THE SMALL CATCHMENT PROJECT AT LA MERCY

By G. G. PLATFORD and C. S. THOMAS

SA Sugar Association Experiment Station, Mount Edgecombe 4300

Abstract

Four catchments each approximately five hectares in size were developed on steep land north of Durban to measure runoff losses. The methods used to monitor water and soil losses from the catchments and some initial results are given. Details of recent work to establish sugarcane and layout systems for fields in the different areas are described. The way in which the objectives of the project are integrated with the overall research programme into soil and water losses, is described.

Introduction

Data on the hydrology and sediment yields of agricultural catchments in the Natal sugar belt are not generally available. The data are needed for designing effective and economic water control structures such as dams, weirs, waterways and terrace banks, and to account for management systems such as strip cropping and minimum tillage. Reasonable estimates can be made for catchments where the land is lying fallow, or has a limited crop cover, but sugarcane produces a large amount of material above the ground which slows down the rate at which excess water moves into natural drainage lines. The amount of this material changes within seasons and between seasons as a result of factors such as repeated harvesting, weather conditions, milling programmes and different methods of crop management. It is difficult to estimate how much water runs off under these changing conditions, and where different field layout patterns have been used, unless some measurements have been made in the field.

The La Mercy small catchment project was designed to provide some of the information required. It forms part of a larger programme which includes the measurement of runoff from plots following natural rainfall, and from plots where a rainfall simulator is used (Platford[3]). The Chemicals, Runoff and Erosion from Agricultural Management Systems (CREAMS) computer model is also used in the programme to predict soil and water losses (Platford[4]). Soil erodibility, tillage practices, the effect of the stage of development of the crop and surface cover conditions can all be studied on different slopes by means of runoff plots. However, the complexity of the interaction between these factors and the disposition of terrace banks and waterways, needs to be studied under large-scale field conditions. Actual runoff and soil losses can then be assessed in terms of particular ground and crop conditions, following measured amounts and intensity of rainfall. The results will not be directly applicable to all sugarcane catchments because these vary greatly in character, but they will provide realistic bench marks which can be used in careful extrapolation to other areas.

Methods and Materials

The small catchment project at La Mercy is conducted on 20 hectares of land north of the Umdloti river (Figure 1). The area is part of a farm which the South African Sugar Association Experiment Station leases for various research projects. Four separate small catchments were selected for this project.

Topography

The area shown in Figure 2 is typical of sugarcane fields on the north coast, where slopes vary from 5 to 35% and where valleys and drainage lines are well defined. Hilltops tend to be rounded and primary catchments are about 5 ha in area. Horizontal distances from crests to drainage channels are usually less than 300 m. The catchments have been numbered from south to north, 101 representing the southernmost catchment and 104, the northernmost catchment. Details of the catchments are given in Table 1.

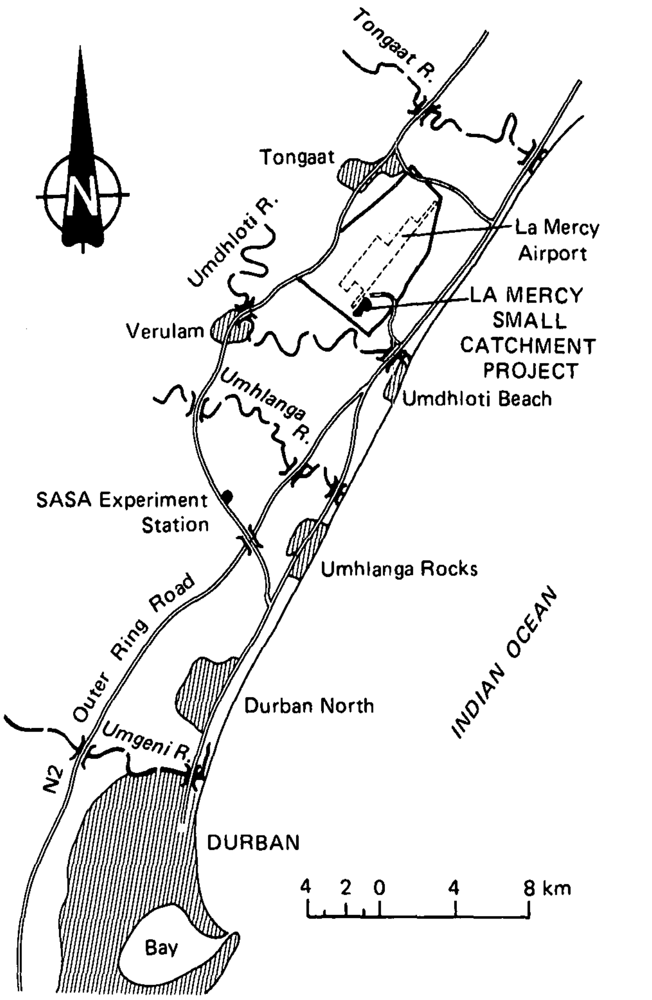

FIGURE 1 The project is adjacent to the new La Mercy Airport site, north of Durban.

TABLE 1
Surface properties of the La Mercy catchments

Catchment no	101	102	103	104
Area (ha)	2,7	4,7	4,4	6,6
Average slope (%)	29	21	12	17
Waterway slope (%)	21	16	8	23
Width (w) (m)	160	155	150	380
Length (l) (m)	260	375	330	325
Ratio w to l	1,6	2,4	2,2	1,2

Soils

Within the project area, 72% of the soils are of the Arcadia form (dolerite), 25% are of the Swartland form (Middle Ecca),

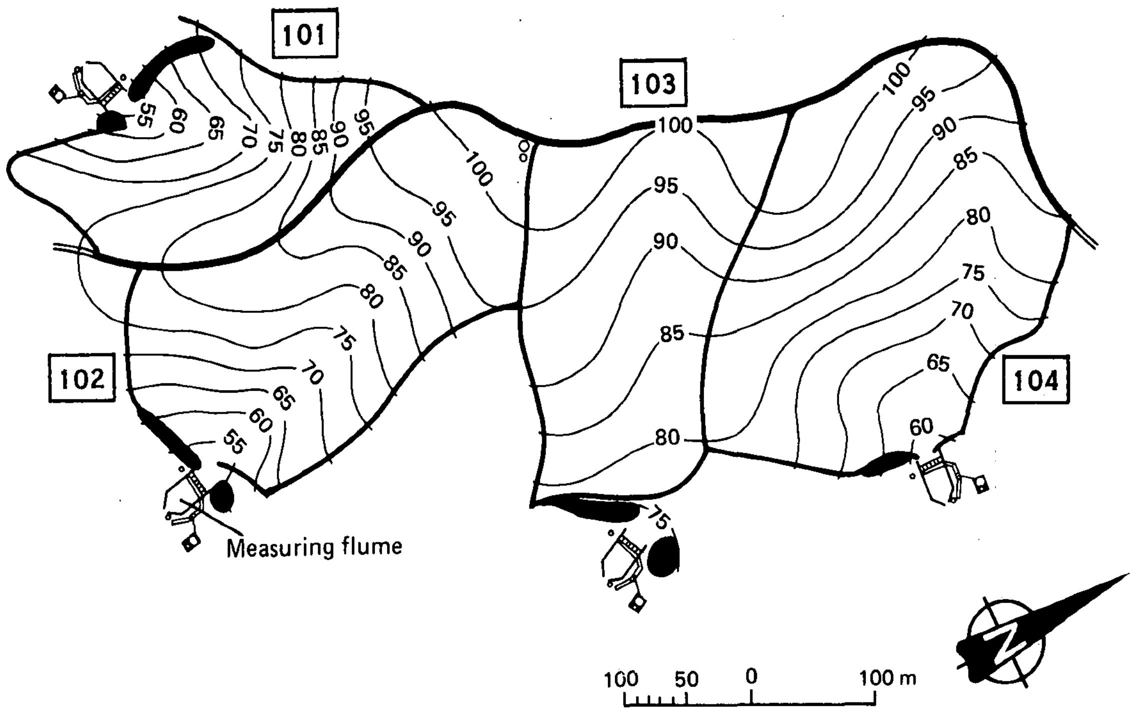

FIGURE 2 The four catchments comprising the La Mercy Project. Contour lines at 5 m intervals indicate the general topographic features.

and the remaining 3% are of the Hutton form (Recent Sand) (Figure 3). The two dominant soil forms are similar in appearance and in those physical characteristics which influence soil tilth. The Swartland form has grey orthic topsoil and is generally shallow, whereas the Arcadia form has a grey to black vertic topsoil. Outcrops of shale occur randomly throughout the area occupied by the Swartland form soil while occasional rounded dolerite boulders are found on the surface in the Arcadia soils. Both forms have a high clay content in the upper horizons. Textural analyses of the three soil types are given in Table 2.

In the undisturbed state or after compaction, there are well defined cracks in the surface of the Arcadia soils when they are

TABLE 2

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

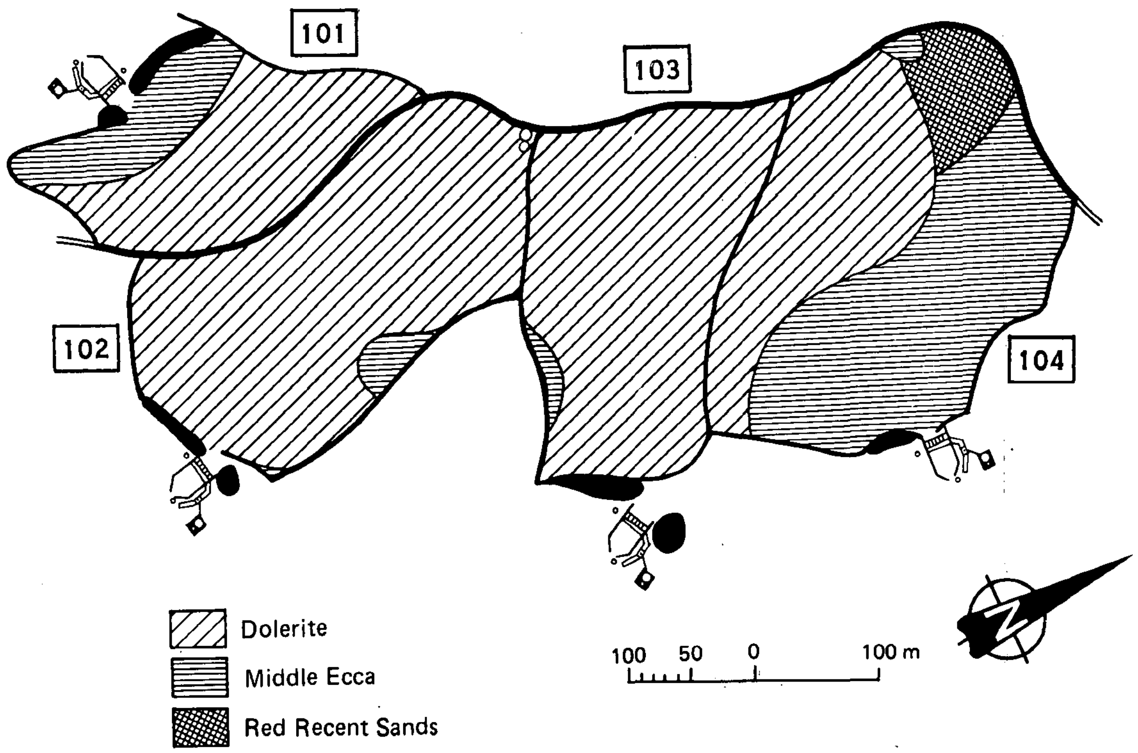

FIGURE 3 Soil parent material map for the different catchment areas.

dry. This is due to the high proportion of montmorillonite in the clay fraction. Rain causes these cracks to close quickly resulting in a low infiltration rate so that runoff occurs shortly after soaking rains begin. Once these soils are cultivated, storage of water in the surface layer and the infiltration rate do increase, but the effects are not sustained because the soil seals and compacts. When the cultivated soil dries, cracking is less pronounced than in the undisturbed state. The Swartland soils crack less than the Arcadia form but the surface seals as rapidly. Both soil forms are very slippery when wet. While depth is a characteristic of a soil form, variations do occur within the individual soil forms. Depths range from 0,3 to 0,9 m in the Arcadia and from 0,0 to 0,6 m in the Swartland form. The small area of Hutton form soil is deeper than one metre. Soils in the valley bottoms are alluvial in character and deeper than on the hilltops and hillsides, and subsurface drainage causes them generally to be wet with a watertable close to the surface.

Measuring equipment

- *Runoff*: after the expected peak flow rates had been estimated, 1,37 m H flumes with a 6 m approach channel were built to record a flow up to 2,36 $m^3 s^{-1}$. The four flumes, details of which are shown in Figure 4, were completed in June 1977.

Holes were made in the wall of the side sheet to connect into the measuring well which was built on the outside of the flume. A Negretti and Zambra recorder was installed adjacent to the well. The pressure plate in the base of the well was connected to the recorder by a capillary tube. Pressure on the plate causes the pen arm to move vertically, and this records on a rotating clock chart. Drains were made so that the well could be cleared after use.

- *Soil loss*: after early attempts at sampling from the discharge end of the flume a modified splitter sampler was installed at its entrance (Figure 5).

This splitter removes a 5% sample and routes it through a second splitter into a channel alongside the flume, where another 5% sample is removed. This sample (1/400th) of the original flow is deposited into a collecting tank which can hold 400 litres. Once this is filled, the overflow is directed onto a 0,8 m Coshocton wheel which extracts a 1/100th sample and places it in a 200 litre tank. After storms, the quantities of the samples are recorded and the sediment loads are determined for each tank (Figure 6).

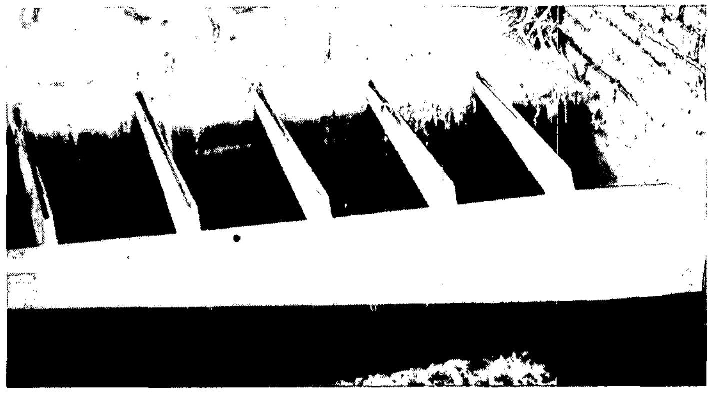

FIGURE 5 Runoff flowing over the entrance sill of the H flume. A 5% sample is removed by the splitter for sediment content analysis.

FIGURE 6 Final discharge of runoff through the mouth of the H flume in catchment 101.

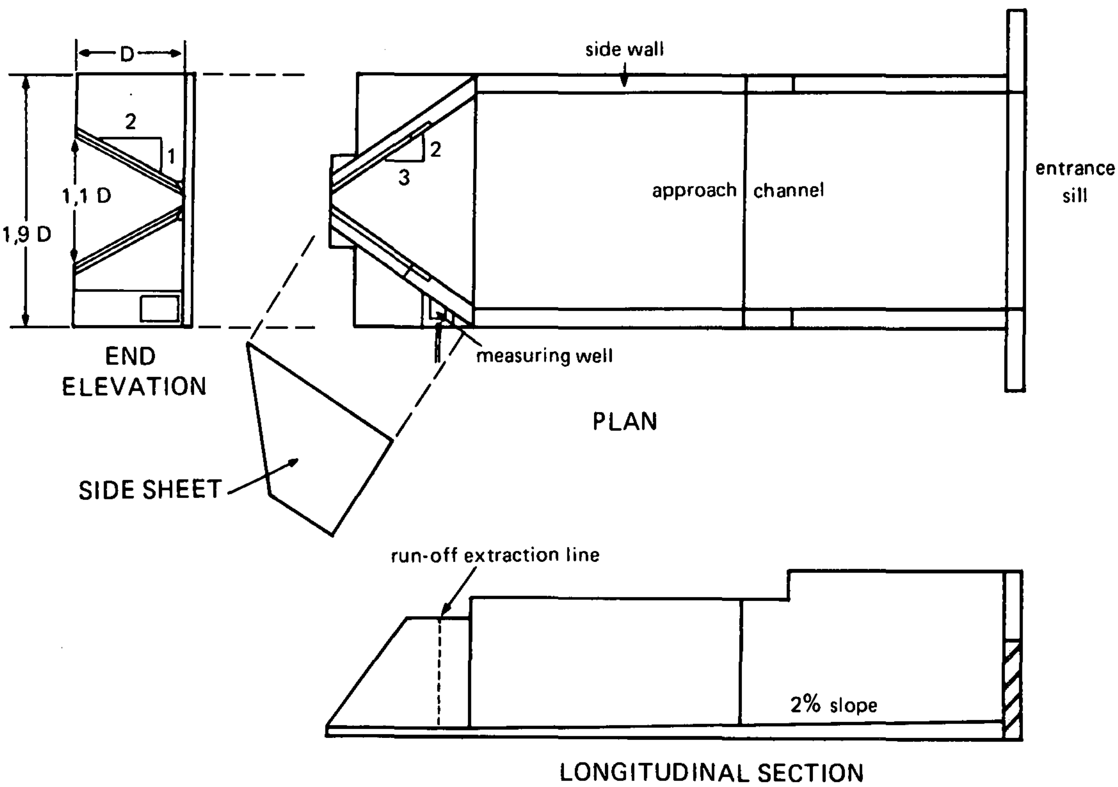

FIGURE 4 General design of the H type runoff measuring flume which was built in each catchment.

- *Rainfall*: a clock-driven rotating drum which records rainfall intensity was built in the instrument workshop at the Experiment Station. A maximum of 350 mm of rain can be recorded before it is necessary to change the recording sheet. One rotation of the drum takes 24 hours. Rain is funnelled into a calibrated container which causes a float to rise and this moves the pen vertically to mark the chart on the rotating drum. This gauge was placed centrally between catchments 102 and 103. A standard rainfall gauge is located at each flume to check for fluctuations in rainfall in the area.

Cultivation

It was not possible to maintain a completely constant bare fallow condition on all four catchments throughout the period before planting sugarcane. Changes in the growth rate of weeds and differences in soil conditions meant that it was not always possible to cultivate when it was desirable. Generally, after a rainstorm or wet period, cultivation was started as soon as it was practical to work the ground. The area was ploughed once a year and two or three cultivations, with an offset disc-harrow, were required each year to maintain the bare fallow.

Recent developments

After the result of runoff and sediment yields had been reviewed for the period of bare fallow up to July 1984, the second phase of the project was started. This involved implementing a different field layout system in each catchment (Figure 7).

- *Catchment 101*: a D5D Caterpillar bulldozer was used to construct a central flat based waterway and spillover bench-type roads at a gradient of 1:150 (0,067%). The roads were constructed at 9 m vertical intervals across the hillside. During October and November, a MF85/2 crawler tracter was used to draw furrows for planting sugarcane in the area. Harvesting of alternate panels will be practised and the minimum tillage system of replanting will be introduced on the panels between roads. Diagonal extraction roads with a gradient of 1:10 (10%) were also built (Figure 7). Subsurface drains, using 75 mm diameter pipes, were installed to drain the wet, lower areas around the flume.
- *Catchment 102*: a standard conservation network of water-carrying terrace banks with a gradient of 1:150 (0,067%) in the channel was built with a two-wheel drive John Deere tractor pulling a reversible two-disc plough. Waterways were constructed in the two drainage lines and planted to grass (*Cyndon dactylon*). Revetts made with bundles of sugarcane tops were pegged in lines across the newly grassed waterways to protect them. Subsurface drains were installed in the flatter, wetter area around the entrance to the flume. Sugarcane was planted in October and November. Conventional tillage equipment will be used when the whole area is replanted.
- *Catchment 103*: no structures have been constructed in this catchment although sugarcane has been planted over the whole area, the rows being parallel to the western boundary road. The waterway area was sown with *Eragrostis curvula* before the cane was planted. Future replanting of the crop will take place using conventional techniques. Only minor drainage work was necessary in this area.
- *Catchment 104*: a standard conservation network similar to that of catchment 102 was built with water-carrying terrace banks leading excess runoff water to grassed waterways. Diagonal extraction roads have also been built. Subsurface drains were used extensively in the flatter areas above the flume. No sugarcane has been planted and a bare fallow will be maintained for as long as it is necessary to continue results for this situation.

Results

Total rainfall, runoff volumes and soil losses for each year are given in Table 3. Measured runoff volumes have been converted to an average depth from the total area. By subtracting this amount from the rain which fell, the water remaining within the catchment has been calculated. Comparisons between the

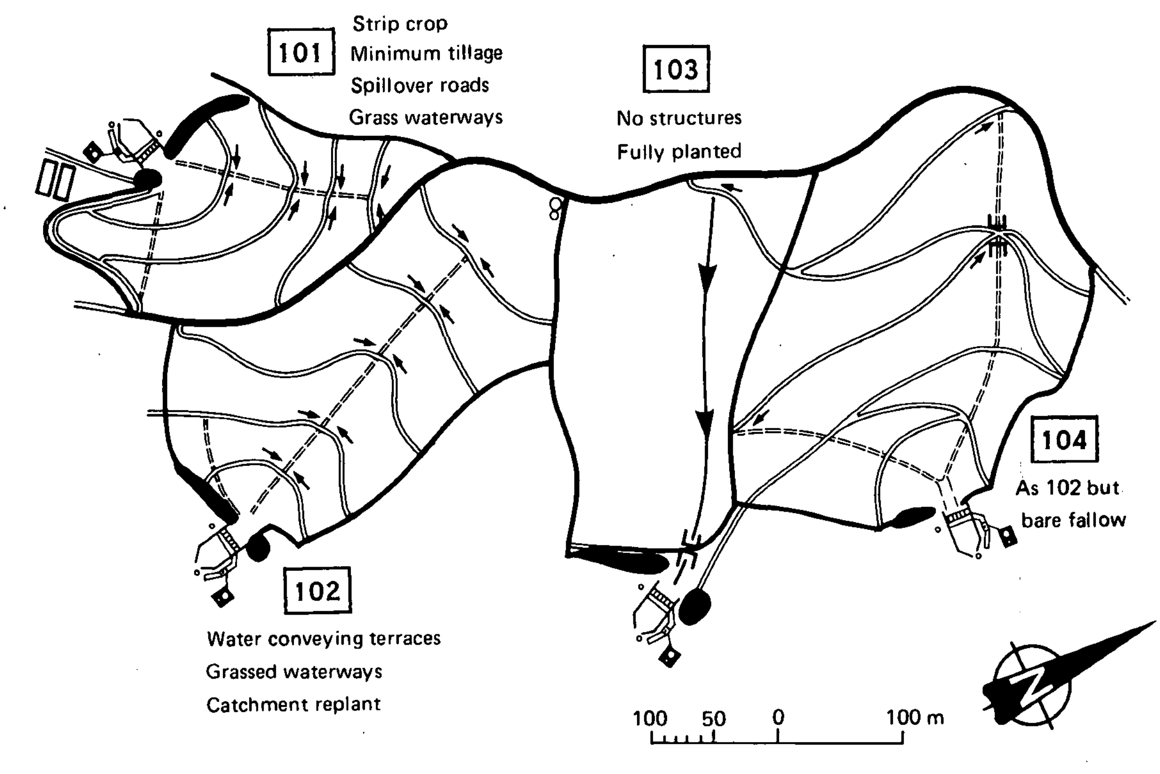

FIGURE 7 The different conservation layouts which have been completed.

amounts of measured effective rainfall and those calculated by one statistical method, are given.

TABLE 3
Annual rainfall, runoff and soil losses from four bare fallow catchments 1978-1984

Year	1978	1979	1980	1981	1982	1983	1984
Rainfall (mm)	984	724	816	969	678	833	1 214
Runoff (average (mm))	64	1	93	154	12	29	241
Effective rainfall (%) (measured)	93	100	88	84	98	96	80
Effective rainfall (%) (discard > 40 mm)	89	98	74	83	89	90	70
Soil loss (average) ($t\ ha^{-1}$)	—	—	*59	**115	6	29	***72
Maximum single storm (mm)	103	17	263	102	62	64	140
Maximum single runoff (mm)	26	1	75	87	2	12	69
Maximum single soil loss ($t\ ha^{-1}$)[11]	—	—	*48	73	6	18	45

* Sample tanks washed away in 104, 103.
** Coshocton wheel blocked in 103.
*** Splitter modified.

The rainfall intensity gauge performed well throughout the period; data for only 1,9% of the 317 storm records were faulty. On these occasions rainfall was taken to be the average of the four volume gauges. As expected, runoff increased as the volume of rainfall increased during the year. Linear regression of the seven yearly results for runoff and rainfall showed a correlation coefficient of 0,903 with zero runoff at an annual rainfall of 725 mm. The slope of the line was 1,91. Further observations on rainfall variability are given in Table 4.

In 1979, rain fell on 61 days and the maximum fall was 67 mm. During 1984, rain fell on only 44 days but the maximum daily fall was 169 mm. In 1980, during which the third lowest rainfall was recorded, the highest fall in one day was 263 mm. Runoff during this storm was not as high as that recorded from a storm in September 1981 when only 102 mm of rain produced 87 mm of runoff. The storms which caused runoff from all four catchments are listed in Table 5.

TABLE 4
Annual rainfall, rainstorm details and runoff data 1978-1984

Year	1978	1979	1980	1981	1982	1983	1984
Annual rainfall (mm)	984	724	816	969	678	833	1 214
Days of rain	66	61	58	61	45	43	44
Days of runoff	23	5	7	9	5	8	19
Minimum daily rainstorm (mm)	3	2	2	2	2	2	2
Maximum daily rainstorm (mm)	103	67	275	130	62	92	169

The highest falls of rain caused runoff in all four catchments except in the dry year 1979. In 1978, eight storms caused 60 mm of runoff; in 1980, only three storms with a total of 356 mm caused 84 mm runoff; in 1981, six storms totalling 394 mm produced runoff of 156 mm; only one storm in 1982 caused any runoff while in 1983 and 1984, four storms caused 27 mm and 157 mm runoff respectively. The number of times that runoff occurred in individual catchments is shown in Figure 8.

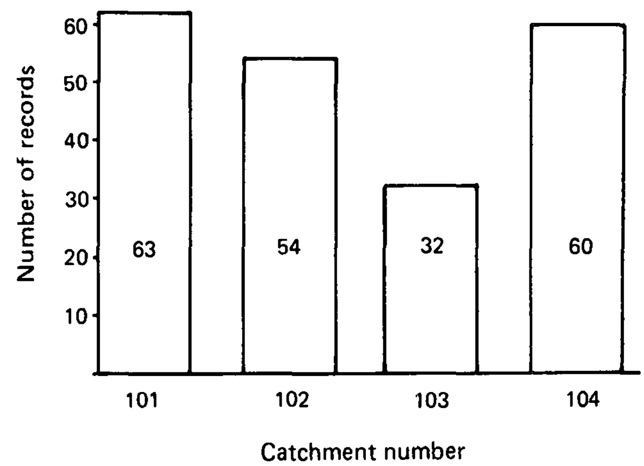

FIGURE 8 Number of runoff records for each catchment: October 1977 to December 1984.

TABLE 5
Rainstorms which caused runoff in all four catchments

1978			1979			1980			1981			1982			1983			1984		
Date	Rain (mm)	Runoff (mm)	Date	Rain (mm)	Runoff (mm)	Date	Rain (mm)	Runoff (mm)	Date	Rain (mm)	Runoff (mm)	Date	Rain (mm)	Runoff (mm)	Date	Rain (mm)	Runoff (mm)	Date	Rain (mm)	Runoff (mm)
23/10	72	9	—	—	—	7/9	263	*75	31/1	102	87	23/3	62	2	14/1	37	4	6/1	37	6
4/10	77	4	—	—	—	8/9	65		18/2	57	28	—	—	—	10/11	60	7	12/1	64	15
11/10	68	10	—	—	—	29/11	28	9	6/5	35	1	—	—	—	29/11	35	4	30/1	140	69
18/10	14	08	—	—	—	—	—	—	16/5	39	5	—	—	—	17/12	64	12	17/2	*160	67
18/11	103	*26	—	—	—	—	—	—	30/8	*118	27	—	—	—	—	—	—	—	—	—
21/11	29	1	—	—	—	—	—	—	10/9	43	8	—	—	—	—	—	—	—	—	—
25/11	10	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
28/11	12	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Total	385	60	—	—	—	—	356	84	—	394	156	—	62	2	—	196	27	—	401	157

* patched data

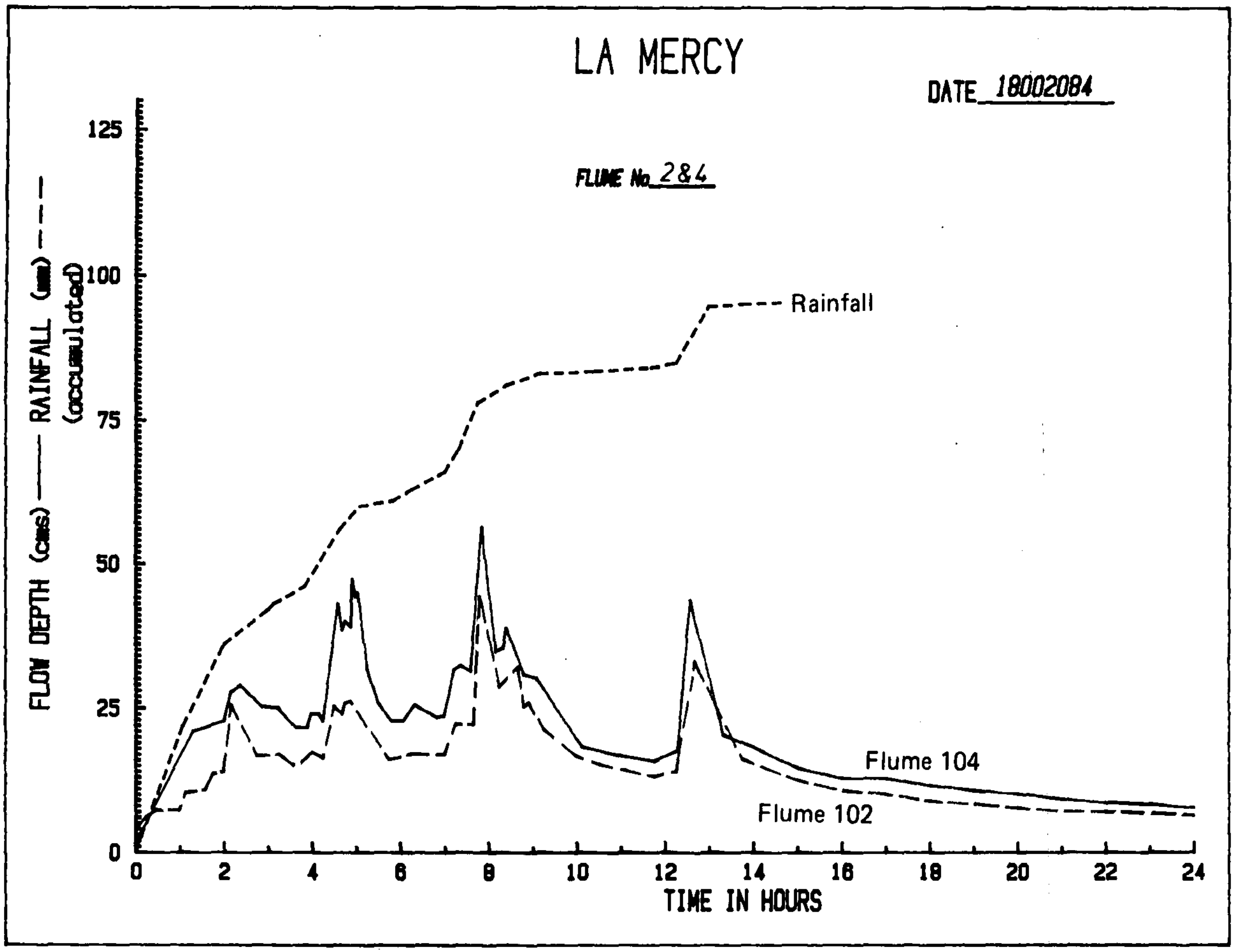

FIGURE 9 Illustration of the relationship between runoff through flumes 102 and 104 and rainfall intensity during a long storm.

In Catchment 101, which is the steepest and smallest catchment, the greatest number of runoff events were recorded although the volumes were not large. Catchments 104 and 102 followed closely and the least number of records were obtained from catchment 103.

Changes in rainfall intensity have been closely followed by changes in runoff rates in all flumes (Figure 9).

Flow depths in flumes 102 and 104 were compared with the rainfall graph for the same time span. The time lag, for the increased rainfall intensity to be reflected by a similar rise in runoff rate, decreases throughout the storm and this pattern was similar for both flumes. This similarity has been recorded for storms of both long and short duration which have caused runoff in all four catchments.

Because it is difficult to obtain sediment samples over the range of recorded runoff volumes of 3 to 15,9 m^3, the results should be treated with caution. In September 1980 a storm produced 263 mm of rain which washed away the sample tanks. The method of sampling was changed and samples were taken from the entrance to the flume. The greatest single sediment yield of 73 $t\ ha^{-1}$ was recorded from the highest single amount of runoff of 87 mm. The results of the sediment yield analyses have been included in Table 3 so that they can be compared with the associated runoff values. Variations in surface tilth, which will have some effect on sediment yield, have been ignored. At low sediment levels, small errors could be magnified when the concentration value is converted to tons of soil lost per hectare. Two or three samples were used for most measurements of sediment load.

The CREAMS (Chemicals, Runoff and Erosion from Agrigultural Management Systems) model was used to predict the volume and rate of runoff as well as the loads from three rainstorms. The result are given in Table 6.

TABLE 6
Comparisons of measured amounts of runoff and values predicted by the CREAMS model for three storms on Catchment 104

Details	Storm 1 7/1/84 42 mm	Storm 2 12/1/84 63 mm	Storm 3 29/11/84 140 mm
Measured runoff (mm)	10	22	91
Predicted runoff (mm)	8	18	97
Measured runoff rate ($\ell\ s^{-1}$)	127	138	266
Predicted runoff rate ($\ell\ s^{-1}$)	103	90	278
Measured soil loss ($t\ ha^{-1}$)	5	47	78
Predicted soil loss ($t\ ha^{-1}$)	1	39	95

Discussion

The results given here are those from the first phase of the catchment project which was used to determine the differences in runoff between the individual catchments in a bare fallow condition. The second phase of the project has now begun and will involve assessing the ability of the crop and field structures to provide protection against soil and water loss. The annual records of precipitation show the expected variation in rainfall in the coastal sugarcane growing areas. The range was from a minimum of 678 mm in 1982 to a maximum of 1 214 mm in 1984. The standard deviation about the mean for the seven year period was 183 mm. This is very similar to the longer term standard deviation for the area found by Schulze,[6] who also shows that there is a coefficient of variability (CV) of 20% about the mean for annual rainfall. This variability is significant for production planning and for estimating yields because there is a close relationship between sucrose production and annual rainfall. The distribution of rainfall over the 20 hectare project area was also subject to some variability, probably as a result of topography and prevailing winds. This variability has been ignored because it is most often less than 2% of the total precipitation.

Although there is constant movement of water throughout the soil matrix only the 'quick flow' element or observed runoff has been considered. The measured volumes of runoff have been converted to a depth of water related to the size of the catchment from which runoff occurred. This amount has been deducted from the storm precipitation to give a value for effective rainfall. All of this amount of water does not necessarily become available for use by the crop. Some may be lost to ground water and some may be held by the soil matrix at high tensions (Johnston[1]). The measured effective rainfall is compared with a calculated value obtained by excluding falls of rain in excess of 40 mm on any one day. The measured values are consistently higher than the calculated values and it is expected that they will be even higher once there is a crop to intercept rainfall and so further reduce runoff.

Throughout the period of the project, those storms with high rainfall intensity and volume, caused runoff from all four catchments, but it was not always the most intense storm that caused the greatest amount of runoff. Antecedent moisture content of the soil and initial retention by storage in the surface irregularities play an important part in the runoff process (Schulze and Arnold[5]).

The number of runoff events recorded through the individual flumes were highest in catchment 101 which is the steepest and smallest and on which runoff was recorded on 63 occasions. In catchments 104 and 102 runoff occurred on 60 and 54 occasions respectively, while in catchment 103 there were only 32 runoff events. Surface conditions were similar throughout the period and it appears that steepness and distance of overland flow have the greatest influence on runoff.

The intensity and changes in intensity of rain during a storm are more important in causing runoff than is the total amount of rain. Comparisons of the rainfall graph and the runoff hydrograph (on the same time scale) show that changes in the intensity of rain are closely related to changes in the hydrograph once flow has been generated. For most major storms, when runoff was recorded in all of the catchments, the depths of flow through the four flumes followed a significant trend. The deepest flow was recorded in flume 104, followed by 103, 102 and 101. The differences between the levels in 103 and 102 were generally small.

The Arcadia and Swartland soils are heavy. Soil erodibility values in the natural state or when the erodibility has been determined by nomograph methods, are small (Platford[3]). The time taken for runoff to be initiated and the infiltration rates on tilled plots, have been given by McPhee.[2] From these properties it would be expected that high volumes of runoff with low sediment yields would occur during rainstorms. Despite the shortcomings in the sediment sampling techniques used at La Mercy, the reverse is apparent. Sediment loads higher than the generally accepted values between 5 and 10 t ha^{-1} have been measured. The cause of these large losses of soil is probably the continuous discing and ploughing operations which pulverized the surface 20 cm of the soil. Below this, the undisturbed subsoil has a low infiltration rate and acts almost as a barrier to water movement. The surface layer therefore becomes saturated and water moving over the surface begins carrying large amounts of sediment. The amount of sediment moved from the catchment seems to be determined by the amount of runoff water. The increase in sediment load as the volume of runoff increases, supports the view that it is the amount of water which determines the sediment load.

The first phase of the project ws completed in August 1984. At that time the construction of different protection systems had started and from September, sugarcane was planted in catchments 101, 102 and 103. During the first two years of the project it became evident that a number of complex factors were involved in the hydrological and sediment production cycles and that absolute response values or ratings would be difficult to obtain. The range of recorded results confirmed that it was imperative to obtain as much data as possible from other parts of the research programme. Infiltration values, soil properties, the effects of cultivations and other data have been extracted from runoff plot and simulator studies and used to interpret the results from the catchments. The usefulness of the plot studies will be highlighted further once the effect of the crop on the catchments increases. The need for research on specific unit areas using plots was also apparent when imput data for the CREAMS model were assembled although locally determined parameters were used in many instances. The model was used to predict runoff and soil losses from three measured storms and there was a good correlation between the predicted values and those measured. The use of the CREAMS model for sugar cane (Platford[4])and the Agricultural Catchment Research Unit (ACRU) model of the University of Natal, Pietermaritzburg, developed by Schulze,[7] will help greatly in predicting the quantity and quality of water which can be expected from ungauged catchments.

Conclusions

The interaction of the many variables which cause or influence runoff from catchments makes it difficult to draw precise conclusions on how the catchments will react to rainstorms. Research in the bare fallow catchments has shown that steepness and distance of overland flow are important in the initiation of runoff. The catchments reacted in a set pattern during heavy storms of different durations. The greatest flow depths were recorded in catchment 104, while in catchments 103 and 102 the flow was less but was consistently similar. Catchment 101 had the lowest flows but the most recordings. The hydrographs were consistently similar to the precipitation intensity pattern. The measured effective rainfall has been constantly greater than was anticipated or estimated from calculated determinations.

Surface tilth conditions are more critical than inherent soil erodibility ratings in causing soil loss. Although the Arcadia and Swartland soils are considered to be relatively resistant to erosion, very high soil losses have been recorded.

There is a great need to gather data on runoff and sediment load from areas on which a sugarcane crop is growing so that the existing design criteria can be improved. Results obtained from the bare fallow period indicate that the magnitude of runoff from an area with a crop cover should be obtained reasonably quickly.

The loss of soil, water and possibly chemicals from field-sized catchments can be predicted if values can be established locally for the parameters that are used in existing models.

Acknowlegdements

Thanks are due to Mr B Worlock for maintaining the catchments and for building the structures. The design and structural work on the measuring flumes was ably done by Messrs JP Fourie and JA George. Thanks are also due to the technicians of the Land and Water Management department and to the meteorological staff for maintaining the equipment and collecting data.

REFERENCES

1. Johnston, MA (1973). Physical properties of sugar belt soils with particular reference to moisture release characteristics. *Proc S Afr Sug Technol Ass* 47: 115–119.
2. McPhee, PK *et al* (1983). The South African rainfall simulator programme for assessing soil loss and runoff. *Proc S Afr Nat Hydrological Symp* TR119: 352–359.
3. Platford, GG (1979). Research into soil and water losses from sugarcane fields. *Proc S Afr Sug Technol Ass* 53: 152–156.
4. Platford, GG (1983). The use of the CREAMS computer model to predict water, soil and chemical losses from sugar cane fields and to improve recommendations for soil protection. *Proc S Afr Sug Technol Ass* 57: 144–150.
5. Schulze, RE and Arnold, H (1979). *Estimation of volume and rate of runoff in small catchments in South Africa, based on the SCS technique.* Univ of Natal, Dept Ag Eng ACRU Report No 8: 20–25.
6. Schulze, RE (1982). *Agrohydrology and climatology of Natal.* Univ of Natal, Dept Ag Eng ACRU Report 14: 42–50.
7. Schulze, RE (1984). *Hydrological models for application to small rural catchments in Southern Africa: refinements and development.* Univ of Natal, Dept Ag Eng ACRU Report 19: 176–177.