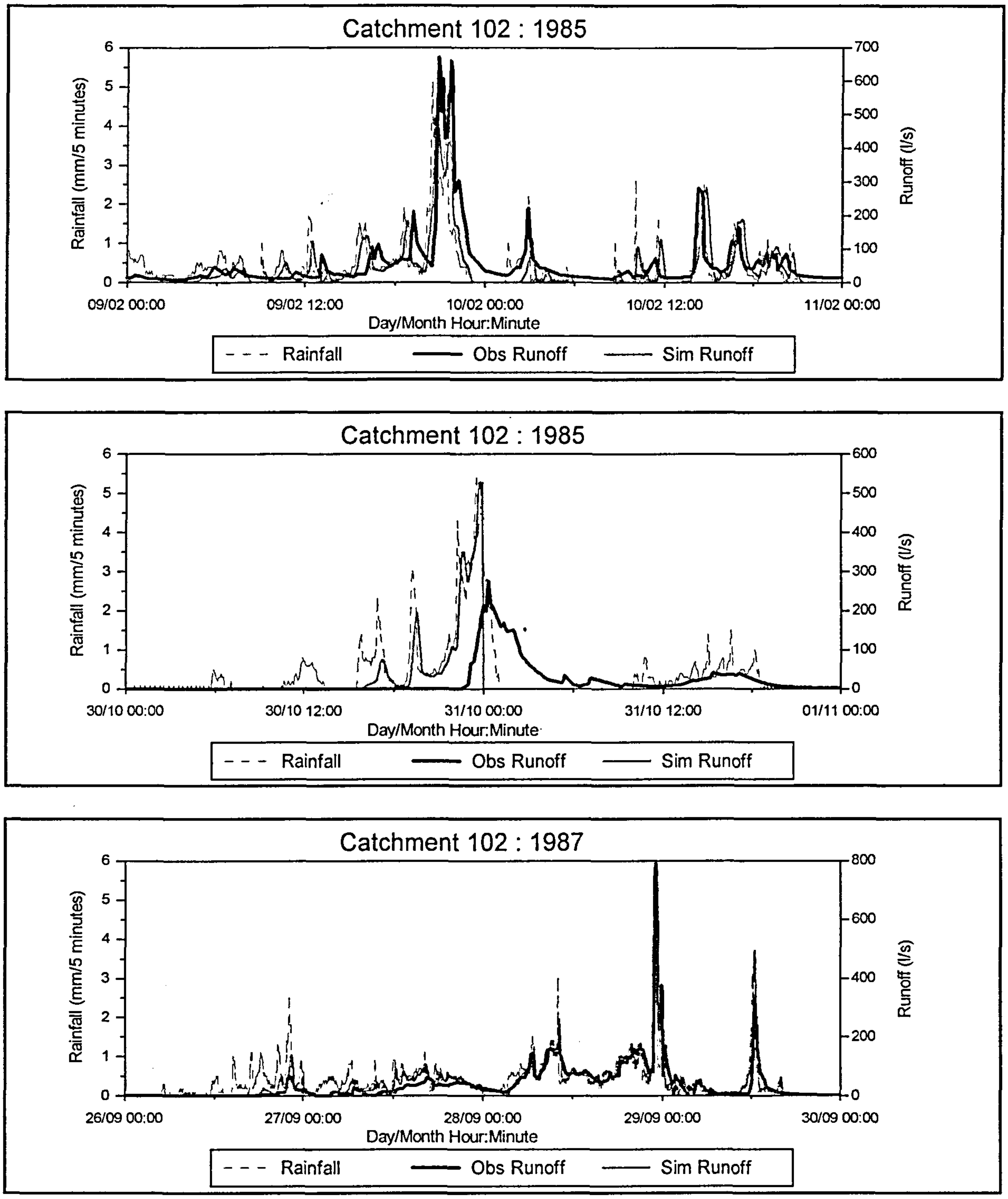
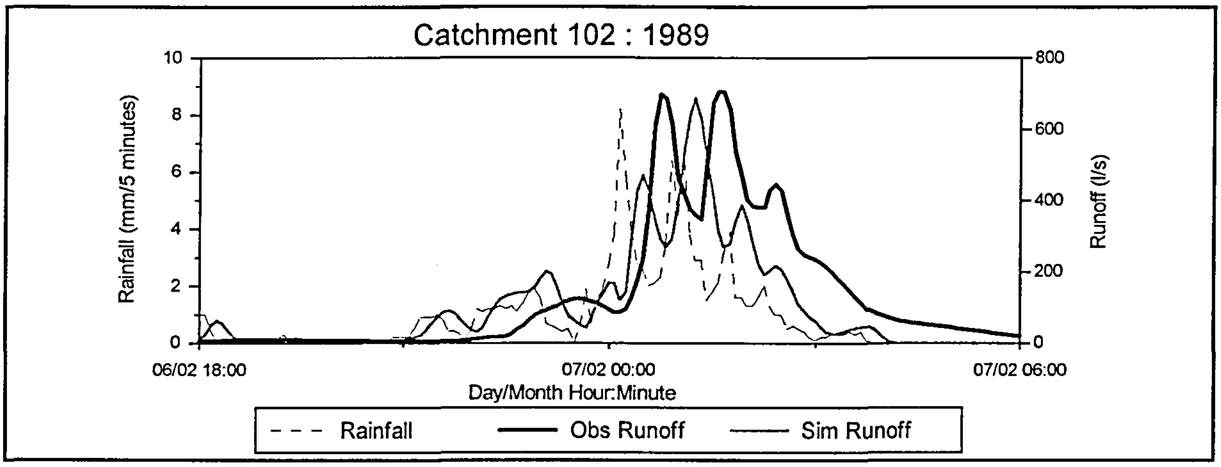


Figure 6.3.2: Hydrographs from Catchment 102 simulated using simulated storm flow volumes and optimised time of concentration



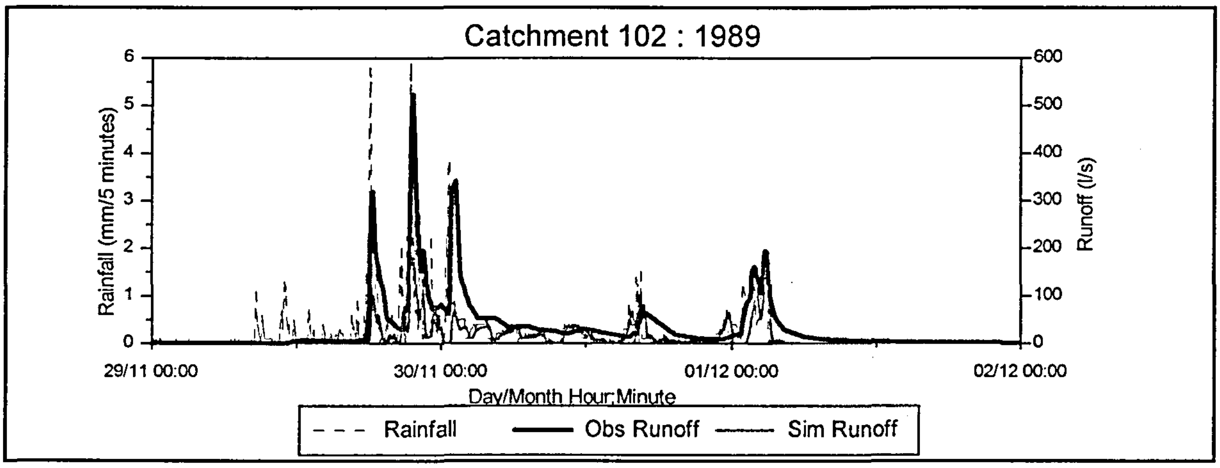
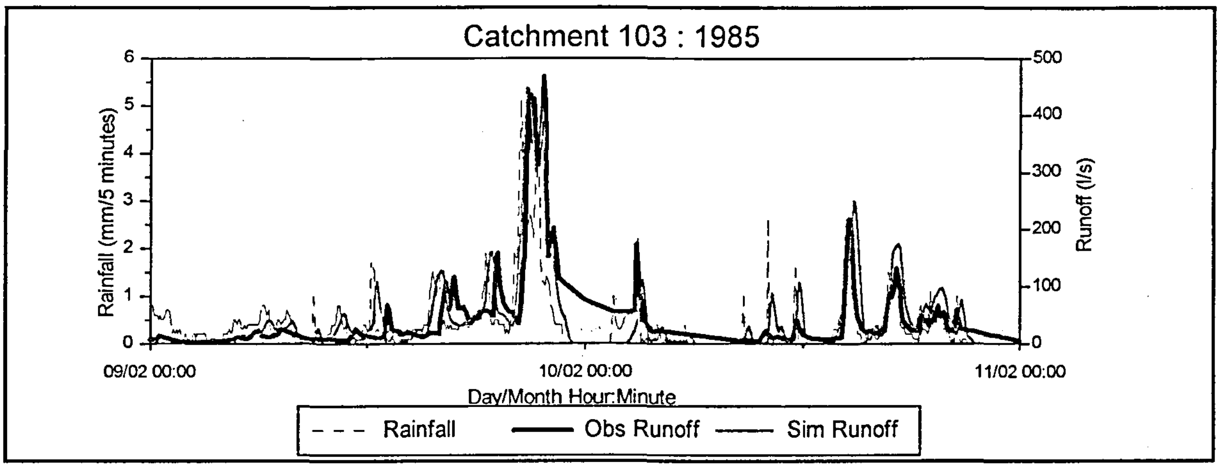
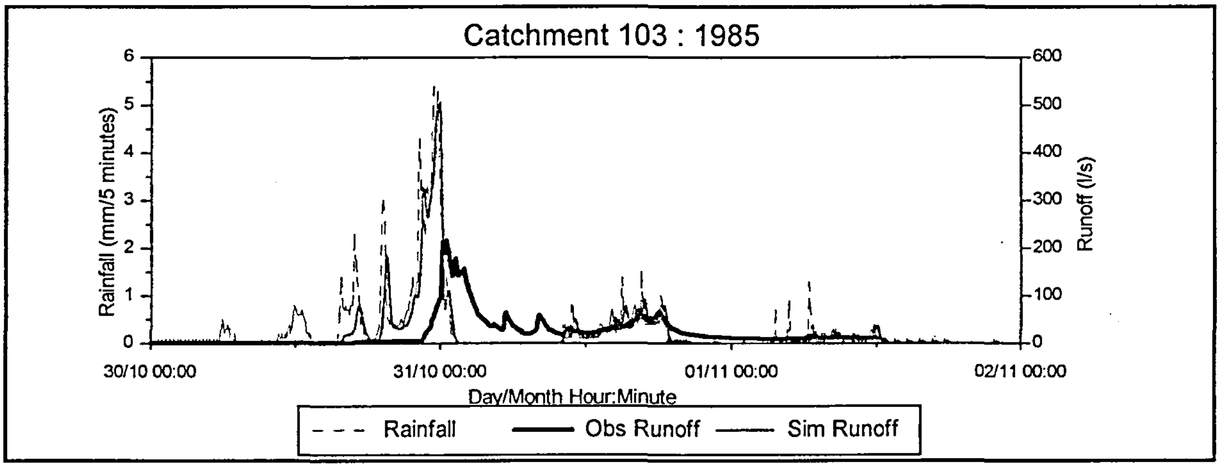


Figure 6.3.2: Hydrographs from Catchment 102 simulated using simulated storm flow volumes and optimised time of concentration (Continued)

6.3.3 Catchment 103

Simulated and observed hydrographs for selected events from Catchment 103 are depicted in Figure 6.3.3. The optimised Tc for Catchment 103 was 0.30 h (see Table 6.2.3), while Tc estimated from hydraulic calculations was 0.06 h.





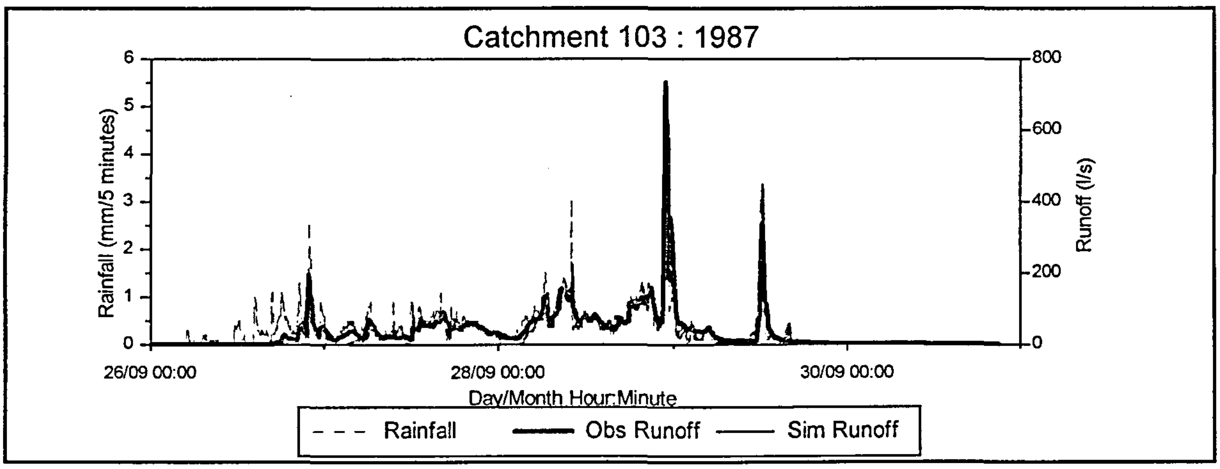
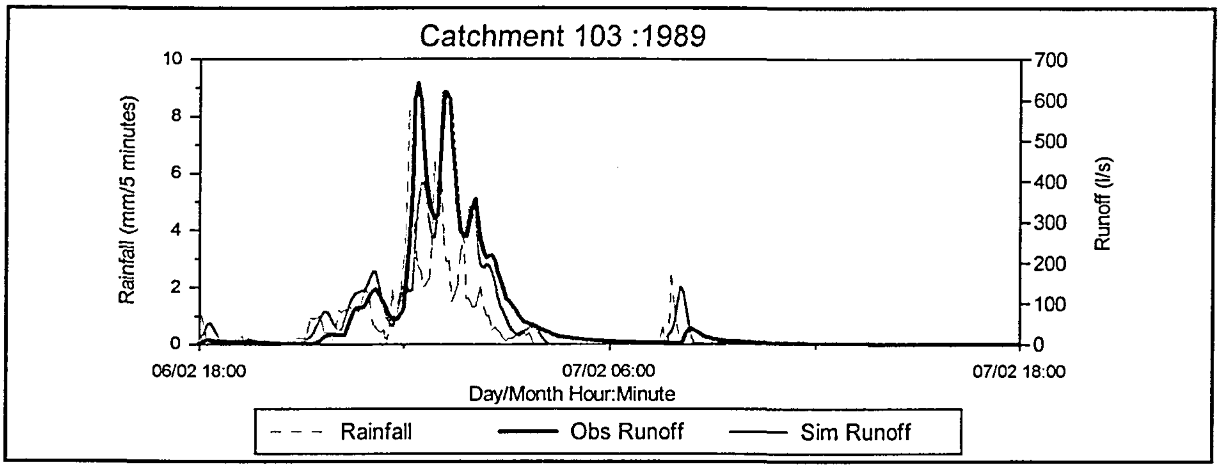


Figure 6.3.3: Hydrographs from Catchment 103 simulated using simulated storm flow volumes and optimised time of concentration



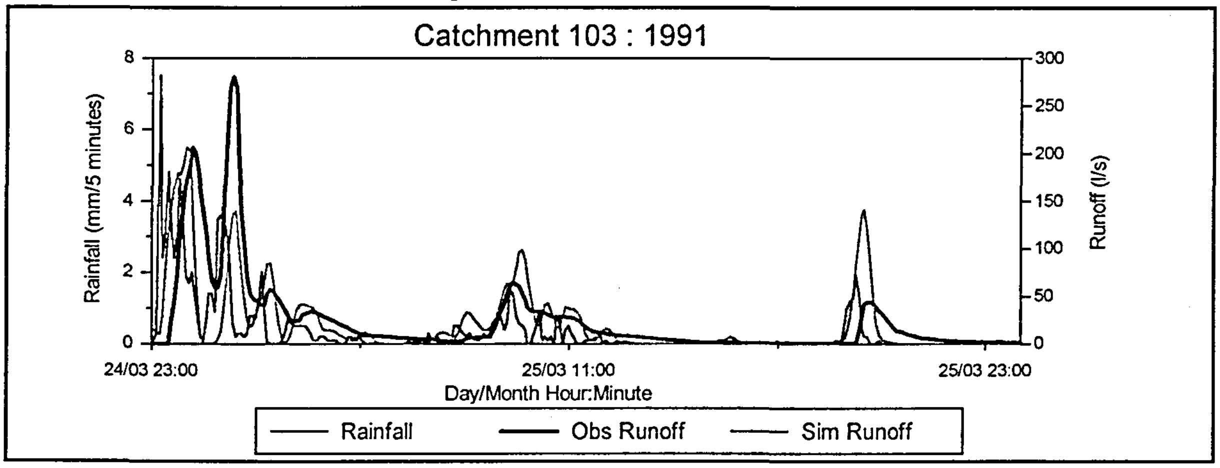


Figure 6.3.3: Hydrographs from Catchment 103 simulated using simulated storm flow volumes and optimised time of concentration (Continued)

6.3.4 Catchment 104

Simulated and observed hydrographs for selected events from Catchment 104 are depicted in Figure 6.3.4. The optimised Tc for Catchment 104 was 0.45 h (see Table 6.2.3), while Tc estimated from hydraulic calculations was 0.26 h.

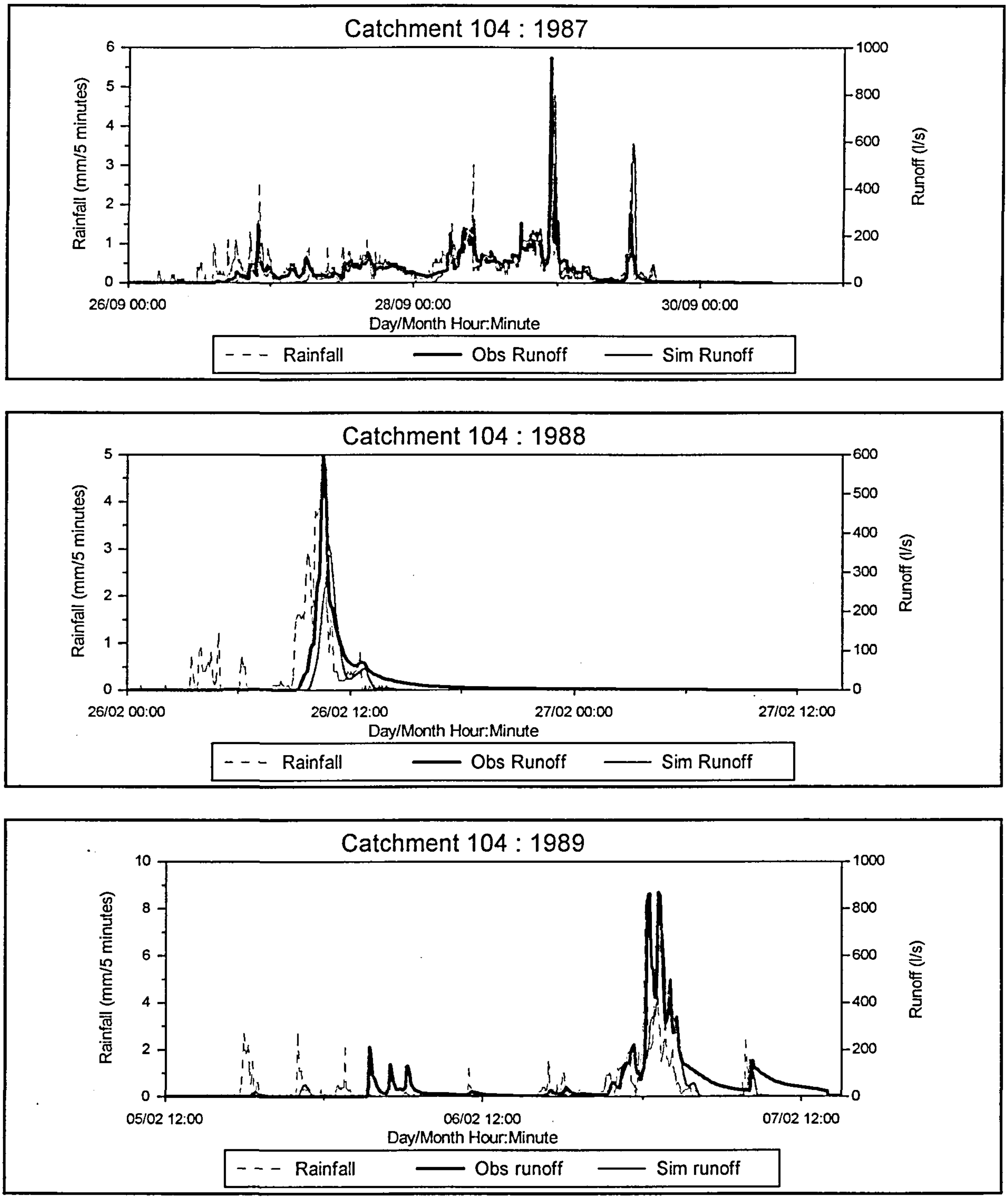


Figure 6.3.4: Hydrographs from Catchment 104 simulated using simulated storm flow volumes and optimised time of concentration

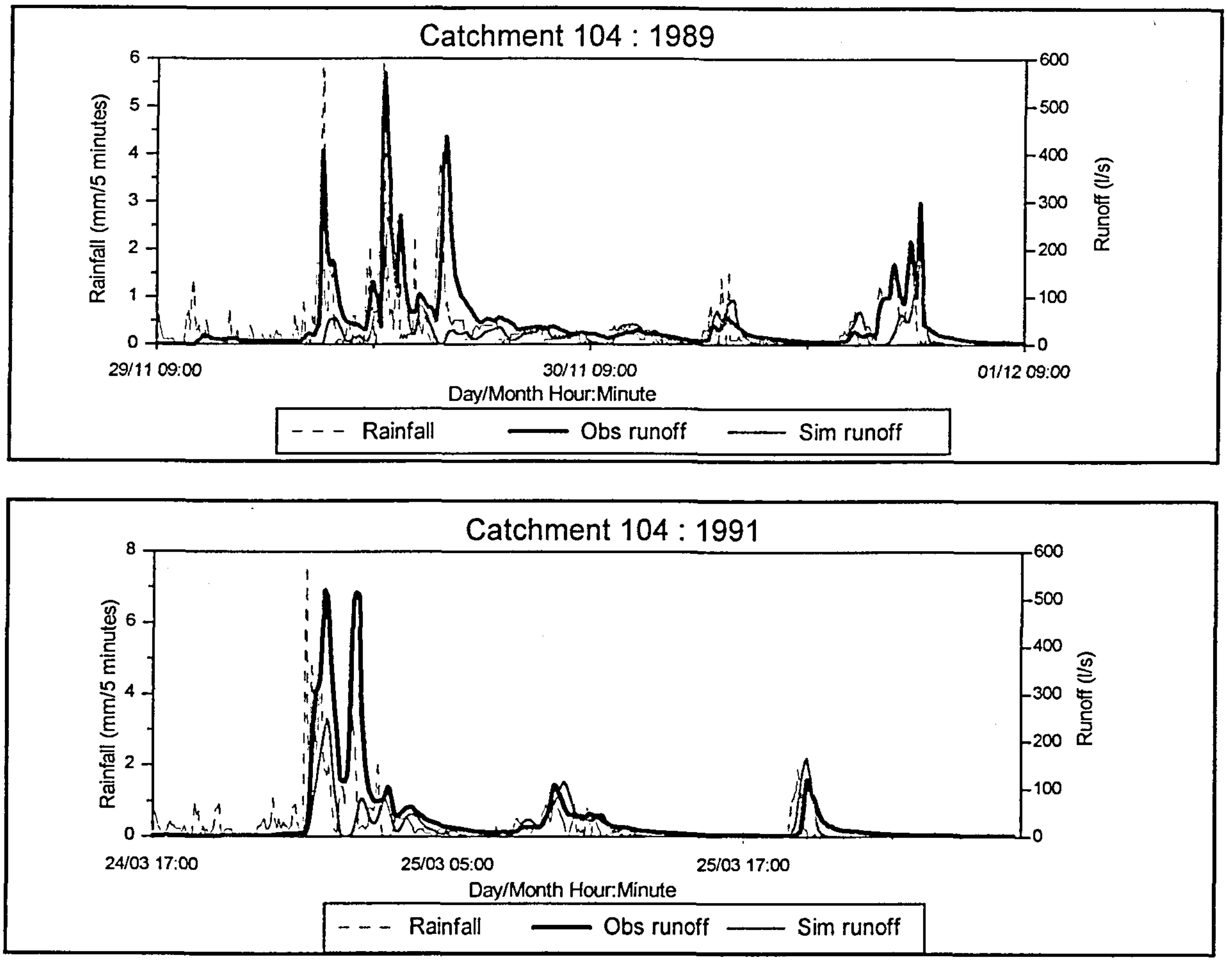


Figure 6.3.4: Hydrographs from Catchment 104 simulated using simulated storm flow volumes and optimised time of concentration (Continued)

6.3.2.5 Concluding remarks

The use of optimised time of concentration values, which in all four catchments are larger than the estimated time of concentration values, resulted in a slight reduction in simulated peak discharge. However, the optimised time of concentration values resulted in hydrographs which are flatter and "smoother" and which better reflect the shape of the observed hydrographs.

It is concluded that the model appears to be simulating the recorded hydrographs reasonably well under sugarcane land cover conditions. No observed hydrographs were available prior to 1985, and hence no comparisons under bare fallow conditions could be performed.

Baseflow is excluded from the simulated hydrographs as it was suspected that the gauging structures do not measure this component of runoff. With some exceptions, this assumption appears to be correct with the hydrograph recession limbs being reasonably simulated.

With some exceptions, the shape of hydrographs are simulated reasonably well. The method in which the model generates they hydrographs by treating each day as a single event requires further research. This is evident by the simulated hydrograph having no flow over midnight (e.g. Catchment 102, 7/2/1989).

6.4 Simulation of Sediment Yield

As shown in Section 5.3. the *ACRU* model simulates sediment yield using the MUSLE equation. The MUSLE equation uses storm flow volume for the event, peak discharge for the event, a soil erodibility factor, a slope-length factor, a cover factor, a management factor and location specific MUSLE coefficients in order to simulate sediment yield for individual events. The objectives in this section were:

(i) assess the adequacy of the *ACRU* model to simulate sediment yield from small catchments which have different management practices and are under sugarcane production, acknowledging that the areas of the catchments are generally considered to be out of the normal range of application of the MUSLE equation;

(ii) determine suitable MUSLE input parameters by using the observed storm flow volume and peak discharge in the simulation of sediment yield; and to

(iii) investigate the sediment yield simulated when simulated storm flow volume and peak discharge are used in order to assess the performance of the model at ungauged sites where stream flow records do not exist.

In addition to storm flow volume and peak discharge, the simulation of sediment yield is particularly sensitive to the estimation of the cover factor. The modelling of sediment yield using a static (i.e. not time dependent) cover factor was improved by means of an example of using a dynamic (i.e. varying with crop growth stage) cover factor.

6.4.1 Initial parameter estimation

The initial inputs selected for the simulation of sediment yield in the La Mercy catchments are presented in Table 6.4.1. The level 1 input option (simplest), outlined by Lorentz and Schulze (1995), was used to estimate the MUSLE parameters for a sugarcane land cover. Observed sediment yield data were not available for the period when the land cover in the catchments was bare fallow and hence the simulation could only be performed for sugarcane land cover. The *ACRU* variable names used in Table 6.4.1 are described below.

SOIFC1 and SOIFC2 are maximum and minimum soil erodibility factors respectively and were calculated and area-weighted according to soil properties. ELFACT is the slope length and steepness factor, calculated using the average catchment gradients. PFACT is the support practice factor, with values obtained from the *ACRU* User Manual (Smithers and Schulze, 1995) according to land slope and practice. COVER(I) is a monthly value of the cover factor with values derived from the *ACRU* User Manual using the estimated catchment curve number. SEDIST is the fraction of the event based sediment yield that reaches the catchment outlet on the day of the event. It is defaulted to the fraction of the total storm flow that will run off from the catchment on the same day as the rainfall event. ALPHA and BETA are location specific coefficients, for which suggested default values have been used.

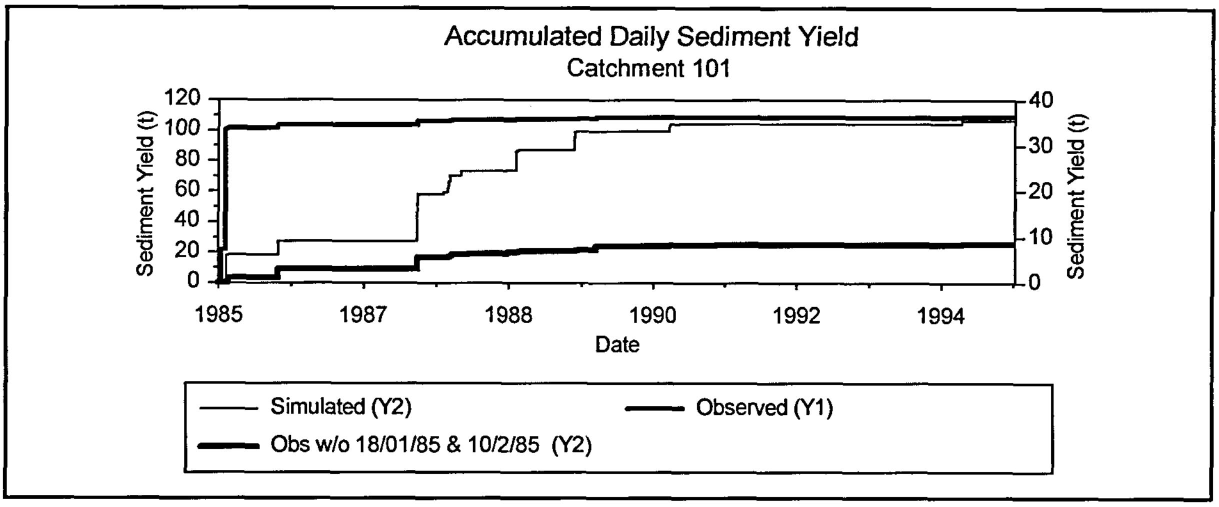
Table 6.4.1: Initial estimates of MUSLE parameters for the simulation of sediment yield

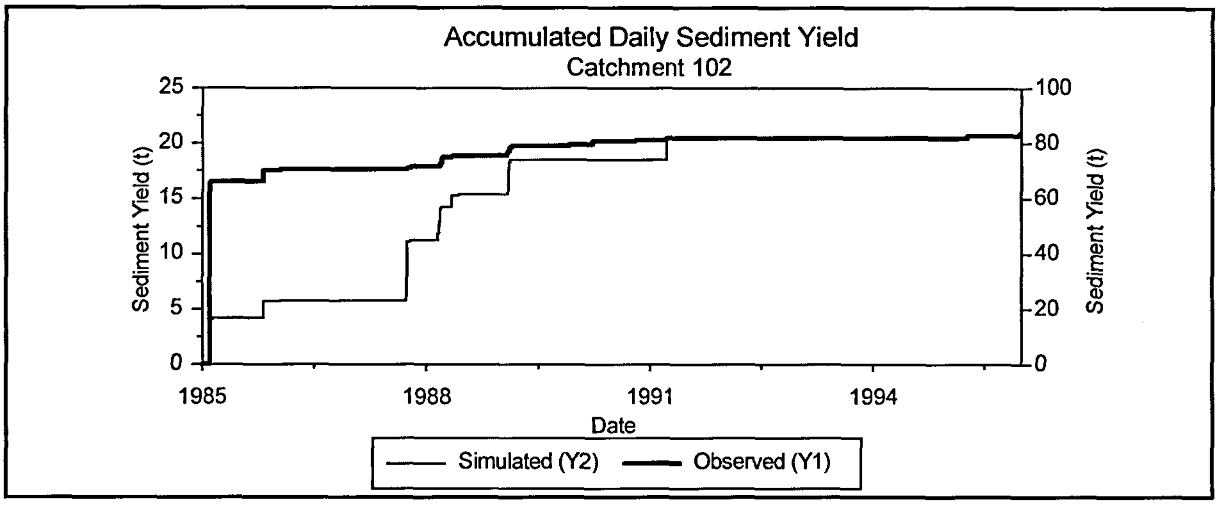
Input parameter/ variable	Catchment 101	Catchment 102	Catchment 103	Catchment 104
SOIFC1	0.35	0.36	0.36	0.30
SOIFC2	0.12	0.12	0.12	0.10
ELFACT	7.51	6.97	5.06	6.59
PFACT	0.18	0.18	1.0	0.16
COVER(I) (bare fallow)	0.63	0.63	0.63	0.63
COVER(I) (sugarcane)	0.13	0.13	0.17	0.09
SEDIST	0.90	0.90	0.90	0.90
ALPHA	8.934	8.934	8.934	8.934
BETA	0.56	0.56	0.56	0.56

The initial set of parameters was used in conjunction with the observed storm flow volume and observed peak discharge to simulate sediment yield. Thus the inaccurate simulation of either or both storm flow volume and peak discharge had no effect on the simulated sediment yield.

6.4.1.1 Observed peaks and volumes

The option in *ACRU* to use the observed storm flow volume and observed daily peak discharge to simulate the sediment yields was invoked. Events were excluded for which observed storm flow volume, but no observed peak discharge data, were available. The results of the sediment yield simulated for Catchments 101, 102 and 103 are shown in Figure 6.4.1. Catchment 104 was excluded from the simulations where observed storm flow volumes were used, as it was not possible to apportion the observed storm flow recorded at the outlet of the catchment to the respective sugarcane and bare fallow land covers, which were modelled as separate sub-catchments.





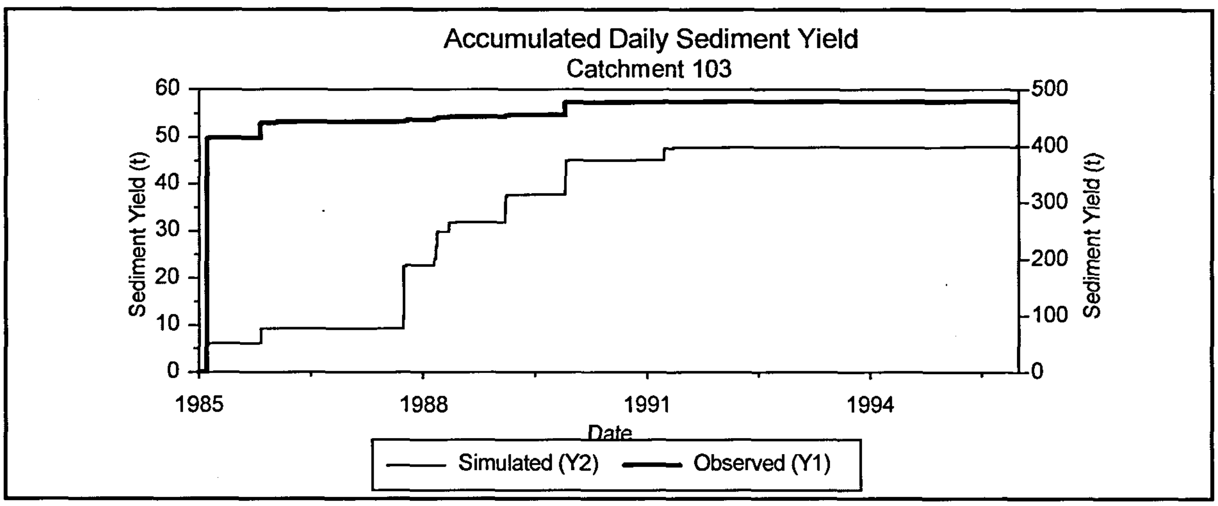


Figure 6.4.1: Accumulated daily sediment yields simulated using observed storm flow volumes and observed peak discharges (Y1 = left hand Y-axis; Y2 = right hand Y-axis)

From Figure 6.4.1 it is apparent that sediment yield was not well simulated by the model when using the inputs from Table 6.4.1. Sediment yield was over-simulated on all catchments with the exception of two extreme values of observed sediment yield from Catchment 101 in January and February 1985. The first event on Catchment 103 was well simulated by the model, whereafter the model over-simulated the sediment yield.

6.4.2 Amended COVER factor

The simulation of sediment yield using the MUSLE equation is particularly sensitive to the cover factor (COVER). In the initial parameter estimates the COVER factor was derived from the catchment Curve Number, which is the simplest option suggested by Lorentz and Schulze (1995). However, other methods of deriving COVER factor indicate that the value may be as low as 0.01 (Lorentz, 1996), and Platford (1996) confirmed that 0.1 would be a maximum value for estimating mean annual sediment yield from sugarcane. Hence a revised value of the COVER factor = 0.03 for sugarcane was used to simulate sediment yield. This revised value, which is within the range of acceptable values, is an optimised value determined by varying the COVER factor for Catchment 101 until a good simulation of sediment yield from that catchment was obtained.

6.4.2.1 Observed peaks and volumes

The results of simulating sediment yield using the amended COVER factor together with observed storm flow volumes and peak discharges are contained in Figure 6.4.2 Based on the assumption that simulated sediment yields shown in Figure 6.4.2 were the best that could be obtained using a time-invariant parameter and by not optimising all the input parameters, the performance of the model at ungauged sites was assessed by using the simulated storm flow volumes and peak discharges in the simulation of sediment yield.

6.4.2.2 Simulated peaks and volumes

Observed and simulated accumulated daily sediment yield are shown in Figure 6.4.3 for sediment yield that was simulated using optimised time of concentration values, COVER = 0.03, simulated storm flow volumes and simulated peak discharges. It is clear from Figure 6.4.3 that the use of simulated storm flow volumes and peak discharges resulted in an over-simulation of sediment yield.

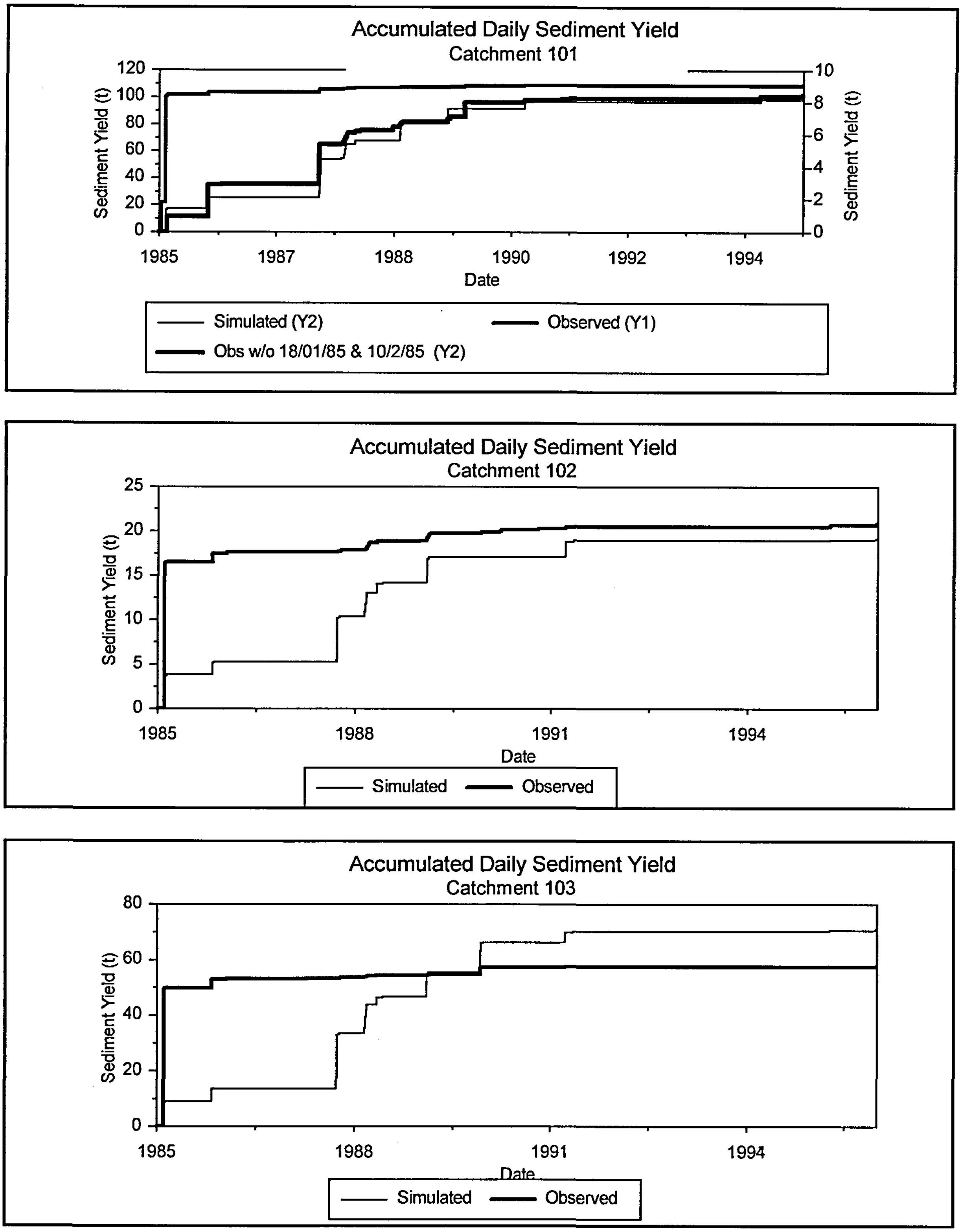


Figure 6.4.2: Accumulated daily sediment yields simulated using observed storm flow volume and observed peak discharge, COVER = 0.03

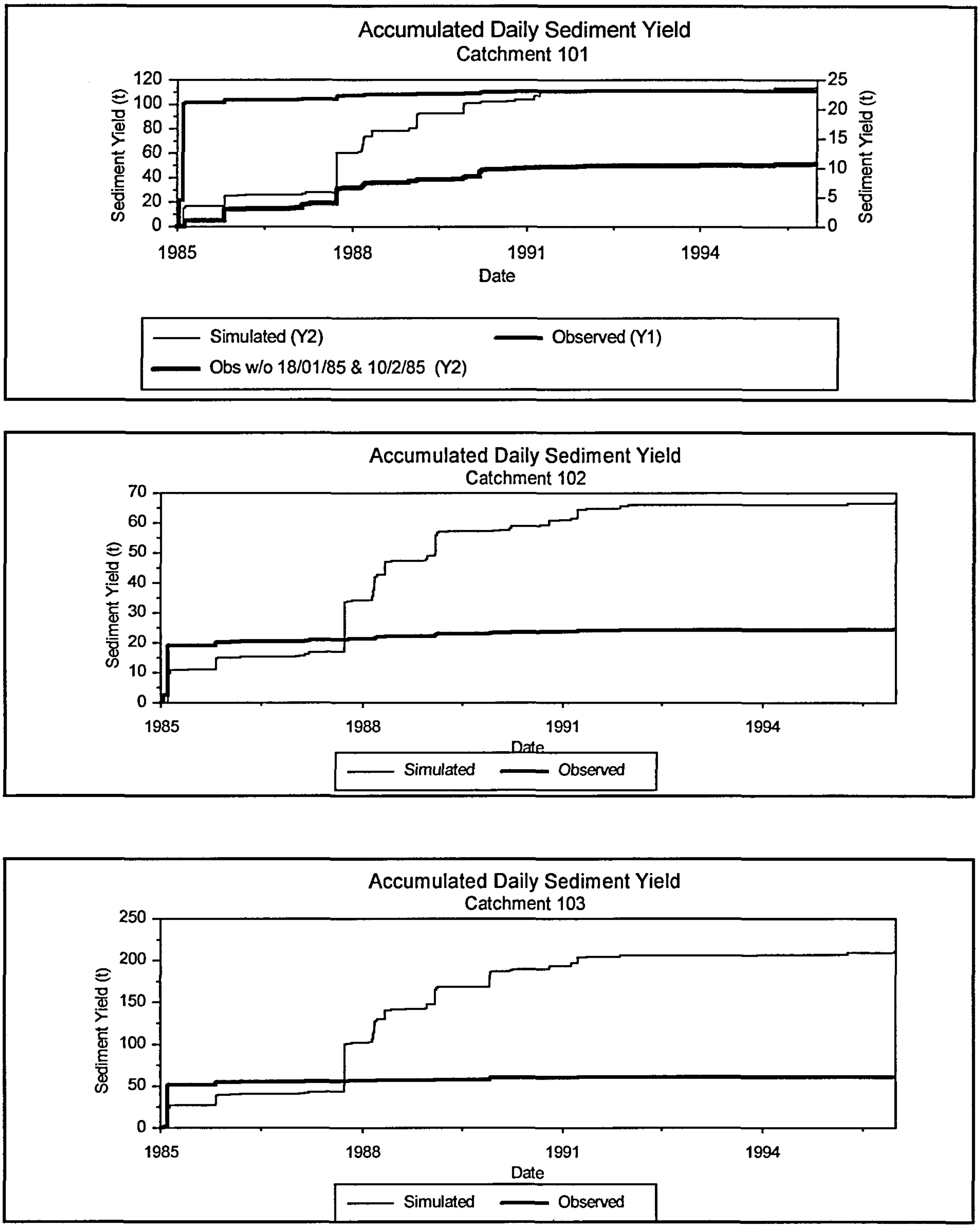


Figure 6.4.3: Accumulated daily sediment yield using input hyetograph, optimised time of concentration, COVER = 0.03 and simulated peak discharges and simulated storm flow volumes

6.4.3 Catchment 104

Sugarcane was established in Catchment 104 in January 1986, and hence the sediment yield measured for 1985 are from bare fallow conditions in the catchment. The simulated (using observed hyetograph and observed volumes and peak discharge) and observed sediment yields for 1985 are shown in Figure 6.4.4. The first event in 1985 (18 January) is excluded from Figure 6.4.4 as no observed peak discharge was available and the second event (7-11 February) is well simulated by the model using the observed runoff volume. However, the observed volume for this event is suspect as the runoff: rainfall ratio for the event is greater than 95%. The event on 31 October 1985 is over-simulated by the model. A comparison of the observed sediment yield for this event from Catchment 104 (0.75 t ha^{-1}) with Catchment 103 (0.72 t ha^{-1}), which was under full canopy, indicates that the measured sediment yield may be have been incorrect.

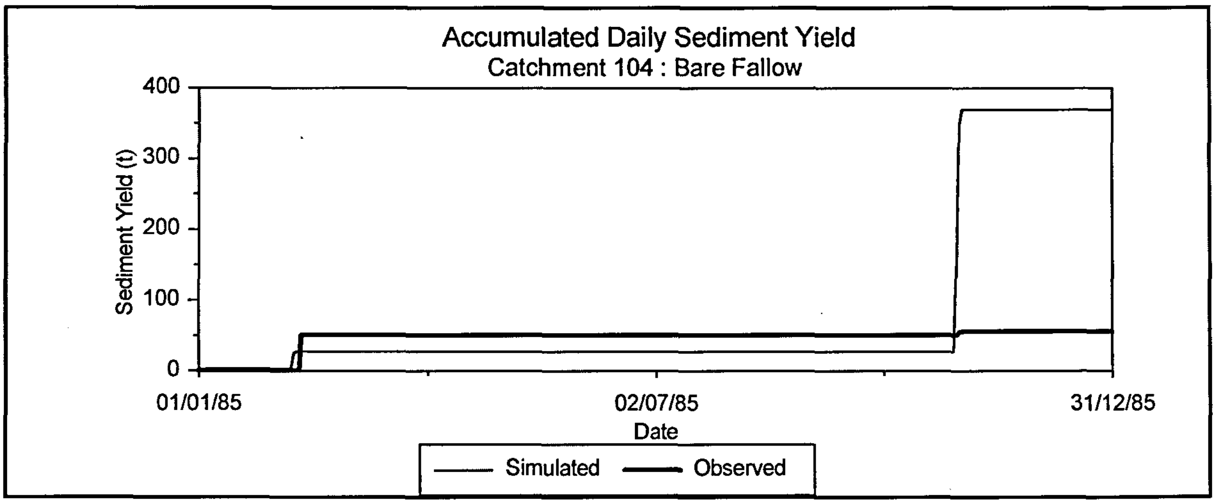


Figure 6.4.4: Accumulated daily sediment yield from Catchment 104 simulated using observed hyetograph and observed peak discharge and volume

Accumulated observed and simulated daily sediment yield after the establishment of sugarcane in Catchment 104 is shown in Figure 6.4.5. The sediment yield is simulated using optimised time of concentration values, COVER = 0.03 and with simulated storm flow volume and peak discharge. In Figure 6.4.5 it was assumed that all the sediment yield from the bare fallow panels is transported to the outlet of the catchment.

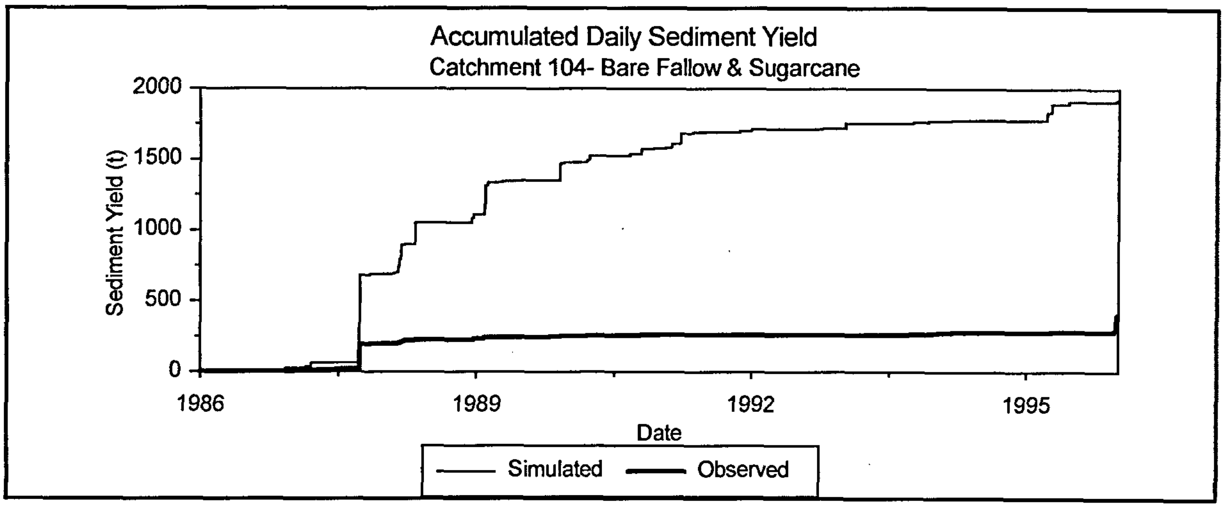


Figure 6.4.5: Accumulated daily sediment yield from Catchment 104 simulated using observed hyetograph, optimised time of concentration, COVER = 0.03 for sugarcane and simulated peak discharge and simulated storm flow volume

6.4.4 Dynamically varied cover factor

A dynamic land cover file, which enabled the input parameters to be varied over time, was created based on the assumption that the COVER factor for sugarcane at full canopy was 0.01 and after harvesting was 0.60 (Lorentz, 1996), and that full canopy was achieved in five months for cane harvested in the summer months and six months for sugarcane harvested during the winter months. The result of simulating sediment yield from Catchment 102 using cover values that vary according to the assumed growth pattern are shown in Figure 6.4.6.

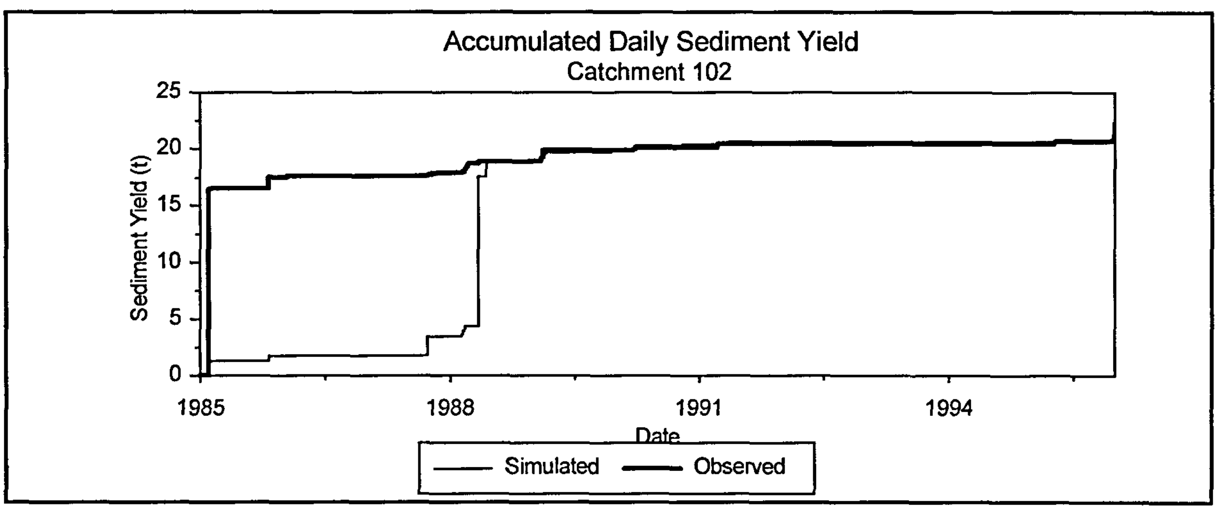


Figure 6.4.6: Accumulated daily sediment yield simulated from Catchment 102 using dynamically varying COVER factor

According to the documented management practises in Catchment 102, the fields were planted in September 1984 and harvested in January and again in December 1986. Hence at the time of the large observed sediment yield event on 11 February 1985, the sugarcane should have been under partial canopy conditions. It is thus suspected that either local land management practises could have had an impact on sediment yield (e.g. waterway or contour bank repairs) or accumulated sediment deposits from previous smaller events could have been flushed down the catchment. Alternatively the documented management practises or the observations may be incorrect.

Similarly, the large amount of sediment simulated on 5 May 1988, is as a result of the documented management practise indicating that the sugarcane was harvested in April 1988, and hence the catchment would have had very little cover on 5 May 1988. While the model and input to the model cannot be entirely discounted as possible reasons for the poor simulation of sediment yield for this event, it is suspected that either the recorded management practises are incorrect or the event on 5 May 1988 was incorrectly recorded. The sediment yield simulated with these two events excluded, is shown in Figure 6.4.7.

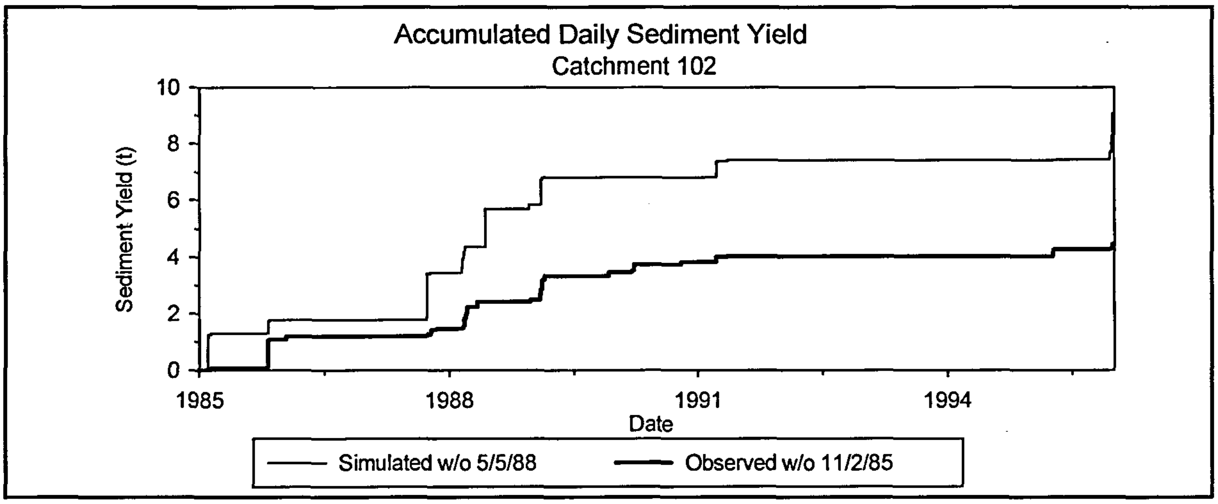


Figure 6.4.7: Accumulated daily sediment yield from Catchment 102 simulated using dynamically varying COVER factor, observed hyetograph, observed volume and observed storm flow volume, but with events on 11/02/85 and 05/05/88 excluded

6.4.5 Concluding remarks

From Figure 6.4.1 it is clear that, even when observed volumes and peak discharges were used to estimate sediment yield, the initial estimates of the parameters for the MUSLE equation were not appropriate. It should be noted that in all simulations which used observed peak discharge to simulate sediment yield, numerous events were not included as no observed peak discharge data were available for these events. The inclusion of all events may alter the performance of the simulation.

Using COVER = 0.03 for sugarcane, which appears to be within the acceptable range for the parameter, resulted in some improvements in the simulated sediment yield as indicated in Figure 6.4.2. However, the simulations were still not satisfactory, and as shown in Figure 6.4.3, were clearly not acceptable when simulated peaks and volumes were used to estimate sediment yield, as would be the case at an ungauged site.

From the above remarks it is evident that a more detailed investigation into the estimation of the parameters for the MUSLE equation is necessary, particularly to account for management practices. The case study of using a dynamic COVER factor in Catchment 102, which improved the simulation of sediment yield, illustrates the need to model the management practises in more detail. It is thus recommended that in future simulations, the management practices on the catchments be modelled in dynamic mode, thus accounting directly for management practices which influence sediment yield.

The soil erodibility factor is a function of the antecedent soil moisture (Lorentz, 1996). Hence if the initial soil water contents are too low at the start of the simulation, high K-factors would result in an over-simulation of sediment yield. The influence of initial soil water content on sediment yield has not been investigated in this report, and it is recommended that future investigations consider this aspect.

The issue of how to simulate sediment yield from a catchment which has panels of different land cover contained within the catchment and where the panels have very different hydrological responses, has not been addressed. This aspect is manifested in the simulation of sediment yield from Catchment 104, where it was not possible to estimate the proportion of soil loss which is transported from the bare fallow panels to the catchment outlet.

7. DISCUSSION AND CONCLUSIONS

A vast amount of data and information for sugarcane from runoff plots and catchments has been collected over a number of years by the South African Sugar Association's Experiment Station (SASEX). A crucial element in the successful collection of data is frequent analysis and use of the data. This enables any incorrect data to be detected in time and steps taken to ensure a minimum loss of data. In analysing trends contained within the data, spurious data have been identified and in some cases have been excluded from further analysis. Recommendations as to the manner in which the data are stored have also been made to ease future analysis of the data. This report has focussed on analysing the runoff data from the La Mercy research catchments.

The substantially more runoff since 1981 from Catchment 104 as compared to the other three catchments, in addition to the inconsistent trends between runoff from Catchment 104 and the other catchments, has led to the conclusion that the runoff data from Catchment 104 may be erroneous and needs further investigation. It is suspected that the rating of the monitoring flume may have been altered in 1981.

During the periods when the catchments were bare fallow (1978-1984), and with the exclusion of Catchment 104, the volume of runoff from the catchments are similar. Thus the expected effect of catchment steepness on runoff volume was not evident.

Subsequent to the establishment of sugarcane, management practices have had a large effect on the volume of runoff. The least volume of runoff was measured from Catchment 101, which may be attributed to the minimum tillage practised in that catchment. Contrary to expectations, the runoff from Catchment 103 (no conservation structures) was less than that from Catchment 102 (conservation structures), thus indicating that the effect of conservation structures under sugarcane production is to increase the volume of runoff. It is postulated that this may be attributed to faster response times (i.e. less time for the re-infiltration of runoff) when conservation structures are present, and possibly to less of the total catchment area covered by sugarcane when conservation structures are present.

Unfortunately no sediment yield data were available for Catchments 101, 102 and 103 under bare fallow conditions. After the establishment of sugarcane relatively little sediment yield was recorded.

The *ACRU* model was applied to the four catchments at La Mercy and runoff volume, daily peak discharge, continuous hydrographs and sediment yield were simulated and compared to observed data. Parameters for the model were initially based on recommended values and expert opinion. Based on the output simulated using the initial set of the parameters, a consistent set of rules termed the SugarCane Decision Support System (SCDSS) was derived. The use of the SCDSS did not improve the volume of runoff simulated on all four catchments in all cases for both bare fallow and sugarcane land covers. However, the "rules" embedded in the SCDSS are deemed to be conceptually correct and consistent between the different management practices. With the use of the SCDSS, the *ACRU* model was able to simulate adequately the volume of runoff from both bare fallow and sugarcane land covers, and with sugarcane under different management practises.

A general problem in the simulation of runoff volume was that under a sugarcane land cover runoff was simulated by the model, particularly during drier periods, when little or no runoff was being observed. The over-simulation of events during dry periods may be due to the resolution of the instruments at the gauging structures, which may not have been sufficiently accurate to measure very small events. Assuming that the observed data are correct, it is suggested that the manner in which the rainfall is abstracted prior to the simulation of runoff by the model be investigated. Currently the rainfall prior to the commencement of runoff is simulated by means of a coefficient. Based on the results from this study and for a dense vegetation such as sugarcane, it appears that the initial abstraction should be an amount per event, which in turn could be a function of antecedent rainfall or soil moisture.

Despite these current inadequacies in the model, it is suggested that the model can be used with confidence to simulate the volume of runoff from catchments under sugarcane production in KwaZulu-Natal.

The use of observed runoff volumes and observed hyetographs in the simulation of daily peak discharge indicated that the estimated catchment times of concentration were incorrect. Improved simulations of daily peak discharge were obtained with the use of optimised, or improved, times of concentration. The daily peak discharge simulated using the observed hyetograph, optimised lag times and simulated storm flow volumes were considered to be highly acceptable. However, the use of the appropriate design rainfall distribution to dis-aggregate daily rainfall totals into shorter durations (i.e. synthetic hyetograph) resulted in the over-simulation of peak discharge.

Based on the hydrographs presented, the simulation of hydrographs by the daily time step water budget model, using the observed hyetograph, was considered to be better than expected, with the shape and peaks generally reasonably simulated during large events.

In order to improve the simulation of peak discharge, it is recommended that research be conducted into:

(i) estimating the lag times from small catchments, where current methods appear to give estimates that are too short, and
(ii) developing rainfall intensity distributions based on actual recorded data, as it has been shown that synthetic hyetographs derived using distributions based on design rainfall are not applicable.

The simulation of sediment yield proved to be the least successful aspect simulated by the model. This may be a result of applying the MUSLE equation, which is used by the *ACRU* model to simulate sediment yield, to catchments that are outside the limits used in the derivation of the equation. However, a wide range of values for the parameters in the MUSLE equation are applicable and improved estimates of the cover factor improved the simulation of sediment yield. The information used to derive the parameters of the MUSLE equation are very detailed, and it is recommended that more generalised parameters be derived for general use. The use of a static cover factor was not adequate to simulate sediment yield from a catchment under sugarcane production, and the use of a dynamic cover factor resulted in an improved simulation. The requirement for an accurate record, detailing not only months, but also exact days when operations were carried out in the catchment, was shown to be important in simulating sediment yield from individual events. It is suggested that further, more detailed modelling of the sediment yield from the La Mercy catchments be instigated in order to verify, and improve, the simulation of sediment yield.

Based on the results and developments from this study, it is concluded that the *ACRU* model is a suitable tool that can be used to investigate the effect of sugarcane production on water resources.

8. LOCATION OF FILES

8.1 *ACRU* Climate Files for La Mercy Catchments

Climate files have been set up for all four catchments in the format required by the *ACRU* model. These files contain daily data for a number of variables from 1978 to the end of 1995. There are no missing data. The variables are listed in columns, and read from left to right are :

1) Catchment name
2) Date (yy,mm,dd)
3) Daily rainfall (mm)
4) Maximum daily temperature (°C)
5) Minimum daily temperature (°C)
6) Daily A-pan evaporation (mm)
7) Observed daily runoff (mm)
8) Observed daily peak discharge ($m^3.s^{-1}$)

The climate files are named and located as follows :

- Catchment 101 : sal101.acr : on disk1
- Catchment 102 : sal102.acr : on disk1
- Catchment 103 : sal103.acr : on disk2
- Catchment 104 : sal104.acr : on disk2

8.2 *ACRU* Menu Files

Input menus for ACRU, which contain the final variable and parameter selections discussed in Chapter 6 and all other relevant inputs, have been set up for all four catchments. There is a separate menu for the bare fallow and sugarcane land cover period in each catchment. The name and location, together with the period of simulation for which the menu was set up, is listed below:

Catchment 101 - Bare fallow	(1978-1983) : sal101_b.001 : on disk 3
Catchment 101 - Sugarcane	(1984-1995) : sal101_a.001 : on disk 3
Catchment 102 - Bare Fallow	(1978-1983) : sal102_b.001 : on disk 3
Catchment 102 - Sugarcane	(1984-1995) : sal102_a.001 : on disk 3
Catchment 103 - Bare Fallow	(1978-1983) : sal103_b.001 : on disk 3
Catchment 103 - Sugarcane	(1984-1995) : sal103_a.001 : on disk 3
Catchment 104 - Bare Fallow	(1978-1985) : sal104_b.001 : on disk 3
Catchment 104 - Sugarcane	(1986-1995) : sal104_a.001 : on disk 3

8.3 Location of Spreadsheets

Figure Number	File Name	Graph Name	Disk Number
4.1.1	Events101.wb2	events101	4
4.1.2	Events102.wb2	events102	4
4.1.3	Events103.wb2	events103	4
4.1.4	Events104.wb2	events104	4
4.2.1	Obs_ro_b.wb2 Obs_ro_a.wb2	fig4.2.1 fig4.2.1	4
4.2.2	Obs_ro_b.wb2	vs102	4
4.3.1	Events101.wb2	sedvsrain sedvsrun	4
4.3.2	Events102.wb2	sedvsrain sedvsrun	4
4.3.3	Events103.wb2	sedvsrain sedvsrun	4
4.3.4	Events104.wb2	sedvsrain sedvsrun	4
6.1.1	1lam101.wb2	101b	5
6.1.2	1lam101.wb2	101a	5
6.1.3	1lam102.wb2	102b	5
6.1.4	1lam102.wb2	102a	5
6.1.5	1lam103.wb2	103b	5
6.1.6	1lam103.wb2	103a	5
6.1.7	1lam104.wb2	104b	5
6.1.8	1lam104.wb2	104a	5
6.1.9	2lam101.wb2	101b	6
6.1.10	3lam101.wb2	101b	7
6.1.11	2lam101.wb2	101a	6
6.1.12	3lam101.wb2	101a	7
6.1.13	2lam102.wb2	102b	6
6.1.14	3lam102.wb2	102b	7
6.1.15	2lam102.wb2	102a	6
6.1.16	3lam102.wb2	102a	7

Figure Number	File Name	Graph Name	Disk Number
6.1.17	2lam103.wb2	102b	6
6.1.18	3lam103.wb2	102b	7
6.1.19	2lam103.wb2	102a	6
6.1.20	3lam104.wb2	102a	7
6.1.21	2lam104.wb2	102b	6
6.1.22	3lam104.wb2	102b	7
6.1.23	2lam104.wb2	102a	6
6.1.24	3lam104.wb2	102a	7
6.2.1	Pe_d_s_1.wb2, Pe_d_s_2.wb2, Pe_d_s_3.wb2, Pe_d_s_4.wb2	peak peak peak peak	8
6.2.2	Pe_d_o_1.wb2, Pe_d_o_2.wb2, Pe_d_o_3.wb2, Pe_d_o_4.wb2	peak peak peak peak	9
6.2.3	Po_d_o_1.wb2, Po_d_o_2.wb2, Po_d_o_3.wb2, Po_d_o_4.wb2	peak peak peak peak	9
6.2.4	Po_d_s_1.wb2, Po_d_s_2.wb2, Po_d_s_3.wb2, Po_d_s_4.wb2	peak peak peak peak	10
6.2.5	So_d_s_1.wb2, So_d_s_2.wb2, So_d_s_3.wb2, So_d_s_4.wb2	peak peak peak peak	10
6.2.6	lo_d_s_1.wb2, lo_d_s_2.wb2, lo_d_s_3.wb2, lo_d_s_4.wb2	peak peak peak peak	11

Figure Number	File Name	Graph Name	Disk Number
	Sa101_le.wb2 Sa101_2e.wb2 Sa101_3e.wb2 Sa101_4e.wb2 Sa101_5e.wb2 Sa101_6e.wb2	graph 2 graph 2 graph 2 graph 2 graph 2 graph 2	12
	Sa102_lewb2 Sa102_2ewb2 Sa102_3ewb2 Sa102_4ewb2 Sa102_5ewb2	graph 2 graph 2 graph 2 graph 2 graph 2	12
	Sa103_le.wb2 Sa103_2e.wb2 Sa103_3e.wb2 Sa103_4e.wb2 Sa103_5e.wb2	graph 2 graph 2 graph 2 graph 2 graph 2	13
	Sa104_le.wb2 Sa104_2e.wb2 Sa104_3e.wb2 Sa104_4e.wb2 Sa104_5e.wb2 Sa104_6e.wb2	graph 2 graph 2 graph 2 graph 2 graph 2 graph 2	13
6.3.1	Sal01_1o.wb2 Sal01_2o.wb2 Sal01_3o.wb2 Sal01_4o.wb2 Sal01_5o.wb2 Sal01_6o.wb2	graph2 graph2 graph2 graph2 graph2 graph2	14
6.3.2	Sal02_1o.wb2 Sal02_2o.wb2 Sal02_3o.wb2 Sal02_4o.wb2 Sal02_5o.wb2	graph2 graph2 graph2 graph2 graph2	14
6.3.3	Sal03_1o.wb2 Sal03_2o.wb2 Sal03_3o.wb2 Sal03_4o.wb2 Sal03_5o.wb2	graph2 graph2 graph2 graph2 graph2	15
6.3.4	Sal04_1o.wb2 Sal04_2o.wb2 Sal04_3o.wb2 Sal04_4o.wb2 Sal04_5o.wb2 Sal04_6o.wb2	graph2 graph2 graph2 graph2 graph2 graph2	15
6.4.1	Sedin1.wb2 Sedin2.wb2 Sedin3.wb2	sediment sediment sediment	15

Figure Number	File Name	Graph Name	Disk Number
6.4.2	Sedam1.wb2 Sedam2.wb2 Sedam3.wb2	sediment sediment sediment	16
6.4.3	Sedsi1.wb2 Sedsi2.wb2 Sedsi3.wb2	sediment sediment sediment	16
6.4.4	Sedsi4.wb2	1985-bare	16
6.4.5	Sedsi4.wb2	sediment	16
6.4.6	Seddy2.wb2	sediment	16
6.4.7	Seddy2.wb2	w/o events	16
	Wqdat.wb2	phav4 phav	7
	Wqdat.wb2	kav4 kav	7
	Wqdat.wb2	caav4 cav	7
	Wqdat.wb2	mgav4 mgav	7
	Wqdat.wb2	naav4 naav	7
	Wqdat.wb2	hc03av4 hc03av	7
	Wqdat.wb2	ecav4 ecav	7
	Wqdat.wb2	sarav4 sarav	7
	Wqdat.wb2	phcav4 phcav	7
	Wqdat.wb2	asarav4 asarav	7
	Wqdat.wb2	eecav4 eecav	7
	Rplot.wb2	mtcumrun mtsoil	7
	Rplot.wb2	lamcumrun lamsoil	7
	Rplot.wb2	cfscumrun cfssoil	7

Figure Number	File Name	Graph Name	Disk Number
	Rplot.wb2	skccumrun skcsoil	7
	Rplot.wb2	mtcumrun mtsoil	7

PART THREE

MODELLING THE IMPACTS OF GRASSLAND, FORESTRY AND SUGARCANE ON CATCHMENT RUNOFF AT THE UMZINTO RESEARCH CATCHMENTS

JC Smithers and RE Schulze

1. INTRODUCTION

The objective of this part of the report is to investigate the seasonal and annual runoff trends from catchments under different land covers. Of particular interest was the effect of grassland, forestry and sugarcane on catchment hydrological responses. The *ACRU* model (Schulze, 1995) was selected to simulate the impacts on runoff from the three different land covers in three catchments which form part of the Umzinto Research Project (URP) and which are operated by the South African Sugar Association Experiment Station (SASEX).

2. THE *ACRU* AGROHYDROLOGICAL SIMULATION MODEL

ACRU is a daily time step, physical-conceptual model revolving around multi-layer soil water budgeting, and has been discussed in Part 2, section 5 of this report. It is a multi-purpose model which simulates all the major processes of the hydrological cycle which affect the soil water budget and has options to output, *inter alia,* daily values of streamflow volume, peak discharge and hydrographs, reservoir yield, sediment yield, crop yield for selected crops and irrigation supply and demand. *ACRU* can operate at a point as a lumped catchment model or as a distributed cell-type model in order to account for variability in climate, land use and soils. *ACRU* is structured (Figure 2.1) to be hydrologically sensitive to catchment land uses and changes thereof, including the impacts of reservoirs, of irrigation practices and of afforestation. It was thus considered appropriate for the purposes of this section of the project. The model has been widely verified under different land covers and climatic conditions (Schulze, 1995) and has been verified for catchments under sugarcane production (section 2 of this report) and forestry (Schulze, Summerton and Jewitt, 1996).

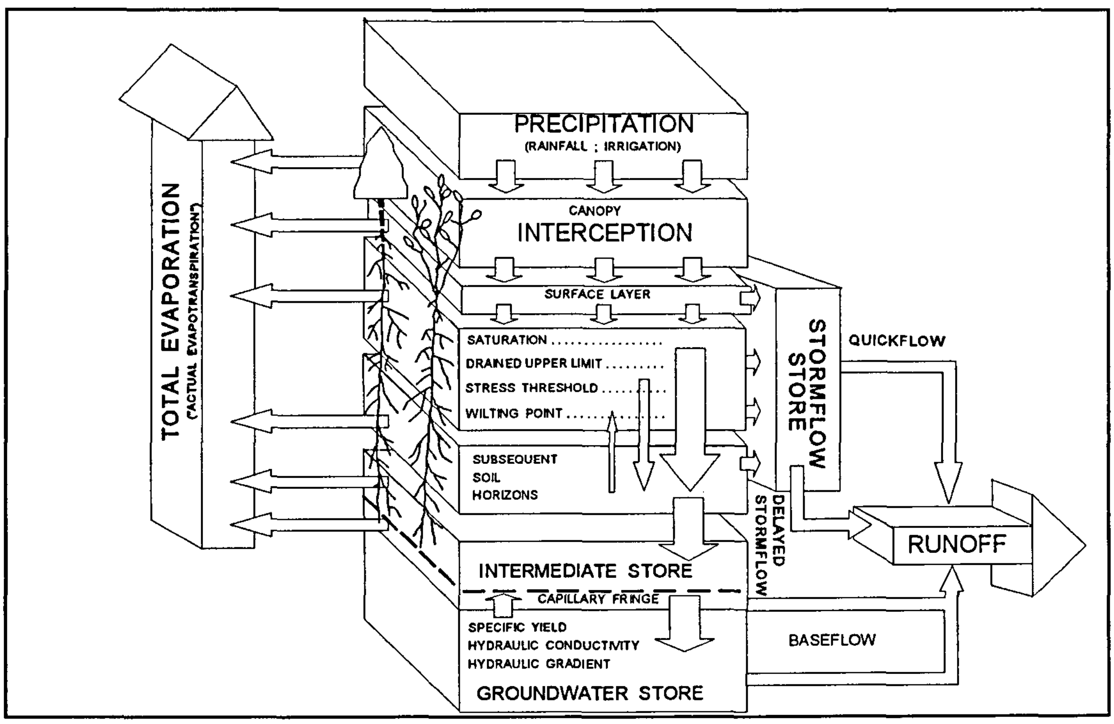


Figure 2.1: *ACRU* : Model structure (Schulze, 1995)

3. METHODOLOGY AND MODEL INPUT

The hydrological response from three different land covers which are found typically along the coastal areas of KwaZulu-Natal was investigated by simulating the runoff from three catchments. Data from Catchments 1, 2 and 6, which form part of the URP, were used to derive information required by the model. The URP is located near Umzinto, KwaZulu-Natal. The climate data used in the simulations were identical on all three catchments. Assessment of recorded runoff data from the catchments indicated that there were insufficient records for meaningful model verification, with between two and seven events being recorded on each catchment over the monitoring period (1993-1995).

The soil water retention characteristics used in the simulation for each of the three catchments were based on the results of a soil survey in Catchments 1, 2, and 6. However, scenarios were simulated for two soil thicknesses. In the first, SCENARIO 1, the soils in the catchment were assumed to be shallow. In the second, SCENARIO 2, soils depths were based on actual surveyed information.

The land covers investigated were grassland in pristine condition, forest consisting of *Eucalyptus grandis* and sugarcane. On each of the three catchments and for both scenarios, runoff was simulated for each of the three different land covers.

3.1 Soils Information

The soils information used in the simulations was obtained from the results of soils surveys of Catchments 1, 2 and 6 of the URP (see Part 1, section 2.2). A summary of the classification of soils in Catchments 1, 2 and 6 is contained in Table 3.1.1. The soils information input into the *ACRU* Utilities (Smithers, Lynch and Schulze, 1995) was derived from the information contained in Table 3.1.1. The soils information used by the model and used in the simulations of scenarios 1 and 2 is contained in Tables 3.1.2 and 3.1.3 respectively.

The effective root depth of the grassland cover was assumed to be 0.6 m. Hence if the total soil thickness exceeded 0.6 m, the root depth of grass was limited to 0.6 m.

For the sugarcane land cover, which was assumed to have a complete soil preparation prior to planting, the porosities of the topsoil horizons were increased by the end-of-season percentages suggested for the different textural classes by Schulze, Angus and Guy (1995), and area-weighted according to the distribution of the texture classes within each catchment. The maximum effective root depth of sugarcane was assumed to be 1.0 m. Hence if the total soil depth exceeded 1.0 m, the root depth for sugarcane was limited to 1.0 m. The fraction of saturated soil water to be redistributed from the topsoil horizon to the subsoil horizon, when the topsoil horizon is above its drained upper limit, was increased by 10% to account for the tillage practice associated with the production of sugarcane (Smithers, Mathews and Schulze, 1996).

For the forest land cover, the *Eucalyptus grandis* was assumed to have an intermediate site preparation prior to planting (i.e. deep ripping). Hence the porosity values of both the top- and subsoil horizons were increased by 8%, as suggested by Schulze, Jewitt and Leenhardt (1995) for forests with intermediate site preparation. The maximum effective rooting depth for *Eucalyptus* *grandis* was assumed to be 1.2 m. However, if the soil thickness was less than this value, the effective rooting depth was limited to the soil thickness after the depth of the subsoil horizon was increased by 0.25 m for the forest land cover to account for the deeper rooting systems of forests (Summerton, 1996). The fractions of both saturated soil water to be redistributed from the topsoil to the subsoil horizon when the topsoil horizon is above its drained upper limit, as well as the fraction of saturated soil water to be redistributed from the subsoil horizon to the intermediate/groundwater store when the subsoil horizon is above its drained upper limit, were increased by 10% to account for the tillage practices in forestry (Schulze, Jewitt and Leenhardt, 1995).

Table 3.1.1: General catchment soils information

Catchment	Soil Form	Textural Class	% Area
1	Glenrosa	SaLm	100
2	Glenrosa Oakleaf	SaLm LmSa	70 30
6	Mispah Nomanci	SaClLm SaClLm	65 35

Table 3.1.2: Soils information used in *ACRU* run: SCENARIO 1

Catch-ment	Land Cover[1]	DEPAHO (m)	DEPBHO (m)	EFRDEP (m)	WP1 ($m.m^{-1}$)	WP2 ($m.m^{-1}$)	FC1 ($m.m^{-1}$)	FC2 ($m.m^{-1}$)	PO1 ($m.m^{-1}$)	PO2 ($m.m^{-1}$)
1	Grass	0.15	0.23	0.38	0.093	0.093	0.189	0.189	0.448	0.448
1	Forest	0.15	0.48	0.63	0.093	0.093	0.189	0.189	0.484	0.484
1	Sugarcane	0.15	0.23	0.38	0.093	0.093	0.189	0.189	0.538	0.448
2	Grass	0.15	0.33	0.48	0.086	0.086	0.175	0.175	0.443	0.443
2	Forest	0.15	0.58	0.73	0.086	0.086	0.175	0.175	0.478	0.478
2	Sugarcane	0.15	0.33	0.48	0.086	0.086	0.175	0.175	0.528	0.443
6	Grass	0.15	0.15	0.30	0.159	0.159	0.254	0.254	0.402	0.402
6	Forest	0.15	0.40	0.55	0.159	0.159	0.254	0.254	0.434	0.434
6	Sugarcane	0.15	0.15	0.30	0.159	0.159	0.244	0.254	0.500	0.402

[1] Details of land cover described in Section 3.2

Legend for Tables 2 and 3	
DEPAHO	Thickness of topsoil horizon (m)
DEPBHO	Thickness of subsoil horizon (m)
EFRDEP	Effective rooting depth of vegetation (m)
WP1	Permanent wilting point of topsoil horizon ($m.m^{-1}$)
WP2	Permanent wilting point of subsoil horizon ($m.m^{-1}$)
FC1	Drained upper limit of topsoil horizon ($m.m^{-1}$)
FC2	Drained upper limit of subsoil horizon ($m.m^{-1}$)
PO1	Porosity of topsoil horizon ($m.m^{-1}$)
PO2	Porosity of subsoil horizon ($m.m^{-1}$)

Table 3.1.3: Soils information used in *ACRU* run: SCENARIO 2

Catch-ment	Land Cover[1]	DEPAHO (m)	DEPBHO (m)	EFRDEP (m)	WP1 ($m.m^{-1}$)	WP2 ($m.m^{-1}$)	FC1 ($m.m^{-1}$)	FC1 ($m.m^{-1}$)	PO1 ($m.m^{-1}$)	PO2 ($m.m^{-1}$)
1	Grass	0.30	0.45	0.60	0.093	0.093	0.189	0.189	0.448	0.448
1	Forest	0.30	0.70	1.00	0.093	0.093	0.189	0.189	0.484	0.484
1	Sugarcane	0.30	0.45	0.75	0.093	0.093	0.189	0.189	0.538	0.448
2	Grass	0.30	0.65	0.65	0.086	0.086	0.175	0.175	0.443	0.443
2	Forest	0.30	0.90	1.20	0.086	0.086	0.175	0.175	0.478	0.478
2	Sugarcane	0.30	0.65	0.95	0.086	0.086	0.175	0.175	0.528	0.443
6	Grass	0.30	0.30	0.60	0.159	0.159	0.254	0.254	0.402	0.402
6	Forest	0.30	0.55	0.85	0.159	0.159	0.254	0.254	0.434	0.434
6	Sugarcane	0.30	0.30	0.60	0.159	0.159	0.244	0.254	0.500	0.402

[1] Details of land cover described in Section 3.2

3.2 Land Cover Information

The three land cover scenarios, viz. grassland, forest and sugarcane, were simulated more specifically as:

- Acocks' (1988) Southern Tall Grassveld (Acocks # 65),
- 5-year old *Eucalytus grandis* plantation established using an intermediate site preparation, and
- sugarcane with conservation structures and conventional tillage.

The reason for selecting an intermediate age *Eucalyptus grandis* forest, was to simulate the average conditions within a catchment which is totally afforested and where the trees, as a result of rotational felling, are not all the same growth stage. Similarly, the vegetation parameters selected for sugarcane attempt to reflect the strip crop harvesting commonly practised. Acocks' (1988) Southern Tall Grassveld is the predominant grassland land cover found in the catchment areas and was used as a base to compare the other two land covers. The land cover variables input to the *ACRU* model are contained in Table 3.2.1. The values selected for the variables were largely based on values suggested by Smithers and Schulze (1995) for grassland cover, on Schulze, Summerton and Jewitt (1996) for forest and on Smithers, Mathews and Schulze (1996) for sugarcane.

Additional information used in the simulations include the following:

- Interception loss of rainfall for all land covers was modelled using the loss per event option in the *ACRU* model.
- The option to model soil water evaporation and plant transpiration as separate entities was invoked in the simulation of runoff from all land covers.
- The option for enhanced forest canopy evaporation was activated for the forestry land cover.
- For all catchments and land covers, 1% of the groundwater store was released per day as the baseflow component of runoff, on the assumption that the groundwater store was connected to the stream system.

3.3 Climate Data

A synthetic daily rainfall series was generated for a 100 year period using the stochastic rainfall generator, incorporated in the *ACRU* Utilities and which is based on models developed by Zucchini and Adamson (1984). The stochastic rainfall series was generated using parameters derived by Zucchini and Adamson (1984) from data recorded at the SASEX rain-gauge number 0211140S at Esperanza. Historical daily rainfall data for the same station for the period 1942 - 1993 were extracted from the daily rainfall database maintained by the Computing Centre for Water Research (CCWR). Days of missing rainfall data were in-filled using pre-selected stations which were ranked from most suitable to least suitable. On days of missing data, data from the rain-gauge classified as the most suitable gauge, which had recorded data on the day in question, was in-filled into the record after an adjustment by the ratio of the mean annual precipitations from the stations of the data being in-filled and the data used to perform the infilling.

Reference potential evaporation was extracted from the gridded mean monthly A-pan equivalent values simulated by Schulze (1996) for a latitude of 30^{O} 22' S and longitude of 30^{O} 39' E.

The suitability of using the synthetic rainfall series to assess the impact of land cover on simulated runoff was investigated by comparing runoff simulated from Catchment 1 using the stochastic series and observed daily rainfall data.

Table 3.2.1: Land cover variables input to the *ACRU* model

Land Cover	Variable	Description	Jan	Feb	Mar	Apr	Ma y	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sourthern Tall Grassveld (Acocks # 65)	CAY	Crop coefficient	0.75	0.75	0.75	0.65	0.55	0.40	0.40	0.50	0.65	0.75	0.75	0.75
	VEGINT	Interception loss (mm.rainday^{-1})	1.80	180	1.80	1.70	1.60	1.50	1.50	1.50	1.60	1.80	1.80	1.80
	ROOTA	Proportion of roots in the topsoil horizon	0.85	0.85	0.85	0.85	0.90	0.95	0.95	0.95	0.90	0.85	0.85	0.85
	COIAM	Coefficient of initial abstraction	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
	SMDDEP	Critical soil depth used in storm flow simulation (m)	0.3											
Forest (5 year old *Eucalyptus grandis*, intermediate site preparation)	CAY	Crop coefficient	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
	LAI	Leaf area index	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7
	VEGINT	Interception loss (mm.rainday^{-1})	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7
	ROOTA	Proportion of roots in the topsoil horizon	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
	COIAM	Coefficient of initial abstraction	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
	SMDDEP	Critical soil depth used in storm flow simulation (m)	0.35											
Sugarcane (conservation structures, conventional tillage)	CAY	Crop coefficient	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
	VEGINT	Interception loss (mm.rainday^{-1})	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80
	ROOTA	Proportion of roots in the topsoil horizon	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
	COIAM	Coefficient of initial abstraction	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
	SMDDEP	Critical soil depth used in storm flow simulation (m)	0.30											

4. STOCHASTIC VS OBSERVED RAINFALL VALUES

Daily runoff was simulated from a grassland cover in Catchment 1 for SCENARIO 1. A frequency analysis was performed on monthly totals of daily runoff simulated using both stochastic rainfall, generated using parameters derived from rain-gauge 0211140S, and observed daily rainfall from rain-gauge 0211140. One hundred years of stochastic rainfall were generated, whereas observed daily rainfall for the same rain-gauge was available for 1942 - 1993. The results of these comparisons for median, 5% (representing the driest year in 20) and 95% (representing the wettest year in 20) non-exceedance of monthly totals of daily runo-ff are contained in Figure 4.1.

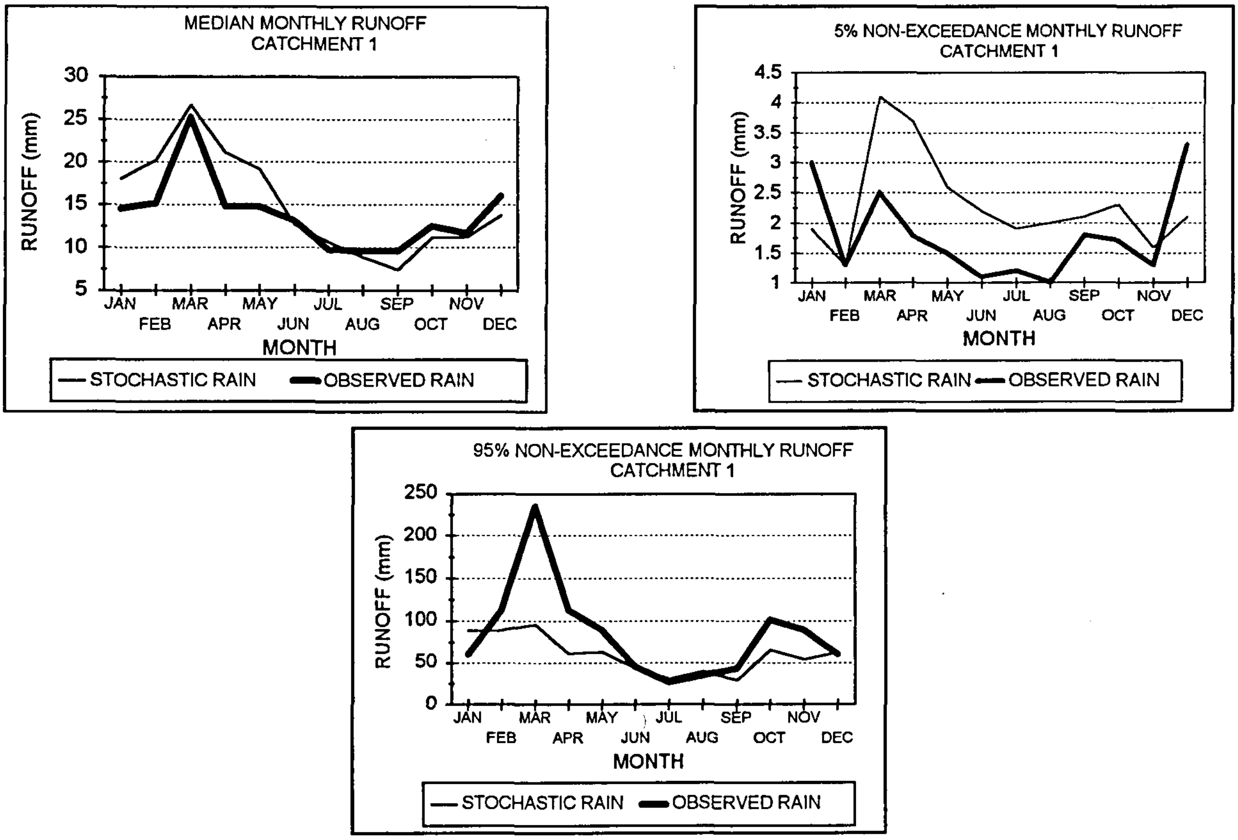


Figure 4.1: Median, 5% and 95% non-exceedance values of monthly totals of daily runoff simulated with the *ACRU* model using stochastic and observed daily rainfall

From Figure 4.1, it is apparent that the stochastic and observed rainfall, with all other model input information the same, result in different simulated runoff. Differences between the rainfalls obtained from the two techniques were thus assessed. A comparison of the median, 5% and 95% non-exceedance values of monthly totals of daily rainfall for both the stochastic series and observed rainfall data is shown in Figure 4.2.

The median monthly values of the stochastically generated rainfall correlate well with the observed rainfall data. However, the stochastically generated rainfall does not simulate the frequency of the observed monthly totals of daily rainfall for dry (5%) and wet (95%) years adequately. In particular, the dry periods for December and the wet periods for March and November, are not well represented by the stochastically generated rainfall data. In order to check that these periods of differences are not an artefact of an individual rainfall record (station 0211140S), a frequency analysis of monthly totals of daily rainfall for the same period (1942 -1993) from a nearby station (0211407) was performed and the results are shown in Figure 4.3.

Median, 5% and 95% non-exceedance values of monthly totals of rainfall data from station 0211407 are similar to values computed for station 0211140S. Thus the use of stochastically generated rainfall was considered not suitable for use in this project. Therefore, the observed rainfall data from site 0211140S, which consisted of 52 years of record from 1942 - 1993, were used in the simulation of runoff from all three catchments for both scenarios.

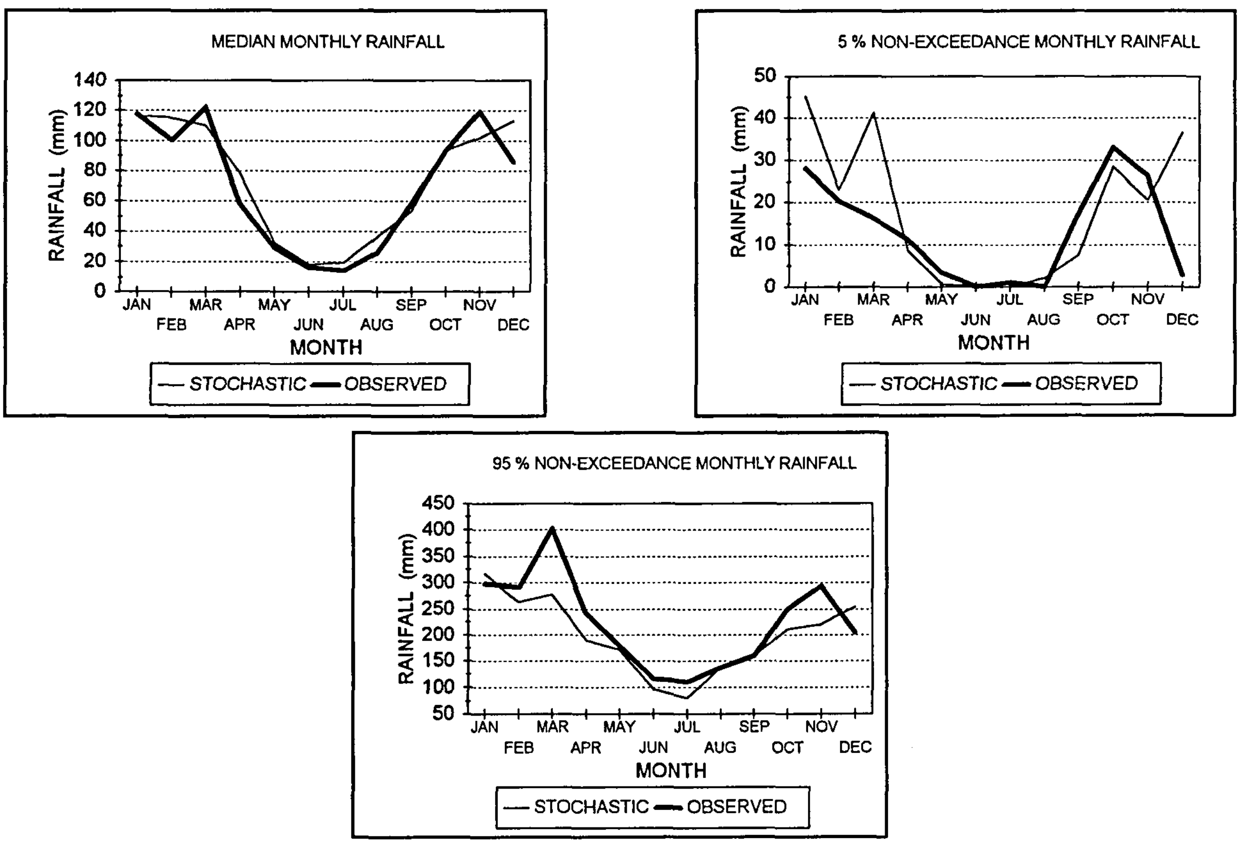


Figure 4.2: Median, 5% and 95% non-exceedance values of monthly totals of daily stochastic and observed rainfall

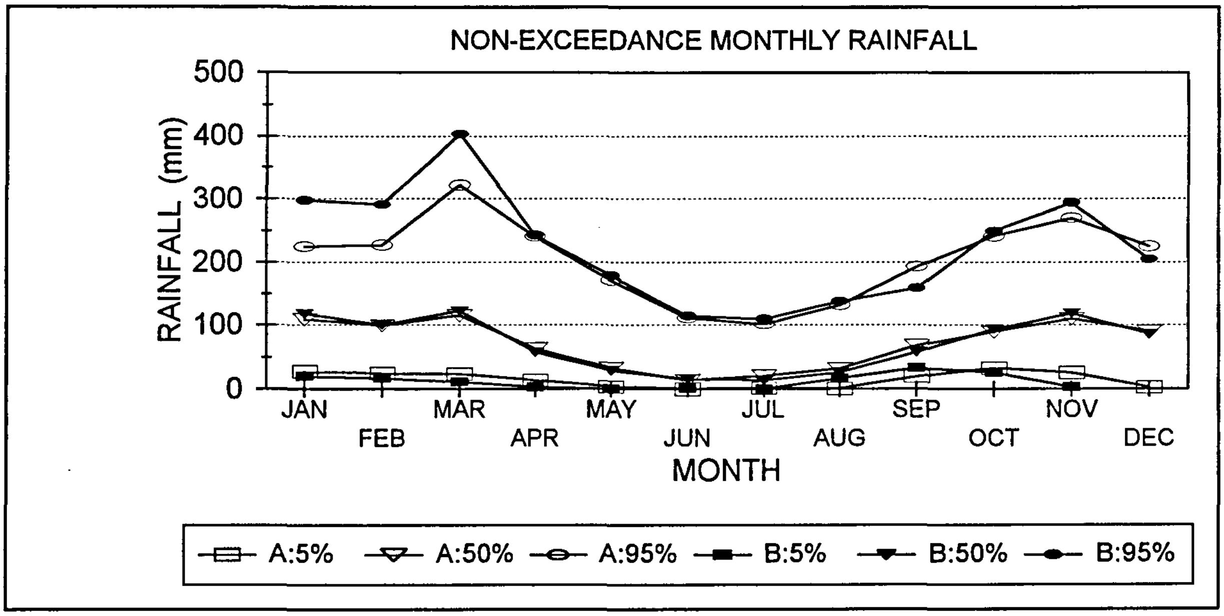


Figure 4.3: Median, 5% and 95% non-exceedance values of monthly totals of daily rainfall: Station 0211407 (A) vs 0211140S (B)

5. SCENARIO 1: SIMULATIONS USING SHALLOW SOILS

In SCENARIO 1, the soil horizons in all catchments were assumed to be shallow (50% of the surveyed thicknesses). On all three catchments, runoff was simulated for grass, forest and sugar cane land covers.

5.1 Catchment 1

5.1.1 Runoff volume

The accumulated volume of runoff simulated from Catchment 1 for the three land covers considered are depicted in Figure 5.1.1.

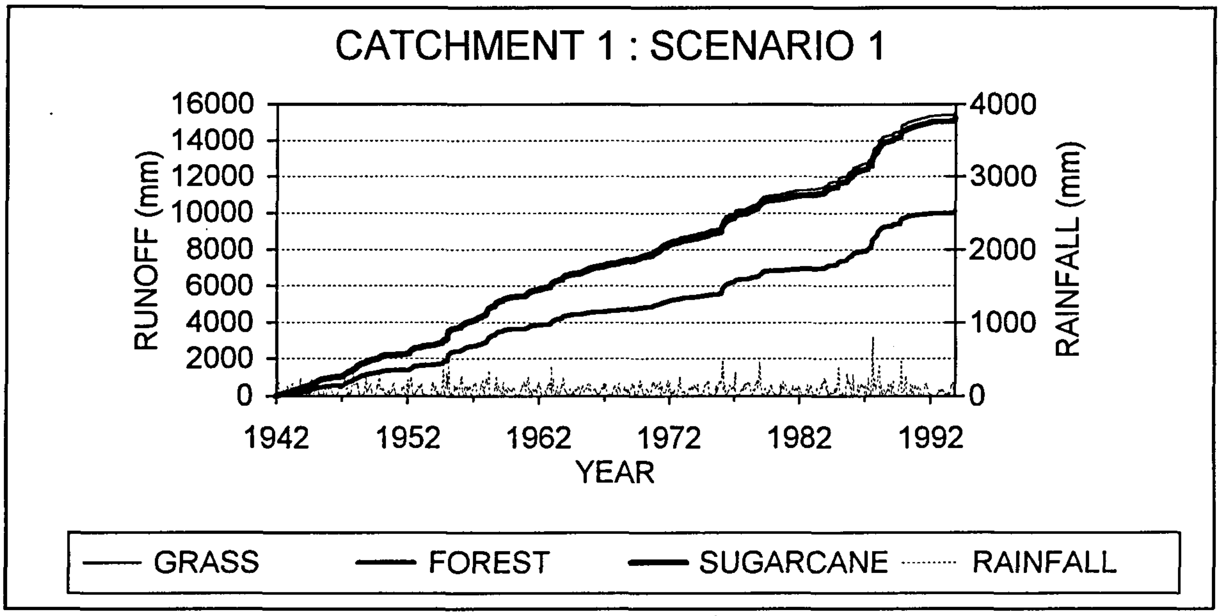


Figure 5.1.1: SCENARIO 1 : Accumulated monthly totals of daily simulated runoff from Catchment 1 for three land covers together with a time series of monthly totals of daily rainfall

5.1.2 Frequency analysis

Median, 5% and 95% non-exceedance levels of monthly totals of daily runoff simulated from Catchment 1 for the three land covers considered are depicted in Figure 5.1.2

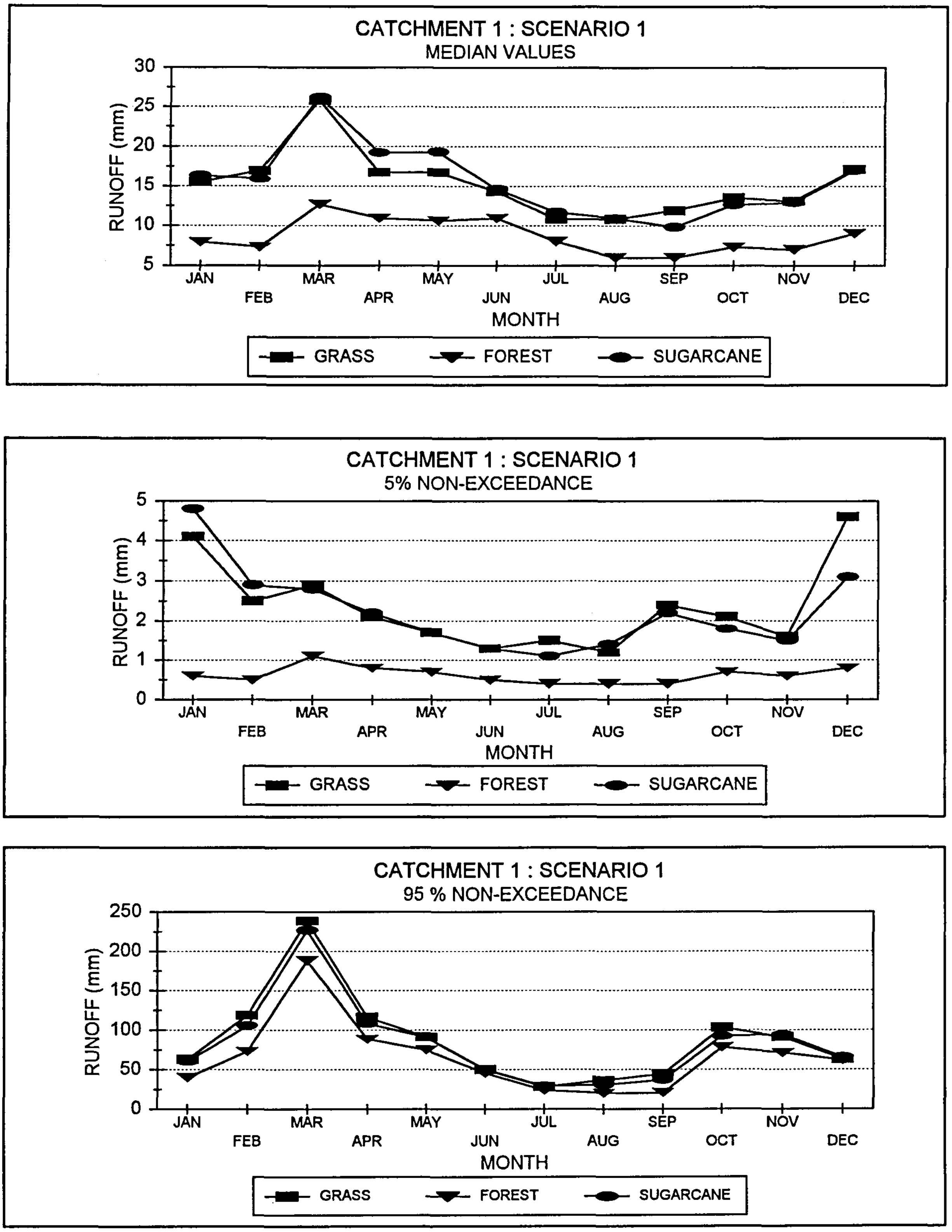


Figure 5.1.2: Catchment 1: Monthly totals of daily runoff simulated for SCENARIO 1 at the 5%, 50% and 95% levels of non-exceedance

5.2 Catchment 2

5.2.1 Runoff volume

The accumulated volume of runoff simulated from Catchment 2 for the three land covers considered are depicted in Figure 5.2.1.

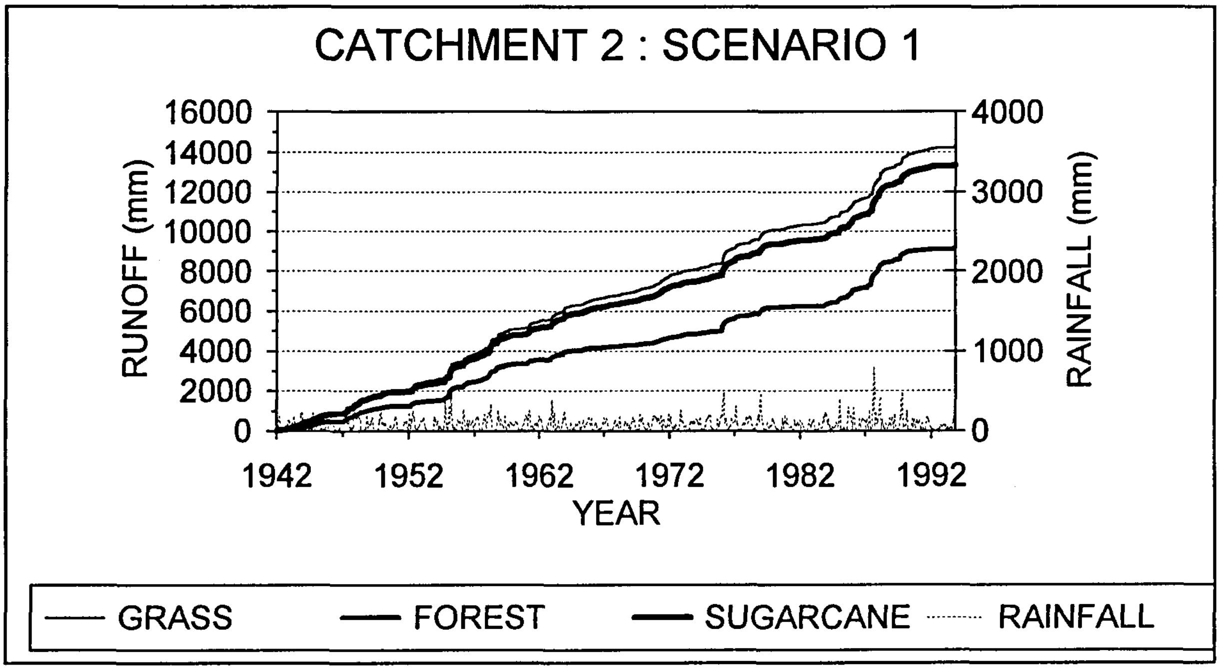


Figure 5.2.1: SCENARIO 1 : Accumulated monthly totals of daily simulated runoff from Catchment 2 for three land covers together with a time series of monthly totals of daily rainfall

5.2.2 Frequency analysis

Median, 5% and 95% non-exceedance levels of monthly totals of daily runoff simulated from Catchment 2 for the three land covers considered are depicted in Figure 5.2.2.

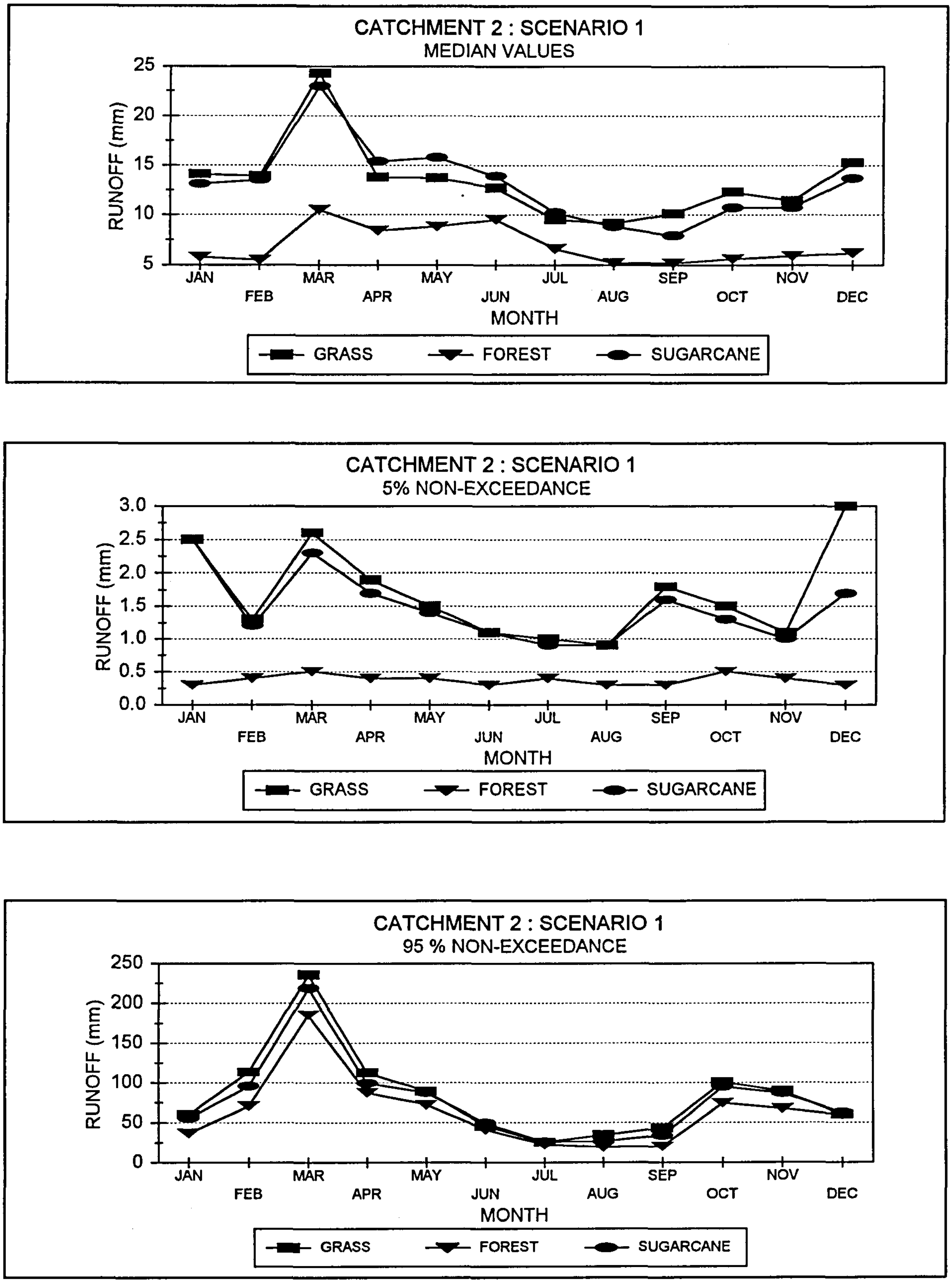


Figure 5.2.2: Catchment 2: Monthly totals of daily runoff simulated for SCENARIO 1 at the 5%, 50% and 95% levels of non-exceedance

5.3 Catchment 6

5.3.1 Runoff volume

The accumulated volume of runoff simulated from Catchment 6 for the three land covers considered are depicted in Figure 5.3.1.

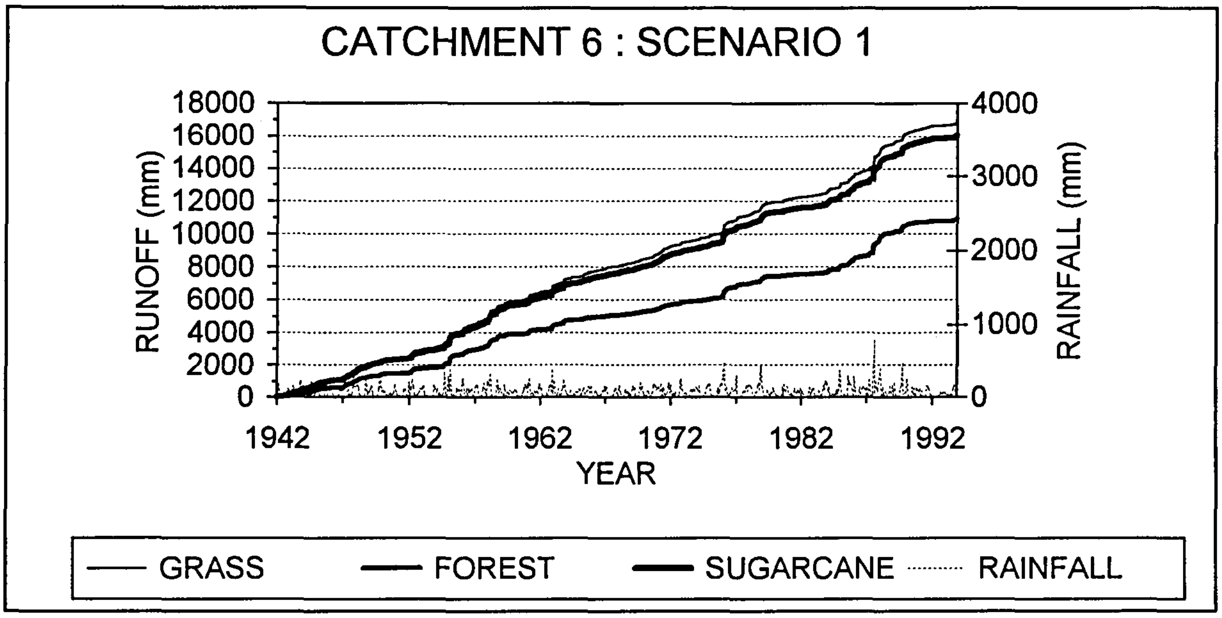
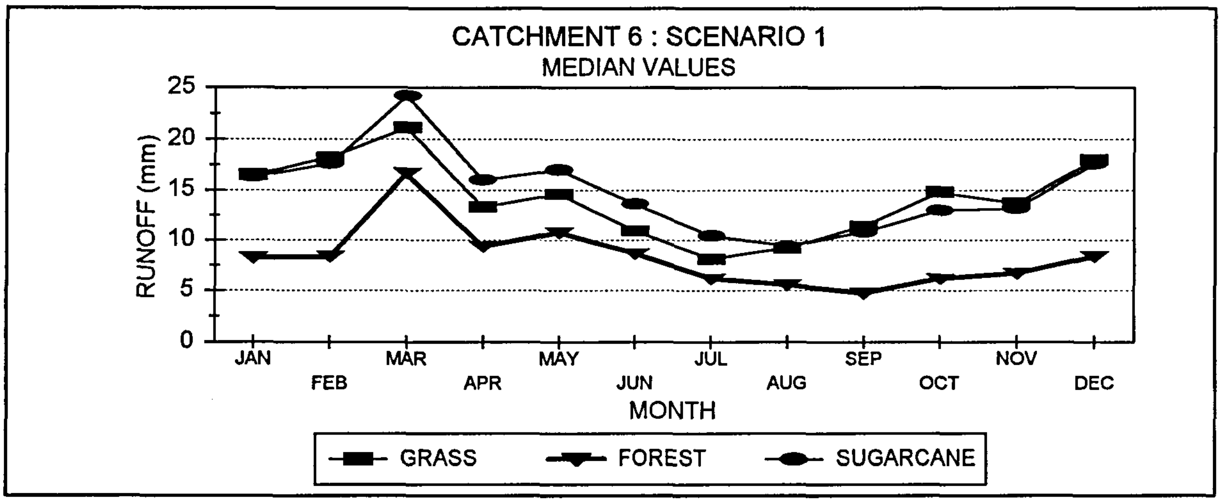
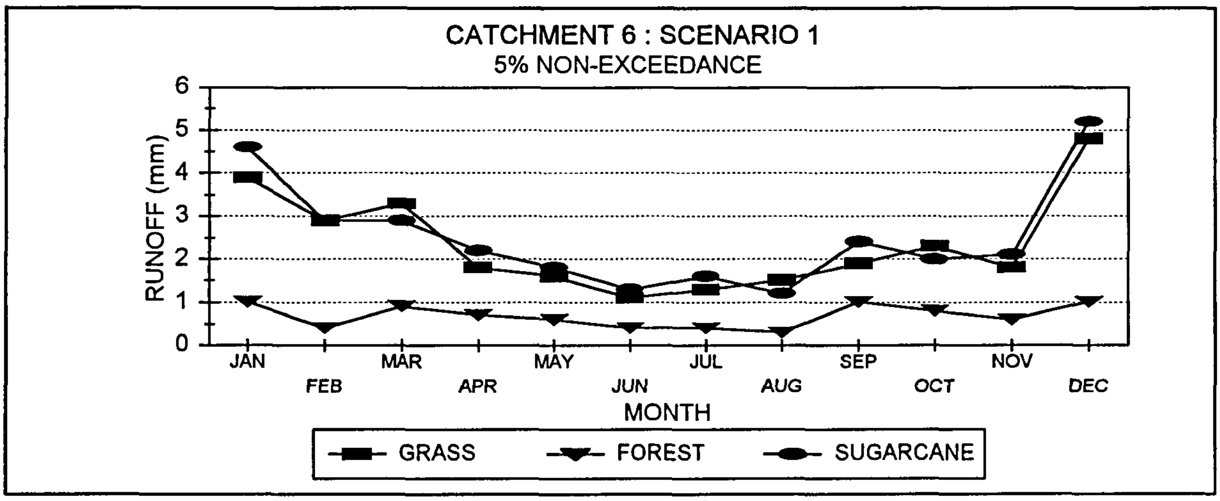


Figure 5.3.1: SCENARIO 1 : Accumulated monthly totals of daily simulated runoff from Catchment 6 for three land covers together with a time series of monthly totals of daily rainfall

5.3.2 Frequency analysis

Median, 5% and 95% non-exceedance levels of monthly totals of daily runoff simulated from Catchment 6 for the three land covers considered are depicted in Figure 5.3.2.





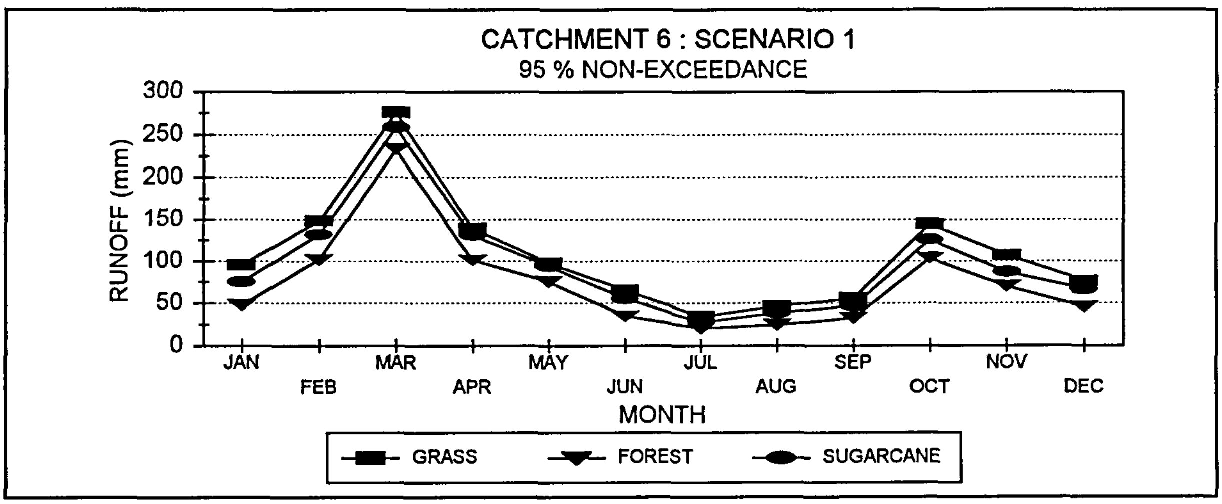


Figure 5.3.2: Catchment 6: Monthly totals of daily runoff simulated for SCENARIO 1 at the 5%, 50% and 95% levels of non-exceedance

5.4 Discussion of Results from SCENARIO 1

The only differences in the simulations presented above are the soils parameters input to the model. On Catchments 1 and 6, the total volume and distribution of runoff simulated for the three land covers were similar and less runoff was simulated from Catchment 2. The reduction in runoff from Catchment 2 when compared to that of the other catchments is attributed to the slightly deeper soils in Catchment 2.

On all three catchments, the monthly distribution of runoff from sugarcane and grass are similar. No trends are evident between the runoff simulated from the land cover during dry and wet periods. However, the graphs of median monthly totals of daily runoff indicate that during April - August the runoff from sugarcane is greater than that from grass, and that during August - November the runoff from grass is greater than that from sugarcane. This may be attributed to the substantially higher crop coefficient for sugarcane during the winter months as compared with grass. This results in the soil under a sugarcane land cover being drier at the beginning of the wet season (August) and hence having less initial runoff response. The higher runoff from sugarcane during the winter months (April - August) as compared to grass may be attributed to more infiltration of rainfall in the sugarcane (larger COIAM and SMDDEP values) during the wet season and hence greater winter baseflows from the sugarcane land cover.

On all three catchments during periods of above average rainfall, both the volume and distribution of monthly totals of daily runoff are similar for all three land covers. However, during periods of normal or below normal rainfall, the runoff simulated from the forest is substantially lower than the runoff from the grass and sugarcane land covers. This is a result of the larger initial abstractions of rainfall by the forest canopy, enhanced forest canopy evaporation and the larger consumptive use of soil water by the forest which result in a drier soil and hence reduced runoff.

Within the limitations of the model and parameters input and with due consideration given to the assumptions made, and based on the simulated results for SCENARIO 1 (thin soils), the following conclusions may be drawn:

(i) For shallow soils, little difference was noted between the runoff from grass and sugarcane land covers.
(ii) The degree of reduction in runoff caused by afforestation is linked to the season's rainfall, and is negligible during above average periods of rainfall.

These results are site and climate specific. It is thus recommended that more generalised investigations be undertaken to determine if any regional and climatic trends exist. In addition to the analysis of runoff as performed in this report, it is further recommended that future investigations include an analysis of both baseflows and storm flows separately.

6. SCENARIO 2 : SIMULATIONS USING ACTUAL SOIL DEPTHS

In SCENARIO 2, the thicknesses of the soil-horizons were based on surveyed information from the catchments. Both the total volume of runoff and monthly distribution of runoff was investigated for the three land covers on all three catchments.

6.1 Catchment 1

6.1.1 Runoff volume

The accumulated volumes of runoff simulated from Catchment 1 for the three land covers considered are depicted in Figure 6.1.1.

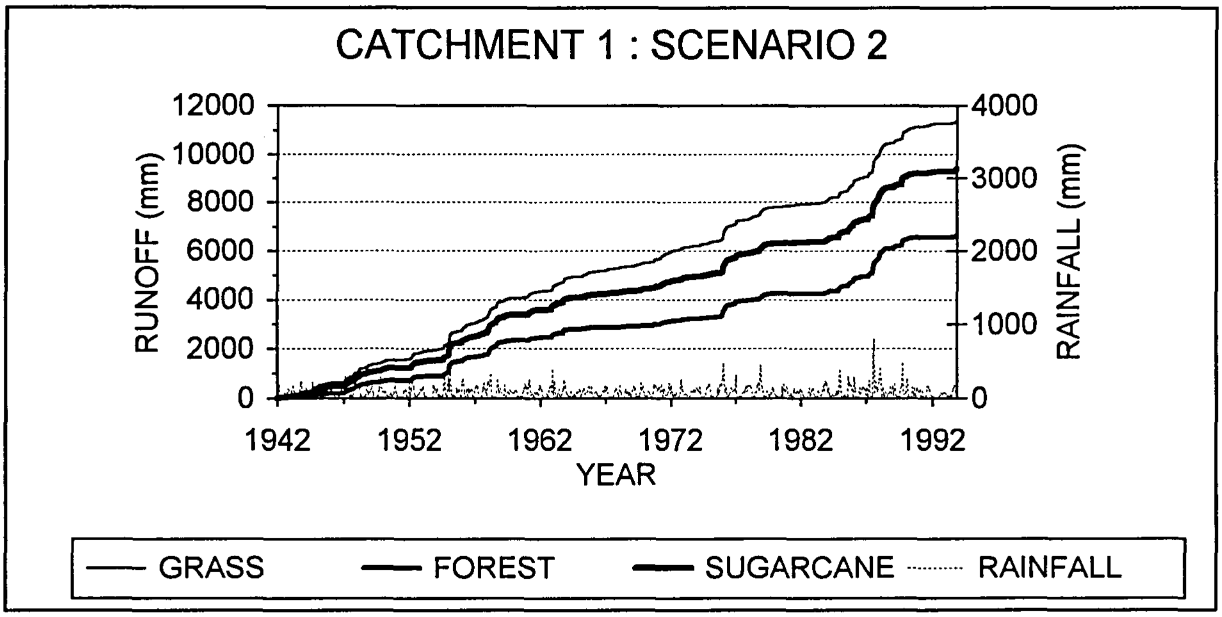
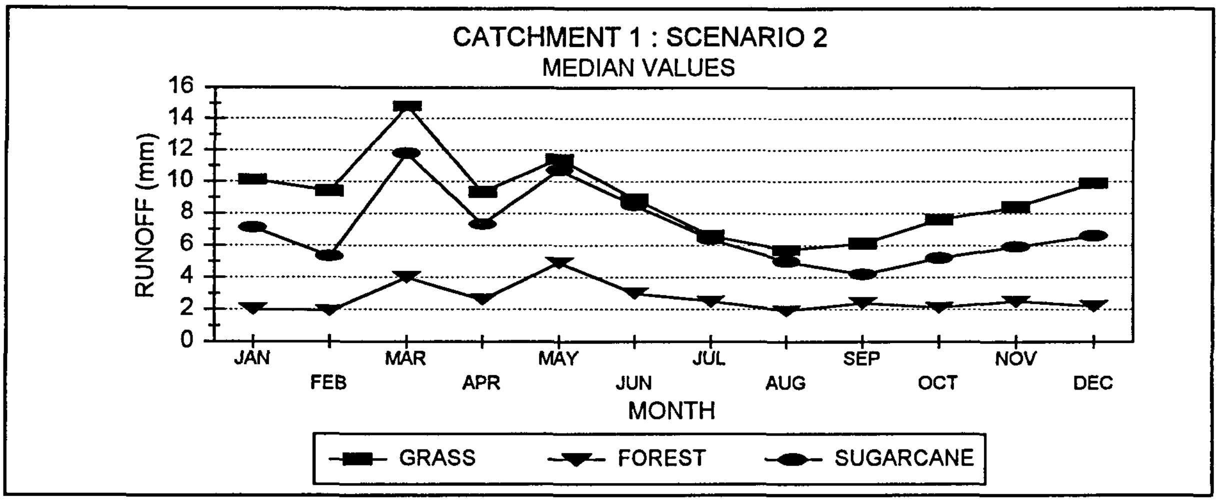
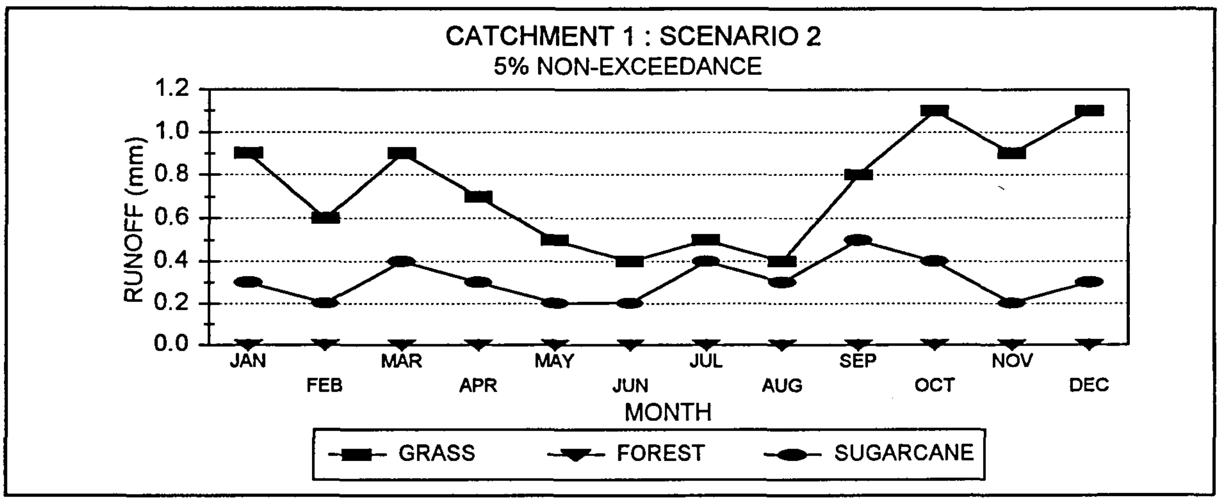


Figure 6.1.1: SCENARIO 2 : Accumulated monthly totals of daily simulated runoff from Catchment 1 for three land covers together with a time series of monthly totals of daily rainfall

6.1.2 Frequency analysis

Median, 5% and 95% non-exceedance levels of monthly totals of daily runoff simulated from Catchment 1 for the three land covers considered are depicted in Figure 6.1.2.





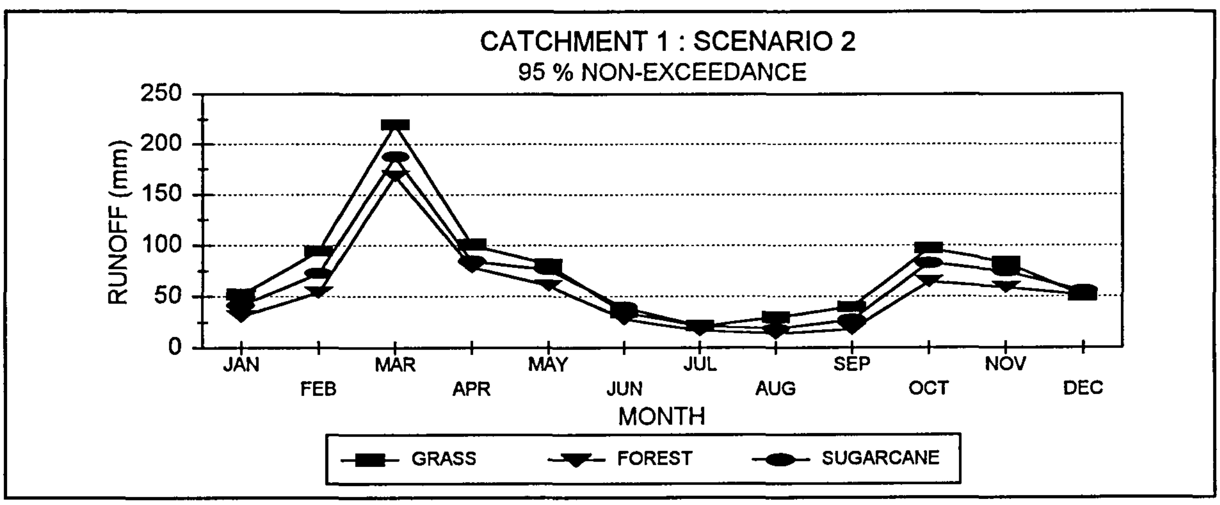


Figure 6.1.2: Catchment 1: Monthly totals of daily runoff simulated for SCENARIO 2 depicted at the 5%, 50% and 95% levels of non-exceedance

exceedance

6.2 Catchment 2

6.2.1 Runoff volume

The accumulated volumes of runoff simulated from Catchment 2 for the land covers considered are depicted in Figure 6.2.1.

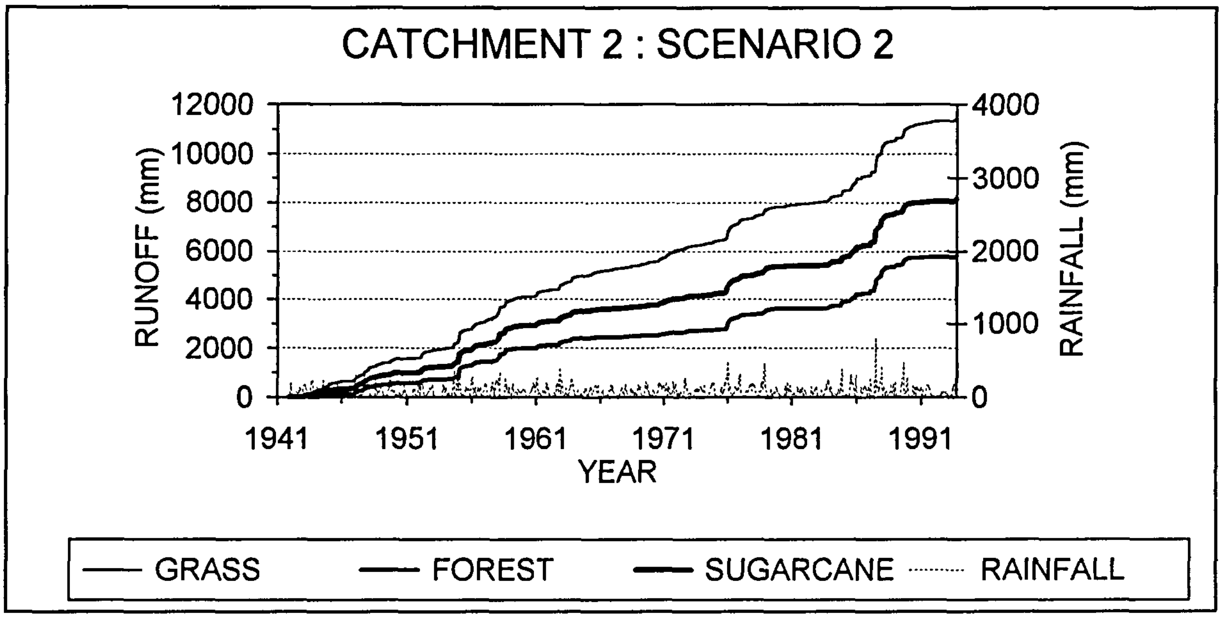
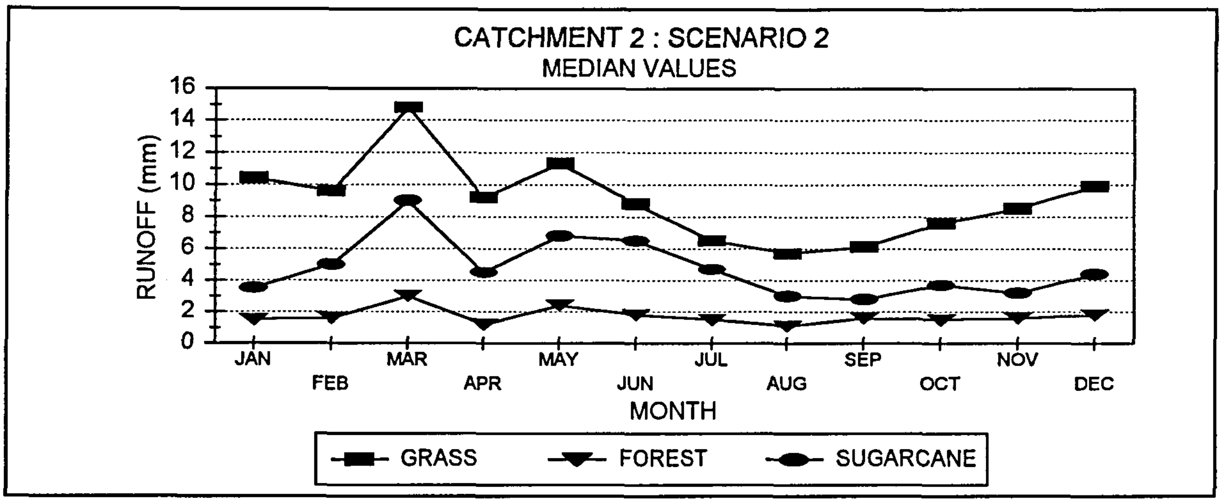
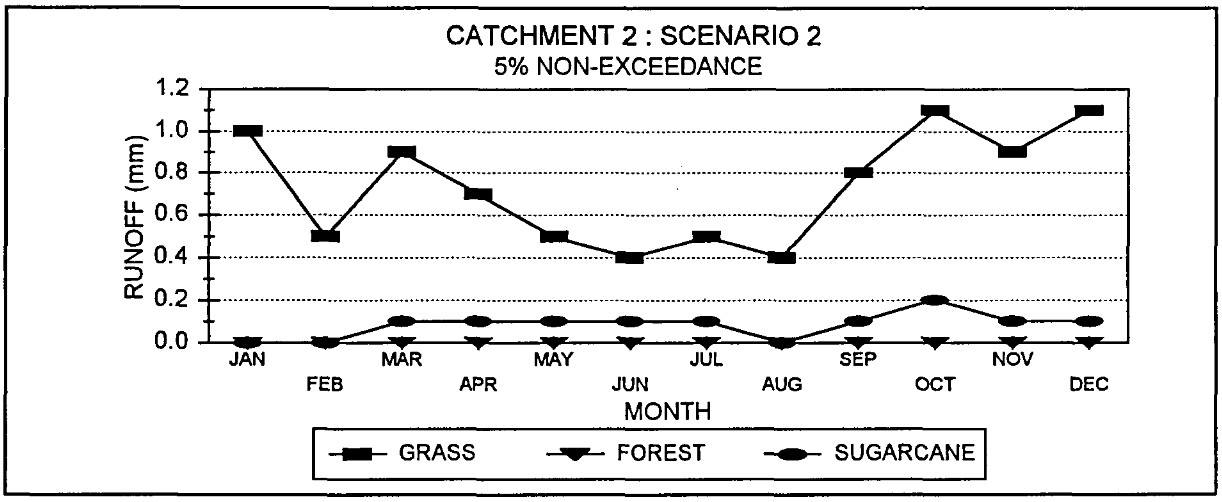


Figure 6.2.1: SCENARIO 2 : Accumulated monthly totals of daily simulated runoff from Catchment 2 for three land covers together with a time series of monthly totals of daily rainfall

6.2.2 Frequency analysis

Median, 5% and 95% non-exceedance levels of monthly totals of daily runoff simulated from Catchment 2 for the three land covers considered are depicted in Figure 6.2.2.





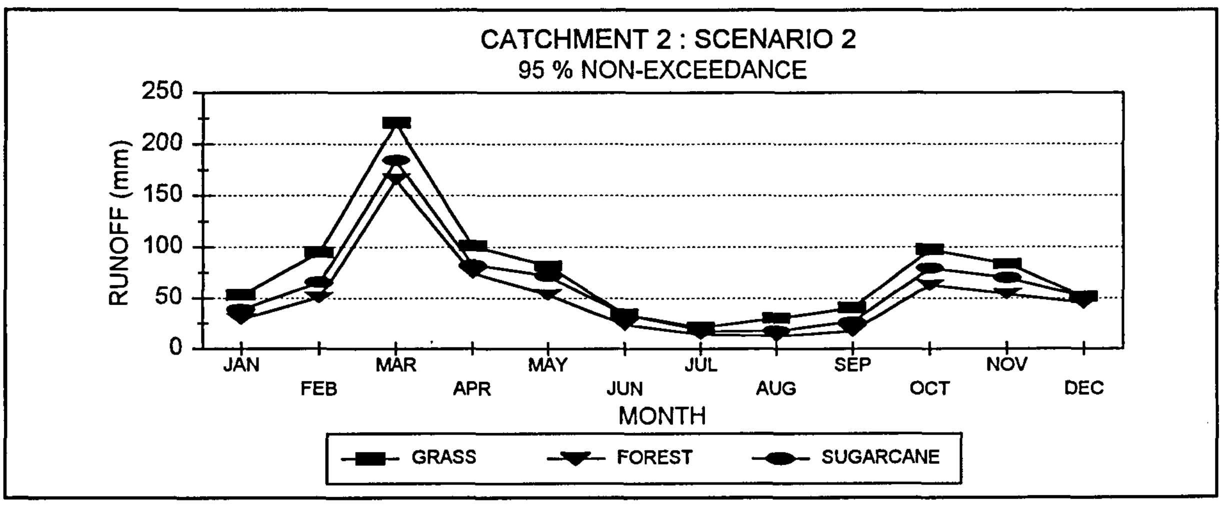


Figure 6.2.2: Catchment 2: Monthly totals of daily runoff simulated for SCENARIO 2 depicted at the 5%, 50% and 95% levels of non-exceedance

6.3 Catchment 6

6.3.1 Runoff volume

The accumulated volumes of runoff simulated from Catchment 6 for the land covers considered are depicted in Figure 6.3.1.

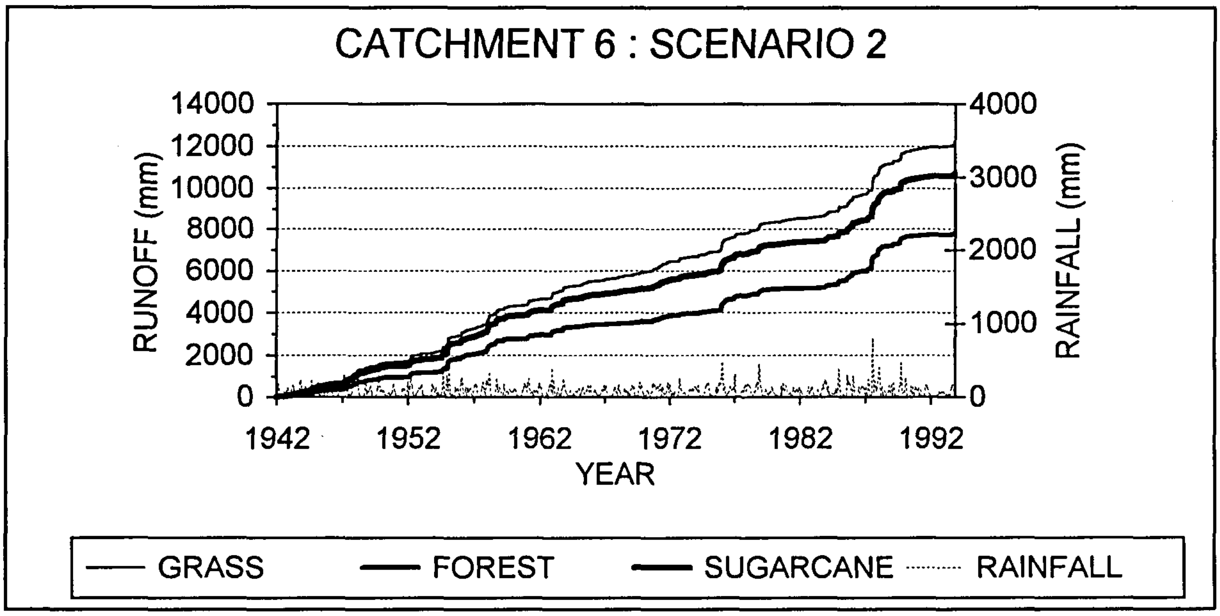
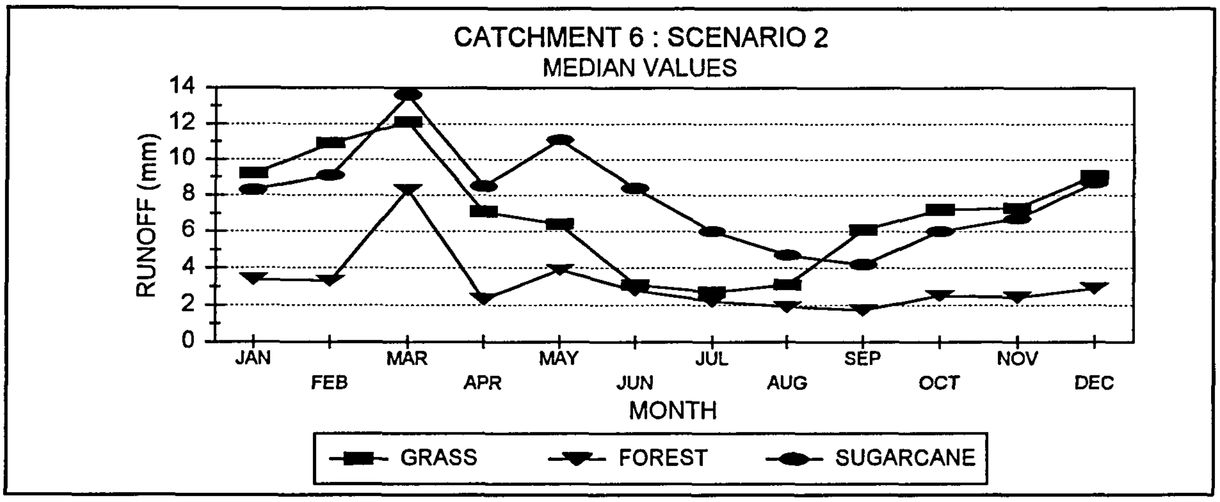
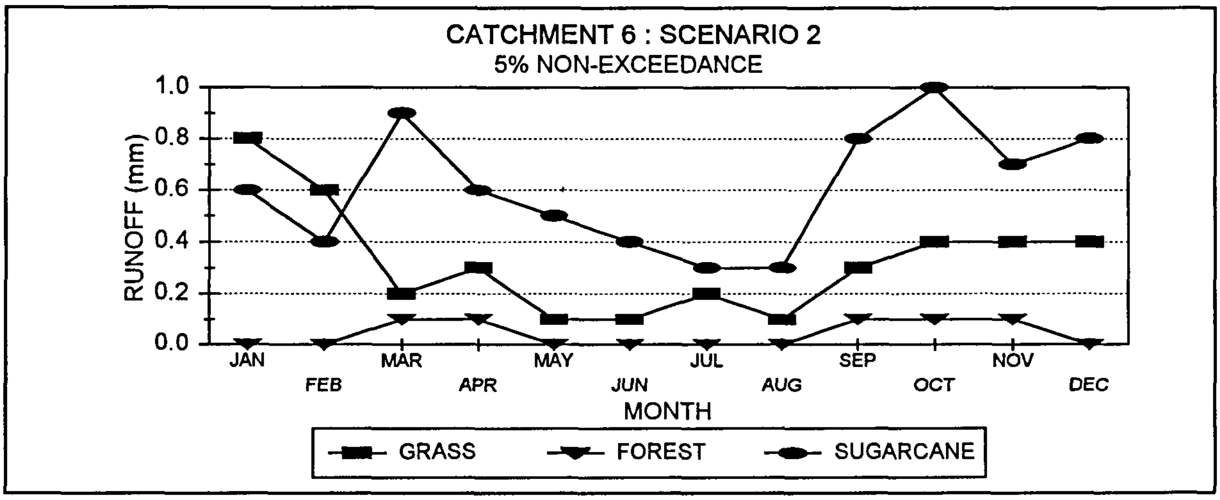


Figure 6.3.1: SCENARIO 2 : Accumulated monthly totals of daily simulated runoff from Catchment 6 for three land covers together with a time series of monthly totals of daily rainfall

6.3.2 Frequency analysis

Median, 5% and 95% non-exceedance levels of monthly totals of daily runoff simulated from Catchment 6 for the three land covers considered are depicted in Figure 6.3.2.





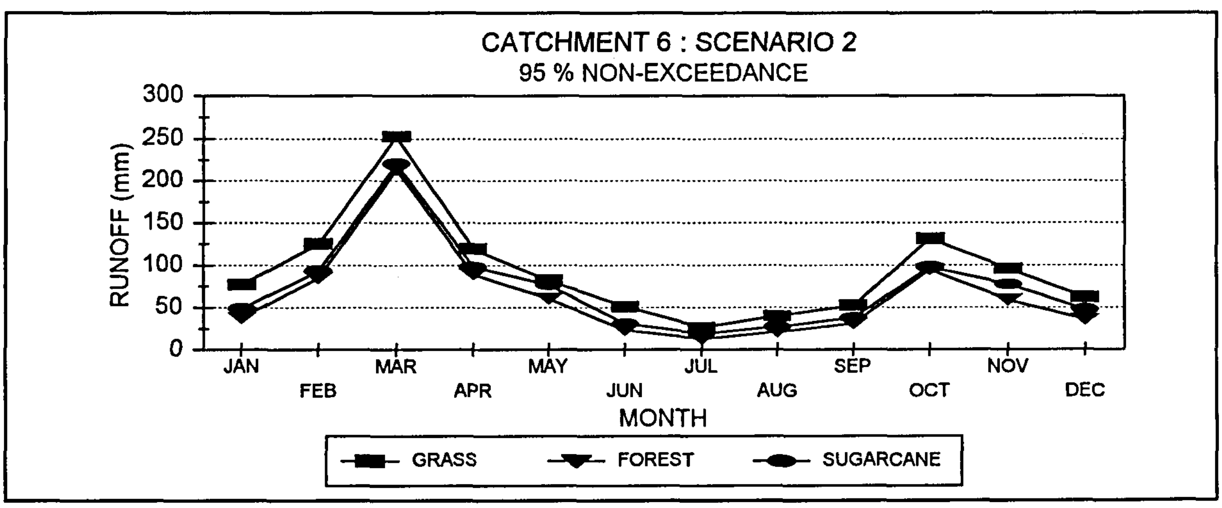


Figure 6.3.2: Catchment 6: Monthly totals of daily runoff simulated for SCENARIO 2 depicted at the 5%, 50% and 95% levels of non-exceedance

6.4 Discussion of Results from SCENARIO 2

For SCENARIO 2, the largest volume of runoff for all three land covers was simulated from Catchment 6, which had the shallowest soils. On all three catchments, the largest volume of runoff was simulated from the grassland cover and the least from the forest land cover. Generally the differences in the total volume of runoff simulated increased with increasing catchment soil thickness.

Similar to the results for SCENARIO 1 and evident in Catchments 1 and 6, during months which have median totals of daily runoff, the runoff for the early spring period (September - November) for the grassland exceeds that simulated from the sugarcane, and during the winter period (May - July), the simulated runoff from the grassland is less than or similar to that simulated from the sugarcane land cover. The larger runoff during winter months from sugarcane may be attributed to the larger baseflows simulated under sugarcane production. On Catchment 2, which has deeper soils than the other two catchments, this trend is not evident with the largest runoff for all months simulated from the grassland cover, and the least runoff from the forest land cover.

During months of below average simulated runoff and on Catchments 1 and 2, the runoff from the forest land cover was zero and the runoff simulated from the sugarcane land cover is substantially lower than that simulated from the grassland cover. On Catchment 6, the runoff simulated from the sugarcane exceeds that from grass for most months during periods of low runoff. The reasons for this trend in Catchment 6 may be attributed to the larger baseflows generated from sugarcane as a result of the increased infiltration of rainfall under sugarcane production.

During periods with above normal monthly totals of daily runoff, the runoff simulated from the different land covers were very similar.

7. DISCUSSION AND CONCLUSIONS

This study has shown that, in the case investigated, stochastic rainfall values generated using the Zucchini and Adamson (1984) techniques are not necessarily adequate in simulating catchment hydrological responses. This has only been determined at one site and it is recommended that this should be investigated at other sites. In addition, the random nature of a stochastic rainfall series may have resulted in the differences between the stochastic and observed rainfall. It is recommended that this aspect be further investigated by generating a number of stochastically generated rainfall series to ascertain if the distribution of the stochastic series encompass the observed rainfall data.

The simulated results obtained are site and climate specific and are limited by the assumptions made and the adequacy of how well the model simulates real-world processes. However, current understanding based on observed data and expert opinion, of the processes associated with the different land covers were incorporated in the modelling. The *ACRU* model has been widely verified under different climatic and catchment conditions (Schulze, 1995) and thus the simulations may be used with some degree of confidence. The focus of the study has been on the relative differences between the scenarios, catchments and land covers, and the relative differences are assumed to be realistic. However, it is expected that as knowledge of the catchment hydrological processes expands, that these simulated results may change.

For both the thin and actual soil thickness scenarios, the runoff simulated by the model indicates that the impact of afforestation on the catchment hydrological response is the greatest. On thinner soils, the runoff simulated from grass and sugarcane land covers are very similar, with increases in runoff simulated from the grass sooner after the start of the wet season than from sugarcane. On thicker soils the runoff simulated from grassland generally exceeds that simulated from the sugarcane land cover. The difference between the runoff simulated from the three different land covers during periods of high runoff was small. However, during periods of low flows, the amount of rainfall infiltrated into the soil and the volume of baseflow simulated resulted in the runoff from sugarcane production generally being larger than that from grassland cover.

The interactions between soil thickness, effective rooting depth and distribution of roots in the soil are important in determining the volume and distribution of runoff simulated. The thinner soil scenario resulted in larger volumes of runoff for all land covers and on all catchments.

The simulated results indicate that the differences in the impact of the different land covers on the simulated runoff from a catchment are least when the soils are shallow, and are exacerbated as the soil thickness increases.

In the simulation results contained in this report, the sugarcane was assumed to be under dryland production. It is expected that the effect on runoff of irrigated sugarcane production would be substantially different to that of dryland sugarcane. As irrigated sugarcane is prevalent in some sugarcane production areas, it is recommended that the impact of both dryland and irrigated sugarcane production on catchment water resource be investigated in future studies.

This study has focussed on a particular site and has shown the effect of soil thickness on the impact of different land covers on catchment hydrological responses. However, within a small region, it has also shown that the impact of different land covers on catchment runoff varies between neighbouring catchments. It is thus recommended that more generalised investigations be instigated to determine whether any regional and climatic trends exist, and to identify catchment attributes that may be used to identify sensitive catchments in which changes in land cover may have a significant impact on the catchment water resource.

8. LOCATION OF *ACRU* INPUT FILES

The files used in the simulations are listed in Table 8.1.

Table 8.1: Location of *ACRU* input files used in the simulations

File Name	Description
0211140.rfl	Climate file for all catchments
C1_1.men	Menu file, Catchment 1, Scenario 1
C1_2.men	Menu file, Catchment 1, Scenario 2
C2_1.men	Menu file, Catchment 2, Scenario 1
C2_2.men	Menu file, Catchment 2, Scenario 2
C6_1.men	Menu file, Catchment 6, Scenario 1
C6_2.men	Menu file, Catchment 6, Scenario 2

1. CONCLUSIONS

This report has described catchment and plot experiments that have been conducted by SASEX over the last 20 years.

An investigation into hydrological trends and relationships from plot experiments and the La Mercy catchments has been presented. The focus of the report has however been on the validation of a physical-conceptual agrohydrological model (ACRU model) using data from the La Mercy catchments.

The ACRU model was also used to model the relative impact of grassland, sugarcane and timber land uses on water yield. Scenarios were developed for the Umzinto catchments in the absence of usable gauged data for validation. Conclusions from the study are summarised below.

1.1 Hydrological Trends and Relationships

1.1.1 Runoff Plots

Rainfall simulator plots have been used to measure runoff and soil loss from a range of sugar industry soils. Results indicated the marked impact soil type and slope have on runoff under bare fallow conditions. Runoff response from a 63 mm/h intensity storm of one hour's duration, falling on a wet profile ranged from 0% to 87% of rainfall, depending on soil type and slope. Soil losses of up to 30 t/ha were recorded for a single storm. The results also indicated a 60% reduction in soil loss and 34% reduction in runoff from a plot planted using minimum tillage as opposed to full tillage methods. The role of minimum tillage in increasing infiltration to reduce runoff and limiting soil detachment through increased residue cover is evident.

Runoff and soil loss data from five sets of natural runoff plots under sugar cane cover were analysed. Average annual runoff response as a percentage of rainfall ranged from less than 1% at a site with soils of high permeability to between 17% and 20% at sites where soil permeability was low. Average annual soil erosion from the plots ranged from 21 $t.ha.an^{-1}$ on 1 site, which is in excess of tolerable levels, to less than 2 t/ha/annum (on three of the five plots) which is well within the acceptable range.

1.1.2 La Mercy Catchments

Trends in runoff and soil loss data from La Mercy were examined in order to better understand hydrological relationships on sugarcane catchments as well as to identify any inconsistencies or anomalies in the data. Annual runoff as a percentage of rainfall (runoff response) varied between 0 and 25%. Typically runoff response is less than 5% during dry years (annual rainfall < 850 mm) and rises to 25% in wet years (annual rainfall >1 200 mm). The majority of runoff is as a result of a few big storms when runoff response was shown on occasions to be in excess of 50%. Rainfall intensity and antecedent moisture conditions have a strong influence on runoff response.

Very few events produced significant soil loss. Periods of large soil loss are generally due to a large storm coinciding with limited crop cover following replanting or harvesting.

Soil loss declined markedly following sugar cane establishment while runoff did not reduce to the same extent. This suggests that canopy and ground cover have more impact on soil loss than runoff generation. Runoff appears to be mostly affected by soil type (infiltration rate), storm intensity and antecedent moisture condition. Crop cover and management practices such as strip cropping, minimum tillage and trash retention appear to reduce runoff and soil loss to a greater extent than conservation structures such as contour banks and waterways.

There do not appear to be signs of excessive wash-off of nutrients or minerals from the catchments. The influence of drought years on mineralisation of N, to decrease pH and on making large concentrations of non-exchangeable K available has been illustrated.

1.2 Simulation of Runoff and Sediment Yield at La Mercy

Recorded hydrological data is site specific and it is difficult to extrapolate trends to other locations or conditions. Simulation modelling can play a major role in evaluating the effect of catchment or crop management practices on runoff or soil loss if a credible model is used. The *ACRU* model, a daily agrohydrological model, was used to simulate runoff volume, peak discharge, hydrograph shape as well as sediment yield from the La Mercy catchments in order to verify its performance for sugarcane catchments with varying management practices. Initial variables used in the model were based on published information and expert opinion. Based on the research, a decision support system (DSS) to estimate model parameters for use on sugar cane was developed.

1.2.1 Catchment Runoff

The extent of over (+) or under (-) simulation using the *ACRU* model based on initial and DSS parameter estimates is given below.

Catchment	Parameter Selection	Bare Conditions %	Sugarcane Cover %
101	Initial DSS	-9 -2	+30 +15
102	Initial DSS	+24 +9	+4 -8
103	Initial DSS	+21 +5	+22 +13
104	Initial DSS	-26 -39	-32 -38

The revised parameters generally gave improved results, the exception being catchment 104. Various comparisons of observed runoff data suggest some systematic error in runoff measurement since 1981 at catchment 104 which requires investigation. Estimates of runoff using the DSS were between 8% below and 15% above observed (catchment 104 excluded). Certain events were not well represented which could be ascribed to lack of representation of rainfall intensity in the daily model and inadequate representation of initial abstractions prior to runoff occurrence, particularly under dry antecedent moisture conditions. Inadequate representation of land preparation, crop management practices and age of crop in model runs also played a role in model accuracy and highlighted the difficulties of runoff simulation on small highly cultivated areas. Notwithstanding the above the simulation of runoff from the catchments was considered adequate.

1.2.2 Peak Discharge

The *ACRU* model gave good results when simulating daily peak discharge from the four La Mercy catchments, with more than 82% of the variance in peak discharge explained. Simulations were based on the recorded rainfall hyetograph and an estimate of the time of concentration (Tc).

Use of recorded runoff volume in calculations resulted in a general improvement in peak discharge estimation however revealed that time of concentration was generally underestimated. This illustrates the difficulty in calculating hydraulic flow lengths and velocity on small agricultural catchments. Optimised Tc values were typically 0,2 h longer than those estimated. Errors in estimating initial abstraction time and overland flow velocity are likely to have a large impact on resulting accuracy in predicted peak discharge.

Simulations were also undertaken using a regional design rainfall intensity distribution. This resulted in over estimation of peak rainfall intensity and over simulation of peak discharge.

1.2.3 Hydrograph shape

Five events were selected from each La Mercy catchment to compare simulated and observed hydrograph shape. The events all occurred during the period when sugarcane was established. The model gave a reasonable representation of hydrograph shape. The use of optimised Tc better represented the storage characteristics in each catchment and gave a more representative flatter and smoother shape to the hydrograph. Peak discharge was however generally underestimated using the longer concentration time.

1.2.4 Sediment Yield

An attempt was made to model sediment yield from the La Mercy catchments. Daily observed sediment yield data was available from 1985 onward following planting of sugarcane. The *ACRU* model uses the Modified Universal Soil Loss Equation (MUSLE) to estimate sediment yield. Sediment yield is estimated based on runoff volume, peak discharge, topography, soil erodibility, canopy cover and management conditions as well as a sediment transport function. Soil loss parameters were selected based on ACRU User manual recommendations. Initially observed runoff volume and peak discharge was used in the analysis. Over the 10 year period total sediment yield was over simulated by a factor of between 300% (catchment 101) and 700% (catchment 104).

Simulation of sediment yield using the MUSLE is sensitive to the cover factor which is difficult to estimate. Changes to the cover factor provided a better estimate of overall sediment yield but did not allow adequate representation of both small and large events.

Introduction of a dynamically varied cover factor improved the ability of the model to account for timing of crop management practices. Certain events could however still not be simulated adequately.

Local land management practices such as crop cultivation, repair to waterways and contour banks can have a major impact on timing and magnitude of sediment yield. Flushing out of previous deposits during a large flood will also play a role. It is recognised that the MUSLE was applied out of its normal range of application (i.e. plot scale) in this study and that the role of sediment transport and deposition is not adequately represented in the model.

1.3 Modelling the Impacts of Grassland, Forestry and Sugar Cane at Umzinto

A major objective of this project was to compare water yield from catchments under sugarcane with that of commercial timber and natural grassland. In the absence of adequate flow data from Umzinto, the *ACRU* model was used to simulate the impacts of these land uses on water yield. The results of the model runs are site specific and limited by the assumptions and adequacy of how well the model represents the real world processes. The ACRU model is however hydrologically sensitive to land use changes and has been widely verified for grassland, sugarcane and timber. The simulations may thus be used with some degree of confidence.

Modelling scenarios were run for three catchments at Umzinto to represent a range of slope and soil conditions. Three land cover scenarios, namely Acock's Southern Tall Grassveld (predominant in the area), five year old eucalyptus grandis plantation established with intermediate site preparation and sugarcane with conservation structures, strip cropping and conventional tillage were represented in the simulations.

The analysis was based on 52 years of daily rainfall data (1942-1993) for the nearby Esperanza met site. An investigation into the use of stochastic rainfall values suggested this method was not adequate in simulating hydrological response. While median runoff conditions were adequately represented when using stochastic rainfall data, low and high flow periods were not.

Model runs were conducted for both thin and actual soil thickness scenarios. Results indicated the impact of afforestation on hydrological response to be the greatest. On thin soils the runoff simulated from grassland and sugarcane land covers were similar. On thicker soils runoff from grassland generally exceeded that from sugarcane. Differences between runoff response under different land covers were smallest during periods of high runoff (ie wet years or wet months). During low flow periods the amount of rainfall infiltrated into the soil and the volume of baseflow simulated resulted in the runoff from sugarcane production generally being larger than that from grassland cover. Thinner soils resulted in larger volumes of runoff for all land covers and catchments. The results indicate that the differences in the impact of land covers on simulated runoff are least when the soils are shallow and are exacerbated as the soil thickness increases.

2. RECOMMENDATIONS

2.1 Data Collection

A crucial aspect in the successful collection of data is frequent analysis and use of the data. This enables any problems in data acquisition methods to be detected and corrected timeously. Based on the analyses undertaken in this project various improvements for further data collection and processing have been identified. Cognisance must be taken of these recommendations in future catchment and plot monitoring.

2.2 ACRU Model Development

Useful guidelines have been developed during this study for improved estimation of parameter values for use in the *ACRU* model for sugarcane catchments. Further refinements to model structure for application to sugarcane is recommended, namely:

- The method of simulating initial rainfall abstractions should be investigated, especially as they are related to antecedent moisture conditions.
- Further research is required into identifying the factors affecting runoff concentration times under various management practices.
- Further research into the use of regional rainfall intensity distributions based on actual daily rainfall amount is required.
- A more detailed investigation is required into integration of the factors affecting sediment yield on sugarcane catchments into the *ACRU* model. Factors that need to be addressed include the role of soil moisture status on soil erodibility, variation of crop and management factors through the year and sediment transport within a catchment.

2.3 Other Water Research

The study focussed on the Umzinto catchments to indicate the impact of different land covers (timber, grassland and sugarcane) on hydrological processes. It is recommended that more generalised investigations be initiated to determine whether the trends evident vary between regions and climatic regimes. Catchment attributes that influence these trends also need to be further investigated.

Further work needs to be undertaken on the appropriateness of using stochastic rainfall series in simulating hydrological response.

This study has focussed only on rainfed sugarcane. The impact of irrigated sugarcane on water resources should be investigated on a regional scale.

Further research is required on the water quality characteristics of surface and sub-surface flow from sugarcane catchment.

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