INTEGRATED STUDIES OF THE GENERATION OF RUNOFF, SOLUTES AND SEDIMENT IN TRIBUTARY CATCHMENT OF THE GREAT FISH RIVER.

By C B SCHULTZ

WRC REPORT NO 100 /1/88

WATER RESEARCH COMMISSION

FINAL REPORT

INTEGRATED STUDIES OF THE GENERATION OF RUNOFF, SOLUTES AND SEDIMENT IN TRIBUTARY CATCHMENTS OF THE GREAT FISH RIVER

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FOREWORD

The research project concentrated on the study of the generation of runoff, solutes and sediments under semi-arid conditions. Process studies where streamflow events are rare, constituted a formidable task. For a little more than three years Dr. J.H. Moolman was the research officer in charge of the project and during this period he concentrated on the instrumentation and collection of data in a subcatchment of the Ecca River. In his report to the Water Research Commission 'Data Collection for the Study of Runoff, Solute and Sediment Generating Processes in a Semi-arid Catchment,' (No.100/1/85) he presented his findings which highlighted the effect of the low rainfall on the soil-water status of the Ecca catchment.

Early in 1985 Dr. Moolman left the project to join the lecturing staff of the University of Stellenbosch. Mr. C.B. Schultz was appointed to replace him on the research project and it is to his credit that, with less than two years to the completion of the project, he was able to familiarize himself with the local conditions and further the research, emphasizing the modelling aspects. Mr. Schultz has been responsible for the final report on the research undertaken.

The project is the first in South Africa which attempts to understand the natural salt producing mechanisms and the hydrological processes of semi-arid regions. The research has not been without its problems and its difficulties but it represents a contribution towards the greater understanding of matters relating to salinization. It is to be hoped that hydrologists will benefit from the results presented and be encouraged to commit themselves to this challenging research field.

The research programme was possible because of funding by the Water Research Commission and the facilities provided by Rhodes University to its Department of Geography. My gratitude and appreciation is accordingly expressed to both organisations. I also wish to thank the members of the Steering Committee for their positive help on all occasions, as well as Dr A. Görgens for his foresight in initiating the project.

J.B.McI. Daniel
(Professor, Head of Department and Project Leader)

ACKNOWLEDGEMENTS

This research could not have been conducted without the aid of numerous persons and organisations whose support and assistance I hereby acknowledge and to whom I express my sincerest thanks :

The Water Research Commission, for funding this project; the cooperation and guidance of its staff are much appreciated.

Prof. J.B. McI. Daniel, project leader and head of the Department of Geography, Rhodes University, for placing at my disposal the facilities of his department, for advice in policy matters concerning the project and aiding with the editorial aspect of this report.

Mr. H.C. Chapman, the project's advisor for the Water Research Commission and chairman of the project's Steering Committee; his guidance and cooperation, together with that of the other committee members, is much appreciated. The committee members included:-

Dr. G. C. Green - Water Research Commission

Dr. D.C. Grobler - National Institute for Water Research, Council for Scientific and Industrial Research

Prof J.B.McI. Daniel - Department of Geography, Rhodes University

Dr. A.H.M. Görgens - Ninham Shand

Mr. G.R. Botha - Steward, Sviridov and Oliver

Mr. P.J. Strumpher - Dept of Agriculture and Water Supply

Mr. E. Braune - Hydrological Research Institute, Dept of Water Affairs

Mr. H. Maaren - Hydrological Research Institute, Dept of Water Affairs

Mr. G.J. Greeff - University of Stellenbosch

Dr. J.H. Moolman - University of Stellenbosch

Mr. P.W. Weideman - Committee Secretary, Water Research Commission.

Mr. J. Landman and Mr. S. Kara for data collection, data processing and general maintenance. Mr. Landman was also responsible for most of the cartographic work contained in this document. Additional cartographic aid was obtained from Mr. O. West, Mr. J. van Wyk and Mr. J. Keulder.

Mrs. J. King, Secretary of the Hydrological Research Unit for word processing and administration.

Dr. D.A. Hughes and Mr. J. Herald, colleagues at the Hydrological Research Unit.

Mr. J. Lucas and Mr. B. Guthrie of the Dept of Physics and Electronics, Rhodes University, for the design and manufacture of data logging systems for tipping bucket raingauges and a radio-activated flow warning system.

Dr. J.H. Moolman, my predecessor to whom I say a special word of thanks for his major role in this project.

Dr. A.H.M. Görgens for initiating this project.

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CHAPTER 1.
INTRODUCTION

Approximately two thirds of South Africa receive less than 500mm of rainfall per annum, yet most of its hydrological research catchments are in the remaining moist area of the country. The Ecca Research Catchments near Grahamstown are an exception. These catchments were established during 1974 and 1975 and have for the past decade been used by Rhodes University's Hydrological Research Unit (HRU) to investigate hydrological responses in semi-arid environments. Prior to 1982 the emphasis of the research was on the ability of conceptual models to predict runoff (Roberts, 1978, Görgens, 1983). The associated data collected consisted primarily of rainfall, runoff and evaporation. The monitoring networks were not geared towards the gathering of information about the sediment and water quality aspects of these catchments. Moreover, most of the parameters used in the hydrological models studied by Roberts, (1978) and Görgens, (1983), were determined by calibration or optimization, rather than field or laboratory measurement.

The scarcity of research catchments in the semi-arid environments of South Africa, and the shortage of transferable information pertaining to factors affecting the quantity and quality of streamflow, gave rise to the need to extend the research approaches in the Ecca catchments to incorporate physically-based modelling techniques and to investigate the processes giving rise to the generation of runoff, solutes and sediments. A new research project was therefore initiated in 1982 by the HRU and funded by the Water Research Commission (WRC). The research concentrated on Catchments B and F (Figure 2.1). The main objective of this five year contract was to contribute towards overcoming the high degree of empiricism in rainfall-runoff and hydrosalinity models currently used in South Africa. Its aims therefore included:

a) The collection of data on the principal processes associated with the generation of runoff, solutes and sediments as dynamically varying, distributed processes.

b) The analysis and interpretation of the collected data with a view to acquiring an improved understanding of relevant processes and their interrelationships.

c) The further development of existing hydrosalinity models by incorporating the knowledge gained about processes.

d) The development and testing of new models that could have a wider range of applications such as the prediction of the effects of changes in land use or catchment management strategies on the quantity and quality of water.

The research has been presented in two reports, namely an interim report by Moolman (1985) and this report which concludes the research contract. While much progress has been made towards achieving the research objectives, additional research is still required in order to substantially reduce the level of empiricism in the hydrosalinity models currently used in South Africa and to develop new models for use in ungauged areas.

The interim report 'Data Collection for the Study of Runoff, Solute and Sediment Generating Processes in a Semi-arid Catchment' (Moolman, 1985) covered the research conducted during January 1982 to March 1985. The emphasis of the report was on the establishment of instrumentation in research catchments in the Ecca River Valley, data collection in the catchment and the problems associated with the drought at the time. It also outlined the instrumentation failures, the in situ studies of the water retention properties of the soils as well as the salt content of rainfall, soil water, and runoff. The main findings of the report were that the south and north facing slopes of Catchment F were distinctly different and spatially heterogeneous with respect to their textural and salt contents. Moolman (1985) concluded that the present knowledge, pertaining to the generation of runoff and the mobilization of solutes and sediments in these semi-arid catchments, is still rather limited. He attributed this limited knowledge to the frequent failures of electronic equipment and flow recording devices at crucial times during runoff events, as well as a limited number of events.

The above instrumentation problems were re-encountered during the subsequent research period April 1985 to October 1986. At the project's Steering Committee meeting of 19 February, 1986 it was decided that the emphasis of the research, during the remaining period of the project, should concentrate on process based simulations of hydrological events and use the sediment and solute data to interpret whether the simulated hydrological processes were correctly distributed in space. The development and testing of hydrosalinity models was to be omitted until more information was available to describe adequately the processes involved. Before discussing the general format of this report a brief outline is given of the philosophical aspects associated with the transition from empirically-based to process-based hydro-salinity models. It is the positioning of models within this transition framework that reflect the degree to which empiricism may be reduced. The extent to which this transition can be breached is limited by knowledge, the financial and practical logistics of extensive data collection and computational constraints, as well as numerous complexities associated with spatial and temporal scale factors. Fleming (1975) describes the transition between empirical and process based models as being comprised of conceptual models. Empirical modelling approaches give minimal consideration to the relationships between parameters and processes while conceptual approaches attempt to incorporate model components representing various processes and to describe their interrelationships. While no conceptual model can simulate all processes exactly, the extent to which any conceptual model can be regarded as process based is possibly related to the extent to which its structure and related equations reflect hydrological processes in time and space.

In order to represent the extent to which conceptual models are either physically or empirically orientated, a classification system is presented for conceptual models. The terminology of Fleming (1975), Beven and O'Connell (1982) and Schulze (1984) has been adapted and redefined to suit the context of this report. The classification is based on a statement by De Coursey (1971) that hydrological predictions required for estimating the consequences of changes in land use are possible if the hydrological processes are simulated using the laws of continuity and the conservation of mass, energy and momentum. The extent to which a model fulfills the above criteria determines its position in the following classification :-

A. EMPIRICAL MODELS : The parameters and equations of these models do not fulfill any of the criteria for the classification system. The parameters used in the model must be calibrated and do not reflect the catchment's characteristics nor the hydrological processes involved, for example, the 'rational formula' (Mulvaney, 1850).

B. CONCEPTUAL-EMPIRICAL MODELS : These are models whose structures do reflect some aspects of hydrological processes but whose equations are empirically based. The models attempt to preserve mass over discrete time intervals. The parameters are not related to the physical environment and must be calibrated. The models can be lumped or semi-distributed but not fully distributed since they do not satisfy the laws associated with the preservation of momentum and energy, for example, the model of Neilson & Hansen (1973).

C. CONCEPTUAL-PHYSICAL MODELS : These are similar to the conceptual - empirical models, except that most or all of their parameters can be related to the physical environment of the catchment. Some calibration should still be necessary because the models do not conserve momentum and energy. However, some of these models are assumed not to require calibration, for example the ACRU model of Schulze (1984).

D. PHYSICALLY-BASED MODELS : These models have been developed by researchers who have made a concerted effort to incorporate physically - based rather than empirical parameters into their models, but have not managed to exclude empirical relationships entirely and therefore parameter optimisation is not completely avoided. The models attempt to conserve mass and momentum and are therefore fully distributed. Energy is not necessarily conserved, for example, the ANSWERS model of Beasley, Monke and Huggins (1977) and the SHE model of Abbott, et al. (1982).

E. PHYSICAL MODELS : These models conserve perfectly all aspects of mass energy and momentum within the four dimensions of space and time. Such models require no calibration and always produce exact answers. These models presently exist as theoretical concepts only.

The suitability of models for application in ungauged situations can be ranked from A to D in the above classification with models in category D being the most suitable. In practice, hydrologists are often constrained in their selection of models by the availability of data and consequently models in lower categories must be used. Models in categories A, B and C have been studied in detail in South Africa by Roberts (1978), Görgens (1983) and Schulze (1984). Models in category D have been tested in the Bethlehem district by Maaren (1985) and Schultz (1985) but they have not been tested in the semi-arid regions.

The present project therefore tests a hydrological model from category D in the semi-arid environment of the Ecca catchment. An attempt is made to utilize the results of the research into the processes associated with the mobilization of salts and sediments, to verify the spatial distribution of simulated hydrological processes.

The first two chapters of this report are of an introductory and descriptive nature, dealing with aspects such as the research objectives, the physical and climatological aspects of the study area as well as the instrumentation of the research catchments. The descriptions deal with the quantitative information required for physically-based, hydrological modelling and minimise repetition of the detailed geographical descriptions, provided in earlier reports by Roberts (1978), Görgens (1983) and Moolman (1984).

The third chapter deals with the soil moisture regime of the catchments. Attention is also given to the ability of a daily moisture budgeting model to simulate daily soil moisture variations using physically-based parameters. These variations are relevant to the research project in the sense that they influence the redistribution of salts in the soil and the antecedent soil moisture conditions. Chapter four deals with runoff generation and the simulation of single events using a physically-based, distributed, hydrological model. The emphasis of the chapter is on the extent to which realistic simulations are possible using spatially distributed parameter values that can be measured in the field or laboratory. The transferability of non-physical parameters across a nested catchment configuration is also discussed.

The fifth chapter discusses the spatial distribution of the physically-based soil parameters which affect soil erosion. It illustrates the variations of sediment loads in response to runoff and the extent to which a single event, physically-based, distributed, hydrological model is capable of predicting sediment variations.

The sixth chapter deals with the generation of solutes in relation to the chemical properties of soils, the salt loads of rainfall, the variations in soil moisture and runoff. An attempt is made to interpret which areas of the catchment and soil profiles contribute towards the solutes found in the streamflow hydrographs. From a hydrological point of view these interpretations are considered relevant in verifying the spatial and temporal distribution of hydrological processes.

The final chapter reviews the project as a whole and makes recommendations for future research.

CHAPTER 2

THE RESEARCH CATCHMENTS

The study area consists of two small catchments, F and B, which form part of a group of six, nested catchments, situated in the Ecca River valley near Grahamstown (Figure 2.1, Table 2.1). Initially it was hoped to conduct detailed hydrological measurements in the smallest of these catchments, F and to test the transferability of research results and findings to the remaining larger Ecca catchments. However, this has not been possible due to the unforeseen decision in 1985 to construct an off-channel storage dam to augment the water supply to Grahamstown. This dam is to be linked, via a tunnel, to the Fish River and a pipe line to Grahamstown. It is centrally located within the Ecca research catchments. The main channel of the Ecca river will be used to transfer water to a downstream irrigated area.

The effect of the dam and the associated scheme is that the research area has now been reduced from six to two nested catchments, viz., F and B. (Figure 2.1). The research area has been reduced from 73,1km² to 9,1km² or to 12,4 percent of its former size. Catchments A, C, and D have been lost as usable research entities. Although Catchment E will not be affected by the dam, it is geographically displaced from Catchments F and B and incorporates geological outcrops of the Cape Supergroup which are not found in Catchments B and F. This geological difference gives rise to an area of relatively flat terrain with soil textures which are not repeated in catchments B and F, therefore making it non-compatible for hydrological parameter transfer study purposes. Consequently this report concentrates on Catchments B and F and only makes minor references to the surrounding catchments.

Attention in this chapter is focussed on the available instrumentation, the rainfall, geology, soils, vegetation and surface drainage of the two catchments. The main purpose of this chapter is to present the spatial distribution of physically-based parameters that can be used in hydrological models. The models used in the project will be described in chapters three and four.

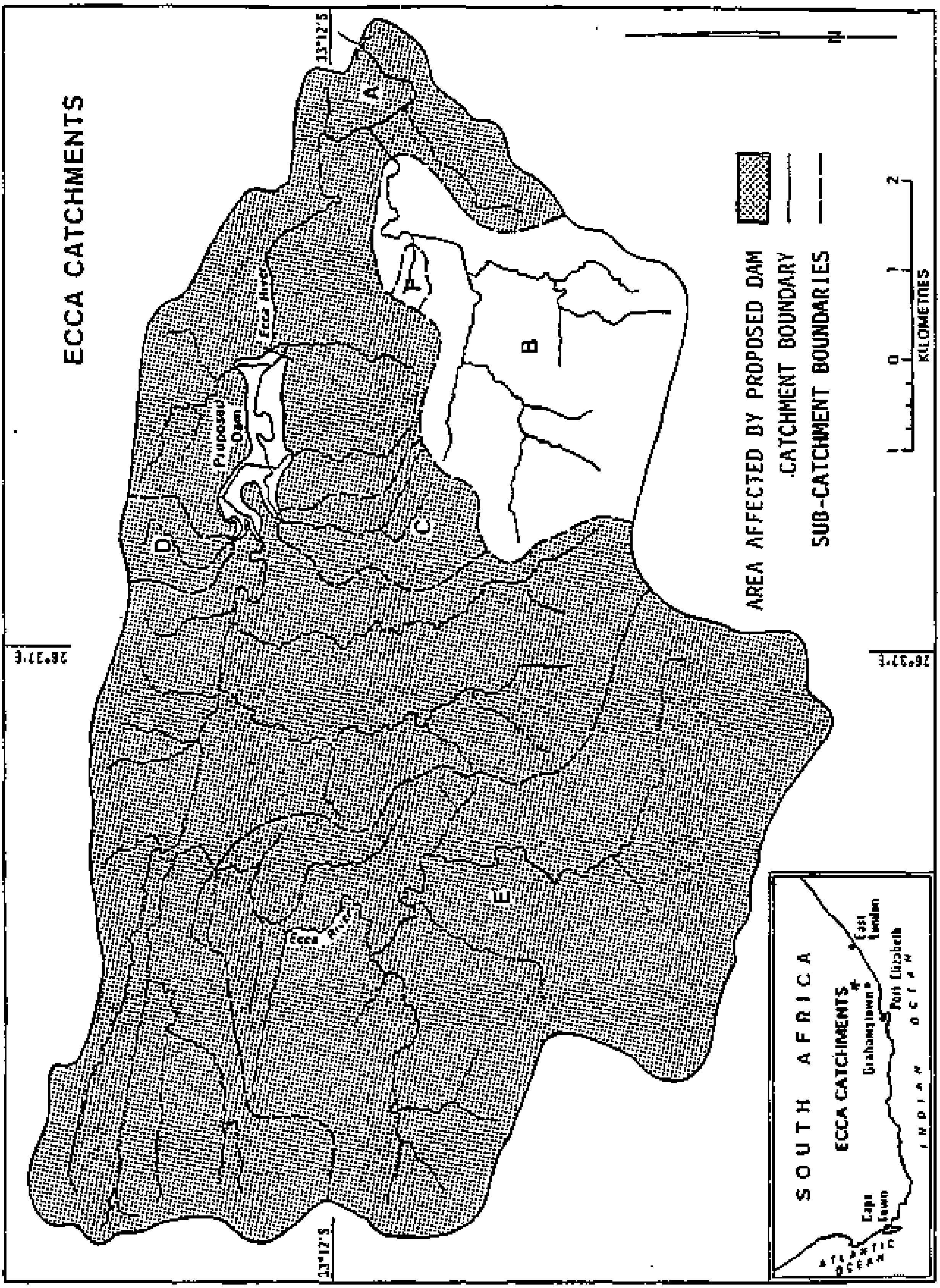


Figure 2.1 The Ecca catchments and the area of hydrological research affected by the construction of a new dam.

Table 2.1 Sizes of the Ecca Catchments (after Görgens, 1983 and Moolman, 1985)

Catchment	Area (km^2)
A	73,1
B	9,1
C	2,0
D	1,1
E	23,1
F	0,28

Instrumentation

The instrumentation of Catchment F has been described in detail in Moolman (1985). That report also evaluated the suitability of the instrumentation used. The following section is essentially a summary of Moolman's discussion and is expanded to include Catchment B and some technical modifications that have been implemented.

Catchment F was instrumented to monitor the following:

(i) continuous stage heights of streamflow
(ii) dissolved and suspended solids
(iii) meteorological properties
 a) air temperature
 b) relative humidity
 c) wind speed and direction
 d) net radiation
 e) free surface evaporation
 f) temporal/spatial distribution of rainfall
(iv) chemical composition of rainfall
(v) soil water content/depth (distribution at 6 sites)
(vi) chemical composition of soil water.

The positions of the instruments in Catchment F are presented in Figure 2.2. The location of raingauges with respect to Thiessen weighted, finite element

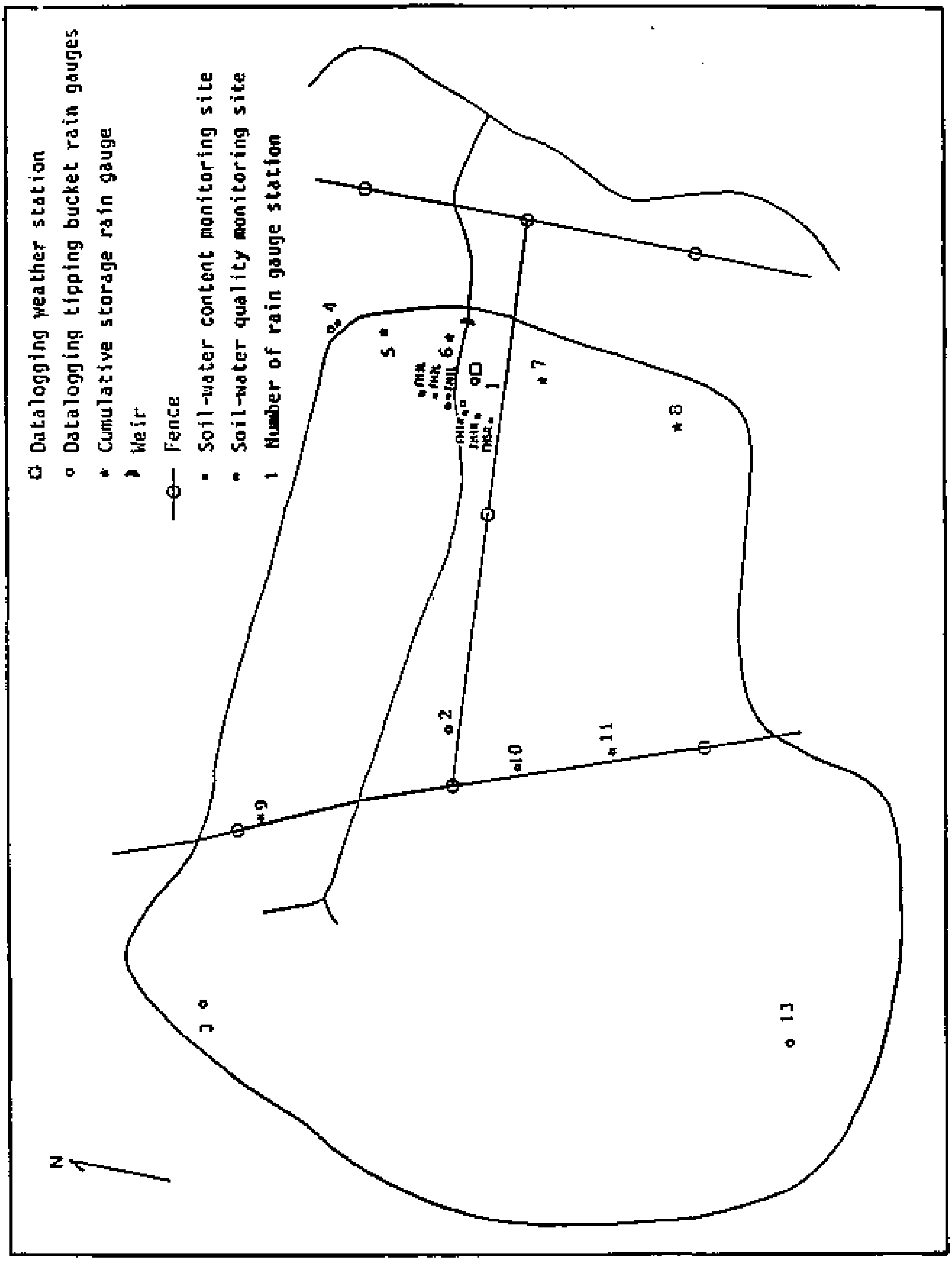


Figure 2.2 The instrumentation of Catchment F.

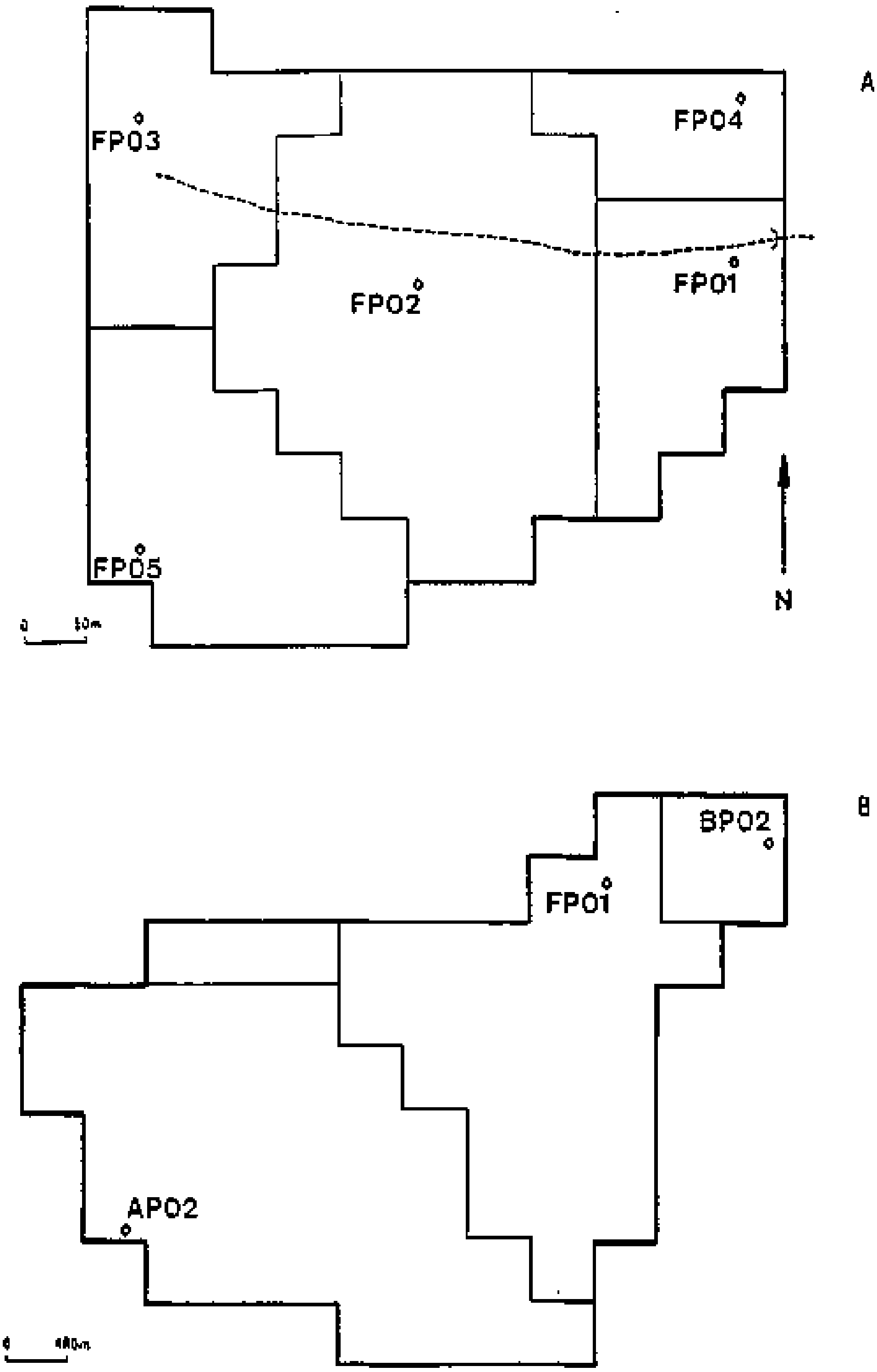


Figure 2.3 Raingauge distributions and Theisson polygons for :
A) 50m x 50m finite elements of Catchment F
B) 400m x 400m finite elements of Catchment B.

configurations for distributed hydrological modelling, is given in Figure 2.3(A).

Instrumentation for Catchment B is less detailed than that of Catchment F. The following aspects are monitored :

(i) continuous stage heights of streamflow
(ii) periodic sampling of dissolved and suspended solids in streamflow
(iii) spatial/temporal distributions of rainfall (Figure 2.3(B)).

The major change since Moolman's report is that power supplies, originally in the form of 12V motor car batteries, have been replaced by a new type of battery which is purpose designed for extended, low draw, current delivery. This has resulted in a longer turnaround time for batteries and hopefully will also lead to longer battery life. This does not however imply that charging devices such as solar cells would not be of benefit. Their introduction would complement the new batteries which are unsealed lead acid batteries and therefore still present transportation problems under rough conditions.

The collection of meteorological data was disrupted by a breakdown of the automatic weather station's data logger during October 1985. Attempts to rectify the logger caused further data losses and eventually necessitated its replacement.

The most reliable instrumentation has been the rainfall monitoring system, the autographic stage recorders and the water sampling devices. The neutron moisture probes have generally also been reliable. Some minor problems encountered with the surface probe did not seriously disrupt the pattern of data collection.

A problem associated with streamflow measurement and water quality sampling is the rapid rate of siltation in the stilling basins. This results in difficulties in ensuring that the intakes for the water quality samplers are not buried by silt. The problem is not easily solved since sediment tends to accumulate to heights in excess of the weir outlet. With the relatively small stage heights that are measured it is not possible to position the sampler intake above the lowest point of the v-notch. Similar problems were encountered at Catchment B.

The water quality samplers also presented problems in that samples were taken at preset, regular intervals. The use of coarse time intervals (hourly) prevented detailed sampling of stage variations during short duration, convective thunderstorms but enabled continued sampling during prolonged rainfall events. The problem has been partly overcome by the installation of a radio-activated warning system to indicate the onset of flow at Catchment B. The system enables the use of shorter (3 minute) time intervals during the initial stages of the streamflow hydrograph. The sampler can accommodate a maximum of 28 samples, allowing the researchers approximately 80 minutes to travel to the catchment, replace the sample bottles, select new sampling intervals, move the sampler intakes and commence with in situ measurements of hydrological processes. The positioning of the sediment sampler intakes within the stilling basins is questionable in that the volume of water within the basins is mixed with the incoming streamflow before samples are taken. This tends to suppress the possibility of measuring rapid fluctuations in sediment and solute concentrations.

It has been observed that the sensistivity of the crump weir at catchment F is not suitable for the observed flow ranges. The gradient of the weir's V-notch is 1:10. A sharper 'V' angle in the notch profile would enhance the sensitivity of the weir to the small flood peaks. The maximum flow rate ever recorded is 92ℓ/s with sustained flows of approximately 0,1 ℓ/s to 0,2 ℓ/s. These flow rates are not large enough, with respect to the weir design, to enable representative measurements to be made or to cause sufficient scour for the removal of sediment from the stilling basin. In addition the stilling basin is too large to enable instantaneous meaningful measurements of the electrical conductivity of the water on a temporal basis. The volume of water retained is slowly mixed with incoming streamflow, resulting in gradual dilution of variations in streamflow quality and a supression of the measured variations. If the pool were shallower a higher throughflow would result with less mixing effect and hence less smoothing of the electrical conductivity values. A modification of this nature might show up the smaller fluctuations in electrical conductivity and therefore salt loads that would otherwise be lost through excessive dilution in the weir pool. It is also recommended that a small H flume (USDA, 1968) be constructed on the downstream side of the existing weir in order to aid in the measurement of low flows (0-50ℓ/s).

Rainfall Characteristics

Characteristics such as the spatial and temporal distributions of rainfall in the Ecca catchments have been described in earlier reports by Roberts (1978), Görgens (1983) and Moolman (1985). The following discussion is therefore limited to a few details which reflect the magnitude of the drought during the project period. The drought adversely affected the project's progress and limited its data base. It is described by comparing the mean annual and monthly rainfall amounts for the project period (1982-1986) with those of the previous five years (1977-1981) as well as the 12 year period (1975-1985). The data described are from catchment B and its nested counterpart, catchment F (Figure 2.3). Data for catchment F were only included from July, 1982. The analyses include all data up to the end of June 1986 and are summarised in Figures 2.4 and 2.5.

The mean annual precipitation (MAP) for the 12 year period was 411,1mm. The MAP for the project period was only 304,2mm as compared to the MAP of 498,9mm for the previous five year period. The average for the years 1982 to 1984 were all below the 12 year mean. The driest year was 1984 with a total of 168.4mm and a mean monthly rainfall of 14,0mm. In comparison, the twelve year monthly mean is 34,3mm and the monthly mean for the period 1977-1981 was 46,6mm. The most significant effect of this drought was that it gave rise to dry antecedent soil moisture conditions which were usually followed by insufficient amounts of rainfall to cause runoff. For dry soils, Moolman (1985) estimated that 59,7mm and 92,2mm of water were needed to wet, to field capacity, the soil profiles at sites FM1L and FM1R respectfully (Figure 2.2). During the initial three years of the project (1982-1984) only 6 runoff producing events occurred. Of these, streamflow was only observed on two occasions in catchment F and on 3 occasions in

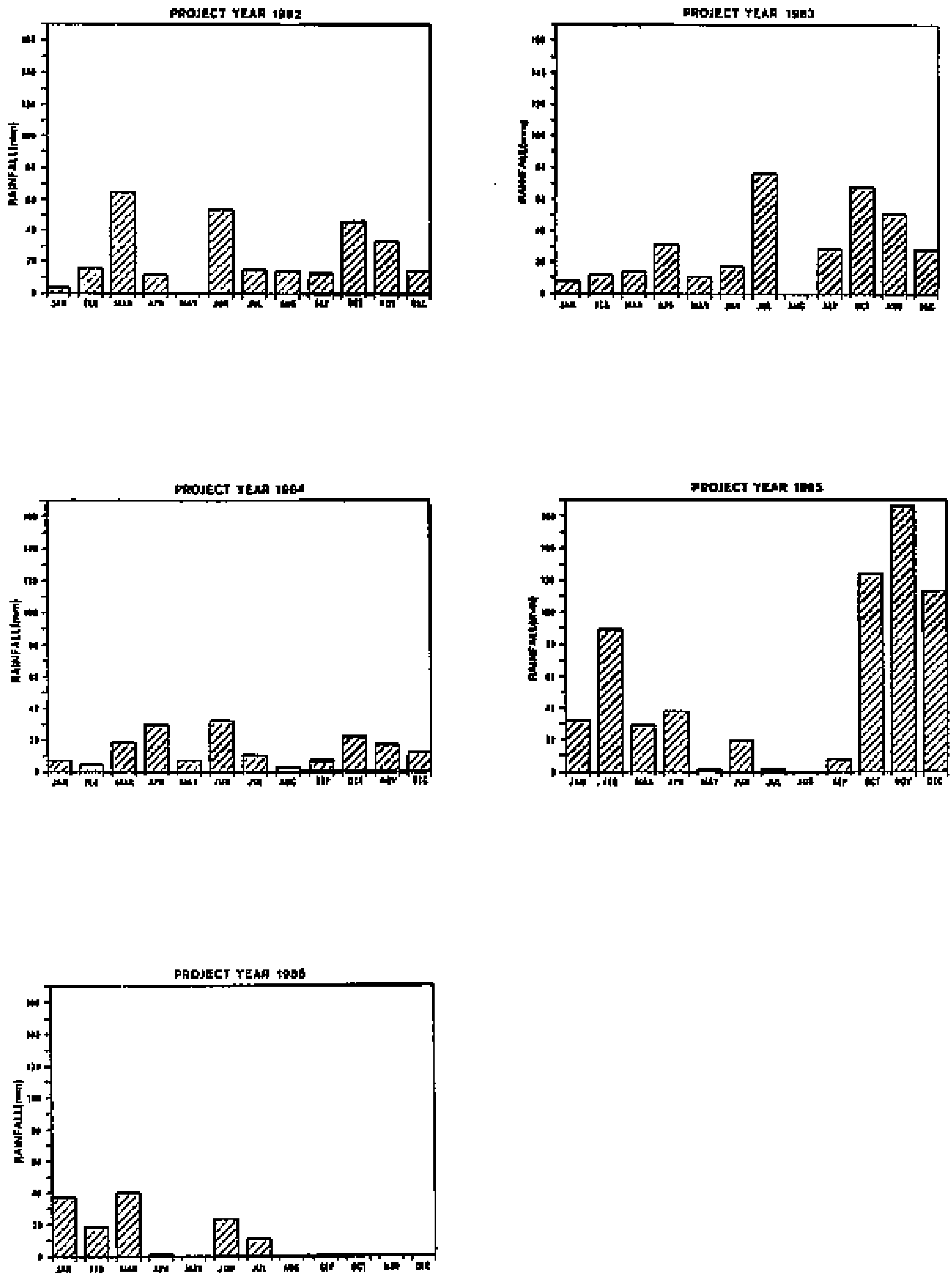


Figure 2.4 Monthly rainfall amounts for the project period January 1982 to July 1986.

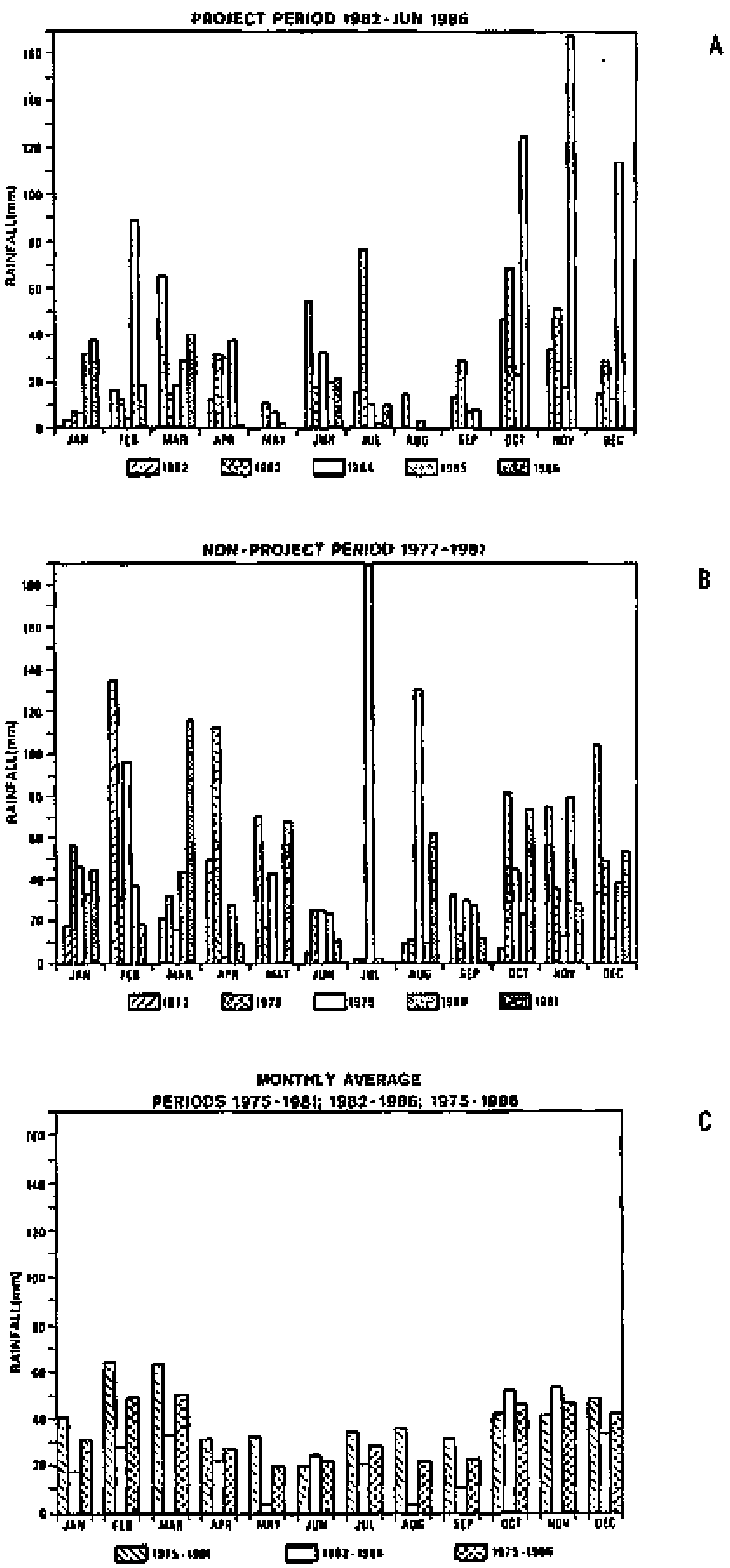


Figure 2.5 A comparison between monthly rainfall amounts for :
A) the 5 year contract period (1982 to 1986)
B) the previous 5 year period (1977-1986)
C) the period since establishment of the Ecca catchments (1975-1986).

catchment B. The events were described in Moolman (1985). The most significant rainfall events that were recorded during the project occurred in the months of October, November and December of 1985. A total of 404,0mm was measured. For catchment F the events gave rise to a period of continuous streamflow which lasted from the beginning of November, 1985 to the 10th January, 1986. The data are summarised in Appendix A. For catchment B the streamflow continued until March 1986 but due to excessive sedimentation of the weir the results are unreliable and are therefore not presented. The following sections describe the physical characteristics of the study area.

Geology of Catchments B and F

Catchments F and B form part of the Karoo Supergroup with the Ecca group being common to both B and F (Figure 2.6). The Dwyka Group outcrops in the southern portion of catchment B. It occupies approximately 45 percent of the area and is comprised largely of tillites. These tillites have surface crusts of silicrete which are less erodable than the steeply dipping (40°) shales and graywackes of the Ecca Group. The resultant relief consists of a relatively flat region in the southern section of catchment B which is predominantly tillite, while the remainder of the catchment is comprised of incised dip and scarp topography. The north facing slopes tend to follow the dip of the strata and vary from 40° to 20° while the scarp slopes are generally in excess of 40°. Figure 2.7 depicts the relief as analysed by Roberts (1978).

Catchment F is nested within that portion of Catchment B which is comprised of the Ecca Group. The rocks in this area consist of graywacke-sandstone and shales. The dip of the strata is 25° NNE. The dip and strike directions remain relatively constant with a gradual reduction in dip towards the north. The shales and sandstones contain secondary fractures. Outcrops of rock do occur but most of the catchment's surface consists of shallow soils of irregular depth, mixed with fragments of weathered shales or greywackes. Figure 2.8 presents the geology of Catchment F. Of hydrological significance is the manner in which this catchment is divided into two

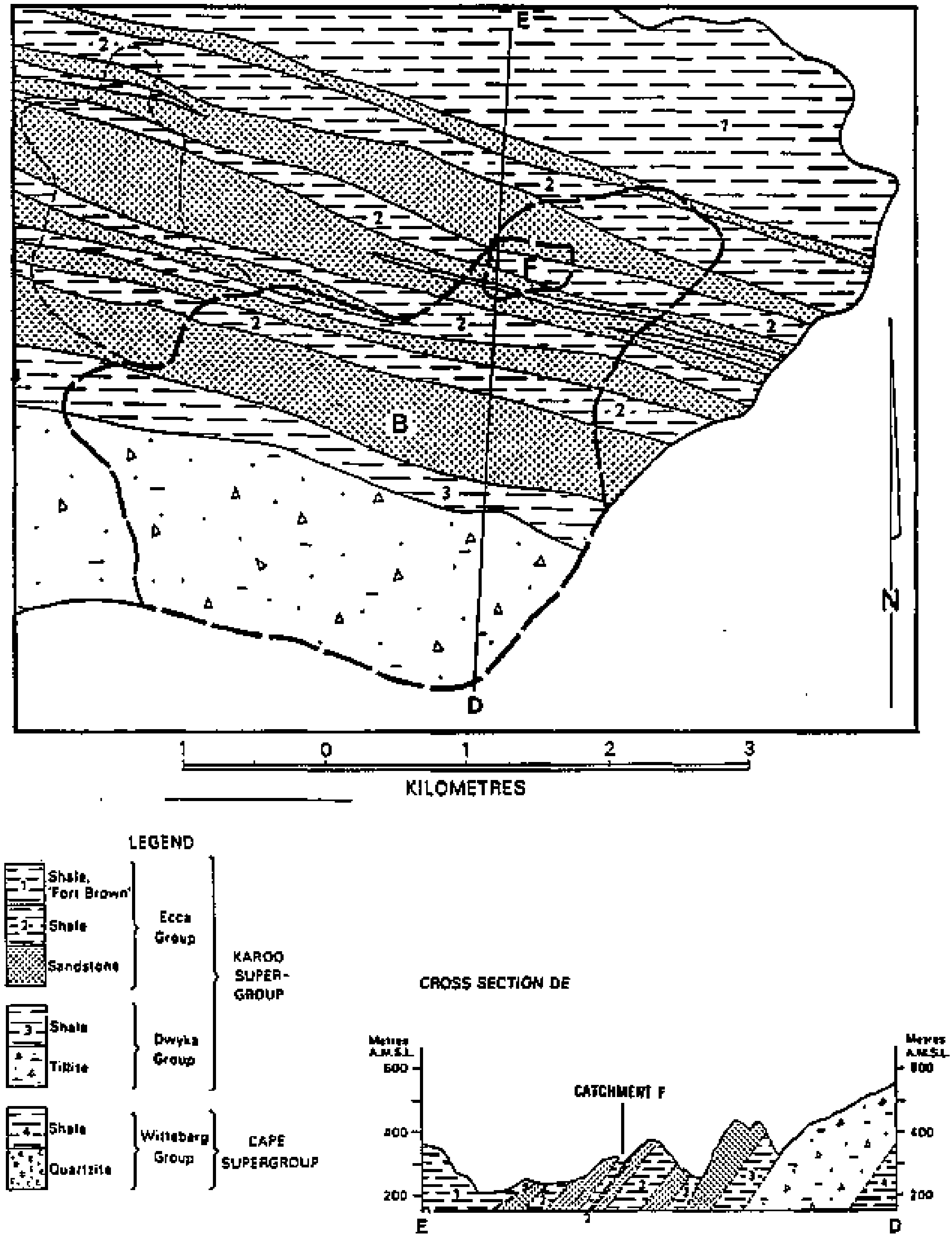


Figure 2.6 The geology of Catchments B and F.
(after Roberts, 1978)

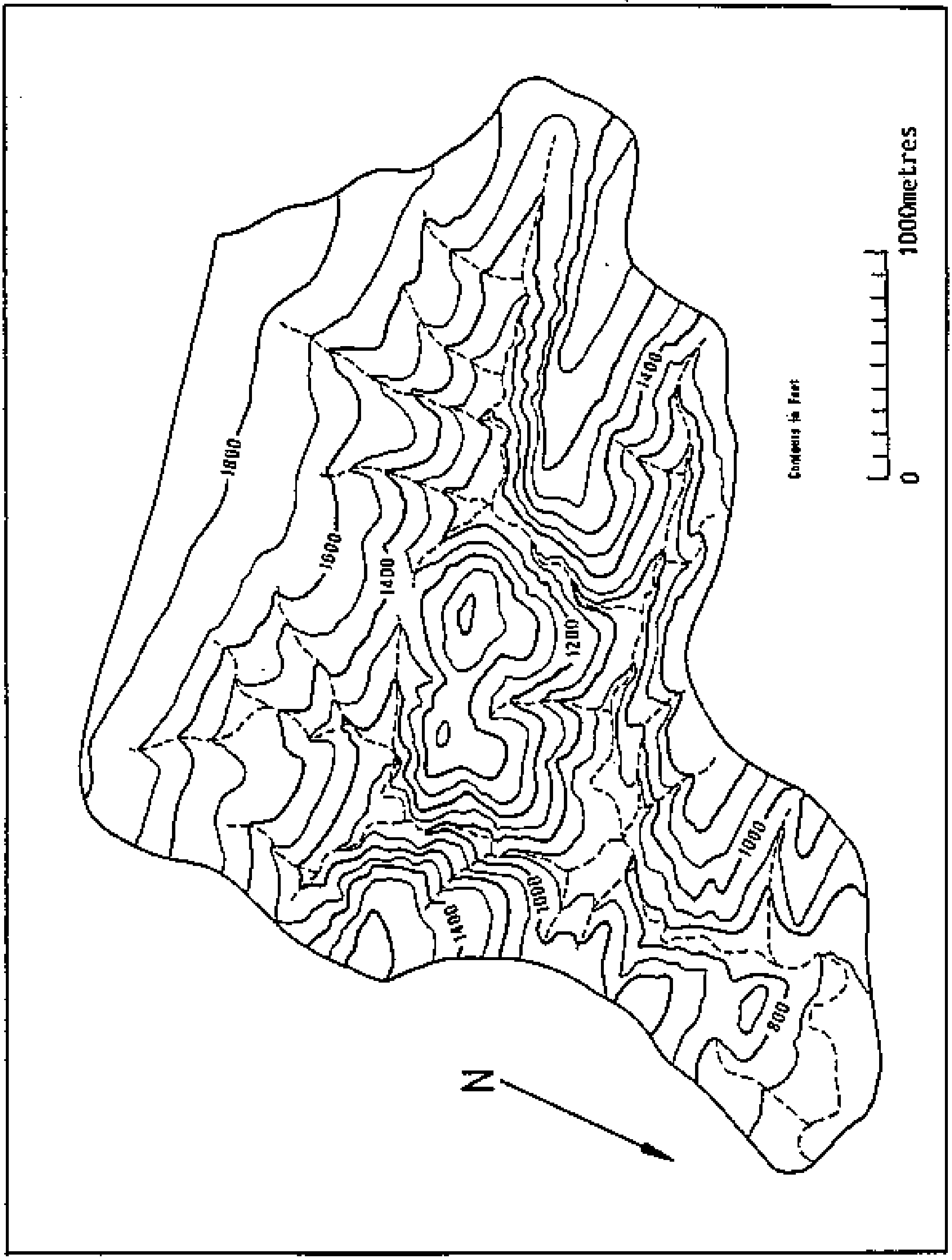


Figure 2.7 The relief of Catchment B.

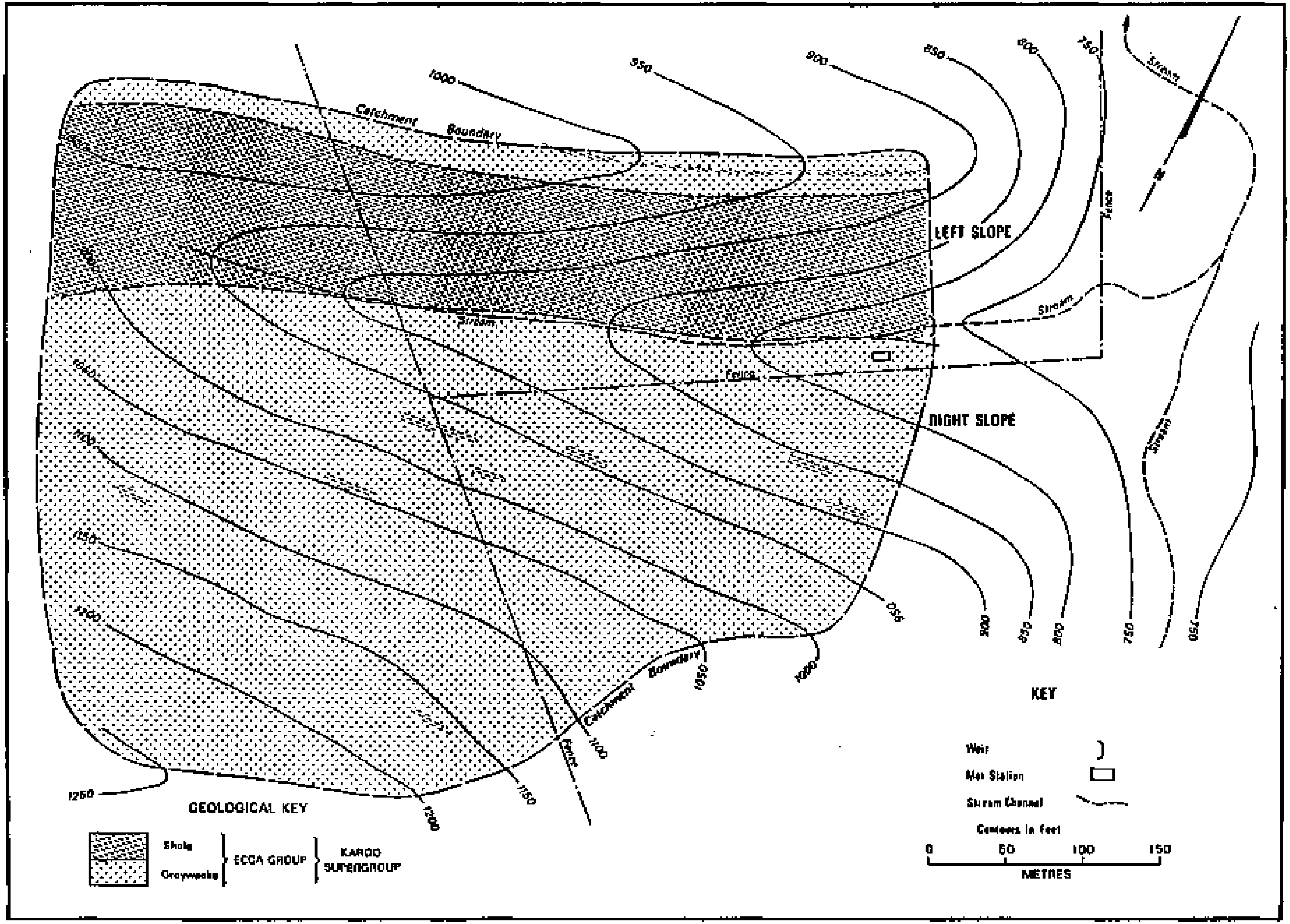


Figure 2.8 The geology of Catchment F.

distinct portions. These sectors are separated by a river which with minor deviations tends to follow the contact between a sixty metre thick unit of shales which overlies a layer of graywacke. In places the contact lies 4 metres above the river. The left bank or the northern section of the catchment is steeply sloping (55 percent) with end-on outcrops of the shale unit. The right bank or southern portion of the catchment has a slope of approximately 37 percent, and its surface geology is predominantly graywacke, with a few lenses of interbedded shales. The continuity of these shale lenses is difficult to map because the gradient of the surface slope is similar to that of the strata. Clusters of dense, thorny vegetation tend to limit access to some outcrops.

Graywackes adjacent to the stream appear to have undergone slight burial metamorphism. This is evident by the presence of the mineral phrenite, which tends to give the graywacke a white spotted appearance. Murray (1985) found that there is a gradual gradation from slightly metamorphased graywacke towards graywacke. This is relatable to distance and altitudinal increases in a southerly direction away from the stream bed. There appeared to be very little benefit in attempting to ascertain changes in the chemical composition of the graywacke in relation to metamorphism since the strata were all derived from the same parent material. Any changes detected in the surface geology would more likely be related to heterogeneous weathering. From a hydrological point of view, there are more advantages in monitoring the spatial changes in water quality from samples extracted within the catchment (discussed in chapter 6).

Murray (1985) was also of the opinion that the shales and graywackes consist mostly of quartz, feldspar and clay minerals. The major difference between the strata is that the fine grained graywackes contain about 20 percent matrix material while the shales are composed almost entirely of matrix material. These differences are possibly related to differences in the transportation abilities of the turbidity currents from which they were originally deposited. Moolman (1985) felt that the textural differences between the soils overlying the strata of left and right slopes are possibly related to their geological origin. For example the mean silt plus clay content of the surface layer on the right slope is 27 percent compared with that of 18 percent on the left slope. Rossiter (1983) showed that slope angles also influenced the textural composition of the soils in the Ecca catchments. Moolman (1985) was of the opinion that the dip of the strata could also influence subsurface drainage with that from the right slope being directed towards the river while that of the left slope is directed away from the channel. However, the presence of secondary fractures implies that the general subsurface drainage through the strata need not necessarily be in the same direction as the dip of the strata and could in fact be vertically downwards. No boreholes were present within Catchment F, but as agreed by Hughes (1986), no visible evidence of a permanent water table exists which might influence the surface hydrology of this semi-arid catchment. Water reoccurring in the stream is possibly derived from either the overland flow, interflow through the soils or through some form of near surface lateral flow via secondary fractures in the weathered surface strata (discussed in chapter 6).

Soils

In an attempt to contribute towards an understanding of the spatial and temporal variations of source areas contributing to the quantity and quality of the streamflow, Moolman (1985) conducted a survey of the spatial distribution of the chemical and hydraulic properties of the soils within Catchment F. The study has since been expanded to include Catchment B. Further, a distributed hydrological model has been applied (Chapters 5 and 6) to these catchments in an attempt to ascertain whether the spatial distribution of the simulated hydrological processes, as influenced by factors such as soil properties, could be verified from the solute concentrations of the streamflow, analyses of water extracts from selected soil sample sites and those of periodic soil moisture samples obtained during rainfall events. The sediment observed in the streamflow is also used as an index of the spatial and temporal distribution of increased overland flow rates, assuming that a physically-based distributed model can be used to illustrate the regions of erosion and deposition within the catchment, and provided that the solute concentrations also indicate that the associated flows could have been derived from the same areas. For this purpose the soil surveys reported in this document are aimed at the spatial distribution of those soil properties which can be used in conceptual-physical or physically-based distributed models to predict the generation of runoff, solutes and sediments.

In obtaining data for physically-based distributed models it is essential, in terms of time and cost, to maintain some form of practical balance between the amount of physical data measured for input to the models and the extent to which assumptions concerning the spatial homogeneity of measured data are tolerable. Generally the fundamental hypothesis used in physically-based distributed hydrological models, such as the ANSWERS model of Beasely, Monke and Huggins (1977) or the MODANSW model of Park and Mitchell (1983) is that at every point within a catchment a functional relationship exists between the rate of surface runoff, and the hydrological parameters of rainfall intensity, infiltration, topography and soil type. Furthermore, these surface runoff rates can be utilized in conjunction with appropriate component relationships as the basis for modelling other transport related phenomenon such as soil erosion and chemical movement within that watershed. Park and Mitchell (1983) emphasized that the hypothesis refers to a concept of point-based relationships which must be relaxed in order to extend the approach to a manageable practical scale in the form of elements representing areas of the catchment within which all hydrologically significant parameters are uniform.

Cousens and Burney (1977) stated that the size of the elements was related to the areal extent over which hydrologically significant parameters were uniform. Park and Mitchell (1983) were of the opinion that the size of the element was not critical provided that each element was small enough to adequately describe the response of a catchment to any arbitrary change in a single element, as accounted for by an associated change in its parameter values. No element can be regarded as being perfectly homogeneous in any particular direction. Therefore attempts to accommodate the spectre of spatial heterogeneity must eventually lead to lumping assumptions within each element (Simmers, 1985). The use of excessively large element sizes would require non-representative lumping assumptions whereas the use of unnecessary small element sizes would require large amounts of data collection, computer storage and also computational processing time. To define an optimal size for an element requires the application of continuous system simulations using distributed hydrological models (Schultz, 1985), integrated with a combination of mapping and statistical techniques (Simmers, 1985). The implementation of such an approach would require a substantial amount of data and time. An alternative approach is to establish element sizes which lie within the range of typical sizes which have been used satisfactorily by other scientists and with which reasonable assumptions can be made from field observations concerning the homogeneity of hydrological responses for the particular catchment. Cousens (1980) used the latter approach by selecting relatively small element sizes which could be nested within larger element sizes, should the need arise, to simplify the data. For example, element sizes of 100m x 100m were initially chosen for an 8km² catchment and elements of 1km x 1km were selected for a 380km² catchment in the Orange Free State. Thereafter Schultz (1985) showed that the 100m x 100m element sizes could be relaxed to 500m x 500m without having a significant influence on the ability of a distributed model to simulate streamflow hydrographs.

For practical purposes in defining spatially distributed inputs for distributed hydrological model applications in this study, rectangular grid systems were used (finite elements) to represent regions of assumed homogeneity with respect to hydrological responses. The length of each element side selected for Catchment B was 400m while the elements of 50m x 50m, demarcated for Catchment F by Moolman (1985), were maintained.

In describing the soils for catchments B and F in this report, emphasis will be placed on the hydrologically relevant soils properties contained within each element. Schulze (1984) defined hydrological properties for each of the soil profiles listed in the classification system of Mc Vicar et al., (1977). Moolman (1985) studied the soil properties of Catchment F and found that soils in the lower regions of Catchment F, adjacent to the channel belong to the Shorrocks (right slope) and to the Dundee series (left slope). Further away from the channel the soils are predominantly of the Mispah series. However, he also found that the textural properties of the soils were highly variable and concluded that it would be too risky to use the properties of "so-called representative soil profiles for modelling purposes" (Moolman, 1985, page D14). Therefore, in order to produce a set of physically-based soils parameters which could be used as inputs to distributed hydrological models in the Ecca catchments, it was necessary to devise a method whereby:-

i) The properties of the soils sampled in Catchment F could be extrapolated to Catchment B.
ii) The properties of soils not mapped by Moolman (1985) could be measured in Catchment B and extrapolated back to Catchment F.
iii) The data could be classified into sets of soils with similar properties in order to reduce the computational storage constraints encountered in distributed hydrological modelling.
iv) The categories could be extrapolated to all elements of the catchments and still reflect the variable nature of the soil samples.

The main steps of the method used to achieve the above objective is outlined below.

a) Moolman's (1985) soil sampling network of 182 sites and associated data were used as the prime source of soils information for Catchment F (Figure 2.6). The data were augmented by the results of the plot studies also conducted by Moolman (1985).

b) A soil survey of Catchment B was conducted and samples were derived from the points presented in Figure 2.7. It was assumed that the spatial variability of the hydrological properties of the soils in Catchment B were similar to those of it's nested counterpart, F, and consequently fewer samples (40) were used.

c) The samples from Catchment B (Figure 2.7) were analysed in a laboratory in order to estimate the particle size distributions, the approximate wilting points (1500 Kpa), the field capacities (10 Kpa), and the major cations and anions present at selected depths.

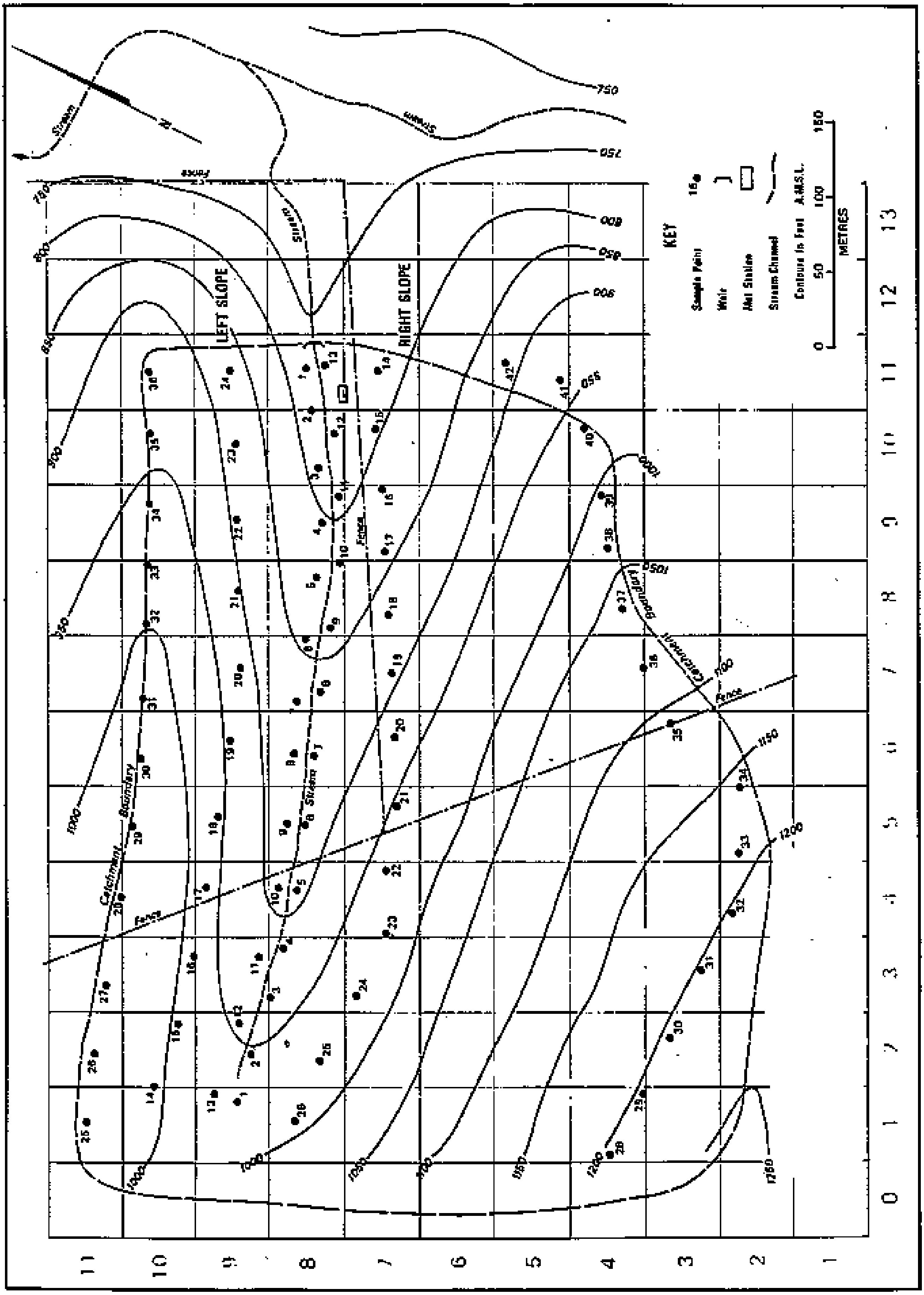


Figure 2.9 The sampling network of Catchment F for studies of soil textures, salt contents and infiltration rates (after Moolman, 1985).

d) The analyses of particle size distribution for Catchment F (Moolman 1985), were plotted onto trilinear diagrams of silt, clay and sand proportions. Separate plots were produced for each of the following assumed hydrological regimes :-

Left bank (Scarp slopes)
- valley floor
- mid slopes
- top slopes

Right bank (dip slopes)
- valley floor
- mid slopes
- top slopes.

The spatial variations in the hydrological properties of these soils have been discussed in detail by Moolman (1985) who emphasised that there is no statistically significant spatial trend for the samples collected within each of the above regimes for Catchment F (Figure 2.11).

e) Step d was repeated for Catchment B using the particle size distributions from the sample sites presented in Figure 2.10. The results were added to the trilinear plots for Catchment F.

f) Deficiencies of certain types of soils information existed for catchments B and F and it was therefore necessary to exchange parameters between those soil samples whose textures and depths were similar, and which were located in similar hydrological regimes. For example, infiltration parameters were transferred from Catchment F to Catchment B, while soil moisture retention parameters were transferred from B to F. The trilinear plots were used to ascertain which samples had similar textural configurations. Only the soil samples from the surface horizons were considered for the exchange of infiltration parameters. Data from the plot studies (Moolman, 1985) were also used in the above procedure.

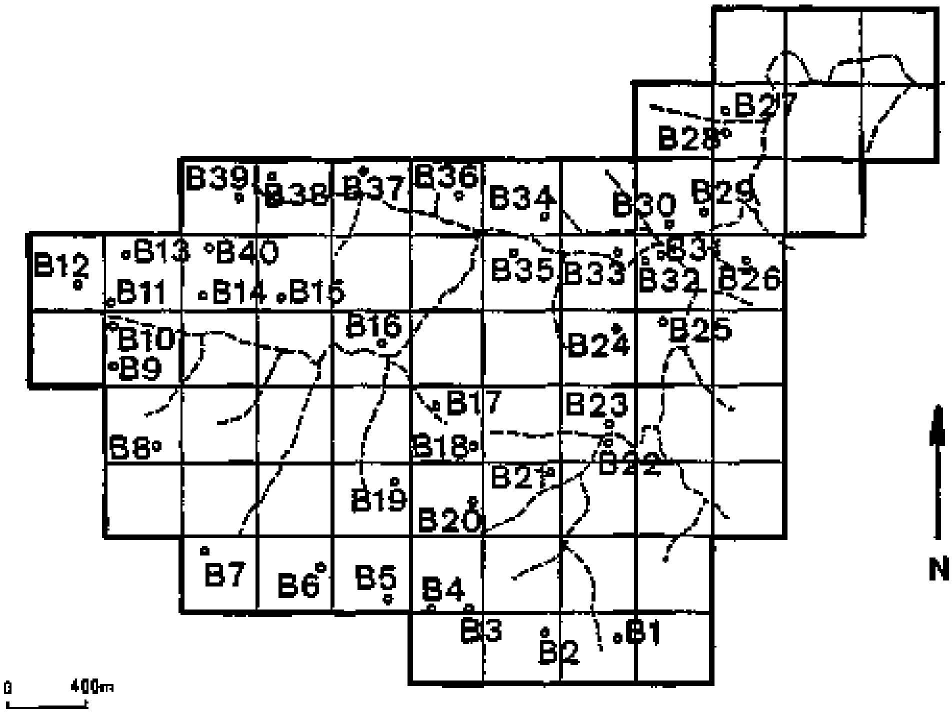


Figure 2.10 The sampling network of Catchment B for studies of soil textures, salt contents and soil water retention properties.

g) The information was then condensed for distributed modelling purposes by classifying the soils according to their hydrological regime, textural, hydraulic and water retention properties. The classification presented below is not based on existing systems proposed by Mc Vicar et al. (1977) or Schulze (1985), its purpose is simply to minimize the size of the multi-dimensional array storages required in distributed models such as the ANSWERS model of Beasely, Monke and Huggins (1977). Further, the categories presented are catchment specific and are essentially summaries of the observed/measured soils information.

This classification was achieved by first ranking the data within each hydrological regime according to its sorptivity and then subdividing the data into classes of similar magnitude. Sorptivity is a coefficient used in the infiltration equation of Phillip (1957):-

$$i = St^{1/2} + kt \qquad \text{eq 2.1}$$

where i = cumulative infiltration
t = time
S = sorptivity
K = saturated hydraulic conductivity.

Moolman (1985) envisaged that the equation could be used in a numerical model to predict runoff. Although the equation is not used for modelling in this report, its coefficient served as a useful index to group the data into sets of similar initial infiltration rates. Sorptivity values were calculated by Moolman (1985) from in situ measurements of initial infiltration rates which he expressed as ratios of the depth of water infiltrated after two minutes, to the square root of two minutes. Attention is drawn to the fact that the above in situ measurements did not account for the effects of surface slope on infiltration rates.

The classes of sorptivity were then further subdivided into subsets of soil samples with similar depth profiles, textural compositions, and water retention properties. Soil properties which were not available from the laboratory or in situ field measurements were augmented from the results of the plot studies conducted by Moolman (1985) on the left and right banks of Catchment F. For example values for steady state infiltration rates were assumed to be equal to the saturated hydraulic conductivities measured in the plots. The assumption may not necessarily be valid for all conditions of soil moisture storages and rainfall intensities but is possibly suitable for the catchments under consideration. For example, Moolman (1985) noticed that the rainfall events measured between July 1983 and December 1984 only wetted the surface soils (15cm) with very little water percolating through to deeper layers. From the plot studies he also noted that an excess of 300mm of water would be required to achieve field capacity at 0.8m below the surface and was of the opinion that it was unlikely that complete saturation would ever be achieved for soils in the Ecca catchments. For event-based simulations the steady state infiltration rates can be adjusted for different depths of soil saturation using the saturated hydraulic conductivities, reflected for different depths in Table 2.2, as guideline indices. The saturation figures presented in the table can serve as substitutes for porosity or soil moisture storage parameters in physically-based models. The soils information as classified in the above procedure is presented in Table 2.3.

h) The first step in presenting the spatial distribution of the soil categories involved was to assign the category of each soil sample to the finite elements from which they were collected. If more than one point was sampled within an element, a point was selected at random. The second step involved extrapolating the soil categories to all the finite elements of the catchments. Moolman had emphasised the lack of a textural spatial structure within the soils and therefore an attempt was made to distribute the soil categories in a spatially heterogeneous manner, while still preserving the statistical properties

TABLE 2.2 In situ soil-water contents and hydraulic conductivities of two plots in catchment F (after Moolman, 1985).

Soil depth (mm)	Infiltration (mm)	Water content Saturation	Water content Field capacity	Sat. hydraulic conductivity ($mm.h^{-1}$)
		Left slope		
0-150	309*	0,232	0,162	10,49
-400	274**	0,179	0,127	0,80
-600	229	0,219	0,167	39,34
-800	186	0,178	0,133	13,26
0-800				
		Right slope		
0-150	360*	0,355	0,290	0,268
-400	307**	0,229	0,204	0,169
-600	249	0,273	0,250	0,469
-800	195	0,234	0,218	0,116
0-800				

* = Observed

** = Calculated for the 150 - 800 mm depth layers

Table 2.3 Soil categories for Catchments B and F

Soil type	Slope position	Field capacity	Wilting point	Infiltration maximum mm/h	Infiltration steady mm/h	exponent$
	Right Bank					
1R£	B*	.384	.260	990	.40	.77
2R	M**	.340	.235	1650	.40	.75
3R	B	.318	.200	2100	.40	.73
4R	TBM	.371	.281	1300	.40	.56
5R	T***	.299	.134	2100	.40	.58
6R	BM	.346	.218	1350	.40	.68
7R	B	.323	.186	2110	.40	.65
8R	TBM	.269	.156	2610	.40	.55
9R	TM	.343	.189	1980	.40	.48
10R	TB	.359	.212	1650	.40	.60
	Left Bank					
11L££	T	.340	.151	1300	40.0	.55
12L	T	.298	.192	1600	40.0	.50
13L	B	.145	.078	1800	10.0	.47
14L	M	.115	.071	3100	2.0	.43
15L	B	.113	.068	3050	2.0	.40
16L	MB	.207	.095	1800	40.0	.60
17L	MB	.190	.086	2150	40.0	.57
18L	BT	.128	.067	2050	13.3	.45
19L	M	.220	.107	2550	17.0	.55

£ R = Right

££ L = Left

* B = Bottom Slope

** M = Mid slope

*** T = Top slope

$ = Exponent used in the ANSWERS model to describe the relationship between infiltration and soil water content. The values were estimated from soil textures using procedures in Park and Mitchell, 1983. The relevant equation (4.1) will be described in Chapter 4.

of each regime. This was achieved by defining the hydrological regime in which each finite element occurred (i.e. dip or scarp slope and subdivisions of upper, middle and channel bank slopes), and then identifying, for each regime, the three nearest sample points to centre of each of the unsampled finite elements. The three points were then identified on the trilinear plots (Figure 2.11) and a point was selected at random from the area enclosed by the three points. The finite element was then assigned the soil category to which the latter point belonged. The spatial distribution of the soil categories used in Catchments B and F are presented in Figures 2.12(A) and 2.12(B) respectively.

The distribution of the major cations and anions in the soils will be discussed in chapter 6. The following section describes the vegetation of the catchments.

Vegetation

The vegetation found in the Ecca catchment has been categorized as valley bushveld (Karoo and Karroid Bushveld types iv), Acocks, 1975. It consists mostly of sub-succulent woodland which thins to low succulent scrub on the flatter areas (Roberts, 1978), and is characterised by dense thickets of succulent and thorny bushes, interspersed with low growing shrubs and grass. The ravines in Catchments B and F tend to be more densely vegetated than the surrounding slopes. The South African names of the main species encountered are speckboom (Portulacaria), soetnoors (Euphorbia bothae), noorsdoring

(Euphorbia pentagonia), boerboom (Schotia afra), wild olive (Olea africana) and the cabbage tree (Cussonia spicata). A number of endemic species in the form of Euphorbias and crane flowers such as the Strelitzia reginae are found throughout the area. According to Beater and Mayr, (1985) the effects of overgrazing in the region are evident by the invasion of Acacia Karoo and the many Karroid shrubs.

Of hydrological importance is the manner in which plants have adapted to the

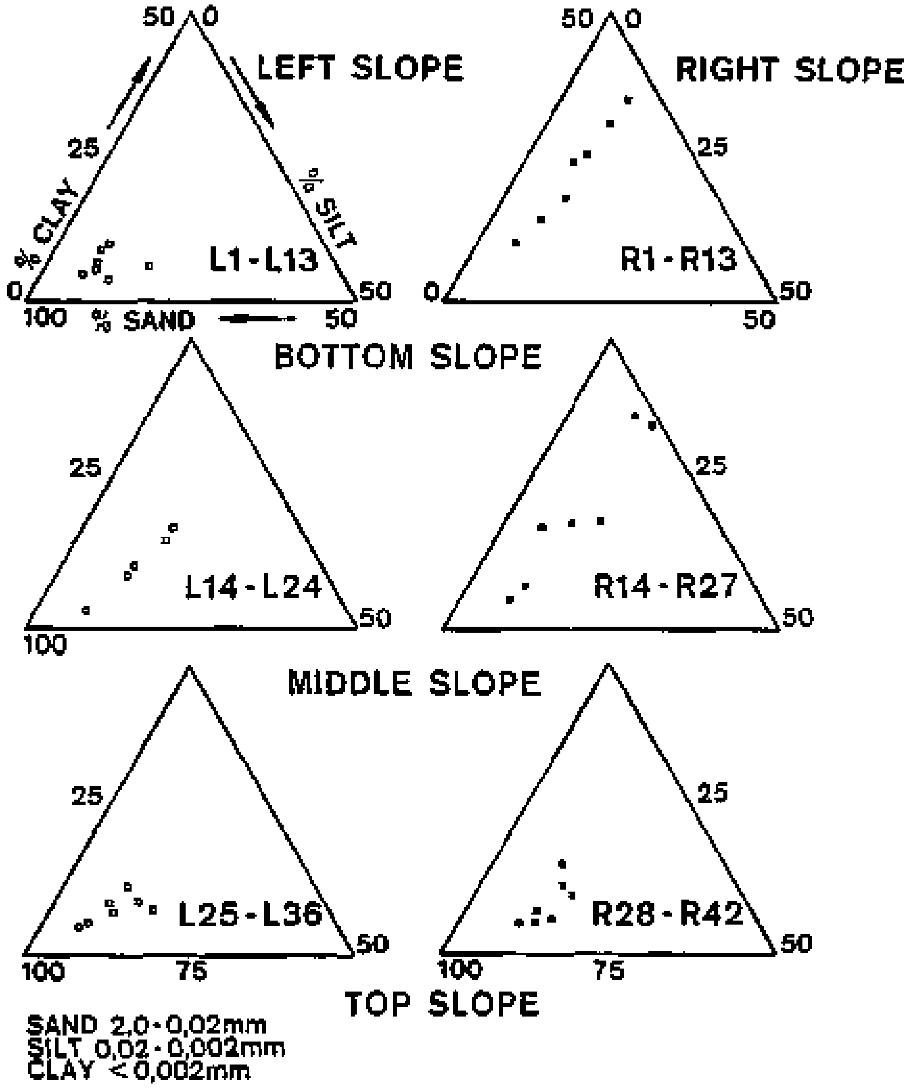


Figure 2.11 Trilinear diagrams illustrating the textural variations of soils in the top, middle and foot slopes of the left and right banks of Catchment F.

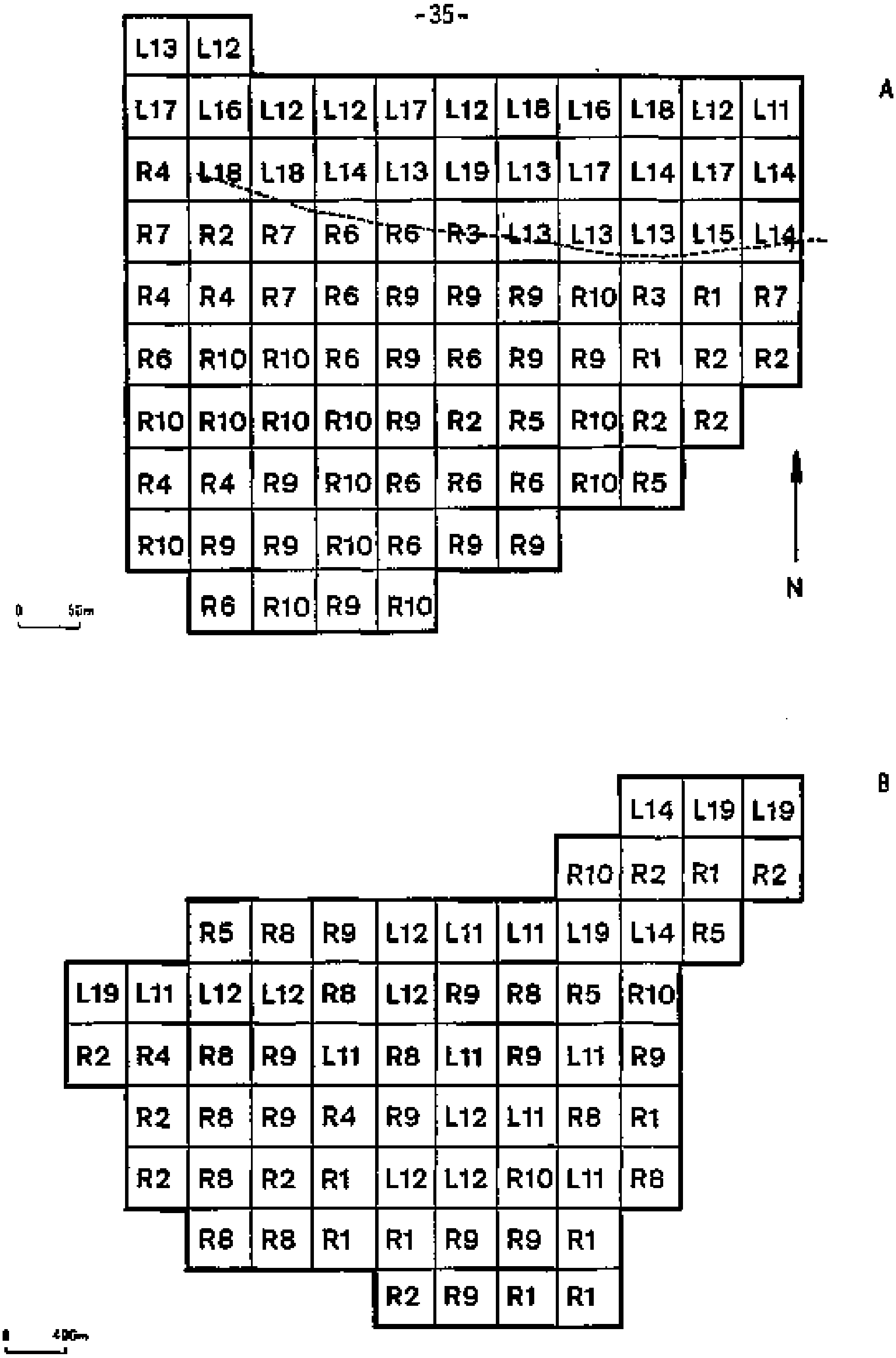


Figure 2.12 The spatial distribution of soil categories for :
A) 50m x 50m finite elements in Catchment F.
B) 400m x 400m finite elements in Catchment B.

semi-arid conditions and the shallow mispah soils. The main adaptations include hardy small leaves, thorns, succulent morphology and stunted growths. These adaptations possibly influence the amounts of interception, transpiration and soil moisture. The irregular dispersion of species and thickets would make it difficult to simulate the spatial distribution of soil moisture variations. Further, Lubke (1986) claims that, unlike agricultural crops, no research has been done in South Africa to ascertain the moisture requirements and transpirative rates of the natural flora occurring in the semi-arid environments. Physically based simulations of evapotranspiration would be complicated by a lack of information pertaining to the amounts of moisture consumed during periods of rejuvenated growth immediately after rainfall events. Also added to this are the uncertainties relating to the amounts of moisture transpired on any particular day which were derived from the soil as opposed to the amounts lost from moisture stored in the plant tissues.

Some research has been conducted to establish vegetative growth relationships between plant species and environmental factors. For example, Palmer (1981) conducted phenological studies of 51 plant species in the Andries Vosloo Kudu Reserve which is in close proximity to the Ecca catchments and also lies in the valley bushveld area demarcated by Acocks (1975). The study related seasonal plant growth and reproductive rates to a range of factors such as rainfall and soil type. It showed significant correlations between the phenology of some plant species and weekly rainfall amounts. From a hydrological point of view much could be gained if parameters for potential interception and the daily moisture requirements could be determined from simplified phenological relationships which could be incorporated into models. Such parameters would be more reliable than seasonal parameters (e.g. monthly crop factors) because of the irregular and uncertain occurrences of rainfall events in semi-arid environments. It is therefore recommended that additional research be conducted before any physically-based model can be used to conduct continuous moisture budgeting in the Ecca catchments without requiring any form of calibration.

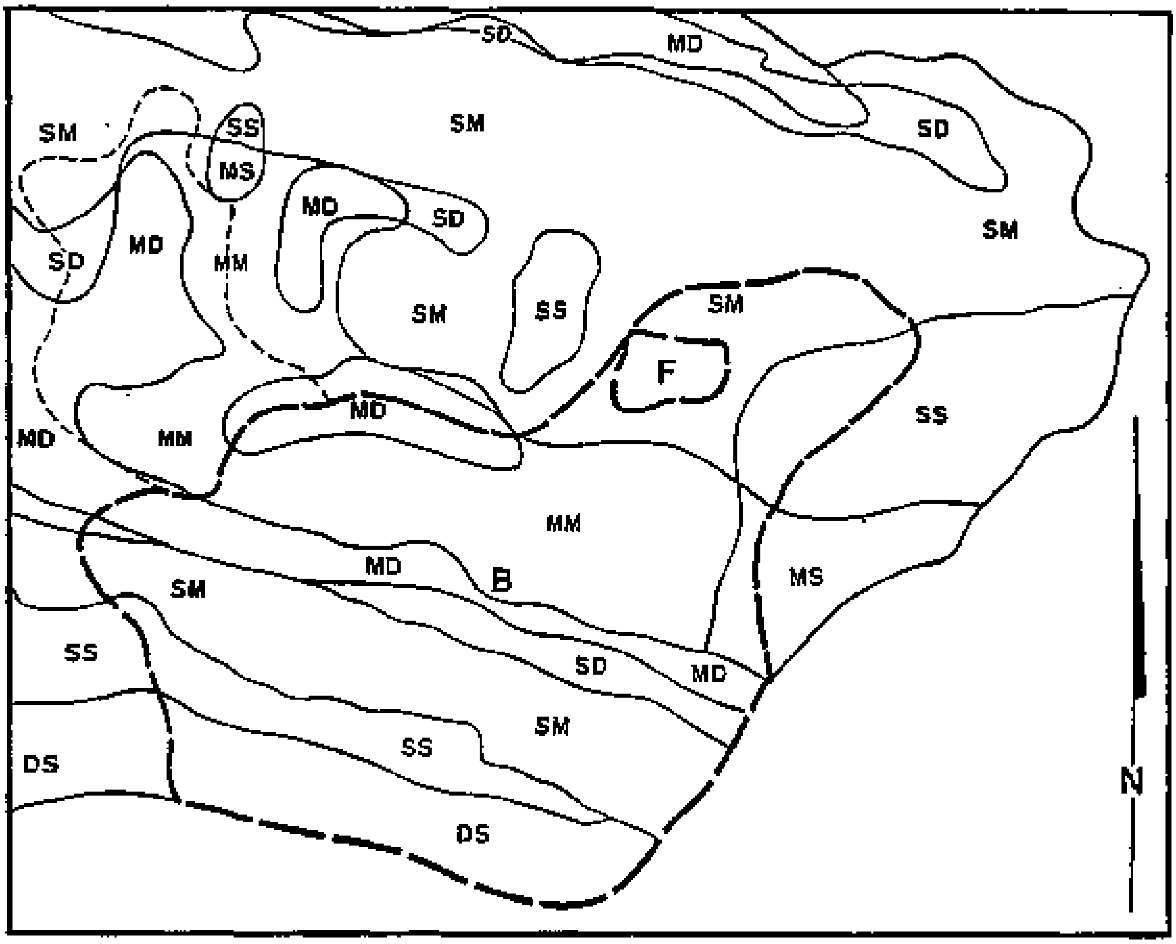
During the project daily moisture budgeting was conducted by means of the ACRU model, but contrary to the recommendation of Schulze (1984) not to calibrate the model but rather to modify its structure to suit the environment, the vegetative components of the model were calibrated due to the lack of information concerning the transpiration rates of the heterogenous assortment of natural vegetation in the area.

For physically-based, single event distributed modelling the transpirational requirements of the vegetation are perhaps less important than the influence of the vegetation on factors such as surface roughness and interception, provided that the antecedent soil moisture conditions are known. Roberts (1978) mapped the vegetation of the Ecca catchment in order to provide an indication of the relative spatial changes in the density of the canopy cover and ground cover (Figure 2.13). Additional mapping was necessary in order to provide detailed information for the 50m x 50m finite elements of Catchment F. Figures 2.14(A) and 2.14(B) illustrate the vegetative distributions for Catchments F and B as simplified on a finite element basis.

For each element, parameters for interception were defined. These parameters as discussed below, were based on the input requirements for the MODANSW model of Park and Mitchell (1983).

Interception is the process whereby precipitation is retained on plant surfaces (Ward, 1975) as temporary storage on the canopy cover and then redistributed by either evaporation into the atmosphere, absorption into plant material or by throughfall to lower canopy covers or to the soil surface (Schulze 1983). Of importance to hydrological estimates is the potential interception volume (PIT) of moisture that could be removed if the area is completely covered by a particular type of vegetation and the percentage of surface area (PER) that is actually covered by the vegetation (Park and Mitchell, 1983). These values can vary on a seasonal basis.

No studies have been done in the Ecca catchments to measure interception amounts. Schulze (1981) compiled a map of average interception values for South Africa using data from De Villiers (1975). The figure indicated that 1,7mm/rainday could be intercepted by natural vegetation in the Grahamstown district. Görgens (1983) used a value of 3.0mm/rainday as an interception



LEGEND

Sparse .... S
Medium .... M
Dense .... D

GROUND	CANOPY	CODE
S	S	SS
S	M	SM
S	D	SD
M	S	MS
M	M	MM
M	D	MD
D	S	DS
D	M	DM
D	D	DD

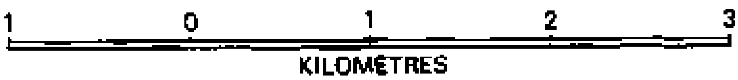


Figure 2.13 Vegetation densities of Catchment B (after Roberts, 1978).

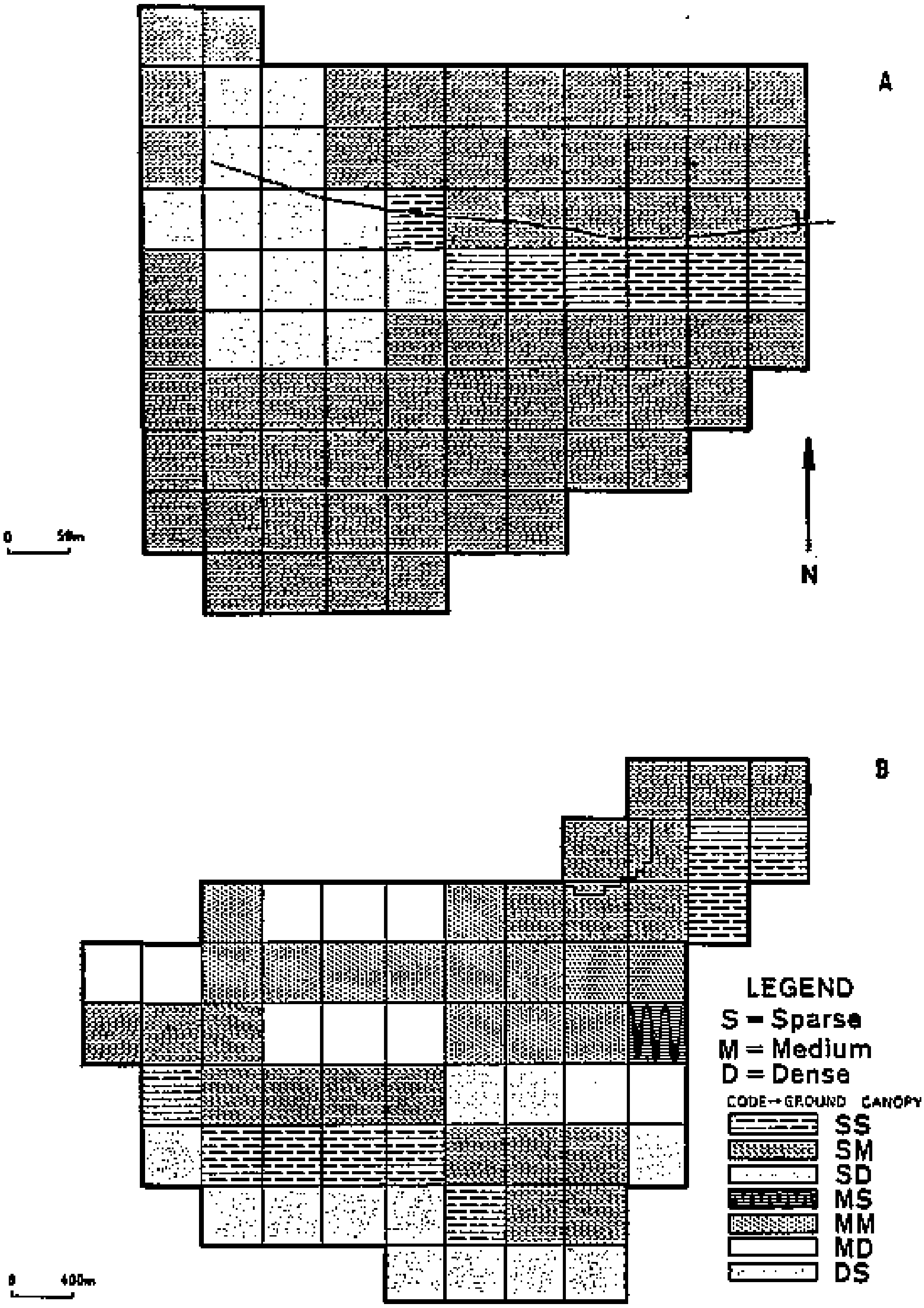


Figure 2.14 Categories of vegetation density for :
A) 50m x 50m finite elements in Catchment F.
B) 400m x 400m finite elements in Catchment B.

parameter for a model by Pitman (1973). Görgens (1986) claims that the latter value may be slightly inflated. Schulze's map presented a value of 0.5mm/day for the eastern portion of the semi-arid Karoo region. The above range of values was used as a guideline in weighting the interception amounts for the various densities of vegetation encountered in the semi-arid Ecca catchments. The formula applied to weight the values was

$$I = W(.33G + .67C) \qquad \text{eq 2.2}$$

where I = Interception (mm/rainday)

G = The density index of the ground cover

C = The density index of the canopy cover

W = Weighting coefficient to alter interception amounts on a seasonal basis or during model calibration runs.

The relative vegetative density was mapped by Roberts (1978) who subdivided the canopy and ground covers of the vegetation into categories of sparse (S), medium (M) and dense (D). Values of 0,5, 1,7 and 3,0 are assumed in this report for the S, M and D categories and used in equation 2.2 to provide spatial indices of interception in accordance with the categories of Roberts (1978). The results are presented in Table 2.4 for using a value of W=1,0 in equation 2.2.

TABLE 2.4 Interception amounts for the combined ground and canopy covers.

Ground cover	0.33G	Canopy cover	0.67C	map code ground:surfacecover	interception mm/rainday
S	0,17	S	0,33	SS	0,5
S	0,17	M	1,13	SM	1,3
S	0,17	D	2,00	SD	2,2
M	0,57	S	0,33	MS	0,9
M	0,57	M	1,13	MM	1,7
M	0,57	D	2,00	MD	2,6
D	1,0	S	0,33	DS	1,3
D	1,0	M	1,13	DM	2,1
D	1,0	D	2,00	DD	3,0
					$\bar{X}$=1,7

The above table provided a quantitative means whereby the spatial distribution of interception could be accounted for in hydrological simulations of the runoff in the Ecca catchments while the parameter W provided a means of adjusting the data to account for seasonal differences in interception or for parameter adjustments during model calibrations. Since the indices reflect the average amount of interception per unit area, rather than per plant, the values of I and W were used to replace the parameters PIT and PER which are used in the MODANSW model.

In implementing the above parameters in physically-based models it would be incorrect to assume that the values are true representations of the exact difference between the gross amount of rainfall that falls on a catchment and the nett amount that actually reaches the surface. However, by virtue of the need to make decisions, trans-scientific judgements such as those implemented above, are unavoidable in the absence of concrete measurements and must of necessity be made in order to implement physically-based models in ungauged situations. Parameter values can often be calibrated in research catchments but are seldom transferrable to other catchments and cannot be used to predict the effects of land-use changes within that catchment. In contrast, physically-based parameters, whether deduced from regional average figures, tables of typical values for assumed representative conditions, in situ field measurements, laboratory analyses or from vague criteria such as user experience for a particular model, have an advantage over calibrated parameters in that they can be implemented immediately in physically-based models to provide runoff estimates. The question of whether or not such runoff estimates are in fact correct, will be discussed in Chapter 5. The following section outlines the approach used to derive those physically-based parameters which are required for the simulation of surface drainage rates.

Surface drainage

The general topography and drainage of the Ecca catchment has been described in detail by Roberts (1978) and Görgens (1983) and will therefore not be repeated in this report. Rather, the emphasis is on providing quantitative information required for those distributed hydrological models which utilise

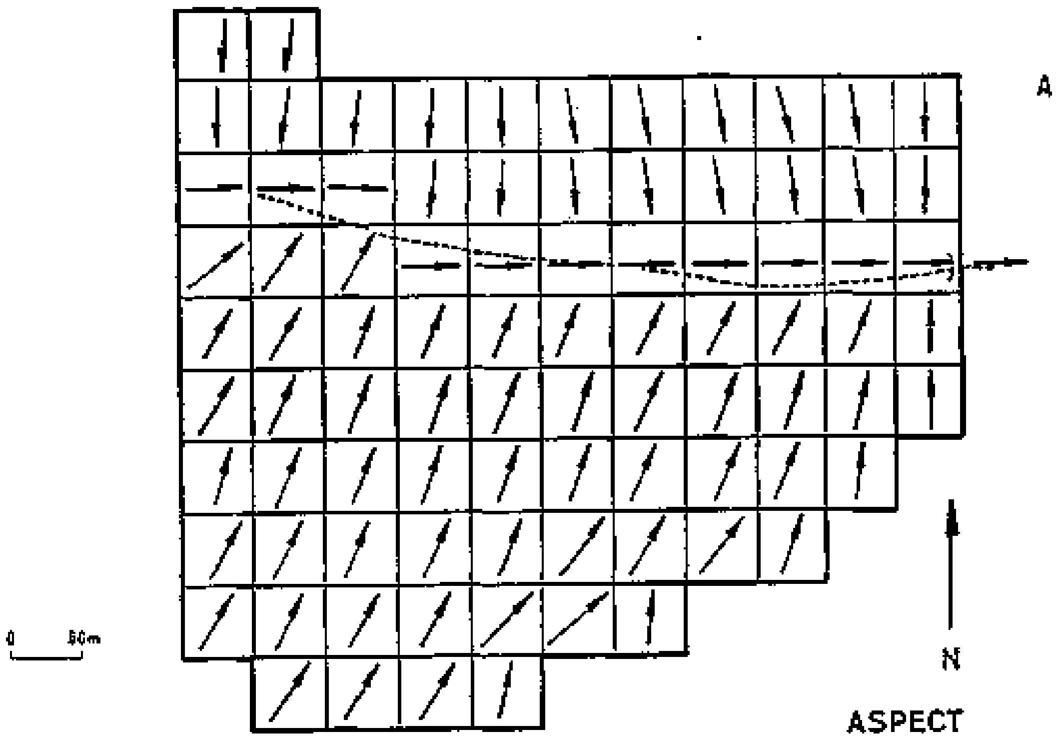
Manning's equation to estimate surface as well as channel flows. The equation has the form

$$V = \frac{C\, R^{.667} S^{0,5}}{n} \qquad \text{eq 2.3}$$

where v = the mean flow velocity
C = unit dependant constant which is 1,0 for SI units and 1,49 for English Units.
R = hydraulic radius
S = slope of the energy grade line
n = Manning's roughness coefficient.

When combined with the continuity equation to form a kinematic equation, it provides a means whereby unsteady flow can be described from a collection of steady flows at successive small time intervals (Constantinides, 1983). The approach requires the assumption that the friction slope is equal to the bed slope. In order to implement the approach on a spatially distributed basis using finite elements, it is necessary to determine the slope aspect, gradient and surface roughness of each element, as well as the width, drainage direction, slope and roughness of the channel segments within each element. Methodologies for determining these values are given in Park and Mitchell (1983). Figures 2.15(A) and 2.15(B) illustrate the slope aspects and gradients of catchment B and F respectively.

For streamflow estimates the widths of the stream channels as measured at representative positions and categorised into 7 sets containing similar roughness coefficients (n) and channel widths are presented in Figure 2.17 and Table 2.5. Some of the high values presented (0,107) are due to poorly defined channels in rocky terrain.



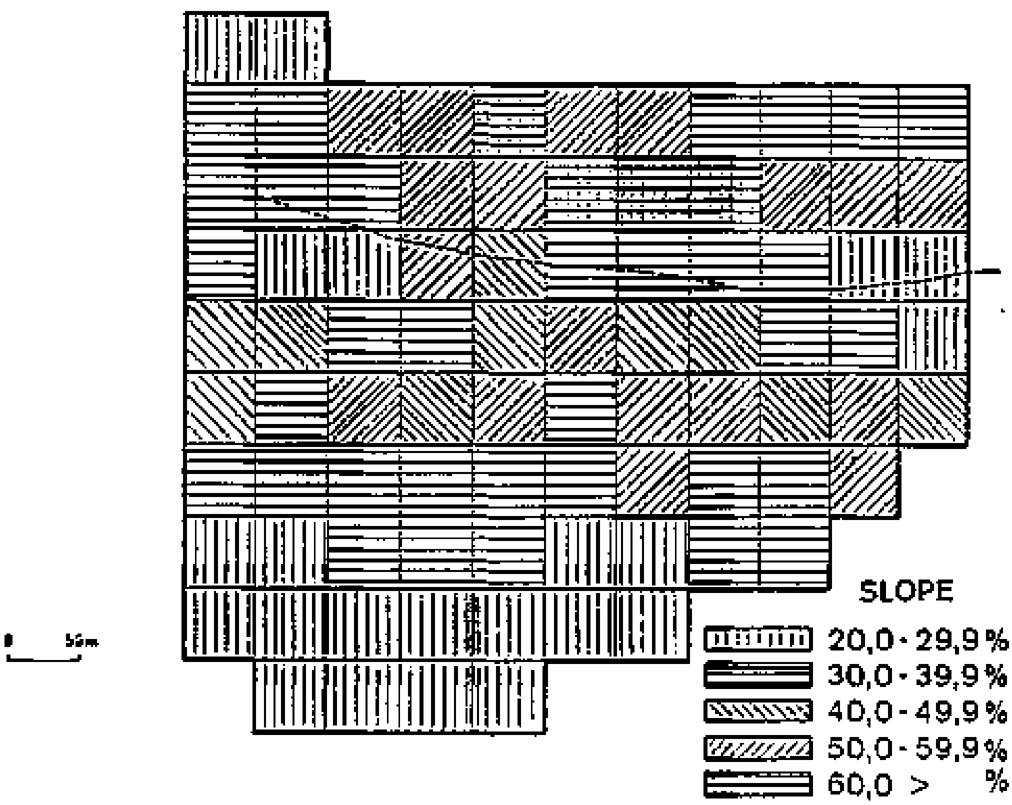


Figure 2.15 Slope aspects (A) and slope gradients (B) for 50m x 50m finite elements in Catchment F.

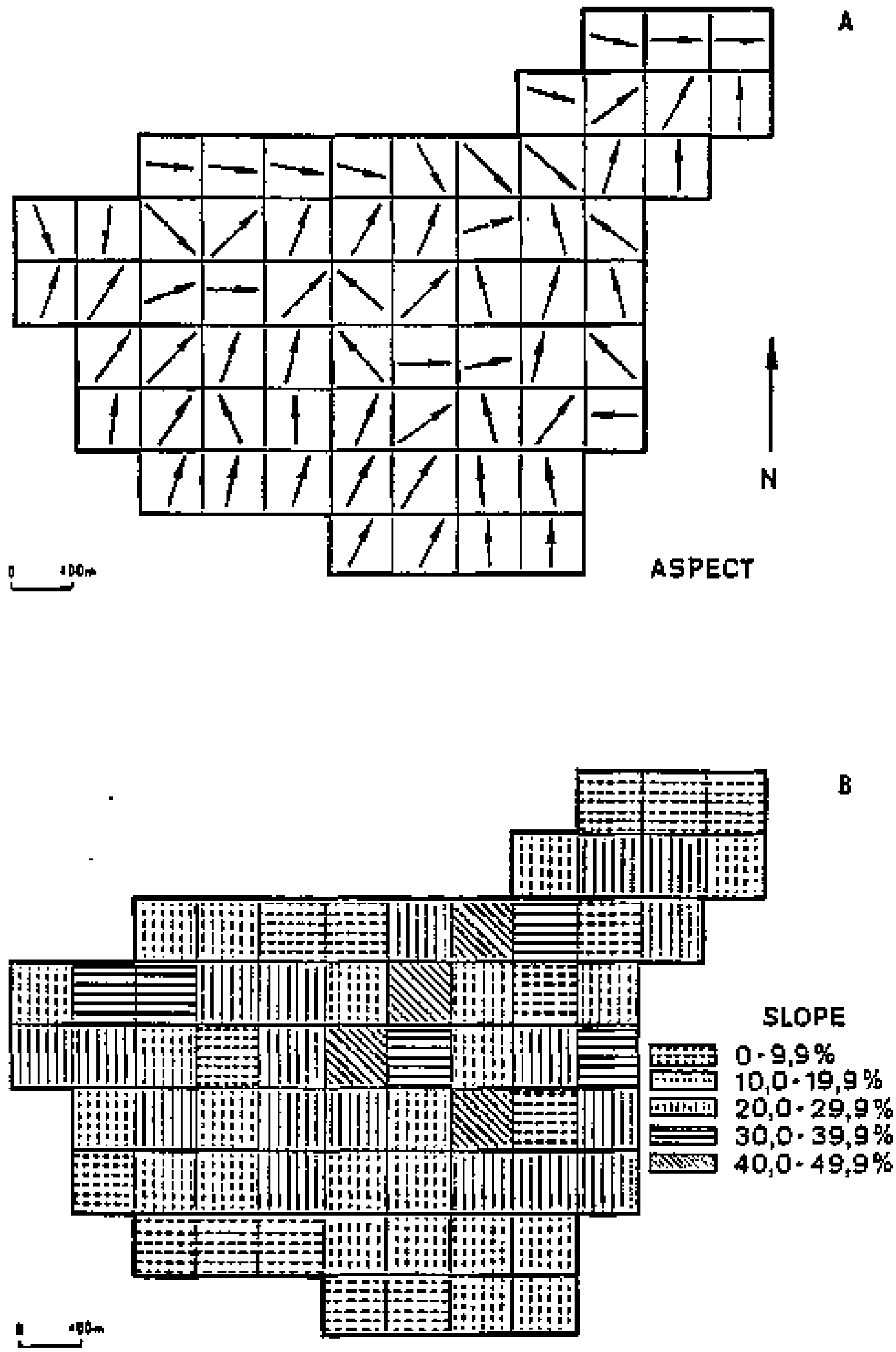
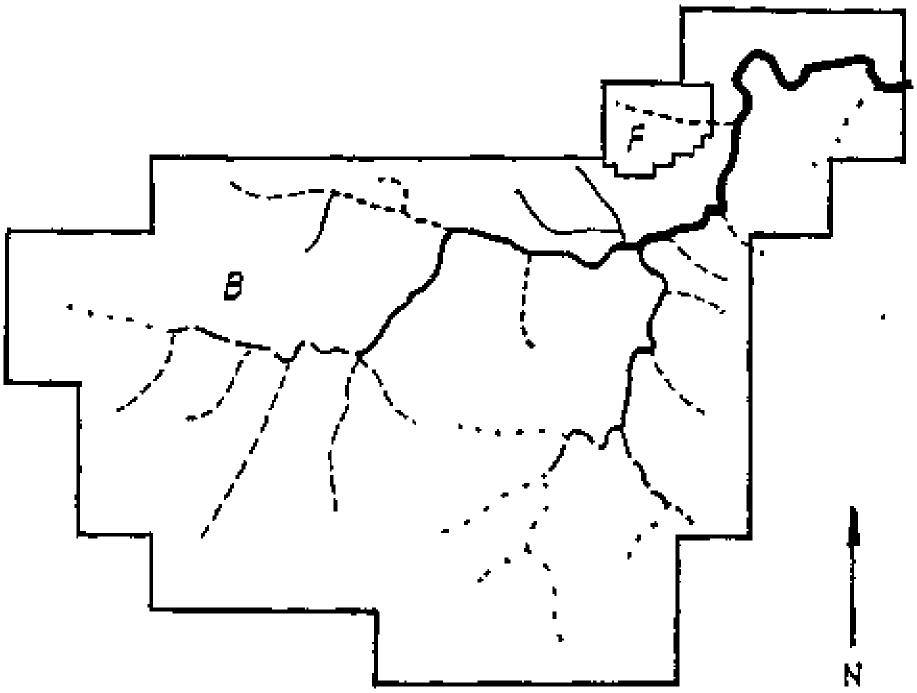


Figure 2.16 Slope aspects (A) and slope gradients (B) for 400m x 400m finite elements in Catchment B



CHANNEL WIDTH	ROUGHNESS COEFFICIENT
1.5	0.063
0.9	0.072
0.5	0.067
0.4	0.105
0.3	0.047
0.3	0.099
0.2	0.045

Figure 2.17 Stream classification based on the roughness and width of the channel.

Table 2.5 : Stream classes based on Manning's n and channel width.

Channel category	Channel width (m)	Manning's n
1	1,5m	,060
2	0,9m	,072
3	0,5m	,067
4	0,4m	,105
5	0,3m	,047
6	0,3m	,099
7	0,2m	,045

The above chapter has concentrated on providing information which is required for physically-based hydrological simulations and the interpretation of hydrological processes. The chapter therefore described the instrumentation of the research catchments, their rainfall, vegetation, soils, underlying geology and drainage. Quantitative parameters were presented for later use in soil moisture budgeting and event-based runoff simulation. The following chapter presents the simulation of daily soil moisture amounts.

CHAPTER 3
SOIL MOISTURE

Soil moisture variations are of relevance to this study in the sense that they affect runoff amounts, the redistribution and concentrations of salts, and provide an indication of plant moisture consumptions. They also influence vegetation densities and thereby affect erosional rates. The purpose of this chapter is to test whether it is possible to simulate soil moisture variations in the Ecca catchments using physically-based modelling approaches. The monitoring of soil moisture content was conducted on a weekly basis at six depth-distributed sites (Figure 2.2 and Appendix B). Moolman (1985) stated that the concentration of salts within soil moisture is increased as soil moisture amounts are depleted by evapotranspiration. Moisture movements, by gravitational and/or capillary forces tend to redistribute the salts. In order to be able to simulate the salt concentrations and any chemical processes within the soil horizons, it is necessary to first simulate the moisture movements and amounts. In addition, Schultz and Schulze (1983), and Schultz (1985), emphasized that a knowledge of antecedent soil moisture was necessary for event-based simulations of runoff. They also showed that such information could be obtained from daily moisture budgeting simulations. However, the approach was not tested in semi-arid environments. In selecting a suitable physically - based model for simulating the soil moisture amount in the Ecca catchment, it was necessary to take cognisance of the temporal and spatial resolutions of the available information which could be used to verify the model's results. The data from the six sites mentioned above, represent the weekly variations of the soil moisture content and illustrate the differences between the moisture contents of the left and right banks (discussed in Moolman 1985). The spatial coarseness of the data does not justify the application to distributed models since there would be no means of verifying the results. Similarly the weekly resolution precludes the testing of fine time interval models such as MOISTRE which integrates moisture movements at intervals of less then 14.4 minutes (Dutt, Shaffer and Moore, 1972). A lumped model such as ACRU (Schulze, 1984) is unsuitable for representing complex moisture movements within the heterogeous soil distributions of the catchment. It could however be modified to simulate daily variations at individual points. Therefore the approach adopted was to locate a physically-based model from which the components for daily, moisture budgeting in a vertical dimension could be extracted in order to simulate the weekly observations of soil moisture amounts separately for each of the soil moisture monitoring points in the Ecca catchments. The technique did not account for horizontal movements of soil water. Moolman (1985) noted that he did not observe any horizontal movements of soil water while conducting plot studies in Catchment F.

The ACRU moisture - budgeting component

The soil-moisture budgeting component of the ACRU model (Schulze 1984) was selected to conduct daily simulations of the soil moisture amounts at individual points in Catchment F. A comprehensive description of the model is given in Schulze (1984) and only a brief summary of the relevant component is presented below.

The adopted component is a physically-based, deterministic, site-specific, vertical dimension, multi-soil layer, daily-moisture-budgeting Fortran program which has been modified to output graphical plots and statistical comparisons of observed vs simulated soil moisture amounts for two soil horizons. It incorporates the soils parameters whose values can be user-field related. Ideally the parameters which relate to vegetation moisture requirements and interception amounts should also be user-field relatable, but as discussed in Chapter 2, these parameters had to be calibrated because of a lack of information concerning the rates of consumptive water use by natural vegetation.

The program is essentially a compilation of cascading equations describing the main hydrological processes affecting daily soil moisture amounts and their redistributions in an attempt to provide realistic hydrological outputs from realistic inputs. The conceptual structure of the model is given in Figure 3.1. The site specific inputs include climatic data in the form of daily rainfall, temperature and evaporation, soil parameters in the form of soil horizon depths, porosities, field capacities and wilting points and monthly distributed vegetation details such as potential interception

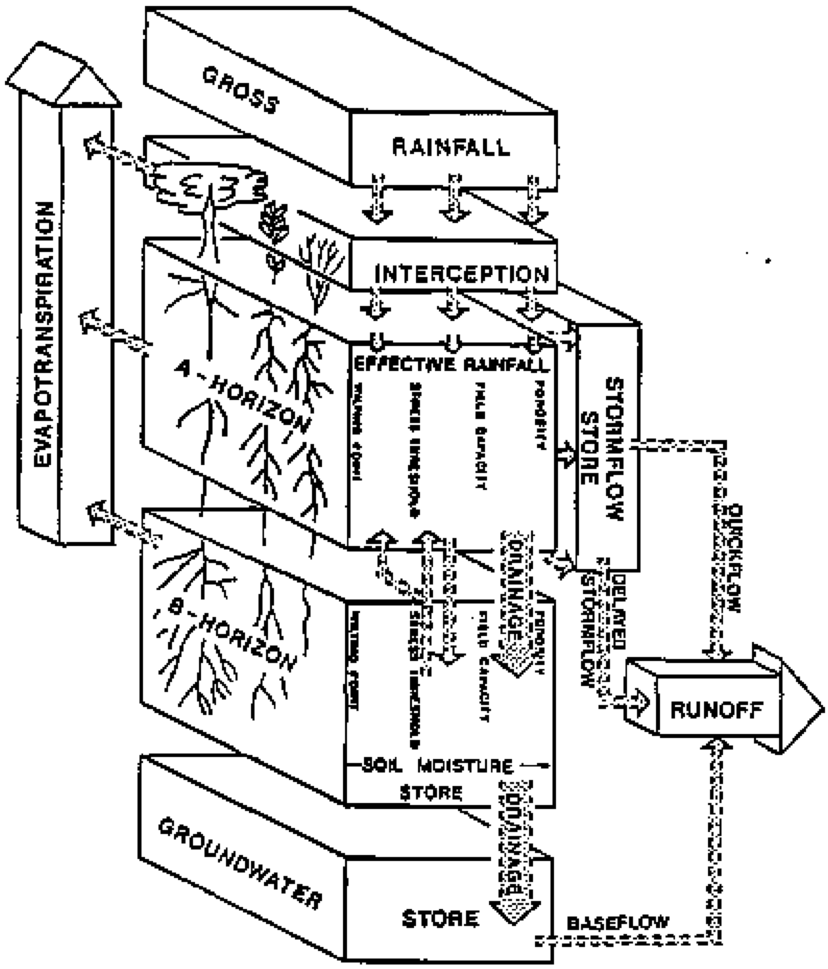


Figure 3.1 Conceptual structure of the ACRU model. (Schulze, 1984)

amounts, crop factors and root distribution fractions for each soil horizon. For statistical and graphical plotting purposes the observed soil moisture values are also included. Appendix C.1 is an example of some of the input parameters used for site FM1L of Figure 2.2. Note that the abbreviation FM1L can be explained as F = catchment name, M = type of measurement (soil moisture), 1 = site number, L = left bank. The input files, containing meteorological and hydrological data were compiled by means of a relatively complex Fortran program "COLLATE" which was developed to conduct data quality control, station sorting and the merging of separate files containing streamflow, soil moisture, rainfall, temperature and evaporation data into one file of site specific inputs for the ACRU moisture budgeting component. Schulze (1984) emphasized that an accurate estimation of potential evaporation is essential for ACRU moisture-budgeting in the ACRU model. A special feature of the program COLLATE is the manner in which daily A-pan data were estimated from the automatic weather station data, weighted according to the weekly A-pan readings and in the event of missing data from the automatic weather station, were distributed on a daily basis using data from the nearest daily A-pan. Appendix C.2 is an example of some of the output from program COLLATE which is used as input to the ACRU moisture budgeting component. Before discussing any of the simulation results, a digression is made to outline the statistical approaches used in interpreting the model performance.

Statistical Considerations

Since one purpose of hydrological simulations is to reproduce, where possible, the measured hydrological phenomena, the objective function selected in this study is a measure of the one to one correspondence between the observed and simulated data. The approach adopted is based on Aitken (1973) and has frequently been used to evaluate the performance of hydrological models in South Africa (e.g. Roberts (1978), Görgens (1983), Schulze (1984) and Schultz (1985)). Aitken (1973) cautioned against the isolated use of the product moment correlation coefficient,r, as measure of one to one correspondence because of the possible presence of systematic errors. These errors exist whenever the least squared regression lines for observed and simulated data do not reflect a one to one correspondence between the values. Under such conditions the coefficient of model efficiency, e, which is a measure of 1:1 correspondence, is less than the coefficient of determination, r^2, which is a measure of the correspondence about the regression line.

The coefficient of model efficiency is calculated as:-

$$e = 1 - \frac{\Sigma(O-S)^2}{\Sigma(O-\bar{O})^2} \qquad \text{eq 3.1}$$

where

O = observed value

$\bar{O}$ = mean of the observed value

S = simulated value

The coefficient of determination is calculated as:-

$$r^2 = \frac{\Sigma(O-\bar{O})^2 - \Sigma(O-E)^2}{\Sigma(O-\bar{O})^2} \qquad \text{eq 3.2}$$

where

E = regression estimate of the variate.

Both r^2 and e have maximum values of 1,0. Model calibration is achieved by minimising the difference between e and unity as well as that between r^2 and e wherever r^2 is greater than e. In addition the observed and simulated data should ideally have the same cumulative totals and statistical distributions. The above approaches were used in the following section to test the performance of the ACRU model.

The ACRU soil-moisture simulations

The aim of simulating soil-moisture by means of the ACRU model is to ascertain whether a conceptual-physical model is suitable for producing realistic outputs of soil moisture variations in an uncultivated semi-arid region and whether its parameters can be transferred within such regions. As mentioned earlier in this chapter, the vegetation parameters used to describe evapotranspiration in the model had to be calibrated. Therefore only the transfer of the latter parameters were tested while all other parameters were based on _in situ_ observations. The simulations were based on data for the period June 1983 to December 1985.

Appendix C.3 presents the statistical results of the calibrated simulations for the 0-15cm soil depth (referred to as A-horizon below) and the 15-45cm soil depth (referred to as B-horizon below) for site FM1L. The coefficient of efficiency, e, for the A-horizon was .703, while that of the B-horizon was .409. It might have been possible to improve these model performances by also calibrating the soils properties, but this would not have been in accordance with the purpose of the exercise which was to test the transferability of the vegetation parameters. The latter parameters were transferred from site FM1L to sites FM2L, FM3L, FM1R, FM4R and FM5R. The model performance (e) was as follows :-

Site name	FM1L	FM2L	FM3L	FM1R	FM4R	FM5R
A-horizon	.703	.245	.021	-3.187	-1.140	-1.735
B-horizon	.409	ND	ND	-2.228	-3.035	-4.306

ND = No data

The results illustrate that the transfer of parameters, over even relatively short distances, within the semi-arid environment give rise to a significant deterioration in model performance. These decreases were largest for parameter transfers from the left to right banks of the catchment. The main reason for this deterioration is possibly due to the heterogeous distribution of the natural vegetation and the associated root densities of the plants at the monitoring points. Other reasons possibly include factors such as differences in the soils and slope aspects of the left and right banks.

Figure 3.2 shows the large differences in the observed soil moisture regimes of the left and right banks of the catchment for the period August 1985 to July 1986. These differences are possibly related to factors such as the different moisture retention abilities of the associated soils as well as the effects of slopes and slope aspects. The ACRU model was not able to reproduce these differences accurately after parameter transfers. Schulze (1984) stated that the ACRU model was undergoing continuous modification and development. He therefore requested that model performances should be

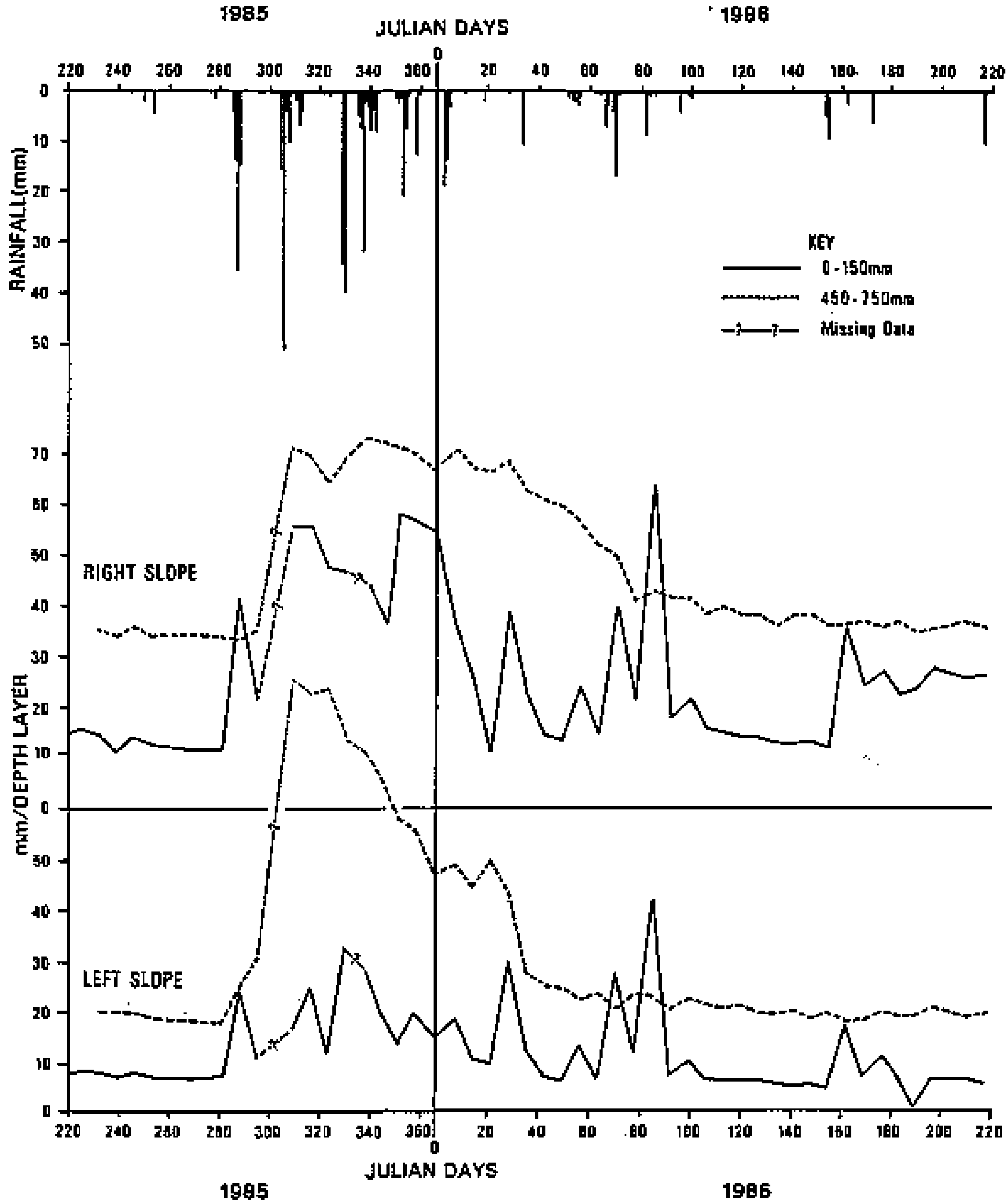


Figure 3.2 Weekly soil moisture variations on left and right slopes of Catchment F for the period August 1985 to July 1986.

improved by modification of the model, rather than by calibration. However, in the above transfer studies it is possible that the problems associated with the model's performance might be related to uncertainties associated with the direct transfer of pre-calibrated parameters, such as the proportions of plant roots in the various soil horizons. One aspect of the model which could be altered to accommodate natural vegetation is its evapotranspirative component. From studies of soil moisture variations it appeared that evapotranspiration was dependant upon the dynamic variations in vegetation densities, in response to the infrequent occurrances of rainfall, as well as on the seasonal variations in the vegetation.

From model tests it was observed that the use of a monthly cropping coefficient (Cay) did not reflect the transpirative consumption of the vegetation in the semi-arid environment. Palmer (1981) described the phenological responses of the natural vegetation in the Fish River area as being sensitive to the occurrences of the rainfall events.

Green (1986) is of the opinion that until more is known about the transpirational patterns of natural vegetation in semi-arid areas, more representative estimates of evapotranspiration would be achieved for the natural vegetation if the model used seasonal fixed daily amounts that were related to the antecedent rainfall, rather than to the daily meteorological conditions. It is therefore recommended that research be conducted in order to establish the relationships between antecedent rainfall and the amounts of water transpired by natural vegetation in semi-arid environments. Such research would enable more representative applications of moisture budgeting models to semi-arid regions.

The above section demonstrates the uncertainties in soil moisture modelling associated with natural vegetation and model parameter transfers over short distances. The following chapter investigates the effects of parameter transfers on event-based simulations of runoff from two nested catchments.

CHAPTER 4
STREAMFLOW SIMULATIONS

A prerequisite to conducting physically-based/physico-chemical simulations of sediment and solute concentrations in semi-arid environments, is the simulation of associated hydrological processes. Similarly the hydrological consequences of changes in land use can be predicted if active hydrological processes are simulated. Such simulations are possible by means of physically-based, deterministic models using the laws of continuity, and the conservation of energy and momentum (De Coursey, 1971). The spatially variable nature of the above processes necessitates the use of distributed models. Therefore, as a first step towards investigating the possibility of conducting non-empirical simulations of the generation of runoff, solutes and sediments, this chapter incorporates the implementation of a physically-based, distributed, hydrological model for the generation of runoff. Because of the large amount of computer storage and processing time required by distributed models (Nicks 1982), it is preferable to conduct event-based, rather than continuous, long term simulations. Hughes (1983) stressed that it can be wasteful to run simulations continuously over long time periods and then extract a few flood events from the output. Park (1981) and Schultz and Schulze (1983) used the approach of coupling two separate models; a daily model for long term moisture budgets and an event based model for detailed hydrological simulations. The daily moisture budgeting models provide the estimates of antecedent soil moisture required by event based models. The approach enables a substantial saving of computer time. Schultz (1985) simulated antecedent catchment indices rather than actual distributed soil moisture values because spatially distributed soil moisture measurements are seldom available to verify distributed moisture budgeting techniques.

For this project two separate sets of antecedent soil moisture indices were simulated for the left and right banks of Catchment F using the ACRU moisture budgeting component discussed in the previous chapter. The model selected for the event based simulations is the MODANSW model (Park and Mitchell, 1983). It is a physically-based, single event, deterministic, distributed-system, conceptual model which is the product of two decades of research involving numerous modifications and improvements to an earlier model by Huggins and Monke (1966). The latter model was tested under South African conditions by Cousens and Burney (1977), who concluded that for small agricultural catchments the model could, with certain modifications, "be an extremely sensitive and powerful tool for flood hydrograph prediction". Perhaps one of the most significant enhancements to the model was the development of the Areal Nonpoint Source Watershed Environment Response Simulation (ANSWERS) model by Beasley, Monke and Huggins (1977). It provided a means of assessing the effects of changes in land use management and agricultural practices on the quantity and quality of streamflow.

Park, Mitchell and Scarborough (1982) introduced further changes to the water quality components of the model and presented a modified ANSWERS model. The MODANSW model (Park and Mitchell, 1983) was introduced to the University of Natal by Mitchell (1982) and tested by Schultz and Schulze (1983). Schultz (1985) introduced further modifications by incorporating statistical and graph plotting subroutines and modifying its inputs to accommodate separate raingauges for each finite element used in the model. The model can accommodate a maximum of 696 finite elements, 20 different soil types, 20 different vegetation and surface roughness combinations and 20 different channel types. A brief description of the model is given below.

The MODANSW Model

MODANSW incorporates those various hydrological components which affect a surface flow system directly, such as interception, retention, infiltration, drainage and flow routing, as well as components for erosional simulations (Park and Mitchell, 1983). The hydrological components are in essence the same as those of the ANSWERS model of Beasley et al. (1977). Based on descriptions by Beasley et al. (1977), Dickey, Mitchell and Scarborough (1979), Park (1981), Park, Mitchell and Scarborough (1982) and Park and Mitchell (1983), the hydrological simulation of MODANSW is submitted in the following manner:-

A rectangular grid system is used to represent a catchment. Each of these finite elements is assumed to be small enough so as to be hydrologically homogeneous. A kinematic approximation is used to define flow rates. The composite hydrograph is simulated by starting at known initial conditions and applying a continuity equation to determine hydrological conditions at all elements one time increment later. The interception component accounts for the total volume of water removed from incoming rainfall by retention on vegetal cover and by evaporation. This component has little influence on the streamflow output. Infiltration rates are determined from an equation described by Holtan (1961) and modified by Huggins and Monke (1966).

The equation can be expressed as

$$f = FC + A\ (S-F)/T_p)^B \qquad \text{eq 4.1}$$

where

f = infiltration rate

FC = steady-state infiltration rate

A = maximum possible infiltration rate

S = storage potential of soil within the infiltration control zone

F = volume of water in the control zone

T_p = total porosity within the control zone and

B = exponent relating rate of decrease in infiltration with increasing soil moisture content.

At the start of an event, the initial value of F is equal to the antecedent moisture content which must be specified. The infiltration rate decreases as the soil moisture storage becomes more saturated. Subsurface drainage occurs whenever the soil moisture content of the control zone exceeds field capacity. This rate increases as the moisture content increases until, at saturation, the rate is equal to the steady state infiltration rate. The drainage rate, D_r, is determined as follows:-

$$D_r = FC\ (1 - (Vol/GWC))^b \qquad \text{eq 4.2}$$

where

Vol = unsaturated pore volume (total porosity minus moisture content)

GWC = maximum volume of gravitational water content (total porosity minus field capacity) and

b = drainage exponent.

Table 4.1 Basic input data required by ANSWERS model (Park, 1981).

Group	Hydrological process	Variable name	Parameter Descriptions
Soils	Infiltration	TP	Total porosity (percent volume)
		FP	Field capacity (percent saturation)
		FC	Steady state infiltration rate (mm/h)
		A	Difference between steady state & maximum infiltration rate (mm/h)
		B	Exponent in infiltration equation
		ASM	Antecedent soil moisture content (percent saturation)
		DF	Infiltration control zone depth (mm)
	Drainage	e_d	Drainage exponent
Crop & surface conditions	Interception	PIT	Potential interception volume (mm)
		PER	Percentage of surface covered by specific land use (percent)
	Depression storage	RC	Roughness coefficient
		HU	Maximum roughness height (mm)
	Overland flow routing	n	Manning's roughness coefficient
	Channel flow routing	WID	Channel width (m)
Topography	Flow routing	S	Slope steepness (1000 x m/m)
		ANG	Direction of slope (degrees)

Overland flow rates and channel flow rates are determined using Manning's equation (eq. 2.5 of chapter 2). In its hydrograph simulations the model considers factors such as surface roughness, vegetation types, channel properties, soil properties, topography and, when applicable, tile drainage. simulations. Table 4.1 presents the input parameters required by the model's hydrological component (ANSWERS) as summarised by Park (1981).

MODANSW Streamflow Simulations

One of the problems in simulating streamflows in Catchments F and B is that the accuracy of the observed data used in the calibrations are uncertain. These problems were mentioned in Chapter 2 and are due to rapid sedimentation in the stilling basins. Further, the sensitivity of the gauging structure for Catchment F is insufficient for accurate recordings of the relatively low flow rates measured. The maximum peak flow ever recorded at Catchment F was only 0,092m^3/S. This event occurred on the 15/4/83. Due to instrument failures and sedimentation, its magnitude was estimated from debris stains on the gauging structure. The MODANSW model was able to reproduce this peak as 0,094m^3/S. The event of 15/2/85 had a peak of 0,0104m^3/S which was simulated as 0,0105m^3/S with a coefficient of efficiency of 0,834. However, it is uncertain whether the stage discharge relationships are sufficiently accurate to represent the relatively small flow rates observed and therefore it can only be concluded that the MODANSW model is capable of simulating flood events in Catchment F to orders of magnitude whose goodness of fit statistics lies somewhere within the range of uncertainties in the observed measurements. Other problems that were encountered in the measurement procedures were that the relatively small and gradual changes in stage heights were not recorded smoothly due to the friction of the recording mechanism. This phenomena was noticable as a series of sharp steps in the flood hydrographs for the months of November and December, 1985 (Figure 4.1).

Although the MODANSW model is physically-based, some parameters such as DF and RC (Table 4.1) can be optimised in order to improve model performance. The transferability of such parameters from Catchment F to B was tested. In conducting the transfer of these parameters it was also assumed that the methodologies described in chapter 2 to spatially extrapolate the results of the detailed soil surveys for Catchment F and the less detailed soil surveys in Catchment B, were representative of the spatially heterogeneous soil properties found in the catchments. The transfer of parameters from F to B was also associated with a change in scale factors. For example the finite element sizes used for Catchment F were 50m x 50m while those used for Catchment B were 400m x 400m. Examples of the results of the MODANSW streamflow simulations are given in Appendix D. The coefficients of efficiency (e), for simulations of Catchment B, which used parameters transferred from Catchment F, were less than 0.0. These results indicated that assumptions concerning the spatial heterogeneity of parameters were not transferable from a small (28ha) to a large (910ha) catchment where less intensive sampling has been conducted and where different scale factors are used in fully-distributed hydrological modelling.

One of the main purposes of implementing the MODANSW model in this study was to ascertain the spatial distribution of hydrological processes in relation to observed sediment and solute movements. These aspects are discussed in the following two chapters.

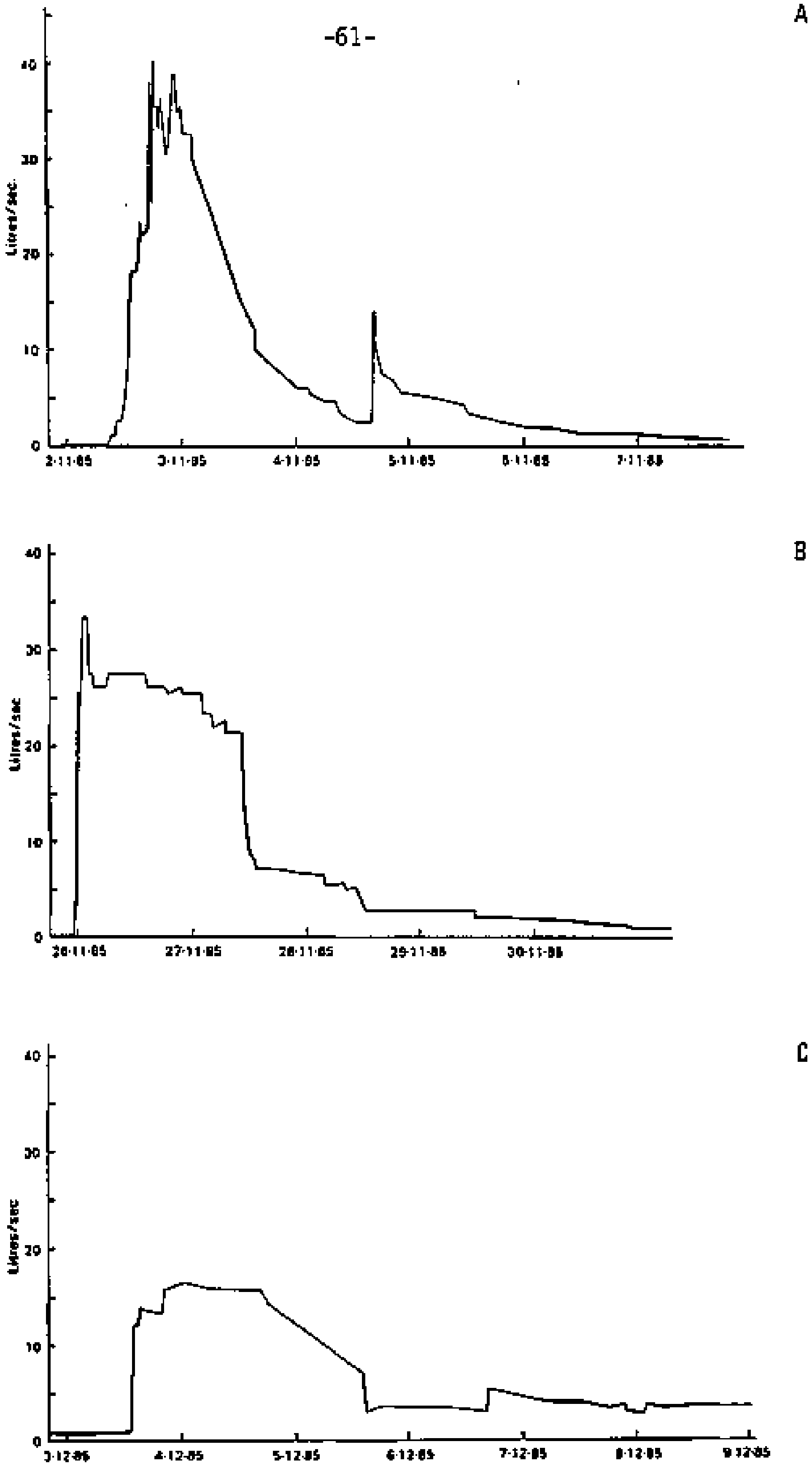


Figure 4.1 Typical hydrographs for Catchment F for the events dated
A) 2 November 1985 and 4 November 1985
B) 26 November 1985
C) 3 December 1985 and 6 December 1985

CHAPTER 5
SEDIMENT SIMULATIONS

Soil erosion and sediment transport processes in a catchment are caused by hydrological/hydraulic processes (Park, Mitchell and Scarborough, 1983). In this project an attempt is made to interpret the principal processes giving rise to the natural generation, storage and transport of runoff, solutes and sediments as dynamically varying, distributed processes. In practice it is extremely difficult to measure all the above interactions in space and time. One way of investigating them is to measure the catchments hydrological outputs, to use physically-based distributed models to simulate the processes on a spatial basis and then to attempt to ascertain, from chemical and surface textural data, whether the simulated processes were in fact correctly distributed in space. For example, one would expect that areas of excessive surface erosion would be spatially distributed in a similar manner to areas in which overland flow occurred and that erosion would be minimal in regions where infiltration rates are high. Interpretations of the spatial distribution of soil chemistry and erosion, in relation to the catchment's solute and sediment output, could be used to further verify the simulated spatial distribution of hydrological processes. This chapter discusses the simulation of spatially distributed sediment processes by means of the MODANSW model.

The MODANSW sediment component

A physically-based, deterministic, distributed system, event-based submodel of sediment detachment, transport and depositional processes was developed by Park (1981) and integrated with the hydrological components of the ANSWERS model (Park, Mitchell and Scarborough, 1982). The following summary of this fluvial component is based on descriptions by Park (1981), Park ,Mitchell and Scarborough (1982) and Park and Mitchell (1983).

The main assumptions used in the fluvial simulations are that :-

i) erosion and transport processes do not affect hydrological processses and flow hydraulics,

ii) the flow conditions are one dimensional and

iii) the effects of soil and surface conditions on erosion and sediment transport are constant during a storm.

The continuity equation used for sediment discharge is

$$E_n = \frac{\partial G}{U \partial t} + \frac{\partial G}{\partial X} - \left(\frac{G}{Q}\right) \left(\frac{\partial Q}{U \Delta t} + \frac{\partial X}{\partial U}\right) \qquad \text{eq. 5.1}$$

where

En = nett rate of erosion or deposition (mass/width/time)

U = flow velocity (length/time)

Q = flow rate (mass/time)

X = axis in direction of flow

t = the time

G = sediment discharge (mass/time)

The partitioning of the one dimensional flow between adjacent finite elements is conducted in accordance with the flow routing methods used in the hydrological components (ANSWERS).

The nett rate of erosion depends upon the sum of the rates of splash erosion and flow erosion or deposition.

The splash erosion rate is caused by raindrop impact and is defined as

$$W_s = 0.182 K_r K_h C_m (2.96(\sin\theta)^{0.79} + 0.56)((1-p)I^e + pC_n I_x{}^e) \qquad \text{eq. 5.2}$$

where

W_s = splash erosion rate (Kg/m²/h)

K_r = soil erodibility factor for splash erosion as defined for the USLE K factor (Wischmeier and Smith, 1978)

K_h = water depth correction factor (Park, 1981)

C_m = crop mulch and subsurface incorporate factor (Wischmeier and Smith, 1978)

p = proportion of area covered by canopy

C_n = Crop canopy factor

I = rainfall intensity (cm/h)

I_x = excess rainfall intensity (excludes interception rate due to canopy (cm/h)

θ = gradient of the surface (degrees)

e = the exponent.

The flow erosion is determined as

$$W_f = 11.02 K_f C_f^{e_2} \qquad \text{eq. 5.3}$$

where

W_f = flow erosion (Kg/m²/h)

K_f = flow erodibility factor (approximated from the USLE K factor)

C_f = crop factor for the combined effects of canopy, mulch and surface conditions (Wischmeier, 1975)

e_2 = an exponent

The flow erosion and deposition processes are assumed to interchange so that no flow erosion can occur when deposition takes place. Deposition is assumed to occur whenever the sediment load exceeds the transport capacity. The nett deposition is therefore the difference between the load and the transport capacity at a given time. The transport capacity is defined from Yalin's bedload equation (Yalin, 1963). The equation has also been used in other physically-based models such as the modified USDAHL-74 (Yoo and Molnau, 1978) and other recent versions of the ANSWERS model (Dillaha and Beasley, 1983). The equation incorporates details concerning the critical shear stresses, particle size distributions and flow hydraulics. For numerical convenience, Park (1981) utilized the Shield's diagram (Mantz, 1977) to develop simplified empirical relationships for computing shear stress (details in Park, 1981). The flow parameters are computed by the ANSWERS hydrological component. The particle size distributions are obtained from laboratory measurements. The model can accommodate a maximum of 10 different categories of particle sizes.

The main computational procedures used to describe the sediment processes within each finite element per time increment are summarised in Figure 5.1. The sedimentation occurring in the channel segments of the finite elements are processed in a similar manner to sedimentation within overland flow, except that splash erosion is ignored. The channel processes are treated as concentrated flows. Sediment processes on the channel floor are accounted for but those factors giving rise to side slope instability are not considered. Consequently the model is unsuitable for simulating the development of gullies or streambank erosion. This disadvantage was assumed negligible for Catchments F and B where no significant change in the

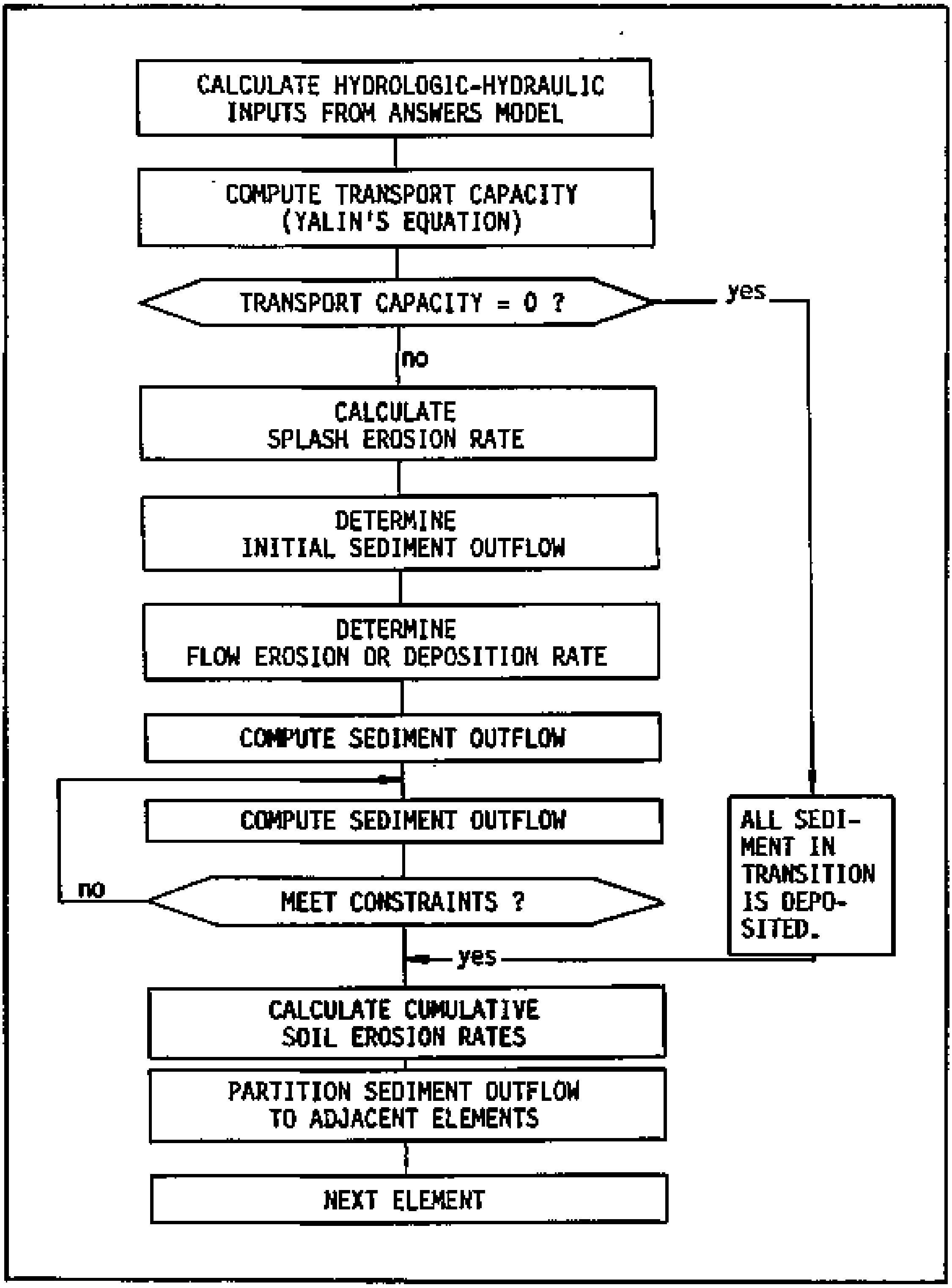


Figure 5.1 Schematic presentation of sedimentation model formulation (after Park, 1981).

channel and gully morphology was observed during the study period (no gullies are present in Catchment F).

Table 5.1 Input parameters required in sedimentation simulation (Park, 1981)

Group	Erosion process	Variable name	Descriptions
Soil	Splash erosion	EXPR	Exponent of rainfall intensity term in splash erosion model
		SRR	Soil coefficient for splash erosion model as determined from the USLE soil erodibility factors in English units
	Flow erosion	EXPF	Exponent of shear stress term in flow erosion model
		SFF	Soil coefficient for flow erosion model as determined from the USLE soil erodibility factors in English units
Crop and surface condi-tion	Splash erosion	CRC	Crop canopy effects for splash erosion
		CRM	Crop mulching and subsurface condition for splash erosion model
	Flow erosion	CRF	Crop coefficient effects due to canopy, mulching, and subsurface incorporates on flow erosion
	Channel erosion	CFCN	Ratio of channel surface condition factor to that of overland element surface conditions
Sedi-ment	Sediment trans-port	SG	Specific gravity of sediment
		DIA	Sediment diameter
		PG	Fraction of sediment distribution in mass

Table 5.1 describes the input parameters required for the sediment simulation. The following section describes the simulated sediment processes in relation to observed information.

MODANSW - sediment simulation

The available sediment data consists of sediment concentrations at outlets of Catchments B and F but no data were available to verify the spatially distributed sediment loads. Therefore the approach involved in comparing sediment movements for different storms was to ensure that the simulated and observed sedimentgraphs at each catchment's outlet were similar. Thereafter the spatially distributed data for sediment loads were ranked and divided into seven categories of similar sediment loads which were mapped as spatial indices of sediment losses.

Figures 5.2 and 5.3 show the variations in the distribution of sediment loss indices for different storm events. An interesting feature of these distributions is that the left bank slopes of Catchments B and F reflect low sediment losses. This observation is in conflict with the intuitive expectation that the left bank slopes should reflect higher sediment losses because of their steeper slopes. However, the soil parameters of the left bank have higher measured infiltration rates and therefore the model produces less overland flow on these slopes and hence less erosion. Field inspections of the left bank provide evidence of regions of concentrated flow and erosion on the left bank. Such features are less common on the right bank. A possible explanation is that crusting and the distribution of rock outcrops on the left bank could give rise to limited areas of concentrated flow.

The irregular distribution of sediment loads in the catchment is possibly related to the combined processes of rainfall distribution, its timing, the heterogeneous distribution of infiltration rates and the convergence of overland flows in lower lying areas of the catchments. The following chapter attempts to further interpret the spatial distribution of hydrological processes by investigating the spatial distribution of solutes.

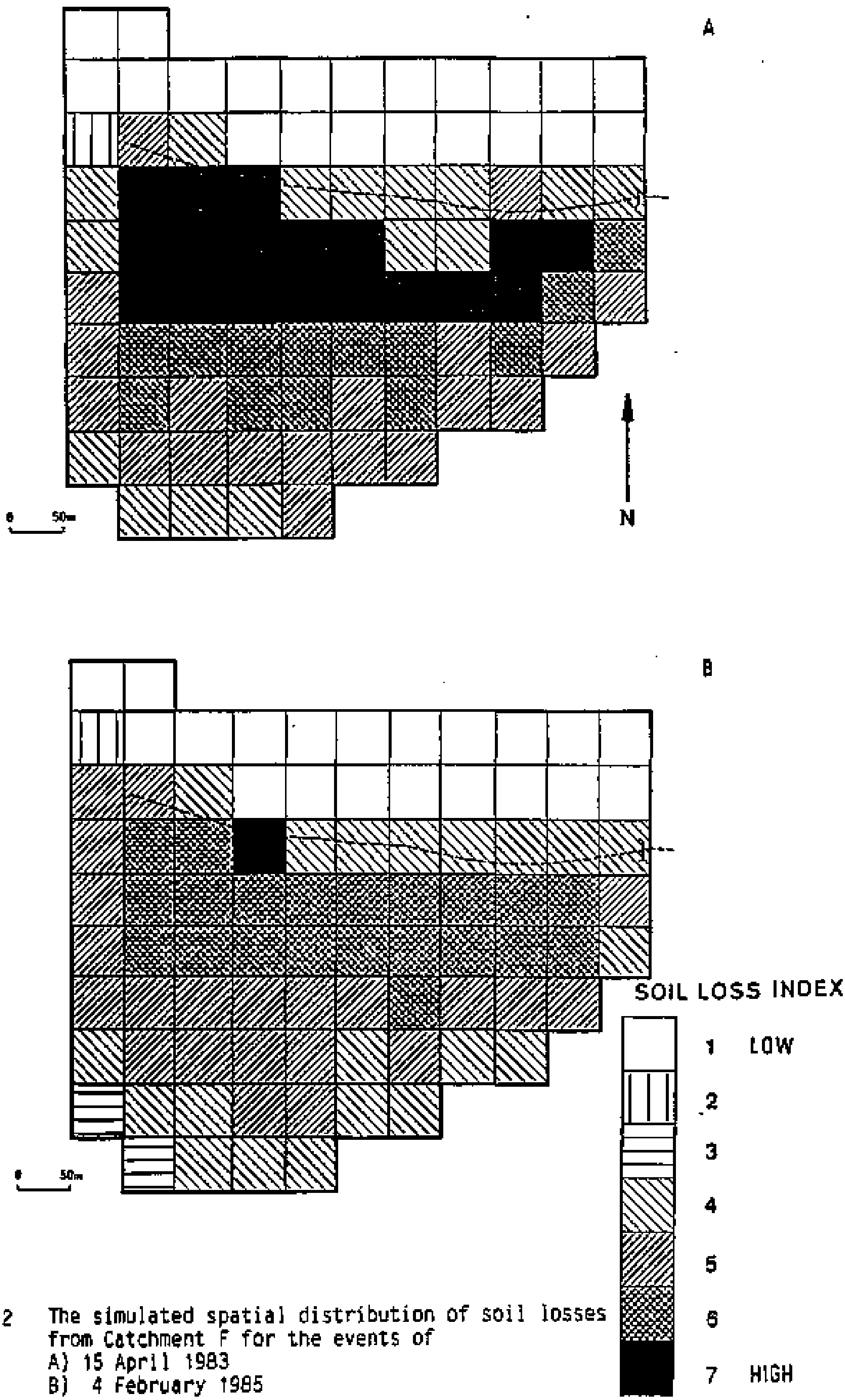


Figure 5.2 The simulated spatial distribution of soil losses from Catchment F for the events of
A) 15 April 1983
B) 4 February 1985

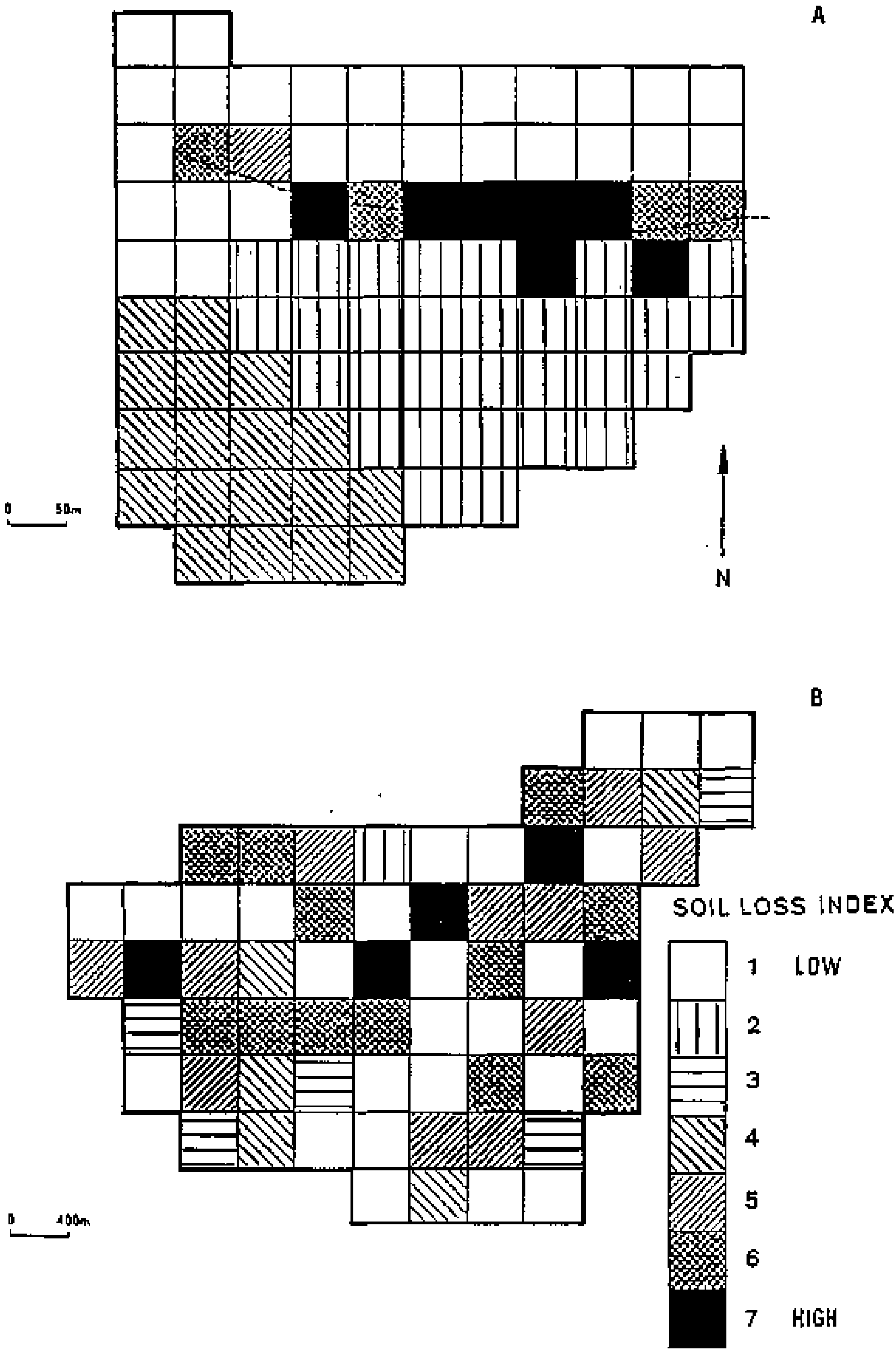


Figure 5.3 The spatial distribution of soil losses for
A) Catchment F on 15 February 1985
B) Catchment B on 1 March 1985

CHAPTER 6
HYDROSALINITY STUDIES

The chemical character of water flowing in a river channel reflects the spatial and temporal integration of a complex sequence of pathways interposed between precipitation inputs into a catchment and its streamflow output, as well as the associated evolution of the water chemistry (Walling and Webb, 1986). In order to attempt to interpret the above interactions in catchment F, the aim of this chapter is to investigate

- the chemical characteristics of the rainfall inputs
- the relative spatial distribution of available soluble salts within the soils
- the temporal variations of solutes in the soil water
- the temporal variations of solutes in the streamflow
- the variations in solute contents in the streamflow along the channel length
- the interrelationships between the above solute distributions as indicators of hydrological pathways
- the extent to which simulated hydrological processes reflect the above pathways.

The study focusses mostly on the rainfall events which occurred during the last three months of 1985. As mentioned in chapter 2, 404 mm of rainfall were recorded during this period. The amount is approximately the same as the mean annual precipitation of 411 mm for the previous twelve years. The investigation consisted of an extensive sampling effort during which approximately 600 water samples were collected for laboratory analyses. The samples consisted of rain water from one site in catchment F, soil water collected <u>in situ</u> from two different depths on the left bank, and from three different depths on the right bank, streamflow samples collected by an automated pump sampler and numerous hand samples from selected positions during rainfall events. The samples were collected on a weekly basis and augmented by samples obtained during ad hoc field trips. The automated pump samplers operated at present intervals of 20, 60 or 120 minutes, depending upon the anticipated weather conditions. Details of the instrumentation and sampling sites are given under instrumentation in Chapter 2 and also in

Moolman (1985). As mentioned in Chapter 2, one of the major problems encountered in the study is the fact that rapid rates of sediment deposition occur in the stilling basins of the streamflow gauging structures in the Ecca catchments. The sedimentation sometimes results in the burial of the sample intake pipes during periods of rapid flow. However, at Catchment F the stilling basin is sufficiently small so that silt and debris can be removed manually within a short space of time. This enabled sampling to continue during periods of sustained flow but no data were collected during periods of rapid flow.

The water samples were analysed to ascertain their specific electrical conductivity (ECe), and soluble salt contents as represented by the major cations; Ca^{++}, Na^{+}, Mg^{++}, K^{+} and anions; Cl^{-}, HCO^{-}_{3} and $SO^{=}_{4}$. The results were plotted onto graphs, Piper diagrams and bar charts to represent the individual as well as the interrelated chemical characteristics of water from the rainfall, soils and in the river channels (Figures 6.1 through to 6.8). These figures are presented in the following sections to discuss the findings of the investigation in accordance with the aims listed at the beginning of this chapter.

The chemical characteristics of the rainfall

Moolman (1985) estimated that the total salt load input into Catchment F by wet fall-out was 25,7 Kg/ha for the period September 1983 to September 1984. This resulted in increases of 3,6 and 2,4 percent of the salts contained in the left and right slopes of the catchment.

The formula

$$\text{Load (kg/ha)} = \text{EC(mS/m)} \times \text{rain(mm)} \times 0.064 \qquad \text{eq. 6.1}$$

was used in the above estimates. The study was repeated for the period October 1985 to December 1986 (Table 6.1). The total salt input during this latter period was 23,34 Kg/ha. The weekly variations in the electrical conductivity of the rainfall ranged from 0.55 to 1.1 mS/m (Figure 6.1).

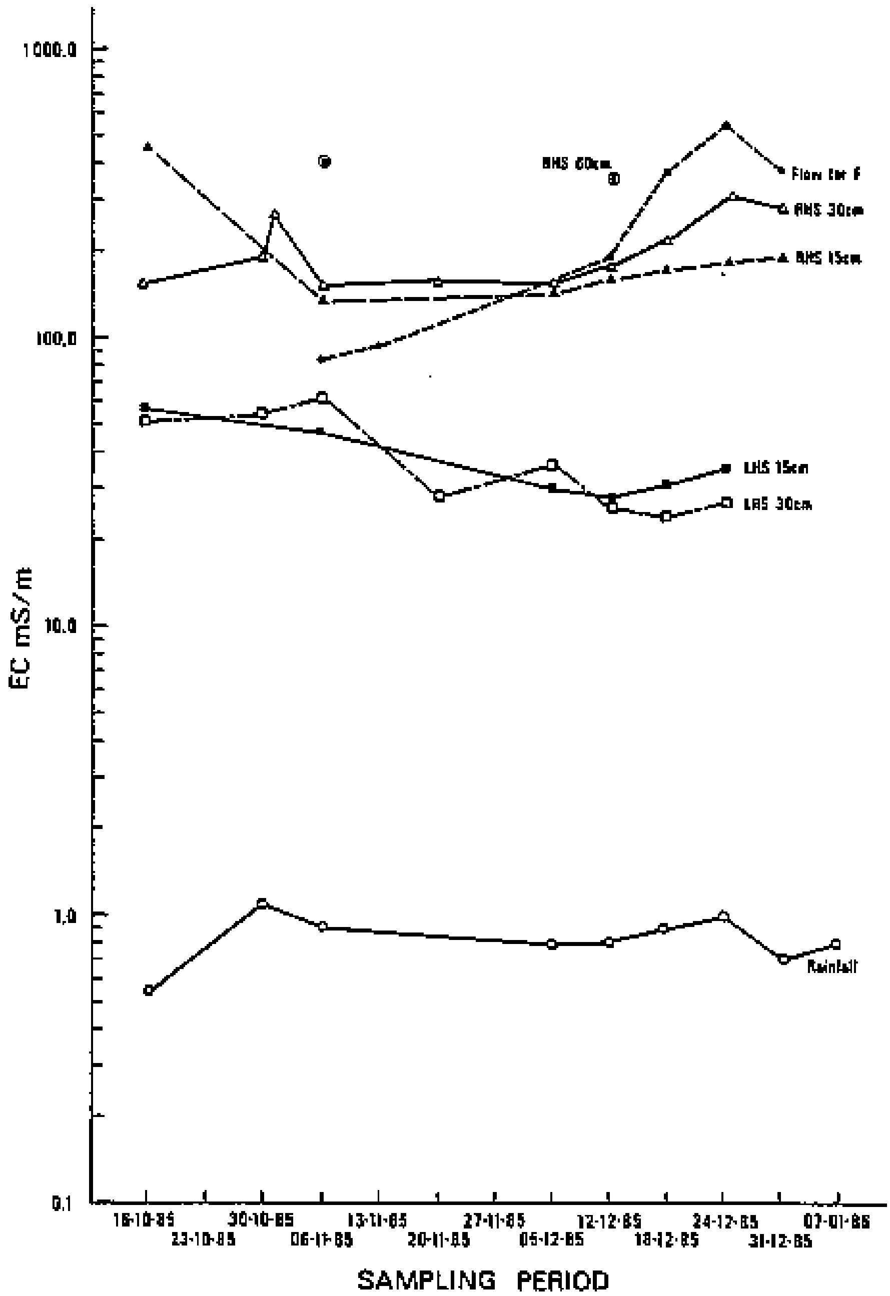


Figure 6.1 Weekly variations in the electrical conductivity of rainfall, soil moisture and streamflow for Catchment F.

The relative proportions of the chemical constituents of the rainfall indicate that two chemically distinct types of rainfall may occur in the study area (Figure 6.2). The one group has high $SO_4^{=}$ but low Cl^- proportions while the other has high Cl^- and low $SO_4^{=}$ proportions. Issar (1986) is of the opinion that these differences may be related to synoptic situations, however, additional research would be required to confirm this. The sample for the week ending 8/1/86 is possibly a mixture of the above rainfall groups. However, further investigations are required in order to confirm whether the laboratory procedures (Franson, 1980) used in the analyses of sulphur were sufficiently accurate for the small concentrations involved.

Spatial variations of solutes in soil water

Moolman (1985) conducted a soil survey of Catchment F and collected 78 samples from depths of 0-30 cm and a further 40 samples from 30-60 cm depths (Figure 2.9). The saturation extracts of the samples were analysed to ascertain the concentrations of the major cations and anions. Statistical and geostatistical techniques used by Moolman (1985) showed that the spatial distribution of the soluble salts was highly variable and that they increased significantly upslope from the channel. The salt content along traverses parallel to the channel were randomly distributed in space. The respective true mean ECe values for the top, middle and channel slopes were 126, 97 and 94 mS/m for the right bank and 166, 101 and 71 mS/m for the left bank. Moolman (1985) speculated that these differences were related to the geological structure of the catchment (discussed in Chapter 2). More water percolates into the ground water regime below the left bank because of it being a scarp slope. In contrast more water reaches the foot-slope area of right bank dip slopes causing it to remain wetter for longer time periods, and because of the greater flux of water, to become more leached than the upslope areas.

In light of the above, one would expect the mean ECe of the wetter and more leached soils to be lower, i.e. that the ECe of the right bank areas adjacent to the channel would be lower than those of the left bank. However, the true mean ECe on the left bank channel is 71 mS/m as opposed to 94 mS/m for the right bank. This difference possibly confirms that

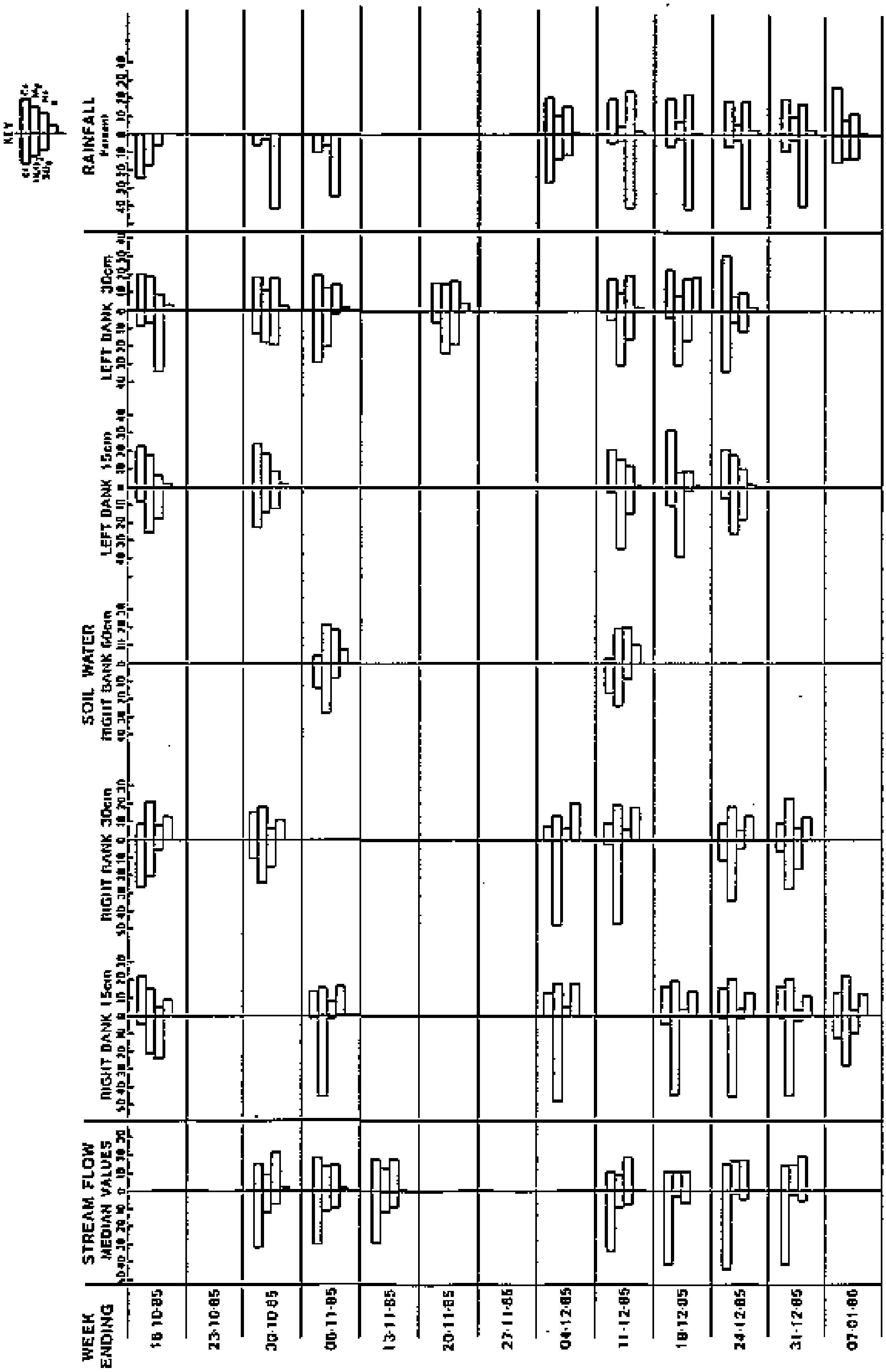


Figure 6.2 Weekly ionic proportions in rainfall, soil water and streamflow for Catchment F. (percentage total equivalents)

additional salts are transported towards the channel through lateral surface movements of water from the higher lying regions of the right bank, while those of the left bank are lost due to downward percolation. Other factors which could also have contributed towards the above differences include the fact that the left bank is steeper and has shallow soils which are more easily drained than those of the right bank. Consequently a larger volume of water is retained for longer periods in the soils overlying the dip slopes than in those overlying the scarp slopes. Typical values of soil moisture at selected sites (Figure 2.2) on the left and right banks are given in Appendix B. During the movement of soil water some solutes are possibly mobilized more easily than others and therefore the following section investigates the in situ distribution of the cations and anions. The data used were extracted from the above mentioned soil survey of Moolman (1985).

The data were plotted onto diagrams of Catchment F and represented as vertical bars indicating the concentration of each constituent in meq/ℓ. The total dissolved salts (TDS) were plotted as concentrations in mg/ℓ. Figure 6.3(A) illustrates the location of the sample points with respect to the river channel, catchment boundary and the left and right banks. Figures 6.3(B) and 6.3(C) present the spatial distributions of the major anions and cations for the 0-30 cm soil depths respectively. Figures 6.3(D) and 6.3(E) present the distributions for the 30-60 cm soil depths.

The spatial distribution of the TDS, as presented in Figure 6.3(B), illustrates the above mentioned variations along transects parallel to the river, the lower salt concentrations in the foot-slopes and the fact that the concentrations of salts adjacent to the channel are slightly higher on the right bank than on the left bank. The diagram also confirms the presence of anomalous pockets of high salt concentrations. The presence of such pockets could complicate attempts to simulate hydro-salinity processes on a spatially distributed basis. A comparison between the positions of anomalous concentrations for different constituents (Figure 6.3(B) and 6.3(C)) indicates that not all of the anomalies occupy the same position. This is possibly due to the fact that the chemical composition of the solute constituents is also spatially heterogeous along each of the transects.

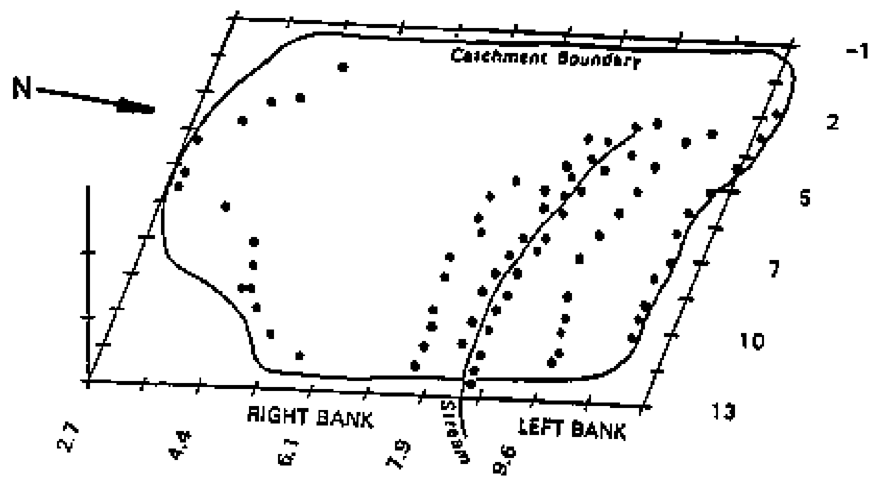


Figure 6.3 A) Explanation of the distribution of sample points in Catchment F for the data presented in figures 6.3 (B), 6.3 (C), 6.3 (D) and 6.3 (E). The points correspond with those presented in figure 2.9.

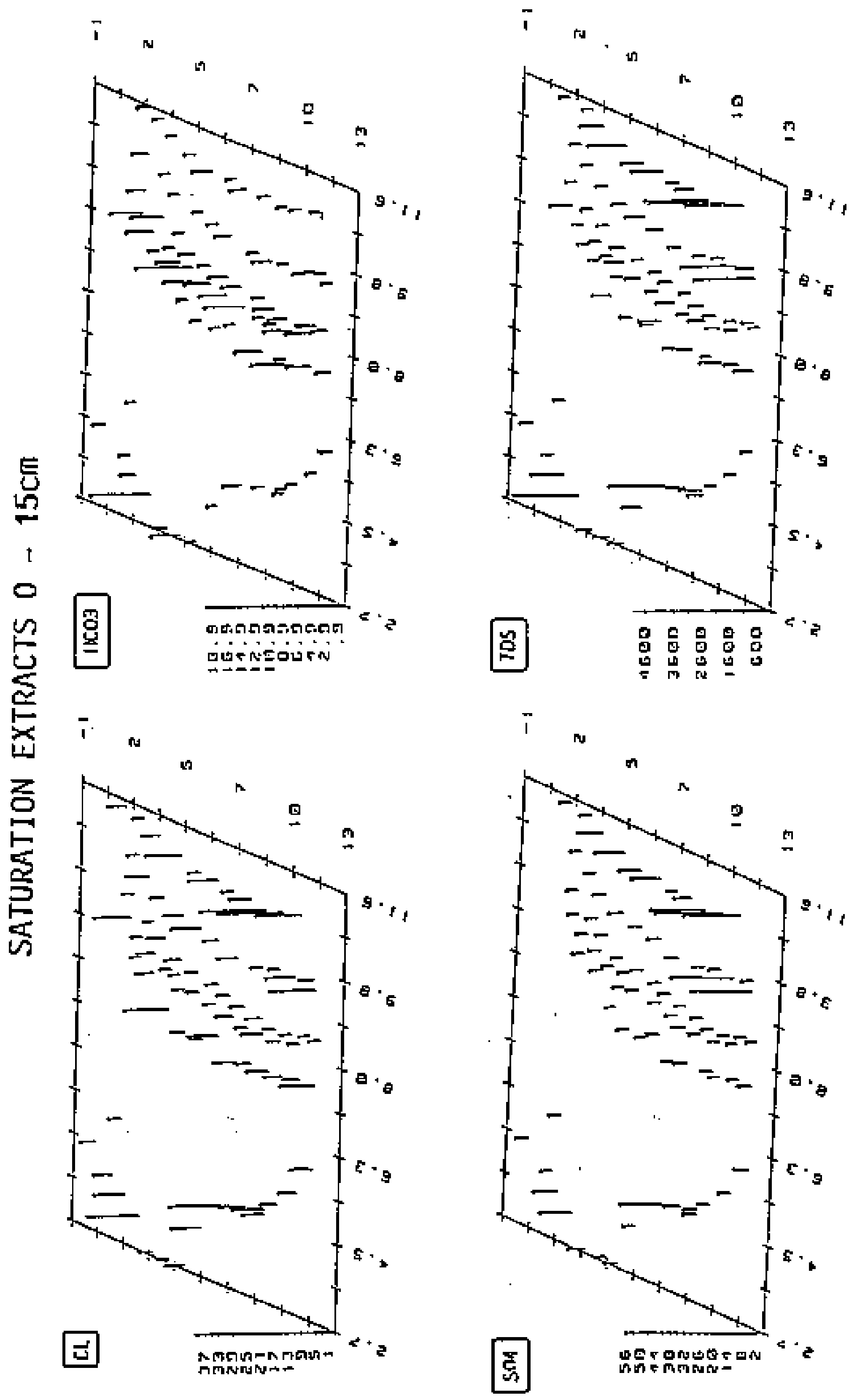


Figure 6.3 B) The spatial distribution of Cl^-, HCO_3^-, $SO_4^=$ (meq/ℓ) and TDS (in mg/ℓ) concentrations for the 0-15 cm soil layers.

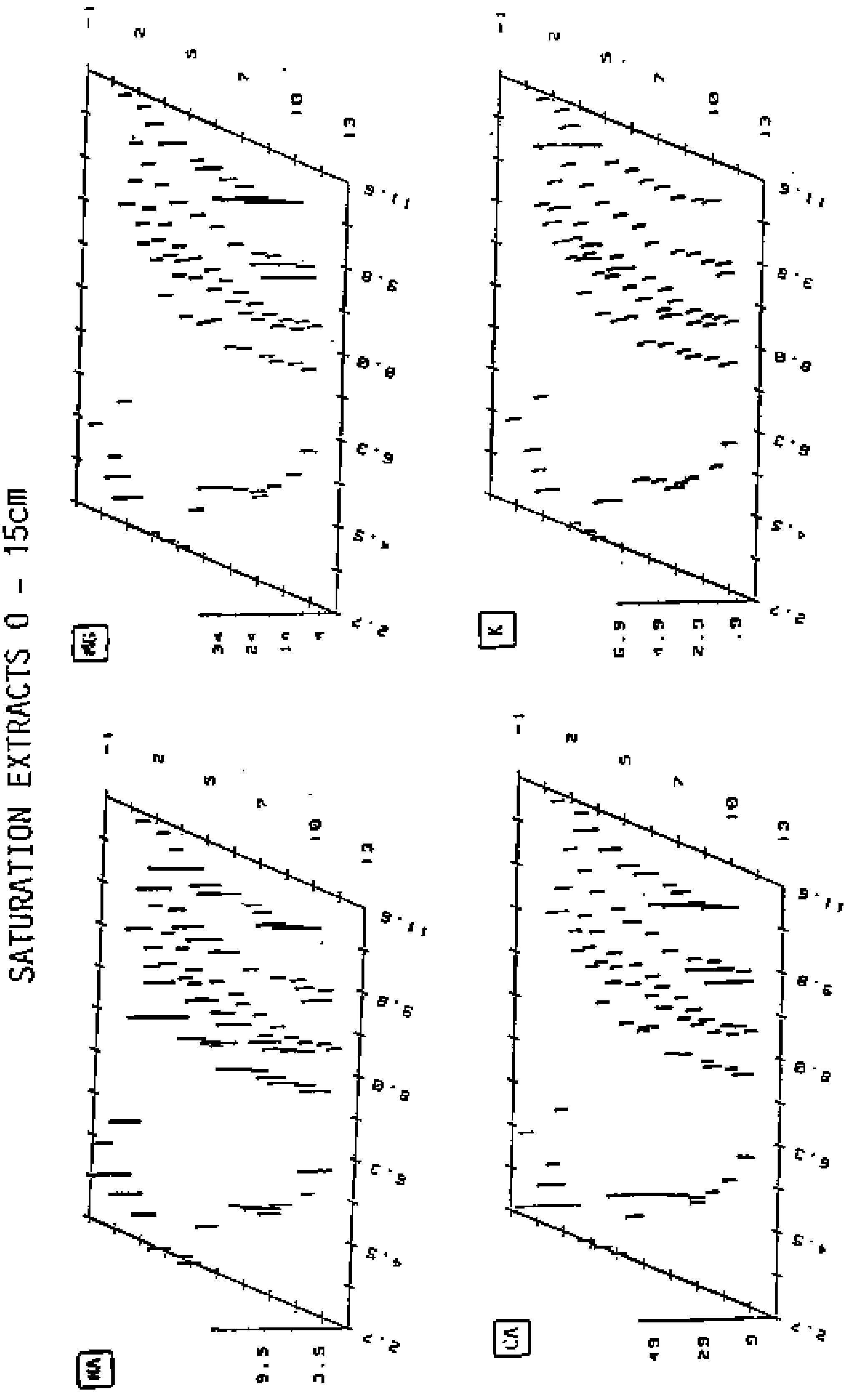


Figure 6.3 C) The spatial distribution of Na^{+}, Mg^{++}, Ca^{++} and K^{+} (meq/l) for the 0-15 cm soil layer.

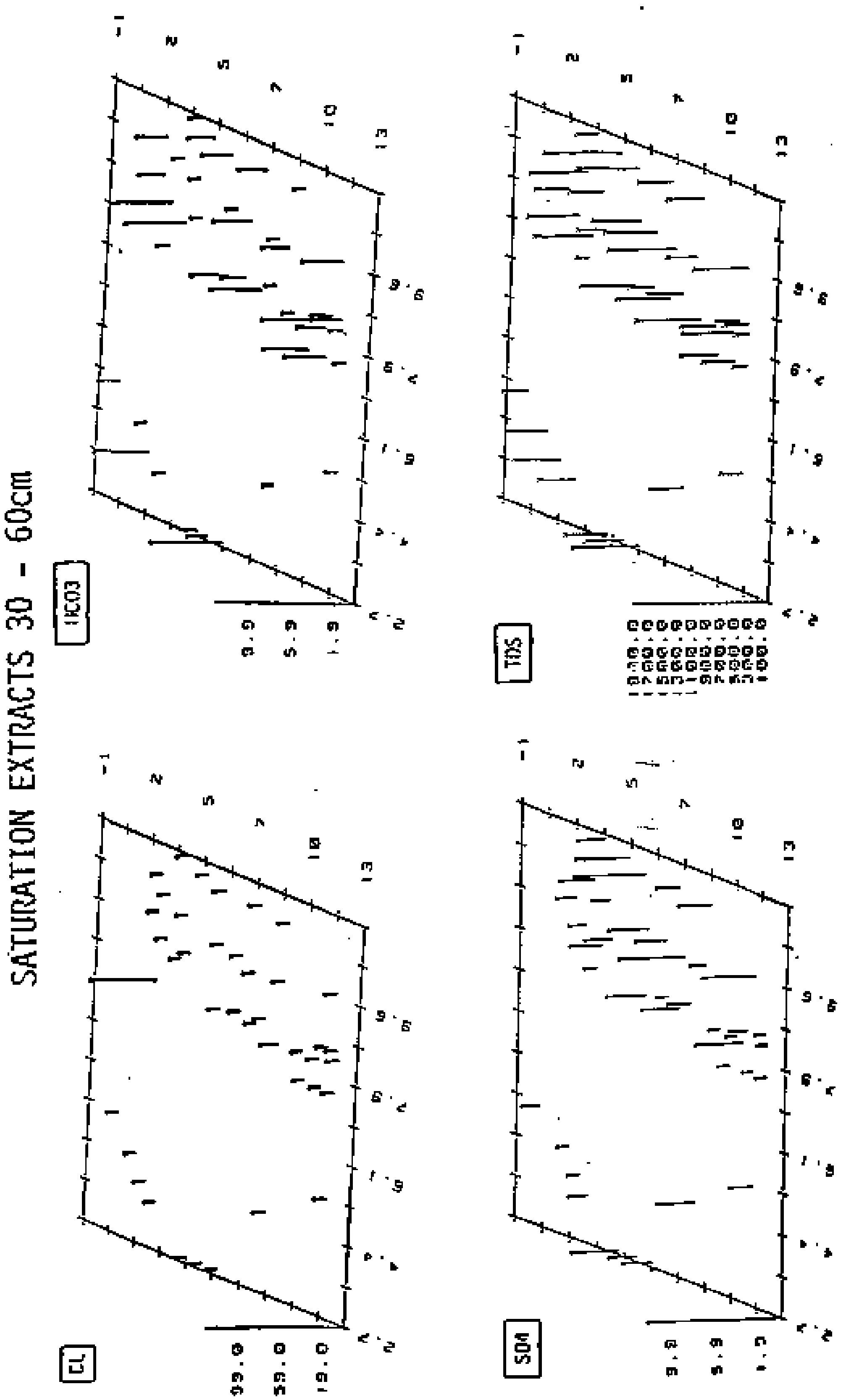


Figure 6.3 D) The spatial distribution of Cl^-, HCO^-_3, $SO^=_4$ (meq/ℓ) and TDS (mg/ℓ) for the 30-60 cm soil layer.

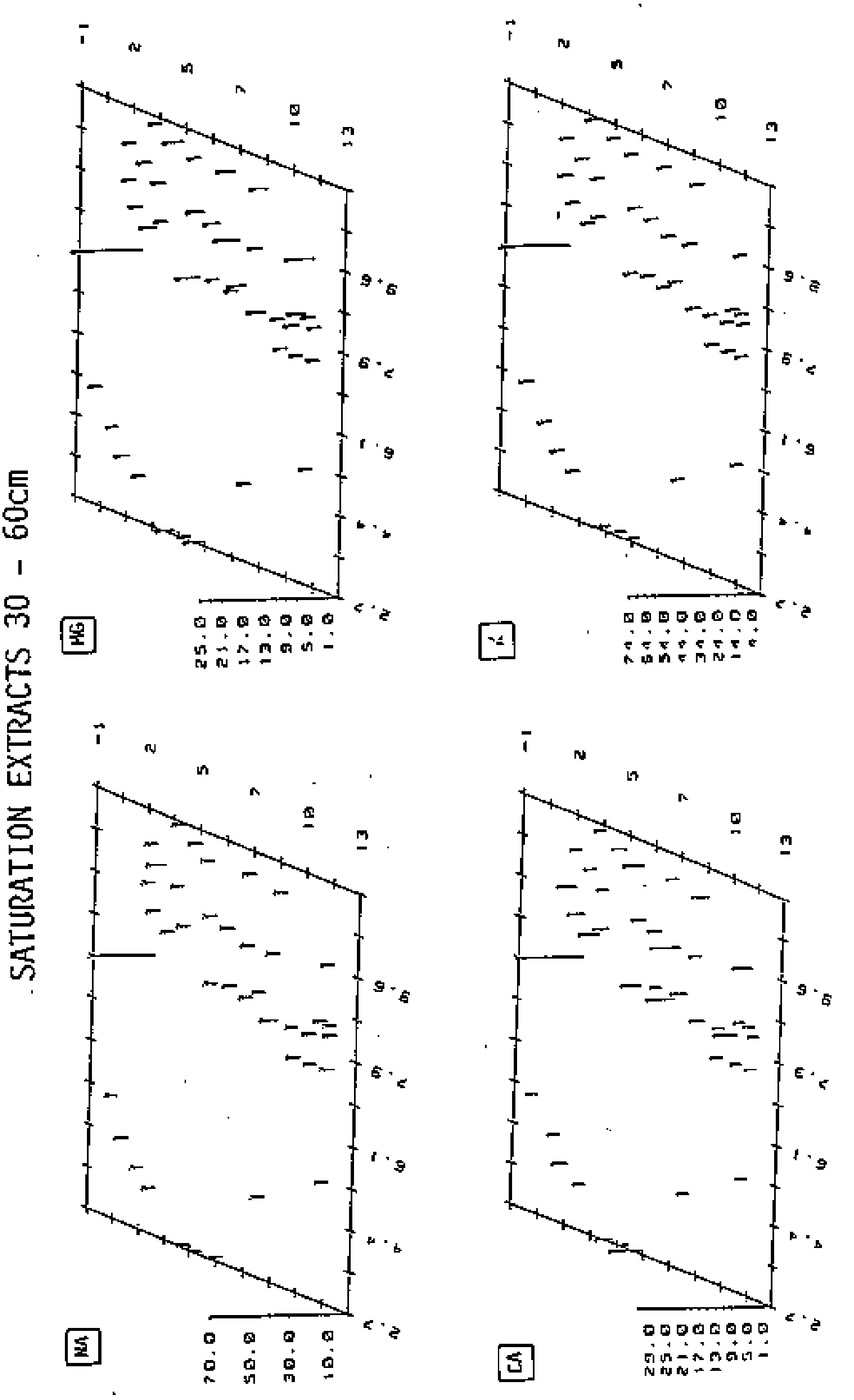


Figure 6.3 E) The spatial distribution of Na^+, Mg^{++}, Ca^{++} and K^+ (meq/ℓ) for the 0-15cm soil layer.

Some spatial differences in the solute trends between the transects are apparent. For example the HCO^{-}_{3} concentrations are higher along the channel banks than the mid and top slopes. This trend is opposite to that of the TDS concentrations and is especially noticeable along the right bank. The Cl^{-}, $SO^{=}_{4}$, Ca^{++}, and to a lesser extent, Mg^{++}, tend to have similar spatial distributions to that of the TDS. The Na^{+} values tend to decrease in the presence of high Ca^{++} values which is in keeping with the Ca-Na exchange reaction. The K^{+} concentrations are generally low with fewer anomalous values than the other elements.

For the 30-60 cm soil depths (Figure 6.3(D) and 6.3(E)) the presence of larger amounts of solute removal along the channel bank regions is not as apparent as for the surface soils. The TDS values are not as high and the presence of anomalous pockets occur along the channel banks as well as in the surrounding areas. The HCO^{-}_{3} and $SO^{=}_{4}$ concentrations tend to increase in the valley floor regions.

The distributions discussed above indicate the heterogeneous nature of the available salts in surface soils but provide no indications of their temporal variations in response to soil moisture movements and amounts.

Temporal variations of solutes in the soil water

Solute levels vary through time in response to the dynamic processes which generate streamflow and its dissolved content. These processes are spatially distributed and reflect the manner in which the water moves through the system of stores and transfer routes in response to hydrometeorological inputs (Walling & Webb, 1985). The temporal behavior of soil water stores as sampled at two <u>in situ</u> sites, FM1L and FM1R (Figure 2.2), form the focus of attention for this section. Their role within the runoff generating system is reflected in figures 6.1, 6.2 and through 6.8. The interrelationships reflected in these figures will only be discussed after the temporal behavior patterns. From Figure 6.1 and Table 6.1 it can be seen that the ECe of the solute contents on the left bank (site FM1L) decreased during the study period in response to the continuous rainfall while the values on the right bank (site FM1R) showed a gradual increase.

Table 6.1 A comparison between the weekly ECe values of rainfall, streamflow and soil water of Catchment F

	RAINFALL			STREAMFLOW				SOIL WATER											
								R. Bank 0-15cm			R. Bank 15-30cm			L. Bank 0-15cm			L. Bank 15-30cm		
Week ending	Depth mm	EC m/Sm	Load kg/ha	Volume m^3/week	Median EC	TDS mg/l	Load kg/ha	0	EC m/Sm	Load kg/ha	0	EC m/Sm	Load kg/ha	0	EC m/Sm	Load kg/ha	0	EC m/Sm	Load kg/ha
09-10-85	68,2	0,55	2,401					,274			,181			,160			,114		
16-10-85								,142	458	624,3	,185	154	273,5	,172	57,5	39,5	,092	50,7	44,8
23-10-85	51,0	1,1	3,590											ND			ND		
30-10-85	82,8	0,9	4.769	3629	85	544	70,5	,371	222	790,1	,227	189		,110	54,1	57,1	,126	50,7	61,3
06-11-85	12,4	0,8*	0,67*	120	94	602	0,4	,368	134	473,4	,205	151	297,2	,162	47,4	73,7	,127	60,1	73,3
13-11-85	-							,315			,207			,078			,094		
20-11-85	74,6	0,8*	4,01*	3716	ND	ND		,310			,217	152	316,6	,215			,208	28,7	
27-11-85	48,4	0,8	2,478	3273	ND	ND		,293	137	385,5	,232	148	329,6	,187			,127		
05-12-85	19,0	0,8	0,973	1412	ND	ND		,241	154	356,3	,230	175	386,4	,129	30,1	37,3	,117	35,8	57,3
12-12-85	4,6	0,9	0,265	35	193	1235	1,5	,386	171	633,7	,225	218	470,9	,092	28,4	25,1	,104	27,6	40,2
18-12-85	28,4	1,0	1,818	133	380	2432	11,6	,378	181	656,8	,225	309	667,4	,130	30,5	38,1	,106	24,8	27,6
24-12-85	12,8	0,7	0,573	627	567	3628,8	81,3	,361	190	658,4	,214	292	599,9	,101	36,4	35,3	,098	27,9	26,2
31-12-85	35,0	0,8	1,792	29	393	2515,2	2,6	,243			,220			,125			,096		

* estimated from mean EC for rainfall

ND - No data

R. - Right

L. - Left

The initial high anomalous value for the 15cm sample on the right bank is possibly related to salt accumulations in the vicinity of the ceramic cup of the soil-water sampler during former periods of limited wetting and drying. Similar observations were recorded by Moolman (1985) for rainfall events on the 27/7/83 and 11/4/84.

Using the data from Table 6.1 the temporal changes in the salt amounts were estimated for the 0-30cm soil horizons. The amounts on the week ending 16/10/85 were 897,8 kg/ha/30cm and 84,3 kg/ha/30cm for the right and left banks respectively of Catchment F. From this date until the 31/12/85 a total of 334mm of rain was measured with an estimated salt input of 20,9 kg/ha. The salt loads at the end of this period were 1258,3 kg/ha/30cm and 60,5 kg/ha/30cm for the right and left banks respectively. The increase in salt loads of the right bank was 1258,3 - 897,8 = 360,5 kg/ha/30cm of which 360,5 - 20,9 = 339 kg/ha/30cm or 94,2 per cent can be attributed to solute processes such as lateral subsurface flow and capillary action. The balance of 5,8 percent can be attributed to rainfall but the amount is possibly less since some of the wet-fallout load may have contributed towards surface runoff or have percolated towards deeper soils and the groundwater system. In contrast the salt loads of the left bank decreased by 84,3 - 60,5 = 23,8 kg/ha/30cm. Considering that 20,9 kg/ha/30cm had been input to the system by wet fallout, the maximum load removed from the left bank was 44,7 kg/ha/30cm. These values could also have been overestimated since the contributions of wet-fallout towards runoff and subsurface flow are unknown.

The temporal variations in the concentrations of the major cations and anions are given in Figure 6.4. Moolman, 1985 stated that apart from chemical processes, solute amounts tend to become concentrated by phenomena such as evaporation and transpiration. The values can become diluted by rainfall inputs. In order to ascertain whether the ratios of the various cations and anions were changing on a temporal basis, their relative proportions were plotted as well (Figure 6.2). From the latter figure it can be seen that the solute proportions for the right bank 15cm samples remained reasonably constant during the period extending from 6/11/85 to 31/12/85. These values are characterised by relative high HCO^-_3 and low Cl^-, $SO^=_4$ and Na^+ proportions. These characteristics were repeated to a limited

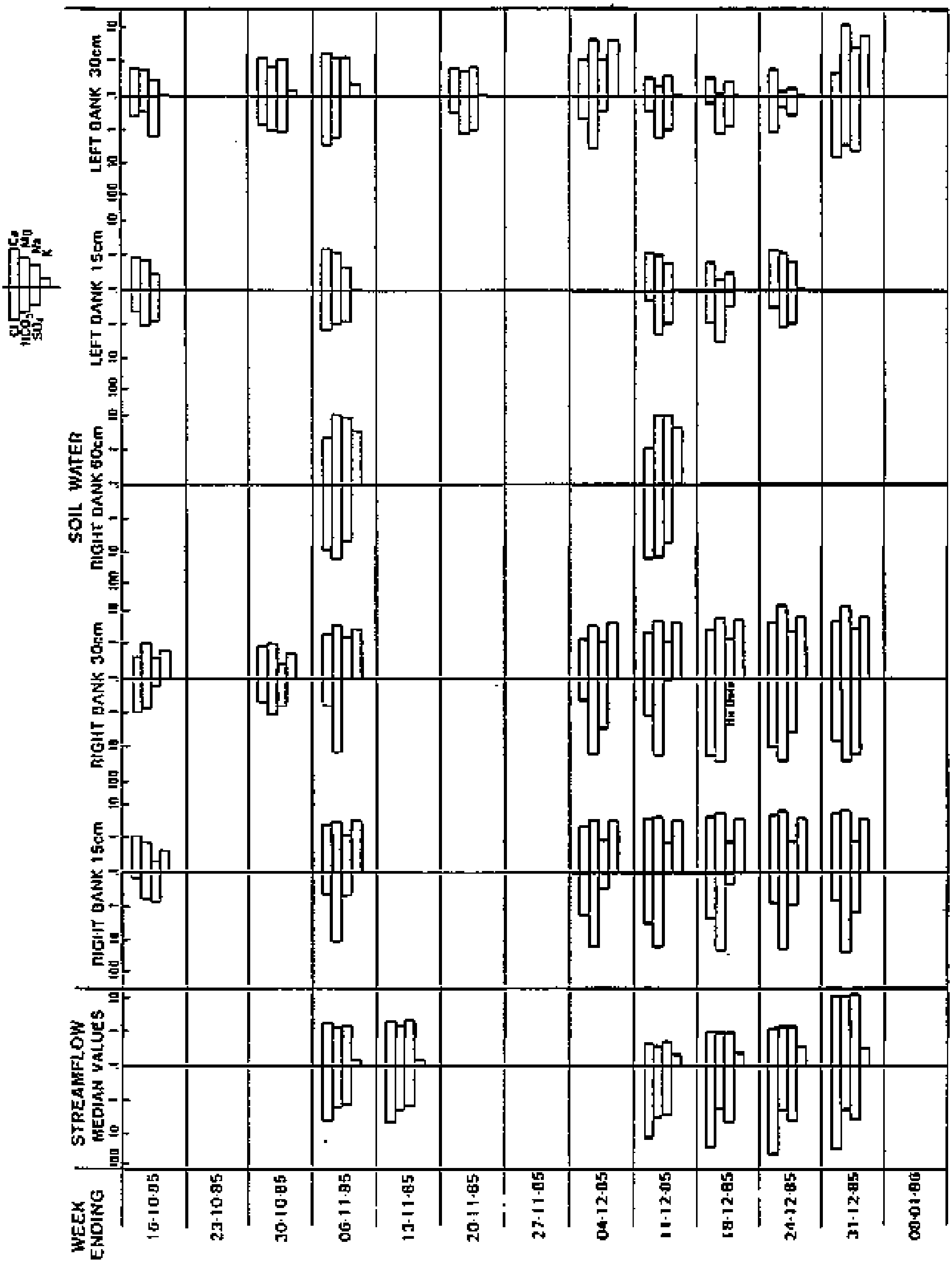


Figure 6.4 Weekly variations of salt concentrations in the streamflow and soil water of Catchment F.

extent in the 30cm soils but with larger temporal variations. The soil moisture samples from the left bank differed from those of the right bank by reflecting larger temporal variations, larger proportions of Cl and lower proportions of K^+. The 15cm samples of the left bank had a characteristic ranking of Ca^{++}, Mg^{++}, Na^+ and K^+ which was not repeated on the right bank and only featured once in the 30cm soils of the left bank.

The above discussion illustrated the dynamic temporal nature of solute concentrations at selected sample points on the left and right banks of Catchment F. As mentioned earlier in this chapter, the chemical characteristics of the soil water is spatially variable as well. Therefore the following discussion attempts to ascertain whether there is any association between the spatial distribution of the soil water chemistry along the channel banks and that of the streamflow.

Chemical characteristics of streamflow along the channel length

Hand samples of streamflow were collected at various points along the channel lengths stretching from the outlet of Catchment B up to its confluence with the main channel from catchment F and then towards the source of Catchment F (Figure 6.5). The sampling was conducted during a period of sustained flow on the 7/11/85. The results were plotted onto bar charts (Figure 6.5), and compared with salt data from the soil water extracts analysed by Moolman (1985). The soil sample positions of Moolman's study are presented in Figure 2.9 and the results are given in Figure 6.6.

The comparison is based on percentages of total equivalents in order to avoid uncertainties caused by factors such as dilution. The main purpose of the exercise was to ascertain whether there were any substantial differences between the water quality in channels F and B and whether the sources of the sustained flow could be ascertained from the soil samples. Only the channel bank situations were considered.

From figure 6.5 it can be seen that the chemical characteristics of the sustained streamflow in the lower reaches of channels B and F are similar. Samples 10 and 11 have dissimilar characteristics. Sample 11 is comparable

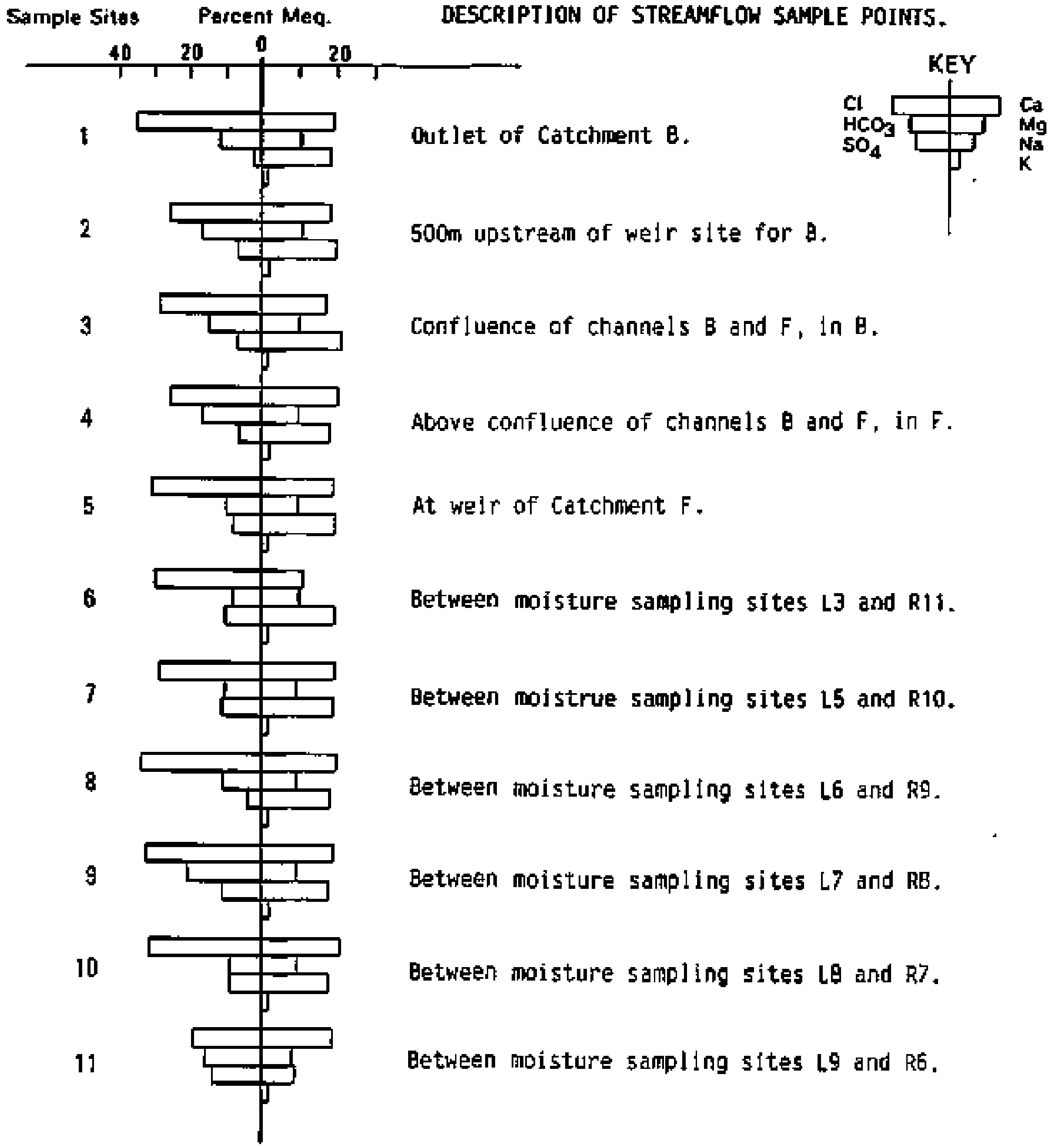


Figure 6.5 Variations in the chemical characteristics of streamflow along the channel length from the outlet of Catchment B to the source of Catchment F. (see also Fig. 2.9)

to the soil sample R6 of the 30-60cm soils on the right bank (Figure 6.6). The high Cl^- proportions of sample 10 are not reflected in the characteristics of the adjacent soils. The characteristic ranking of the cations (Ca^{++} Mg^{++} Na^+ K^+) in most of the 0-30cm soil samples along the left bank is not reflected in any of the streamflow samples. The characteristic low Mg^{++} and K^+ proportions of the right bank samples from the 0-30cm depths is reflected in the streamflow samples. However, the high Cl^- proportions of the streamflow are not reflected in all of the streamflow samples along the right bank, and do occur in some soil samples along the left bank. The streamflow samples do not reflect the same degree of chemical variability along the channel length as that of the soil water extracts.

Piper diagrams (Ward, 1975) were also used to compare the solute proportions of the sustained flow on the 7/11/85 to those for the study period 1/10/85 to 31/12/85 in order to ascertain whether they were representative of this period and further substantiate whether the sustained flows in channels B and F were similar. Figures 6.7(A) and 6.7(B) show that the above streamflow data occupy similar positions on the piper diagram and therefore have similar solute characteristics.

Piper diagrams in Figures 6.7(C) and 6.7(D) compare the chemical characteristics of the sustained flows for Catchment F with those of the soil samples along the channel banks of the left and right slopes for the respective soil depths of 0-30cm and 30-60cm. The latter diagrams are a further aid in interpreting the results presented in Figures 6.5 and 6.6. The plotting positions for the sustained flows in relation to the 0-30cm soil samples indicate very few soil samples occupying the same positions as the streamflow samples. The manner in which the plotting positions of the soil samples surround those of the streamflow indicate that some form of mixing occurred. The higher Cl^- and lower carbonate proportions of the streamflow possibly indicates a higher residence time for the sustained flows and the possible loss of some of the high carbonate proportions by precipitation of calcium carbonate. Some of the soil water may have been lost to the ground water system and some of the Cl^- rich streamflow could have been leached from the rock strata close to the surface. Issar (1986) is of the opinion that high carbonate values should be found in the foot

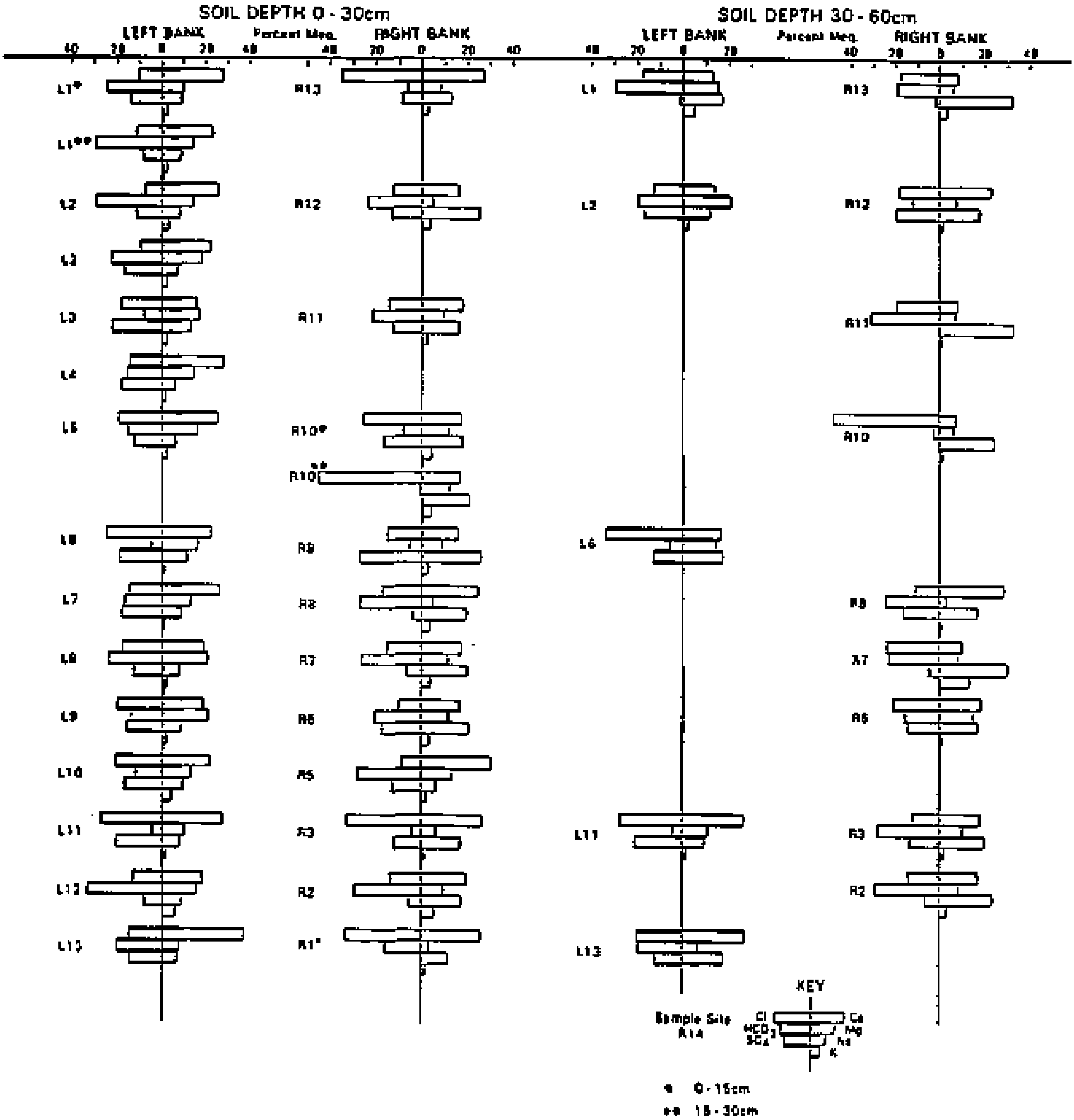
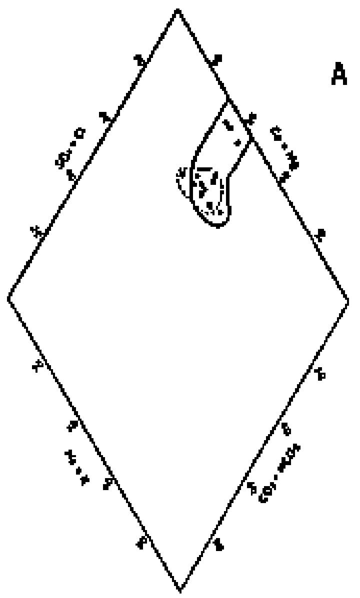
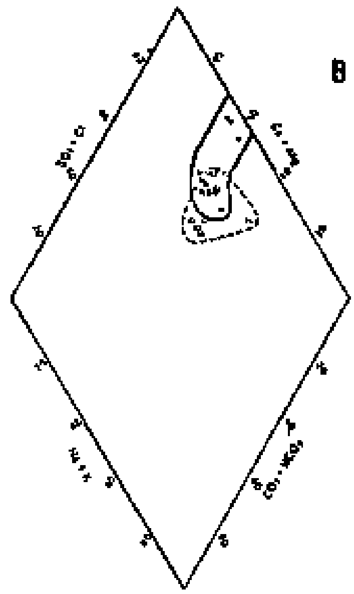


Figure 6.6 Variations in the chemical characteristics of soil water extracts along the left and right banks of Catchment F (data from Moolman,1985).

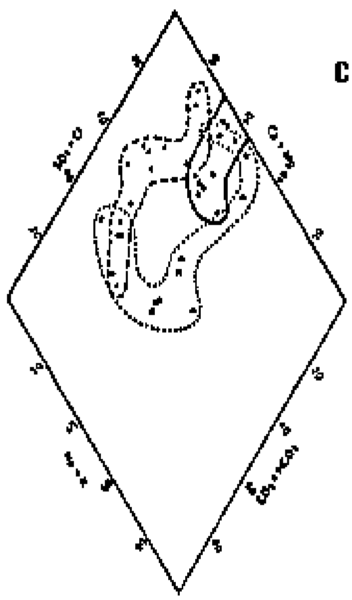
(see also Fig. 2.9)



Median Streamflow samples
■ Catchment F
○ Catchment B

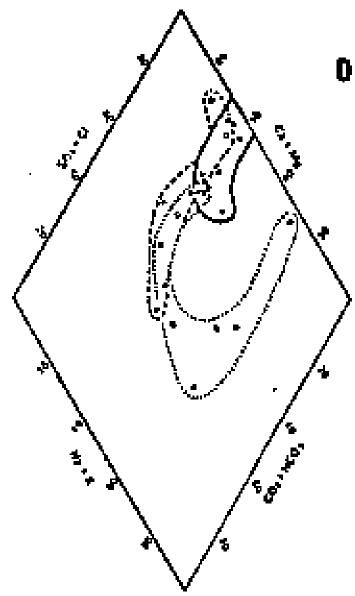


■ Median Streamflow samples Catchment F
○ Channel length distributed samples
(from source of Catchment F to
outlet of Catchment B)



0 - 30cm DEPTH

⊙ Sites L1-L13
▲ Sites R1-R13



30 - 60cm DEPTH

◇ Sites L1-L13
⊡ Sites R1-R13

■ Median Streamflow values

Figure 6.7 A comparison between the sustained streamflow of Catchment F for the study period 9 October 1985 - 31 December 1985 and
A) the sustained streamflow of Catchment B for the same period
B) the channel length distributed samples for 7 November 1985.
C) the soil water salt contents of the 0-30cm soil layers in the channel bank areas
D) the soil water salt contents of the 30-60cm soil layers in the channel bank areas.

slope areas of the catchment as deposits along the channel banks in order to substantiate the above mentioned deposition of calcium carbonate. This was confirmed by in situ observations of such deposits while the data presented in Figure 6.3(C) also indicated the relatively higher spatial concentrations of total alkalinity in the channel bank areas. One weakness in the above comparisons is that they do not account for temporal variations in solute concentrations. The following section therefore compares the temporal variations in the chemical contents of the streamflow to those of rainfall and the soil water.

The chemical characteristics of sustained flow in relation to rainfall and soil water

In order to ascertain whether the sources of sustained streamflow could be established from the chemistry of the rainfall and the soil water, the ionic proportions of these variables were compared using the weekly data presented in Figures 6.2 and 6.4. The results were plotted onto Piper diagrams as well (Figures 6.8(A) and 6.8(B)). The information is not easily interpreted because of the mixing of non-point sources, the possible additions of water from regions of the catchment that were not sampled and the evolution of water chemistry along paths of movement. From Figure 6.1 and Table 6.1 it can be seen that the initial ECe values of the streamflow lie between those of the soil moisture values for the left and right banks. This implies that the sustained streamflow could be a mixture of water from the two banks. Thereafter the ECe values of the streamflow increase with time and coincide more closely with those of the soil moisture for the right bank. The soil moisture ECe values of the right bank increase with depth, implying that the anomalous ECe values for 26/12/85 could come from these soils.

The chemical characteristics of the soil water sample for the 6/11/85 from the 30cm depth of the left bank (Figures 6.2 and 6.4) are similar to those of the initial base flows but the concentrations and relative salt proportions for subsequent events are dissimilar. From Figure 6.2 the proportions of Cl^- to HCO^-_3 are not the same for the streamflow and soil moisture configurations of the right bank for the period 11/12/85 to 31/12/85.

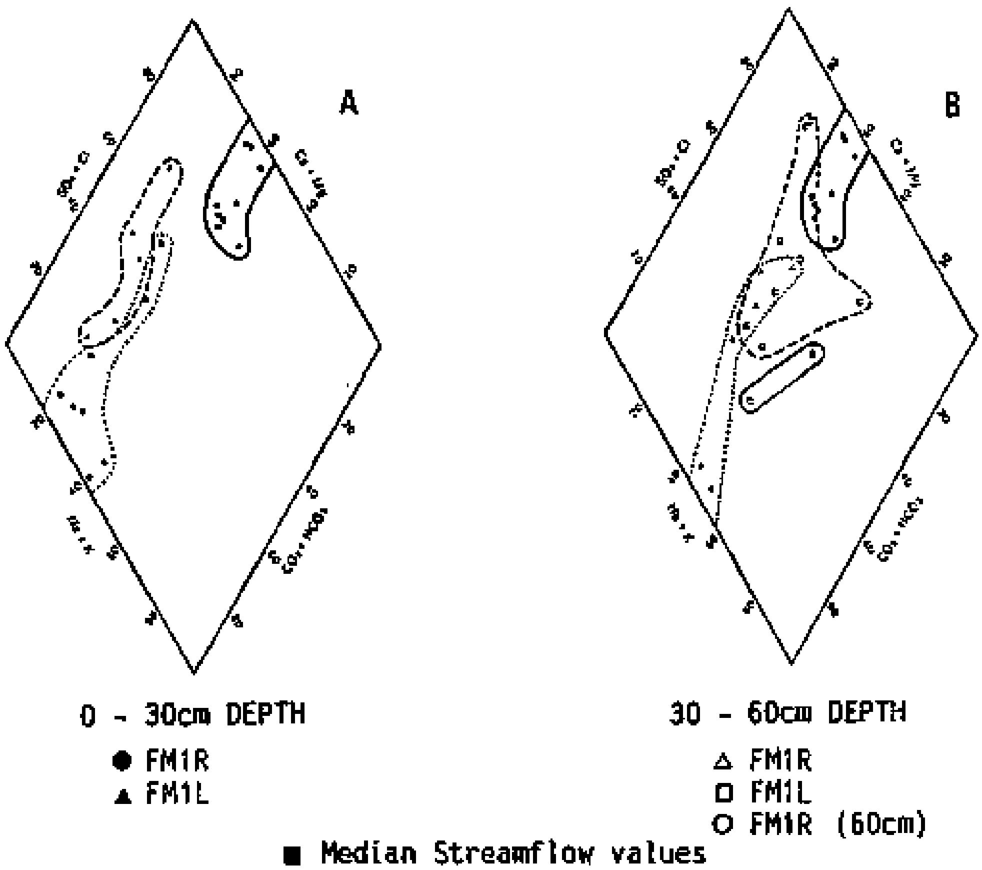


Figure 6.8 A comparison between the chemical characteristics of the sustained streamflows for the study period 9 October 1985 - 31 December 1985 and

A) The soil water hydrochemistry of the 0-30cm soils at sites FM1L and FM1R

B) The soil water hydrochemistry of the 30-60cm soils at sites FM1L and FM1R.

However, from Figure 6.4 it can be seen that the magnitude of the Cl^- concentrations in the 30cm and deeper soil of the right bank are comparable to the concentrations in the stream, again confirming the earlier mentioned view of Issar (1986) that calcium carbonate is being deposited in the soil close to the channel. The Piper diagrams (Figures 6.8(A) and 6.8(B)) illustrate the large temporal variations of the soil water quality at sample sites FM1L and FM1R. Attempts to define patterns of hysteresis in response to the variations in solute levels during the study period were unsuccessful and are therefore not presented. Walling and Webb (1986) stressed that the form and timing of solute responses could be appreciably affected by contrasts in the chemical concentration of surface and subsurface flow components and by the timing of these concentrations from the hillslope system. It is possible that the 7 day sampling interval used to interpret the solute changes within the soil horizons, is too coarse for plotting patterns of hysteresis. The spatial variations in the ionic concentrations of the soils suggest that additional soil-water sample points will be required in further interpretations of the hydro-salinity processes (Figure 6.3).

Issar (1986) has suggested that a series of linear transects of soil water sampling sites would be more useful for interpreting future solute movements within the catchments. These transects should be placed parallel to the drainage directions of the slopes and also along the channel banks. He also suggested that natural isotopes should be included in future water quality analyses in order to provide representative "fingerprints" of the non-point sources of the streamflow. There is also a need to sample the quality of the water that moves through the weathered and fractured strata underlying the shallow (0-60cm) soils of the catchment. The current sampling network only considers the first 30cm of the soils on the left bank and 60cm of the soils on the right bank.

The main benefit of the solute studies is that the results which indicate the spatial distribution of solute movements, are in agreement with the spatial distribution of the MODANSW hydrological simulations (chapter 5) thereby implying that the MODANSW model could possibly be adapted to simulate solute movement as well.

CHAPTER 7

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Introduction

This chapter presents the main findings, conclusions and recommendations of the Water Research Commission funded project conducted at the Hydrological Research Unit of the Department of Geography, Rhodes University, during the period 1982-1986. It also summarises the main aspects of this report and includes, for purposes of completeness, a summary of the research presented in an earlier interim report (Moolman, 1985).

Motivation

The project was motivated because of the large degree of empiricism associated with hydrosalinity models currently used in South Africa. Because of the high level of empiricism any application of a model that assumes realistic parameter values and realistic sub-component interaction is a hazardous procedure. Consequently existing models are inadequate for predicting the influence of landuse changes, on both the hydrological and salinity regimes, as well as the prediction of catchment management effects on the yield and salinity of runoff from catchments. Predictions of hydrosalinity responses in ungauged areas are uncertain when using empirical modelling approaches.

Objective and aims

The main objective of the research project was to overcome the high degree of empiricism of rainfall-runoff and hydrosalinity models currently in use in South Africa. In order to achieve its objective the aims of the research project, as stated in the original contract were :-

i) The collection of data on the principal processes associated with mineralisation, such as the natural generation, storage and transport of runoff, solutes and sediments as dynamically varying, distributed processes at suitable locations in uncultivated semi-arid research catchments near Grahamstown.

ii) The analysis of the collected data with a view to test and improve existing hypotheses and assumptions regarding the natural processes listed in (i) and their interrelationships.

iii) The improvement of existing hydrosalinity models incorporating the improved knowledge of processes.

iv) The development and testing of new hydrosalinity models.

The research concentrated on the use of physically-based models as an alternative to empirical modelling approaches. The application and improvement of these models requires in situ measurements of the physical characteristics of a catchment as well as a knowledge of the interrelated processes giving rise to the generation of runoff, solutes and sediments. Consequently in situ drainage studies and intensive data collection were conducted in a 28 ha catchment in the semi-arid environment of the uncultivated Ecca River Valley which drains into the Great Fish River. This ·hment is nested within a 910ha catchment which was used to test the transferability of physically-based model parameters.

Modification of aims by Steering Committee

The project was conducted during a period of prolonged drought. The mean annual precipitation for the project period (1982-1986) was only 304mm as compared to the previous five year (1977-1981) mean of 499mm. The last quarter of 1985 was a wetter period that yielded useful data. The drought adversely affected the aquisition of sufficient data for model development during the initial three and a half years of the project. The problem was compounded by sedimentation in the streamflow gauging structure and the failure of electronic data logging equipment at crucial times during scarce events. Despite these limitations a large amount of in situ data were collected and numerous process studies were conducted. As a result of the drought the project's Steering Committee, at it's meeting in February 1986, recommended that the modelling aspects of the project should only concentrate on the testing of physically-based hydrological models.

The implications of this decision, in terms of the project's aims, were that no new models were to be developed and no simulations of solute processes were to be attempted. The committee also recommended that the available solute data were to be used to interpret, where possible, the hydrosalinity processes in the catchment. The overall objective of the research project was not, however, altered

Major results and conclusions

The research results have been presented in the form of two reports, viz., an interim report by Moolman (1985) titled 'Data collection for the study of runoff, solutes and sediment generating processes in a semi-arid catchment' and a concluding report by Schultz (1987) titled 'Integrated studies of the generation of runoff, solutes and sediment in tributary catchments of the Great Fish River'

a) The Interim Report

The interim report (Moolman, 1985) describes the research conducted during the first three years of the project. The main topics presented were :

i) the instrumentation of the catchments,

ii) the results of extensive climatic, hydrological, sediment and chemical data collection as well as

iii) the results of extensive soil surveys, in situ drainage studies and laboratory analyses of the physical and chemical properties of the catchment's soils.

The few runoff events that were monitored were mostly related to short duration, high intensity convective storms.

Conclusions of the interim report

i) With respect to instrumentation it was found that the streamflow gauging structure used in the study area could not accommodate the large sediment loads produced in the semi-arid catchment.

ii) The results of intensive soil surveys and laboratory analyses showed that the soils in the research catchments were spatially heterogeneous with respect to their depths, textural compositions, salt contents, soil water retention properties, infiltration properties and also their salt content. Due to the spatial heterogeneity and the non-linearity of hydrosalinity responses it was concluded that lumped averages should not be used as input parameters for physically-based hydrosalinity modelling in the Ecca catchments.

iii) In situ drainage studies and geological investigations showed that the underlying shales and greywackes were interbedded, steeply dipping, weathered and fractured. These strata gave rise to a dip and scarp topography. The subsurface drainage of the dip slopes is directed towards the channel while that of the scarp slopes is not. The soils overlying the dip slopes are generally less permeable and greater proportions of runoff and salt are derived from these slopes.

iv) The generally dry antecedent soil moisture status of the catchments is not condusive to the generation of runoff. In situ soil moisture measurements indicated that as much as 92mm and 60mm of rainfall would be needed to raise the moisture contents of the soil profiles on the dip and scarp slopes respectively to their field capacities.

v) During flash floods the peak salt concentrations occurred on the rising limb of the flood hydrographs with marked decreases in concentrations on the falling limb. Attempts to identify source areas of salt concentrations indicated that the spatial distribution of salts in the catchment is highly variable and log-normally distributed. It was therefore concluded that arithmetic means could not be used in hydrosalinity modelling.

vi) The main conclusion of the interim report was that the current degree of knowledge associated with the generation of runoff, solutes and sediments in semi-arid regions of South Africa is still rather limited.

The main value of the interim report lay in the fact that it provided a large amount of physically-based data that can be incorporated directly into physically-based, distributed models or used in further research into hydrosalinity processes. It also served to pinpoint specific problems concerning research in semi-arid catchments.

b) The second or concluding report

The main aspects covered in the concluding report (Schultz, 1987) were:

i) The description and classification of spatially distributed, physically-based parameters for use in physically-based hydrological models.

ii) The testing of physically-based hydrological models and the transferability of physically-based model parameters.

iii) The interpretation of spatially distributed hydrological, chemical and sediment data.

Two hydrological models were used :-

i) The ACRU model (Schulze, 1984) - moisture budgeting component of this model was used to conduct physically-based, deterministic, site specific, vertical dimension, two-soil layer simulations of daily soil moisture amounts.

ii) The MODANSW model - the model was used to conduct physically-based, deterministic, fully distributed simulations of sediment generation and streamflow hydrographs.

Conclusions of the second report

i) Almost all of the input parameters for the ACRU model (Schulze, 1984) were determined from in situ measurements or laboratory analyses. Exceptions were the parameters required for estimating evapotranspiration. Attempts to calibrate soil moisture variations indicated that the rejuvenated growth of natural vegetation after prolonged dry periods, or irregular occurrences of rainfall events, in semi-arid regions gave rise to problems in simulating evapotranspiration.These problems were not easily accommodated using fixed parameters such as monthly crop factors.

ii) The evapotranspiration and vegetation parameters of the ACRU model are not transferable over relatively short distances (less than 50m) in uncultivated semi-arid regions where a diversity of species are heterogeneously distributed in space.

iii) The uneven distribution of vegetation, soil textures and soil depths gives rise to an uneven distribution of soil water content during wet periods. Closely associated with these spatial variations are heterogeneously distributed pockets of high salt content. From these variations and the non-linearity of hydrosalinity responses it can be concluded that physically-based and physico-chemical modelling approaches should not be attempted in uncultivated semi-arid regions using lumped or semi-distributed modelling approaches unless ways can be found of overcoming the problem of spatial heterogeneity.

iv) Event-based simulations of flood hydrographs, for a 28ha catchment, by means of the MODANSW model indicated that it is possible to obtain representative hydrograph outputs using fully distributed, physically-based inputs.

v) A methodology was presented whereby the spatially heterogeneous hydrological and pedological data were classified into groups of quantitative parameters for use in physically-based, distributed hydrological models. The approach involved a random selection procedure to spatially extrapolate the categorised data from surrounding sample points to all finite elements in the catchment. The extrapolations were based on the results of analyses of approximately 200 soil samples and were aimed at preserving the spatial heterogeneity of a 28ha catchment. It was assumed that a surrounding 910ha catchment would have the same spatial variations in its soil parameters. MODANSW model simulations indicated that assumptions concerning the spatial heterogeneity of physically-based parameters were not transferable from a small to a large catchment where less intensive sampling has been conducted and where different scale factors are used in fully-distributed modelling.

vi) The MODANSW model was used to produce indices which showed the relative amounts of sediment transported from various parts of the research catchments. The results were used to interpret the spatial distribution of overland flow. It was found that more runoff and sediment occurred on the dip slope than on the scarp slope. This is possibly due to the higher infiltration rates on the scarp slope.

vii) A comparison between the chemical characteristics of rainfall, the spatial distribution of the soil water chemistry, the temporal variations in soil moisture and the chemical characteristics of streamflow, was undertaken in order to investigate the relationship between the distribution of hydrological processes and salt contents. The results showed that :

a) The amount of salt contributed from rainfall towards the build up of salts in the soil was different on the dip and scarp slopes due to differing amounts of soil water throughput. On the dip slopes the salt content was increased by six percent during 1985. On the scarp slopes the permeability of the soils is higher and more salts are leached from the soils than the amount of salt input from rainfall. Approximately 52 percent of the initial salt contents for 1985 were washed out of the scarp slope. However, 25 percent of the initial salt contents were replaced by rainfall thereby resulting in a nett loss of 28 percent.

b) The spatial and temporal characteristics of salt concentrations were highly variable within the catchment's soils and the regions in close proximity to the stream channel had a lower total dissolved salt content but larger proportions of calcium carbonate than surrounding areas.

c) In general the results indicated that the salts in the streamflow are a mixture of salts from various non-point sources and that the majority of salts are being derived from the dip slope of the catchment. These findings were in agreement with the spatially distributed hydrological and sediment outputs produced by the fully distributed, physically-based, MODANSW model. The implication of this is that the MODANSW model could be adapted to conduct simulations of spatially distributed solute processes.

Assessment of the research

The research did help to 'overcome' elements of empiricism in hydrosalinity models, but it can't be claimed that empiricism was eliminated altogether. 'Overcome' implies a complete description of all spatially and temporally integrated hydrosalinity processes operating within a catchment. 'Complete' or 'total' descriptions of processes in natural environments are essentially idealistic research concepts. It is therefore doubtful whether empiricism can ever be completely avoided in hydrosalinity modelling. Although the idealistic objective of the research project remained unchanged throughout its duration, its aims had been modified by its steering committee. The aims were achieved and the results did indicate that the element of empiricism could be reduced in hydrosalinity models. The research contributed towards this reduction by :-

i) Making a concerted effort to show that physically-based hydrological model outputs were spatially distributed in a similar manner to observed sources of solutes and sediments, thereby paving the way for the inclusion of suitable chemical components into a physically-based hydrological model such as MODANSW.

ii) Describing the complexities of the spatial and temporal distributions and interrelationships between processes giving rise to the generation of runoff, solutes and sediment.

iii) Identifying some of the practical problems encountered in attempting to study and monitor hydrosalinity processes in remote, uncultivated catchments.

Recommendations for future research

For future hydrosalinity research based on work done in the Ecca catchments it is recommended that :

i) Research should be conducted into the improvement of electronic data logging devices and the design of streamflow gauging structures for use in a semi-arid environment where events are scarce and sedimentation is high.

ii) A longer record ($\pm$10 years) of hydrosalinity data should be obtained in order to understand the solute processes of uncultivated semi-arid catchments.

iii) As large a number of depth distributed soil water sampling sites as possible should be established in order to gain a better understanding of hydrosalinity processes. Intensive soil water sampling should be conducted at relatively short intervals during wet periods in order to describe the dynamic nature of spatially distributed solute processes. Data collection during dry periods could be de-emphasised.

iv) In accordance with the recommendations of Prof. Issar of the Ben Gurion University of the Negev, Israel (personal communication,

1986) water samples should be analysed for natural isotopes as well as their major cations and anions. Such analyses should aid in attempts to identify the source areas of salts and their hydrological pathways.

v) Hydrosalinity model development should concentrate on uncultivated as well as cultivated areas of South Africa since both areas contribute towards the saline pollution of South Africa's scarce water resources.

vi) Optimal water resource and catchment management strategies are vital for minimising factors such as saline pollution. For this purpose a clearer understanding of hydrosalinity processes and the continual development of hydrosalinity models is necessary.

vii) One of the most time consuming and labour intensive aspects of the research project was the aquisition of quantitative, physically-based model parameters. In the light of this and the uncertainties associated with accommodating the spatial heterogeneity of physically-based parameters, it is suggested that continued research into hydrosalinity models should concentrate on empirical as well as physically-based and physicochemical modelling approaches.

This project, which was the first of its kind in South Africa, has contributed towards an understanding of hydrosalinity processes in small uncultivated catchments. It is hoped that there will be continued research to the development of methods for predicting the hydrosalinity response of ungauged areas.

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APPENDICES

LIST OF APPENDICES

APPENDIX A

Volumetric soil water content,
Theta (mm/mm) for the period July, 1983
to December, 1986 for Catchment F.

(Note: The data are from the six, depth distributed, sites presented in figure 2.2 of the main text.)

SOIL-WATER CONTENT(THETA,MM/MM) FOR MONTH 7 ,YEAR 83

JDAY	DATE	FM1L			FM2L	FM3L	FM2R			FM4R			FM5R	
		150	450	600	150	150	150	450	750	150	450	750	150	450
207	26	.171	.000	.000	.166	.155	.286	.000	.000	.269	.000	.000	.235	.000
209	28	.161	.000	.000	.165	.153	.299	.000	.000	.272	.000	.000	.248	.000

SOIL-WATER CONTENT(THETA,MM/MM) FOR MONTH 8 ,YEAR 83

JDAY	DATE	FM1L			FM2L	FM3L	FM2R			FM4R			FM5R	
		150	450	600	150	150	150	450	750	150	450	750	150	450
213	1	.124	.000	.000	.152	.116	.259	.000	.000	.202	.000	.000	.155	.000
214	2	.121	.000	.000	.149	.114	.266	.000	.000	.200	.000	.000	.148	.000
215	3	.111	.000	.000	.143	.104	.250	.000	.000	.177	.000	.000	.141	.000
217	5	.093	.000	.000	.135	.095	.246	.000	.000	.178	.000	.000	.133	.000
220	8	.063	.000	.000	.105	.083	.207	.000	.000	.153	.000	.000	.125	.000
222	10	.068	.000	.000	.113	.083	.215	.000	.000	.145	.000	.000	.121	.000
229	17	.048	.000	.000	.092	.062	.193	.000	.000	.131	.000	.000	.112	.000
236	24	.044	.000	.000	.065	.056	.173	.000	.000	.109	.000	.000	.087	.000
243	31	.041	.000	.000	.072	.049	.153	.000	.000	.081	.000	.000	.080	.000

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SOIL-WATER CONTENT(THETA,MM/MM) FOR MONTH 9 ,YEAR 83

JDAY	DATE	FM1L			FM2L	FM3L	FM2R			FM4R			FM5R	
		150	450	600	150	150	150	450	750	150	450	750	150	450
250	7	.038	.000	.000	.068	.035	.131	.000	.000	.080	.000	.000	.073	.000
257	14	.082	.000	.000	.120	.088	.212	.148	.153	.139	.127	.000	.122	.000
264	21	.091	.000	.159	.132	.107	.217	.166	.148	.140	.130	.125	.122	.128
271	28	.083	.000	.141	.116	.085	.206	.160	.142	.117	.125	.115	.113	.128

SOIL-WATER CONTENT(THETA,MM/MM) FOR MONTH 10 ,YEAR 83

JDAY	DATE	FM1L			FM2L	FM3L	FM2R			FM4R			FM5R	
		150	450	600	150	150	150	450	750	150	450	750	150	450
278	5	.148	.000	.147	.148	.140	.287	.172	.140	.226	.126	.119	.196	.122
285	12	.000	.000	.161	.000	.000	.000	.175	.146	.000	.126	.118	.000	.134
292	19	.157	.000	.161	.143	.126	.268	.182	.156	.193	.125	.114	.188	.121
299	26	.093	.000	.000	.101	.088	.200	.172	.146	.134	.125	.116	.117	.126

SOIL-WATER CONTENT(THETA,MM/MM) FOR MONTH 11 ,YEAR 83

JDAY	DATE	FM1L			FM2L	FM3L	FM2R			FM4R			FM5R	
		150	450	600	150	150	150	450	750	150	450	750	150	450
306	2	.039	.000	.163	.040	.032	.109	.169	.154	.066	.122	.119	.057	.126
313	9	.043	.000	.147	.069	.034	.113	.166	.151	.079	.125	.124	.064	.122
320	16	.085	.000	.122	.089	.074	.184	.158	.144	.159	.125	.120	.157	.115
327	23	.111	.000	.117	.093	.064	.171	.143	.000	.191	.124	.116	.163	.119
334	30	.093	.000	.116	.077	.103	.169	.144	.137	.186	.123	.117	.162	.121

SOIL-WATER CONTENT(THETA,MM/MM) FOR MONTH 12 ,YEAR 83

JDAY	DATE	FM1L 150	FM1L 450	FM1L 600	FM2L 150	FM3L 150	FM2R 150	FM2R 450	FM2R 750	FM4R 150	FM4R 450	FM4R 750	FM5R 150	FM5R 450
341	7	.069	.000	.099	.049	.039	.093	.136	.139	.068	.125	.123	.075	.121
355	21	.029	.000	.000	.040	.017	.079	.000	.000	.055	.000	.000	.047	.000

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SOIL-WATER CONTENT(THETA,MM/MM) FOR MONTH 1 ,YEAR 84

JDAY	DATE	FM1L 150	FM1L 450	FM1L 600	FM2L 150	FM3L 150	FM2R 150	FM2R 450	FM2R 750	FM4R 150	FM4R 450	FM4R 750	FM5R 150	FM5R 450
4	4	.036	.000	.084	.054	.029	.090	.000	.127	.088	.130	.124	.075	.123
18	18	.027	.047	.079	.033	.011	.062	.129	.118	.061	.124	.119	.052	.120
25	25	.022	.035	.080	.028	.009	.072	.110	.118	.052	.122	.121	.046	.122

SOIL-WATER CONTENT(THETA,MM/MM) FOR MONTH 2 ,YEAR 84

JDAY	DATE	FM1L 150	FM1L 450	FM1L 600	FM2L 150	FM3L 150	FM2R 150	FM2R 450	FM2R 750	FM4R 150	FM4R 450	FM4R 750	FM5R 150	FM5R 450
32	1	.025	.000	.000	.033	.012	.074	.000	.000	.056	.000	.000	.046	.000
39	8	.025	.000	.000	.038	.010	.072	.000	.000	.053	.000	.000	.041	.000
46	15	.025	.000	.000	.036	.011	.078	.000	.000	.052	.000	.000	.042	.000
53	22	.036	.000	.000	.033	.015	.076	.000	.000	.050	.000	.000	.044	.000
60	29	.038	.000	.000	.043	.020	.085	.000	.000	.060	.000	.000	.048	.000

SOIL-WATER CONTENT(THETA,MM/MM) FOR MONTH 3 ,YEAR 84

JDAY	DATE	FM1L 150	FM1L 450	FM1L 600	FM2L 150	FM3L 150	FM2R 150	FM2R 450	FM2R 750	FM4R 150	FM4R 450	FM4R 750	FM5R 150	FM5R 450
67	7	.054	.000	.000	.066	.038	.101	.000	.000	.088	.000	.000	.057	.000
74	14	.074	.042	.074	.080	.054	.145	.122	.110	.113	.116	.125	.078	.108
81	21	.000	.040	.076	.000	.000	.000	.122	.103	.000	.116	.126	.000	.109
88	28	.000	.042	.074	.000	.000	.000	.116	.116	.000	.113	.122	.000	.110

SOIL-WATER CONTENT(THETA,MM/MM) FOR MONTH 4 ,YEAR 84

JDAY	DATE	FM1L 150	FM1L 450	FM1L 600	FM2L 150	FM3L 150	FM2R 150	FM2R 450	FM2R 750	FM4R 150	FM4R 450	FM4R 750	FM5R 150	FM5R 450
95	4	.040	.036	.069	.039	.017	.088	.120	.113	.068	.114	.114	.046	.106
102	11	.161	.041	.072	.130	.105	.252	.115	.119	.226	.115	.121	.161	.110
109	18	.071	.044	.072	.094	.067	.215	.116	.111	.155	.123	.119	.127	.106
116	25	.056	.045	.070	.061	.037	.159	.122	.107	.105	.126	.124	.074	.111

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SOIL-WATER CONTENT(THETA,MM/MM) FOR MONTH 5 ,YEAR 84

JDAY	DATE	FM1L 150	FM1L 450	FM1L 600	FM2L 150	FM3L 150	FM2R 150	FM2R 450	FM2R 750	FM4R 150	FM4R 450	FM4R 750	FM5R 150	FM5R 450
123	2	.049	.039	.076	.066	.050	.158	.122	.118	.106	.122	.119	.076	.114
137	16	.033	.037	.069	.051	.029	.110	.120	.108	.080	.119	.114	.068	.107
144	23	.031	.040	.073	.051	.026	.114	.119	.111	.085	.118	.122	.076	.110
151	30	.050	.038	.069	.064	.043	.133	.124	.112	.090	.117	.119	.080	.113

SOIL-WATER CONTENT(THETA,MM/MM) FOR MONTH 6 ,YEAR 84

JDAY	DATE	FM1L 150	FM1L 450	FM1L 600	FM2L 150	FM3L 150	FM2R 150	FM2R 450	FM2R 750	FM4R 150	FM4R 450	FM4R 750	FM5R 150	FM5R 450
158	6	.043	.043	.068	.049	.033	.105	.119	.114	.084	.120	.121	.071	.104
165	13	.067	.035	.067	.083	.058	.146	.122	.108	.117	.119	.116	.092	.111
172	20	.000	.039	.065	.000	.000	.000	.121	.110	.000	.116	.119	.000	.113
173	21	.161	.045	.073	.174	.129	.279	.124	.108	.299	.147	.114	.242	.108
179	27	.138	.045	.070	.124	.246	.258	.132	.111	.221	.147	.120	.160	.109

SOIL-WATER CONTENT(THETA,MM/MM) FOR MONTH 7 ,YEAR 84

JDAY	DATE	FM1L 150	FM1L 450	FM1L 600	FM2L 150	FM3L 150	FM2R 150	FM2R 450	FM2R 750	FM4R 150	FM4R 450	FM4R 750	FM5R 150	FM5R 450
186	4	.072	.047	.077	.085	.065	.179	.130	.112	.166	.141	.124	.136	.110
193	11	.071	.045	.076	.085	.066	.194	.132	.110	.141	.138	.123	.133	.112
200	18	.069	.043	.073	.064	.049	.157	.127	.114	.121	.134	.114	.113	.109
207	25	.078	.047	.076	.078	.076	.216	.125	.111	.140	.128	.118	.125	.117

SOIL-WATER CONTENT(THETA,MM/MM) FOR MONTH 8 ,YEAR 84

JDAY	DATE	FM1L 150	FM1L 450	FM1L 600	FM2L 150	FM3L 150	FM2R 150	FM2R 450	FM2R 750	FM4R 150	FM4R 450	FM4R 750	FM5R 150	FM5R 450
214	1	.137	.045	.075	.130	.098	.239	.124	.112	.192	.127	.117	.164	.110
221	8	.054	.043	.074	.077	.050	.173	.124	.118	.126	.125	.114	.117	.109
228	15	.054	.041	.075	.064	.043	.146	.125	.112	.114	.127	.118	.104	.112
235	22	.059	.044	.073	.067	.038	.130	.124	.114	.109	.126	.120	.095	.111
240	27	.050	.040	.078	.071	.000	.000	.119	.111	.000	.125	.122	.000	.111

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SOIL-WATER CONTENT(THETA,MM/MM) FOR MONTH 9 ,YEAR 84

JDAY	DATE	FM1L 150	FM1L 450	FM1L 600	FM2L 150	FM3L 150	FM2R 150	FM2R 450	FM2R 750	FM4R 150	FM4R 450	FM4R 750	FM5R 150	FM5R 450
249	5	.069	.045	.076	.075	.041	.119	.123	.116	.109	.124	.120	.105	.110
256	12	.053	.044	.077	.058	.027	.107	.122	.108	.086	.119	.115	.078	.110
263	19	.056	.041	.071	.065	.026	.101	.125	.109	.088	.121	.122	.087	.111
271	27	.060	.042	.072	.067	.030	.108	.121	.112	.087	.125	.114	.085	.110

SOIL-WATER CONTENT(THETA,MM/MM) FOR MONTH 10 ,YEAR 84

		FM1L			FM2L	FM3L	FM2R			FM4R			FM5R	
JDAY	DATE	150	450	600	150	150	150	450	750	150	450	750	150	450
277	3	.079	.040	.072	.069	.044	.118	.124	.111	.105	.124	.118	.094	.113
284	10	.067	.040	.071	.064	.045	.131	.123	.111	.120	.123	.123	.112	.109
291	17	.051	.039	.073	.049	.027	.097	.123	.112	.093	.121	.118	.089	.107
298	24	.045	.043	.072	.047	.028	.099	.125	.114	.093	.125	.121	.094	.111
305	31	.051	.042	.071	.042	.027	.088	.121	.114	.087	.121	.120	.087	.107

SOIL-WATER CONTENT(THETA,MM/MM) FOR MONTH 11 ,YEAR 84

		FM1L			FM2L	FM3L	FM2R			FM4R			FM5R	
JDAY	DATE	150	450	600	150	150	150	450	750	150	450	750	150	450
312	7	.041	.043	.071	.037	.013	.068	.120	.112	.071	.123	.116	.074	.112
319	14	.046	.041	.071	.037	.014	.074	.123	.114	.000	.119	.123	.000	.109
326	21	.076	.042	.071	.068	.034	.118	.124	.106	.112	.121	.115	.107	.104
333	28	.046	.042	.071	.033	.019	.075	.122	.107	.080	.116	.119	.076	.111

SOIL-WATER CONTENT(THETA,MM/MM) FOR MONTH 12 ,YEAR 84

		FM1L			FM2L	FM3L	FM2R			FM4R			FM5R	
JDAY	DATE	150	450	600	150	150	150	450	750	150	450	750	150	450
340	5	.091	.044	.073	.103	.069	.155	.121	.117	.158	.121	.119	.158	.109
347	12	.050	.041	.072	.058	.033	.086	.123	.113	.089	.118	.118	.091	.110

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SOIL-WATER CONTENT(THETA,MM/MM) FOR MONTH 1 ,YEAR 85

		FM1L			FM2L	FM3L	FM2R			FM4R			FM5R	
JDAY	DATE	150	450	600	150	150	150	450	750	150	450	750	150	450
9	9	.063	.037	.072	.067	.036	.097	.121	.110	.094	.117	.117	.103	.108
16	16	.144	.047	.070	.102	.087	.233	.120	.108	.212	.123	.118	.200	.108
23	23	.038	.042	.072	.038	.038	.117	.125	.109	.123	.123	.116	.081	.109
30	30	.074	.041	.074	.070	.070	.096	.124	.110	.103	.122	.120	.087	.109

SOIL-WATER CONTENT(THETA,MM/MM) FOR MONTH 2 ,YEAR 85

		FM1L			FM2L	FM3L	FM2R			FM4R			FM5R	
JDAY	DATE	150	450	600	150	150	150	450	750	150	450	750	150	450
37	6	.145	.050	.076	.106	.084	.282	.125	.112	.222	.124	.122	.210	.113
44	13	.152	.087	.094	.116	.100	.255	.165	.115	.233	.149	.123	.232	.129
51	20	.053	.084	.124	.057	.037	.155	.168	.115	.129	.148	.116	.148	.132
58	27	.049	.078	.134	.044	.037	.135	.165	.106	.100	.142	.126	.110	.129

SOIL-WATER CONTENT(THETA,MM/MM) FOR MONTH 3 ,YEAR 85

		FM1L			FM2L	FM3L	FM2R			FM4R			FM5R	
JDAY	DATE	150	450	600	150	150	150	450	750	150	450	750	150	450
65	6	.057	.076	.139	.047	.027	.129	.164	.118	.102	.139	.121	.056	.125
72	13	.040	.071	.128	.022	.015	.103	.162	.115	.091	.134	.120	.094	.122
79	20	.071	.056	.125	.064	.033	.129	.153	.116	.109	.130	.119	.108	.120
86	27	.036	.063	.118	.018	.017	.099	.149	.113	.082	.124	.120	.091	.117

SOIL-WATER CONTENT(THETA,MM/MM) FOR MONTH 4 ,YEAR 85

		FMIL			FM2L	FM3L	FM2R			FM4R			FM5R	
JDAY	DATE	150	450	600	150	150	150	450	750	150	450	750	150	450
93	3	.034	.055	.105	.012	.011	.094	.146	.115	.080	.124	.113	.074	.113
100	10	.122	.055	.099	.041	.051	.226	.142	.121	.192	.121	.125	.179	.120
107	17	.062	.058	.098	.022	.021	.148	.143	.113	.117	.122	.122	.104	.118
114	24	.107	.057	.096	.059	.046	.192	.140	.114	.159	.125	.118	.155	.117

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SOIL-WATER CONTENT(THETA,MM/MM) FOR MONTH 5 ,YEAR 85

		FMIL			FM2L	FM3L	FM2R			FM4R			FM5R	
JDAY	DATE	150	450	600	150	150	150	450	750	150	450	750	150	450
121	1	.059	.053	.095	.048	.039	.162	.142	.124	.119	.126	.125	.118	.114
128	8	.059	.053	.093	.022	.026	.139	.143	.116	.111	.124	.125	.105	.117
135	15	.064	.053	.095	.020	.015	.112	.138	.120	.082	.123	.119	.087	.117
142	22	.022	.051	.087	.009	.008	.099	.140	.117	.076	.122	.120	.064	.114
149	29	.036	.045	.083	.036	.036	.085	.128	.111	.246	.123	.120	.246	.111

SOIL-WATER CONTENT(THETA,MM/MM) FOR MONTH 6 ,YEAR 85

		FM1L			FM2L	FM3L	FM2R			FM4R			FM5R	
JDAY	DATE	150	450	600	150	150	150	450	750	150	450	750	150	450
156	5	.053	.043	.082	.030	.028	.125	.128	.118	.093	.125	.121	.093	.116
163	12	.079	.050	.082	.061	.055	.150	.127	.114	.126	.120	.119	.092	.107
170	19	.057	.047	.085	.071	.049	.141	.129	.116	.090	.123	.117	.084	.113
177	26	.142	.052	.084	.124	.096	.233	.129	.119	.220	.122	.120	.194	.116

SOIL-WATER CONTENT(THETA,MM/MM) FOR MONTH 7 ,YEAR 85

		FMIL			FM2L	FM3L	FM2R			FM4R			FM5R	
JDAY	DATE	150	450	600	150	150	150	450	750	150	450	750	150	450
184	3	.083	.049	.079	.102	.075	.196	.130	.115	.171	.120	.121	.139	.114
191	10	.067	.051	.089	.087	.095	.091	.129	.113	.079	.124	.122	.076	.110
198	17	.056	.047	.082	.064	.045	.121	.131	.115	.107	.119	.122	.097	.115
205	24	.059	.048	.079	.062	.058	.124	.124	.109	.108	.122	.117	.101	.114
212	31	.066	.041	.077	.063	.043	.103	.127	.117	.098	.119	.121	.090	.112

SOIL-WATER CONTENT(THETA,MM/MM) FOR MONTH 8 ,YEAR 95

		FM1L			FM2L	FM3L	FM2R			FM4R			FM5R	
JDAY	DATE	150	450	600	150	150	150	450	750	150	450	750	150	450
219	7	.049	.050	.076	.051	.037	.095	.129	.110	.085	.122	.121	.076	.111
226	14	.053	.000	.000	.048	.046	.101	.000	.000	.089	.000	.000	.085	.000
233	21	.051	.043	.079	.049	.038	.095	.126	.117	.084	.122	.117	.080	.113
240	28	.043	.049	.080	.033	.028	.079	.126	.112	.075	.116	.124	.068	.110

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SOIL-WATER CONTENT(THETA,MM/MM) FOR MONTH 9 ,YEAR 85

JDAY	DATE	FM1L 150	FM1L 450	FM1L 600	FM2L 150	FM3L 150	FM2R 150	FM2R 450	FM2R 750	FM4R 150	FM4R 450	FM4R 750	FM5R 150	FM5R 450
247	4	.049	.047	.078	.039	.038	.093	.126	.118	.083	.122	.121	.073	.108
254	11	.044	.045	.076	.041	.033	.083	.127	.112	.078	.119	.113	.070	.105
261	18	.055	.045	.072	.049	.037	.087	.128	.112	.086	.120	.120	.074	.110
268	25	.043	.045	.073	.038	.036	.078	.127	.114	.077	.120	.122	.071	.110

SOIL-WATER CONTENT(THETA,MM/MM) FOR MONTH 10 ,YEAR 85

JDAY	DATE	FM1L 150	FM1L 450	FM1L 600	FM2L 150	FM3L 150	FM2R 150	FM2R 450	FM2R 750	FM4R 150	FM4R 450	FM4R 750	FM5R 150	FM5R 450
275	2	.043	.040	.072	.034	.030	.074	.125	.113	.064	.117	.119	.065	.108
282	9	.046	.043	.070	.040	.030	.074	.124	.112	.076	.119	.124	.069	.107
289	16	.160	.114	.098	.163	.146	.274	.181	.111	.319	.127	.114	.300	.123
296	23	.072	.092	.121	.079	.056	.142	.185	.116	.134	.136	.117	.129	.140
303	30	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000

SOIL-WATER CONTENT(THETA,MM/MM) FOR MONTH 11 ,YEAR 85

JDAY	DATE	FM1L 150	FM1L 450	FM1L 600	FM2L 150	FM3L 150	FM2R 150	FM2R 450	FM2R 750	FM4R 150	FM4R 450	FM4R 750	FM5R 150	FM5R 450
310	6	.110	.126	.229	.000	.000	.371	.227	.236	.317	.215	.155	.259	.220
317	13	.162	.127	.137	.000	.000	.368	.205	.114	.318	.135	.122	.331	.162
324	20	.078	.094	.182	.000	.000	.315	.207	.211	.200	.176	.180	.125	.181
331	27	.215	.208	.294	.194	.169	.310	.217	.230	.310	.153	.167	.290	.188

SOIL-WATER CONTENT(THETA,MM/MM) FOR MONTH 12 ,YEAR 85

JDAY	DATE	FM1L 150	FM1L 450	FM1L 600	FM2L 150	FM3L 150	FM2R 150	FM2R 450	FM2R 750	FM4R 150	FM4R 450	FM4R 750	FM5R 150	FM5R 450
339	5	.187	.127	.285	.141	.127	.293	.232	.242	.278	.205	.242	.282	.215
345	11	.129	.117	.262	.134	.085	.241	.230	.239	.208	.208	.245	.197	.205
352	18	.092	.104	.230	.085	.020	.386	.225	.236	.287	.196	.227	.235	.143
358	24	.130	.106	.222	.000	.000	.378	.225	.233	.305	.197	.222	.268	.178
365	31	.101	.098	.188	.000	.000	.361	.214	.222	.264	.187	.211	.210	.158

SOIL-WATER CONTENT(THETA,MM/MM) FOR MONTH 1 ,YEAR 86

JDAY	DATE	FM1L 150	FM1L 450	FM1L 600	FM2L 150	FM3L 150	FM2R 150	FM2R 450	FM2R 750	FM4R 150	FM4R 450	FM4R 750	FM5R 150	FM5R 450
8	8	.125	.096	.196	.097	.067	.243	.220	.236	.226	.178	.197	.200	.153
15	15	.072	.119	.178	.062	.042	.165	.217	.223	.145	.155	.186	.116	.137
22	22	.064	.073	.159	.054	.027	.073	.211	.221	.119	.159	.147	.090	.196
29	29	.198	.059	.132	.166	.122	.256	.215	.227	.281	.163	.194	.231	.141

SOIL-WATER CONTENT(THETA,MM/MM) FOR MONTH 2 ,YEAR 86

		FM1L			FM2L	FM3L	FM2R			FM4R			FM5R	
JDAY	DATE	150	450	600	150	150	150	450	750	150	450	750	150	450
36	5	.083	.059	.110	.045	.045	.151	.202	.209	.147	.066	.056	.118	.051
43	12	.049	.058	.102	.027	.024	.097	.193	.203	.087	.162	.179	.077	.133
50	19	.042	.050	.098	.019	.017	.088	.176	.198	.080	.150	.180	.065	.132
57	26	.088	.089	.090	.065	.059	.160	.165	.187	.140	.151	.177	.121	.142

SOIL-WATER CONTENT(THETA,MM/MM) FOR MONTH 3 ,YEAR 86

		FM1L			FM2L	FM3L	FM2R			FM4R			FM5R	
JDAY	DATE	150	450	600	150	150	150	450	750	150	450	750	150	450
64	5	.046	.055	.094	.040	.030	.099	.149	.173	.099	.150	.166	.089	.128
71	12	.184	.049	.084	.110	.105	.263	.146	.166	.298	.143	.120	.243	.131
78	19	.081	.055	.094	.053	.028	.145	.165	.136	.390	.142	.153	.130	.124
85	26	.280	.055	.094	.167	.180	.422	.140	.143	.369	.147	.150	.359	.130

SOIL-WATER CONTENT(THETA,MM/MM) FOR MONTH 4 ,YEAR 86

		FM1L			FM2L	FM3L	FM2R			FM4R			FM5R	
JDAY	DATE	150	450	600	150	150	150	450	750	150	450	750	150	450
92	2	.052	.047	.084	.033	.024	.120	.143	.140	.096	.138	.149	.103	.128
100	10	.070	.052	.092	.059	.031	.145	.143	.139	.103	.128	.139	.107	.131
106	16	.046	.048	.088	.033	.014	.107	.142	.128	.088	.139	.143	.093	.131
113	23	.044	.053	.085	.032	.020	.101	.139	.133	.091	.132	.146	.085	.131
120	30	.043	.049	.087	.030	.016	.095	.136	.128	.084	.134	.143	.084	.132

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SOIL-WATER CONTENT(THETA,MM/MM) FOR MONTH 5 ,YEAR 86

		FM1L			FM2L	FM3L	FM2R			FM4R			FM5R	
JDAY	DATE	150	450	600	150	150	150	450	750	150	450	750	150	450
127	7	.046	.050	.081	.027	.012	.096	.139	.128	.084	.136	.144	.074	.129
134	14	.041	.045	.080	.033	.012	.089	.133	.121	.080	.134	.141	.082	.124
141	21	.038	.047	.082	.028	.011	.088	.134	.128	.069	.132	.139	.066	.125
148	28	.040	.042	.077	.028	.015	.090	.132	.128	.073	.131	.137	.075	.126

SOIL-WATER CONTENT(THETA,MM/MM) FOR MONTH 6 ,YEAR 86

		FM1L			FM2L	FM3L	FM2R			FM4R			FM5R	
JDAY	DATE	150	450	600	150	150	150	450	750	150	450	750	150	450
155	4	.036	.046	.081	.029	.010	.081	.133	.121	.073	.131	.138	.066	.122
162	11	.119	.044	.076	.088	.088	.238	.137	.123	.194	.132	.141	.167	.126
169	18	.053	.046	.076	.051	.038	.163	.127	.125	.125	.128	.137	.086	.124
177	26	.078	.045	.083	.061	.046	.184	.131	.121	.143	.124	.135	.126	.126

SOIL-WATER CONTENT(THETA,MM/MM) FOR MONTH 7 ,YEAR 86

		FM1L			FM2L	FM3L	FM2R			FM4R			FM5R	
JDAY	DATE	150	450	600	150	150	150	450	750	150	450	750	150	450
183	2	.054	.040	.079	.046	.035	.149	.135	.124	.109	.129	.137	.096	.126
190	9	.011	.044	.079	.000	.000	.167	.137	.117	.057	.129	.140	.050	.122
197	16	.049	.046	.086	.000	.000	.188	.132	.119	.142	.125	.138	.129	.122
211	30	.047	.043	.079	.000	.000	.176	.134	.124	.128	.127	.136	.115	.122

SOIL-WATER CONTENT(THETA,MM/MM) FOR MONTH 8 ,YEAR 86

		FM1L			FM2L	FM3L	FM2R			FM4R			FM5R	
JDAY	DATE	150	450	600	150	150	150	450	750	150	450	750	150	450
218	6	.045	.042	.080	.000	.000	.177	.133	.120	.125	.129	.136	.116	.126
225	13	.046	.045	.070	.000	.000	.100	.133	.166	.136	.129	.143	.118	.126
230	18	.046	.045	.075	.000	.000	.177	.131	.123	.000	.127	.134	.131	.127
232	20	.053	.039	.084	.000	.000	.177	.133	.119	.212	.120	.131	.120	.126
239	27	.051	.044	.075	.000	.000	.196	.131	.120	.149	.133	.137	.133	.120

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SOIL-WATER CONTENT(THETA,MM/MM) FOR MONTH 9 ,YEAR 86

		FM1L			FM2L	FM3L	FM2R			FM4R			FM5R	
JDAY	DATE	150	450	600	150	150	150	450	750	150	450	750	150	450
246	3	.075	.044	.079	.000	.000	.204	.129	.126	.194	.123	.132	.169	.121
253	10	.063	.045	.083	.000	.000	.199	.129	.125	.175	.120	.136	.153	.126
260	17	.049	.044	.079	.000	.000	.173	.133	.120	.157	.129	.130	.149	.125
267	24	.054	.043	.073	.000	.000	.181	.133	.117	.149	.126	.129	.135	.126

SOIL-WATER CONTENT(THETA,MM/MM) FOR MONTH 10 ,YEAR 86

		FM1L			FM2L	FM3L	FM2R			FM4R			FM5R	
JDAY	DATE	150	450	600	150	150	150	450	750	150	450	750	150	450
274	1	.081	.050	.077	.000	.000	.226	.131	.117	.232	.126	.127	.229	.125
281	8	.085	.052	.084	.000	.000	.223	.133	.122	.245	.129	.131	.244	.129
288	15	.085	.060	.099	.000	.000	.237	.140	.144	.217	.146	.147	.245	.130
295	22	.079	.047	.080	.000	.000	.175	.132	.119	.140	.125	.129	.159	.123
303	30	.011	.040	.052	.000	*****	.035	.120	.120	.032	.125	.132	.073	.126

SOIL-WATER CONTENT(THETA,MM/MM) FOR MONTH 11 ,YEAR 86

		FM1L			FM2L	FM3L	FM2R			FM4R			FM5R	
JDAY	DATE	150	450	600	150	150	150	450	750	150	450	750	150	450
316	12	.046	.047	.070	.023	.022	.005	.133	.117	.004	.124	.120	.142	.120
323	19	.056	.047	.082	.029	.015	.070	.132	.110	.064	.121	.120	.111	.122
330	26	.044	.044	.077	.020	.016	.089	.126	.117	.085	.121	.129	.135	.120

SOIL-WATER CONTENT(THETA,MM/MM) FOR MONTH 12 ,YEAR 86

		FM1L			FM2L	FM3L	FM2R			FM4R			FM5R	
JDAY	DATE	150	450	600	150	150	150	450	750	150	450	750	150	450
337	3	.045	.049	.082	.029	.015	.072	.131	.125	.084	.132	.136	.119	.123
344	10	.024	.046	.073	.010	.004	.062	.129	.121	.057	.120	.127	.099	.118
351	17	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
358	24	.026	.045	.077	.015	.020	.059	.125	.116	.060	.117	.119	.099	.113
365	31	.024	.043	.079	.009	.019	.057	.124	.115	.060	.117	.121	.096	.110

APPENDIX B

Streamflow data for the period
October, 1985 to January, 1986
for Catchment F.

TOTAL DAILY FLOWS IN: 1CATCH F
DATE OF EVENT START :
31 10 85
DAY STARTS AT 0.00 HOURS
1269

EVENT DAY 1 DATE 31 10 85
HOURLY TOTALS (LITRES)

.000	.000	.000	.000	.000	.000
.000	.000	.000	.000	.000	.000
.000	.000	.000	.000	.000	.000
.000	.000	.000	.000	.000	.000

DAY TOTAL .000

EVENT DAY 2 DATE 1 11 85
HOURLY TOTALS (LITRES)

.000	.000	.000	.000	.000	.000
.000	.000	.000	.000	.000	.000
.000	.000	227.700	360.000	360.000	360.000
360.000	360.000	360.000	360.000	360.000	360.000

DAY TOTAL 3467.700

EVENT DAY 3 DATE 2 11 85
HOURLY TOTALS (LITRES)

517.500	3504.600	7471.800	9971.100	19361.700	58316.400
66240.000	77260.500	98296.200	102588.300	120207.800	126479.700
115541.100	111766.500	137353.500	129969.000	119169.900	117720.000
112086.800	102705.300	97300.100	92071.800	86594.400	80942.400

DAY TOTAL 1983524.400

EVENT DAY 4 DATE 3 11 85
HOURLY TOTALS (LITRES)

75288.600	69636.600	63982.600	58330.800	53524.800	49866.300
46286.000	37779.300	34413.300	32906.700	31320.600	29626.200
27931.500	26237.700	24543.000	22850.100	21960.000	21960.000
21070.900	18814.500	18186.200	17397.900	16929.000	16920.000

DAY TOTAL 837602.100

EVENT DAY 5 DATE 4 11 85
HOURLY TOTALS (LITRES)

15698.700	12326.400	11228.400	10328.400	9670.500	9478.800
9296.100	9114.300	46155.600	32400.000	26794.800	26096.400
24918.300	22184.100	19953.000	19800.000	19694.700	19395.000
19092.600	18798.200	18487.800	18185.400	17856.800	17490.600

DAY TOTAL 454436.100

EVENT DAY 6 DATE 5 11 85
HOURLY TOTALS (LITRES)

17124.300	16650.000	16036.200	14677.200	12058.200	11646.000
11233.000	10821.600	10410.300	9998.100	9598.500	9223.200
8046.100	8470.200	8096.400	7718.400	7525.300	7466.400
7405.200	7345.000	7286.400	7225.200	6960.600	6546.600

DAY TOTAL 240571.100

EVENT DAY 7 DATE 6 11 85
HOURLY TOTALS (LITRES)

6129.900	5715.000	5300.100	4883.400	4600.000	4600.000
4600.000	4600.000	4600.000	4600.000	4600.000	4600.000
4600.000	4600.000	4600.000	4600.000	4590.000	4406.400
4222.000	4039.200	3855.600	3672.000	3564.000	3586.400

DAY TOTAL 110044.800

EVENT DAY 8 DATE 7 11 85
HOURLY TOTALS (LITRES)

3447.900	3387.600	3330.000	3272.400	3185.100	3064.500
2943.900	2824.200	2703.600	2583.000	2491.200	2430.000
2368.800	2307.600	2246.400	2185.200	2124.000	2066.400
2008.000	1951.200	1890.000	1832.400	1800.000	1800.000

DAY TOTAL 60244.200

EVENT DAY 9 DATE 8 11 85
HOURLY TOTALS (LITRES)

1800.000	1800.000	1800.000	1450.000	720.000	720.000
720.000	720.000	720.000	720.000	720.000	720.000
720.000	720.000	720.000	720.000	720.000	720.000
720.000	720.000	720.000	720.000	720.000	720.000

DAY TOTAL 21250.000

EVENT DAY 10 DATE 9 11 85
HOURLY TOTALS (LITRES)

720.000	720.000	720.000	720.000	694.800	637.200
576.000	517.500	457.200	398.700	360.000	360.000
360.000	360.000	360.000	360.000	360.000	360.000
360.000	360.000	360.000	360.000	360.000	360.000

DAY TOTAL 11201.400

EVENT DAY 11 DATE 10 11 85
HOURLY TOTALS (LITRES)

360.000	360.000	360.000	360.000	360.000	360.000
360.000	360.000	360.000	360.000	360.000	360.000
360.000	360.000	360.000	360.000	360.000	360.000
360.000	360.000	360.000	360.000	360.000	360.000

DAY TOTAL 8640.000

EVENT DAY 12 DATE 11 11 85
HOURLY TOTALS (LITRES)

360.000	360.000	360.000	360.000	360.000	360.000
360.000	360.000	360.000	360.000	360.000	360.000
360.000	360.000	360.000	360.000	360.000	360.000
360.000	360.000	360.000	360.000	360.000	360.000

DAY TOTAL 8640.000

EVENT DAY 13 DATE 12 11 85
HOURLY TOTALS (LITRES)

360.000	360.000	360.000	360.000	360.000	360.000
360.000	360.000	360.000	360.000	360.000	360.000
360.000	360.000	360.000	360.000	360.000	360.000
360.000	360.000	360.000	360.000	360.000	360.000

DAY TOTAL 8640.000

EVENT DAY 14 DATE 13 11 85
HOURLY TOTALS (LITRES)

360.000	360.000	360.000	360.000	285.300	.000
.000	.000	.000	.000	.000	.000
.000	.000	.000	.000	.000	.000
.000	.000	.000	.000	.000	.000

DAY TOTAL 1725.300

TOTAL DAILY FLOWS IN: ICATCH F
DATE OF EVENT START :
25 11 85
DAY STARTS AT 8.00 HOURS
1554

EVENT DAY 1 DATE 25 11 85
HOURLY TOTALS (LITRES)

360.000	360.000	360.000	360.000	360.000	360.000
360.000	360.000	360.000	360.000	360.000	360.000
360.000	360.000	360.000	8678.700	85955.400	120240.000
99963.900	94709.700	94320.000	94320.000	98073.900	99000.000

DAY TOTAL 800661.600

EVENT DAY 2 DATE 26 11 85
HOURLY TOTALS (LITRES)

99000.000	99000.000	99000.000	99000.000	99000.000	99000.000
94632.300	94320.000	94320.000	94320.000	92746.200	92513.700
93430.000	92964.600	91000.000	91000.000	91000.000	89752.500
84240.000	83085.300	79757.100	86674.200	80366.400	77040.000

DAY TOTAL 2193540.300

EVENT DAY 3 DATE 27 11 85
HOURLY TOTALS (LITRES)

77040.000	77040.000	54103.500	35100.900	29429.100	25560.000
25560.000	25560.000	25560.000	25560.000	25376.400	25083.000
24789.600	24496.200	24202.800	23909.400	23760.000	23760.000
23760.000	21374.200	19800.000	19800.000	20118.500	20559.600

DAY TOTAL 721315.800

EVENT DAY 4 DATE 28 11 85
HOURLY TOTALS (LITRES)

10253.800	18808.200	17031.600	13001.400	10100.800	10080.000
10000.000	10000.000	10000.000	10000.000	10000.000	10000.000
10000.000	10000.000	10000.000	10000.000	10000.000	10000.000
10000.000	10000.000	10000.000	10079.100	10035.000	9965.700

DAY TOTAL 268635.600

EVENT DAY 5 DATE 29 11 85
HOURLY TOTALS (LITRES)

9895.500	9826.200	9757.800	7800.300	7560.000	7560.000
7560.000	7560.000	7560.000	7560.000	7528.500	7470.000
7410.600	7351.200	7292.700	7232.400	7147.800	7020.100
6900.400	6780.700	6669.900	6550.200	6407.100	6228.900

DAY TOTAL 180654.300

EVENT DAY 6 DATE 30 11 85
HOURLY TOTALS (LITRES)

6049.800	5871.600	5693.400	5514.300	5357.700	5238.000
5118.300	4999.500	4879.800	4761.000	4681.000	4549.500
3896.100	3600.000	3600.000	3600.000	3600.000	3600.000
3600.000	3600.000	3600.000	3600.000	3571.200	3510.000

DAY TOTAL 106092.000

EVENT DAY 7 DATE 1 12 85
HOURLY TOTALS (LITRES)

3452.400	3393.000	3333.600	3276.000	3214.800	3155.400
3095.100	3034.800	2974.500	2915.100	2880.000	2880.000
2880.000	2880.000	2880.000	2880.000	2880.000	2880.000
2880.000	2880.000	2880.000	2880.000	2898.900	2956.500

DAY TOTAL 72268.100

EVENT DAY 8 DATE 2 12 85
HOURLY TOTALS (LITRES)

3016.800	3076.200	3135.600	3195.900	3220.200	3162.600
3100.500	3039.300	2977.200	2915.100	2880.000	2880.000
2880.000	2880.000	2880.000	2880.000	2880.000	2880.000
2880.000	2880.000	2880.000	2880.000	2880.000	2880.000

DAY TOTAL 71159.400

EVENT DAY 9 DATE 3 12 85
HOURLY TOTALS (LITRES)

2880.000	2880.000	2880.000	2880.000	3368.700	7391.700
43200.000	47583.000	49272.300	48800.000	48498.200	48097.800
54385.200	57609.000	58343.400	59874.200	59167.800	58750.200
58332.600	57915.000	57497.400	57079.800	56880.000	56880.000

DAY TOTAL 999719.100

EVENT DAY 10 DATE 4 12 85
HOURLY TOTALS (LITRES)

56880.000	56880.000	56880.000	56880.000	56880.000	56880.000
56880.000	56880.000	56806.100	52936.200	50781.600	49491.900
48202.200	46913.400	45622.800	44334.000	43043.400	41754.600
40465.800	39175.200	37886.400	36595.800	35307.000	34017.300

DAY TOTAL 1157573.700

EVENT DAY 11 DATE 5 12 85
HOURLY TOTALS (LITRES)

32727.600	31438.800	30148.200	28859.400	27569.700	26280.000
17535.600	11310.300	12150.900	12990.600	13320.000	13320.000
13320.000	13320.000	13320.000	13320.000	13320.000	13320.000
13320.000	13320.000	13320.000	13319.100	13204.800	13026.600

DAY TOTAL 417081.600

EVENT DAY 12 DATE 6 12 85
HOURLY TOTALS (LITRES)

12846.600	12668.400	12489.300	12310.200	12048.300	11732.400
11415.600	11098.800	14418.900	19075.500	18837.000	18477.000
18117.000	17757.000	17397.000	17036.100	16648.100	16226.100
15812.100	15398.100	14983.200	14569.200	14400.000	14400.000

DAY TOTAL 360153.900

EVENT DAY 13 DATE 7 12 85
HOURLY TOTALS (LITRES)

14400.000	14400.000	14400.000	14400.000	14184.000	13828.500
13473.900	13118.400	12762.900	12409.200	12395.700	12693.600
12998.600	12593.700	10676.700	10484.100	10292.400	10623.600
13199.400	12929.400	12650.500	12386.700	12322.800	12502.800

DAY TOTAL 306126.900

EVENT DAY 14 DATE 8 12 85
HOURLY TOTALS (LITRES)

12683.700	12864.600	13044.600	13224.600	13320.000	13320.000
13320.000	13320.000	13320.000	13320.000	13320.000	13320.000
13320.000	13320.000	13320.000	13320.000	13320.000	13320.000
13320.000	13320.000	13320.000	13320.000	13235.400	13056.300

DAY TOTAL 317069.200

EVENT DAY 15 DATE 9 12 85
HOURLY TOTALS (LITRES)

12870.100	12699.000	12521.700	12342.600	12068.900	11639.700
11218.500	10797.300	10376.100	9954.900	9720.000	9720.000
9720.000	9720.000	9720.000	9720.000	9720.000	9720.000
9720.000	9720.000	9720.000	9720.000	9675.900	9557.100

DAY TOTAL 252361.000

EVENT DAY 16 DATE 10 12 85
HOURLY TOTALS (LITRES)

9439.200	9320.400	9281.600	9083.700	8897.400	8567.100
7737.300	5835.600	4964.400	5247.000	5400.000	5400.000
5400.000	5400.000	5400.000	5400.000	5400.000	5400.000
5400.000	5400.000	5400.000	5400.000	5400.000	5400.000

DAY TOTAL 153093.700

EVENT DAY 17 DATE 11 12 85
HOURLY TOTALS (LITRES)

5400.000	5400.000	5400.000	4561.200	396.000	.000
.000	.000	.000			
.000	.000	.000	.000	.000	.000

DAY TOTAL 21157.200

TOTAL DAILY FLOWS IN: ICATCH F
DATE OF EVENT START :
13 12 85
DAY STARTS AT 8.00 HOURS
137
EVENT DAY 1 DATE 13 12 85
HOURLY TOTALS (LITRES)

720.000	720.000	720.000	720.000	720.000	720.000
720.000	720.000	720.000	720.000	720.000	720.000
720.000	720.000	720.000	720.000	720.000	720.000
720.000	720.000	720.000	720.000	720.000	720.000

DAY TOTAL 17280.000

EVENT DAY 2 DATE 14 12 85
HOURLY TOTALS (LITRES)

720.000	720.000	720.000	720.000	720.000	720.000
720.000	720.000	720.000	577.600	.000	.000
.000	.000	.000	.000	.000	.000
.000	.000	.000	.000	.000	.000

DAY TOTAL 7057.600

TOTAL DAILY FLOWS IN: ICATCH,F
DATE OF EVENT START :
18 12 85
DAY STARTS AT 8.00 HOURS
141
EVENT DAY 1 DATE 18 12 85
HOURLY TOTALS (LITRES)

360.000	360.000	360.000	360.000	360.000	360.000
360.000	360.000	369.000	383.400	394.200	408.600
423.000	434.700	448.200	462.600	475.200	487.800
502.200	515.700	527.400	541.800	556.200	567.000

DAY TOTAL 10377.000

EVENT DAY 2 DATE 19 12 85
HOURLY TOTALS (LITRES)

581.400	595.800	607.500	621.000	635.400	648.000
660.600	675.000	688.500	700.200	714.600	.000
.000	.000	.000	.000	.000	.000
.000	.000	.000	.000	.000	.000

DAY TOTAL 7128.000

TOTAL DAILY FLOWS IN: ICATCH F
DATE OF EVENT START :
24 12 85
DAY STARTS AT 0.00 HOURS
691

EVENT DAY 1 DATE 24 12 85
HOURLY TOTALS (LITRES)

360.000	360.000	360.000	360.000	3960.900	4498.200
4357.800	4217.400	4077.000	3936.600	3795.300	3654.900
8229.600	8119.900	8009.100	7899.300	7789.500	7679.700
7569.000	7460.100	7349.400	7238.700	7124.400	7085.600

DAY TOTAL 125412.300

EVENT DAY 2 DATE 25 12 85
HOURLY TOTALS (LITRES)

6886.800	6760.900	6651.000	6532.200	6400.000	6400.000
6400.000	6400.000	6400.000	6400.000	6379.200	6199.200
6018.300	5837.400	5657.400	5477.400	5400.000	5400.000
5400.000	5400.000	5400.000	5400.000	5400.000	5400.000

DAY TOTAL 144487.800

EVENT DAY 3 DATE 26 12 85
HOURLY TOTALS (LITRES)

5400.000	5400.000	5400.000	5400.000	5334.300	5215.500
5097.600	4978.800	4860.000	4742.100	4680.000	4680.000
4680.000	4680.000	4680.000	4680.000	4680.000	4680.000
4680.000	4680.000	4680.000	4680.000	4680.000	4680.000

DAY TOTAL 117348.300

EVENT DAY 4 DATE 27 12 85
HOURLY TOTALS (LITRES)

4680.000	4680.000	4680.000	4680.000	4680.000	4680.000
4680.000	4680.000	4680.000	4680.000	4680.000	4680.000
4680.000	4680.000	4680.000	4680.000	4619.700	4499.100
4379.400	4259.700	4139.100	4019.400	3960.000	3960.000

DAY TOTAL 108716.400

EVENT DAY 5 DATE 28 12 85
HOURLY TOTALS (LITRES)

3960.000	3960.000	3960.000	3960.000	3934.800	3873.600
3812.400	3752.100	3691.800	3630.600	3600.000	3600.000
3600.000	3600.000	3600.000	3600.000	3627.000	3686.400
3744.900	3805.200	3862.800	3924.000	3938.400	3877.200

DAY TOTAL 90601.200

EVENT DAY 6 DATE 29 12 85
HOURLY TOTALS (LITRES)

3818.700	3758.400	3699.000	3639.600	3648.600	3781.800
3908.600	3329.100	2970.000	3144.600	3240.000	3240.000
3240.000	3240.000	3240.000	3240.000	3240.000	3240.000
3240.000	3240.000	3240.000	3240.000	3240.000	3240.000

DAY TOTAL 81850.400

EVENT DAY 7 DATE 30 12 85
HOURLY TOTALS (LITRES)

3240.000	3240.000	3240.000	3240.000	3240.000	3240.000
3240.000	3240.000	3240.000	3240.000	3212.100	3150.000
3087.900	3026.700	2964.600	2903.400	2880.000	2880.000
2880.000	2880.000	2880.000	2880.000	2847.600	2790.000

DAY TOTAL 73662.300

EVENT DAY 8 DATE 31 12 85
HOURLY TOTALS (LITRES)

2736.000	2678.400	2620.800	2563.200	1019.700	.000
.000	.000	.000	.000	.000	.000
.000	.000	.000	.000	.000	.000
.000	.000	.000	.000	.000	.000

DAY TOTAL 11618.100

TOTAL DAILY FLOWS IN: 1CATCH F
DATE OF EVENT START :
4 1 86
DAY STARTS AT 8.00 HOURS
114
EVENT DAY 1 DATE 4 1 86
HOURLY TOTALS (LITRES)

40.500	142.200	243.000	957.600	878.300	642.600
586.500	519.300	437.200	395.100	360.000	360.000
360.000	360.000	360.000	360.000	360.000	360.000
360.000	360.000	360.000	360.000	381.600	441.900

DAY TOTAL 9991.800

EVENT DAY 2 DATE 5 1 86
HOURLY TOTALS (LITRES)

502.200	561.600	622.800	682.200	180.000	.000
.000	.000	.000	.000	.000	.000
.000	.000	.000	.000	.000	.000
.000	.000	.000	.000	.000	.000

DAY TOTAL 2548.800

TOTAL DAILY FLOWS IN: 1CATCH F
DATE OF EVENT START :
7 1 86
DAY STARTS AT 8.00 HOURS
335
EVENT DAY 1 DATE 7 1 86
HOURLY TOTALS (LITRES)

360.000	360.000	360.000	360.000	360.000	360.000
360.000	360.000	360.000	360.000	404.100	479.700
555.300	631.800	708.300	783.900	860.400	936.800
1012.500	1088.100	1163.700	1240.200	1316.700	1392.300

DAY TOTAL 16173.800

EVENT DAY 2 DATE 8 1 86
HOURLY TOTALS (LITRES)

1468.000	1544.400	1620.900	1696.500	1773.000	1755.000
1684.000	1614.600	1544.400	1474.200	1409.400	1349.100
1288.000	1227.600	1167.300	1107.000	1080.000	1080.000
1080.000	1080.000	1080.000	1080.000	1142.100	1260.000

DAY TOTAL 32607.900

EVENT DAY 3 DATE 9 1 86
HOURLY TOTALS (LITRES)

1378.000	1497.600	1615.500	1734.300	1719.000	1536.300
1352.700	1170.000	987.300	803.700	720.000	720.000
720.000	720.000	720.000	720.000	747.900	807.300
867.600	927.900	987.300	1047.600	1053.000	993.600

DAY TOTAL 25547.400

EVENT DAY 4 DATE 10 1 86
HOURLY TOTALS (LITRES)

935.100	874.200	817.200	756.000	720.000	720.000
720.000	720.000	720.000	720.000	621.900	313.200
.000	.000	.000	.000	.000	.000
.000	.000	.000	.000	.000	.000

DAY TOTAL 8638.200

APPENDIX C.1

An example of some of the input parameters used in the ACRU simulations of soil moisture variations at site FM1L.

ECCA-CATCHMENT:LEFT SLOPE

AREA OF CATCHMENT (KM SQ)	=	.28	
LATITUDE (S)	=	33.20	
LONGITUDE (E)	=	26.25	
ELEVATION (M)	=	238.00	
POTENTIAL EVAPORATION BY DAILY A-PAN DATA			
LAG EQUATION BY SCS			
COEFFICIENT OF DRAINAGE RELEASE	=	.05	
COEFFICIENT OF QUICKFLOW RESPONSE	=	.60	
COEFFICIENT OF BASEFLOW RESPONSE	=	.02	
COEFFICIENT OF INITIAL ABSTRACTION	=	.05	
DEPTH OF SOIL IN A-HORIZON (M)	=	.15	
DEPTH OF SOIL IN B-HORIZON (M)	=	.45	
WILTING POINT OF A-HORIZON (M/M)	=	.027	(= 4.1MM)
WILTING POINT OF B-HORIZON (M/M)	=	.069	(= 31.1MM)
FIELD CAPACITY OF A-HORIZON (M/M)	=	.162	(= 24.3MM)
FIELD CAPACITY OF B-HORIZON (M/M)	=	.167	(= 75.2MM)
POROSITY OF SOIL IN A-HORIZON (M/M)	=	.375	
POROSITY OF SOIL IN B-HORIZON (M/M)	=	.375	
LENGTH OF GROWING SEASON	=	150	

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
CROPPING FACTOR	.65	.50	.45	.34	.36	.36	.37	.37	.37	.41	.41	.41
PROP OF ROOTS IN A HORIZON	.65	.77	.85	.85	.80	.70	.70	.70	.70	.79	.79	.79
INTERCEPTION LOSS (MM)	.90	.90	.90	.90	.70	.60	.50	.50	.70	.60	.90	.90
TEMP: MEAN MAXIMUM (C)	25.1	25.1	24.7	22.6	20.7	18.8	19.5	20.6	22.2	22.5	23.2	24.8
MEAN MINIMUM (C)	14.9	14.9	13.6	10.2	6.1	2.8	3.1	5.1	8.5	10.5	12.4	13.9

APPENDIX C.2

An example of some of the output from program COLLATE which was used as input to the ACRU model

DATE	RAIN	T-MAX	T-MIN	EVAP	FLOW	A-HOR	B-HOR
85 1 1	.0	33.4	19.7	5.8	.000	0.	0.
85 1 2	.0	41.8	21.9	7.1	.000	0.	0.
85 1 3	.6	44.0	19.5	4.7	.000	0.	0.
85 1 4	.0	27.0	17.5	4.0	.000	0.	0.
85 1 5	.0	30.4	17.7	5.6	.000	0.	0.
85 1 6	.0	40.4	24.6	10.9	.000	0.	0.
85 1 7	.4	32.5	17.8	6.6	.000	0.	0.
85 1 8	.2	23.3	17.6	2.0	.000	0.	0.
85 1 9	.0	47.0	17.7	3.3	.000	63.	37.
85 1 10	.0	28.9	20.8	3.8	.000	0.	0.
85 1 11	.0	30.0	15.0	3.6	.000	0.	0.
85 1 12	.0	37.3	22.1	6.8	.000	0.	0.
85 1 13	.6	26.0	15.5	1.5	.000	0.	0.
85 1 14	24.6	23.6	15.7	2.9	.000	0.	0.
85 1 15	1.4	23.6	16.8	.0	.000	0.	0.
85 1 16	.6	25.3	17.0	1.5	.000	144.	47.
85 1 17	.0	36.7	12.5	6.6	.000	0.	0.
85 1 18	.0	23.0	19.1	5.9	.000	0.	0.
85 1 19	.0	29.0	16.3	5.6	.000	0.	0.
85 1 20	.0	29.0	16.4	6.1	.000	0.	0.
85 1 21	.0	45.0	15.3	7.6	.000	0.	0.
85 1 22	.0	33.1	20.3	6.1	.000	0.	0.
85 1 23	.0	23.8	16.2	.6	.000	38.	42.
85 1 24	.0	28.9	19.3	3.3	.000	0.	0.
85 1 25	.0	34.4	17.7	5.6	.000	0.	0.
85 1 26	.0	35.0	17.0	5.8	.000	0.	0.
85 1 27	.0	26.4	19.0	1.5	.000	0.	0.
85 1 28	.0	40.9	21.6	7.6	.000	0.	0.
85 1 29	3.9	43.9	20.3	6.3	.000	0.	0.
85 1 30	.0	20.7	17.5	.2	.000	74.	41.
85 1 31	.0	32.6	19.3	4.1	.000	0.	0.
85 2 1	.0	34.9	21.2	6.1	.000	0.	0.
85 2 2	16.4	29.4	19.5	.8	.000	0.	0.
85 2 3	.2	22.4	19.0	2.1	.000	0.	0.
85 2 4	18.0	32.0	14.5	.0	.000	0.	0.
85 2 5	5.0	25.3	11.7	6.4	.000	0.	0.
85 2 6	3.8	21.0	11.8	.4	.000	145.	58.
85 2 7	4.2	21.2	9.8	4.1	.000	0.	0.
85 2 8	9.8	15.9	9.6	.8	.000	0.	0.
85 2 9	10.0	12.2	8.2	.0	.000	0.	0.
85 2 10	7.8	15.6	9.9	5.3	.000	0.	0.
85 2 11	.2	.0	.0	4.2	.000	0.	0.
85 2 12	2.4	.0	.2	1.6	.000	0.	0.
85 2 13	.0	.0	.0	2.5	.000	152.	87.
85 2 14	.0	.0	.0	5.2	.000	0.	0.
85 2 15	9.0	.0	.2	6.3	.000	0.	0.
85 2 16	.0	.0	.0	5.1	.000	0.	0.
85 2 17	1.6	.0	.0	6.1	.000	0.	0.
85 2 18	.0	.0	.0	3.6	.000	0.	0.
85 2 19	.0	.0	.0	3.1	.000	0.	0.
85 2 20	.0	34.9	10.8	.6	.000	55.	94.
85 2 21	1.2	25.9	11.3	5.5	.000	0.	0.
85 2 22	.2	29.6	12.4	7.2	.000	0.	0.

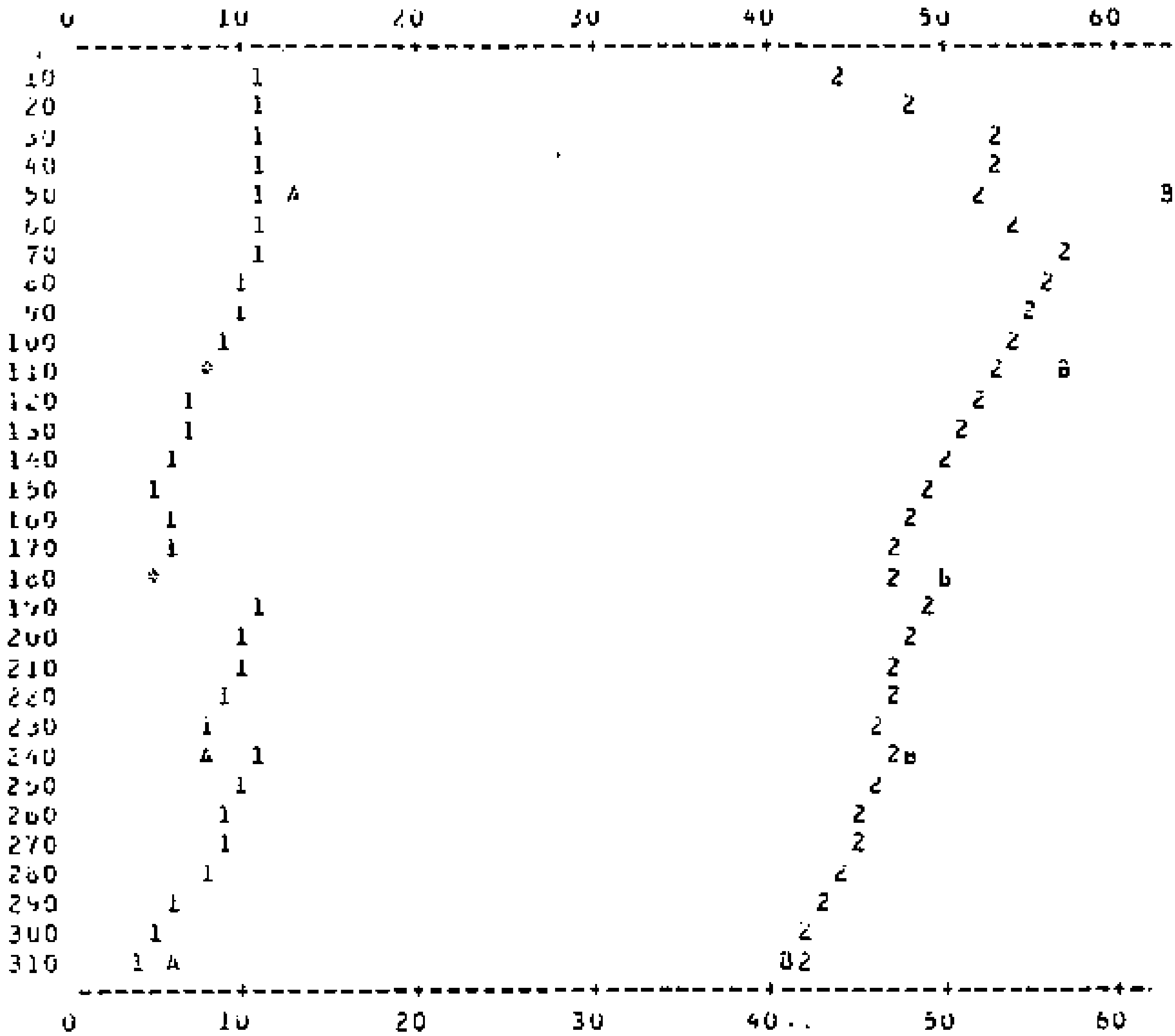
APPENDIX C.3

An example of some of the output from the ACRU soil moisture simulations for the 0-15cm (A-horizon) and 15-45cm (B-horizon) soil depths at site FM1L of Catchment F (see also Figure 2.2 of the main text).

PLOT OF OBSERVED(M) AND SIMULATED(S) SOIL MOISTURE

MONTH = 12   YEAR = 85

1=SIMULATED MOISTURE IN STORAGE 1
2=SIMULATED MOISTURE IN STORAGE 2
A=OBSERVED MOISTURE IN A HORIZON
B=OBSERVED MOISTURE IN B HORIZON
C=VARIABLES OCCUPY THE SAME POSITION



STATISTICS OF PERFORMANCE OF ACRU

SIMULATED

FOR A-HORIZON

TOTAL OBSERVED MOISTURE	=	1517.100
TOTAL SIMULATED MOISTURE	=	1437.409
MEAN OF OBSERVED MOISTURE	=	10.684
MEAN OF SIMULATED MOISTURE	=	10.123
CORRELATION COEFFICIENT	=	.868
STUDENTS T VALUE	=	20.725
REGRESSION COEFFICIENT	=	.932
BASE CONSTANT FOR REGRN. EQN.	=	.163
STANDARD ERROR OF SIMULATED MOISTURE	=	37.582
VARIANCE OF OBSERVED MOISTURE	=	37.247
VARIANCE OF SIMULATED VALUES	=	42.504
STANDARD DEVIATION OF X VALUES	=	6.103
STANDARD DEVIATION OF Y VALUES	=	6.520
PERCENTAGE DIFFERENCE IN STANDARD DEVIATION	=	-6.824
COEFFICIENT OF DETERMINATION	=	.754
COEFFICIENT OF EFFICIENCY	=	.703

STATISTICS OF PERFORMANCE OF ACRU

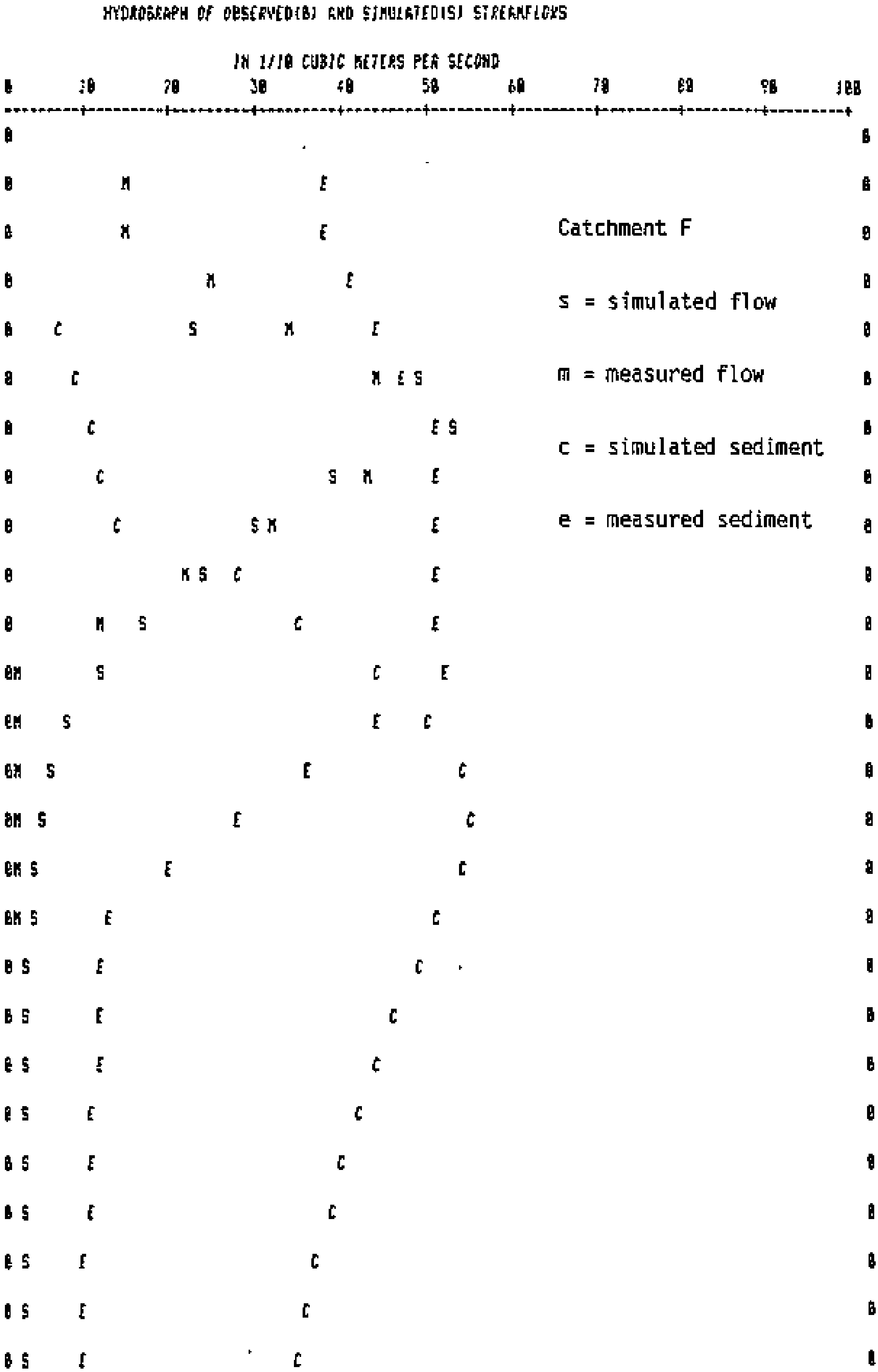
SIMULATED

FOR B-HORIZON

TOTAL OBSERVED MOISTURE	=	5152.950
TOTAL SIMULATED MOISTURE	=	5537.955
MEAN OF OBSERVED MOISTURE	=	36.265
MEAN OF SIMULATED MOISTURE	=	39.000
CORRELATION COEFFICIENT	=	.627
STUDENTS T VALUE	=	9.527
REGRESSION COEFFICIENT	=	.345
BASE CONSTANT FOR REGRN. EQN.	=	26.464
STANDARD ERROR OF SIMULATED MOISTURE	=	127.369
VARIANCE OF OBSERVED MOISTURE	=	646.553
VARIANCE OF SIMULATED VALUES	=	212.787
STANDARD DEVIATION OF X VALUES	=	25.427
STANDARD DEVIATION OF Y VALUES	=	14.587
PERCENTAGE DIFFERENCE IN STANDARD DEVIATION	=	42.720
COEFFICIENT OF DETERMINATION	=	.393
COEFFICIENT OF EFFICIENCY	=	.409

APPENDIX D

Examples of streamflow simulations
by means of the MODANSW model


HYDROGRAPH OF OBSERVED(B) AND SIMULATED(S) STREAMFLOWS
IN 1/10 CUBIC METERS PER SECOND
0 10 20 30 40 50 60 70 80 90 100
Catchment F
s = simulated flow
m = measured flow
c = simulated sediment
e = measured sediment

Catchment = F

Date = 15/2/85

(no parameter transfers involved)

A COMPARISON OF SIMULATED AND OBSERVED FLOW RATES

FOR SINGLE EVENT IN L/S

CUM.TOT. OBSERV. FLOW RATES	=	59.735
CUM.TOT. SIMU. FLOW RATES	=	64.614
MEAN OF OBSERVED FLOWS	=	1.358
MEAN OF SIMULATED FLOWS	=	1.469
CORRELATION COEFFICIENT	=	.917
STUDENTS T VALUE	=	14.848
REGRESSION COEFFICIENT	=	.843
BASE CONSTANT FOR REGRN. EQN.	=	.375
STANDARD ERROR OF SIMULATED FLOW	=	6.556
VARIANCE OF OBSERVED FLOW	=	7.7
VARIANCE OF SIMULATED VALUES	=	6.5
STANDARD DEVIATION OF X VALUES	=	2.767
STANDARD DEVIATION OF Y VALUES	=	2.549
PERCENTAGE DIFFERENCE IN STANDARD DEVIATION	=	7.863
COEFFICIENT OF DETERMINATION	=	.848
COEFFICIENT OF EFFICIENCY	=	.838

(For catchment B using parameters transferred from catchment F)

STATISTICS OF PERFORMANCE OF MODANSE MODEL

A COMPARISON OF SIMULATED AND OBSERVED SEDIMENT RATES

FOR SINGLE EVENT IN L/S

CUM.TOT. OBSERV. SEDIMENT RATES	=163016.000
CUM.TOT. SIMU. SEDIMENT RATES	=257303.829
MEAN OF OBSERVED SEDIMENT	= 3704.909
MEAN OF SIMULATED SEDIMENT	= 5847.814
CORRELATION COEFFICIENT	= -.171
STUDENTS T VALUE	= -1.125
REGRESSION COEFFICIENT	= -.148
BASE CONSTANT FOR REGRN. EQN.	= 6366.578
STANDARD ERROR OF SIMULATED SEDIMENT	= 10698.866
VARIANCE OF OBSERVED SEDIMENT	=13445498.2
VARIANCE OF SIMULATED VALUES	=10197033.0
STANDARD DEVIATION OF X VALUES	= 3666.829
STANDARD DEVIATION OF Y VALUES	= 3193.279
PERCENTAGE DIFFERENCE IN STANDARD DEVIATION	= 12.914
COEFFICIENT OF DETERMINATION	= .029
COEFFICIENT OF EFFICIENCY	= -1.376

###CAUTION### SYSTEMATIC ERROR DETECTED ###